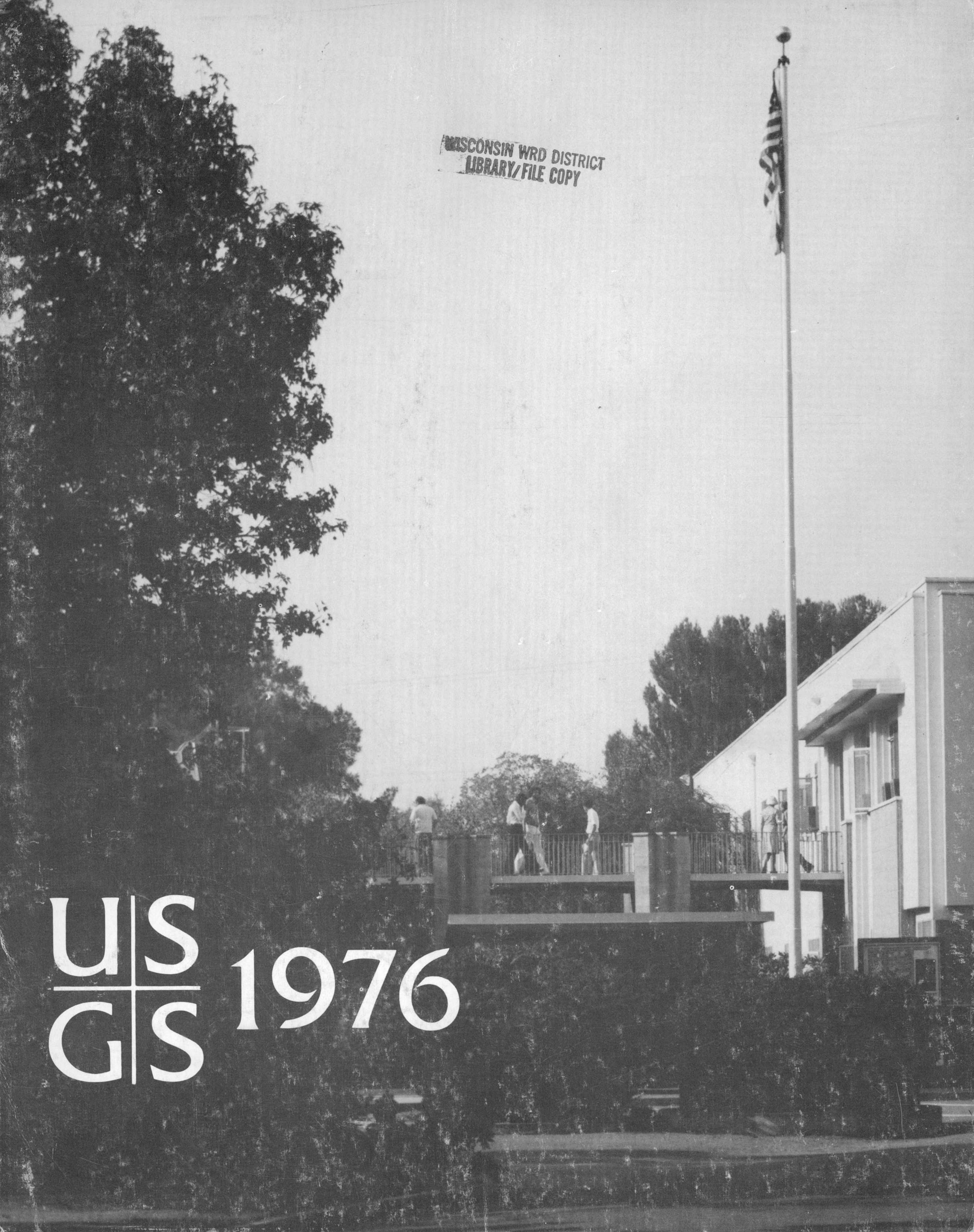

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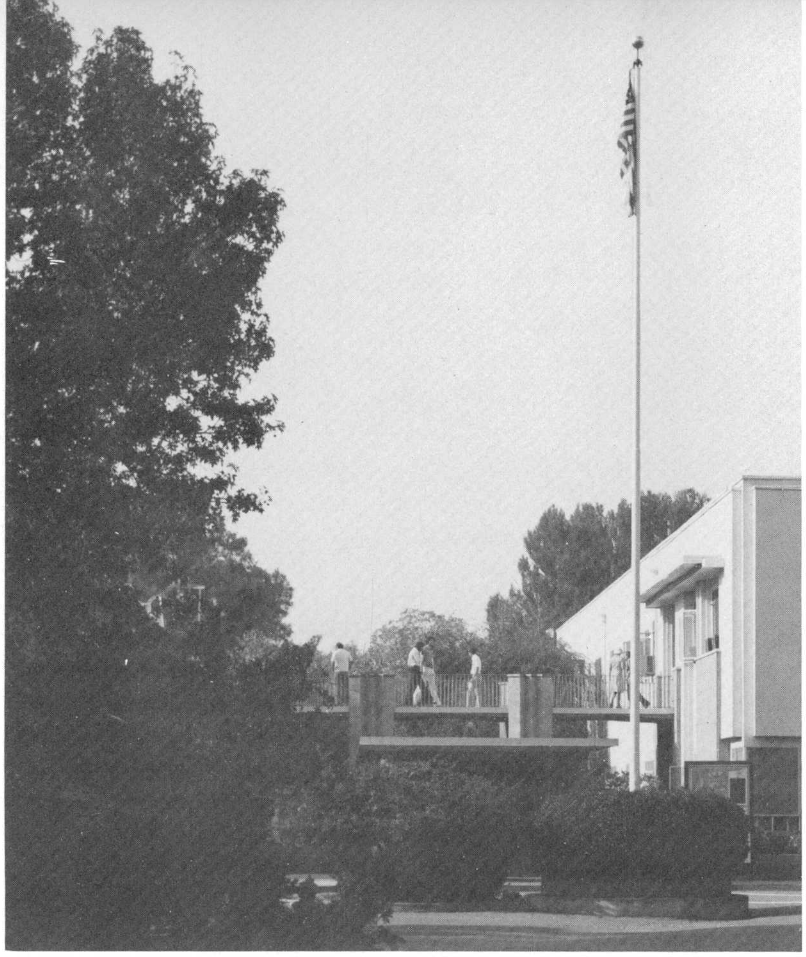

United States Geological Survey Annual Report, Fiscal Year 1976

Foreword

On July 4, 1976, the United States of America celebrated its Bicentennial. This report summarizes the progress made by the U.S. Geological Survey during the last year of the Bicentennial in collecting, analyzing, and publishing information about the Nation's mineral, water, and land resources and in supervising mineral operations authorized by lease and permit on the Federal lands.

As the Nation reflects on its first 200 years of history, the Geological Survey would like to call attention to the years ahead. Perhaps a quarter of a century from now this country will mark the passage of yet another milestone, namely the completion of the building of a Second America.

What this means is that, if one were to add up the resource production, construction, and consumption that has taken place until now as the First America, the equivalent accomplishment will likely be completed by the end of the 20th Century. Thus we shall have to grow, mine, transport, build, manufacture, and distribute as much in the way of material goods as has been done in all previous American history. It has taken us more than 400 years to build the First America. We will build the Second in 25.

What exactly will this entail? To meet the needs of an estimated population of 270 million people by the year 2000, major urban areas will have to be expanded. They are already increasing at the rate of 2,590 square kilometers (1,000 square miles) annually, which is like adding a new Boston or Washington, D.C., each year. The areas coming under the economic, planning, and development influence of these metropolitan centers is expanding at 10 times this rate—25,900 square kilometers (10,000 square miles) a year—an area larger than the State of New Hampshire. It is projected that the land areas expected to undergo development, coupled with those needed for highways and surface mining, will amount to more than 233,000 square kilometers (90,000 square miles) during this time period—nearly equivalent to the State of Wyoming.

Building this Second America will require prodigious amounts of resources, including energy, materials, water, and land. Just to maintain the present levels of consumption of oil and gas, for example, will require about 150 billion barrels of oil and more than 500 trillion cubic feet of gas—substantially more than we have produced and used throughout our history.

The task of finding and producing the increased volume of materials that will be needed in the next quarter of a century will be a formidable assignment. Some of these materials will be purchased from sources abroad, but most of them will have to come from our own soil. The Nation will have to produce them within the context of rising costs and increasing difficulty in finding and extracting the necessary materials with minimal damage to the environment. If the Second America is not built intelligently, the Nation could do as much environmental damage as was done in building the First America; however, we are much closer to the limits of tolerance than ever before, and the risk of such environmental damage is much more serious than in the past.

To build and sustain the Second America, and do it right, will be a challenge to all—politicians, scientists, engineers, economists, businessmen, the labor force, and the public at large.

The Geological Survey is ready to do its part in meeting the challenge of the future. For the past 98 years the Agency has been accumulating the data necessary to assess and inventory the Nation's mineral and energy resources. During the years ahead, efforts will continue to improve these estimates, fill in the gaps in the data banks, and pinpoint new potential sources and deposits. New thrusts will be made in mapping, assessing water resources, conservation, and in providing other earth-science data for public use.

To understand how the Geological Survey will respond to the challenge of the future, it is useful to look at the national trends which currently influence the direction and content of the Survey's activities. Some of these are:

- Continued population and urban growth, increasing the human use of the land and water, increasing the natural hazard risk to the population, and increasing concern for land-use and zoning information.
- Economic growth, increasing the demand for minerals and fuels.
- Continued withdrawal of public lands from mineral entry, resulting in an increasing need for areal resource appraisal.
- Growth in the development and use of toxic and hazardous materials (including nuclear energy), increasing problems of waste disposal.

- The opening up and exploration of new domains and frontiers, such as the subsea, the arctic, the deep crust, and other planets.
- Deterioration of environmental quality and increased public interest in environmental protection.

The Geological Survey's primary missions have not been affected very much by these trends because of the way the 1879 Organic Act, under which the Survey operates, was written. Broadly read, the Act is as descriptive of the Survey's principal missions now as it was in the 1800's. Many of the secondary missions of the Geological Survey, however, have been influenced by these national trends. Some examples are:

- Growth of the Conservation Division's lease-management activity and inception and growth of its tract-evaluation function.
- Inception of the Environmental Impact Analysis program and growth in environmental studies.
- Inception of a national land-use and land-cover mapping and analysis program.
- Growth of natural hazard studies and inception of research for developing a prediction capability for these phenomena.
- Inception of automation in data storage and handling.
- Increasing activities in the coastal zone and the identification of this area as a critical one for topographic mapping, land-use mapping, studying the onshore impact of offshore activities, and for water, estuarine, and geologic studies.
- Inception and growth of the Earth Resources Observation Systems (EROS) program, the EROS Data Center and planetary, subsea, and antarctic studies and exploration.
- Inception of wilderness and native-land mineral resource evaluations.
- Growth in energy and mineral resource assessments and new responsibilities for exploration and environmental protection on the Federal lands.

These are some of the new programs and activities that the Geological Survey has recently implemented in response to national trends and issues. In addition to creating new programs and influencing the secondary missions of the Geological Survey, national trends have also changed the character of the organization in terms of its methods of operation. Some examples include:

- A shift to carrying out an increasing percentage of the operation through grants and contracts.
- Replacement of professionals by highly trained and skilled technicians and subprofessionals.
- Establishment of basic research and factfinding studies that are more diverse and becoming more multidisciplinary in character.
- The initiation of a shift to the metric system.

The reader will find that throughout this report all measurements are in metric units followed by the English-system equivalents in parentheses. The use of this measurement system is part of an effort by the Survey to help the Nation shift to the metric system, as called for by Public Law 94–168. The impact of the conversion on Geological Survey programs is illustrated by an essay in the "Perspectives" section entitled "Metrication—What It Means to Mapping."

Probably the most difficult problem and greatest challenge that the Geological Survey will face in the future is how to communicate its information more effectively to the public, the States, other Federal agencies, the Congress, and the Administration. One way is through the publication of an annual report. This year's report for fiscal year 1976 consists of five parts:

- The Year in Review—a review of the major issues, events, achievements, and program accomplishments of the Geological Survey.
- Perspectives—a series of short essays covering activities related to national issues, interdivisional programs and recent advances in the earth sciences.
- Missions, Organizations, and Budget—a description of the major roles of the Geological Survey and the organization and budget it takes to carry out these missions.
- A description of significant activities and program highlights for each of the eight operating divisions and offices.
- A set of statistical tables and related information which documents workloads, production, and accomplishments.

Supplemented by Professional Paper 1000, "Geological Survey Research 1976," the latest in a series of annual reviews of technical results of the Geological Survey's research programs, this Annual Report provides a comprehensive description of the activities of the Federal Government's largest earth-science agency.

V. E. McKelvey,

Director, U.S. Geological Survey


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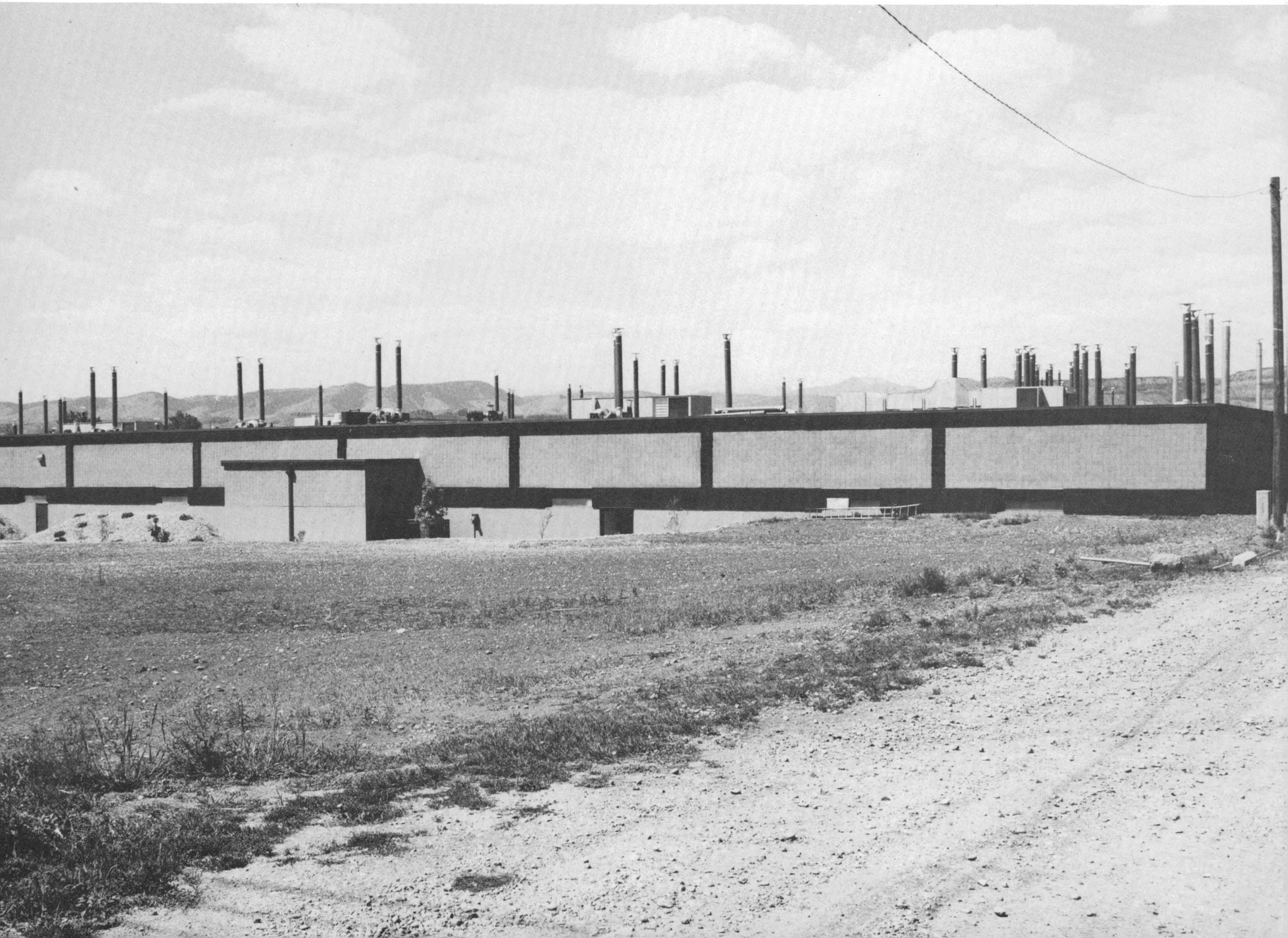
Two new USGS facilities: Top, Mid-Continent Mapping Center in Rolla, Missouri; bottom, National Water Quality Laboratory in Denver, Colorado.



The Year in Review

INTRODUCTION

During fiscal year 1976, the Geological Survey was involved in many critical issues of national significance such as the identification and assessment of potential energy and mineral sources, appraisal of the magnitude and quality of water resources, the reduction of hazards from earthquakes and other geologic processes, land-use mapping, and the supervision of lease operations on the Federal lands. The Survey was also involved in assessing the Nation's geothermal potential, in developing a reliable earthquake-prediction capability, collecting and analyzing water data, and producing topographic, geologic, and hydrologic maps in support of energy and mineral programs.

Statistics for fiscal year 1976 indicate that 10,000 maps of all types were produced, that 3,400 reports were approved for publication, and that 158,000 water-quality analyses were made. Additional ground- and surface-water measurements were made at 33,820 stations throughout the United States. The Geological Survey also supervised 2,557 leases on the public lands covering 3.7 million hectares (9.1 million acres) and collected $950,000,000 in royalties and rentals. During fiscal year 1976 and the transition quarter, the library acquired 142,000 new publications. In addition, more than 407,000 photographs and digital tapes were ordered from the EROS Data Center, and 398,965 inquiries for data and information were handled by the Public Inquiries Offices.

FACILITIES

The Geological Survey operates three major field centers in Rolla, Mo., Menlo Park, Calif., and Denver, Colo. During fiscal year 1976, the facilities at each of these centers were expanded.

On May 19, 1976, a new center was dedicated at Rolla. The $2 million facility was built on a 2.8-hectare (7-acre) tract and provides a gross area of over 8,825 square meters (95,000 square feet).

The new center allows the consolidation under one roof of a number of functions that were previously performed in several separate facilities in the Rolla area. The facility houses about 340 scientists, hydrologists, engineers, cartographers, technicians, and administrative personnel from the Survey's Administrative, Computer Center, Conservation, Topographic, and Water Resources Divisions. The center will also serve as a headquarters for about 110 field employees. Additionally, the General Services Administration maintains a small force at the center, and a Health Unit affords emergency medical treatment and conducts routine health services for all personnel.

In June 1976, construction was completed on the Geological Survey's National Water Quality Laboratory in Denver. The new 4,600-square-meter (49,000-square-foot) building will house 150 people and bring together 5 water-quality analytical and research laboratories that were previously scattered around the Denver area. The facility will enhance the Survey's capability to handle the growing load of chemical analyses of water, sediment, and related substances from projects ranging from the analysis of water-quality effects of mining to the measurement of pesticide concentrations in the hydraulic environment.

Also in Denver, the Geological Survey Library and several geology laboratories were moved into the Stevenson Building adjacent to the Denver Federal Center. Remodeling efforts were also begun in Building 85 at the Federal Center to ready 5,600 square meters (60,000 square feet) of space for the Conservation Division.

Denver was also the scene of an unfortunate event of major consequences. On Friday, March 19, 1976, a fire occurred during the night in Building 25 at the Denver Federal Center. This building houses the Central Region Headquarters of the Geological Survey. The areas burned included approximately 2,700 square meters (29,000 square feet) on the second floor, including one major Water Resources Division laboratory, five major Geologic Division laboratories, and nine two-man geologic laboratories and supporting office space. Heat, smoke, and water caused damage to more than 11,600 square meters (125,000 square feet) of the two-story building. The cost of reconstructing the building was estimated at $4.5 million, and the repair and replacement cost of equipment totaled $2.4 million.

In California, the Geological Survey leased the 7,500-square-meter (81,000-square-foot) Shell Building adjacent to the main Survey complex in Menlo Park. The building will house offices of the Geologic and Computer Center Divisions. Occupancy began in September 1976.

ENERGY, MINERALS, AND GEOLOGY

The task of assessing and developing the energy resources of the Nation's lands continued to shape and direct many of the activities of the Geological Survey.

During 1976, the Geologic Division made available to the public 68,000 records of the Petroleum Data System and 35,000 records of the Computerized Resource Information Base (CRIB) System and, in addition, either developed or expanded 14 other data bases, including those for isotopic ages, geologic map indexes, United Nations seabeds data, oil shale, geothermal energy, and uranium and thorium. The first phase of the National Coal Resource Data System, involving regional coal-resource information, became operational, with the capability of data manipulation and retrieval.

The Geological Survey continued to produce general reports on topics of broad national earth-science interest. During fiscal year 1976, the Survey published, among others, reports on the probablistic estimates of maximum earthquake accelerations, on paleotectonic investigations of the Pennsylvanian System, and on landslide occurrence and landslide susceptibility.

A new map of the United States showing equal lines of magnetic declination was published in August 1975. It is the first declination map issued since 1970. Magnetic declination, also referred to as "variation of the compass," is the angle between true north and magnetic north. Because the Earth's magnetic field is constantly changing, new measurements must be made at regular intervals. From these measurements, magnetic lines are depicted on periodically updated maps which are used extensively by marine and aircraft navigators, civil engineers, surveyors, cartographers, and earth scientists.

During fiscal year 1976, the first in a series of Geological Survey regional assessments that will inventory the vast and largely unappraised mineral resources of Alaska was completed and published as an introductory circular and 12 separate maps. The prototype assessment area lies in the Nabesna quadrangle about 363 kilometers (225 miles) north of Anchorage and is the first to be completed under the Geological Survey's Alaska Mineral Resources Assessment program authorized by Congress on July 1, 1974. The maps show the surface distribution of copper, lead, gold, chromium, and cobalt and include three-dimensional diagrams showing the relative distribution and concentrations of these and seven other metals, including silver, nickel, and zinc.

Similar regional assessments now underway in other parts of Alaska are designed to produce a badly needed, rapid, yet accurate assessment of Alaska's mineral resources. In view of the growing mineral shortages and the large role that Alaska is expected to have in supplying the Nation's future mineral needs, the assessment will play an important part in the planning of a viable long-range national minerals policy. Assessment began this year on nine quadrangles covering 122,247 square kilometers (47,200 square miles) after the completion of five sheets during fiscal year 1975. A total of 32 quadrangles will have been assessed when the project is completed.

The first report for the Minerals for Energy Production program was released as Professional Paper 1006. This program responds to the need to know what nonfuel minerals will be required to assure that U.S. energy-material production goals can be met. This initial report is in two parts: (1) Assessment of demand for nonfuel minerals, 1975–80; and (2) evaluation of available supplies of those materials that will be stressed. The report states that present production rates of most of these materials are considerably below estimates of the anticipated need for meeting energy goals by 1990.

In August 1975, the Geological Survey published, as Circular 726, the first comprehensive assessment of geothermal resources of the Nation. The report shows that huge quantities of heat exist in "hot spots" in the Western States and in some geologically favorable zones of the Gulf coast. The assessment was made with the support of the Energy Research and Development Administration.

Although there are numerous locations where geothermal systems exist, for most of them very little is known about exact size, temperature, and especially how much heat can be recovered. While geothermal energy is not a panacea, it is an extremely important alternative energy source, and the study shows that the potential is large enough to justify both exploration and technological research and development.

As part of a small international cooperative program, a team of Geological Survey scientists, working with their counterparts in the Saudi Arabia Directorate General of Mineral Resources announced in May 1976 that a mine in western Saudi Arabia is now believed to have been the principal producer of King Solomon's gold. Although many mines scattered throughout the region may have contributed gold to King Solomon's treasuries, the principal producer and most likely candidate to be the fabled Biblical Ophir is the Mahd adh Dhahab (Cradle of Gold) mine, located about midway between Mecca and Madinah.

A joint Department of the Interior and Department of State program that provides on-the-spot information about the availability of mineral resources was begun during the fiscal year. The key new element was the establishment of a Geological Survey/Bureau of Mines training program for State Department personnel that will help people on foreign assignments acquire resources information overseas. The early success of the program has already encouraged the Department of State to expand it.

In February 1976, it was announced that the U.S. Geological Survey would represent the United States on the Executive Committee of the recently established World Coal Reserves and Resources Service of the International Energy Agency. The Service, established last November, will act as a central clearing house for the collection and distribution of computerized data on world reserves and resources of coal for determining the location, amount, quality, minability, and usability of coal resources throughout the world. The Service will also provide basic information from which nations can plan fossil-energy production and consumption, the interplay of energy sources, future commitments, gas and oil conversion from coal, and location of industrial complexes.

The International Energy Agency is a group of industrial Nations—Belgium, West Germany, Italy, the United Kingdom, and the United States—joined in an effort to reduce the impact of oil-price increases through a variety of measures, including research on alternate energy sources, especially coal. Members of the Agency belong to the Organization for Economic Cooperation and Development. Implementing agreements establishing the World Coal Reserves and Resources Service were signed in Paris on November 20, 1975, by the U.S. Ambassador to the Organization for Economic Cooperation and Development. Through the U.S. Geological Survey and the Bureau of Mines, the United States will provide the computer capability for the Service and, with Britain's National Coal Board, will jointly run the Service for member nations.

Interest in coal increased this year because of recent legislation and because of the pressing need to develop this valuable and abundant resource. The Department of the Interior has lifted its moratorium and resumed its Coal Leasing program. The Geological Survey has been assigned the lead role in preparing three environmental impact statements on proposed coal development and is involved in four similar statements being directed by the Bureau of Land Management. In addition, because of the strong interest in coal at the State government level, a special Coal Committee comprised of State geologists was formed to provide inputs to the Geological Survey and to review environmental impact statements, resource assessments, and work plans. As part of a Federal-State Cooperative program, several State geological surveys provide data directly to the Coal Data System through contracted efforts.

During the summer of 1976, two Viking spacecraft landed on the surface of the planet Mars. The site-selection team, comprised of employees from the Geological Survey's Flagstaff, Ariz., operation, played a key role in the success of this venture.

As the Nation's major civilian mapping agency, the Geological Survey has prepared more than 100 maps of Mars, Mercury, Venus, and the Moon in support of manned and unmanned exploration efforts by the United States and the Soviet Union. Preliminary geologic mapping of the Moon has been completed, and the work on mapping of Mars is nearing completion. About 40 percent of Mercury has been mapped from Mariner–10 data, and preliminary mapping of Venus is underway. Such mapping of the planets not only aids in the selection of future landing sites but also serves to summarize our present knowledge of astrogeology. The staff at the Flagstaff Computation Center also provided computer support for the Viking mission and assisted in making cartographic digital-image enhancements of the photographs sent back to the Earth.

LEASE MANAGEMENT AND EVALUATION

On June 11, 1976, the Secretary of the Interior signed new Geological and Geophysical Regulations. These regulations will provide additional data for the Government, make it available to the public in a timely manner, and help to control the geological and geophysical exploration procedures. Also issued were Outer Continental Shelf Orders (the basic guidelines or regulations under which lessees carry out their activities) for the Gulf of Alaska and the Atlantic Ocean.

In November 1975, the Geological Survey announced that final approval had been granted for the first of two deep stratigraphic test wells to be drilled in Federal waters on the mid-Atlantic Outer Continental Shelf. Drilling began on December 14, 1975, and was completed in March 1976. The well was drilled to a depth of 4,890 meters (16,043 feet), 146 kilometers (91 miles) seaward from the New Jersey shoreline in 91 meters (298 feet) of water. The area is known as the Baltimore Canyon.

A second well, in the Georges Bank area, was approved in March 1976. This area lies about 120 kilometers (75 miles) seaward from Cape Cod, Mass., in about 43 meters (140 feet) of water.

These Atlantic Outer Continental Shelf tests will provide useful geologic information to participating companies and to the Federal Government as an aid in evaluating tracts to be offered in the mid-Atlantic lease sale. The data from the first well were made available to the public through Open-File Report 76–774 on November 1, 1976.

Final Revised Coal Mining Operating Regulations were issued on May 17, 1976. These regulations were issued to ensure that coal mining would be carried out in an environmentally acceptable manner.

NATIONAL PETROLEUM RESERVE OF ALASKA

In April 1976, the Naval Petroleum Reserves Act (Public Law 94–258) was passed by Congress. This act transferred jurisdiction of the National Petroleum Reserve in Alaska, formerly Naval Petroleum Reserve Number 4, from the Department of the Navy to the Department of the Interior and required continuation of an exploratory drilling program begun by the Navy. On April 22, 1976, the responsibility for carrying out the provisions of this Act was assigned to the Geological Survey. Assumption of the responsibilities will take place on June 1, 1977.

The National Petroleum Reserve in Alaska encompasses some 95,830 square kilometers (37,000 square miles) of Alaska, or an area roughly the size of Indiana. The Geological Survey's major responsibilities consist of management of the following programs:

1. The evaluation and assessment of the petroleum resources of the reserve.
2. Exploration, development for production, and operation of the South Barrow gas field, or such other fields as may be necessary, to supply gas at reasonable and equitable rates to the village of Barrow and other nearby communities and installations of the Department of Defense and other agencies.
3. Restoration of certain areas within the reserve that have been disturbed by previous petroleum exploration activities to an environmentally acceptable state.

A planning group for the National Petroleum Reserve in Alaska has been established to provide for continuation of the Navy plan to collect more than 16,000 kilometers (10,000 miles) of seismic data and to drill 26 wells, to study and plan for the evaluation and assessment of the petroleum reserves, and to continue service from the South Barrow gas field. Additional efforts are underway for the review and preparation of environmental impact statements covering the activities associated with drilling and overall management of the reserve.

GEOLOGIC HAZARDS

The Geological Survey is engaged in major efforts to delineate the hazards associated with earthquakes, volcanic eruptions, landslides, mudflows, ground subsidence, and floods.

The Survey's Reactor Hazards Research program has delineated reverse faults in Virginia and Georgia, the presence of which suggests that movement has occurred in recent geologic time. Investigations are continuing on the history and nature of the movement to provide a basis for assessing the safety and environmental problems in siting important engineering structures, such as nuclear facilities.

Two reports were produced in fiscal year 1976 related to land subsidence, or the sinking of the land surface. The reports, produced in cooperation with the California Department of Water Resources and the U.S. Army Corps of Engineers, indicate that subsidence is taking place in several parts of the Nation and could become more prevalent in the future.

The reports note that at least 11,100 square kilometers (4,300 square miles) of economically important farmland in the San Jacquin Valley of California has subsided more than 3 meters (1 foot) since the 1920's and that an area around Baytown, Tex., has suffered from tidal flooding because the land surface has subsided more than 2.4 meters (8 feet) since 1920; it could subside another meter (3.28 feet) by 1980.

Most of the Nation's subsidence problems are caused by large withdrawals of ground water and petroleum. Certainly, one can expect subsidence problems to multiply during the coming decades as more underground water, oil, gas, and other mineral resources are withdrawn to meet the Nation's growing needs.

In February 1976, the Geological Survey announced that a recent land uplift of as much as 25 centimeters (12 inches) had been discovered astride a large section of California's San Andreas fault, about 64 kilometers (40 miles) north of Los Angeles.

The land swelling, the shape of a huge kidney, has a 193-kilometer (120-mile) axis oriented roughly east-west and extending from the Pacific Ocean into the Mojave Desert. This uplift is receiving close attention from the Survey's earthquake specialists because similar swelling has occurred before some earthquakes in California and elsewhere. Such uplifts, however, have also occurred without subsequent earthquakes.

Centered north of Los Angeles, near Palmdale in the western Mojave Desert, the swelling apparently began about 1960 near the junction of the San Andreas and Garlock faults. Since then, it has grown east-southeastward to include an area of about 12,000 square kilometers (4,500 square miles). The significance of the rapid uplift is not fully understood. Concern, however, is warranted because it occurs astride a sector of the San Andreas fault that has remained "locked" since a great earthquake in 1857. Thus, considerable strain is building up in this area.

Since the initial identification of the uplift, and recognition that it could be a precursor to a significant earthquake event, the Survey's efforts to monitor geodetic changes in the area and to evaluate the phenomenon have been expanded to include installation of additional instruments (seismographs, tiltmeters, strainmeters, creepmeters, magnetometers, and others). The National Science Foundation and the Geological Survey have provided funds to begin the new studies.

Responsible State and local officials in the affected area have been notified of the potential for a hazard and are being kept abreast of current developments.

Disastrous earthquakes during 1975 and 1976 in China, Guatemala, the Soviet Union, and the Philippines increased public concern about the possibility of a similar event occurring here in the United States.

On November 7, 1975, the Geological Survey proposed a specific Federal plan for the issuance of earthquake predictions and warnings for consideration by Federal, State, and local agencies. Even though there is no operational capability for reliable earthquake prediction at the present time, such a capability is developing.

In the proposed plan, the U.S. Geological Survey has the responsibility for issuing the prediction, including advice and instructions as to defensive measures to be taken.

A major eruption of Mauna Loa Volcano on the Island of Hawaii before July 1978 has also been predicted by Survey scientists on the basis of an analysis of the volcano's past eruptive history. This eruption, which is likely to occur along Mauna Loa's northeast rift zone, could destroy parts of the city of Hilo, 48 kilometers (30 miles) to the east, depending upon the volume of extruded lava and the duration of volcanic activity. The volcano's summit eruption on July 5 and 6, 1975, is regarded as a precursor to, first, another small summit eruption and, second, a much larger, potentially dangerous flank eruption. The location of the predicted flank outbreak is based largely on the occurrence along the northeast rift in July 1975 of thousands of small earthquakes inferred to be associated with the injection of large amounts of magma (molten rock) into the rift zone.

SURVEYING AND MAPPING

The Geological Survey is responsible for carrying out the National Mapping program. In addition to producing and distributing topographic maps of the United States, the organization is also responsible for handling all cartographic data, for providing simplified public access to the data, for defining Federal mapping standards, and for developing a digital cartographic base for the country.

In fiscal year 1976 and the transition quarter, the Topographic Division produced 291 intermediate-scale products, including 1:100,000-scale quadrangle maps and 1:50,000- and 1:100,000-scale county maps. The switch to this intermediate-scale product is also a step toward the eventual shift from the English to the metric system of measurement since these maps are metric in scale. This effort was in response to the immediate requirements of the Bureau of Land Management, the Soil Conservation Service, and several States, but the maps will meet the needs of other organizations as well.

Another notable accomplishment was the acquisition and installation of advanced equipment that will simultaneously produce an orthophoto, a contour plot, and a digital terrain model. This new equipment provides improved orthophoto production capability and allows the economical preparation of digital terrain information, which previously has been an expensive and time-consuming process.

A new 50-State map produced during the Bicentennial fiscal year is the first detailed Survey map of the United States to show Alaska and Hawaii in their proper size and geographic position relative to the other 50 States. Not shown on the five-color, 39-by-58-inch, 1:6,000,000-scale—one centimeter equals 60 kilometers (1 inch equals approximately 95 miles)—map is the string of uninhabited islands and reefs in the Hawaiian chain which stretches northwestward for about 1,930 kilometers (1,200 miles) from the main inhabited Hawaiian Islands to Midway Island.

To improve the Geological Survey's capability to systematically review and revise out-of-date maps, a new inspection and review procedure was also adopted and implemented during the fiscal year.

To facilitate the collection, reproduction, and sale of space and aircraft imagery and photography, the Geological Survey operates the EROS Data Center near Sioux Falls, S. Dak. This facility also serves as the data center for the Topographic Division's National Cartographic Information Center. In December 1975, NCIC announced that, in addition to the 6 million frames of data held at the EROS Data Center, information on more than 7 million aerial photographs is being added to the files as a result of an agreement with the Department of Agriculture.

Under the agreement, two agencies of the Department of Agriculture—the Soil Conservation Service and the Agricultural Stabilization and Conservation Service—are supplying the Survey's National Cartographic Information Center with descriptions—such as location, date, area covered, scale, and film characteristics—of their aerial photographs, which cover most of the United States. The agencies will also supply information on their plans for collecting new photographs.

The addition of this information contributes substantially towards the goal of the Survey's National Cartographic Information Center of providing complete centralized information and access to cartographic data in the form of maps, aerial photographs, space imagery, and geodetic control. Efforts will also continue to provide access to other data held by Federal, State, and private organizations.

WATER RESOURCES

The Geological Survey has the principal responsibility for appraising the source, quantity, quality, and movement of the Nation's water resources. In addition, it is the lead agency for coordinating the activities of all Federal agencies in the acquisition of certain water data on streams, lakes, reservoirs, estuaries, and ground water.

In September 1975, the Survey announced that the first part of a new water-quality monitoring network designed to provide a balanced yearly picture of water quality in U.S. streams on a national and regional scale was in operation. Known as the National Stream Quality/Quantity Accounting Network (NASQAN), the network now consists of 345 stations that measure 46 physical, chemical, and biological water-quality characteristics, including temperature, specific conductance, and a variety of bacteria, dissolved minerals, trace elements, nutrients, and organic and biological constituents. Measurements are made either continuously, daily, monthly, or quarterly, and the network will be expanded to 525 stations.

The primary objectives of NASQAN are to account for the quantity and quality of water moving within and from the United States, to depict a real variability of water quality, to detect changes in stream quality, and to lay the groundwork for future assessments of changes in stream quality.

The Water Resources Division also announced that more than 150 million streamflow, water-quality, and ground-water measurements collected at more than 100,000 sites across the country are now available through the National Water Data Storage and Retrieval System (WATSTORE). The WATSTORE system contains several data files in which water data are grouped and stored by common characteristics and data-collection frequencies. Currently, files are maintained for the storage of: (1) surface-water, quality-of-water, and ground-water data measured on a continuous or daily basis, (2) annual peak values for streamflow stations, (3) chemical analyses for surface- and ground-water sites, and (4) geological and inventory data for ground-water sites.

LAND INFORMATION AND ANALYSIS

The Geological Survey continued its efforts to interpret and display land-resource information in ways that are readily accessible and understandable to a wide range of earth-science data users. During fiscal year 1976, a consolidation of several multidisciplinary land-resource and environmental programs known as the Land Information and Analysis Office completed five urban area study projects located in the Baltimore-Washington area, the Connecticut Valley, the greater Pittsburgh area, the Tucson-Phoenix area, and the San Francisco Bay region. An evaluation of the San Francisco Bay region study by the consulting firm A. D. Little indicated that the study has significant value in advancing the region's receptivity to earth-science data in the planning process.

As part of the Resource and Land Information (RALI) program, the survey released two reports, a "Guide to State Programs for the Reclamation of Surface Mined Areas" (Circular 731) and a "Directory of U.S. Geological Survey Program Activities in the Coastal Areas, 1974–76" (Bulletin 1428).

Under the Geography program, 1:250,000-scale land-use and land-cover maps completed for 1,170,000 square kilometers (450,000 square miles), including the entire States of Kansas, Florida, and Pennsylvania. This brings the total area mapped to 1,950,000 square kilometers (750,000 square miles) since the nationwide program began in fiscal year 1973. Work was also expanded in the area of Landsat digital imagery land use and land-use change, and in the search for semiautomated techniques to detect land-cover change.

The Earth Resources Observation Systems program published "ERTS–1, a New Window on Our Planet" (Professional Paper 929). The book consists of 85 case histories on the use and application of ERTS–1 (now Landsat–1) data to earth-resource mapping, monitoring, and inventory.

In October 1975, the 1st William T. Pecora Memorial Symposium was held at the EROS Data Center in Sioux Falls, S. Dak. The symposium was named for the late Director of the Geological Survey and Under Secretary of the Department of the Interior. Dr. Pecora played a lead role in the establishment of the EROS program in 1966. The meeting focused on the use of satellite imagery and other remotely sensed data in exploring for new mineral and fuel deposits.

In the Environmental Impact Analysis program, the Survey held the lead or joint-lead responsibility for the preparation of 20 environmental impact statements during fiscal year 1976. They also participated in a nonlead capacity in the preparation of 15 other impact statements and reviewed 2,812 additional impact statements and related documents to assist other agencies in areas of Geological Survey jurisdiction and expertise.

ADMINISTRATION AND TECHNICAL SUPPORT

For Geological Survey employees in the Washington area, May 1976 marked the completion of a 1-year experiment with an alternative work schedule called "Flexitime." This particular working-hour arrangement allows employees to start their workday any time betwen 7:00 a.m. and 9:00 a.m. and quit 8½ hours later. The experiment proved so successful that it has since been adopted as a permanent policy for Survey employees throughout the United States. The use of Flexitime, which gives workers more control over the structure of their lives, resulted in not only noticeable increases in employee job satisfaction but a 20 percent decrease in short-term absences, a substantial reduction in traffic congestion and tardiness, and, in some cases, longer hours for service to the public. In an evaluation of the experiment, employees cited decreases in commuting time, greater ability to schedule personal activities, and a new absence of anxiety about getting to work "on time" as the most important benefits of the new system. Supervisors noted decreases in overtime usage, better utilization of specialized equipment over a longer operating day, and effective use of "quiet time" at the beginning and end of the day. The Survey is now the largest Federal organization using Flexitime, and its approach is being used as a model for dozens of other similar experiments now underway in both the public and private sectors.

To expand the computational capability of the computers operated by the Geological Survey, an agreement was signed in August 1975 for three compatible time-sharing computers. The three systems will be placed at the major Geological Survey offices in Reston, Va., Denver, Colo., and Menlo Park, Calif. Benchmark testing, technical evaluation, and cost evaluation of equipment proposed by vendors were completed during fiscal year 1976. A contract was awarded to the Honeywell Corporation on August 10, 1976, and installation is scheduled for the three locations in fiscal year 1977.

The technical and scientific information collected by the Geological Survey has to be made available to the general public in the most effective, efficient, and timely manner possible. Three major improvements in this public service were realized during fiscal year 1976: (1) The revision of Government Printing Office procedures for the sale of out-of-print books, which enabled the Eastern Region's Branch of Distribution to receive and fill 5,867 orders for a total of 23,561 out-of-print books that would otherwise not have been available; (2) the use of commercial typesetting and printing contracts to cut down on lengthy delays involved in printing publications; and (3) the addition of a new five-color press, which has significantly increased the Survey's ability to react quickly to the public demand for printed maps.

Approximately 5 years ago the Geological Survey began a program for increasing minority participation in the earth sciences. Currently there are 21 active projects underway with an annual budget of $450,000. The projects are directed to a few major objectives:

- To help establish earth-science programs, or strengthen existing earth-science departments, at colleges with substantial minority enrollments.
- To help young minority people who aspire to careers in the earth-sciences to realize their ambitions by providing study-related employment opportunities for them in the Survey during the summer months and the opportunity for full-time employment upon graduation.
- To stimulate interest in the earth sciences and earth-science careers among younger children of minority groups.

In addition to the assistance programs, the Geological Survey also built an exhibits trailer containing rocks, minerals, instruments, maps, and other paraphernalia of the earth-science profession. From 1972 to 1974, the trailer toured some 27 States, visiting more than 152 minority colleges and secondary schools, and received more than 110,000 visitors. In 1975 the trailer was placed in Rock Creek Park in Washington, D.C., where it now serves as a field laboratory for college students and for the District's public schools.

One of the most successful Geological Survey programs to help advance minority participation in the earth sciences is the joint geology program carried out in cooperation with Howard University in Washington, D.C. After discussions in 1971 with officials of the university, it was decided to re-establish a geology department at Howard. Initially the Geological Survey provided an acting chairman for the department along with three part-time instructors, laboratory equipment, teaching aids, and an assortment of rocks, minerals, fossils, and maps.

In 1972–73, seven courses in geology were offered, and by the fall of 1973 six geology majors had been enrolled. This past year the department had 30 majors enrolled and had acquired a permanent chairman and two full-time faculty members. The Geological Survey still provides some part-time teaching, but by and large the Howard University Geology Department is now self-sustaining.

Perspectives

Role of Earth Sciences in Federal Coal Development in the West

By William R. Keefer

INTRODUCTION

Beneath the prairies and tablelands of the Rocky Mountains and Northern Great Plains lie some of the most valuable natural resources in the United States. Their worth, in terms of present market values, exceeds $1 million an acre over extensive areas. These statements, of course, refer to the vast deposits of coal and lignite (figs. 1 and 2) which make up some two-thirds of the country's estimated total coal resources of nearly 4 trillion tons (Averitt, 1975, p. 14). Largely by-passed in favor of coals from the eastern and central parts of the United States in earlier years, western coal is now considered by many energy experts to be the key to the current national effort to gain a greater measure of energy self-sufficiency.

But the sudden burst of interest in western coal has met vigorous opposition. As the realization of the magnitude of the proposals being made for new mining, processing, and utilization of coal began to grow in the early 1970's, citizens—not only from the affected regions but from across the entire country—commenced to worry seriously about the potential environmental, social, economic, and political problems. Searching questions arose that demanded immediate attention and study. Did the United States in fact need that much additional coal to solve its projected energy shortages? What were the alternatives? Should coal from mines in the West be converted into electrical power at mine-mouth generating plants, or should it be shipped to powerplants closer to the large power markets? Could the arid and semiarid regions of the West be satisfactorily restored after surface mining? Would the influx of new people into sparsely inhabited areas significantly change prevailing life styles and social and economic structures? Were local governments capable of providing the necessary new community services? What would be the effects on air and water quality, on wildlife habitats, and on recreational and scenic values? Should water—already in short supply for traditional uses—be diverted for industrial purposes? These and many other complex and highly controversial matters were identified, debated, and, in some instances, referred to the courts for legal action. Policymakers and decisionmakers thus faced, and continue to face, formidable tasks in providing satisfactory answers and solutions. In many cases, such tasks have been severely hampered by a general lack of information upon which to base solid conclusions.

Much of the hard questioning has been aimed at the Federal Government, which owns a substantial share of the western coal lands and whose surface- and resource-management agencies exert a strong influence over coal development. In response to public pressures, and to conform to the requirements of the National Environmental Policy Act of 1969, the Federal Government has redoubled efforts in recent years to promote policies and programs that seek to strike a proper balance between resource development, land-use planning, and environmental protection. Accordingly, extensive investigations, such as the Southwest Energy Study and the Northern Great Plains Resources Program, were undertaken during the early 1970's, and numerous legislative acts and other regulations have been imposed to achieve this broad objective. An important milestone in Federal coal policy was marked in 1971 by a decision to suspend all Federal coal leasing, except in special circumstances, to allow for a period of time in which

◀The Wilderness Act of 1964 directs the USGS to help in the mineral surveys of national wilderness and primitive areas.

FIGURE 1.—Index map showing major coal-bearing areas (stippled) in the Rocky Mountains and Northern Great Plains.

FIGURE 2.—The Wyodak-Anderson coal bed exposed in the south pit of Wyodak mine, about 8 kilometers (5 miles) east of Gillette, Wyo. This deposit, which is the principal strippable coal in the eastern Powder River Basin, is 27 meters (90 feet) thick and overlain by less than 15 meters (50 feet) of overburden at this locality.

to study the status of existing leases and to determine whether additional leases would indeed be needed to spur new production. At the time of that decision, leases and pending preference rights lease applications, which are a prelude to actual mining operations, existed for lands that contained an estimated 16 and 11 billion tons of federally owned coal, respectively. It was not until early 1976 that new policies were formulated, including specific requirements to speed the development or relinquishment of deposits already under lease and calling for tightly controlled procedures for the granting of new leases (see below).

The Department of the Interior plays a dominant role in surface- and resource-management activities on the public lands. Within Interior, the U.S. Geological Survey is the principal agency that gathers data on the physical characteristics of the land and on the nature of its water and mineral resources. In addition, the Survey is charged with responsibilities for approving, controlling, and monitoring all mining and reclamation on federally owned coal lands. The full range of the professional and technical capabilities of the agency—in geology, hydrology, geochemistry, geophysics, mining engineering, topography, and geography—are currently being brought to bear on the many decisions that have to be made, in the public interest, about the orderly management and development of these resources and on the proper treatment of compex environmental problems inherent in increased coal exploitation and utilization.

PRINCIPAL ELEMENTS OF THE FEDERAL COAL LEASING PROGRAM

The current leasing policy of the Department of the Interior was outlined by a press release issued on January 26, 1976. It includes six major elements:

Energy Mineral Activity Recommendation System (EMARS).—This program, designed by the Bureau of Land Management as the chief surface-management agency of the Department of the Interior, calls for a careful analysis to determine the need for coal and to minimize environmental impacts through (1) development of land-use plans that identify and inventory not only mineral resources but also other values such as agriculture, wildlife, recreation, and water resources; (2) nomination of specific tracts, either for leasing or for nonleasing, by State and local governments, industry, environmental groups, and the public at large and comparison of these nominations with information contained in the land-use plans; (3) analysis of the environmental effects of the proposed lease offering and, if deemed necessary, issuance of an order for the preparation of an environmental impact statement; and (4) determination of the economic value of the coal deposit(s) being considered for lease. As will be noted, EMARS incorporates much of what is listed in the following five policy elements and thus depends heavily upon geologic, hydrologic, coal-resource, and related earth-science data from the U.S. Geological Survey.

Competitive leasing.—All future lease offerings are subject to competitive bidding based on fair market values as determined by Survey coal-resource specialists. The new surface-management and leasing procedures for federally owned coal are detailed in the Federal Register of May 17, 1976 (Vol. 41, No. 96, p. 20252–20261).

Regulation of surface mining and reclamation.—New regulations, adopted by the Department of the Interior on May 17, 1976 (Federal Register, Vol. 41, No. 96, p. 20261–20273), provide strict standards to be enforced by mining supervisors of the U.S. Geological Survey for all coal-mining activities on Federal lands. Included in the new regulations are requirements for coal-mine operators to minimize, control, or prevent adverse environmental effects—such as soil erosion, pollution of surface or ground water, and disruption of the normal flow of surface and ground water—and to restore the land to useful purposes after surface mining.

Regional Environmental Impact Statements (EIS).—Situations in which Federal actions concerning coal development involve the granting of individual leases at widely separated localities, but which nevertheless combine to produce a cumulative effect within a defined geographical area, require that regional environmental impact statements be prepared according to the provisions and guidelines set forth in the National Environmental Policy Act of 1969 (see discussion below). Nine such regional statements have been or are being prepared, principally by personnel of the U.S. Geological Survey and the Bureau of Land Management, for areas of planned or proposed development in North Dakota, Montana, Wyoming, Utah, Colorado, and New Mexico.

Diligent Development.—Requirements for actual performance in mining operations and schedules for payment of royalities are designed to foster development of Federal coal in a timely fashion, but only of those coals that can be produced in an environmentally safe and economically sound manner. Specific consideration must therefore be given by the U.S. Geological Survey staff to the quality and quantity of coal resources and to environmental conditions in order to evaluate the potential for mining in existing and future lease tracts. This procedure is aimed particularly toward processing existing preference right leases and toward eliminating speculation in the leasing of federally owned coal.

Adherence to "Commercial Quantities" Criteria.—Determination of "commercial quantities" is based on whether a given coal deposit is judged by resource specialists to be of such character and size that a prudent person would be justified in the expenditure of his time and money with a reasonable prospect of profitability in developing a mine. This definition is being applied in the processing of existing preference right lease applications to determine whether a given lease should be granted or denied.

Coal Leasing Amendments Act

Recently (August 1976), legislative action termed the "Federal Coal Leasing Amendments Act of 1976" (for purposes of amending the Mineral Leasing Act of 1920) directs the Secretary of the Interior to initiate a comprehensive exploratory program within the U.S. Geological Survey to obtain sufficient information for evaluating the extent, location, and development potential of the known recoverable coal resources of Federal coal lands. Further, the act calls for such data as are necessary to estimate the amounts of coal that are recoverable by deep-mining operations and by surface-mining operations, respectively, within a given lease tract and requires that these data be made an integral part of a comprehensive land-use plan for the area in question.

Compliance with NEPA

One of the most far-reaching influences on the conduct of Federal coal development in the West is that embodied in the National Environmental Policy Act (NEPA) passed in 1969. This act requires that an environmental impact statement be prepared for all situations in which a major Federal action is being proposed. As mentioned previously, it has already been determined that proposals involving the development of several individual but scattered coal lease tracts within a defined geographic area constitute a major Federal action and therefore require the preparation of a regional environmental impact statement. Among its many provisions, the act directs Federal agencies to adopt procedures which will insure that presently unquantified environmental values are given appropriate consideration in decision-making along with economic and technical considerations. A report detailing the characteristics and conditions of the existing environment is therefore specifically required, together with an analysis of the environmental impacts of the proposed action as well as evaluations of the impacts related to suggested alternative courses of action. All these items require basic and interpretive earth-science-data inputs from the U.S. Geological Survey.

Adherence to air quality standards

Air quality standards established by the Environmental Protection Agency place a maximum limit on the amount of sulfur dioxide fumes—0.52 gram per million joules (1.2 pounds per million British thermal units)—that can be emitted during coal combustion. Although western coals commonly contain less than 1 percent sulfur, their heat value is also low enough to become a critical factor in many cases. Strict adherence to Environmental Protection Agency standards therefore requires obtaining specific data on coal quality—data such as are now being obtained in U.S. Geological Survey and U.S. Bureau of Mines laboratories—for all deposits being considered for development.

EARTH-SCIENCE DATA REQUIREMENTS AND THE ROLE OF THE U.S. GEOLOGICAL SURVEY

Knowledge and understanding of coal resources, and of the physical environment in which these resources are located, form the cornerstone for all phases of the Federal coal-leasing and coal-development process. Because coal is a layered sedimentary rock occurring only in certain geologic formations, geologists usually know where to find it and can estimate roughly about how much is present. These kinds of general information, obtained during many decades of geologic mapping and coal-resource and related studies by U.S. Geological Survey and other geologists throughout the sedimentary basins of the West, in former years met most of the needs for data about coal-bearing public lands. At present this accumulated body of general knowledge is of considerable value, especially in the making of broad, basinwide resource appraisals. But the new coal programs clearly depend upon more detailed information than is now available for most of the principal coal fields of the West if these programs are to achieve orderly and optimum development of federally owned coal resources with an acceptable environmental impact and are to assure a fair monetary return to the public.

Currently, U.S. Geological Survey geologists are engaged in a wide range of investigations designed to upgrade the existing coal-resource data bases. The bulk of the work in progress involves detailed geologic mapping and stratigraphic studies of coal beds and related rocks and limited drilling in selected areas within most of the major western coal basins. The resulting maps and other reports show the distribution, thickness, and other characteristics of coal beds, and the information can be used for comprehensive coal-resource evaluations at specific sites and for determinations of fair market value for competitive leasing purposes (for example, see Bowers, 1973; Fassett, 1966; Kent, 1976; and Roehler, 1976). To a lesser extent, broad regional compilations and syntheses of data are also being pursued to establish regional stratigraphic and structural relations and coal depositional patterns that can be applied to predict coal occurrences in areas yet to be explored in detail (fig. 3). These kinds of data are especially useful in preparing regional land-use plans, in providing a basis for the initial selection of tracts for future leasing, and in identifying critical information gaps that need to be filled by new mapping and drilling. Additional activities are directed toward improving methods for identifying and delineating coal beds through use of seismic, magnetic, sonar, and borehole techniques. Another important program element is a computerized coal-resource information system (National Coal Reserve Data System) which is being maintained for updating and manipulation of data.

Coal quality is another vital factor in resource evaluation and environmental impact assessment. Physical and chemical properties of coal may vary markedly from one bed to another within the same area and from place to place within the same bed. Rank, heat value, sulfur content, and proportions of moisture and ash determine, in large measure, the overall value and best uses of coal. In addition, the amounts and distribution of minor constituents, some of which may be harmful to human and animal health and some of which may have economic potential as by-products, must also be thoroughly studied and evaluated. Considerable efforts are currently being made by U.S. Geological Survey geologists and geochemists to obtain and analyze representative samples of coal from all the western coal fields. Many data have already been accumulated and published (for example, see Swanson and others, 1976, p. 337–479), and investigations are continuing across a broad front.

Water is a critical commodity in the arid and semiarid regions of the West. In fact, water availability—rather than coal availability—may be the most critical factor in determining the kind and size of the development that eventually takes place in some

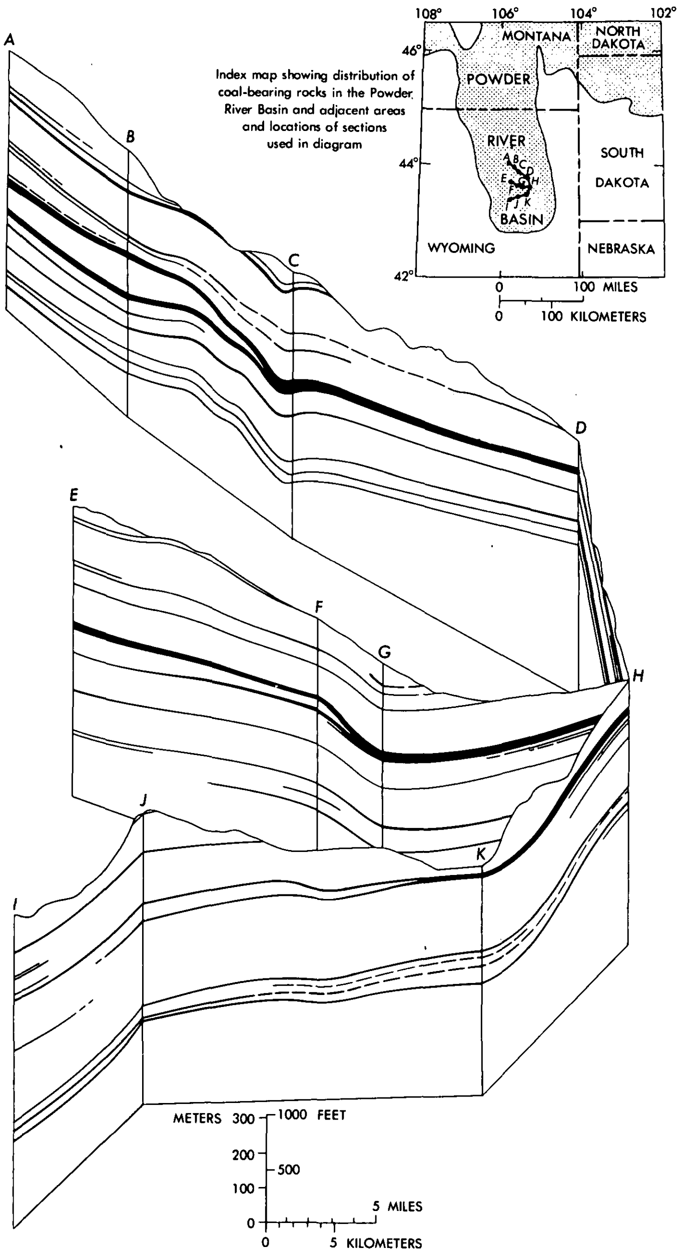


FIGURE 3.—Diagram showing distribution of coal beds (solid lines, but dashed where correlations are uncertain) within several hundred square miles of the Powder River Basin in northeastern Wyoming. Information is based chiefly on interpretation of drill data (sections *A*, *B*, *C*, and so on are drill holes) by N. M. Denson and J. H. Dover, U.S. Geological Survey. The present land surface is shown by the uneven profile at the top of each section panel.

areas. Concerns over water supplies, as well as the potential disruption and pollution effects of surface mining on existing surface- and ground-water systems, have resulted in Federal programs calling for the extensive collection of baseline hydrologic data throughout the western coal areas. Information on depth and movement of shallow ground water and on patterns of weathering, erosion, and sediment yield is also required by regulations controlling the mining of federally owned coal.

Studies of the quality and quantity of surface and ground water in the Western United States have long been a traditional part of the basic program of the U.S. Geological Survey. The large body of accumulated hydrologic data is now being applied toward (1) evaluating water availability to meet the water needs for coal mining and processing, for energy conversion plants, and for surface-mine reclamation; (2) assessing potential effects of surface mining on existing hydrologic conditions; and (3) monitoring changes in hydrologic conditions as mining and reclamation proceed. New and/or expanded hydrologic investigations, tailored to specific requirements in the new Federal coal programs, have also been initiated. One of the most significant of these is an evaluation of the potential of the Madison Limestone aquifer in the Powder River Basin of northeastern Wyoming and southeastern Montana to supply water for coal-slurry pipelines and other industrial uses.

The overriding goals of Federal coal policies and programs are to produce adequate supplies of coal and to avoid significant damage to the existing environment. To achieve these goals, and to assist in the preparation of required environmental analysis reports and impact statements and in the enforcement of Federal mining regulations, it has become necessary to establish a baseline of existing environmental conditions in each of the principal coal-bearing areas of the West. Such baseline data are needed for predicting the changes in the environment that will be caused by future mining and associated activities and are also needed then for monitoring those changes through close observations and quantitative measurements as they take place. Because potential environmental problems vary considerably from one area to another, both in kind and in degree, it is just as important to pursue broad regional investigations to assess the cumulative effects of long-term, large-scale development on an entire region as it is to determine impacts at specific local sites.

The preparation of a comprehensive environmental baseline involves the acquisition of large amounts of integrated geologic, hydrologic, geochemical, and engineering data, a task for which the U.S. Geological Survey is well suited in view of the multidisciplinary aspects of its professional and technical staff. Currently, Survey earth scientists are engaged in mapping and related studies of land forms, landscape characteristics, and active geologic processes in selected areas of the western coal fields. Interpretations of these data are being used to predict how future mining, reclamation, and industrial activities may be affected by alteration or disturbance of the present landscape, and, conversely, how the landscape may react to these modifications. One such area being investigated is in the eastern Powder River Basin of Wyoming (fig. 1), for which preliminary results have been published (Keefer and Hadley, 1976). Additional studies are directed toward identifying geologic hazards, determining surface- and ground-water conditions, measuring erosion rates and sediment yields (fig. 4), and evaluating factors that bear on reclamation potential, all of which contribute to advance understanding of potential environmental problems.

Knowledge of the distribution and concentration of chemical elements in the natural environment is likewise of prime importance in efforts to predict, measure, and interpret changes in existing environmental conditions as coal exploitation and related industrialization take place. Redistribution of elements in landscape materials resulting from these activities, for example, could be detrimental, or in some instances beneficial, to future uses of the affected land and to the quality of ground and sur-

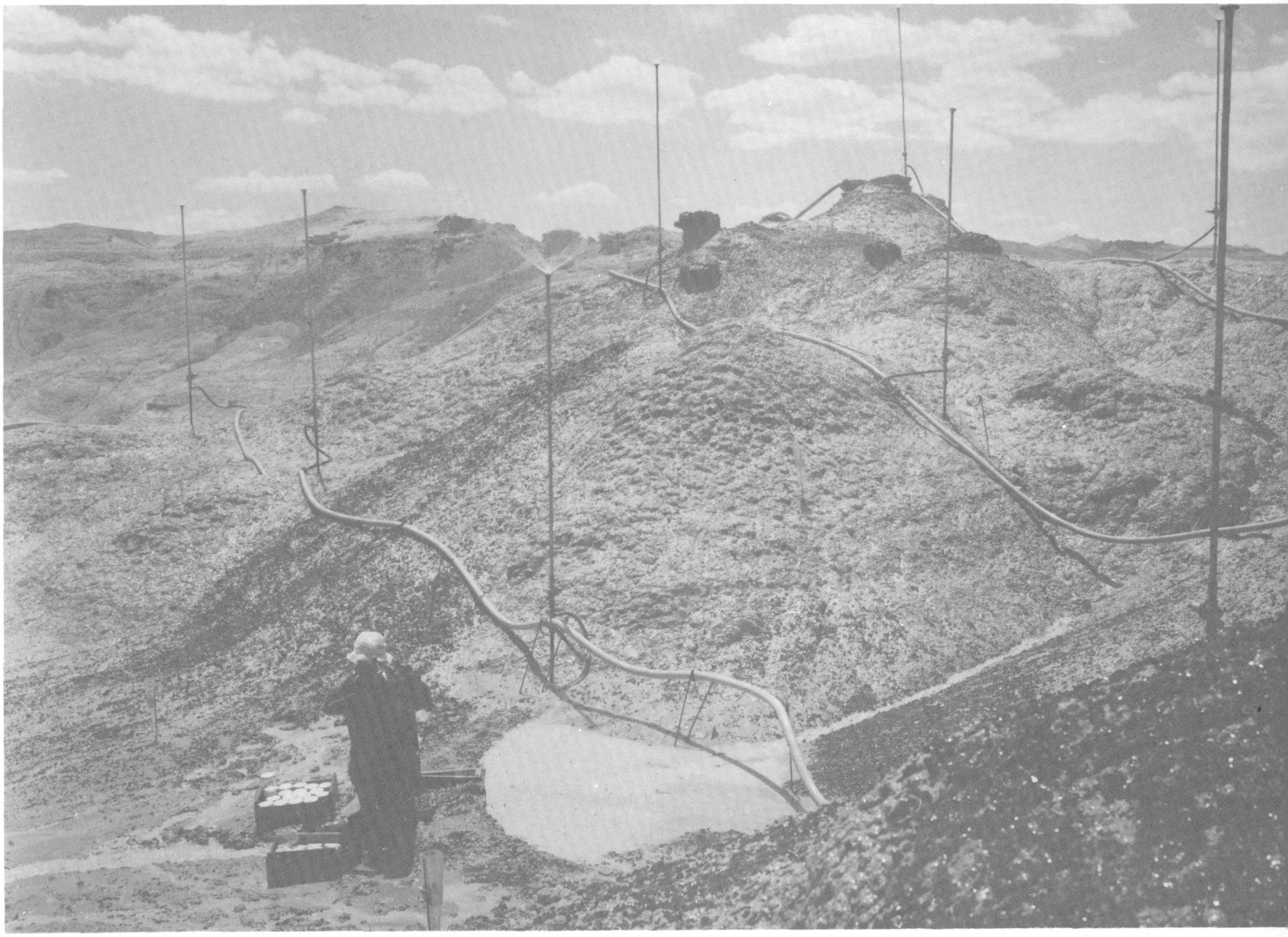


FIGURE 4.—A recently developed rainfall simulator is used by the Geological Survey to determine runoff and erosion rates from various types of terrain. The simulator is shown here in operation on badlands of the Cretaceous Fruitland Formation in New Mexico, a possible coal surface mining site. About 3.8 centimeters (1½ inches) of "rainfall" in 45 minutes is applied to an area of approximately 325 square meters (3,500 square feet). Outflow from the area is trapped in the small pond (center foreground) and then released and measured through a calibrated flume (left side of the pond). Water samples are then obtained periodically (the boxes are filled with containers for this purpose) to determine the concentration of sediment in the runoff from the test area.

face water. Geochemical studies and sampling programs are being conducted by U.S. Geological Survey personnel in several of the coal-bearing regions of the West with current emphasis on the Northern Great Plains (U.S. Geological Survey, 1976). Soils, plants, rocks (including coal), and surface and ground water are being analyzed to determine their geochemical properties, both locally and regionally, as a basis for establishing baselines in advance of the large-scale modifications that are now anticipated from mining and related activities. Concentrations of trace metals, such as arsenic, mercury, and selenium, and other potentially harmful elements receive special attention because they can cause environmental problems if not detected and treated accordingly. In addition to baseline geochemical studies, sampling and analytical programs are also being undertaken near some of the existing coal-fired electrical generating plants to determine what effects, if any, stack emissions may have on the natural materials of the surrounding landscapes (see, for example, Connor and others, 1976, p. 56).

All the U.S. Geological Survey earth-science data-gathering programs discussed above focus directly on the agency's decisionmaking responsibilities in coal-resource management and mining regulation. Specific responsibilities include classifying federally owned coal lands, defining known coal-resource areas, delineating logical mining units, assessing nominations for competitive coal leasing, determining fair market value for purposes of evaluating competitive bids and establishing royalty payments, and approving and supervising all mining and reclamation activities on federally owned coal lands. The needs for earth-science data are clearly evident in all phases of these activities, but perhaps the needs are best exemplified by the duties imposed on the Survey's mining supervisors for enforcing the many provisions embodied in the Federal coal-mining regulations. Proper and effective discharge of these responsibilities involves not only detailed knowledge of coal resources and mining and reclamation practices, but of the whole range of environmental matters as well.

SUMMARY

U.S. Geological Survey scientists, engineers, and technicians bring a unique, integrated team approach to the acquisition and interpretation of basic land, water, mineral resource, and environmental data and to the application of these data for the sound management of federally owned coal resources and for the solution of complex environmental problems inherent in increased coal production and utilization. The multidisciplinary aspect of the Survey's earth-science data-gathering activities can be summarized as shown in the following table:

	Some principal elements in the Federal coal-leasing and coal-development system that require earth-science data				
Major supporting disciplines in the U.S. Geological Survey	Coal-resource evaluation	Land-use planning	Environmental impact analysis	Lease tract selection	Regulation of mining and reclamation
Geology	X	X	X	X	X
Hydrology	---	X	X	X	X
Geochemistry	X	---	X	X	X
Geophysics	X	---	---	---	---
Mining Engineering	---	---	---	X	X
Topography	X	X	X	X	X
Geography	---	X	---	---	---

X, important data input from the discipline indicated.

Earth science plays a vital role in each step of the decisionmaking process from the initial coal-resource assessment for the selection of lease tracts to the final approval and supervision of actual mining operations. Much of the current U.S. Geological Survey involvement in western coal development is but an expansion or modification of scientific, technological, and management activities that have formed an integral part of the agency's basic program for many years. But the coal regions of the West cover vast areas, and only a cursory inventory of data indicates that existing knowledge is as yet inadequate for many of the tasks and decisions that lie ahead. However, new Federal coal programs, and the correspondingly enlarged responsibilities of the U.S. Geological Survey, have had the immediate effects of sharply focusing attention on the urgency for more extensive earth-science data-gathering activities and of emphasizing a greater need to direct them in the most timely, efficient, and coordinated manner.

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How Much Water in a 12-ounce Can? A Perspective on Water-Use Information

By I. C. James II, J. C. Kammerer, and C. R. Murray

A pint a day,
is all I say,
to keep my whistle wet.
But so much more,
I have to pour,
before my table's set!

B. L. Anon.

WATER USE AND ITS VARIATIONS

The 12-ounce can

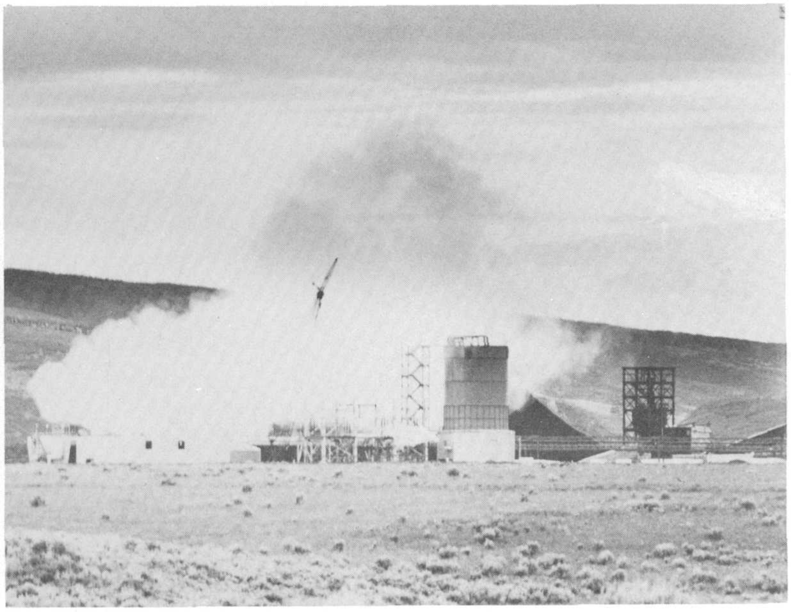
On a hot afternoon after mowing the lawn, or after returning home from a round of golf, or when just resting from your daily toil, have you ever gone to the refrigerator to satisfy your thirst with a 12-ounce (355-milliliter) can of your favorite beverage? You want to relax and reflect on the activities of the day, but your act of consuming the contents of that 12-ounce can is the culmination of a long chain of processes requiring energy, materials, water, labor, and management. Let us consider your effect as a consumer on the water resources of the Nation and try to answer the question, "How much water is in a 12-ounce can?" Twelve ounces, of course—three-eighths of a quart, or, in the metric system, 0.355 liter (0.000355 cubic meter). But wait a minute; let's rephrase the question to "How much water did it take to manufacture the 12-ounce can?" Doesn't it take water to clean the can before it is filled, water to produce the steel or aluminum used in the can, water to mine the coal that is used in converting iron ore to metallic iron in making steel used in the can, and water for cooling in the thermal electric plants that supply these industries with electric energy?

Let us use that can from which you were about to pour your 12-ounce drink as an example for exploring the ramifications of one of our simple daily water-consumption decisions. The fabrication of metal cans requires a small quantity of water for a variety of in-plant purposes such as cooling and washing. In 1968 nationwide water withdrawals for this industry totaled 7 billion liters (7.4 billion quarts). The average in-plant water use per can is about 0.2 liter of water withdrawn. This small direct use of water is an obvious consequence of your consumption of a beverage in a 12-ounce can. But what of the indirect uses of water necessary to sustain the industries that directly supply the can manufacturers with goods and services?

Using 1967 data, it is estimated that supporting industries directly supplying the metal-can fabrication industry withdraw about 23 liters (24.3 quarts) of water per can produced. Each of these supporting industries in turn must purchase goods and services from still other industries. As those purchases "ripple out" through our economy, additional economic sectors become involved. The accumulated water withdrawals for all the indirect suppliers total 40 liters (42.3 quarts) per can, thus increasing water withdrawals by both direct and indirect suppliers to about 63 liters (66.6 quarts) per can.

You might question the need for this type of information; certainly, your individual decision to

Cooling-water intake.



Powerplant and cooling towers.

Cooling-water discharge.

ELECTRIC POWERPLANT NEAR HAYDEN, COLO.

consume the contents of one can has little impact on water use. In the aggregate, however, the water-use decisions of a large group of individuals, or national policy decisions on water use that affect many individuals, may have a considerable impact. Also, the accumulated indirect effects of an industrial water use are often more significant than the direct water use in that industry, as in the example where an additional 63 liters (66.6 quarts) per can is withdrawn by direct and indirect suppliers to a can manufacturer.

Estimates of indirect water-use effects are made by utilizing a technique known as input-output analysis. For this type of analysis, a table is constructed to show the value of direct input from each economic sector in the United States that goes into a unit value of output for all the other economic sectors. By applying mathematical procedures to the information in the table, a new table can be constructed to show total direct and indirect inputs from each economic sector for a unit value of output in each of the other economic sectors. Multiplying these values by the average water use per unit value of output in all of the economic sectors gives the water use for a unit value of output from any particular economic sector. Figure 5 shows in simplified form how this concept may be developed and applied to the water use required to produce one 12-ounce can.

As the total amount of water used by both direct and indirect suppliers for the production of a 12-ounce can was found to be about 63 liters (66.6 quarts), many times the direct use, so may indirect water use for the support of production in other economic sectors be estimated, using similar methods. For example, an estimate can be made of the amount of water used for the production and shipment of $10 billion worth of grain, as can an assessment of water-use effects of national legislation concerning highways, housing, energy, and environmental measures. Possibly too often the prescribed solution to a national problem has been proposed without a thorough evaluation of the impacts of that solution. Would a legislative ban on nonreturnable containers alleviate solid-waste disposal problems? And how would that ban affect costs, energy use, water use, and mineral use? Because almost all regulations have negative as well as positive effects, it is desirable that all effects be expressed in specific numbers, if possible, and then debated before a legal or policy commitment is made so that water-use changes can be estimated.

A beverage can may be made entirely of aluminum, or it may be bimetallic, having a steel bottom and steel sides and an aluminum top. The steel industry and the aluminum industry differ from each other in their requirements for water, energy, minerals, and other economic inputs. The aluminum-reduction industries (converting ore to metal), for instance, require a relatively large amount of electric energy; therefore, traditionally, aluminum-reduction plants have been located in areas where hydroelectric power is plentiful and relatively inexpensive. The

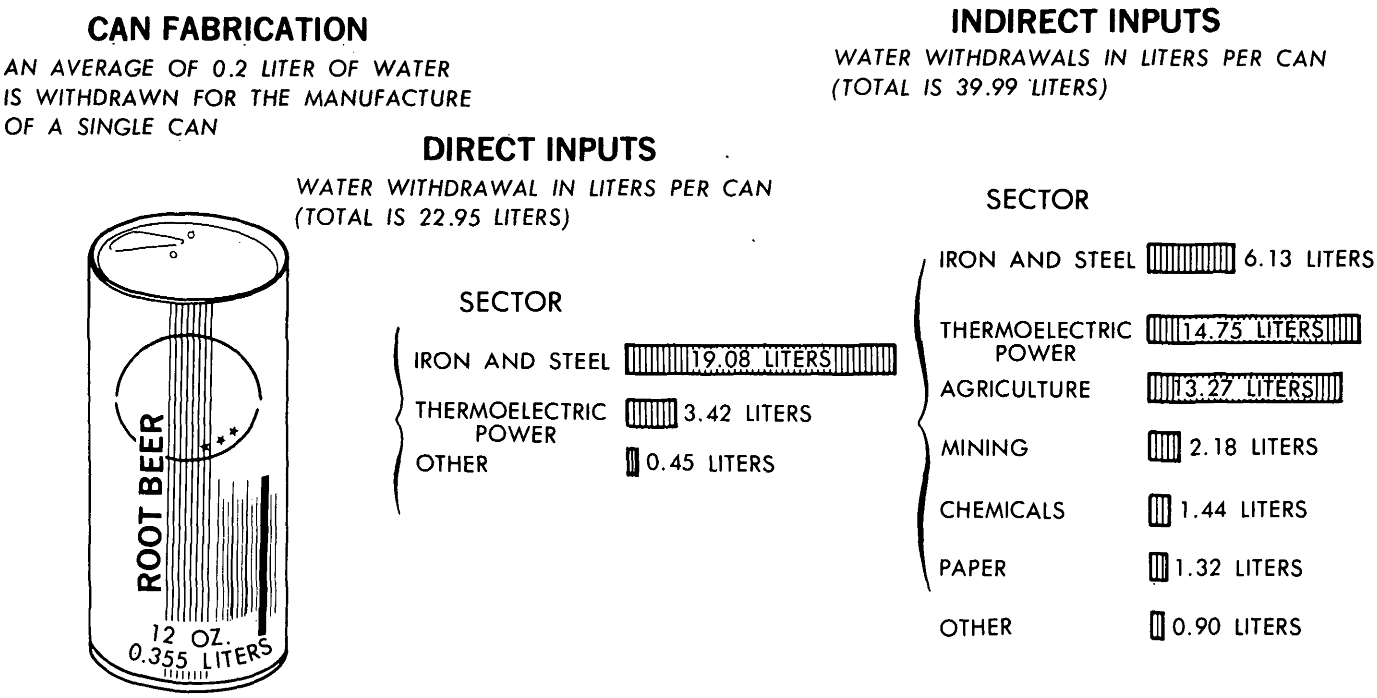


FIGURE 5.—Water withdrawals by direct and indirect suppliers for the fabrication of a 12-ounce beverage can. (1 liter equals approximately 1 quart.)

production of one aluminum can requires the equivalent of 10 cubic meters (about 11 short tons) of water going through turbines in a 15-meter (50-foot) high dam. This also is a water use, but the water is not withdrawn from the river; therefore, the quantity and the quality of the water are not perceptibly affected.

Water for steel: wide variations

The largest indirect water use in the example of the 12-ounce can is in the iron and steel industry. A more detailed look at this industry illustrates some interesting water-use facts that must be considered in producing water-use information.

Steel-industry data have often been used to show the wide range in water use that occurs within a single industry. Inasmuch as more than 95 percent of gross water use in steel plants is for cooling, comparisons of quantities used for cooling are very significant. Data (gross use, including reuse) compiled by Walling and Otts (1967, p. 364) for 25 integrated steel plants and steel-processing plants showed ranges of 14 to 409 cubic meters (3,750 to 108,000 gallons) required to produce 907 kilograms (1 short ton) of ingot steel. As these authors pointed out, some factors that affect cooling-water requirements are the age and condition of a plant, procedures of operation, and quality of cooling water. Costs of water withdrawal also significantly affect the amount withdrawn. Russell and Vaughan (1976) estimated that a change in the price of water from $0.0044 to $0.01 per cubic meter would reduce water withdrawals by more than 80 percent; further price increases, however, would have little additional effect. The quantity of water actually consumed would remain about the same or increase slightly with price increases.

Water uses in the home and per capita use

Household uses of water also vary greatly in magnitude. Household uses are internationally expressed in terms of liters (1 liter equals 1.0567 quarts) per day per person, and depend upon such characteristics as climate, accessibility (connected or not connected to a public water-supply system), water quality, water pressure, cost, outdoor needs (lawn, garden, pool), and whether or not the water supply is metered. Although a person needs less than 2 liters (2.1 quarts) of water a day (from liquid and solid foods) to survive, in the United States, the actual daily household use (indoor and outdoor) ranges from less than 40 liters (42.3 quarts) per capita in some homes without plumbing to several hundred liters per capita in affluent homes with watered lawns. Lawn watering and toilet flushing are the two largest household uses of water. Table 1 shows a hypothetical example of average daily water use in the future by a family of four (assuming that family has two bathrooms, a garbage-disposal unit, a dishwasher, an automatic laundry, and two automobiles).

TABLE 1.—*Anticipated daily domestic uses of water by a family of four. (Adapted from Reid, 1965, p. 18.)*

Family use of water	Average daily use: Liters per day per family	Liters per day per capita	Gallons per day per family	Gallons per day per capita
Drinking and water used in kitchen	30	7.6	8	2
Dishwasher (3 loads per day)	57	14	15	3.75
Toilet (16 flushes per day)	363	91	96	24
Bathing (4 baths or showers per day)	303	76	80	20
Laundering (6 loads per week)	129	32	34	8.5
Automobile washing (2 carwashes per month)	38	9.5	10	2.5
Lawn watering (180 hours per year)	379	95	100	25
Garbage disposal unit (1 percent of all other uses)	13	3	3	0.75
Total	1,312	328.0	346	86.50

Daily per capita water use in the United States is sometimes expressed as a nationwide average for a given year. The average daily per capita *household* use for 1970 was about 280 liters (297 quarts) per person for homes connected to public water-supply systems; however, the total average daily per capita use of freshwater for *all* withdrawal uses—for agricultural irrigation, self-supplied rural homes (domestic and livestock uses), self-supplied industries, and public supplies—was nearly 6,000 liters (6,360 quarts) per capita for the same year (table 2).

TABLE 2.—*Estimated daily per capita use of freshwater in the United States.*

	Gallons per person per day	Liters per person per day
Water required for survival	Less than ½	Less than 2
Average personal consumption of water (liquids and water in foods).	About 1	About 4
	National averages in 1970	
Domestic uses of all kinds (indoor and outdoor uses); home connected to public water-supply system.	75	280
Public water systems, including public-supply water for domestic, industrial, commercial, and public (fire-fighting, parks, etc.) uses and water-system losses (population[1] served in 1970: 165,000,000).	166	628
Self-supplied industrial use (total population[1] in 1970: 205,900,000).	777	2,940
Combined public, rural, industrial, and irrigation uses (excluding hydroelectric power).	1,550 (If saline water use is added, per capita use is 1,800 gallons, or 6,810 liters.)	5,870
Water for hydroelectric power	13,600	51,500

[1] Includes Puerto Rico and Virgin Islands (U.S.).
Sources of data for 1970: Murray and Reeves, 1972; but for domestic uses, Kammerer, 1976.

WATER AS A COMMODITY: HISTORY AND LEGAL CONCEPTS

One of the most significant trends in our water-use picture is the change since colonial times, when water was considered an essentially free resource, to the present, when water has become a very expensive commodity in some locations.

English common law regarded water as a common-property resource for those who owned land along streams (riparian owner) to use freely. The only large uses were for power in milling and manufacturing processes, and those uses were not consumptive or otherwise detrimental to water used by other riparian owners. This doctrine was brought by the colonists to the Eastern United States where it still strongly influences the water laws of the Eastern States. On the other hand, water legislation in most of the Western States was more influenced by Spanish law and custom, and it was generally adapted to meet the particular needs of miners, farmers, and ranchers in arid regions. The appropriation doctrine which evolved as a key element of western water law held that the person who first diverted water and put it to a beneficial use had a right to maintain that diversion and use. Any subsequent upstream diverters could only operate on the condition that prior rights were being satisfied. This was a doctrine that recognized water rights as real property, but it frequently did not provide for marketing arrangements, and the concept of setting a price for water still had not been developed. The idea of free water for those who would develop and use it fit well with the concepts of westward expansion; the natural resources of the West were presumed to be available for those with the initiative to exploit them.

As water needs of the public increased for such purposes as fire protection, dust control, sanitation, disease eradication, and domestic consumption, there was a significant increase in the extent of water-supply systems, leading to a general transition from private to public ownership of water companies. In the West, the simple irrigation systems on individual farms gave way to large irrigation districts that required the capital and efforts of many. User charges to recover the capital costs and provide for operating and maintenance costs became accepted, but the mechanisms for pricing and marketing water rights developed slowly.

As increases in water use deplete the easily developable supplies, more costly additional supplies are being sought. As the costs of water go up, water resources become more and more like other economic commodities for which there are supplies, demands, and a pricing and marketing structure to balance the supplies and demands. The influences and concepts of economists are being utilized in the study of water use. More commonly, water is being thought of as another input to a production process for which substitutions can be made. In the case of industry, treatment and recycling of water can substantially reduce withdrawals, but only with the expense of additional capital investments and increased energy and chemical costs. To be able to predict water use, some knowledge of the options for substitution that the factory, farm, or home manager has available is necessary so that the impacts of their decisions can be anticipated as the prices of water and other commodities change.

These few examples of water use and its variations and economic ramifications illustrate only some of the complexity and importance of water-use information. U.S. Geological Survey programs that define the time and space availability of the Nation's water supplies provide information, which—when compared to the water demands of industrial, agricultural, and municipal users—provide an assessment of our abilities to meet these current and future demands. However, studies and assessments of water use have not achieved the detail or degree of accurracy that is now found in water-supply information. Because water use is substantially affected by variables—economics, technology, and custom—much different than those affecting water supply, the methods and techniques for measuring and projecting water use must be developed from concepts and technical disciplines that go beyond the natural and physical sciences. The U.S. Geological Survey is cognizant of these needs and, in cooperation with State and local governments, is developing programs to acquire water-use data that are of the same order of accuracy as its water-supply data.

Simply stated, in the hydrologic cycle water moves from the atmosphere to the land and sea and back again into the atmosphere. Water use—both natural and controlled—occurring during the land-sea part of the hydrologic cycle includes (1) evapotranspiration from irrigated, nonirrigated, and wild vegetation, (2) evaporation from water surfaces, (3) withdrawal of water from streams, lakes, reservoirs, and wells, (4) dilution, assimilation, and transport of wastes, and (5) occupancy of surface waters as a habitat (by fish, wildlife, and so forth), a transport route (navigation), and a recreational facility.

For purposes of estimation and measurement, these water uses are grouped into three principal categories:

1. Withdrawal (or "off-channel") uses, such as withdrawal from a well or diversion from a stream, for public supplies, irrigation, and industry;
2. Nonwithdrawal, such as for hydroelectric power, navigation, recreation, preservation of wildlife and sport fishing habitat, salinity control, waste dilution, and transport;
3. Nonsupply uses (also sometimes referred to as "water losses" or "preemptive consumptive use"), such as evaporation from lakes and reservoirs and evapotranspiration from nonirrigated food and fiber crops.

Withdrawal uses are the most measurable and measured of the three categories of use, but they are measured far less frequently and systematically than water supplies (for example, the flow of water in streams). Figure 6 compares a few of the national water-use statistics for 1970 with respect to average quantities withdrawn and the part of the withdrawals that was consumed.

Nonwithdrawal uses (water uses that are not dependent on diversion of water from ground- or surface-water sources) may be categorized as flow uses and onsite uses. Navigation, hydroelectric power, sport fishing habitat, freshwater sweetening of saline estuaries, and the disposition and dilution of waste-

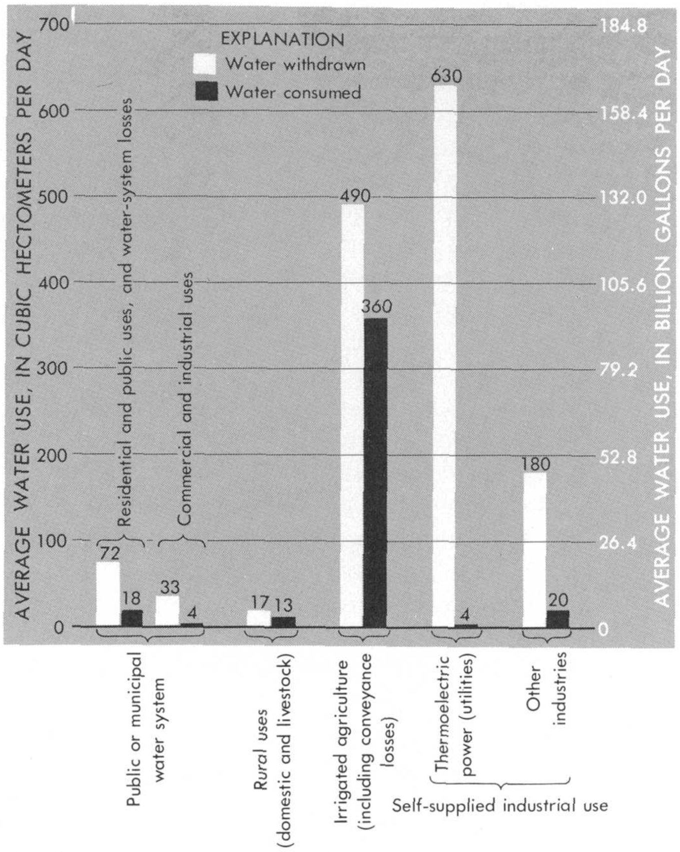


FIGURE 6.—Estimated water withdrawn and water consumed in the United States in 1970. Totals above each bar are in metric units; 1 cubic hectometer=1 million cubic meters=264 million gallons. (Adapted from Murray and Reeves, 1972.)

water are commonly classified as flow uses; all these uses are accomplished by free-flowing water moving in a defined channel. Onsite uses are of two principal types: (1) water use which occurs in a watercourse, lake, reservoir, or other body of water, and (2) water use resulting from improvement of natural conditions, a use that is sometimes called "preservation use." Stream evaporation from an increased heat load is an example of the first type of onsite use, and water lost from improvements to swamps, wetlands, and fish hatcheries are examples of the second type. Many of the nonwithdrawal uses cannot be readily measured, thus presenting a hydrologic challenge for more accurate determination and for evaluation of their effect on the quantity and quality of water resources for all uses.

Perhaps surprisingly, more than 10 times as much water is used consumptively—in the category, "nonsupply uses"—by the naturally occurring processes of evaporation and transpiration in the growth of vegetation (forests, grasses, and nonirrigated crops) in the United States than is supplied nationwide for all withdrawal uses. The "nonsupply" water returned to the atmosphere by this natural process is also referred to as a "consumptive and preemptive use," or sometimes as "water losses"; it is the remainder after runoff (streamflow) has been subtracted from precipitation. The sustained availability of large quantities of this nonsupply water—most of which occurs as soil moisture—constitutes a major natural resource. Without significant amounts of local soil moisture, commercial agriculture, as well as public parks and residential lawns and gardens, would not be possible unless there were major importation of water from other locations. Another nonsupply use is the evaporation of water from large water surfaces, such as lakes, rivers, and snow and ice fields. An extremely rough estimate of average nonsupply water use in the conterminous United States is 16,000 cubic hectometers per day (20 inches per year times 3 million square miles), most of which is evapotranspiration from vegetation. Nace (1967, p. 4) has pointed out that actual daily per capita water use for all purposes in an advanced society amounts to "many thousands of gallons, drawn chiefly from soil moisture."

SUPPLY VERSUS DEMAND (WATER USE) IN 1970

In the general terms of average nationwide water supply (based on streamflow), the United States has a great abundance of water—more than 3 times as much as was withdrawn in 1970 and 14 times as much as was consumed during usage and therefore unavailable for reuse. Table 3 shows some supply-versus-demand relationships for the aggregated eastern, central, and western parts of the Nation as well as for all the 48 conterminous States. What these data do not reveal is the great time and space variability and inequality of supply versus demand.

With respect to variability of supply, table 4 shows the wide variations in flow of 8 large streams during the past 15 years. Even the range in long-term average runoff per unit drainage area among these streams is significant. For example, using the 30-year reference period, 1941 to 1970, as a common time base for making comparisons, the runoffs from the Delaware River and Ohio River basins are more than 11 and 8 times, respectively, the runoff of the Missouri River basin; this fact is obviously a natural consequence of the drier climate of the Missouri River drainage area in comparison with the more humid conditions that prevail in the Eastern States.

The Southwestern United States is the only area of the Nation where the amount of freshwater that is consumed actually exceeds the average runoff. Murray and Reeves, describing water use in 1970 (1972,

TABLE 3.—*Estimated water supply versus water demand—regional (eastern, central, and western) water use in the conterminous United States in 1970. (Adapted from Murray and Reeves, 1972.)*

Region	The water we have . . . Average flow of streams in the 48 conterminous States (Includes ground-water component of base streamflow): Area, 1,000 square kilometers	Area, 1,000 square miles	Stream discharge, Cubic hectometers per day	Stream discharge, Thousand cubic feet per second	The water we use . . . . Water withdrawn and water consumed: Population in 1970, Million people	Withdrawals in 1970, Cubic hectometers per day	Withdrawals in 1970, Billion gallons per day	Water consumed 1970, Cubic hectometers per day	Water consumed 1970, Billion gallons per day
31 Eastern States [1] (8 eastern regions)	2,713	1,047	2,800	1,100	144.7	770	200	45	12
10 Central States [2] (parts east of Continental Divide; 5 central regions)	2,980	1,150	640	260	27.1	240	64	110	28
7 Western States (parts west of Continental Divide; 5 western regions)	2,132	823	1,100	460	30.3	370	100	170	45
48 States (conterminous United States)	7,825	3,020	4,500	1,800	202	1,400	360	320	85

[1] Excludes some parts of Arkansas, Iowa, Louisiana, Minnesota, and Missouri.
[2] Includes parts of an additional 5 States.
NOTE: Stream-discharge and water-use data rounded to 2 significant figures.

p. 13), stated "Both water withdrawals and consumption in the Lower Colorado Region exceed the supply originating in the area; this is made possible by augmentation of the supply by inflow of water from the Upper Colorado Region, importation of surface water, repeated withdrawals of the same surface water, and mining of ground water."

Water use in 1970 is compared with average annual runoff in figure 7. The first number shown within each region is the percentage of average runoff *withdrawn*

FIGURE 7.—Water withdrawn (used) in 1970 as a percentage (first number) of annual runoff (long-term average), and water consumed in 1970 as a percentage (second number) of annual runoff, in each water-resource region in the conterminous United States. (Adapted from Murray and Reeves, 1972, p. 17.)

TABLE 4.—*Maximum and minimum flows and runoff of eight large rivers since 1960*

[The flow of streams (and therefore the supply of surface water) varies not only from place to place, but also from year to year, season to season, month to month, day to day. For example, on the eight large streams listed below, the highest flow of a given stream since 1960 was from 9 to nearly 600 times greater than the lowest flow on the same stream]

Station	Drainage area, in square kilometers	Highest flow since October 1960			Lowest flow since October 1960			Average runoff 1941–70, in cubic meters per day per square kilometer	Average runoff 1970, in cubic meters per day per square kilometer
		Date	Discharge, in cubic hectometers per day	Runoff, in cubic meters per day per square kilometer	Date	Discharge, in cubic hectometers per day	Runoff, in cubic meters per day per square kilometer		
Delaware River at Trenton, N.J	17,560	June 30, 1973	330	18,800	Oct. 31, 1963	2.89	165	1,550	1,480
Potomac River near Washington, D.C	29,940	June 24, 1972	878	29,300	Sept. 10, 1966	1.47	49.1	825	858
Ohio River at Louisville, Ky	236,100	Mar. 12, 1964	1,920	8,130	Aug. 2, 1965	12.5	52.9	1,140	1,080
Apalachicola River at Chattahoochee, Fla	44,500	Mar. 8, 1966	401	9,010	Nov. 8, 1962	14.9	335	1,190	1,060
Missouri River at Hermann, Mo	1,368,000	Apr. 25, 1973	1,220	890	Dec. 23, 1963	14.8	10.8	137	151
Mississippi River at Vicksburg, Miss	2,964,300	May 12, 1973	4,800	1,620	Jan. 8, 1964	308	104	466	460
Sacramento River at Verona, Calif	55,056	Jan. 26, 1970	190	3,450	Oct. 11, 1961	14.9	271	867	1,050
Snake River at Weiser, Idaho	179,230	Dec. 25, 1964	177	988	July 18, 1961	18.9	105	243	254

Approximate equivalents:
1 square kilometer=0.386 square mile.
1 cubic hectometer per day=409 cubic feet per second.
1 cubic meter per day per square kilometer=0.001 cubic foot per second per square mile.

in 1970, and the second number is the percentage of average runoff *consumed* in 1970. Average runoff is the maximum amount of water that would be perennially available if the maximum water-resource development and management were accomplished. However, the actual dependable supply, even under those circumstances, might be as little as one-third of the average runoff in some parts of the Nation because of wide variations in flow from season to season and from year to year and because of topographic, geologic, hydrologic, ecologic, and economic constraints on reservoir construction.

WHAT ARE SOME OF OUR INFORMATION NEEDS?

Water-use information is needed at all levels of water-resource planning—from the designing of an individual household's self-supplied water system to planning for the development of our largest river basins. The analyses of the effects of potential legal or policy water decisions also require water-use information, whether the issue at hand is a temporary ban on lawn watering or a national policy on nuclear-powerplant siting.

The past few years have demonstrated how rapidly radical changes can affect the directions of some sectors of the U.S. economy and can affect the national pattern of water use. The growth in energy demand had been mostly satisfied by increasing oil imports during the 1960's and early 1970's. However, with the realization of possible interruptions of oil imports and their subsequent momentous increases in price, national attention has been focused on developing our extensive reserves of coal as a less expensive, more secure alternative to oil imports.

Most of this attention is now being directed toward the development of surface-minable (strip-minable) coal reserves in the water-short Western United States. Surface-minable coal is the only energy resource that can be brought into production rapidly, and it is usually less costly to produce than underground coal. The semiarid Western States have 63 percent of the demonstrated reserve base of strippable coal in the United States, and much of this has a desirably low sulfur content. Figure 8 shows the location of some of the principal western deposits of coal, including those minable by surface methods. Comparing this with the existing water uses in figure 7, it can be seen that the coal deposits occur in areas in which the existing water use is high.

Direct water requirements for surface coal mining are not large; the modest demands for sanitary and dust-control purposes can usually be met locally. Irri-

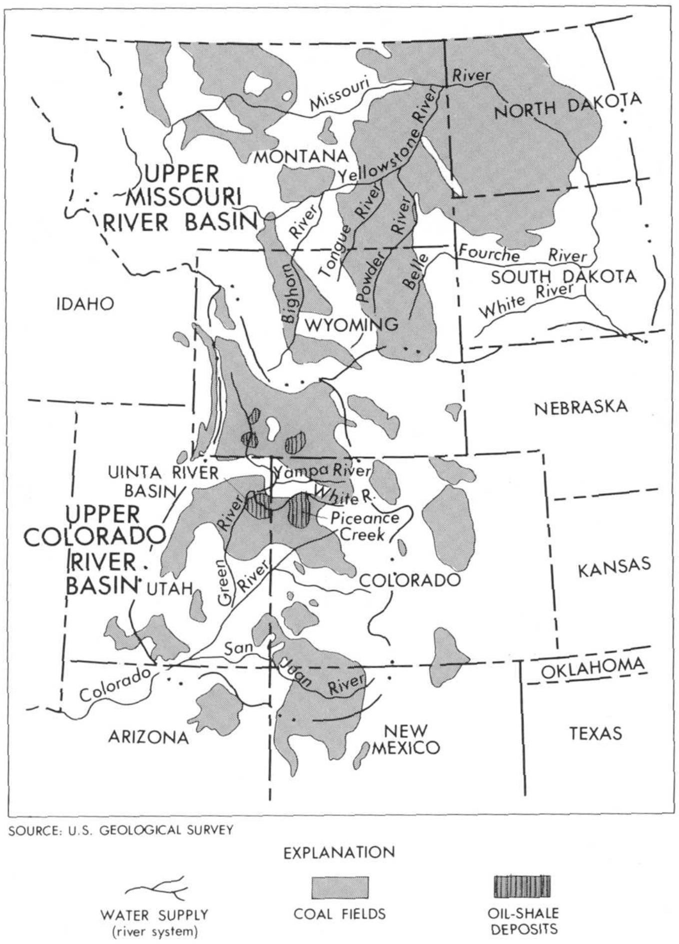


FIGURE 8.—Location of coal fields and oil-shale deposits in upper Missouri River and upper Colorado River basins, Western United States.

gation of spoils undergoing reclamation in arid areas may require more water than is available on a mine site but only in amounts that will not cause significant water-use problems. In contrast to these relatively modest water needs for mining and reclamation, the conversion of coal to secondary forms of energy such as gas, oil, or electricity for transportation, distribution, and consumption will constitute a significantly large water use. These secondary industries will also generate associated industrial and commercial growth that will also increase the water use.

The preponderance of high-grade oil-shale deposits are also located in the semiarid West (fig. 9). In addition to water used for processing and cooling in shale-retorting operations, water is used for compacting the spent shale material.

The very great demands that will be made on water and environmental resources for energy conversion are only "the tip of the iceberg" compared to the ensuant demands that will be made for industrial, residential, and commercial development. These in-

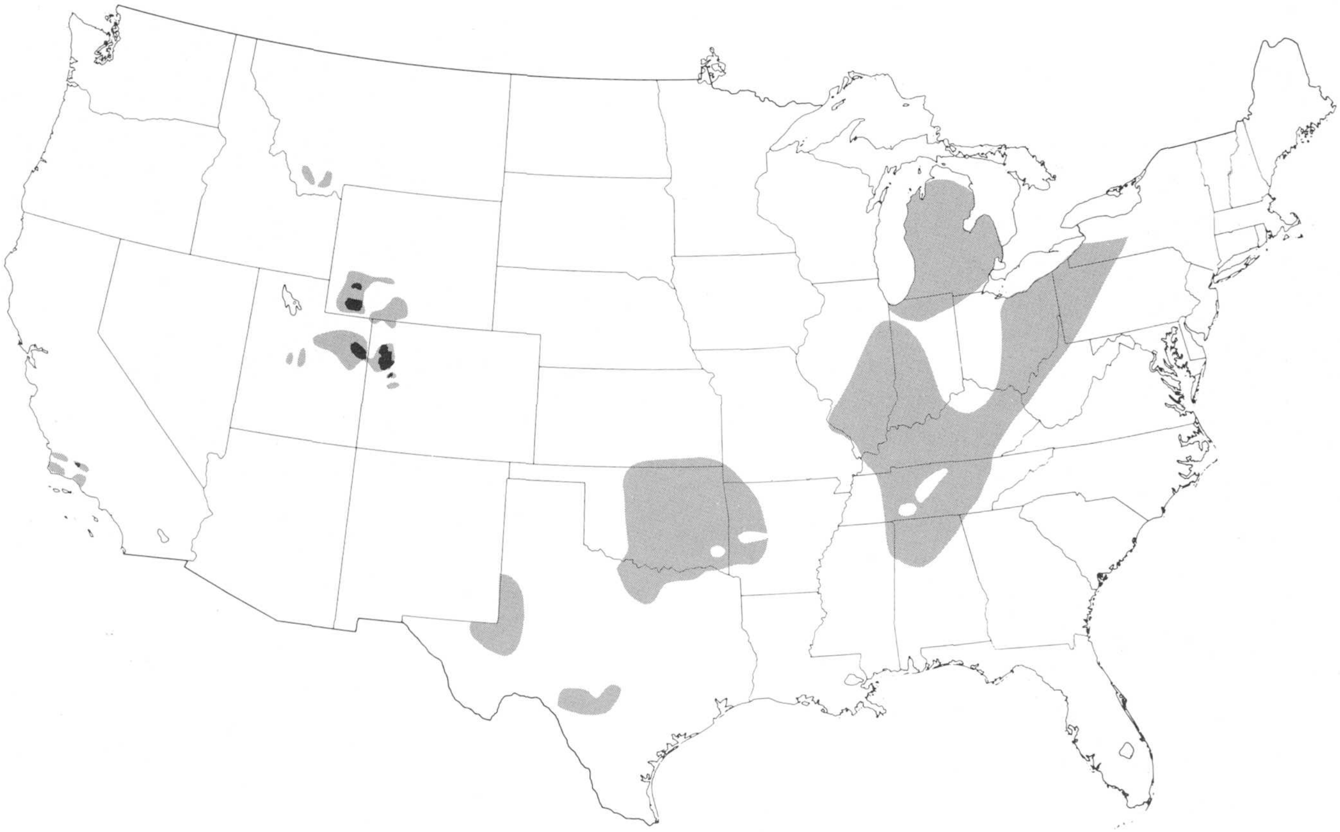


FIGURE 9.—Principal reported oil-shale deposits in the conterminous United States. Solid-black areas in Colorado, Utah, and Wyoming are known to contain high-grade deposits.

creased water-use needs cannot be met by the already overcommitted available water supply; rather, they must come from a transfer of water rights from one type of use to another.

This will often mean that water which up to now has been used for agricultural purposes will subsequently be sold to industrial users. If the water was used to irrigate hay and feed-grain crops, its loss might considerably change the character of ranching and, hence, change the ambience of the area. Most water users, especially industrial users, have options for using less water, but these options require higher capital investments and operating costs. If a user can legally buy water from other users, he will do so, but if water transfers are not permitted, the costs of reducing water use will eventually be passed on to consumers. To thoroughly evaluate the social, environmental, and economic effects of energy development, detailed information on water-use options and their costs must be developed for the energy-conversion industries and for other major water users who will be directly or indirectly involved in energy production and development. Also to be considered are industries that are purposely located near energy-conversion industries in order to utilize products or byproducts of energy-conversion processes.

Detailed analyses of plant-level options for converting coal to gas, oil, and electricity and the effects of these options on water use have been undertaken, and some are near completion. Methods for projecting water use for secondary development resulting from increased energy development and for relating these water demands to supply capabilities and environmental resources are being studied.

HOW ARE WATER-USE INFORMATION SYSTEMS DEVELOPED?

It is necessary for a planner or designer of a new water-supply system to study other similar systems in order to estimate water demands for the new system, but, because this type of information is often scattered throughout thousands of reports from towns, cities, public-health agencies, and engineering firms, it is not always easy to find. Aggregate water-use information for a region or an industry is even more difficult to assemble because some companies are hesitant to disclose information about their operations that might be useful to competitors.

The need for a more centralized source of water-use information has led to the development of some data-collection and data-reporting systems. These have usually been based on periodic assessments made by conducting many interviews and canvasses, collecting data from secondary sources, and estimating to fill the gaps. The quality of water-use information ranges from the accuracy obtained for metered uses to the uncertainty of hydrologic estimates of irrigation conveyance losses. In fact, a major proportion of existing water-use data consists of estimates that are of such limited accuracy as to be useful only in very general assessments of water problems.

The economic fact that consumers usually use less of a commodity as it becomes more expensive, but use more of it as their incomes increase, indicates that information on income and water prices, as well as a number of related items of information about household size, house-lot size, and property values, may be helpful in estimating variations in water use. Equations can be developed to make these estimates, but statistical analyses must be based on data that include economic and demographic information as well as water-use information.

For estimating the effects of changing prices and technology on industrial water use, another type of detailed analysis can be made on an industry-by-industry basis for industries that use large amounts of water. These plant-level analyses of the processes involve detailed engineering-economic studies of how existing plants are operated or how new plants should be designed and operated in order for the company operating the plant to maximize profits under current prices and regulations. Existing plants often cannot significantly change their rate of water-use without extensive retrofitting. New plants, however, have a much wider range of process technologies to choose from for minimizing production costs under changed economic conditions. For cooling purposes, one of the largest uses of industrial water, a lower water use can usually be achieved at a cost of increased water consumption, and the converse is also usually true. The recent increases in energy prices relative to water costs may alter the historical trend toward less water-intensive cooling systems. Plant-level analyses of the total costs of various cooling systems can be used to determine the directions that future changes in water use will take.

SUMMARY AND CONCLUSIONS

We can estimate past and present water uses, but total water needs for most withdrawal uses are changing; water use is responsive to prices, technology, customs, and regulations. Although inventory systems for estimating water use are good indicators of past and present uses, such systems are not as accurate or as frequently reported as we would like, and they do not show us future water-use trends.

Providing more complete and accurate water-use information will involve the work of many hydrologists, engineers, and economists. It will require more detailed and complete water-use data and a wider knowledge of local factors. Much of the information can be collected by State or local agencies, and a well planned, nationally consistent effort can produce data that will serve many purposes. However, providing water-use information for *all* purposes will require additional comprehensive statistical-data and engineering analyses of water-use options at the plant level. These analyses can provide information on changing conditions, and, with this knowledge, it will be possible to construct computer models for regional assessments of water use in relation to water supply.

For most of our Nation, the period of free and easily developed water supplies has ended; in some areas, water use is approaching or exceeding the available supply. We are, however, not running out of water. Much still remains to be done toward modifying the occurrence of water to better fit regional demands, and, more importantly, many options for modifying water use and reuse remain to be explored. The development of new water supplies will take more time than the development of methods for better utilizing water through reuse, conservation, and new technologies.

Sometime in the future, the manufacture of a 12-ounce beverage can will have considerably different water-use effects. We must prepare for these effects if that 12-ounce can is to continue to be available to us.

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The Federal- State Cooperative Water-Resource Program, A Unique Partnership in Government

By J. S. Cragwall, Jr.

The Federal-State Cooperative water-resources program of the U.S. Geological Survey is a unique, mutually beneficial working partnership between the U.S. Geological Survey on the one hand and public agencies in all 50 States on the other. It began in 1895 and in the ensuing decades has produced water data and reports that are used as a basis for national and local decisionmaking and planning wherever water-resources and water-quality problems exist. It is a partnership in equity, funded primarily on a 50–50 basis, an arrangement that has stood well the test of time.

ORIGIN AND DEVELOPMENT

From its inception in 1879, the U.S. Geological Survey has regarded cooperation on scientific matters, both formal and informal, as essential. The first formal cooperative arrangement was with the State of Massachusetts in 1884 for preparation of a topographic map of the State. The Director of the Survey, Major Powell, and the Board of Commissioners of the State of Massachusetts agreed that the State would pay one-half the expense of topographic fieldwork and the Federal Survey one-half, the latter to engrave the maps and give transfers of the plates to the State Commissioners.

Cooperation that offered the advantage of pooling severely limited resources toward gaining mutual advantages increased steadily and by 1895 included water-resources investigations. The States and their subdivisions offering more funds or other resources than the Survey could match because of its limited budget or because the Survey was anxious that the work done contributed to the fulfillment of its national responsibilities. It was this condition that was elaborated by Director Wolcott in the Survey's annual report of 1901.

> One important point to be considered in all such work is that the general plans and methods of the Federal Survey cannot be set aside on account of State cooperation. At the present time the funds available for cooperation are so limited that its further extension is dependent upon increase of appropriations by Congress. It is against the policy of the Survey that work on important areas or subjects should be stopped in order that cooperation with individual States may be extended. The Director is willing to enter into a cooperative agreement only when the interests of the country as a whole will be benefited.

With that brief account of its roots, we turn our attention to the Federal-State Cooperative program of the Survey's Water Resources Division.

Although cooperation was begun with Kansas in 1895 for stream gaging, appropriations earmarked specifically for cooperative studies were first made to the Survey by Congress in fiscal year 1906. Thus began the partnership between the States and the Geological Survey that continues to this day as the foundation of the Water Resources Division's program. Records of the Division's first cooperative ventures with State and local agencies are vague. The agreements were rather informal and varied a great deal from State to State. In some instances most of the money was furnished by the Survey; in others, by the State. In general, however, because of the usefulness of the work to them and the very small size of the Federal appropriation, the States contributed more than half the cost of the studies.

Beginning with fiscal year 1929, and in response to the demands of State officials and engineering organizations, Congress established the principle of 50–50 matching funds between the Survey and State and local agencies. This principle recognizes a mutuality of benefit from the partnership arrangement. On the one hand, State willingness to participate is prima facie evidence of value to the State. It should be recognized, however, that in view of the rapid offerings of cooperative funds by the States, it has been the skills and impartiality of the Survey that have been so eagerly sought by the States and local governments. Most water projects studied or undertaken are under controversy among conflicting interests. Data and studies produced by the Survey are accepted by both sides in interstate, intrastate, State-local, and international disputes. In these days of growing tendencies toward adversary proceedings, it is important to preserve those impartial services that tend to broaden the base of acceptability and narrow the scope of controversy.

On the other hand, information required to carry out Federal-agency missions, interstate and international compacts, Federal law and court decrees, congressionally mandated studies, and regional and national assessments and planning activities is patently in the Federal interest. All these various studies and projects depend heavily on the data base acquired through the cooperative program as well as through special investigations made with Federal funds appropriated for that purpose or transferred from other Federal agencies. For example, in 1976 the Survey stream-gaging stations used for river forecasting by the National Weather Service represented an outlay of $5 million for work by the Geological Survey; of this amount, the Federal-State Cooperative program provided more than $2 million. As another example, in 1976, Survey-funded stations providing data used by the U.S. Army Corps of Engineers represented an outlay of $6 million, of which $2 million was from the cooperative program.

THE PROGRAM TODAY

The program has grown and has changed with time. Today the program is a composite of activities covered by more than 500 cooperative agreements with jurisdictions in all the States and several of the territories, wherever there are water problems. Through this network of contacts with the "real" world of water conservation, development, and use, the Survey's Water Resources Division has been able to anticipate and to respond to changing priorities. Thus, the work is diversified, problem oriented, and strongly interdisciplinary. For example, the activities listed in a recent sampling of a few State programs include: collection of long-term multipurpose data (surface water, ground water, and water quality); special interpretive studies of the physical, chemical, and biological characteristics of water resources; and appraisals for environmental impact analysis, energy development, coastal-zone management, subsurface waste storage, waste utilization, land-use planning, flood-plain management, and flood-warning systems.

The Federal-State contribution to the water-resources mission of the Geological Survey can be measured in terms of dollar support to the overall effort of the Water Resources Division. From 1941 to 1976, a period for which reliable records are available, 57 cents of each dollar spent on data collection and research by the Water Resources Division came from the Federal-State cooperative program. Other measures are activity and output. For example, in 1976, of the 8,000 stations comprising the basic streamflow network, the cooperative program was the sole support for 2,600 stations and contributed to the support for 2,500 others. Of about 1,200 active projects (areal, topical, and research) underway, about 700 were in the cooperative program, and of about 750 reports published on water resources, about 500 came from the cooperative program.

Administratively the cooperative program has several distinctive characteristics. It is decentralized; the work is done through 47 district offices, nearly one for each State. Details of programs are negotiated at State or local level by representatives of the Survey with representatives of the cooperating agencies. Implementation is under Survey direction and by Survey staff, principally, but there is an accountability for performance to the State partners. Mutual trust based on years of satisfactory collaboration has minimized the paperwork usually associated with cost-shared programs, and to formalize the arrangement a simple one-page standard cooperative agreement is used with few exceptions.

Advantages from the administrative arrangement accrue to both Federal and State sides. Most evident is the cost-sharing that approximately doubles the activity that might be afforded by each. Additionally, what is in effect a pooling of manpower in the relatively small field of hydrology provides advantages of scale for recruiting, training, and career opportunity; for supportive activities such as laboratories and research; and for mobility to meet new needs where and as they develop. Cost-sharing and decentralization increase the responsiveness of the program to grass-roots, real-world needs and provides early indication of emerging local problems that often merge and become national problems. Unified management provides common standards nationwide, uniformly reliable and comparable output, and assures the availability of that output to the public at large.

AN EVALUATION

The Nation's ability to cope with new and challenging problems in water management rests largely on data and surveys made over the preceding years in the cooperative program. For example, flood-plain management (including flood-plain zoning and flood insurance) is a relatively new concept in the national scene for abating flood damages. But the procedures and data on which flood-plain management programs depend have their origin in the Survey's cooperative programs with State and local agencies. As another example, ground water—so important to the community, the farm, and the home—was investigated in the early days almost entirely within the cooperative program, when there was little recognition of ground water as a national problem. Today, the potential for pollution of ground water is receiving national attention, for, once contaminated, ground water may be ruined as a resource and become instead a danger to health. The source of most knowledge of ground water now being used by concerned national agencies was first evolved as part of the cooperative program. Similarly, environmental assessment, now part of all national planning, uses water-resources information from many of the reports that have stemmed from the cooperative program.

The long reliance of State and local authorities upon the U.S. Geological Survey for water facts and water studies and for funds and staff to do the work reflect the cooperators' experience that the Survey has been an effective supplier of data and services and has at the same time maintained high scientific and engineering standards. The Survey offers a core of talent that is rooted in research—and so advances the application of research to practice; it assures impartiality—if one party pays for the work, the adversary party will credit the results; it offers continuity—water information gains in value with length of record; it offers transferability—lessons learned in a study anywhere in the country are available for another.

Perhaps the strongest point of all in evaluating the existing Federal-State Cooperative program, and determining whether any change is desirable, is the uncertainty about what direction the future is taking. This Nation—along with most other nations—is in the midst of convulsive changes, the only certain factor being the continuity of basic human needs on an ascending scale. Water is one of the most valuable resources, and to fail to have it assessed correctly could result in failure to use it intelligently, with far-reaching disastrous effects. Because the availability of water of suitable quality is a fundamental limiting factor in an expanding economy, a comprehensive and forward-looking data-collection operation is imperative to the best planning for the future development and use of the Nation's water resources. The job is too large to be supported at either Federal or State level alone; on the other hand, the jointly planned and funded cooperative program provides budget-makers with the most convincing assurance that the work is designed to meet both national and local needs.

THE OUTLOOK

In looking ahead, the main purpose of the Federal-State Cooperative program from the national point of view will continue to be to provide facts needed to maintain relevance to problems in advance of their blossoming as national crises, to match resources to the work to be done, and to assure availability of information nationally to all users. From the State and local point of view, the objective will be to assure impartiality, skill, and continuity in the maintenance of an adequate water-data base. The cooperative program has successfully satisfied both objectives in the past and should continue to do so in the future.

Prospects for Automated Mapping

By Morris M. Thompson and Madonna K. Elliott

Cartographers have been talking about the prospects for complete automation of map production ever since modern computers first displayed their wondrous powers. There is relatively little realization of these prospects today, however, because research has usually been fragmented, and few developments have proved to be cost effective. At the same time, optical and mechanical improvements have upgraded mapping equipment to the extent that, with the computer plugged in at a few points, mapping productivity has steadily increased. For example, in 1965 it look about 27 man-hours to complete 1 square mile of topographic mapping at the scale of 1:24,000; in 1975 the same work took only about 12 man-hours. Even so, only some 36,000 of the 54,000 1:24,000-scale general-purpose topographic maps it takes to cover the 48 conterminous States have been published, and a fourth of these need revision. The fact is that current methods of producing and maintaining cartographic information are not meeting all of today's needs, let alone the projected needs of the future.

By all accounts, our Nation faces extensive shortages of natural resources before the turn of the century. Consumption of resources is at an all-time high and is steadily increasing to fulfill society's expectations for a better quality of life. The land is pressured relentlessly by population growth, urbanization and suburbanization, new technology, and increased leisure time for outdoor recreation.

Planners, decisionmakers, environmentalists, and developers all face the need to analyze millions of acres of land, often without a complete inventory of the resources and physical features or of the interactions of the environment and human activities. The prerequisite for such an inventory is a cartographic base of one kind or another. The demand today is not only for conventional maps and charts in increased

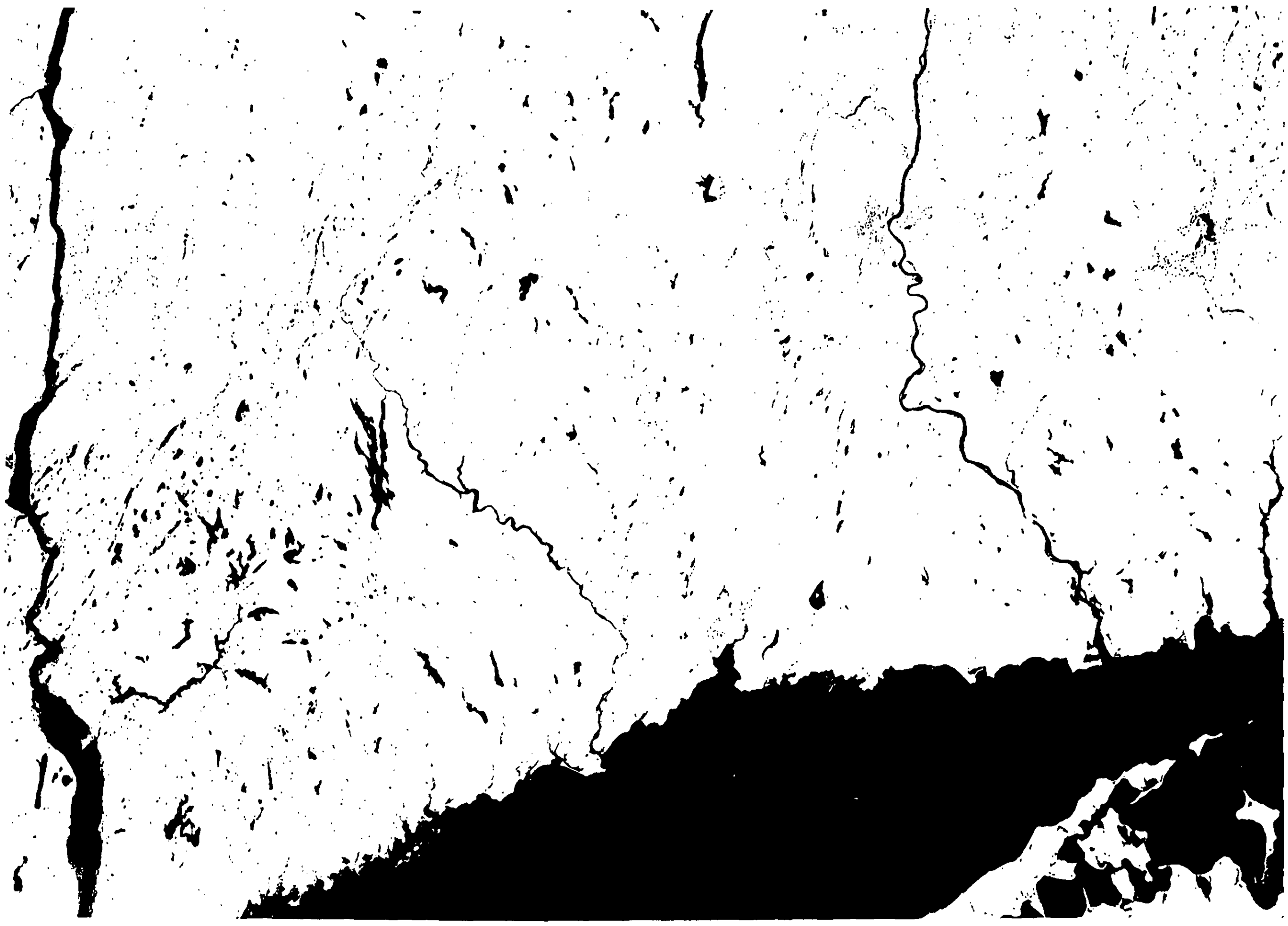

FIGURE 10.—Autographic theme extraction of open water from space (Skylab) image data. Area shown is same as area covered by the Hartford, Conn., 1:250,000-scale quadrangle (1° × 2°). The prominent stream at left is the Hudson River; Long Island Sound is at the bottom.

quantities, but for photomaps, slope maps, land-use maps, county maps, regional maps, urban maps, flood-insurance maps, and thematic maps (fig. 10) of endless variety. The key to storing, updating, and quickly retrieving this vast body of information is the computer. When the data are digitized, that is, coded in computer-readable form, they can be rapidly manipulated to produce maps of any desired content and form, and they can be correlated with other geographically related information systems for total problem analyses.

Fortunately, automated mapping techniques are now emerging from research laboratories to give new hope of meeting the immense cartographic requirements of the days to come. The techniques are based on powerful data-processing systems, on ingenious inertial-guidance packages, on sophisticated use of spacecraft, on highly selective remote sensors, and on wide-ranging methods for processing and analyzing imagery. Conventional map-production methods will be changed radically, mainly to expedite the process. In each major phase of the mapping operation the prospect of automation is becoming reality. These major phases can be set down in outline form:

1. Acquisition of *geodetic data* to tie the map to correct positions and elevations on the Earth's surface.
2. Acquisition of *image data* in the form of aerial photography or other sensing systems to provide detailed map information.
3. *Compilation* of the map from the image data, in proper relationship to the geodetic data.
4. *Finishing the map* by preparation of color-separated printing plates from the manuscript material for line maps, or completion of appropriate cartographic requirements for image maps.

Let us now consider the outlook for automation in each of these phases:

Geodetic data

Ground surveys to establish horizontal position and elevation have constituted one of the costliest and most time-consuming tasks of mapping. But now even the modern electronic distance-measuring instruments are being rendered obsolete by new automatic systems that provide continuous determination of position, elevation, and azimuth through the use, in a moving vehicle, of an inertial-navigation package containing extremely accurate gyros, accelerometers, and a computer. The Auto-Surveyor mounted in a rough-terrain vehicle is one such system that the Geological Survey is testing on mapping projects in remote areas (fig. 11). Acceptable ground data are being obtained from this system in a fraction of the time normally required and regardless of most weather changes. An airborne version is the Aerial Profiling of Terrain System being developed primarily to obtain stream-valley data for the Survey's Water Resources Division. Mounted in a light plane, the system includes an inertial-navigation package and also a laser altimeter which is expected to result in very reliable ground profiles useful to mapping. Manufacturers of these inertial-guidance systems are becoming more aware of the possible ground applications and are producing more effective and affordable models. In a few years a surveyor may hand-carry a small inertial measuring system that will provide positions and elevations accurate enough for property records.

Another type of advanced surveying system is particularly useful for establishing the locations of isolated points in remote areas such as Antarctica. With this system, it is now possible to determine the geographic coordinates and elevations of ground positions directly by observing Earth satellites with ground-based wave analyzers (such as the Geoceiver) or by laser ranging to satellite-borne retroflectors.

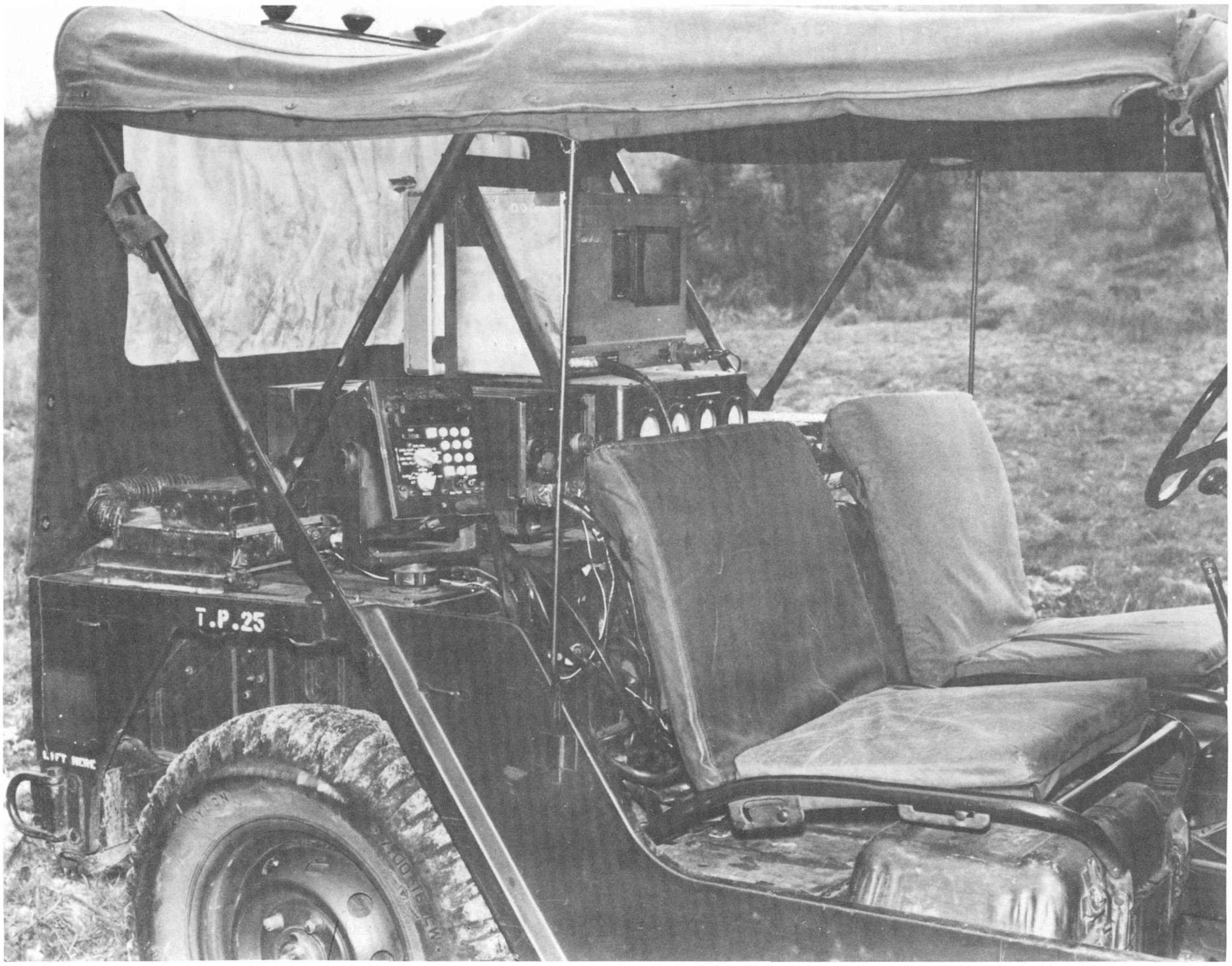

FIGURE 11.—Four-wheel-drive vehicle equipped with an inertial package for automated surveying. The system, which includes gyroscopes, accelerometers, and small computer, provides a continuous record of the position and elevation of the vehicle as it proceeeds along its course.

Image data

Since most map information is derived from aerial photographs and other images obtained in either digital or graphical form, the planning, taking, and processing of the image data are crucial tasks in mapmaking. Today's high-resolution cameras and multispectral sensors will be tomorrow's imaging systems in a high-flying aircraft or a cartographic satellite (fig. 12). The image will generally be in digital form and fully manipulable by computers. Unseen pictures will be formed digitally from the sensors' records to show selected data suitable for thematic maps. Already we are able to computer-produce a stereopair of photographs from a single satellite image. The development of powerful new techniques for image processing has already led to a growing production of image maps. On the increasingly popular satellite image maps, cartographic detail is shown by images derived from photographs or other sensors, instead of by the lines and symbols of conventional line maps.

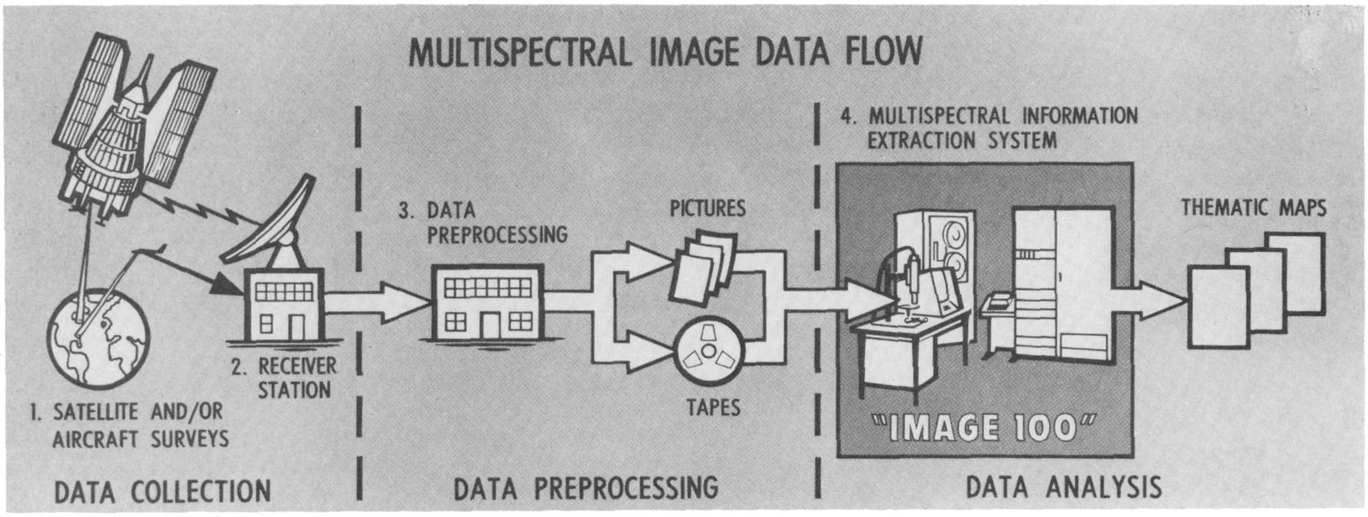

FIGURE 12.—Automated imaging system.

Cartographic compilation

A breakthrough in automating the laborious and exacting compilation of topographic data occurred this year. The Geological Survey acquired a fully automated photogrammetric machine (p. 80) in which the photographs are automatically scanned and correlated to provide concurrently a contour drawing, a digital terrain model (dense grid of elevations) recorded on magnetic tape, and an orthophotograph (correctly positioned imagery). Here automation will cut production time from weeks to days and reduce the incidence of error. This and similar future systems will provide a ready means of accomplishing relief shading, slope mapping, production of a line or image map at any desired scale, or solution of interdisciplinary problems. This impressive new system, called the Gestalt Photo Mapper II, is in operation at the Survey's Eastern Mapping Center in Reston, Va.

Map finishing

Even though the image maps are gaining wide acceptance, there will always be a need for the line map. However, for the application of automated techniques to the preparation of color-separated plates for lithoprinting, the line map must bear new symbols that are computer-compatible and that enable efficient use of automated precision-plotting systems now on the market. Duplication in drafting will be eliminated by the current development of instruments and techniques for digitizing map data in the course of compilation. Given map data in digital form, the system of the future will make press-ready reproducibles at a variety of scales and with selected content. It will also be possible to gain rapid access to map data through local computer terminals.

The cogent question

Thus automation promises many things for cartography: speeding mapmaking, increasing product quality and desirability, improving access to the information, and extending the usefulness of the data. Right now, the installation of automated equipment and techniquse entails large capital investments, as much as a million dollars a unit, and the question is frequently raised: "Can we afford to automate?" In view of the complete and up-to-date national cartographic data base within our grasp—a new resource that society will find indispensable as it seeks to manage the environment, a unique resource that will continually grow to supply the demand—the more cogent question is: "Can we afford not to automate?"

Metrication—What It Means to Mapping

by Marshall S. Wright, Jr.

WHERE WE HAVE BEEN

Recently the Congress of the United States authorized the use of the metric system throughout the country. Recently? Well, not too recently . . . one hundred and ten years ago, to be exact. Nothing much happened as a result of that legislation, and the next significant mile post was in 1875 when the Treaty of the Meter was signed by 18 nations including the United States. The treaty provided for improved metric weights and measures and the establishment of an international organization devoted to matters of weights and measures, but, again, the implementation of metrication in this country made little gain. Then, in 1968, Public Law 90–472 authorized a 3-year metric study to determine the impact of increasing use of the metric system on the United States. The study was made by the National Bureau of Standards, and in 1971 a report to the Congress, entitled "A Metric America—A Decision Whose Time Has Come," was submitted. The report recommended, among other things, that the Nation change to the metric system "deliberately and carefully," that the change be done through a coordinated national program, that various sectors of our society work out their own detailed plans and timetables, that priority be given to educating school children and the public at large to think in metric terms, and that the Congress establish a target date 10 years ahead by which time the United States will have become "predominantly, though not exclusively, metric."

The latest metric legislation is contained in Public Law 94–168, called the "Metric Conversion Act of 1975" enacted by the Congress and signed by the President in December of 1975. The act states "that the policy of the United States shall be to coordinate and plan the increasing use of the metric system in the United States and to establish a United States Metric Board to coordinate the voluntary conversion to the metric system." This is not a particularly strong law (note "plan the increasing use" and "voluntary conversion"). No specific timetable is set forth in the act, but it unquestionably moves the Nation a major step forward toward the inevitable day of metric conversion. Inevitable? Yes, absolutely! After all, we and Barbados, Burma, Gambia, Ghana, Jamaica, Liberia, Muscat and Oman, Nauru, Sierra Leone, Southern Yemen, Tonga, and Trinidad are the only nations left in the entire world that are not fully committed to the metric system. The United States cannot hold out much longer, and the Geological Survey believes that the time has come to move firmly and intelligently toward the metrication of the maps and other cartographic data it produces under the National Mapping Program for the benefit of the Nation.

The production of maps in the metric system is not new to the Survey's Topographic Division even though more than 99 percent of its standard quadrangle maps are in the English system with contours shown in foot units and map scales usually keyed to inches, feet, and/or miles. The exceptions are the standard quadrangle maps of Puerto Rico at a scale of 1:20,000 with the contours in metric intervals and maps of some areas in Alaska that were made at a scale of 1:25,000 with metric contours. A number of other new maps of areas within the conterminous United States have also been prepared at a scale of 1:100,000 with metric contours. Thus, from a technical and operational viewpoint, we have the ability to compile and publish maps in the metric system now. The problems lie elsewhere.

WHERE WE ARE TODAY

A brief description of just what the metric system is may be in order. The system is called the International System (SI) throughout the world. (SI is the standard abbreviation for the official name, Systeme International D'Unites.) The great advantage of the system is its simplicity, there being only seven basic units covering all weights and measures: (1) the meter for length, (2) the kilogram for weight, (3) kelvin for thermodynamic temperature,[1] (4) the second for time, (5) the ampere for electric current, (6) the candela for luminous intensity, and (7) the mole for amount of substance. A special case is the liter which is the unit for measuring volume—this is not considered a basic unit, however, since the liter is actually defined in terms of the meter. The system is further simplified by the fact that it is based on 10 and that the base units can thus be multiplied or divided by simply moving the decimal point in working with numbers or by using standard prefixes in working with words. Typical prefixes are kilo (meaning one thousand) as in kilogram and kilometer, milli (meaning one thousandth) as in milliliter and millimeter, and centi (meaning one hundredth) as in centimeter

[1] Degrees celsius (°C=K−273.15) are also acceptable and most familiar.

and centigram. Thus, if one wants to know how many meters there are in 2.36 kilometers, the answer is instantly perceived to be 2,360, whereas if one wants to know how many feet there are in 2.36 miles, it is necessary to multiply by 5,280.

The precise definition of just what some of these basic units represent is not always so simple. Some people may not know that the official definition of the meter is "the length equal to 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the Krypton-86 atom." And this is one of the simpler definitions! Fortunately, however, the average person need never be concerned with such a basic definition of the length of a meter. It should suffice to know that the meter is about the height of a doorknob or a workcounter. It is also fortunate for map users that they are primarily concerned with only one of the seven basic metric units in the conversion of maps to the International System—the meter for horizontal and vertical measurement.

The Topographic Division of the U.S. Geological Survey began a preliminary investigation into the pros and cons of converting its mapping effort to the metric system several years ago with the appointment of a "metrication" committee that was charged with considering the ramifications of metrication and with drawing up recommendations on how to proceed. A number of experimental maps were prepared to evaluate various combinations of metric scales and contour intervals and to evaluate transition products with metric units and equivalents and vice versa.

Then, in the summer of 1975, before the "Metric Conversion Act of 1975" became a reality, the Division decided that the time had come to assume firm leadership in the mapmaking community and to move ahead deliberately with this clearly inevitable task. While the in-house production problems associated with the conversion were well understood and solvable, the impact on, and the desires of, the map-user community were not adequately documented. Accordingly, in December 1975, a questionnaire was sent to about 150 representative map-using agencies and individuals throughout the country. The list included all State cooperators, other selected State offices, all map-using Federal departments and agencies (about 40), a number of university professors, private mapping companies, and several professional societies. The list provided a representative cross section of those who make use of the National Mapping program products.

A letter accompanying the questionnaire explained the Survey's desire to prepare a specific metrication plan and detailed the steps already taken in that direction. It described metric mapping practices in other countries and also set forth, for consideration, various sequences of contour intervals. The questionnaire itself asked for comments and advice concerning: (1) the most suitable and practical scales for a metric map series; (2) the most suitable and practical contour intervals; (3) whether the standard quadrangle maps for the 48 conterminous States should be completed in the English system or whether transition to the International System should be begun; (4) when the 7.5-minute series is converted to metric should it be at a scale of 1:20,000; 1:24,000; or 1:25,000?; (5) what special problems would users encounter if new mapping continued to be at a scale of 1:24,000 but with metric contours?; (6) what problems would be encountered if the scale were changed to 1:20,000 or 1:25,000?; and (7) what special information would best help users to convert from the English to the metric system?

The response to the questionnaire was gratifying. Seventy percent responded, and most returns clearly reflected serious thought and consideration. Persuasive logic was present in the reasoning behind some of the answers, and some of the opinions were expressed vehemently. Of course, many conflicting views were expressed, but the responses to the questionnaire may be summarized briefly, as follows:

1. There was a 2½-to-1 preference for a scale series of 1, 2.5, 5, 10 (1:10,000; 1:25,000; 1:50,000; 1:100,000; 1:250,000; 1:500,000; 1:1,000,000) compared to the 1, 2, 5, 10 series (1:10,000; 1:20,000; 1:50,000; 1:100,000; 1:200,000; 1:500,000; 1:1,000,000). A few people, however, prefer some other scale series.
2. There was a 5-to-1 preference for contour-interval sequence of 1, 2, 5, 10, 20, 50 or 100 meters compared to a sequence of 1, 2.5, 5, 10, 25, 50, or 100 meters. A few people indicated a preference for some other series, including a sequence of 1, 2, 4, 8, 16, 32 meters.
3. There was a 4-to-3 preference for completing the mapping of individual States at 1:24,000 before converting to the metric system. It should be noted here, however, that State officials were overwhelmingly in favor of completing their own States at 1:24,000 before converting, with 32 being in favor of completing at 1:24,000 and 10 favoring immediate conversion; 5 of those 10 were States which are already completely mapped at 1:24,000, and therefore their "votes" on this subject can be discounted to some extent.

4. There was a 2-to-1 preference for converting the 7.5-minute quadrangle maps to a scale of 1:25,000 rather than 1:20,000. Several people recommended retaining the 1:24,000 scale.
5. As to the problems to be encountered, if metric contours are shown on 1:24,000 maps, the answers ranged from "no problem" to "the user would be utterly confused." Many pointed out the obvious difficulty of matching metric contours on one sheet to foot contours on adjoining sheets.
6. Only about 20 percent of the responders made specific comments about problems that would be caused by changing the map scale from 1:24,000 to 1:20,000 or 1:25,000. Of those, a number objected to the 1:20,000 scale because the map sheets would be too large for existing files. Many pointed out the problem of matching adjacent sheets at two different scales.
7. The comments on special information that would help users convert from the English to the metric system included "show horizontal and vertical bar graphs," "put warning flags stating boldly that these are metric maps," "make all maps put out in the metric system distinctly different," "put instructions for use on the face of the maps," and "show contour numbers in red."

A review of the responses pointed out one inescapable fact: it is not possible to make everyone happy about certain basic decisions that must be made. There were impassioned pleas for going to the 1:20,000 scale, equally impassioned pleas for changing to 1:25,000, and pleas for staying at 1:24,000; it is quite impractical to adopt a multiscale policy (except possibly during a transition period). This situation is also true for the metric contour intervals to be adopted, although there was much less sharply divided opinion on that matter among the map users. Among the map producers, however, there were strong differences of opinion on the optimum contour-interval sequence. Within the Topographic Division, the contour interval, not the scale, was the tough nut to crack. Some individuals felt that a halving (or doubling) sequence—such as 1, 2, 4, 8, 16, 32 meters or 1.25, 2.5, 5, 10, 20, 40 meters—would lend itself best to the use of supplemental contours and to the derivation of a map series at other scales and contour intervals, whereas others felt that the use of fractional numbers or unconventional numbers—such as 8, 16, and 32—would be difficult for many users to handle. However, after much in-house discussion of the pros and cons of various sequences, a consensus was reached. The following basic decisions have been made:

1. The scale of 1:25,000 will be the basic scale for the metric 7.5-minute quadrangle mapping series.
2. Contour intervals of 1, 2, 5, 10, 20, 50, and 100 meters will be the basic intervals for the various maps in the National Mapping Program.
3. All new county maps will be prepared as metric editions at scales of either 1:50,000 or 1:100,000.
4. Sixty-minute by 30-minute quadrangle maps will be prepared as metric editions at 1:100,000.
5. Complete revisions of 1:250,000-scale maps will be metric editions.

These basic decisions were reached after very careful consideration of the impact on the user community, compatibility with other mapping systems (the military does much mapping at 1:25,000 and the National Oceanic and Atmospheric Administration plots 1-meter underwater contours on its charts, for example), in-house production and maintenance problems, and the economy of conversion. Every attempt has been made to accommodate the preferences of other mapping agencies as well as those of users in reaching these decisions.

Fortunately, considerable latitude and flexibility is possible during the transition period, and the Survey's Topographic Division is, therefore, in a position to accommodate the varying wishes of different users as to how the conversion work is implemented and thus to keep the majority of the users happy. With this desire to accommodate well in mind, the following operating procedures were formulated:

1. New 7.5-minute maps will be prepared as full metric versions (1:25,000 scale with metric contours) for all those States willing to accept such mapping.
2. New 1:24,000 maps will be prepared with metric contours for those States that are willing to accept metric contours but have such a pattern of completed mapping that 1:24,000 scale is needed to maintain scale continuity.
3. New 1:24,000 maps will be prepared with foot contours for those States which insist on delaying metric conversion until complete 1:24,000 coverage of those States is available.
4. Any complete revisions of existing 7.5-minute maps will be metric editions.

The Topographic Division believes that this accommodation of the unique problems of the individual States is appropriate and reasonable. It is easy to understand the argument that a State, especially one with a patchwork quilt coverage of 1:24,000 mapping, should have its program completed at that scale before a conversion is made. It should be pointed out, however, that this feeling is not universal among States that are only partially mapped at 1:24,000. In fact, seven such States have expressed a definite desire to begin conversion immediately with all new maps to be metric. One State even hinted that it would withdraw its cooperative funds if there was any delay in converting to the metric system.

Metric mapping was actually underway during fiscal year 1976 in several geographic areas and in various types of mapping. In New York (one of the States wishing to convert immediately even though the State is not completely mapped at 1:24,000), a 40-quadrangle mapping project in the Lake Placid area (the site of the 1980 Winter Olympics) is being done at a scale of 1:25,000 with metric contours. This area includes 32 quadrangles in New York and 8 in neighboring Vermont. Far to the South, in Georgia, which is almost completely mapped at 1:24,000 because of a very large cooperative program over the past few years, a complete revision project involving more than forty 7.5-minute quadrangles is being done in the metric system. Several States have requested a limited amount of quadrangle mapping with metric contours at the standard scale of 1:24,000. A county map of King County, Wash., the Killdeer 30- by 60-minute quadrangle in North Dakota, and the map of the North Cascade National Park in Washington have all been published at a scale of 1:100,000 with metric contours, the forerunners of things to come.

WHERE WE ARE GOING

With the basic decisions having been made about the conversion of new mapping to the metric system and with some such mapping actually in production, the Survey's Topographic Division is buckling down to the enormous task of working out the exact details of an efficient conversion plan. There are actually two very different tasks involved in the conversion of the National Mapping program products, one having to do with any new mapping to be undertaken and the other with changing some 36,000 existing English-system quadrangle maps to the metric system. The first task will be simpler from a production viewpont than the second task but rather complicated from a planning viewpoint because the Division is dealing with 50 different States that, conceivably, have many different ideas about how their programs should be phased into the metric system. Probably four or five different approaches will be necessary for converting the programs of the 50 States, but separate negotiations with each State will be needed to work out the best approach for both the States and the Survey. Some of these negotiations have already taken place, and others are in progress.

Concurrently, the groundwork necessary for making the conversion is underway. Typical of this effort is the preparation of a plan for the use of metric contour intervals for the entire United States and its territories. This plan, developed painstakingly by highly experienced topographers, assigns a specific metric contour interval to every quadrangle in the country and its territories; the intervals to be used are assigned primarily on the basis of the amount of relief in the area and, to some extent, the land use. According to the plan, five different contour intervals, 1, 2, 5, 10, or 20 meters, will be used. The 1-meter interval will be used in some coastal plain areas and in other areas with very little relief, and the 20-meter interval will be used in extremely rugged terrain such as Glacier National Park. It is estimated that less than 5 percent of the Nation's 54,000 7.5-minute quadrangles will have 1-meter contours and that only about 2 percent will have 20-meter contours; the remaining 93 percent will have contours at 2-, 5-, or 10-meter intervals.

Plans are also being made to accomplish new mapping under two different approaches, one with complete metric conversion and the other with only a partial conversion. The simplest approach, of course, is to compile and publish new maps at 1:25,000 with metric contours. The production problems involved are practically nil, and the transition to this type of mapping would be smooth and would cause no increase in the cost of map production. A more complicated and less efficient approach will be necessary for States in which the mapping officials are opposed to the use of metric contours now or opposed to changing to 1:25,000 scale before their State is completely mapped at 1:24,000. The scale problem is less difficult than the contour problem. With the knowledge that the maps will be converted to 1:25,000 at some time in the future, two sets of negatives can be made, one at 1:24,000 for immediate publication and the other at 1:25,000 to be held until the 1:25,000 publication is authorized. The contours, however, are another matter because there is no magic way to convert satisfactorily from foot contours to metric contours. Two sets of contours can of course be compiled, one for immediate use and one to be used for the subsequent metric edition, but this is certainly time consuming and costly. A possible alternative—the derivation of metric contours from foot contours by use of an automatic scanning and/or computer-aided plotting system—is being investigated.

One other option is available for converting foot contours to metric contours, and this leads to the matter of "soft" conversion as compared to "hard" conversion. Soft conversion involves simply a relabeling of a particular measurement without making any change in the interval or size being measured, whereas hard conversion involves the actual changing of the interval or size to an even standard metric size. A good example is the milk, soft-drink, or liquor bottling industry which has millions of quart bottles in use and also has a major investment in machinery to manufacture quart bottles. Under the soft conversion concept, it is a relatively simple matter to relabel these bottles "0.95 liters" (or "0.946353 liters" to be more precise), but it is a quite different matter, under hard conversion, to scrap millions, or perhaps billions of existing quart bottles and the machinery that makes them and retool for the manufacture of liter bottles. The economics involved will undoubtedly lead to a combination of soft and hard conversions in the bottling industry and in a great variety of other industries as well, with soft conversion dominating the early phases of the transition period and the hard conversion catching up and finally taking over completely at the end of the transition period. The length of the period will probably be related significantly to the normal "life" of the particular product involved, and these different "lives" of course make it difficult to set one inflexible period of time during which all phases of our society must be totally converted to the SI system. It's easier to convert sign boards than locomotives.

The matter of soft and/or hard conversion or a combination of both for existing maps is being studied by the Survey's Topographic Division at this writing, and costs must be measured against user impact. It is not extremely difficult to remake printing plates at 1:25,000 and to relabel English values to metric values, but it would be a major undertaking to recompile the contours into the adopted even metric intervals. Relabeling of the contours on a 20-foot-contour-interval map (to the nearest whole metric value) would result in the 800-foot contour becoming a 244-meter contour, the 820-foot contour becoming a 250-meter contour, and so on, and the contours would of course portray the terrain just as well as they did before this soft conversion. But would this type of conversion be satisfactory to the majority of the users? Or is such a conversion necessary at all? Should the maps be converted to the new scale only in the near future with true metric contouring being delayed until the maps are due for complete revision anyway? These questions are being seriously considered by the Topographic Division and will be discussed with the various State officials and other map users.

Educating the map-user community to the use of metric maps is an educational process that probably will evolve in two ways, one being a general campaign at the national level and the other being a specific program to be developed by the Topographic Division. The general national program is already underway on an informal basis; some elementary, junior high and high schools are already teaching the International System, and a majority of others are making plans to do so. The recently enacted "Metric Conversion Act of 1975" will add substantial impetus to the systematic education of the general public. To aid the user in adapting to the new metric maps, educational information probably should be mainly limited to that which can be printed right on the metric editions of the maps, such as dual horizontal and vertical bar scales, a prominent note calling the user's attention to the scale and contour interval, and possibly a conversion table. A possible supplement under consideration is a one-sheet "throw away" to be furnished with each quadrangle map distributed during the first year or two of the conversion period. This sheet might include a cut-out 1:25,000 scale to facilitate measurement on the map. Considered for a time was dual numbering on the map itself, showing, for example, 800 feet in brown for an index contour and 244 meters in red. This idea has been discarded because the experience of other countries in converting from English to metric units indicates clearly that, as long as dual units are shown, the average person uses the unit he is familiar with and ignores the other, thus not really learning to think in the metric system.

When will the National Mapping Program be completely converted to the metric system? A precise timetable cannot be drawn up at the present for one simple reason—uncertainty as to the availability of funds. This timetable primarily concerns the conversion of the 36,000 existing quadrangle maps because new mapping in the metric system should cost no more than mapping in the English system. The 36,000 existing maps could all be converted in a relatively short period of time—possibly 3 years— with a massive infusion of funding and allocation of personnel. On the other hand, the conversion, per se, could cost almost nothing if left to normal attrition, that is, the conversion to metrication of maps only when they are to be completely revised. More practical, however, than either of these two approaches would be a combined program with a reasonable level of funding set aside annually to convert a certain percentage of maps with others being converted through the complete revision process. Done this way, conversion would, of course, take longer, but funding and manpower needs could be better planned. And this approach would permit the Division to have all presently existing maps converted within about 10 years. As to new mapping, it is the Division's goal to have all new maps of those States willing to convert immediately compiled in the metric system beginning in fiscal year 1977 and to have all other new maps compiled in a manner to permit ready and economical conversion to metric editions, also beginning in fiscal year 1977.

Thus, the Survey's Topographic Division has faced the issue of map metrication, developed a plan that pays attention to both map users and map producers, and is moving ahead with implementation of the plan. Metrication in the National Mapping program is underway and will increase substantially over the next few months. Fiscal year 1977 should see the myriad of details of conversion worked out and the program moving into high gear.

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Plate Tectonics and Man

By Warren Hamilton

INTRODUCTION

Coastal and inland California ground past one another for less than a minute, at 5:13 a.m. on April 18, 1906, and produced the San Francisco earthquake. The coastal side lurched as much as 6 meters (20 feet) northwestward, along a fracture, a part of the San Andreas fault, 430 kilometers (270 miles) long. In those catastrophic moments, the two sides released strains which had been building for about a century as the part of the Earth's outer shell beneath the Pacific Ocean moved slowly but inexorably past that part beneath North America. The steady motions are continuing, and future great earthquakes are a certainty. The year 1976 has seen an unusual abundance of destructive earthquakes around the Pacific Ocean.

Like most earthquakes, that of 1906 was a manifestation of the fragmentation of the Earth's outer shell into large and small plates, all moving relative to all others with steady velocities that reach 13 centimeters (5 inches) per year—pulling apart here, slipping past one another there, sliding beneath another somewhere else, and in other places colliding slowly to build some of our most spectacular mountain ranges. Earthquakes are the most dramatic way in which these plate motions affect man, and our new understanding of the motions permits a comprehension of earthquakes which could not be approached until a decade ago. Most volcanic eruptions are also produced by the plate motions. The distribution of the mineral deposits and fossil fuels upon which our civilization depends has to a large extent been controlled by plate motions and interactions.

The basic understanding of plate motions was developed primarily during the 1960's in a conceptual revolution as profound for the earth sciences as was the earlier development of the concept of evolution in biology and of atomic and molecular structure in physics and chemistry. We know the new field as plate tectonics: the "plate" is the basic unit of the system, and "tectonics" (from the Greek work *tekton,* meaning builder) refers to the processes and products of motions within the Earth.

This essay ranges broadly over Earth processes and materials in an attempt to give an integrated view of their relationships. Many of the concepts presented are accepted by most earth scientists, but others are controversial.

DEVELOPMENT OF THE CONCEPTS

Science is cumulative, and advances are made in the light of knowledge gained painstakingly by many researchers. A survey of the development of plate tectonics illustrates the progressive and cooperative nature of science and the way in which research in diverse fields produces unifying concepts of practical value to society. The concepts of plate tectonics were developed slowly at first, then with a rush, by earth scientists, government and academic, of many nations. Some of those scientists and their contributions are mentioned here. Many others were important also.

The reality of continental drift was reasonably well established during the 1930's, as Alexander Du Toit of South Africa and others followed up on the pioneering work a decade and more earlier by Alfred Wegener of Germany and Emile Angand of Switzerland. The distribution of indicators of past climates—for example, the presence in now-tropical India of continental glacial deposits of the same 300-million-year age as fossilized tropical reefs and equatorial forests in lands now in the Arctic—required that the continents had moved slowly about the globe. Reassembly of continents in patterns suggested by their shapes provided remarkable continuity for similar, truncated geologic terrains. The "drifters" mostly visualized continents, mistakenly, as rafts sliding over the ocean floors; most geophysicists regarded this as impossible, and only a vocal minority of earth scientists supported the concepts. David Griggs, then at Harvard, had a view of ideas to come when he suggested that the mountain systems around the Pacific were caused by the ocean floors plunging beneath the continents.

Geophysicists changed sides in increasing numbers in the 1950's as the science of paleomagnetism expanded rapidly and provided powerful new evidence for drift. Many rocks, such as volcanic rocks crystallized from lava, contain tiny grains of magnetite and other magnetic minerals which retain the magnetic orientation of the Earth's magnetic field of the time at which the rocks formed. Early studies of this phenomenon had been made mostly in France and Japan during the 1920's, but scientists in other nations became involved subsequently. The magnetic orientations of rocks indicated fossil latitudes, which proved to be about the same, for the various continents, as those indicated by paleoclimatology and other geologic and paleontologic criteria. Among the "drifter" geologists, still a minority, S. Warren Carey of Australia was adding important new concepts.

The 1950's also saw the gathering of an enormous amount of geophysical data from the oceans, particularly by research vessels from American oceanographic institutions, and the 70 percent of the Earth's surface that is covered by water began to yield its secrets. A globe-girdling system of interconnecting submarine ridges was recognized, in part lying midway between continents, like Africa and South America, that appeared, on geologic grounds, to be moving apart. Bruce Heezen of Columbia University suggested that new oceanic crust was being formed at the ridges and added to great plates moving apart. Great submarine trenches were also delineated, particularly along the convex oceanic sides of the volcanic arcs which make up the "ring of fire" around the Pacific, and from these trenches inclined zones of earthquakes dip as deep as 700 kilometers (450 miles) into the mantle beneath and behind the volcanic arcs. Harry Hess of Princeton University was probably the first to see the broad outline of what was to emerge as plate tectonics when he reasoned that oceanic crust was formed at spreading ridges behind drifting plates and was destroyed at the same rate elsewhere as oceanic plates tipped down at the trenches and slid deep into the mantle along the seismic zones. Robert Coats of the U.S. Geological Survey and Robert Dietz of the National Oceanographic and Atmospheric Administration were among those who early suggested applications of these processes to the geology of the continents. Others saw the motions of the continents themselves clearly enough, but not the way these motions involved the floors of the oceans.

Paleomagnetic researchers demonstrated that the Earth's magnetic field has been "normal" during about half of geologic time and "reversed" (a magnetic compass would point south instead of north) the other half and that the intervals of contrasted polarity were extremely irregular. Allan Cox, Richard Doell, and Brent Dalrymple, all then of the U.S. Geological Survey, built up during the early 1960's a precise magnetic-reversal time scale for these polarity periods during the past 4 million years. Frederick Vine and D. H. Matthews, English scientists, suggested that the alternating belts of highly and weakly magnetic oceanic crust, known by then to trend along the mid-ocean ridges, represented magnetic recordings as new crust formed in the gap behind separating plates and that the belts would record symmetrically, on opposite sides of the young ridges, the periods of time represented by the magnetic-chronology time scale. They tested the suggestion against several small ridge sectors and showed that it fit. The Lamont Geological Observatory of Columbia University then became involved with its unique computerized data bank of marine magnetic surveys, and James Heirtzler, Ellen Herron, Xavier Le Pichon, and Walter Pitman, III, showed in the late 1960's that ridge after ridge fit the pattern, and they carried the magnetic time scale back 75 million years. Only 3 years previously, Heirtzler and Le Pichon had written that no spreading was needed to explain the magnetic stripes—but they abandoned their previous position when it became untenable.

Also in the late 1960's Le Pichon (a Frenchman), Dan McKenzie (English), and Jason Morgan (American, at Princeton) deduced from magnetic, bathymetric, and other data the geometric principles by which the great pieces moved. Bryan Isacks, Jack Oliver, and Lynn Sykes, all then of Lamont, showed that seismic data, including the distribution and slip directions of earthquakes, fit the new concepts in detail. John Bird (then at the State University of New York at Albany), Gregory Davis (University of Southern California), John Dewey, (English and now at Albany), William Dickinson (Stanford University), Tanya Atwater and Daniel Karig (both then at the Scripps Institution of Oceanography, University of California), George Plafker and Warren Hamilton (U.S. Geological Survey), among others, showed how the geology of continents and volcanic island arcs could be explained in terms of the new concepts.

By 1970, the concepts had been developed, proved, and broadly applied. The 1970's have produced an enormous amount of additional evidence. The research drilling of the ocean floors by the Deep Sea Drilling Project, for example, has confirmed the ages of the magnetic "stripes," the recognition of which provided the breakthrough in the initial concepts. There have already been many refinements and extensions of our knowledge and understanding. Soviet and Eastern European earth scientists are slowly recognizing the importance of the new field, but have yet to contribute significantly to its concepts.

THE CONCEPTS

The Earth's crust is broken into moving plates of "lithosphere" (fig. 13). There are seven very large plates, each consisting of both oceanic and continental portions, and a dozen or more small plates (not all of which are shown on fig. 13). Each plate is about 80 kilometers (50 miles) thick and can be pictured as having a shallow part that deforms by elastic bending or by brittle breaking, and a deeper part that yields plastically, beneath which is a viscous layer on which the entire plate slides. The plates tend to be internally rigid, and they interact mostly at their edges. Spherical geometry requires that any motion between two portions of a spherical surface be expressed as the rotation of one relative to the other, defined by an angular displacement and by a pole of relative rotation, and that all trajectories of relative motions be along small circles to that pole. (Latitude lines are small circles relative to the Earth's geographic pole). These theoretical constraints are largely met by all of the criteria by which plate motions are demonstrated. The magnetic "stripes" along the midocean ridges define spherical angles: velocities of separation of adjacent plates are constant in angle, not in linear value. The direction of slip in earthquakes along plate boundaries, and the orientation of strike-slip faults that form or offset those boundaries, are in the corresponding small-circle directions.

All plates are moving relative to all others. There are grounds for suggesting that the African plate may now be approximately fixed relative to the deep mantle, but if so it is the only such plate. Velocities of

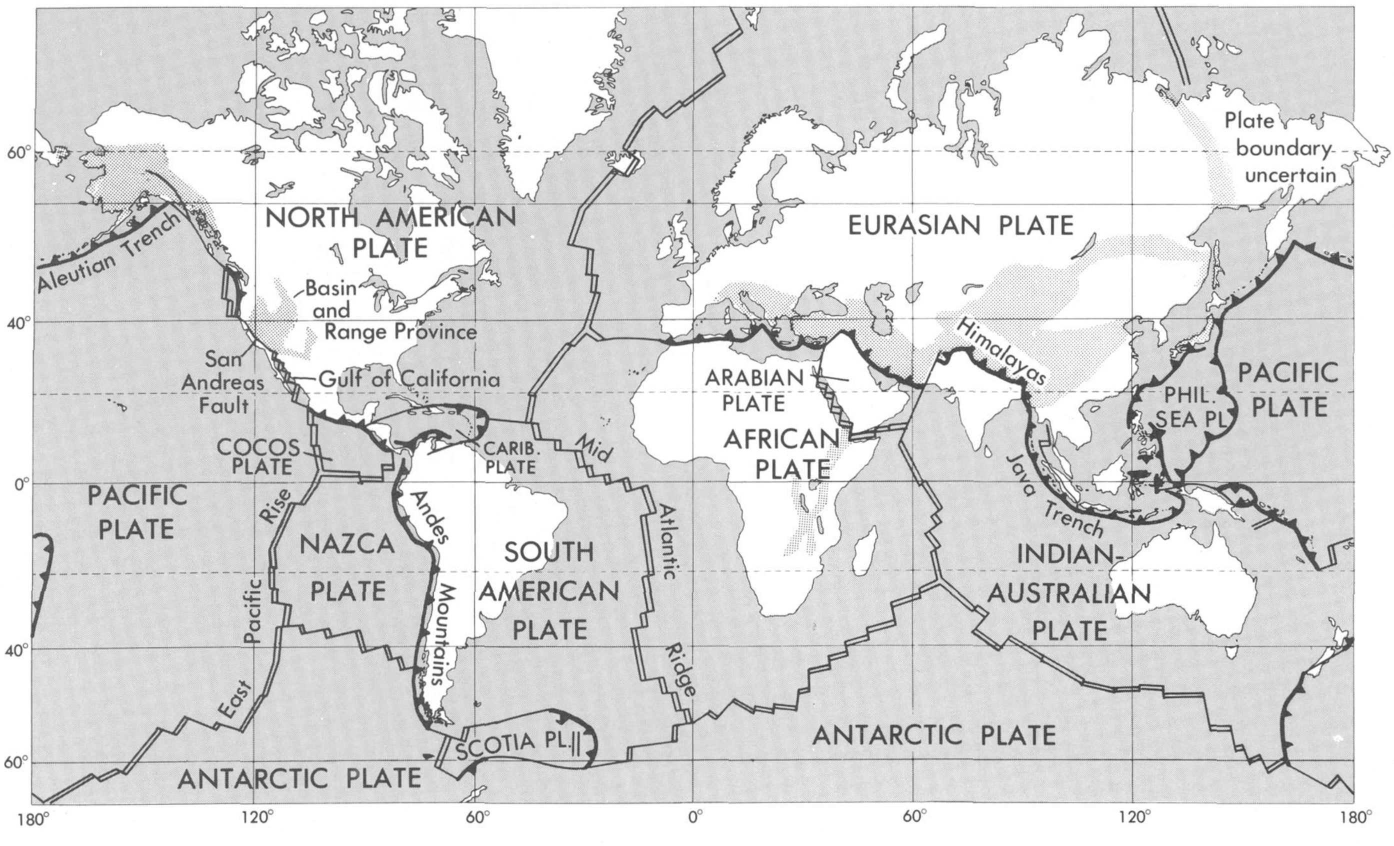


FIGURE 13.—Lithosphere plates of the world, showing boundaries that are presently active. Double line: zone of spreading, from which plates are moving apart. Line with barbs: zone of underthrusting (subduction), where one plate is sliding beneath another; barbs on overriding plate. Single line: strike-slip fault, along which plates are sliding past one another. Stippled area: part of a continent, exclusive of that along a plate boundary, which is undergoing active extensional, compressional, or strike-slip faulting. Compiled and adapted from many sources; much simplified in complex areas.

relative motion between adjacent plates range from less than 1 centimeter (a small fraction of an inch) to about 13 centimeters (5 inches) per year. Although these velocities are slow by human standards, they are extremely rapid by geologic ones: a motion of 5 centimeters (2 inches) per year, for example, adds up to 50 kilometers (30 miles) in only 1 million years, and some plate motions have been continuous for 100 million years.

Plates are now pulling apart primarily along the system of great submarine ridges in the world's oceans. Hot material from the deeper mantle wells up into the gap, and some of it melts and is erupted on the surface as lava or is injected near the surface to crystallize as other igneous rocks. The ridge stands high because its material is hot, and hence low in density. As the plates move apart, the ridge material gradually cools and contracts, and its surface sinks. Ridges generally form steplike alternations of spreading centers perpendicular to the direction of motion and of strike-slip faults parallel to that direction. (The actual sense of movement along these "transform" faults, conceptualized first by Canadian Tuzo Wilson —an antidrifter of the 1950's, but a major contributor to plate tectonics in the 1960's—is opposite to the apparent direction of offset of the ridge, and the demonstration that earthquake slip directions on them are indeed in this "opposite" sense is one of many kinds of evidence for plate tectonics.) The spreading center of the Mid-Atlantic Ridge is exposed on Iceland (fig. 14).

Where plates converge, one tips down and slides beneath the other. Generally, an oceanic plate slides ("subducts") beneath a continental plate (for example, along the west coast of South America) or another oceanic plate (for example, the east side of the Philippine Sea plate). A trench is formed where the undersliding plate tips down, and the ocean-floor sediment it carries is scraped off against the front of the overriding plate (fig. 15). We now know much about the mechanics of these junctions from geophysical studies and particularly from seismic-reflection profiles made across them with instruments developed for oilfield exploration. Farther back under the overriding plate, zones of earthquakes, inclined down into the mantle to depths that reach 700 kilometers (450 miles), show the trajectory of the descending plate. Typically, a belt of volcanoes lies above that part of this inclined earthquake zone, which is about 125 kilometers (80 miles) deep. The melting which ultimately produces the volcanoes may start with the forcing out of water, previously combined in the crystal structures of various minerals, by the increase of pressure on the downgoing plate; the released water lowers the melting temperature, and so permits melting, of surrounding rock.

FIGURE 14.—Tension rift on the spreading crest of the Mid-Atlantic Ridge, as exposed in southwest Iceland. The faults and fissures break a plain of basalt lava flows a few thousand years old. The foreground fissure has a maximum width of about 60 meters (200 feet), and a maximum depth of about 45 meters (150 feet) below the rim on the near side and twice that below the rim on the far side. View is northeastward along the Almannagja (Great Fissure). Photograph by Bruce Heezen, Lamont-Doherty Geological Observatory of Columbia University.

New oceanic-plate (lithosphere) material is generated by the upwelling processes at spreading ridges. Old lithosphere is consumed, and recycled deep into the mantle, at the same rate at the convergent trenches. The balance is global only: the formation of lithosphere at the Mid-Atlantic Ridge is compensated by subduction primarily in the western Pacific.

Plates slide past one another along strike-slip faults, which can be either on land or at sea. The best known

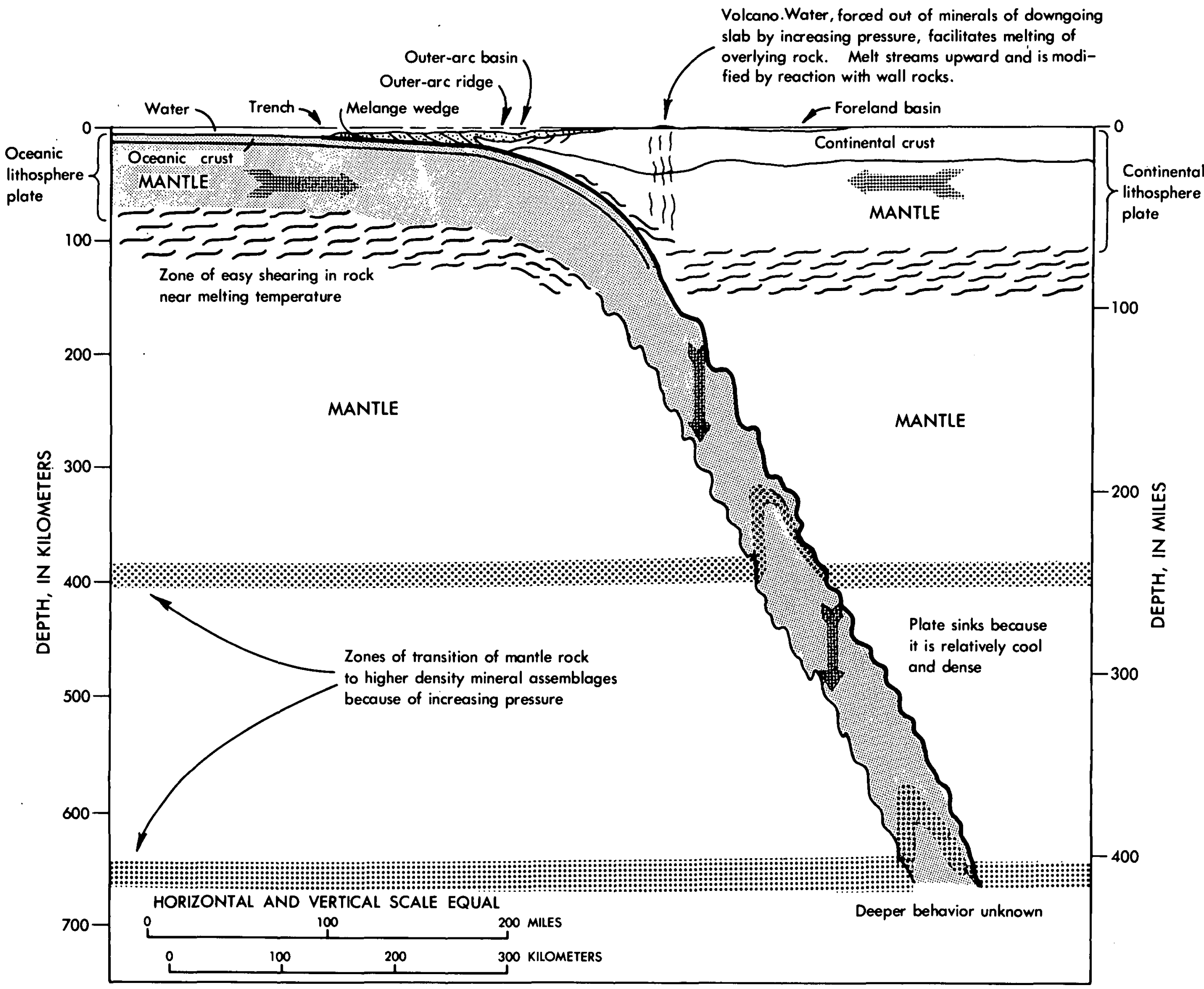
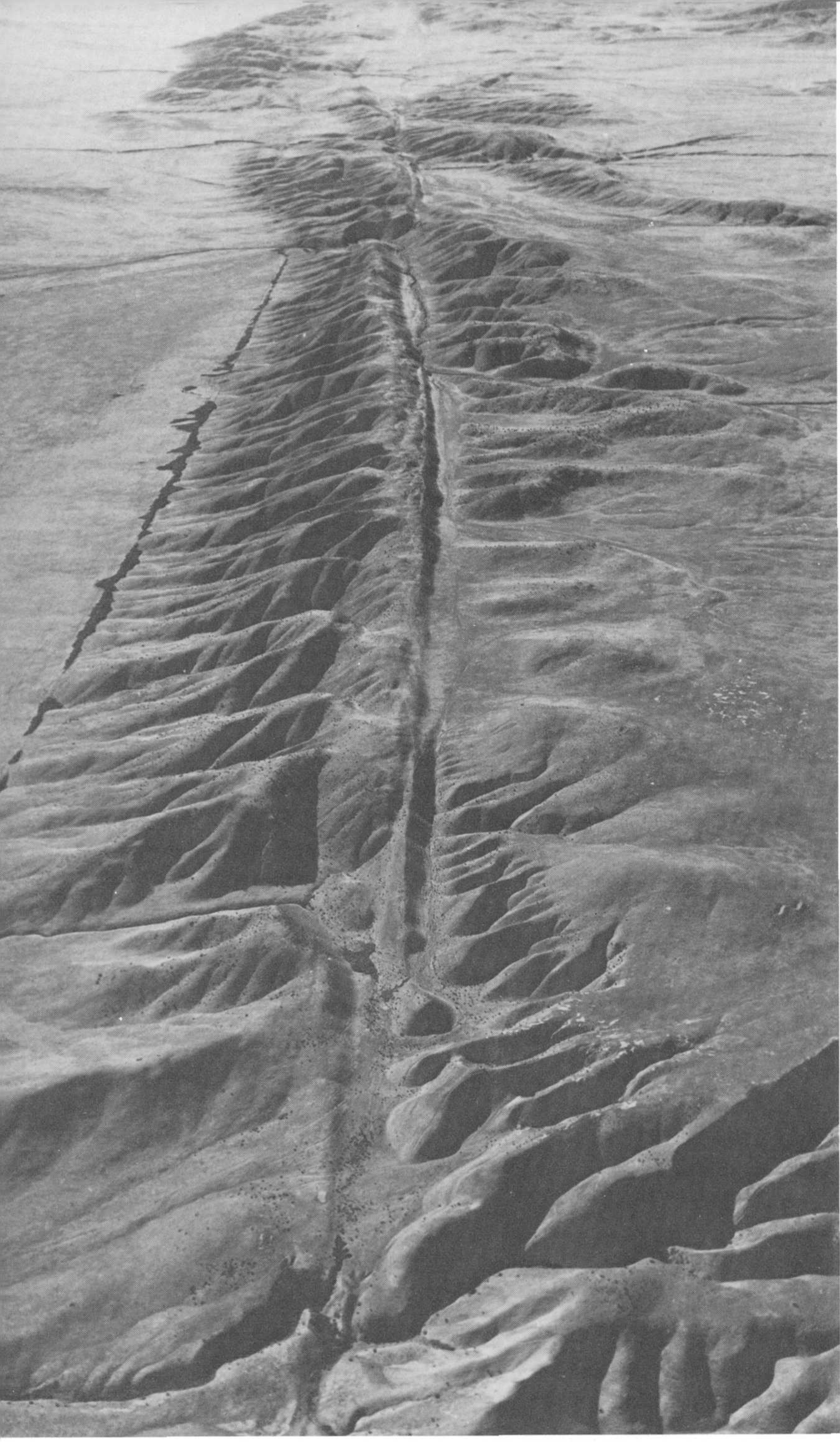


FIGURE 15.—Cross section through a subduction system where an oceanic lithosphere plate is converging with and sliding beneath a continental one. Details and dimensions are those for western Java and the Java Trench system, but other continental-margin systems are similar.

of these faults is the San Andreas fault of California (fig. 16) now being studied exhaustively by geoscientists of the U.S. Geological Survey and other institutions.

Large parts of some of the continents depart from ideal rigid-plate behavior, and undergo much internal deformation (fig. 13). The western conterminous United States is now being broadly stretched and sheared: although most of the relatively northwestward motion of the Pacific plate past North America is taken up along the San Andreas fault, a part is distributed far inland, and the continental crust is stretched and shattered into the many block ranges and basins and other structures. Slight extension is affecting eastern Africa. Most complex is Eurasia, into which Arabia and India are now being rammed, with a broad belt being deformed in front of the advancing pieces. As India is pushed north into and beneath interior Asia, a huge region is being shoved obliquely northeastward out of the way.

Although the integrated concepts of plate tectonics were proved primarily by geophysical studies—and by deep-sea drilling—of the ocean basins, they have revolutionized our understanding of continental geology. By seeing how the geologic features of modern environments relate to present plate boundaries, we can deduce how similar features in the ancient geologic record related to ancient boundaries. Plate motions have dominated tectonic and magmatic processes for the past 2,500 million years. During that time, however, the interior of the Earth has become cooler and less mobile, so that details of the processes



◀ FIGURE 16.—Aerial view northwestward along the San Andreas fault in central California. The Carrizo Plain is on the left. The fault marks the major boundary between the Pacific and North American plates, which are moving inexorably past one another at a rate of about 5 centimeters (2 inches) per year; about two-thirds of the total motion is taken up on the San Andreas. Photograph by Robert Wallace, U.S. Geological Survey.

have changed gradually. Rocks formed between about 2,500 and 3,800 million years ago show that the Earth then had a solid crust, and also oceans, but that the crust was much more fragmented and mobile and underlain by much hotter mantle than is now the case. There are no known rocks older than 3,800 million years. The Earth accreted from the collapsing solar nebula mostly between about 4,600 and 4,400 million years ago and likely was completely molten during part of the period before 3,800 million years.

All present oceanic plates will sooner or later vanish beneath other plates. The oldest ocean floor remaining anywhere in the world is less than 200 million years old. Continents stand high because they are composed of thick, light material—too light to be dragged deep into the mantle, along with oceanic-plate material, so continents are jammed together when an intervening ocean floor disappears beneath one of them. If present major plate motions continue for another 50 million years, Australia will be crowded against China, and the island complexes of Indonesia and the Philippines will be squashed into a mountain system between the colliding continents. Many such past collisions can be recognized in the geology of the continents.

The propulsive mechanism for plate motions is still a matter of speculation, and those working with the problem hold conflicting opinions. The greater part of the motions represent very slight differences in spin velocity about the Earth's axis: spreading ridges and subduction zones tend to be alined more north-south than east-west, and poles of relative rotation between moving plates are concentrated at high latitudes. These facts indicate that the Earth's rotation is an important part of the mechanism.

EARTHQUAKES

Most earthquakes occur along or near the boundaries of lithosphere plates, and narrow earthquake belts outline the plates. Conversely, the recognition, accompanying the ability to locate distant earthquakes precisely, that earthquakes are mostly confined to narrow connecting zones which have distinctive bathymetric settings, was one of the major developments that led to the concepts of plate tectonics. Narrow zones of earthquakes follow the spreading centers and strike-slip faults shown on fig. 13. Inclined zones of earthquakes extend deep into the mantle from the indicated subduction-zone trenches. There are also many earthquakes within those continental terrains undergoing distributed deformation. Shallow earthquakes represent sudden slippages that release strain stored elastically in rock over long periods. Whether deep-mantle subduction-zone earthquakes represent similar elastic rebound or an abrupt contraction of part of a descending lithosphere plate into rock of higher-density minerals is uncertain; these deep earthquakes are mostly small enough, and distant enough from the surface, so that their potential for human disaster is small.

Only a small fraction of the energy released in an earthquake goes into the seismic waves. Most is absorbed locally by moving, deforming, and heating rock, and the proportion so absorbed increases irregularly with increasing size of earthquakes. The size of an earthquake is normally expressed as its "magnitude," an imperfect indication of seismic energy alone. An increase in magnitude of one unit (the maximum recorded is about 8.7) denotes an increase in amplitude of seismic waves by a factor of 10 and an increase in total seismic energy by an irregular factor of about 30. The number of earthquakes in each magnitude interval decreases by about a factor of 10 with each unit of increased magnitude, so the energy released by great earthquakes is far greater than the total released by small and intermediate ones. Minor earthquakes do not generally represent a safety valve adequate enough to dissipate the energy that is stored for great earthquakes, although slow creep along a fault can provide at least a partial release. On the other hand, the occurrence of a great earthquake does not prove that all dangerous strain has been released, for during this century there have been a number of pairs of great or severe earthquakes, separated by only months, days, or even hours, at virtually the same locations.

The magnitude of an earthquake depends upon the length and breadth of the fault plane of slippage, as well as on the amount of slip. The spot locations ("epicenters") given for earthquakes are the sites of initial breakage, but from such a site the slip propagates along the fault, with a velocity up to that of the outward-radiating seismic shear-wave front (3 kilometers, or nearly 2 miles, per second), until the entire affected segment can be in motion at once. Oceanic spreading centers are so hot at shallow depth that the solid rock above them can not store enough elastic strain to produce great earthquakes, and the infrequent large earthquakes that do occur in ridge systems are mostly on the longer strike-slip ("transform") faults, along which spreading on one ridge segment is stepped to that on the next. Great earthquakes occur primarily along convergent (subducting) and strike-slip plate boundaries and within those parts of the continents undergoing intraplate deformation (fig. 17), for these are the settings where fault breaks of adequate size are possible. Matters dealing particularly with the earthquakes of the Western United States are discussed here in these terms.

SUBDUCTION-ZONE EARTHQUAKE: ALASKA, 1964

A great subduction-zone earthquake of magnitude 8.5 struck south-central Alaska on March 27, 1964. Here Pacific lithosphere that is moving northwestward tips down at the Aleutian Trench and slides, with gentle inclination, beneath a melange wedge similar to that illustrated by fig. 15, dragging the base of the wedge very slowly northwestward. Compressive strain stored slowly at the base of the wedge resulted in sudden faulting that broke violently through to the surface. The results of the earthquake were studied exhaustively by Geological Survey and other scientists, whose work, reported in the many separate chapters of Professional Papers 541 through 546 and in other publications, makes this the best documented earthquake of subduction-zone type.

During the several minutes of the earthquake, the continental shelf and the deep-water slope from it down to the Aleutian Trench were uplifted by amounts that locally reached at least 9 meters (30 feet). The sea floor was raised an average of perhaps 3 meters (10 feet) over an area approximately 800 kilometers (500 miles) long, trending southwestward past the Kenai Peninsula and Kodiak Island, and 250 kilometers (150 miles) wide. Simultaneously, the uplifted terrain was narrowed, and the coastal part of it moved as much as 18 meters (60 feet) toward the trench. These changes represent by far the greatest movements of rock yet demonstrated to have accompanied an earthquake, although presumably other great subduction-zone earthquakes around the Pacific (fig. 17) have had comparable submarine effects. Analysis of the seismic record and geologic results of the earthquake indicate that a large part of the melange wedge behind the Aleutian Trench suddenly slipped forward, up the gently dipping surface of the oceanic lithosphere beneath, releasing strain stored as its base had been dragged back slowly over many decades. The slippage did not continue along the base of the wedge to the trench but rather broke up through the wedge, thrusting its rear part upward.

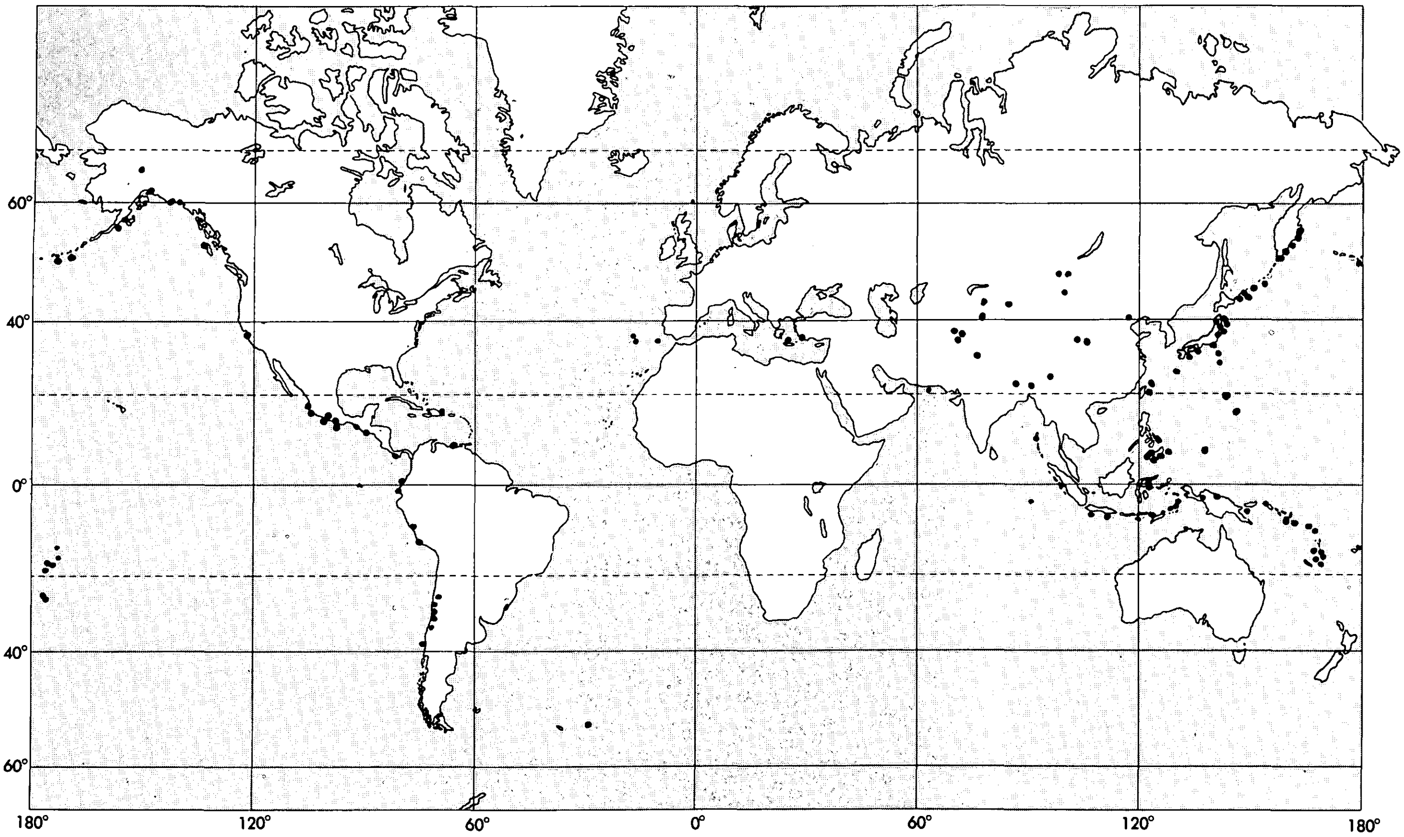


FIGURE 17.—World map showing the location of earthquakes of magnitude 8.0 and higher, 1897–1976. These great earthquakes occur primarily along convergent or strike-slip plate boundaries and in zones of compressive or strike-slip deformation within continents. Data from the "World Seismicity Map," compiled by Arthur Tarr and printed by the U.S. Geological Survey in 1974, with newer locations added.

SEISMIC SEA WAVES

When the sea floor is raised suddenly during a great earthquake, water is raised with it, the sea surface is tipped, and water rushes away; or, if the floor is dropped, water rushes in. An enormous mass of water is suddenly set in motion, and complex sloshing back and forth continues for many hours. The result is a train of water waves of a unique type, the seismic sea wave or "tsunami" (its Japanese name). The velocity of a water-wave form increases with its length, and in the deep ocean these uniquely long waves travel at about 800 kilometers (500 miles) per hour. The waves at sea are something like an hour apart at a given point, are only perhaps 30 centimeters (1 foot) high, and are virtually undetectable. As a wave approaches land, however, its bottom is slowed down by contact with the shallowing sea floor, whereas the top is slowed much less and catches up with the bottom. Where sea-floor topography and orientation are optimal for a tsunami from a given direction, the wave can hump up into a breaking wall of water 9 meters (30 feet) or more high, and rush onto the shore to cause enormous destruction. Nearby coastal points, where the bottom configuration is different, may record the same wave only as a rapid surge and withdrawal of water, with much lower height.

The most extensive sudden changes in depth of the sea floor, and hence the greatest seismic sea waves, result from shallow subduction-zone earthquakes, such as the Alaska earthquake of 1964. The enormous change in sea-floor configuration during that earthquake produced a train of seismic sea waves which battered Alaskan coastal communities facing the uplifted region. Damage was most severe at Kodiak Harbor, where the first wave rose as a high swell and did little damage, but the second, an hour after the first, and the third, another hour later, hit as breaking-water walls that ran up on shore as high as 9 meters (30 feet) above high-tide levels. Away from Alaska, the waves in the train were highest going southeastward, perpendicular to the axis of the uplift, and did much damage along the Pacific coast as far south as San Diego. The most severe damage at a long distance from Alaska was at Crescent City in northern California, where the fifth wave, following a train of four successively decreasing waves an hour or so apart, crested 6 meters (20 feet) above mean lower low water.

Another great subduction-zone earthquake of magnitude about 8.0 off southwest Mindanao in the Philippine Islands in August 1976 produced tsunamis that killed 5,000 people along nearby coasts. The 1964 Alaska earthquake represented part of the motion between the gigantic Pacific and North American plates, whereas the 1976 Philippine one resulted from motion between two small, young plates that have complex boundaries.

STRIKE-SLIP EARTHQUAKES: THE SAN ANDREAS FAULT SYSTEM

From the Gulf of California to the corner of the Gulf of Alaska, the Pacific lithosphere plate is sliding relatively northwestward past the North American plate. (Complications along Oregon, Washington, and southern British Columbia, much simplified on fig. 13, are mentioned in the subsequent section on volcanoes.) The strike-slip fault along which most of this motion is presently being taken up is exposed on land along most of the length of California, where we know it as the San Andreas fault. The effect of the 1906 earthquake of magnitude 8.5, during which the northern sector of the fault broke, was described briefly in the opening paragraph of this essay.

The Pacific and North American plates are sliding past one another at a steady 5 or 6 centimeters (2 or 2½ inches) per year. About two-thirds of this movement is taken up by slippage along the San Andreas and related structures, whereas the rest is taken up by other structures, mostly farther inland in the Basin and Range province. The sides of each active fault, like the San Andreas, generally remain stuck together until enough strain has accumulated in the flanking, bending rocks to rupture the bond and permit the lagging parts to suddenly catch up with the rest. Earthquakes on the San Andreas rarely reach deeper than about 15 kilometers (10 miles), and presumably the two sides flow smoothly past each other, without sudden ruptures, in the hot region of easy recrystallization beneath this depth. In some areas, notably that near Hollister, south of San Francisco, the two sides of the surface fault slide past one another almost constantly, with only small earthquakes, steadily increasing the offset of such features as fences and roads.

The overall San Andreas rate is about 3 or 4 centimeters (1½ inches) per year, and a great earthquake like that of 1906 releases strains accumulated over 50 to 200 years. One cannot, however, predict recurrence intervals from this simple relationship. Moderate, large, and great earthquakes may be interspersed, and even great earthquakes do not release all stored energy. Some of the plate motion is stored in elastic bending of the rocks, to be released during earthquakes; but some is taken up in permanent, slow deformation by rock folding and other processes.

A long sector of the San Andreas fault, extending from well south of the part that broke during 1906 southeast to near Los Angeles, broke during an 1857 earthquake that may have been more severe than the 1906 San Francisco event. Historical documentation is poor, but geological evidence within the sector pictured in figure 16 indicates that horizontal shifts during the 1857 earthquake probably reached 15 meters (50 feet), and averaged 10 meters (30 feet) over a considerable length. Moderate earthquakes in 1899, 1907, and 1916 occurred along and southeast of the southeast part of the 1857 sector, but the whole sector is now very quiet seismically. The growth during the last 15 years of the "Palmdale bulge," more than 250 kilometers (150 miles) long and up to 25 centimeters (10 inches) high, across the southeast end of the 1857 sector, leads some fault watchers to anticipate another major earthquake here soon.

Farther southeast along the San Andreas system in the Imperial Valley region of southeastern California, the deformational style changes, and with it earthquake patterns, in accord with the changing geometry of the lithosphere plate boundary. The Pacific plate is moving northwestward relative to North America, so it is sliding past North America through California, but it is pulling obliquely away from North America in northern Mexico, thus moving Baja California away from the mainland and opening the Gulf of California (fig. 13). This pulling apart is accomplished by a series of short spreading centers stepped to one another by transform faults, and the northernmost spreading centers have produced much of Imperial Valley itself. There were severe earthquakes, near magnitude 7, along transform and related faults in and near the Imperial Valley of California and the adjacent Colorado River Delta region of Mexico in 1899, 1903, 1915, 1918, 1934, 1948, and 1968. The transform faults proper may be too short to store enough strain to produce great earthquakes, but other active strike-slip faults farther west in southwestern California and northern Baja California are long enough to do the job.

A very severe earthquake, magnitude about 7.7, east of Peking in northeast China in July, 1976, killed perhaps half a million people in one of the greatest natural disasters of recorded history. Unsafe buildings, urban congestion, and unstable, alluvial ground contributed to the extremely high casualties from this earthquake, which released far less energy than did the many great earthquakes during this century. The shock resulted from intra-plate strike-slip motion along a fault about 150 kilometers (90 miles) long. Subsidiary compressional faulting on related structures accompanied the main shock, and an extensional-fault earthquake of magnitude 7.2 followed only 15 hours later in the same area.

COMPRESSIVE DEFORMATION WITHIN THE CONTINENT: SAN FERNANDO, 1971

Both the Pacific and North American plates are moving relative to the deep mantle; thus, so also is the San Andreas fault boundary itself, which is slowly changing its shape as the adjacent plates deform. In southern California, the sector of the fault from north of Los Angeles to east of San Bernardino has rotated slowly counterclockwise, from a northwest to a west-northwest trend. The result is that in this sector pure strike-slip (sideways) motion is becoming more difficult, and oblique compression of the continental crust is taking place. The San Fernando earthquake of February 9, 1971, was a small manifestation of this changing pattern. The effects of the earthquake were described in Professional Paper 733, published soon after the event, and subsequent more detailed reports by Geological Survey and other scientists.

The San Fernando earthquake was of only moderate size, magnitude 6.5, and resulted in surface slips of mostly less than 30 centimeters (1 foot) along short, discontinuous breaks in a zone 15 kilometers (9 miles) long. The surface faults trend eastward along the south edge of the San Gabriel Mountains, and the earthquake represented an increment in the growth of the range, the frontal part of which shifted southwestward and upward, ramping obliquely about 1 to 2 meters (3 to 7 feet) up a fault surface dipping moderately northward beneath the range. Most of the shift was displayed at the surface as a broad bulge, identified by surveying, and only locally did a large part of it appear in the surface breaks.

Despite the modest size of the earthquake, 64 people were killed by it, and property damage approached $1 billion. Damage was particularly heavy above the ramplike fault; accelerations locally exceeded gravity, which most seismic engineers had assumed to be improbable. The earth-filled Lower Van Norman Dam, holding back a large reservoir above the San Francisco Valley city area, was so heavily damaged that likely it would have failed had the earthquake continued much longer.

Other damaging earthquakes within the southern California oblique-compression region include events in 1902, 1925, 1927, 1933, and 1952 which ranged in magnitude between 6.3 and 7.7. Much larger earthquakes have occurred in analogous settings on other continents; hence they may occur here also, and, indeed, an 1812 earthquake centered in the Santa Barbara Channel might have had a magnitude as large as 8.

TENSIONAL DEFORMATION: THE BASIN AND RANGE PROVINCE

The San Andreas fault is the most important single structure in the broad boundary zone between the Pacific and North American plates, but some northwestward motion is distributed far inland across the Western United States. The resulting oblique extension of the continental plate has produced the Basin and Range province, which includes eastern California, Nevada, and western Utah, and similar terrains in western Montana, Idaho, eastern Oregon, southern Arizona, and New Mexico (fig. 13). Because the general direction of motion, relative to the continental interior, is northwestward and the amount of that motion increases westward toward the Pacific, the deformation tends to be expressed by strike-slip faulting on structures oriented approximately northwestward and by extensional ("normal") faulting on structures with other orientations. The tensional faults have blocked out the mountains and basins which characterize the province. The surface faults tend to follow the pre-extension structural grain of the near-surface rocks: the mechanical properties of the crust determine the details of its response to the regional stresses.

West-central Nevada had oblique-slip and normal-slip earthquakes with magnitudes of 7.1 to 7.6 in 1915, 1932, and 1954. A normal-fault earthquake of magnitude 7.1 struck the West Yellowstone region of southwestern Montana in 1959 (see Professional Paper 435) and provided a particularly good example of the discordance between large surface faults (lengths to 23 kilometers, or 14 miles, and slips to 6 meters, or 20 feet) and crustal deformation at depth. Owens Valley in east-central California was struck by a magnitude 7 plus earthquake in 1872, and the oblique-extension fault slip reached 8 meters (25 feet).

The major extensional faults, both as observed geologically and as known from earthquake offsets, have near-surface dips commonly near 60° toward their downdropped sides. Extension is obviously required to accommodate such dropping down an inclined surface. The majority view holds that the observed steep fault dips continue downward until a more plastic substrate is reached and that the total amount of extension across the Basin and Range province during the last several tens of millions of years has been on the order of 10 percent of the width of the province. A contrary argument is that the faults must instead flatten downward and give way to horizontal laminar shear at depth and that the width of the province has been almost doubled by the extension. The province is characterized by a thin crust, by high temperatures at shallow depth, and by volcanism of a type which typically accompanies extension; these features may be products of the thinning of the crust by extreme extension.

Fault scarps no older than a few thousand years are present in many parts of the Basin and Range province and attest to the frequency of major earthquakes. The length and height of some of these scarps, and the amount of associated tilting and warping, suggest that some of the earthquakes—for example those in the Centennial Valley region of southwestern Montana and the Death Valley region of eastern California—had magnitudes near 8. Much of the seismicity during this century has been concentrated along a belt trending northward from southern Nevada through central Utah and into southwestern Montana. Some of the young fault scarps are within this belt, but most are not; the most imposing young scarps anywhere in the province, for example, are in the Death Valley region, which is presently almost aseismic. We still know little about stress-transfer mechanisms, strain-accumulation rates, and similar problems in the province, but it appears that recurrence intervals on individual active faults are typically thousands of years and that the faults tend to remain locked and aseismic during most of the strain-buildup period between episodes of breaking.

VOLCANOES

Most volcanoes are products of lithosphere-plate motions. The "ring of fire" around the Pacific represents one type of this volcanism. The chains of volcanoes in the island arcs (such as the Aleutian Islands) and continental margins (such as the Andes) around much of the ocean form above undersliding oceanic plates. The main volcanic axis is typically about 125 kilometers (80 miles) above the inclined zone of earthquakes that marks the descent of the lithosphere plate into the deep mantle (fig. 15), so processes related to the descent and to that depth must control the melting of the magmas. The melts that arrive at the surface, to erupt in volcanoes, have been profoundly modified by reactions with the mantle and crustal rocks through which they have risen. Lavas formed in this setting have distinctive compositions and systematic variations that relate directly to their height above the subducting plate. These characteristics permit us to recognize rocks formed in similar settings in the geologic past and to estimate even the depths to the long-dead seismic zones above which they formed. Where, in ancient terrains, the volcanic rocks have been eroded away, we now see granites and other rocks which crystallized slowly within the crust from similar magmas.

The high volcanoes of the Cascade Range in Oregon and Washington—Mount Hood and Mount Rainier, for example—form a short chain of this type, vigorously active until not many thousand years ago but now showing only infrequent activity. The decline in volcanism reflects a plate-boundary change now underway to the west: there was until recently rapid subduction of a small Pacific plate beneath northern California, Oregon, and Washington, but the pattern is presently changing; the San Andreas fault system is now breaking across the small plate. Small quantities of magma are still rising into the volcanoes, and small eruptions are likely to occur every 50 years or so. Of the possible eruptive types, lava itself poses little hazard, but glowing avalanches and volcanic mudflows (see next paragraph) could be damaging.

In the tropics, volcanoes of this type are a boon as well as a bane. Tropical soils are heavily leached, but volcanic areas generally have fertile soils because mineral nutrients are replenished by frequent ash falls. Java, half the size of California, can support its population of 90 million people only because of its young volcanic soils. But Javanese volcanoes—many of which show continuous hot-water and steam activity and actually erupt every few years—also cause much destruction. The common major hazard is the volcanic mudflow, for which the Javanese term "lahar" is generally used in geology. Lahars are mixtures of mud and volcanic rock which flow down volcano sides and thence down stream valleys beyond, sometimes as far away as 65 kilometers (40 miles). A lahar can be either cold, triggered by heavy rains or earthquakes affecting the steep, unstable slope of a volcano, or hot, representing a mixture of new lava, water from crater lakes (or from melting ice, in a site such as the Cascades), and surficial materials picked up along the way. Still more destructive, but fortunately rare, are great volcanic explosions, of which that of the island of Krakatoa in 1883 is the most famous. Here, between Java and Sumatra, sea water and magma combined to produce a steam explosion which blew the top 20 cubic kilometers (5 cubic miles) of the volcano into the air; the resulting giant sea waves killed 35,000 people.

The volcanoes of the western conterminous United States away from the Cascades are byproducts of the rifting of continental crust. The deeper part of the continental crust is hot enough so that it would melt if the pressure could be released; thinning of the crust does decrease the pressure and permits partial melting. There have been no historic eruptions of these rifting-type volcanoes in the non-Cascade West, but there were prehistoric eruptions every few hundred years, so more can be expected in the future. The common activity has consisted of the building of a cinder cone and the eruption of small lava flows, likely completed within a decade in many cases. Much less frequent, perhaps every 100,000 years, has been the huge ash-flow tuff type of eruption; a very large mass of magma reaches the surface and erupts as giant fountains, perhaps a kilometer or two (a mile) high, which collapse and spread thin sheets of lava and hot frothy ash over areas that can reach more than 5,000 square kilometers (several thousand square miles). No eruption of this type has been observed, but study of the products indicates that successive fountains and outflows can be only minutes or hours apart and that composite sheets a hundred meters or more (hundreds of feet) thick can be built in days. Yellowstone National Park is formed mostly of such ash-flow sheets and related lavas and probably is underlain now by a large magma chamber, to which is due the geyser activity; future ash-flow eruptions are probable, but there is no reason to anticipate one soon.

The Hawaiian Islands are huge volcanoes. Hawaii, largest of the islands, rises about 9,000 meters (30,000 feet) above the deep-ocean floor and has volcanic eruptions typically every few years. The volcanoes have been largely built in succession, each one to the northwest being older than than that to the southeast, and Hawaii itself is at the southeast end. The chain of volcanoes continues northwestward as the foundations for atolls as far as Midway and then as submarine mountains—sunken volcanoes—all the way to Kamchatka, and the general age progression continues throughout. A popular explanation for the volcanism and its age progression is that the Pacific lithosphere plate is drifting slowly northwestward over a "hot spot," in the deeper mantle, from which magmas keep rising through the plate above.

MINERAL DEPOSITS

Many mineral deposits have a plate-tectonic explanation. The great bulk of the metallic minerals mined in the Western United States—copper, molybdenum, tungsten, gold, silver, lead, and so on—formed from magmas above subduction zones, like that of fig. 15, during the period from 100 to 15 million years ago. Pacific Ocean lithosphere was then sliding rapidly beneath North America, and belts of volcanoes formed, with granites crystallizing from the large magma chambers beneath the volcanoes. The metals were concentrated in the last-remaining liquids in the magma chambers, after crystallization of the voluminous silicate minerals. Where conditions were favorable, as generally they were not, these enriched liquids altered and replaced the igneous rocks or the nearby wall rocks to form ore deposits. Different combinations of metals concentrate at different levels in the chamber, so the depth of erosion into an igneous complex controls the type of ore deposit that may be found within it. There are also provincial variations in types of deposits, and it is likely that depth of melting of the initial magma (which would be very different in composition from the final magma reaching the surface) and the composition of the mantle and crustal rocks through which the magma rises and reacts are important in determining what, if any, metals are concentrated within it.

Copper occurs, for example, in and near the tops of granite masses that crystallized near the surface, after their magmas had risen through thick crust, either old-continental or young-volcanic, but generally not where similar magmas rose through very thick sedimentary rocks. Much silver occurs in the throats of volcanoes, the magmas of which in many cases did rise through thick strata. Tin forms primarily from granites generated by melting within the crust, rather than by melting within the mantle. Overall, our knowledge of these relationships is fragmentary and more empirical than genetic.

Other ore deposits occur in the zones of tectonic accretion where oceanic materials are scraped off against continental margins from undersliding oceanic plates. Large masses of mantle rocks are in many places sliced into these complexes; such rocks contain a small fraction of nickel, which is concentrated in residual soils by tropical weathering and there forms enormous potential resources. Mercury occurs primarily in such accretion settings, although its genesis is unclear. Copper formed within oceanic crust can also be added to continental margins in the scraped-off complexes. Volcanic island arcs, complete with whatever ore deposits formed within and beneath their volcanoes, are plastered against continents in these zones.

Secondary processes can obscure the plate-tectonic relationships. Tin most commonly reaches commercial concentrations where the effects of tropical weathering are superimposed on those of magmatic processes. Gold, present in tiny quantities in either magmatic or subduction complexes, is concentrated as placer deposits by streams. The uranium ores in Wyoming and the Colorado Plateau may have formed when volcanic ash, washed and blown 800 kilometers (500 miles) inland from volcanic belts, was deposited in strata from which the traces of uranium were leached out by oxidizing ground water to be redeposited as concentrates in other strata containing organic matter.

Many important ore deposits do not appear to be related to plate motions. Most iron ore is sedimentary rock, formed on shallow marine shelves 1,800–2,400 million years ago when the Earth probably had an atmosphere that contained almost no oxygen. (Oxygen is produced primarily by photosynthesis of plants, which release oxygen as they combine hydrogen from water with carbon dioxide to make carbohydrates.) Ancient placer uranium deposits, such as the Blind River deposits in Canada and the Witwatersrand gold deposits of South Africa, probably owe their origins also to an oxygen-free atmosphere. The lead and zinc of the Mississippi Valley region were dissolved out of limestone, in which they occur in minute proportion, and then precipitated as concentrates. The copper and nickel at Sudbury, Canada, and the platinum at Rustenburg, South Africa, occur as precipitates from great pools of magma which may have been melted by meteorites or comets that collided with the Earth and exploded nearly 2,000 million years ago.

PETROLEUM AND NATURAL GAS

Oil and natural gas occur in sedimentary strata in wedges and basins that mostly are byproducts of the motions of lithosphere plates. Oil and gas are generated by the breakdown of organic matter, which makes up 1 percent of typical dark-shale source rock. Time-temperature processes—the higher the temperature, the shorter the time—change the organic material into a small amount of gas and liquid petroleum and a larger amount of solid hydrocarbons; the gas and liquid migrate through pore spaces. Too high a temperature produces gas only or destroys all of the hydrocarbons. The migrating components tend to move upward, channeled along permeable strata, and accumulate where migration paths are blocked by impermeable materials. The formation of an oil field requires an uncommonly fortunate combination of organic source beds, an appropriate thermal history, and a migration path ending in a trap. Only a minute proportion of the Earth's sedimentary rock contains recoverable petroleum and gas. Most petroleum occurs in rocks less than 200 million years old, is trapped in anticlines in either porous sandstone or limestone, and is shallower than 3,000 meters (10,000 feet).

Most oil, including that of the Persian Gulf, which represents more than half of the global total of reserves, occurs in continental-shelf strata. These sedimentary rocks are deposited on rifted continental margins. When a continent is split and the pieces are separated as an ocean spreads between them, the edge of the continental crust slowly spreads oceanward, thins, and subsides. Sedimentation keeps the top of the subsiding shelf subhorizontal, whereas deeper layers tend to have progressively greater, but still gentle, oceanward dips. Oil generated in such strata migrates mostly up-dip, toward the continent. Gulf coast American oil, both onshore and offshore, formed in this setting. The exploration now underway on the offshore Atlantic Outer Continental Shelf of the Eastern United States is based on the hope that there may be large quantities of oil there, but drilling of possible trapping structures identified by geophysical methods will of course be necessary to test the hope.

Another important setting for oil accumulation is the foreland basin, which in various forms develops on the landward side of subduction systems (fig. 15). In the United States, small oil fields in western Wyoming and the large Prudhoe Bay field of northern Alaska exemplify this setting. The latter field may prove to be the largest ever found in North America.

The outer-arc basins, which occur between trench and volcanic belt in an active subduction system (fig. 15), commonly contain strata and structures which appear from geophysical studies to be favorable for petroleum. Drilling has generally shown, however that subsurface temperatures are too low for the generation of oil. The presence deep beneath the basins of cool oceanic plates insulates the basins from the normal flow of heat from the interior of the Earth. Here is an example of a negative way in which plate-tectonic concepts are used to guide oil exploration: most companies have written off outer-arc basins.

Oil also occurs in broad basins within continents. Some of these basins are products of the wrenching of continental plates during collisions with other plates, whereas others are not related directly to plate interactions and perhaps have subsided because of cooling at the base of the lithosphere plate.

COAL

Coal is formed from wood and other plant debris, buried beneath other sediments and transformed slowly, under the influence of heat and pressure, from a mixture of cellulose and other carbohydrates to a high-carbon residue. Most coal represents swamp deposits, and practically all is younger than 350 million years old. Recoverable coal contains about 10 times as much energy as did the initial total supply of oil and gas available to man, so our society will be fueled by coal long after oil and gas are exhausted.

Coal swamps mostly originated through interactions of lithosphere plates. The Appalachian coal of the United States, for example, formed about 275–310 million years ago in a foreland basin, analogous in its early stages to that of figure 15 but complicated in later stages by the collision of Africa with North America. (The modern Atlantic Ocean began to open about 200 million years ago, rifting approximately along the previous collision suture.) The basin was alternately flooded by the sea, then drained, the coal swamps forming during the emergent periods. The fluctuations of sea level were themselves byproducts of plate motions. Although the Appalachian coal swamps lay near the equator, North America having since drifted to its present position, there was then a large continent—whose fragments now comprise South America, Africa, India, Australia, and Antarctica—which had drifted over the south pole. This southern continent underwent repeated glaciation and deglaciation, comparable to the much younger glacial cycles of the Pleistocene of North America and Eurasia. Sea level dropped 100 meters or more (hundreds of feet) each time ice sheets expanded on the southern continent, and coal swamps developed elsewhere.

The Western United States coals are younger, mostly 50 to 80 million years old. The older of these formed in a broad foreland basin, typically in coastal swamps along the west side of a shallow inland sea. The presence of the sea—that is, the high sea level of the time—may have been due to rapid sea-floor spreading. New sea floor formed by spreading stands high and subsides slowly with age, so the faster the spreading the higher the general level of the sea floor and the greater the volume of water that overflows onto the continents. The younger and much more important of the coals in the Rocky Mountain region formed in vast swamps in more local basins that were produced by oblique compression of the continental crust of the entire western interior, crumpling it into broad basins and ranges of a type altogether different from those formed later in the Basin province farther west. These younger coals represent one of the world's great energy reserves and include coals of uncommon thickness; one extensive layer of pure coal is 70 meters (230 feet) thick.

LIFE

The formation of planets must be a common byproduct of the condensation of stars, and there must be countless planets in other stellar systems upon which highly evolved living organisms are present. Not on all planets, of course. Life on Earth reflects various fortunate circumstances; for example, our planet is large enough to hold hydrosphere and atmosphere, and the Sun is at a distance which gives the Earth a surface temperature mostly within the narrow range of liquid water.

The course of evolution of life on Earth has been much influenced by plate motions. The Earth has had contrasted areas of land and sea throughout its 3,800 million years of geologic history, although how much of the present water was early at the surface and how much has since been differentiated out by volcanic processes is debatable. The initial continents of an internally stable Earth, without the rejuvenating processes of uplift, mountain building, formation of new continental material, and magmatism, would long since have disappeared beneath the sea, leveled by land and sea erosion, limiting potential life forms.

Unicellular organisms were certainly present by 2,000 million years ago, and less convincing evidence puts them back as far as 3,300 million years. Metazoa—multicellular organisms in which differentiated cells perform different functions—appeared about 700 million years ago. Only about 600 million years ago did the oxygen content of the atmosphere reach a level, still far below that of the present, at which animals could afford the oxygen-expensive luxury of shells, hard parts, and large muscles, and only then did the rush of evolution of higher organisms get underway.

As continental pieces have drifted about the Earth, they have carried biotas that had been shared with other lands before rifting but then evolved in isolation during the transport period. The modern flora of Australia, for example, has evolved from three dominant stocks. The longest isolated was shared with Africa before the rifting between them, and the next-longest was shared with New Zealand, Antarctica, and South America, before these too were sundered; the youngest assemblage, a tropical flora of Asian affinity, was carried in on an island arc that collided with New Guinea, which is the north part of the Australian continent, only about 25 million years ago. When continents collide or are connected by volcanic or other land bridges, their independently evolved passengers mingle, and, at least among the mammals, those of the larger landmass are generally better suited to the new competition and tend to replace those of the smaller. The primitive placental ungulates and marsupial carnivores of South America, for example, evolved and thrived in isolation on the island continent after it separated from Africa but mostly vanished quickly when the Panama land bridge was built by volcanoes only a few million years ago, permitting interchange with North American and Eurasian faunas. Much of the geological evidence for the details of past plate motions comes from subcontinents now juxtaposed but carrying fossil assemblages that must have originated far apart.

Dinosaurs thrived in warm, equable climates and disappeared some 70 million years ago when, and possibly because, climates in most parts of the world became more sharply seasonal. The major cause of climatic change was a lowering of sea level, draining vast climate-moderating inland seas, which might have been due to a slowdown in oceanic spreading rates and hence to a deepening of average ocean depths. The mammals, with their superior mechanisms for conserving or dissipating heat, had previously been small and primitive, but their evolution then accelerated. Man is of course one product of that evolution.

SUMMARY

Plate-tectonic concepts permit an understanding of the interrelationships between the processes operating within the Earth. We have begun to integrate into a genetic, unifying framework the descriptive findings of the earth sciences. The geologic processes which affect society—both harmfully through earthquakes and other catastrophic events, and beneficially through mineral and fuel resources—are largely controlled by the motions of lithosphere plates.

Outer Continental Shelf Safety in Oil and Gas Operations

By Ronald W. Taylor and Richard B. Krahl

As the Nation continues to expand its efforts to find more oil and gas, the role of the U.S. Geological Survey's Conservation Division in supervising and regulating these activities is becoming more significant, especially for operations on the Outer Continental Shelf.

The general public still recalls the Santa Barbara oilspill of 1969 and the two major-oil platform fires the following year in the Gulf of Mexico. The concern for the environment that resulted from these incidents spread nationwide.

To help prevent similar events from occurring and to insure strict adherence to safety and pollution-prevention regulations, Geological Survey inspectors visit oil and gas operations on the Outer Continental Shelf to make unannounced safety and operations inspections. They check to see that the drilling and production platforms are properly marked for air/sea navigation, safety, and identification and to make sure that there are blowout preventers installed and that the casing and casing cements are correct. They may also check to see that abandoned wells are properly plugged or that the operating wells are producing oil and gas in paying quantities. They check flow rates, maintenance, and inspection records and make sure that waste materials are disposed of properly. Their checklists also require them to inspect such things as welding permits, electrical circuits, fireproofing, safety and escape devices, and the conditions of drip pans under motors and to analyze the drilling mud.

The Survey's inspection program has been designed to assure that petroleum from the Nation's offshore resources is produced with the greatest possible regard for human life and the safety of the marine environment. Through uniform enforcement of regulations and periodic inspections, the public can be assured of safe, prudent, and pollution-free operations.

Safety is an ongoing and continual consideration in the conduct of petroleum operations on the submerged lands of the Outer Continental Shelf contiguous to the coasts of the United States. Procedures instituted by the U.S. Geological Survey and other Federal Government agencies are aimed at protecting human life, the waters and biota overlying the shelf, and the adjoining coastal State waters and shorelines. The term "safety," therefore, is used in the context of protection of human life and prevention of environmental harm.

The importance of safety and pollution control to petroleum operations on the Outer Continental Shelf cannot be overemphasized. This fact is recognized by the Code of Federal Regulations throughout Title 30 CFR Part 250, the regulations under which the Geological Survey administers the provisions pertaining to oil and gas operations on the Outer Continental Shelf. Included in this part is the Survey's responsibility (under Title 30 CFR Part 250.12) to "prevent damage to, or waste of, any natural resource, or injury to life or property." Also Title 30 CFR Part 250.30 charges the lessees with a like responsibility.

The Survey's annual report for fiscal year 1975, as well as this current report for fiscal year 1976, lists under *Conservation of Lands and Minerals,* "Regulation of Operations," a number of major studies of oil and gas operations on the Outer Continental Shelf. As mentioned therein, a Geological Survey work group was established on OCS safety and pollution control, chaired by the Associate Director. This work group reviewed the major studies on the subject (list given in above references) and recommended the implementation of 19 major categories for improvement in a report issued in May 1973 and supplemented in May and November 1974.

These categories and their status in fiscal year 1976 are listed in table 21 elsewhere in this annual report.

The Geological Survey's OCS Lease Management Safety and Pollution-Prevention program for oil and gas drilling and producing operations includes the following management responsibilities:

- The Director, through the Chief of the Conservation Division, is responsible for establishing the general safety, pollution-prevention, and pollution-control policy and for providing management direction and review of the lease management program.
- The Associate Director, as chairman of the Work Group on OCS Safety and Pollution Control, is responsible for the overall results of the Work Group's review program.
- The Chief of the Conservation Division, through regional conservation managers, area supervisors, and district supervisors, is responsible for implementing the Survey's Safety and Pollution-Prevention Policy in accordance with the program document.

Documentation of the program shows 16 functional elements that involve Government and industry responsibilities in safety on the Outer Continental Shelf, as follows:

1. Pre- and post-lease information development and evaluation.
2. Research and development.
3. Development and use of standards.
4. Development and use of OCS Orders and other orders to lessee compliance.
5. Review of lessee applications and plans.
6. Platform/structure design and construction verification.
7. Pipeline approval and inspection.
8. Field compliance evaluation.
9. Equipment-failure reporting, analysis, and information exchange.
10. Pollution surveillance and cleanup.
11. Accident investigation and reporting.
12. Enforcement actions.
13. Training and qualification of lessee personnel.
14. Training of Geological Survey personnel.
15. Motivation.
16. Audit and review.

These functions are being actively pursued, with a very strong tie-in with the day-by-day supervision of drilling and producing operations in the Outer Continental Shelf, including on-site inspections.

U.S. Geological Survey supervision begins before any drilling by an operator on the Outer Continental Shelf, as an operator must submit an Application for Permit to Drill to the Survey. This application must contain a contingency plan for handling emergencies, such as spills or fires, during drilling; a plan of exploration and development; significant geological markers anticipated; and specific information concerning the drilling rig, casing program, cementing program, drilling-fluid program, and blowout-preventer equipment. Geological Survey geologists, geophysicists, and engineers review the application for compliance with appropriate Outer Continental Shelf Orders and Regulations. Hazardous conditions such as surface faulting, potential sea-bottom slides, shallow gas pockets, or deeper abnormal pressures are made known to, and discussed with, the operator. Appropriate changes are required in the drilling program before the Permit to Drill is approved.

The design of the integrated casing, cementing, drilling mud, and blowout-preventer system must take into account the depths at which petroleum-bearing formations are expected to be penetrated, the formation fracture gradients, and the pressures to be encountered.

The operator is required to case and cement all wells with a sufficient number of strings of casing to prevent the release of fluids from any stratum, to prevent communication between separate strata, to support unconsolidated segments, and to provide a means of control of formation pressures and fluids (fig. 18). Drive pipe may be set by drilling, driving, or jetting to a minimum depth of about 30 meters (100 feet) beneath the ocean floor to support unconsolidated deposits and to provide hole stability for initial drilling operations. If this portion of the hole is drilled, the drilling fluid utilized may not contain oil or toxic substances, and the entire length of drive casing must be cemented back to the ocean floor. All subsequent casing strings must be securely cemented. Before drilling below the drive pipe, at least one remotely controlled annular-type blowout preventer, as well as equipment for circulating the drilling fluid to the drilling structure, must be installed. Choke and kill lines must be provided for diversion of hydrocarbons and other fluids. The diverter system must be equipped with automatic remote-controlled valves which open, prior to shutting-in the well, at least two lines venting in different directions to accomplish downwind diversion.

Subsequent to drilling below the drive pipe, the conductor and surface casing strings are set and cemented. Vertical depth at this point varies between 450 and 1,370 meters (1,500 and 4,500 feet). Prior to drilling below the surface casing string, or an intermediate casing string, additional requirements are imposed upon the blowout-preventer system. At this time, the blowout-preventer system must include a minimum of: (1) four remotely controlled, hydraulically operated blowout preventers including two equipped with pipe rams, one with blind rams and

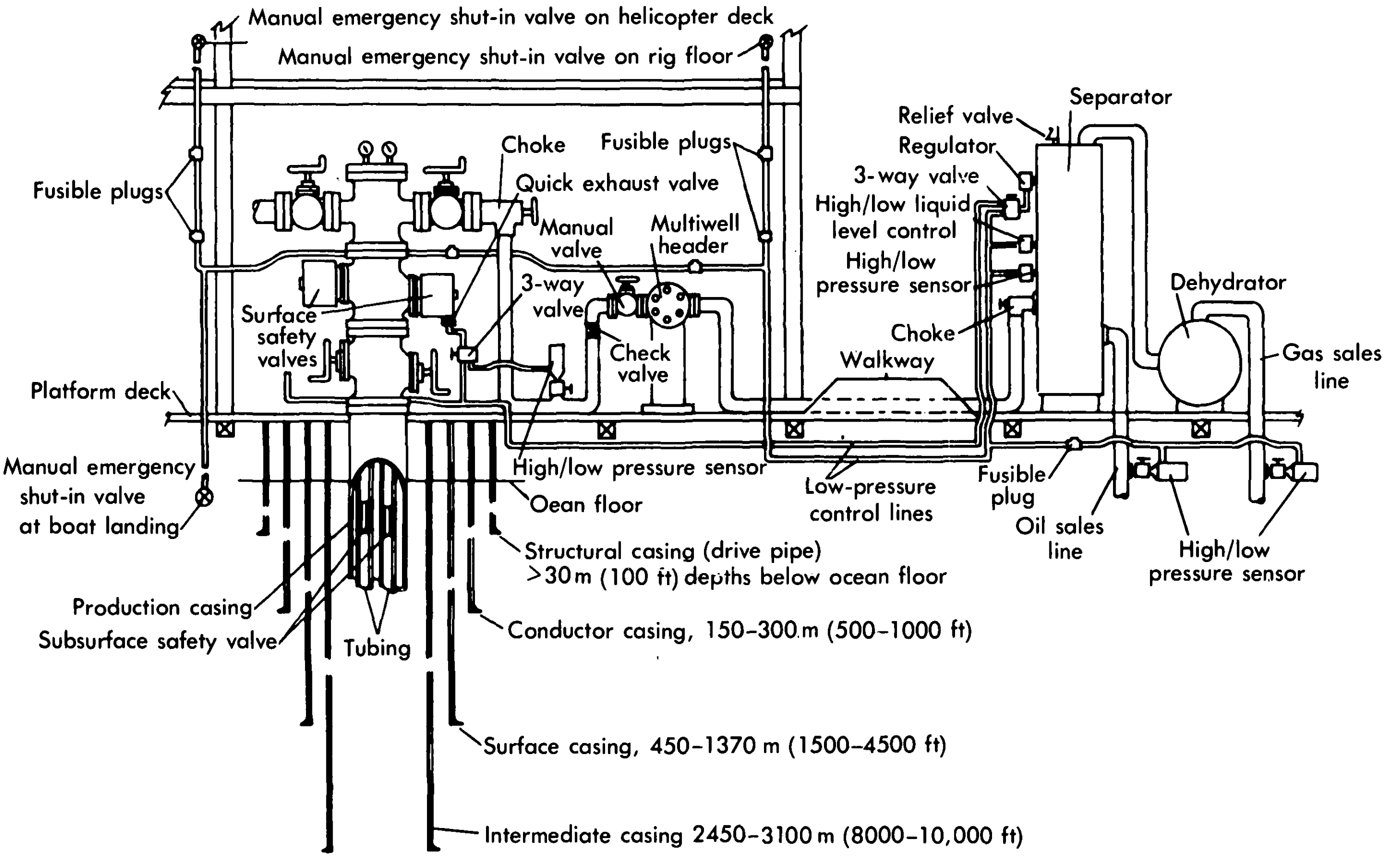


FIGURE 18.—Schematic diagram of an offshore drilling rig showing required features for the safety of personnel and equipment and the prevention of pollution.

one annular type; (2) a drilling spool with side outlets, if side outlets are not provided in the blowout-preventer body; (3) a choke line and manifold; (4) a kill line separate from a choke line; and (5) a fill-up line. Subsea blowout-preventer stacks used with floating drilling vessels must be equipped with blind-shear rams.

Ram-type blowout preventers and related control equipment must be tested at the rated working pressure of the stack assembly or at 70 percent of the minimum internal yield pressure of the casing, whichever is the lesser. Annular-type preventers must be tested at 70 percent of these pressure requirements. These tests are conducted: (1) when installed, (2) before drilling out after each string of casing is set, (3) not less than once each week from each of the control stations, and (4) following repairs that require disconnecting a pressure seal in the assembly. While drill pipe is in use, ram-type blowout preventers must be actuated to test proper functioning once each trip, but in no event less than once each day. The annular-type blowout preventers must be actuated on the drill pipe once each week. Accumulators or accumulators and pumps must maintain a pressure capacity reserve at all times to provide for repeated operation of hydraulic preventers. An operable remote blowout-preventer control station must be provided in addition to the one on the drilling rig floor.

Blowout-prevention drills are conducted weekly for each drilling crew to insure that all equipment is operational and that the crews are properly trained to carry out emergency duties. These drills and tests must be recorded in the driller's log.

Geological Survey personnel also oversee production operations. Production-system analyses include a review of the proposed mechanical-flow and safety-system schematic diagram of the platform to insure that the production system conforms to safety standards. The design of the structure, the production processing equipment, the personnel facilities, and the incoming and departing pipelines are checked for compliance with requirements to assure that these components will properly integrate into an effective platform-safety system. This safety system includes subsurface safety valves, an automatic fail-close wellhead valve, a flowline which is protected by high- and low-pressure sensors, a check valve, and pressure vessels protected with high and low pressure and liquid-level sensors (fig. 18). Any abnormal operating condition will result in an automatic production-system shut-in. Pneumatic and hydraulic control systems are equipped with fusible links which melt in the event of a fire and, as a result of the loss of pressure, activate fail-close valves. Emergency shut-in controls, located at strategic points on the platform, are an integral part of the safety shut-in system and afford a backup means for manually effecting a complete shut-in of the entire facility. In addition to such manual controls at the central panel, others are located on the boat landing and helicopter pad for use in the event of an emergency evacuation of the facility. In establishing safety-system requirements, stress is placed on requiring backup devices and procedures that provide for an additional margin of safety even if a critical item of equipment fails.

The Geological Survey has the specific responsibility to inspect, monitor, and document the day-to-day activities and operations of the petroleum industry on the Outer Continental Shelf by making on-site inspections and witnessing the tests of safety and pollution-prevention equipment. The inspection program administers a fair, but firm, uniform enforcement policy that insures conformance to standards that result in operations that are as safe, prudent, and pollution free as is possible.

To facilitate inspections, the Outer Continental Shelf Orders and Regulations have been condensed into a computerized checklist composed of questions that are answered by the inspection team either positively for compliance or negatively for noncompliance. Each incident of noncompliance requires that the inspector take a prescribed enforcement action which will result in either a warning or a shutdown of operations. If the incident requires a shutdown, the condition must be corrected before operations can be resumed.

The checklist used by the inspectors is a listing of potential incidents of noncompliance. The actual incidents of noncompliance observed are counted at each inspection site, and the ratio, actual to potential, is used as a basic measurement of the degree of compliance.

Inspection teams of petroleum engineering technicians travel to the OCS facilities by helicopter or boat, observing the water surface en route for any evidence of pollution. Inspections of drilling rigs and related equipment in the Gulf of Mexico are conducted at least once during the drilling of each wildcat well and during the drilling of the first development well from a platform. New production facilities are inspected upon commencement of operations. All major platforms are scheduled for inspection semiannually. Drilling rigs in frontier areas are inspected daily.

Blowouts, fires, pipeline leaks, and other accidents are investigated by inspection teams. These investigations establish the contributing factors in accidents in order to help avoid similar incidents in the future. The Geological Survey has instituted "Safety Alert" notices to inform all operators of the probable cause of individual accidents and to describe the hazardous situations that resulted in these accidents. This information enables all operators not involved in a particular incident to evaluate similar situations in their jurisdiction.

Table 5, which gives accident and spillage statistics, shows the progress over the last 6 calendar years towards safe and pollution-free oil and gas operations on the Outer Continental Shelf. The total oil spillage steadily declined except for three large spillages in 1973 and two large pipeline spillages in 1974. The statistics for total accidents from all causes show a large drop in fatalities in 1971; they have remained essentially constant since then. During this 6-year period, oil/condensate (1971) and gas (1974) production have peaked. New well starts (drilling) have remained fairly constant although there was an 8 percent increase during the last year. However,

TABLE 5.—*Accident and spillage statistics for the Outer Continental Shelf, calendar years 1970–75*

Calendar year	Total accidents [1]			Total of all spills		Oil and condensate production (barrels, in millions)	Gas production (cubic feet, in billions)	New well starts	Active leases	Fixed structures (end of year)	Estimated mileage of pipeline supervised
	Number	Fatalities	Injuries	Number	Barrels of oil spilled						
1970	24	33	58	Unknown	Unknown	361	2,419	900	1,017	1,800	4,000
1971	35	11	16	1,256	2,778	419	2,777	841	1,083	1,891	5,000
1972	41	10	9	1,161	1,182	412	3,038	847	1,023	1,935	6,000
1973	44	9	15	1,175	23,096 [2]	395	3,212	820	1,266	2,001	6,450
1974	39	9	22	1,137	23,388 [3]	361	3,515	816	1,590	2,054	6,700
1975	46	17 [4]	14	1,128	977	330	3,459	882	1,792	2,079	7,150

[1] Includes blowouts, fires, explosions, falls, vessel collisions or sinkings, drownings, electrocutions, asphyxiations, blows, etc.
[2] Includes (a) 9,935 barrels—structure supporting oil storage tank bent, ruptured tank;
(b) 7,000 barrels—barge developed a leak in heavy seas and partially sank, releasing oil, and
(c) 5,000 barrels—internal corrosion caused numerous pipeline leaks.
[3] Includes (a) 19,833 barrels—dragging anchor snagged and ruptured pipeline and
(b) 2,213 barrels—pipeline break apparently caused by hurricane.
[4] Includes six men who died in a blaze resulting from a tanker collision with a platform (escaping oil from tanker ignited and tanker caught fire).

the number of active leases supervised, the mileage of pipelines supervised, and the number of fixed structures at the end of the year have all steadily increased. For instance, the number of active leases which were supervised (with all drilling and production operations being inspected) increased by 24 percent, 26 percent, and 13 percent for each of the last 3 years, respectively. In effect, the consistency in fatalities, when considered along with the increased activities, represents a reduction in the fatal accident rate.

It is not realistic to think that a 100-percent accident- and pollution-free environment can ever be achieved in offshore oil and gas operations. Such things as human error and equipment/material failure probably will always contribute to accidents and pollution. Good examples of this may be found in the footnotes at the bottom of table 5. However, Government's role on the Outer Continental Shelf involving safety, which includes the studies on safety and the procedures and equipment required by the Geological Survey in drilling and production operations, is to constantly strive to make the Outer Continental Shelf as safe and pollution free as is technically possible.

Several major USGS research projects involve Mount Rainier, including glaciology and the stratigraphy of volcanic rocks and glacial deposits.

Missions, Organization, and Budget

For nearly a century, the U.S. Geological Survey has served Federal, State, and local governments, and the public, by collecting, analyzing, and publishing detailed information about the Nation's mineral, land, and water resources. The Geological Survey was created in 1879 to study the geologic structure and mineral resources of the public domain and to provide information to support development of the West. Congress and the Secretary of the Interior later expanded the Survey's responsibilities to include topographic mapping; chemical and physical research; stream gaging and water-supply assessments; supervision of mineral exploration and development activities on Federal and Indian lands; engineering supervision of waterpower permits; and administration of a minerals exploration program.

Although the emphasis and balance of the Survey's programs have changed over the years, they still reflect the fact-finding mission described in the brief authorizing legislation of 1879. Today, that mission has two objectives. First, the Survey is charged with increasing the knowledge of the extent, distribution, character, and origins of the Nation's natural resources and of the geologic processes that affect the use of the land so that man may adjust his activities to the constraints imposed by the environment and so that the Earth's resources may be managed wisely. Second, and no less important, are the Survey's regulatory responsibilities—classifying Federal lands and supervising mineral lease development on Federal and Indian lands. By working closely with the Bureau of Land Management and other land-management agencies, the Survey seeks to identify and conserve the Nation's public resources and supervise their development so that the public receives its fair share for leased resources and so that damage to other resource, environmental, and social values is minimized during exploration and development.

Both missions call for objective and impartial reporting of investigations, identification of natural constraints on land use and resource development, and analyses of the consequences of alternative policies or actions related to resource development, conservation, and environmental protection.

ORGANIZATION

The scientific and regulatory mission of the Geological Survey is carried out by five organizational units, each of which is responsible for one of the Survey's major programs or budget activities (see the organizational chart and table 26 in the section entitled "Organizational and Statistical Data").

- The Topographic Division produces maps delineating the physical features of land areas in the United States and its outlying areas and in Antarctica. The division also collects and distributes information on the availability of aerial photographs and space images, maps and charts, geodetic data, and related cartographic information through the National Cartographic Information Center.
- The Geologic Division conducts research on geologic processes and the Earth's history and thereby provides information that permits man to adjust intelligently to the Nation's environment and to use the Earth's resources wisely. The Geologic Division determines the composition and structure of the rocks and materials that lie at and beneath the Earth's surface, identifies potential energy and mineral resources (including those of the Outer Continental Shelf), and develops and distributes knowledge about natural hazards such as earthquakes, volcanic eruptions, and land subsidence.
- The Water Resources Division assesses the quantity and quality of the Nation's water supply, develops the knowledge necessary to predict the environmental consequences of alternative plans for developing water resources, coordinates Federal water-data-acquisition activities, collects and distributes information about the availability of water data through the National Water Data Exchange, and develops and distributes information about natural hazards such as floods and land subsidence.
- The Conservation Division classifies the public lands with respect to leasable mineral and waterpower sites and supervises exploration and development authorized under leases and permits on Federal and Indian lands.

- The Land Information and Analysis Office coordinates and administers interrelated, interdisciplinary programs of the Geological Survey, as well as other units of the Department of the Interior, with the objective of interpreting and displaying resource information in ways that are readily accessible and understandable to a wide range of potential users, particularly land-use planners and decisionmakers.

The structure of the Survey's budget closely parallels the structure of its organization. Each program division (Topographic, Geologic, Water Resources, Conservation, and the Land Information and Analysis Office) is responsible for one of the Survey's major budget activities (tables 6 and 7). A small program—Alaska Pipeline Related Investigations—is currently administered by the Geologic Division with technical assistance from the Water Resources Division.

TABLE 6.—*Geological Survey obligations for fiscal year 1976, by activity (dollars in thousands)*

[Data in other chapters may differ because of rounding]

Activity	FY 1976	Percent change relative to FY 1975	Transition quarter (estimated)
Total	$353,970	+4	$102,816
Direct program	264,434	+4	77,756
Reimbursable program	89,536	+5	25,060
Alaska Pipeline Related Investigations	287	−17	112
Topographic Surveys and Mapping	52,220	−1	13,393
Direct program	45,354	--	11,553
Reimbursable program	6,866	−5	1,840
Geologic and Mineral Resource Surveys and Mapping	115,554	+1	32,997
Direct program	92,322	+4	24,837
Reimbursable program	23,232	−9	8,160
Water Resources Investigations	112,480	+11	29,726
Direct program	57,176	+7	15,922
Reimbursable program	55,304	+15	13,804
Conservation of Lands and Minerals	41,677	+16	13,487
Direct program	41,489	+15	13,440
Reimbursable program	188	+276	47
Land Information and Analysis	17,278	+2	8,859
Direct program	14,908	−4	7,806
Reimbursable program	2,370	+55	1,053
General administration	3,398	−7	1,493
Facilities	9,500	−8	2,593
Miscellaneous services to other accounts	1,576	−45	156

These research, fact-finding, and regulatory programs receive executive direction from the Office of the Director and technical and administrative support from the Administrative, Computer Center, and Publications Divisions. The "General administration" and "Facilities" budget activities fund the Office of the Director, the Administrative Division, and the operation of the Survey's National Center facilities, located in Reston, Virginia. Other administrative and management services provided by the Administrative Division and technical services provided by the Computer Center and Publications Divisions are financed through assessments of the program divisions. Although it is not a budget activity, the entry "Miscellaneous services to other accounts" represents reimbursements received from other Federal agencies for data-processing and publication services and for the sale of materials from stock.

BUDGET

The total funds obligated by the Geological Survey in fiscal year 1976 amounted to $354 million, an increase of $15.2 million over fiscal year 1975. (See fig. 19.) The increase was understated because of a provision in a new law that allowed obligational authority to be carried forward into what was called a transition quarter (the period between fiscal years 1976 and 1977—July 1 to September 30, 1976). This change was authorized by the passage of the Congressional Budget and Improvement Control Act of 1974 (Public Law 93–344). Thus, the fiscal year, which used to begin on July 1, now starts on October 1. During this period an unobligated amount of $8.4 million from fiscal year 1976 was carried forward. Obligations from appropriated funds in fiscal year 1976 provided about 75 percent of the total funds available to the Survey. The remaining 25 percent was from Federal, State, and local agencies and from miscellaneous non-Federal sources (fig. 20).

The allocation of funds to the Survey's five principal budget activities (Topographic Surveys and Mapping, Geologic and Mineral Resource Surveys and Mapping, Water Resources Investigations, Conservation of Lands and Minerals, and Land Information and Analysis), which had been changing dramatically in the past few years, remained relatively unchanged in fiscal year 1976 (fig. 21). The Water Resources Investigations activity share increased from 30 percent of the total funding to 32 percent. The Conservation of Lands and Minerals activity share increased from approximately

11 percent to 12 percent. The other major activities showed small decreases in the percentage share of funding. (See fig. 22.)

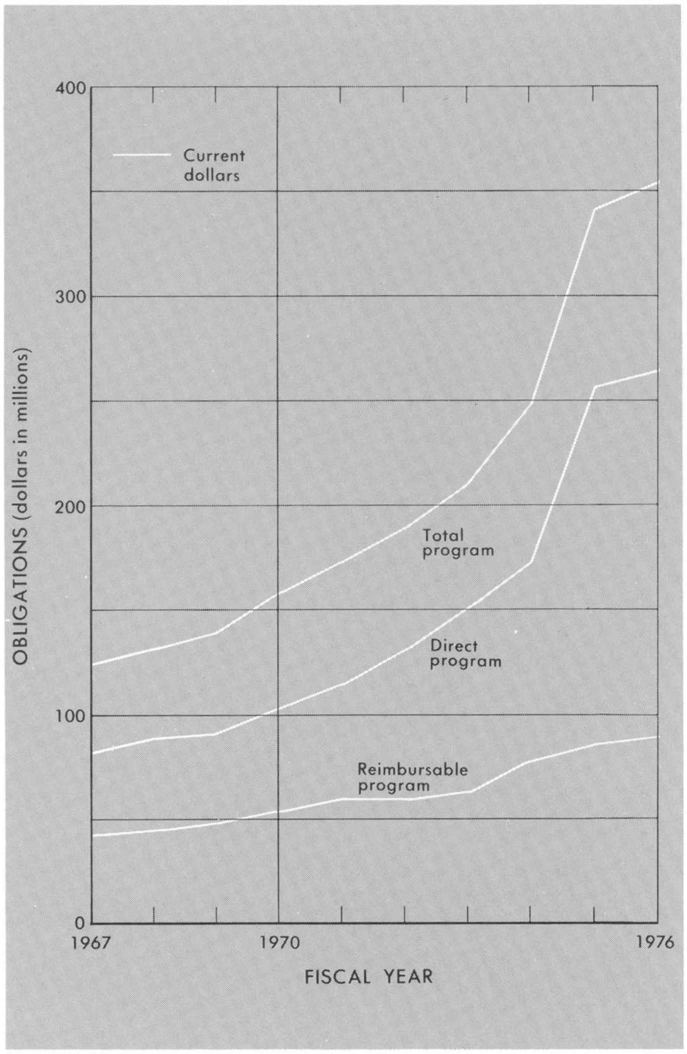


FIGURE 19.—Geological Survey budget, by source of funds, fiscal years 1967–76.

An alternative way of looking at the Survey's budget is by area of study (fig. 23).

PERSONNEL

Unlike the budget, which has increased 185 percent since 1967, the number of permanent full-time employees involved in the Survey's programs remained more or less constant through fiscal year 1973 (fig. 24 and table 45). In fiscal years 1974–76, 785 additional permanent full-time positions were filled, an increase of 13 percent over fiscal year 1973. The distribution of permanent full-time employees by organizational unit is shown in figure 25. The Water Resources Division employs 32 percent of the permanent full-time

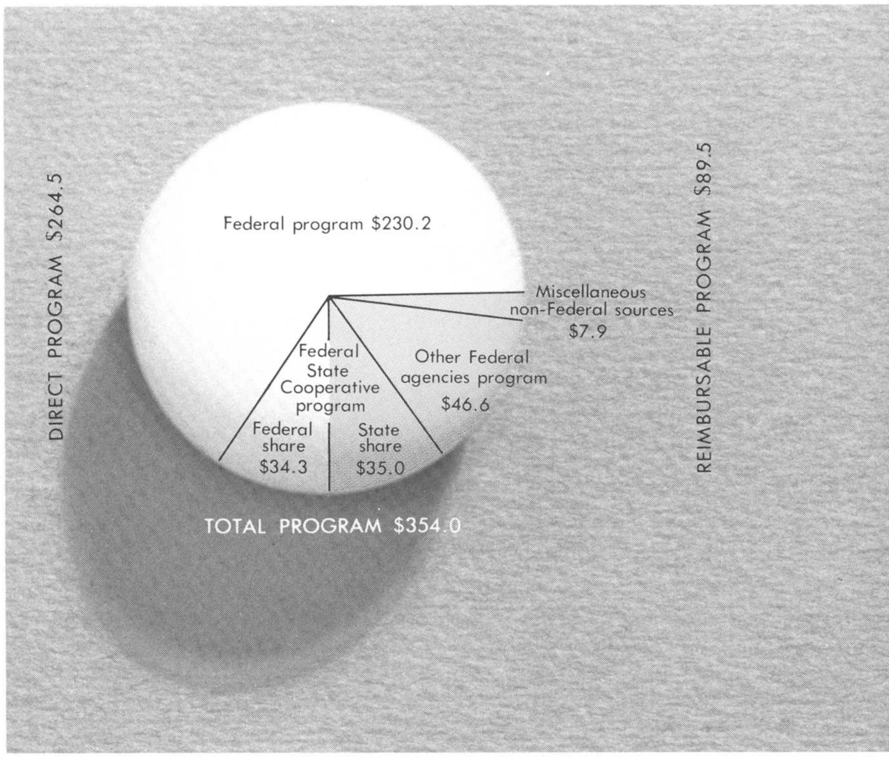


FIGURE 20.—Sources of Geological Survey funds in fiscal year 1976 (dollars in millions).

employees; Geologic Division, 23.2 percent; Topographic Division, 18.5 percent; and Conservation Division, 12.4 percent.

Again, as in fiscal year 1975, the professionalism of the Survey's programs is reflected in the composition of its work force. At the end of fiscal year 1976, the Survey employed 9,142 people on a permanent full-time basis, 78 percent of whom (up 2 percent from fiscal year 1975) were employed in professional or technical positions (figure 26). The Survey's trained work force provides the Federal Government with an important pool of scientific expertise and specialized skills in the earth sciences. To augment this trained permanent work force, at the end of fiscal year 1976, 1,730 people were on the rolls in employment categories other than permanent full time.

DEFINITIONS

Some of the terms used to describe the Geological Survey's budget, which appear frequently throughout the next few chapters, are explained here. Funds appropriated directly to the Survey are categorized under several budget activities or broad functional areas, such as Topographic Surveys and Mapping and Water

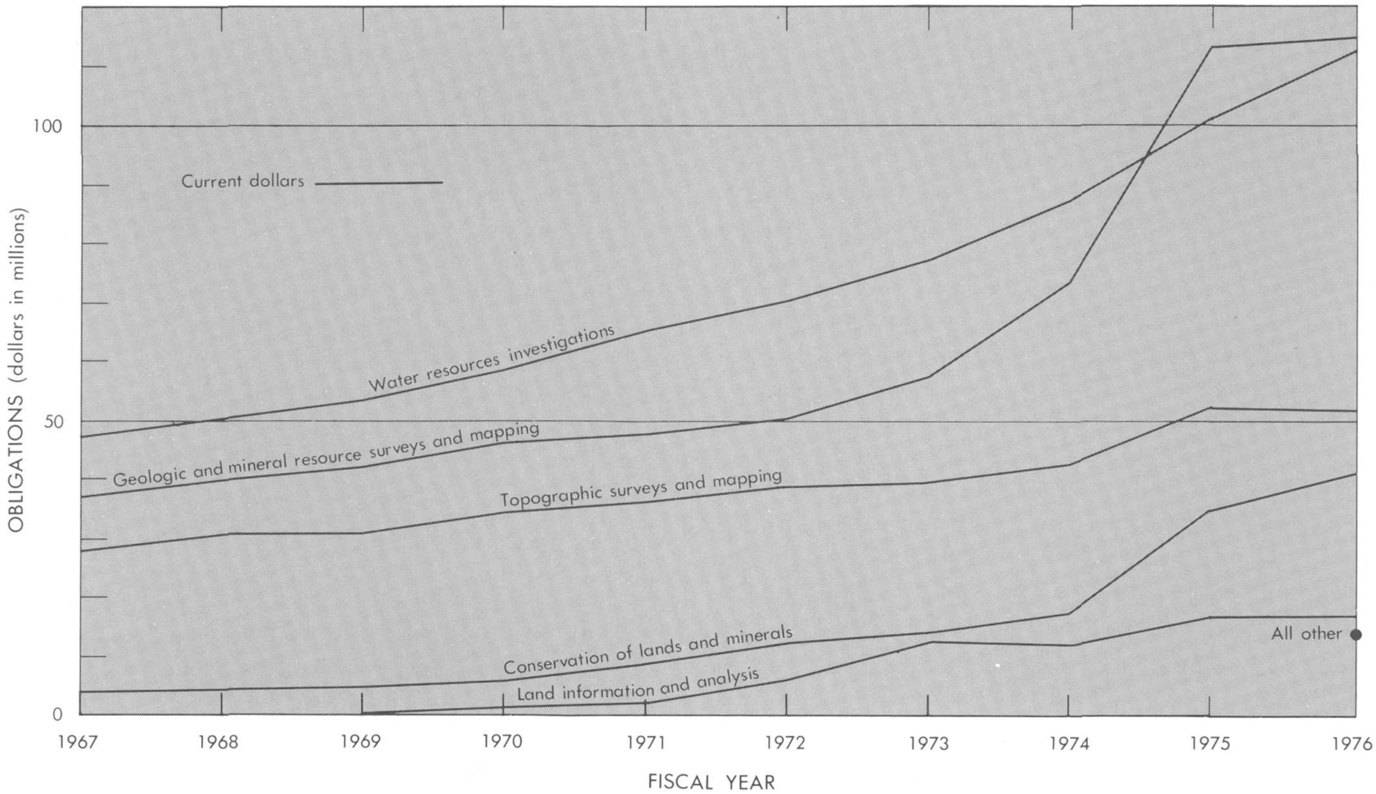


FIGURE 21.—Geological Survey budget by activity, fiscal years 1967–76.

TABLE 7.—*Participation of Survey organizational units in areas of study included in the fiscal year 1976 budget*

Area of study	Topographic Division	Geologic Division	Water Resources Division	Conservation Division	Land Information and Analysis Office	Office of the Director and Administrative Division
Energy:						
OCS oil and gas	--	×	--	×	--	--
Onshore oil and gas	--	×	--	×	--	--
Coal	--	×	×	×	--	--
Uranium and thorium	--	×	×	×	--	--
Oil shale	--	×	×	×	--	--
Geothermal energy	--	×	×	×	--	--
Minerals:						
Metallic and nonmetallic minerals	--	×	--	×	--	--
Mineral and fuels information system	--	×	--	--	--	--
Multipurpose geologic baselines	--	×	--	--	--	--
Hazards:						
Earthquakes	--	×	--	--	--	--
Volcanoes, landslides, and engineering	--	×	--	--	--	--
Floods	--	--	×	--	--	--
Water quality	--	--	×	--	--	--
Water:						
Water-data networks	--	--	×	--	--	--
Areal water-resource appraisals	--	--	×	×	--	--
Special water-resource studies	--	--	×	--	--	--
Standard topographic mapping	×	--	--	--	--	--
Modernization of mapping technology	×	--	--	--	--	--
Land resource decision products	×	--	--	--	×	--
Environmental impact statements	--	--	--	--	×	--
Earth Resources Observation Systems	--	--	--	--	×	--
General administration and facilities	--	--	--	--	--	×

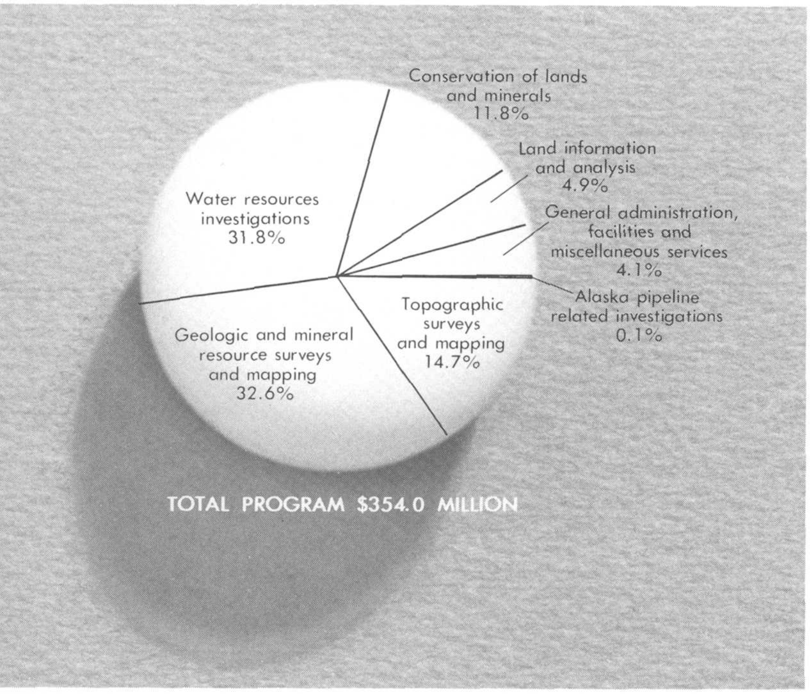


FIGURE 22.—Distribution of Geological Survey funds by budget activity in fiscal year 1976.

Resources Investigations. These activities are further subdivided and categorized as subactivities, programs, and program elements, depending upon the size and complexity of the activity. But the term "program" is used more generally and may refer to the entire budget, a budget activity, or a subactivity or may denote work supported by funds from a particular source, especially in the case of funds received from reimbursement.

Funds to support Survey programs come from two sources: (1) An annual Congressional appropriation and (2) reimbursements from Federal and non-Federal agencies. Federal funds, under the title "Surveys, Investigations, and Research," support the Survey's directly appropriated programs under each budget activity. Other funds from State and local agencies, Federal agencies, permittees and licensees of the Federal Power Commission, foreign countries, and international organizations pay for various information products and services provided by the Survey's reimbursable programs.

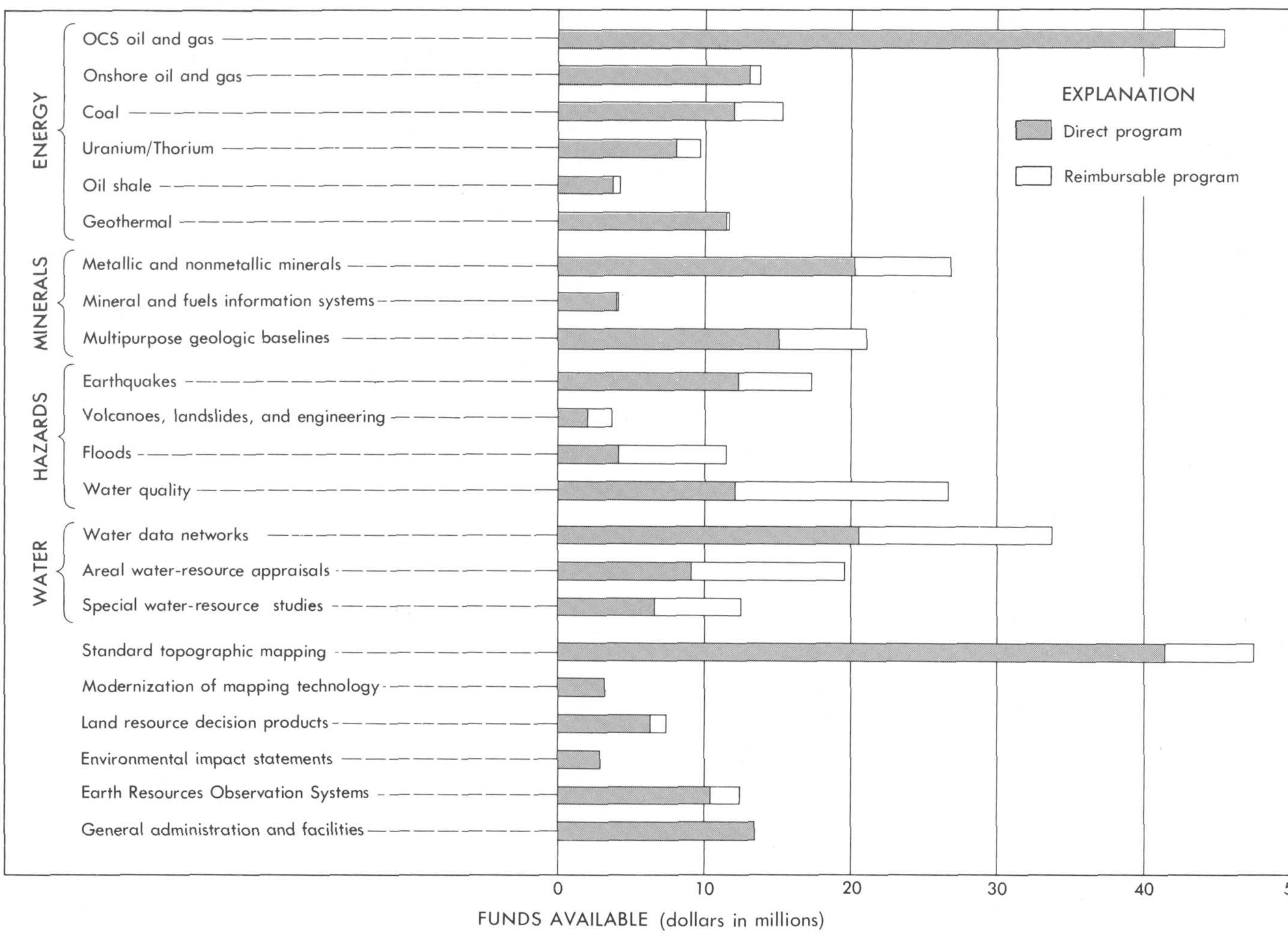
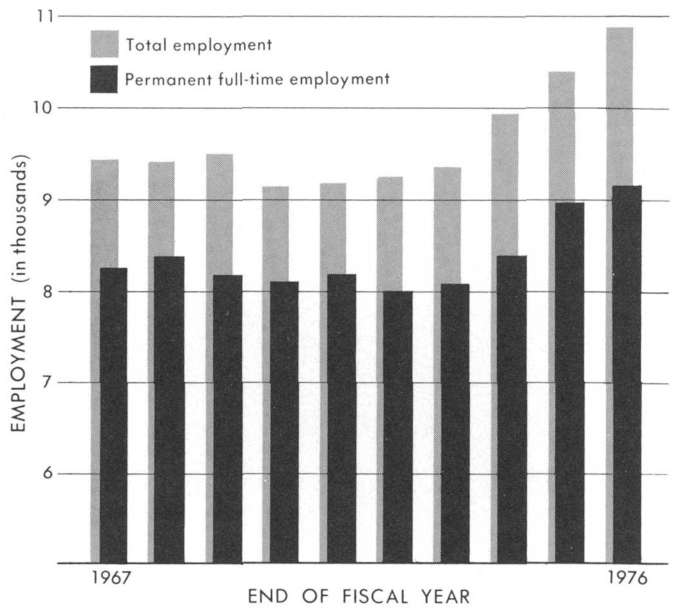


FIGURE 23.—Distribution of Geological Survey obligations for fiscal year 1976, by areas of study.

Whereas directly appropriated programs are aimed at resource investigations and research on problems of nationwide concern, the reimbursable programs enable the Survey to apply its earth-science expertise to the specific problems of Federal, State, and local agencies. The results of these investigations contribute in a very substantial way to the solution of urgent national resource problems and respond directly to the changing mutual needs of Federal, State, and local governments for earth-science information. Agencies and organizations with which the Survey had formal agreements for fiscal cooperation in fiscal year 1976 and the transition quarter are listed in the section entitled "Organizational and Statistical Data."

Work done for State, county, or municipal agencies may be performed on a cost-sharing basis. Funding arrangements may vary according to the type of investigation, and the Survey's annual appropriation act

FIGURE 24.—Geological Survey end-of-year employment, fiscal years 1967–76. ▼



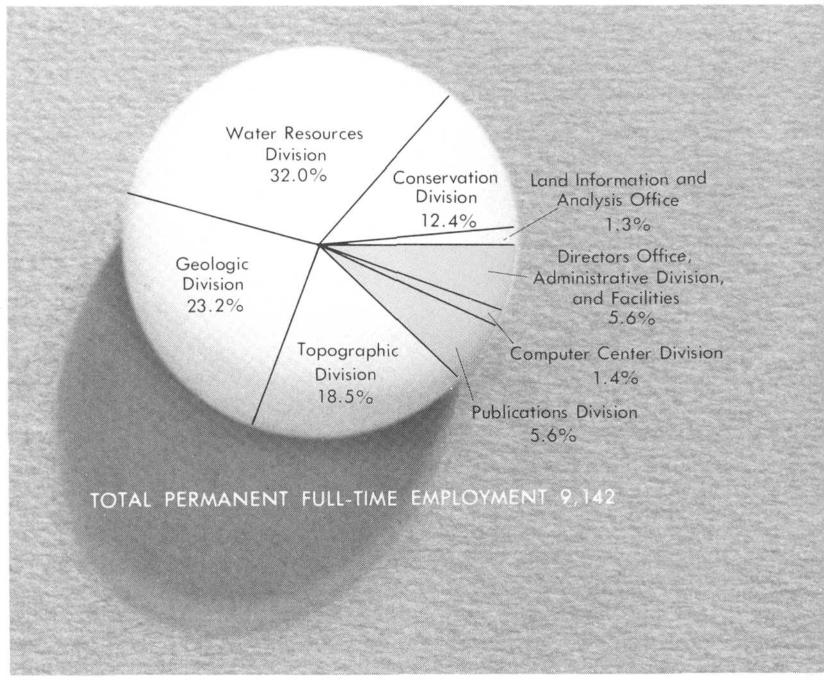
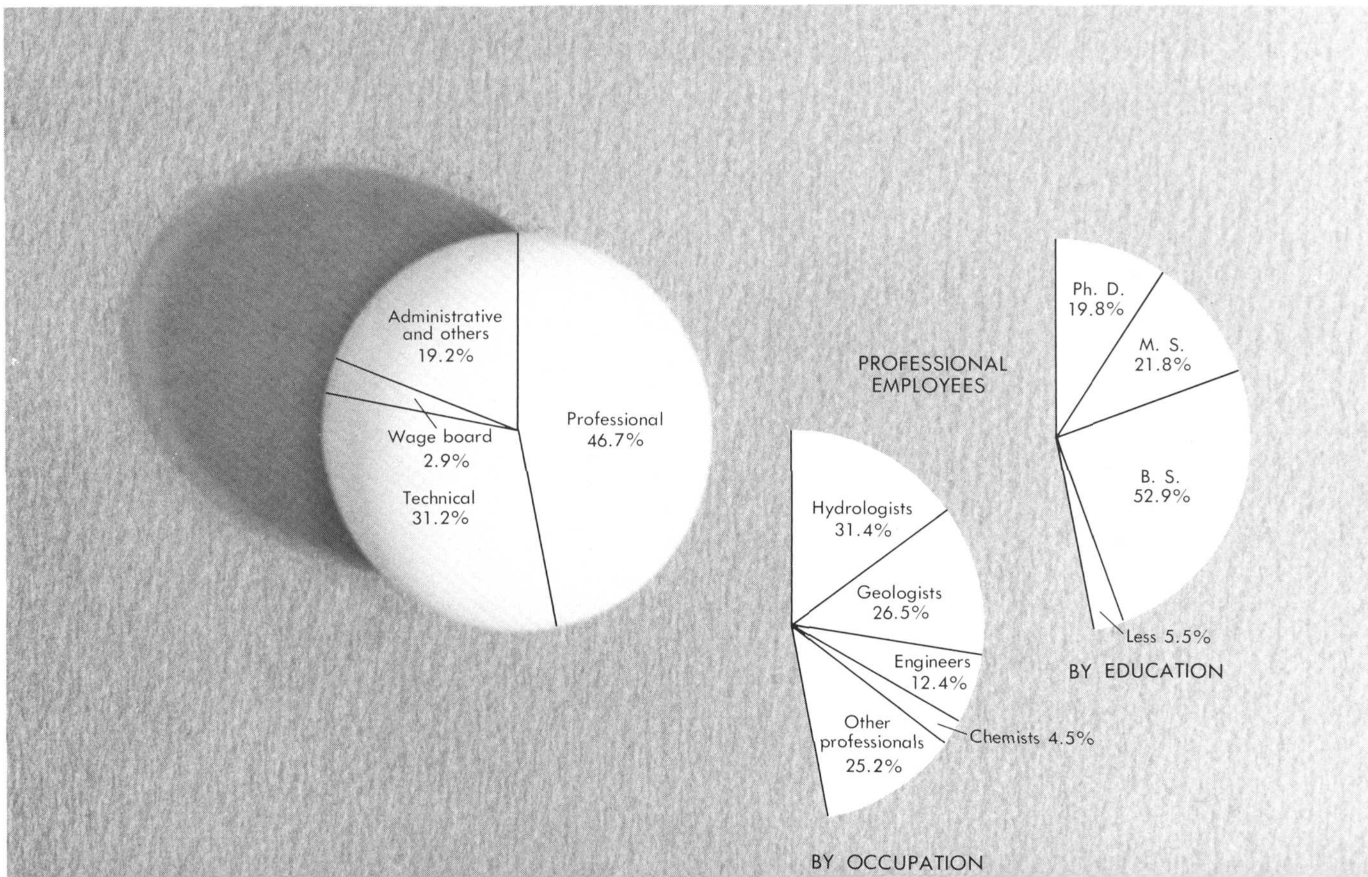
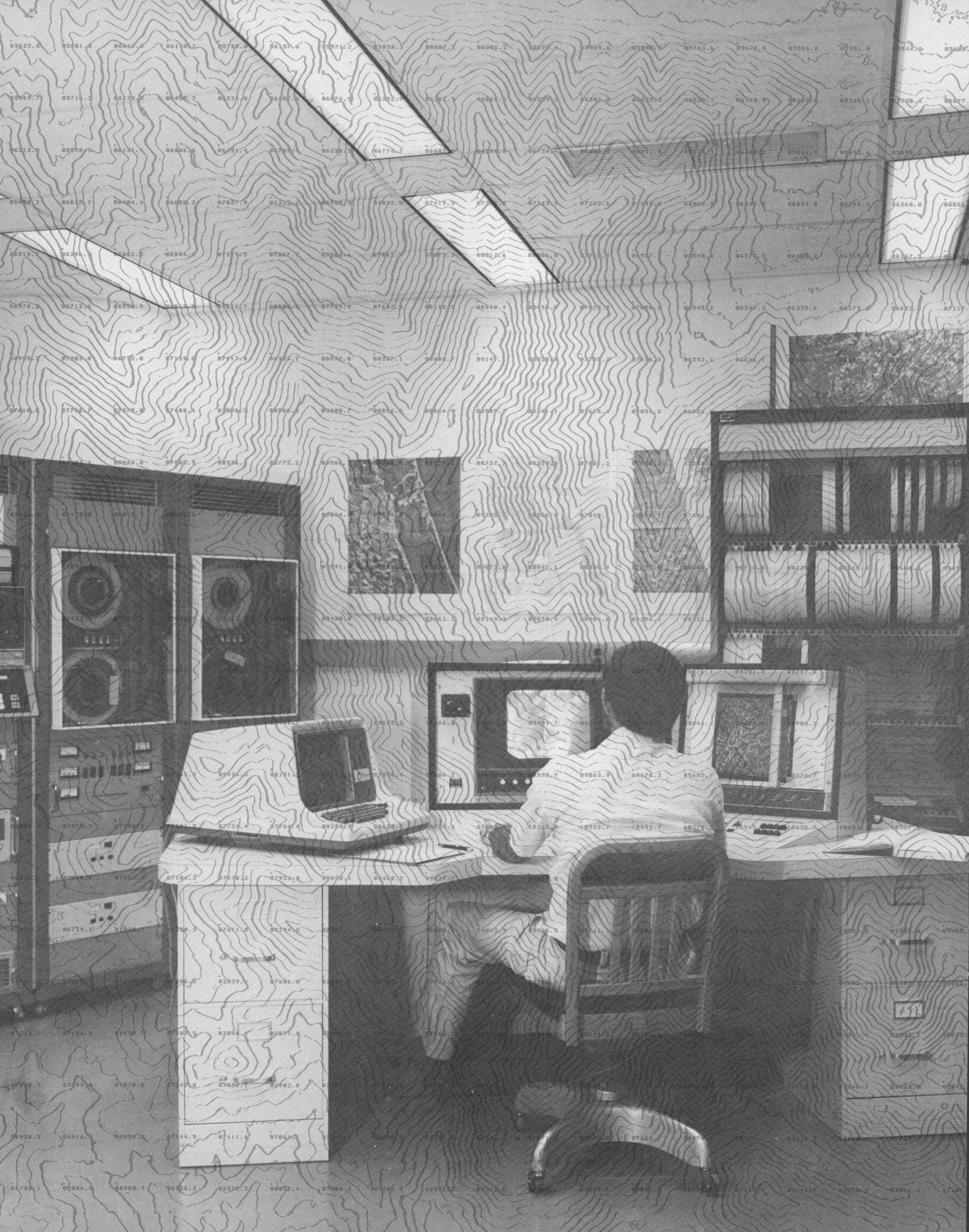


FIGURE 25.—Distribution of permanent full-time employees by organizational unit as of the end of fiscal year 1976.

FIGURE 26.—Geological Survey permanent full-time employees by type. ▼



stipulates that Federal funds may not be used to finance more than one-half the cost of any topographic mapping or water-resource investigation carried on in cooperation with a State or municipality. Within this general 50-percent limitation, each annual appropriation act also specifies the dollar amount of Federal funds that shall be available for cooperative water-resource investigations. On the other hand, appropriated funds may be used to pay for more than 50 percent of the cost of other Survey cooperative programs. The activities jointly funded by State and local reimbursable program funds (State share) or direct program funds (Federal share) are collectively referred to as the Federal-State Cooperative program. Other work done by the Survey for specific Federal agencies and non-Federal organizations is usually performed on a fully reimbursable basis.



Topographic Surveys and Mapping

OVERVIEW

The National Mapping program is designed to provide accurate and up-to-date basic cartographic data for the United States in forms that can be readily applied to dealing with the problems of the day. Topographic maps, with detailed and precisely referenced information about the natural and manmade features on the Earth's surface, continue to be the most important product, with 1,444 new 1:24,000-scale topographic maps produced during the year ending June 30, 1976, plus 295 in the transitional quarter ending September 30 (table 8). However, more orthophotoquads (photoimage maps) were produced during the year than any other type of map, providing useful

TABLE 8.—*Mapping production for fiscal year 1976 and transition quarter (TQ) (in square miles)*

State or territory	1:24,000-scale topographic		1:24,000-scale orthophotoquads		1:24,000-scale revisions		Intermediate scale	
	FY 1976	TQ	FY 1976	TQ	FY 1976	TQ	FY 1976	TQ
Alabama	854	248	2,772	-----	1,869	306	12,298	2,641
Alaska[1]	1,525	-----	-----	-----	-----	-----	-----	250
Arizona	2,982	1,117	2,480	2,418	778	-----	8,098	-----
Arkansas	2,177	120	2,013	-----	4,685	-----	5,057	-----
California	2,021	549	12,285	595	4,123	1,404	46,473	11,015
Colorado	5,810	174	2,088	-----	1,040	-----	10,799	9,383
Connecticut	166	-----	2,408	-----	-----	-----	-----	-----
Delaware	-----	-----	-----	-----	7	-----	1,070	-----
District of Columbia	-----	-----	-----	-----	-----	-----	-----	-----
Florida	7,651	64	-----	-----	455	376	1,878	-----
Georgia	7,126	631	6,804	630	626	63	480	-----
Hawaii	-----	-----	-----	-----	-----	-----	1,772	-----
Idaho	5,178	2,868	17,874	3,672	54	-----	22,124	1,698
Illinois	234	-----	3,990	6,270	513	1,180	6,319	453
Indiana	-----	-----	-----	-----	344	-----	1,615	870
Iowa	-----	-----	-----	4,218	500	432	971	875
Kansas	4,318	580	2,867	-----	2,487	-----	2,317	257
Kentucky	-----	-----	-----	1,711	237	72	6,707	-----
Louisiana	1,698	-----	7,424	-----	612	384	902	-----
Maine	74	-----	901	-----	-----	-----	798	-----
Maryland	-----	-----	-----	-----	1,675	110	1,628	-----
Massachusetts	-----	-----	-----	-----	999	-----	1,441	-----
Michigan	-----	830	10,962	-----	386	1,451	1,711	-----
Minnesota	10,503	442	416	-----	-----	398	1,691	-----
Mississippi	-----	-----	7,371	-----	558	-----	1,752	762
Missouri	1,060	-----	936	3,978	2,762	-----	3,465	-----
Montana	5,126	2,115	10,098	1,836	-----	-----	33,752	3,296
Nebraska	-----	-----	8,176	-----	-----	-----	1,803	-----
Nevada	1,574	772	19,488	2,030	2,243	-----	30,333	9,018
New Hampshire	-----	-----	1,620	-----	220	-----	1,806	-----
New Jersey	-----	-----	-----	-----	-----	-----	339	-----
New Mexico	4,860	371	6,704	369	54	-----	2,849	-----
New York	-----	-----	-----	770	968	55	1,022	-----
North Carolina	1,214	121	12,705	3,267	-----	1,870	607	-----
North Dakota	-----	104	4,646	707	-----	-----	2,182	1,302

See footnote at end of table.

◀ A contour plot, derived from digital terrain data produced by the Gestalt Photo Mapper II, superimposed on a photograph of the equipment. The capabilities of the photo mapper are described on page 80.

TABLE 8.—*Mapping production for fiscal year 1976 and transition quarter (TQ) (in square miles)*—Continued

State or territory	1:24,000-scale topographic		1:24,000-scale orthophotoquads		1:24,000-scale revisions		Intermediate scale	
	FY 1976	TQ	FY 1976	TQ	FY 1976	TQ	FY 1976	TQ
Ohio	-----	-----	-----	-----	4,021	54	1,660	-----
Oklahoma	2,110	-----	4,719	-----	3,637	-----	9,912	-----
Oregon	1,822	854	9,180	2,700	-----	20	29,262	-----
Pennsylvania	-----	-----	-----	-----	468	-----	4,771	-----
Rhode Island	-----	-----	-----	-----	752	-----	186	-----
South Carolina	321	-----	4,464	-----	1,508	-----	-----	-----
South Dakota	3,131	700	4,173	-----	3	-----	1,975	-----
Tennessee	-----	-----	-----	-----	1,553	302	2,237	-----
Texas	7,383	1,903	192	-----	2,774	942	962	-----
Utah	1,561	1,116	3,480	1,334	48	-----	2,100	-----
Vermont	32	-----	-----	-----	-----	-----	1,621	-----
Virginia	-----	-----	2,006	-----	1,430	-----	2,568	-----
Washington	-----	249	3,788	2,626	3,379	53	16,542	3,740
West Virginia	-----	-----	-----	-----	233	2,406	1,812	-----
Wisconsin	1,124	622	2,173	1,696	357	1,149	1,631	-----
Wyoming	327	-----	1,526	-----	-----	-----	9,598	88
Guam	-----	-----	-----	-----	-----	-----	-----	-----
Puerto Rico [1]	-----	-----	-----	-----	-----	-----	-----	-----
Samoa	-----	-----	-----	-----	-----	-----	-----	-----
Virgin Islands	-----	-----	-----	-----	-----	-----	-----	-----

[1] 1:63,360 and 1:25,000-scale for Alaska; 1:20,000-scale for Puerto Rico.

land information for 3,197, plus 730 in the transition quarter, 7.5-minute quadrangle areas. Considering the year's output of maps and the rapid rate of man's changes in his use of the land, it is not surprising that revision mapping now amounts to about 900 quadrangles annually.

Fiscal year 1976 and the transition quarter saw a collaboration between mapmakers and map users that resulted in a wider variety of products. Agronomists of the Soil Conservation Service and engineers of the Bureau of Land Management now work from Geological Survey base maps for land classification and management. Techniques were developed to provide customs officials with current rectified aerial photographs at 1:25,000 scale overlaid with map information for border surveillance. County officials in several States can refer to a single map of their jurisdiction for assistance in resolving many questions. Through a cooperative program with the National Ocean Survey, Department of Commerce, both the developers and the protectors of the Nation's coastal wetlands will soon be working from the same base data—maps with both topographic and bathymetric information.

Other new roles for the Geological Survey are being suggested—programs for large-scale urban mapping, systematic high-altitude photography, and digitization of planimetric and relief data. These apparently diverse requirements must be addressed by the National Mapping Program because of the need for coordination and standardization. Systems are being developed for putting map and image information in digital form, either during the mapping process or after the map is completed. With this capability, it will be possible to develop a national cartographic data bank that can respond more quickly to new and changing user requirements.

The current plan is to complete 1:24,000-scale topographic coverage of the country as rapidly as practical—in about a decade at the present rate—and in the interim to provide orthophotoquads for areas unmapped at this scale. The capability to provide base map data at intermediate scales (primarily 1:100,000) will be expanded. And guidelines for large-scale mapping of urban areas are in the offing. Equipment and techniques will continue to be updated to accommodate the increasing demand for new and revised maps, the economic and timely production of digital data, and conversion to the metric system. At the same time, the States will be encouraged to enlarge the national network of cartographic information centers.

Coordination of mapping

Federal domestic mapping activities are coordinated by the Geological Survey for the Department of the Interior. According to procedures established by the Office of Management and Budget Circular A-16 (Bureau of the Budget, 1967), the Survey requests other Federal agencies to identify their mapping requirements and considers their requirements in formulating the mapping program. State and local governments also indicate requirements for cartographic data; 15 States (Alaska, Colorado, Idaho, Illinois, Iowa, Maine, Michigan, Minnesota, Montana, Nebraska, Nevada, New Mexico, Texas, Utah, and Wyoming) each have a State mapping advisory committee that provides advice and guidance for planning the mapping program. Requests from private individuals are also considered in setting priorities. In fiscal year 1976, under cooperative mapping agreements (costs are shared equally) with 37 States and Puerto Rico, the cooperating agencies participated directly in the selection of areas to be mapped.

Yearly requests for new and revised topographic maps—a total of 41,869 requests for 27,478 quadrangles in 1976—far exceed the Survey's production capability and funding level. As a result, requests are increasing for orthophotoquads as preliminary coverage for unmapped areas or as updating supplements to available line maps. The Survey recently acquired its first automated photomapping system capable of concurrently producing corrected aerial imagery and the corresponding terrain elevations in both digital and contour form. This new system offers an alternative to current mapping methods that will make basic cartographic data available faster when most needed. A principal user of cartographic data is the Geological Survey itself, which is responsible for mapping the location and determining the extent of the Nation's physical resources and for helping to solve a wide range of environmental problems.

Highlights

Noteworthy achievements and events of fiscal year 1976 and the transition quarter include:

- Formulation of a flexible policy for metrication in the topographic mapping program. Implementation considers impact on the user as determined from an extensive survey.
- Opening of National Cartographic Information Center regional offices (in Virginia, Missouri, Colorado, and California) to provide easier customer access and more complete acquisition of information.
- Agreement with Texas establishing the first Federal-State information center in Austin for collecting and distributing cartographic data.
- Completion of 2,700 (plus 600 in the transition quarter) new and revised maps, ranging in scale from 1:24,000 to 1:250,000. In addition, about 3,200 (plus 730 in the transition quarter) orthophotoquads were produced.
- Addition of over 1.36 million square kilometers (525,000 square miles) of aerial photography to the national aerial photo data base (plus 435,000 square kilometers, or 168,000 square miles, in the transition quarter).
- Accommodation of a large increase in intermediate-scale mapping to meet the special needs of Government and State agencies (259 intermediate-scale maps this year, plus 32 in the transition quarter, compared with 9 last year).
- Acquisition of an automated photomapping system to expedite production of basic cartographic data in image, contour, and digital form.
- Development of a technique to make color orthophotoquads from dual-camera, black-and-white photographs with a resultant improvement in interpretability and, hence, value to users.
- Expansion of photoinspection and map revision procedures to provide a more systematic review of map completeness.
- Completion of new facilities for Mid-Continent Mapping Center in Rolla, Mo., to consolidate operations and modernize laboratories.
- Completion of the pilot large-scale mapping projects, including user reviews and development of guidelines for large-scale mapping.

Budget

The Topographic Surveys and Mapping budget covers three subactivities: (1) Quadrangle mapping and revision, the primary responsibility of mapping centers in Reston, Va., Rolla, Mo., Denver, Colo., and Menlo Park, Calif., (2) small-scale and special mapping, the primary responsibility of a fifth mapping center in Reston, and (3) the National Cartographic Information Center, headquartered in Reston with offices in the mapping centers.

For fiscal year 1976, Topographic Surveys and Mapping amounted to $52.2 million (plus $13.3 million in the transition quarter) (fig. 27 and table 9). Included are funds from 37 States and Puerto Rico, which, when matched by Federal funds, amounted to $7.4 million (plus $1.8 million in the transition quarter) for cooperative mapping. Cooperative projects mutually benefit the State and the national program.

The National Mapping Program was carried out by 1,693 career employees, many with special training in

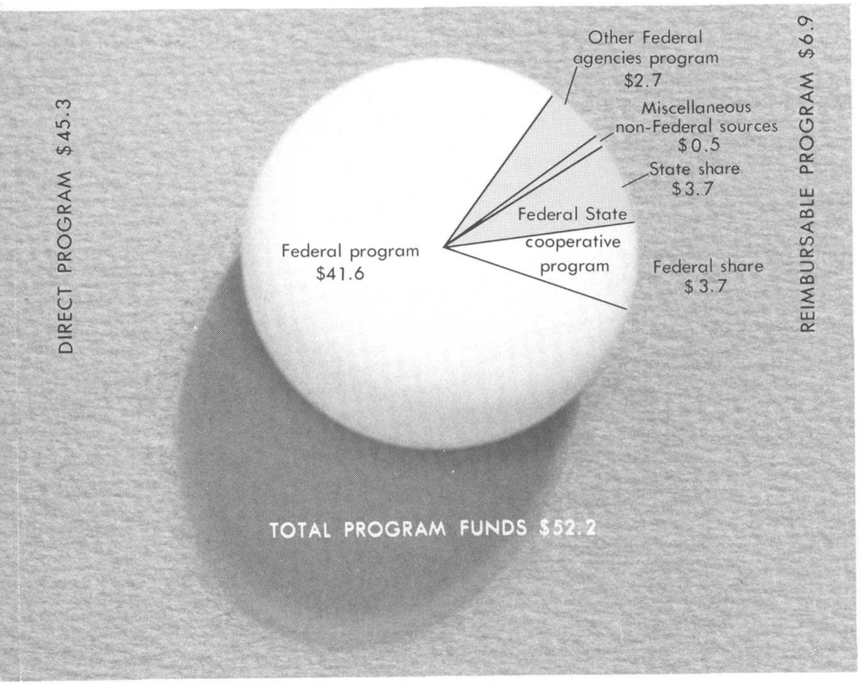


FIGURE 27.—Sources of fiscal year funds for Topographic Surveys and Mapping (dollars in millions).

TABLE 9.—*Topographic Surveys and Mapping activity obligations for fiscal years 1975 and 1976 and transition quarter, by program (dollars in millions)*

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

Program	Fiscal year 1975	Fiscal year 1976	Transition quarter
TOTAL	$52.60	$52.22	$13.29
Direct programs [1]	45.35	45.35	11.55
Quadrangle Mapping and Revision	41.15	38.26	9.40
Small-Scale and Special Mapping	2.66	5.36	1.73
National Cartographic Information Center	1.54	1.73	.42
Reimbursable programs	7.25	6.87	1.74
States, counties, and municipalities	5.00	3.67	.88
Miscellaneous non-Federal sources	.59	.50	.13
Other Federal agencies	1.66	2.70	.73

[1] Includes matching reimbursable funds from States, counties, and municipalities.

cartography, data processing, engineering, photographic technology, and physical sciences. About 200 additional employees, many on work-study programs, served as temporary aides and professional consultants.

QUADRANGLE MAPPING AND REVISION

Aerial photographs of the land surface are essential to the mapping process. In fiscal year 1976, the Survey contracted for 1.36 million square kilometers (525,000 square miles) of aerial photography, 10 percent more than last year (plus 435,000 square kilometers, or 168,000 square miles, in the transition quarter). Three-fourths of the photographs were taken from altitudes higher than 11,700 meters (39,000 feet) for use in photomapping and map revision. The aerial mapping cameras used by private contractors on photomissions for the Survey and other governmental agencies must meet accuracy specifications. For this purpose, the Survey operates the Optical Calibration Laboratory, which, during the year, tested and calibrated 88 complete cameras and 14 lenses (fig. 28).

Field control surveys are needed to present map features in correct relationship to each other and to the Earth's surface. Horizontal ground control establishes and maintains correct scale, position, and orientation of the map. Vertical control governs the contours and spot elevations which show the shape of the terrain. The resulting *geodetic data*—positions, elevations, and descriptions of control points—are used to prepare the map base, the framework on which map detail is compiled. The Survey is in the process of transferring computer records of its geodetic surveys to the National Geodetic Survey Information Center of the National Oceanic and Atmospheric Administration. By 1985 the national bank of reliable geodetic information should be readjusted to a new North American Datum.

During fiscal year 1976, 1,405 *standard topographic maps* were published, covering 211,120 square kilometers (81,200 square miles) (plus 237 maps covering 35,440 square kilometers, or 13,680 square miles in the transition quarter), or 2.2 percent of the U.S. domain (fig. 29). Most of the maps are in the 7.5-minute series, 1:24,000 scale (15-minute series, 1:62,500 scale until replaced; 1:63,360 and 1:25,000 in Alaska). In addition to meeting the needs of many users, these are the basic maps from which smaller scale and special maps are usually derived. As national coverage in the 7.5-minute series increases, the revision mapping workload increases. With special emphasis on coverage of urban, coastal-zone, transportation corridor, and other areas where changes in culture are rapid, published maps are checked against current aerial photographs at appropriate intervals and, if necessary, revised. About 656 7.5-minute maps were revised in 1976 (plus 165 in the transition quarter).

By reprocessing the aerial photographs to correct for distortions, orthophotographs are produced that can be applied in many ways. In a standard quadrangle format with grid and name information superimposed, the orthophotograph is called an *orthophotoquad*. About 3,200 orthophotoquads were

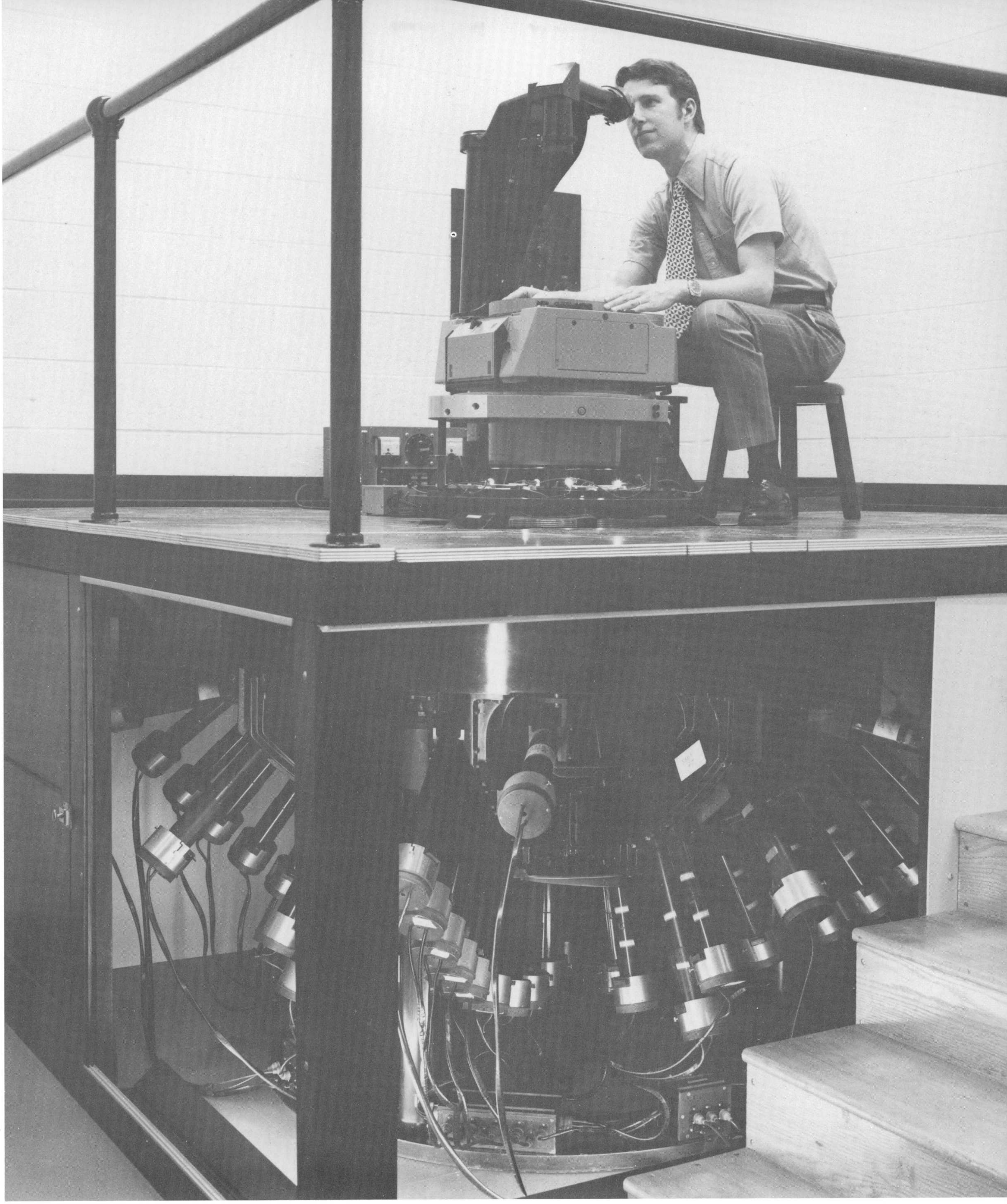


FIGURE 28.—Aerial mapping camera being tested atop multicollimator camera calibrator.

FIGURE 29.—Status of standard topographic mapping and revision.

prepared in 1976 (730 in the transition quarter); printed stock is available for a small percentage of these, with the majority available for reproduction on request (fig. 30). Orthophotoquads are black-and-white products, although techniques are being developed for adding color to aid the user in interpreting the imagery (p. 81).

The orthophotograph may also be combined with the line detail of a topographic map. In many areas where conventional line maps are ineffective in portraying the special character of the terrain, orthophotomaps are standard rather than the usual line maps. About 600 orthophotomaps are in various stages of production; the largest projects cover Florida swamps, Minnesota lake regions, and coastal stretches of Louisiana and Georgia.

SMALL-SCALE AND SPECIAL MAPPING

The *1:250,000-scale topographic map series* provides the largest scale complete coverage available for the United States and is thus valuable to many Federal and State agencies with regional concerns. The maps are also used by the Survey for preparing State base maps, the 1:1,000,000-scale International Map of the World, various geologic maps, and special-purpose maps such as those produced for the Land Use Data and Analysis program. The 1:250,000-scale maps of Standard Metropolitan Statistical Areas are generally revised every 5 to 7 years. Most other quadrangles in this series are revised every 8 to 10 years; in fiscal year 1976, 46 revisions were completed (plus 11 in the transition quarter), and 100 more were in production. *Terrain data* digitized from the contours on the 1:250,000-scale maps are available on magnetic tape from the National Cartographic Information Center (fig. 31).

To meet the need for basic map data at various levels of detail and at scales between 1:24,000 and 1:250,000, the *intermediate-scale map series* was introduced in 1975. The user can select the map content from 21 categories of data and choose county, regional, or 30′×60′ quadrangle format. County maps are also being prepared on request at 1:50,000 scale with a choice of five to seven categories of data. The capability is being developed to provide intermediate-scale map data in digital as well as graphic form. In fiscal year 1976, priority was given to completing 259 intermediate-scale maps for Federal and State agencies (plus 32 in the transition quarter) (fig. 32).

Because of a critical need for map data in the coastal areas, the Geological Survey and National

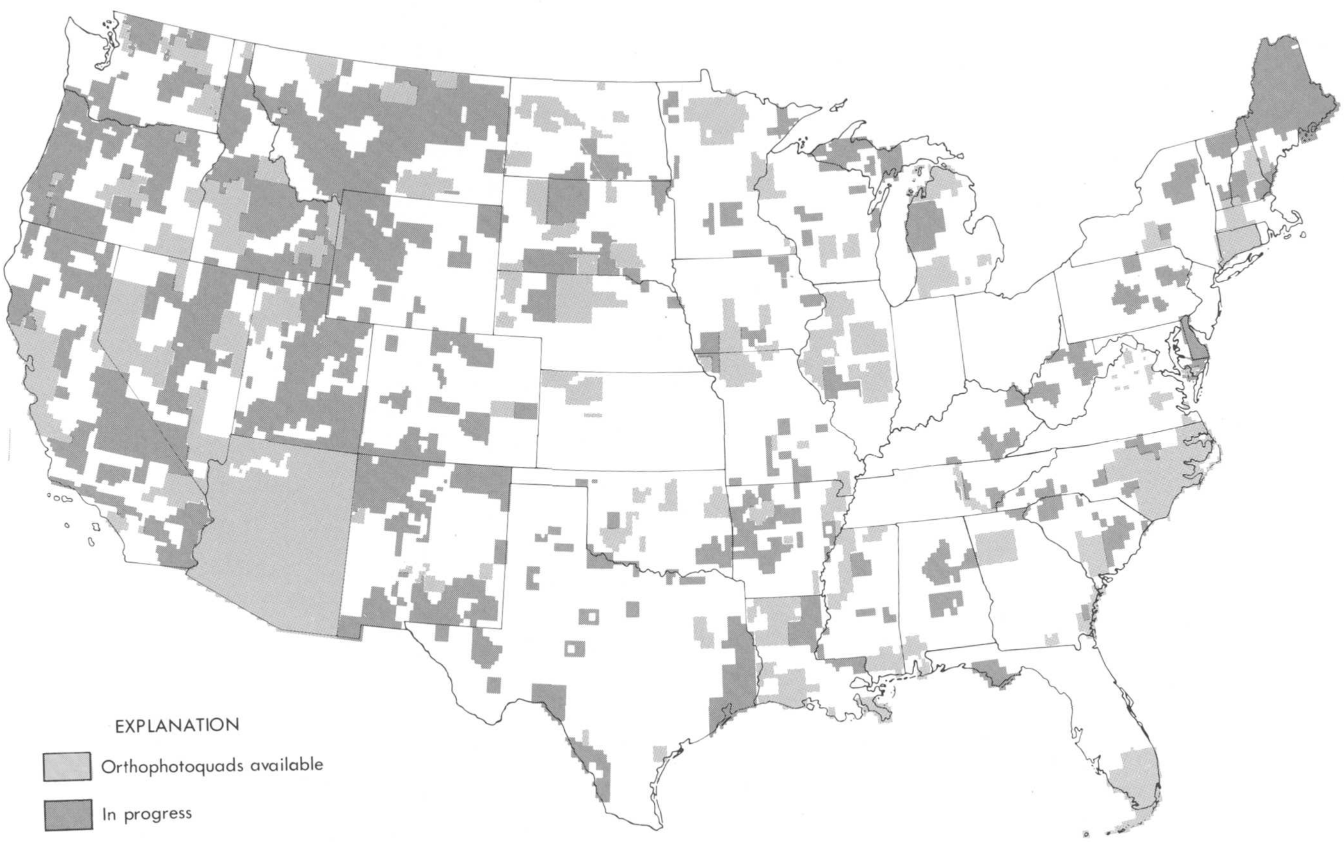


FIGURE 30.—Status of orthophotoquad production.

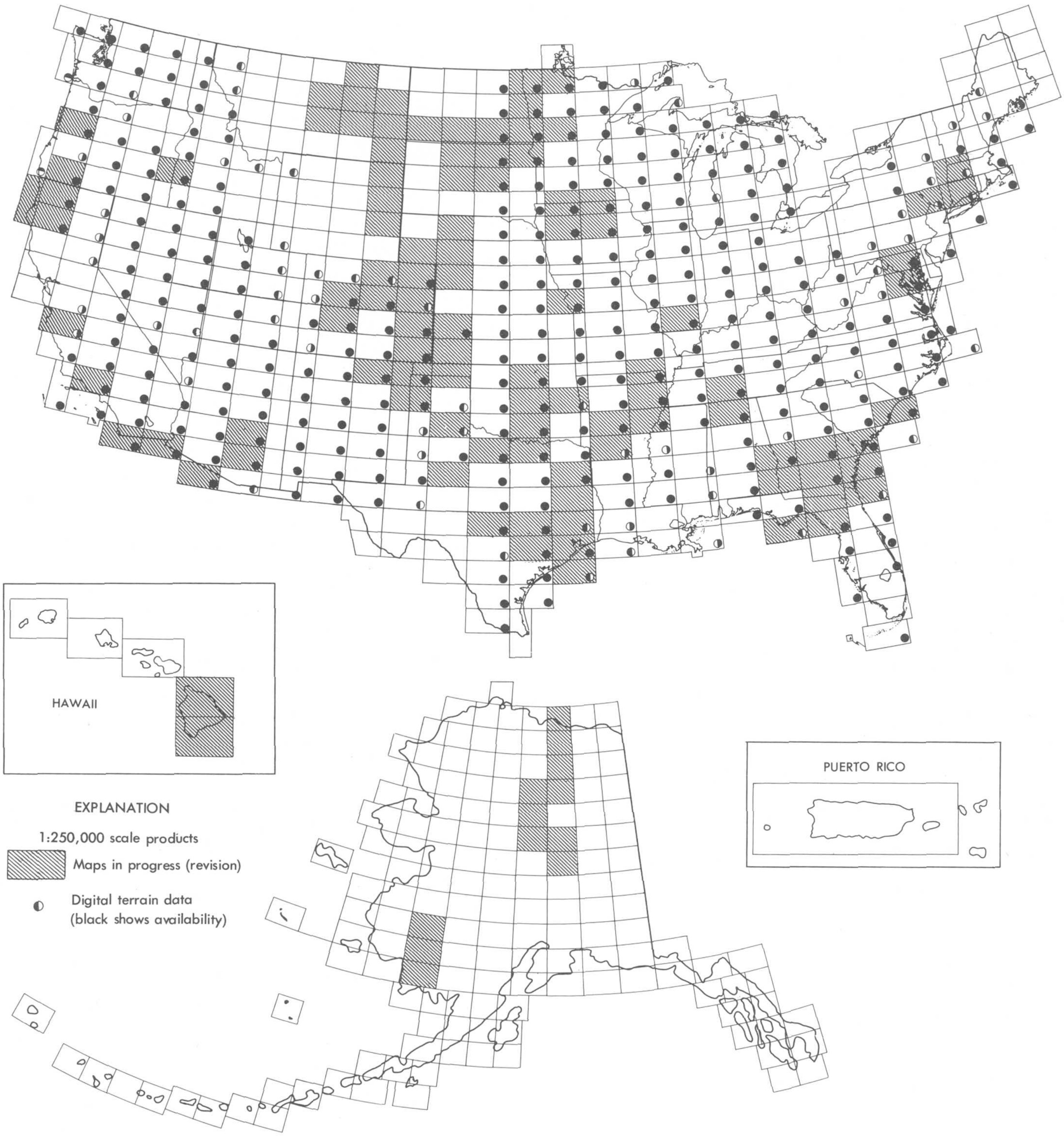


FIGURE 31.—Status of 1:250,000-scale map revision and digital terrain data.

Oceanic and Atmospheric Administration, Department of Commerce, have started producing *topographic-bathymetric maps* for the coastal zones of the United States. Three versions of a topographic-bathymetric map of the Fort Pierce, Fla., 7.5-minute quadrangle—an orthophotoquad (fig. 33), orthophotomap, and interim-revised line map—were completed for evaluation by representative users. Dual-scale coverage of the Georgia coastline—topographic-bathymetric at 1:100,000 and orthophoto-bathymetric at 1:24,000—is in production. Bathymetric data are also being added to ten 1:250,000-scale topographic maps.

The Survey also produces *national park maps,* normally standard topographic maps combined into one or more sheets covering the park area with, in some cases, companion shaded-relief editions. During 1976 and the transition quarter, six new park maps were published, and seven more were in production. A folded and jacketed map of Mount Rainier National Park, Wash. (1:50,000), was distributed during the summer by the National Park Service for user appraisal.

INTERNATIONAL COOPERATION

The Geological Survey provides technical assistance and training in surveying and mapping to many other countries under formal agreements and reimbursable funding. An agreement between the Survey and the Ministry of Hydraulics of Algeria provides for preparation of Landsat image mosaics, for personnel training, and for establishment of a technical user assistance office for remote sensing data. A Fourth Extension Agreement was made with Saudi Arabia to aid the Ministry of Petroleum and Mineral Resources in topographically mapping areas for geologic investigations, under which 545 square kilometers (210 square miles) were mapped this year. The Survey has agreements with Canada's Department of Energy, Mines, and Resources and with Mexico's Comisión de Estudios del Territorio Nacional to exchange cartographic data for the international border areas. This year the agreements were renegotiated to include aerial photographs and various photoimage products.

Fiscal year 1976 marked the 19th consecutive year that the Survey participated in the National Science Foundation's U.S. Antarctic Research Program. In support of geophysical and glaciological studies, Survey personnel conducted ground surveys and operated satellite-tracking and seismological equipment. A variety of maps of Antarctic regions were prepared: 1:250,000 topographic maps (fig. 34*A*), 1:500,000

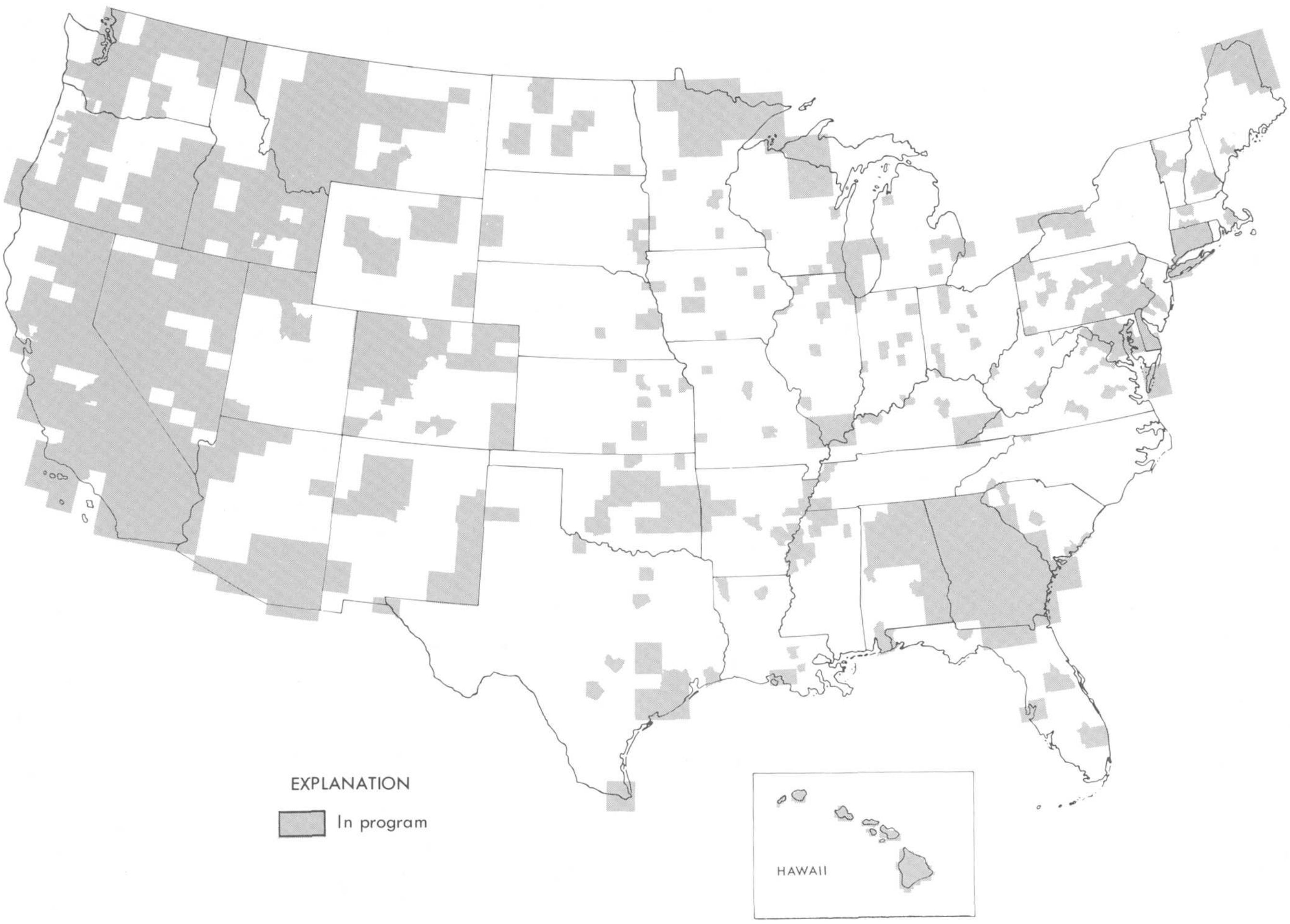


FIGURE 32.—Status of the Intermediate-Scale Mapping program.

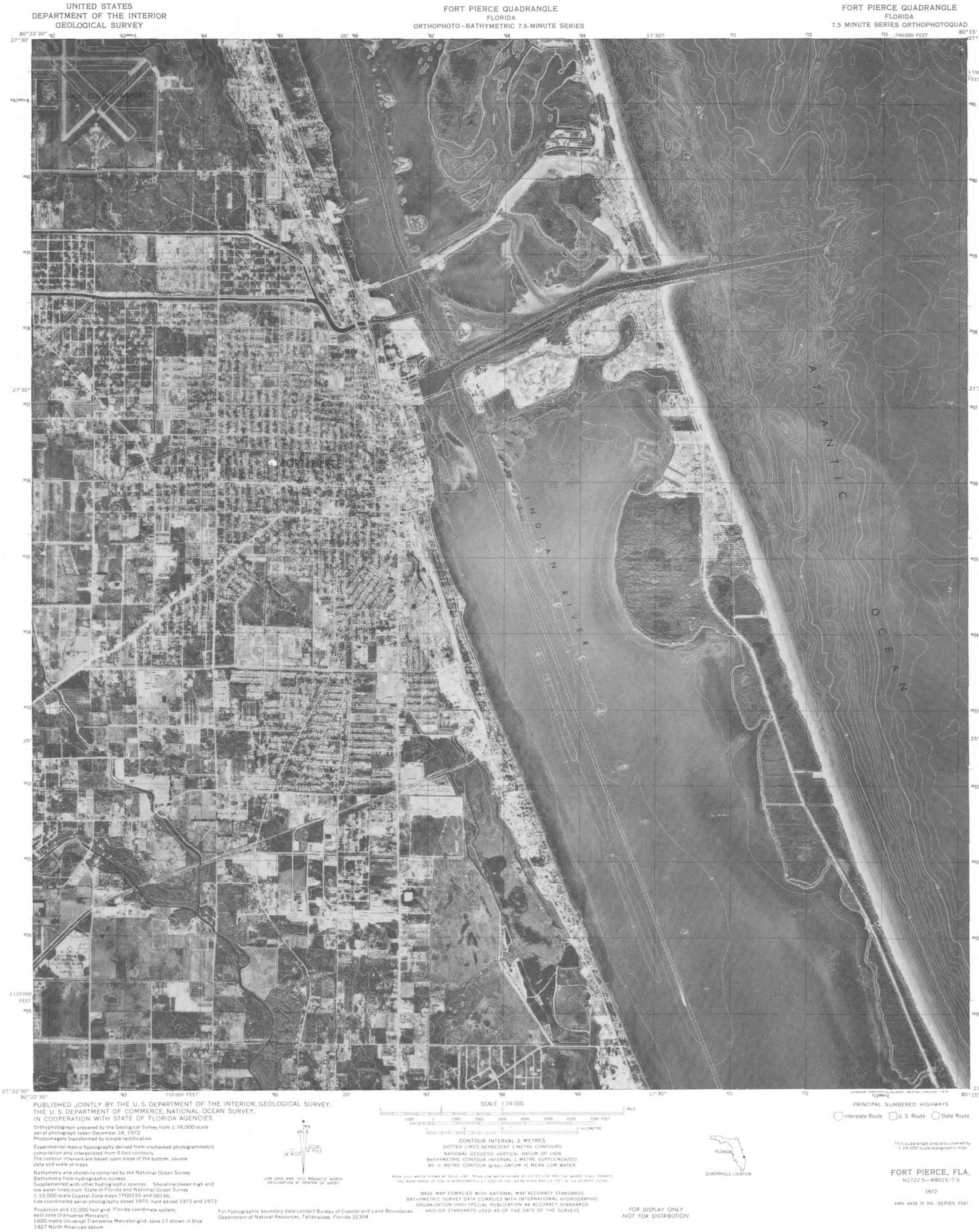


 FIGURE 33.—Experimental orthophotoquad showing both topography and bathymetry (Fort Pierce, Fla.; scale of original is 1:24,000).

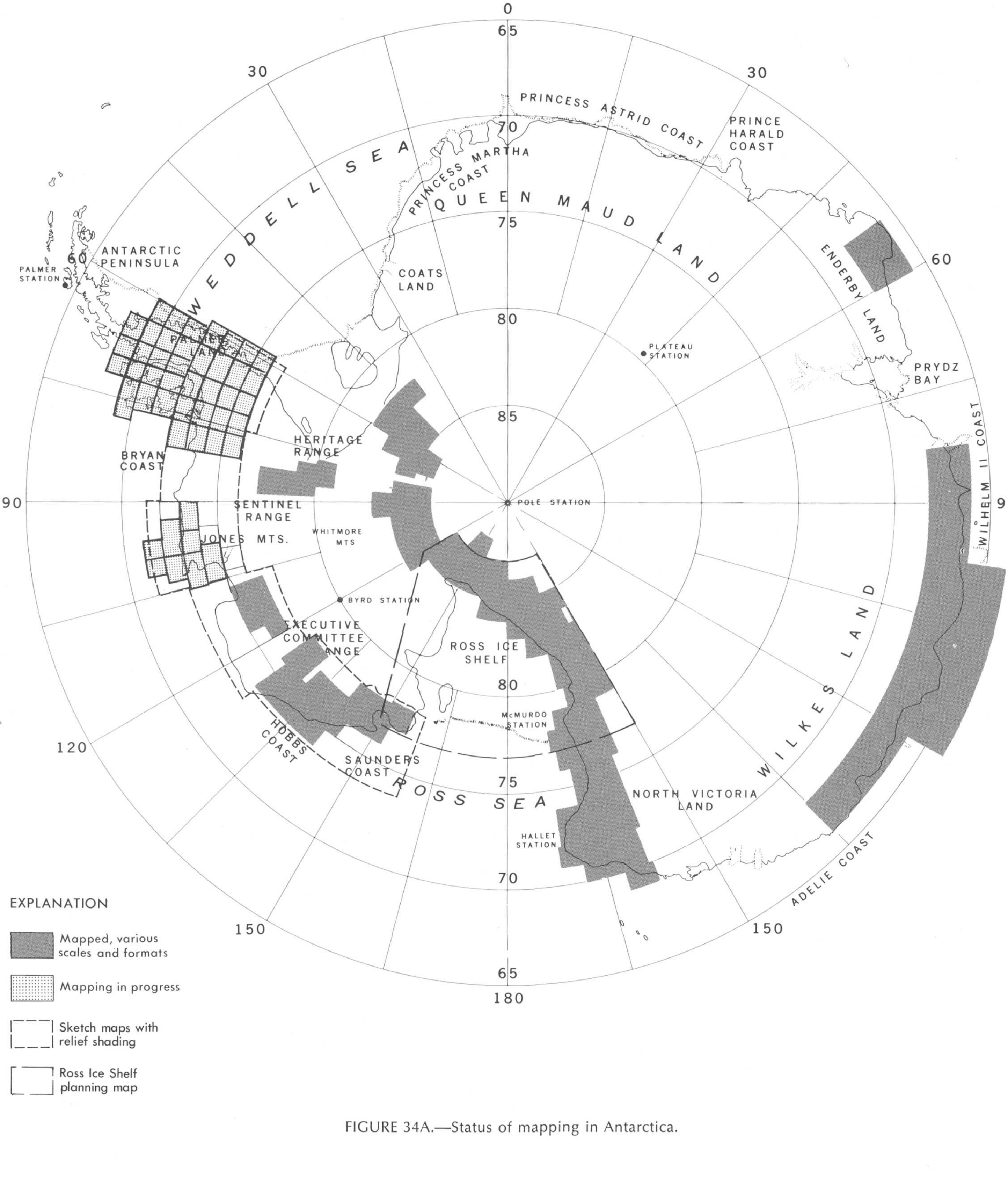


FIGURE 34A.—Status of mapping in Antarctica.

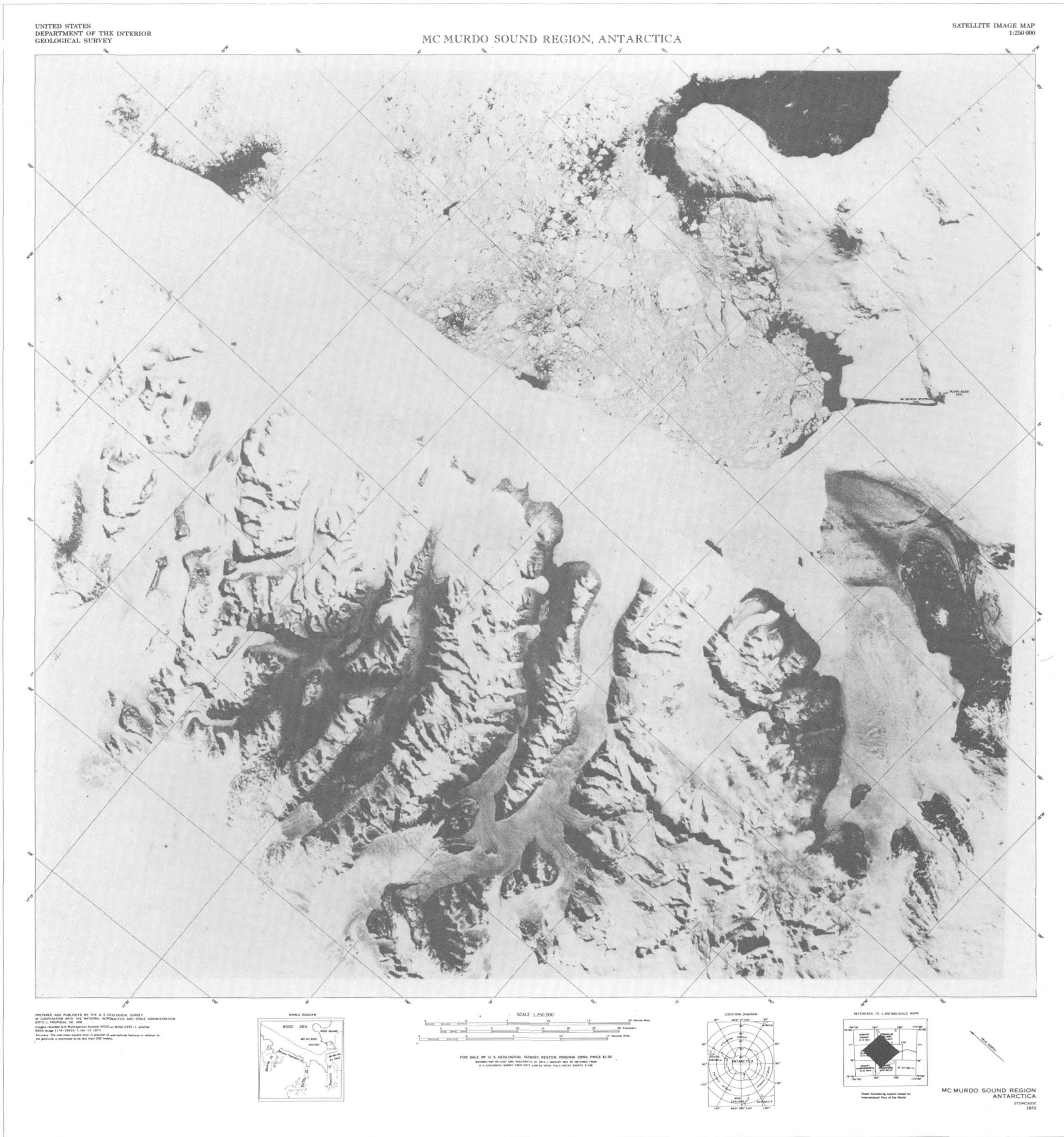


FIGURE 34B.—Landsat image map of McMurdo Sound region, Antarctica.

planimetric sketch maps, and small-scale satellite image maps. This year six Landsat image maps of portions of Antarctica were prepared at scales of 1:250,000, 1:500,000, and 1:1,000,000; the 1:250-000-scale map of McMurdo Sound (fig. 34*B*) offers a spectacular view of volcanic mountains and sea ice.

NATIONAL CARTOGRAPHIC INFORMATION CENTER

The goal in establishing the National Cartographic Information Center in 1974 is to improve public access to cartographic data collected by Federal, State, and local agencies and by private firms. In the Federal sector alone, the cartographic data holdings are estimated at 1.5 million maps and charts, 25 million aerial and space photographs, and 1.5 million geodetic positions. The Center generally does not obtain the actual cartographic data but rather collects and organizes information about the data and, if possible, about acquisition plans of participating organizations and provides this information and ordering assistance to users. The headquarters office has been receiving about 5,000 inquiries a month.

Many government and private organizations have shown serious interest in the mission of the National Cartographic Information Center. In fiscal year 1976, five more Federal agencies formally agreed to supply information on their cartographic holdings. The first State to participate in the network is Texas; a joint information center will be opened in Austin with a telecommunications link to the EROS Data Center, the principal affiliate for aerial and space imagery. This pilot cartographic information center may well become a model for similar outlets in other States. By the year's end, other agencies that have agreements with the National Cartographic Information Center that relate to cartographic information management included the:

Agriculture Stabilization and Conservation Service
Bureau of Land Management
Defense Intelligence Agency
Forest Service
National Archives and Records Service
National Oceanic and Atmospheric Administration, National Ocean Survey
Soil Conservation Service
Texas Water Development Board, Texas Natural Resources Information System

In addition, four regional offices were opened, in Reston, Va., Rolla, Mo., Denver, Colo., and Menlo Park, Calif., to provide convenient customer access and complete acquisition of information at the local level.

For information on aerial photography, the National Cartographic Information Center has developed the Aerial Photography Summary Record System. To date, nine Federal agencies have provided the Center with data on coverage and technical characteristics of vast photograph collections and on plans for new photography projects, in digital form for direct input to the system. Several workshops were held with the cooperating agencies to explain the system's capabilities and how to code and retrieve information.

The National Cartographic Information Center is coordinating the transfer of Geological Survey geodetic data to the National Oceanic and Atmospheric Administration, which is assembling the National Geodetic Data Base. This year, the Survey mapping centers began organizing the records for 40,000 horizontal control stations. The tasks of evaluating and formatting the numerical observation data have begun, and new text-processing equipment is being acquired for digitizing the station descriptions. The transfer of data is slated for completion in time to lend support to the upcoming readjustment in 1983 to the new North American Datum.

RESEARCH AND RELATED DEVELOPMENTS

The Survey is continually searching for ways to improve mapping productivity and to respond more quickly to users' diverse requirements. Among the new instruments and technological developments investigated during the year (U.S. Geological Survey, 1976), the following seem particularly important to the future of cartography:

- *Inertial surveying systems.*—Adaptation of inertial navigation systems to ground surveying problems promises to provide the needed accuracy and to make control surveys far more productive. Ground positions and elevations can be established automatically by inertial measuring systems carried in a truck, helicopter, or light plane. A Litton Auto-Surveyor owned by the Bureau of Land Management was brought to Denver for tests oriented to Geological Survey map control requirements; the resulting horizontal positions generally agreed within half a meter, but vertical accuracy was inadequate for most 1:24,000-scale mapping. A military version of the system, on loan from the Defense Mapping Agency, was used for the first production test in Maine, a mapping project requiring ground data for nearly one-quarter of the State; the results are currently being evaluated. The Aerial Profiling of Terrain

System is being designed for the Survey by the Charles Stark Draper Laboratory (Cambridge, Mass.) to carry a three-coordinate scheme of reference in a light airplane, to an accuracy of 0.15 meter vertically and 3 meters horizontally. Design of the system was prompted by the need for flood-plain delineation, but other potential field applications include establishing map control and obtaining map elevation information. The contract work has focused on maximum accuracy with light-weight and low-power elements, and the design phase is expected to be completed in December 1976.

- *Advanced image-correlation system.*—This year the Survey acquired a Gestalt Photo Mapper II (GPM2), the first production model in the United States or elsewhere. The GPM2 (fig. 35) automatically corrects for the distortion in the aerial imagery and concurrently produces orthophotographs and the corresponding terrain data in contour and digital (magnetic-tape) form. The entire process is executed under computer control with the operator intervening occasionally to assist in correlating the images. Production time is related to various characteristics of the aerial photographs and of the terrain pictured; during 2 months of operation, production time has ranged from 1 to 7 hours to process the overlap area of a stereographic pair of photographs.
- *Digital cartographic data.*—In digital form cartographic data can be processed rapidly and eco-

FIGURE 35.—The Survey has acquired a Gestalt Photo Mapper II, an advanced mapping system that concurrently produces an orthophoto, a contour drawing, and digital terrain data.

nomically and can be related with other types of data. The product can be a computer model or a map of selected content and scale. This year the Survey began equipping the mapping centers for digitizing mapped information (planimetric features such as the public land net) or for digitizing directly from aerial photographs (topographic features such as drainage and relief). An interim structure for the Digital Cartographic Data Base is being designed for use with the new hardware. Special-purpose cartographic data bases are being acquired from the Bureau of the Census and other agencies and adapted for Survey use. A pilot project is being carried on within the Survey, in connection with research on energy sources, to determine how best to digitize terrain elevations and planimetric data; the objective is to combine the surface data with digitized subsurface data on geologic structures in a National Coal Resources Data System so as to readily provide statistics on coal volume and overburden.

- *Digitally controlled differential rectifiers.*—The Digital Profile Recording and Output System was developed by the Survey to provide terrain data that can control the offline production of orthophotos, contour plots, and slope information. The first production unit went into operation this year. The design of the system is sufficiently flexible to accommodate several types of profiling instruments and film-exposing units. This approach is proving worthwhile and is thus being adapted to three other profiling instruments and two other exposing units.
- *Digital processing of imagery.*—The Geological Survey Center of Astrogeology at Flagstaff, Ariz., has been developing techniques for digitally correlating imagery and elevation data to form a new altered image. A stereographic pair of Landsat images was produced by digitally introducing relief displacement (parallax) into one image; when the original and processed images are viewed together, the observer sees a stereoimage. Another application is the production of shaded-relief renditions of maps. The digital terrain data are converted to values of slope, which are used to compute the brightness levels (based on the desired Sun angle and direction) that control production of the shaded image. Computer-generated shaded-relief maps were prepared that range in scale from 1:24,000 to 1:250,000.
- *Coastal Zone Mapping Handbook.*—A draft edition of the Coastal Zone Mapping Handbook, a joint project of the Geological Survey and the National Oceanic and Atmospheric Administration, was completed and subsequently reviewed by 200 Federal and State agencies. The handbook includes general guidelines for mapping coastal areas, sources of technical assistance and data, and product samples. Many people think that a more definitive map representation of the nation's wetlands is needed and should be based on a standard wetland classification system. The Survey is investigating the problem by experimentally mapping wetlands in Florida, Georgia, Mississippi, and South Dakota, areas which vary significantly in vegetation and other characteristics.
- *Experimental color orthophotoquad.*—Success in applying color to Landsat multispectral imagery shifted attention back to the earliest method of obtaining color pictures from black-and-white records. That method is to obtain at least two spectrally filtered records of the same area on black-and-white film and apply suitable color inks on a printing press. In this way, the Survey is experimentally adding color to the orthophotoquad. Real contrast and high resolution are obtained by taking simultaneous aerial pictures on panchromatic and black-and-white infrared films. The color contrasts provided in lithoprinting help the user interpret the perhaps unfamiliar aerial view. This technique was used to prepare several color renditions of a specimen image map for the U.S. Customs Service; one of these renditions will be chosen to complete the mapping of a 320-km strip along the United States-Canadian border.
- *Metrication.*—After the passage of the Metric Conversion Act of 1975, a representative group of 150 Federal, State, and private organizations that will be affected by metric conversion in mapping were asked for opinions and advice on technical details of metrication. The replies showed preference for the 1:25,000 scale for 7.5-minute quadrangle maps and the contour-interval sequence of 1, 2, 5, 10, 20, 50, and 100 meters. The replies from States varied widely, from preferring to metricate now to insisting on waiting until 1:24,000-scale coverage is complete for the State. Individual State plans for completing 7.5-minute coverage and metricating will consider the problems and requirements of the State concerned. New metric topographic mapping commenced in New York with a project comprising thirty-two 1:25,000-scale quadrangles covering the area where the 1980 Winter Olympics will be held. Also, all new 1:100,000-scale maps will be metric as well as complete revisions of published maps.

VIRGINIA

Index to Topographic and other MAP COVERAGE

Published and distributed by
United States
Department of the Interior
Geological Survey

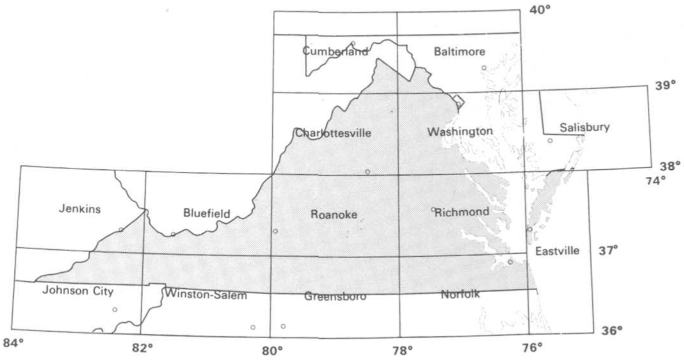
See CATALOG OF PUBLISHED VIRGINIA MAPS for details about

Standard series maps	*Special maps*
1:24 000-scale, 7½-minute	National parks and monuments
1:62 500-scale, 15-minute	Orthophotomaps
1:100 000-scale	Orthophotoquads
1:250 000-scale	County maps
1:1 000 000-scale International Map of the World	State maps
	National Atlas products
	Maps of the United States

See CATALOG OF VIRGINIA MAP DATA for details about

Color and feature separates	Maps on microfilm
Aerial photographs	Copies of out-of-print maps
Satellite images	Status maps
Advance materials	Geodetic control data
Slope maps	Digital terrain tapes
Land use data	Orthophotoquads

1:250 000-scale Series

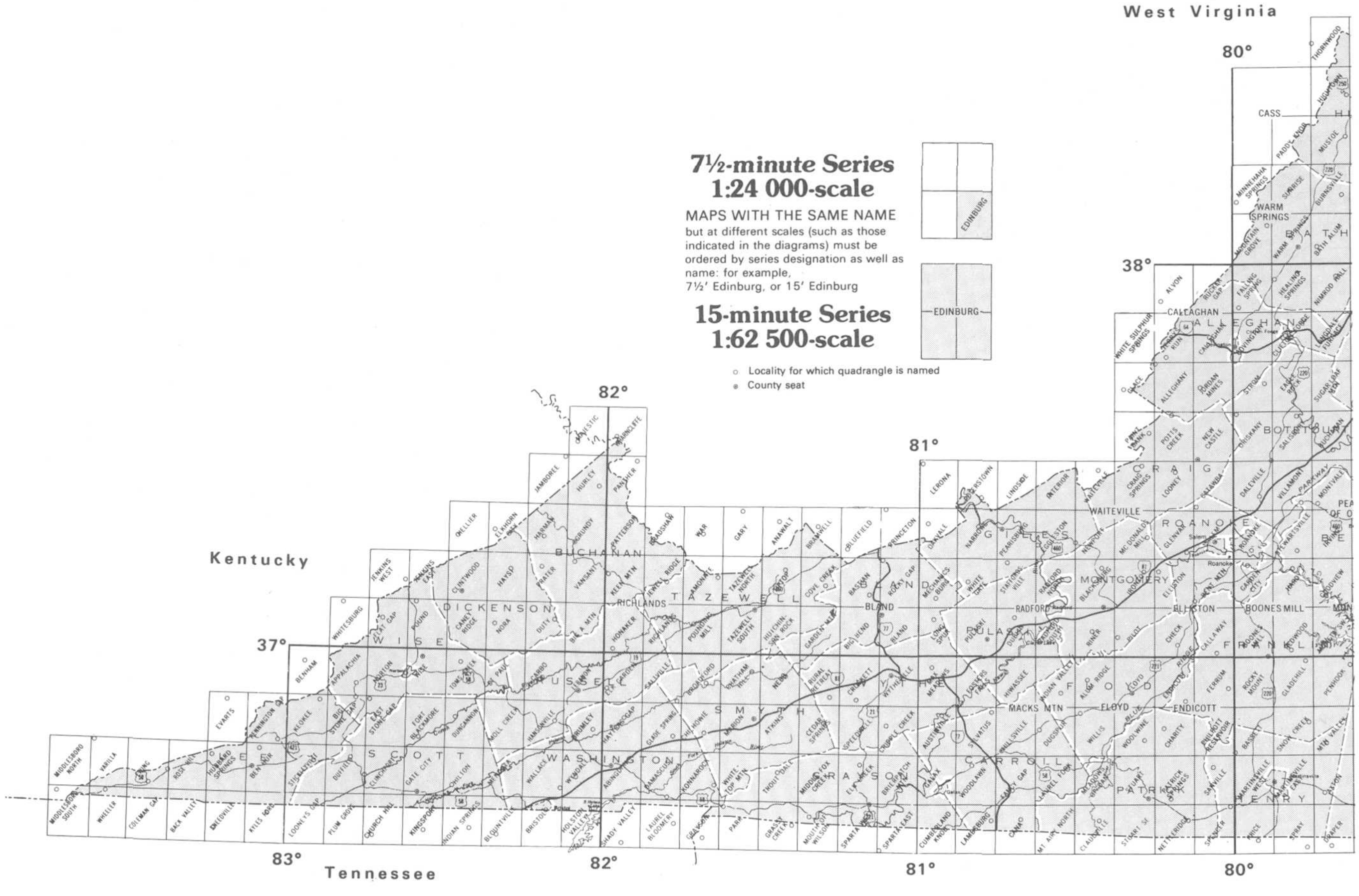


7½-minute Series 1:24 000-scale

MAPS WITH THE SAME NAME but at different scales (such as those indicated in the diagrams) must be ordered by series designation as well as name: for example, 7½' Edinburg, or 15' Edinburg

15-minute Series 1:62 500-scale

○ Locality for which quadrangle is named
● County seat



INDEX SCALE 1:1 000 000

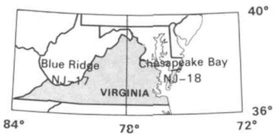
10 0 10 20 30 40 50 Kilometers

10 0 10 20 30 40 Miles

Index and CATALOG OF PUBLISHED MAPS available free from: Branch of Distribution, U. S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202

CATALOG OF MAP DATA available free from: National Cartographic Information Center, U. S. Geological Survey, 507 National Center, Reston, Virginia 22092

International Map of the World Series
1:1 000 000-scale



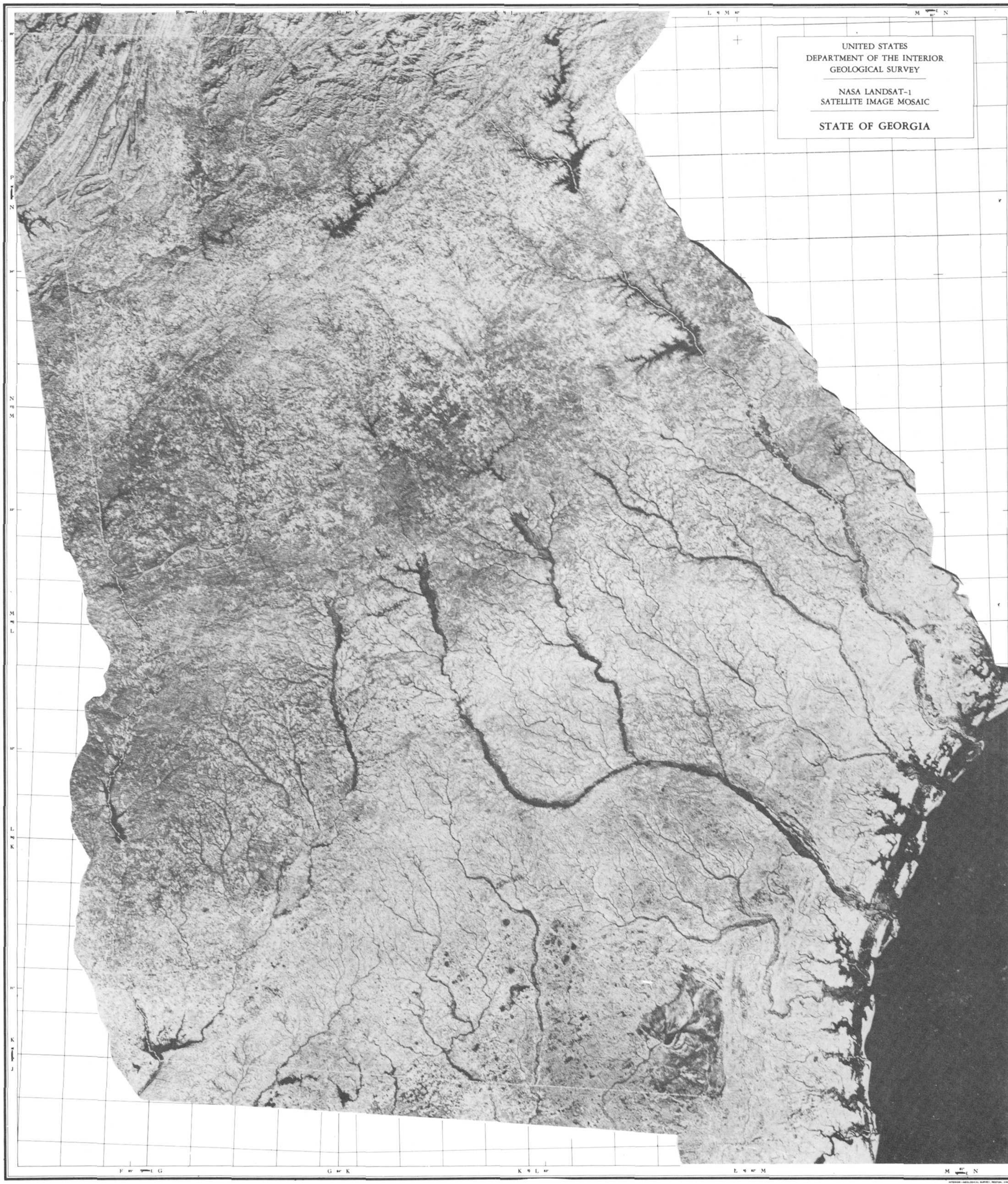
Sectional Map Series, 1:2 000 000-scale
National Atlas Sheet 8: Middle Atlantic States

State Map Series
1:500 000- and 1:1 000 000-scale

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1976

Virginia Index

FIGURE 36.—The Virginia index to topographic maps is the first to be produced in an experimental format consisting of three elements: The index to topographic and other map coverage (above), a catalog of published Virginia maps, and a catalog of map data that provides information on other available products.



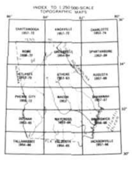
Prepared and published by the U. S. Geological Survey in cooperation with the National Aeronautics and Space Administration and the Earth and Water Division of the Georgia Department of Natural Resources

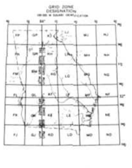
Imagery recorded in discrete spectral bands with Multispectral Scanner (MSS) on NASA LANDSAT-1 (formerly ERTS-1). Orbital altitude 920 km (570 mi)

Generally in this false color imagery clouds appear white, cleared areas are white or light gray, vegetation is shades of red, urban areas are blue-gray, and open water is shades of blue. The water shades do not directly relate to depth. Repetitive imagery obtained by LANDSAT sensors will show different conditions of vegetation, hydrography, and urban areas

Band 5 printed in yellow and magenta; band 7 printed in cyan

Imagery controlled to photoidentified ground positions. UTM grid based on Lambert projection. The root-mean-square error in position of well-defined features in relation to the grid is estimated to be 200 metres





Scale 1:500 000

Projection—Lambert Conformal Conic based on standard parallels 33° and 45°

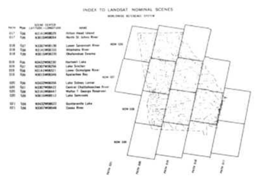
20 000-metre Universal Transverse Mercator grid, zones 16 and 17

1927 North American Datum

FOR SALE BY U. S. GEOLOGICAL SURVEY, RESTON, VIRGINIA 22092

INFORMATION ON COST AND AVAILABILITY OF LANDSAT IMAGERY COVERING THIS AREA MAY BE OBTAINED FROM U. S. GEOLOGICAL SURVEY, EROS DATA CENTER, SIOUX FALLS, SOUTH DAKOTA 57198

THE NOMINAL SCENE PATH AND ROW OR THE CENTER LATITUDE AND LONGITUDE SHOULD BE USED TO DESIGNATE THE AREA OF INTEREST



GEORGIA
SATELLITE IMAGE MOSAIC
1973–1974

- *Prototype State index to topographic maps and other map products.*—The present system of providing information on the availability and coverage of cartographic data was critically reviewed. The first result is a new format for State map sales indexes, redesigned to improve readability and economy of maintenance. The new Virginia index map (fig. 36, p. 83) in black, gray, and red is much easier to read than the former light-green rendition with black overprint. One standard fold will replace the 11 fold sizes now used. New typefaces were chosen, and insets were added to show coverage in several map series. Two companion catalogs, one for published maps and the other for map data, with detachable order forms, will accompany the new index map.
- *Cartographic applications of satellite imagery.*—The studies of cartographic applications of satellite imagery continued, with both Landsat-1 and -2 still functioning. A 1:500,000-scale satellite image mosaic of Georgia (fig. 37) that shows the general extent of the flood plains was prepared for State use in regional geologic studies. A fundamental problem is the best way of processing Landsat data for distribution in image form. A second edition of the Upper Chesapeake Bay satellite image map shows the improvement due to digital image processing. Other experiments indicated that conventional photoprocessing of spectral records into a color composite may not be optimum for some mapping purposes. Consultation and coordination with mapmakers and others throughout the world indicate that cartographic applications of Landsat data are manifold and accelerating. For example, Canadians are using Landsat imagery to revise maps at scales as large as 1:50,000, and the U.S. Defense Mapping Agency has used the imagery to revise hydrographic charts of international waters. However, should operational spacecraft retaining the basic specifications of the experimental Landsats be launched to maintain the established sequence and flow of repetitive and consistent coverage now relied on by several nations that have established receiving stations, it must be understood that the data are directly usable only at small scales—generally 1:500,000 and smaller. Experience shows that Landsat imagery must be supplemented by other more detailed and larger scale data to provide cartographers with all the information they need to produce complete topographic maps at scales of 1:250,000 and larger.

References

Bureau of the Budget, 1967, Coordination of surveying and mapping activities: Bureau of the Budget Circular A–16 (revised), May 6, 1967, 3 p.

U.S. Geological Survey, 1976, Mapping—An annual report of USGS cartographic research: USGS Topographic Division, 520 National Center, Reston, Va. 22092, 75 p.

◀ FIGURE 37.—Satellite image mosaic of Georgia (scale of the original is 1:500,000).

Paleontological sample preparation. ▼ ▲ Installing tiltmeter. Geological surveying. ▼ ▲ Petrology.

▼ Geophysical surveying.

Geologic and Mineral Resource Surveys and Mapping

OVERVIEW

The national program of geologic research and investigations, under the direction of the Geologic Division, continues to study the physical resources and geologic processes that substantially influence our lives. The relationship of geologic research to human welfare is particularly significant in:

- Geologic hazards such as earthquakes, volcanic eruptions, and landslides in urban and suburban areas.
- Development and use of energy resources, including oil and gas, coal, uranium, and geothermal waters, and the effects on the environment of the Earth's surface and atmosphere.
- Depletion of known mineral reserves and the corresponding impacts on national and world economies.

To assist in the solution of such problems, the Geologic Division conducts an extensive research and investigation program that provides geological, geophysical, and geochemical information on geologic hazards, land resources, and mineral and energy resources. The national geologic program is divided into four subactivities: Land Resource Surveys; Mineral Resource Surveys; Energy Resource Surveys; and Offshore Geologic Surveys.

Land Resource Surveys provide basic geological, geophysical, and geochemical data required to evaluate the Nation's land resources. Other research programs of this subactivity are aimed at mitigating geologic hazards, identifying the environmental problems created by developing and utilizing energy resources, and investigating the geologic processes and historical geologic events that lead to the physical and chemical composition and structure of the Earth, Moon, and planets.

Mineral Resource Surveys provide information on the resource assessment of metallic and nonmetallic minerals by studying the geology, geochemistry, and geophysics of known mineral occurrences and potentially mineralized areas and by developing new or improved exploration techniques. The mineral resource assessment programs respond to legislative actions such as the Geological Survey's Organic Act (1879), the Strategic Raw Materials Act (1938), the Wilderness Act (1964), the Mining and Minerals Policy Act (1970), and the Alaska Native Claims Settlement Act (1971).

Energy Resource Surveys provide updated information on the location, quantity, and quality of the Nation's energy resources through studies of coal, oil and gas, oil shale, uranium and thorium, and geothermal areas.

Offshore Geologic Surveys provide assessment of the potential mineral and energy resources of the submerged continental margins of the United States and determine the geologic hazards that may affect the environment in developing and utilizing off-shore resources.

Budget and Personnel

In fiscal year 1976, obligations of the Geologic and Mineral Resource Surveys and Mapping activity were $92.3 million. This amount was supplemented by approximately $1.5 million from 15 States and $21.6 million from other Federal agencies and non-Federal sources (table 10 and fig. 38).

At the end of fiscal year 1976, the Geologic Division had 2,119 permanent full-time employees and 590 temporary or part-time employees.

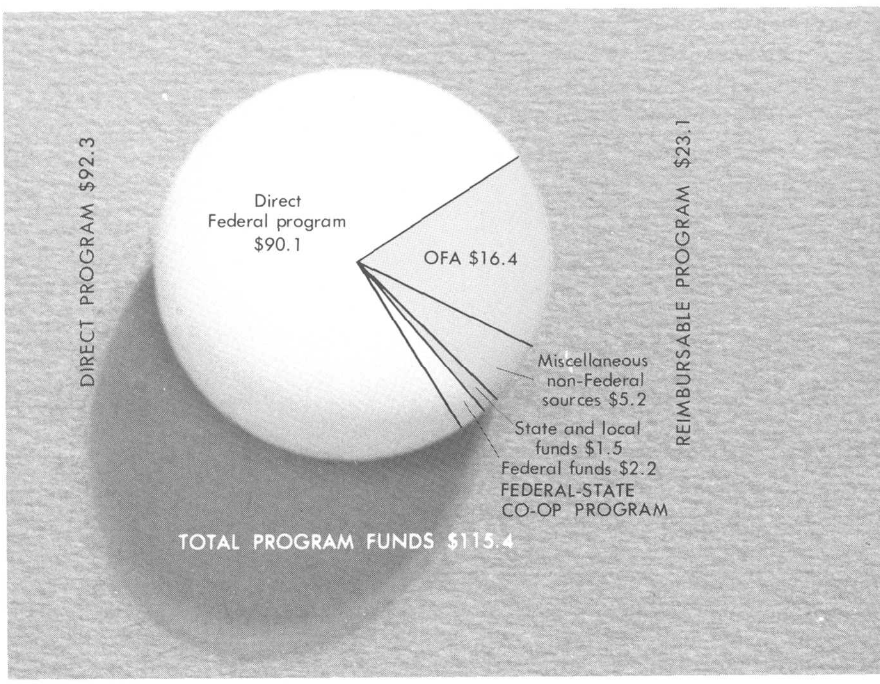


FIGURE 38.—Sources of fiscal year 1976 funds for Geologic and Mineral Resource Surveys and Mapping (dollars in millions).

Highlights

Major highlights of fiscal year 1976 included the following events and accomplishments:

- Discovery of an anomalous uplift, up to 25 centimeters (12 inches) in an area larger than 12,000 square kilometers (4,600 square miles) in southern California, which may be a precursor to an earthquake.
- Revision of the standard classification chart of landslides and slope movement for use by engineers.
- Location of significant mineralization in the Scotchman Peak Wilderness study area, Montana-Idaho, which is similar to the strata-bound copper deposit being developed 3.2 kilometers (1.9 miles) to the east.
- Completion of mineral resource assessment for approximately one-third of the land area being considered for preservation under Section 17(d)(2) of the Alaska Native Claims Settlement Act.
- Compilation of mineral resource information for 23 Indian reservations totaling 3.2 million hectares (7.9 million acres) in Colorado, Michigan, Nevada, New Mexico, Utah, and Wisconsin.
- Description of the geologic character, age, and origin of United States ball clay and fireclay deposits used for making high-grade refractories.
- Compilation of the mineral and water resources report for the State of Wisconsin.
- Comparison of the approach and efficiency of resource programs conducted in Canada and

TABLE 10.—*Geologic and Mineral Resource Surveys and Mapping activity and Alaska Pipeline Related Investigations activity obligations for fiscal years 1975 and 1976 and transition quarter by programs (dollars in millions)*

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

Program	Fiscal year 1975	Fiscal year 1976	Transition quarter
Total	$114.48	$115.44	$32.17
Direct Programs	89.02	92.32	24.81
Land Resource Surveys	33.38	34.08	9.68
Earthquake Hazards	10.97	11.26	3.78
Volcano Hazards	.64	.68	.17
Environmental Aspects of Energy	5.35	5.23	1.21
Arctic Environmental Studies	.40	.37	.10
Engineering Geology	1.26	1.29	.36
Regional Mapping and Analysis	14.76	15.24	4.06
Regional Geology			
Geophysical Surveys	9.34	9.22	2.48
Geochemical Surveys			
Dating and Correlation	4.32	4.76	1.26
Geologic Processes	1.10	1.26	.32
Mineral Resource Surveys	18.02	19.78	5.31
Mineral Resource Assessment	7.77	6.97	1.89
Wilderness Areas	1.24	1.46	.35
Alaska	2.52	3.48	1.03
Conterminous States	1.67	1.85	.46
Mineral Discovery Loan Program	.25	.18	.05
Mineral Commodity Assessment	2.09	2.02	.54
Critical Commodities	1.50	1.48	.42
Minerals for Energy Production	.59	.54	.12
Mineral Information Systems and Analysis	.96	1.66	.69
Resources Processes Technology	5.14	5.23	1.27
Resource Techniques in Geochemistry and Geophysics	4.14	3.90	.92
Energy Resources Surveys	22.38	23.00	5.86
Coal	1.64	2.32	.51
Oil and Gas	4.93	5.14	1.23
Oil Shale	1.19	1.07	.28
Uranium and Thorium	4.23	4.45	1.07
Geothermal Energy	9.06	8.65	2.55
Energy Resource Data System	1.33	1.38	.22
Offshore Geologic Surveys	15.24	15.47	3.96
Oil and Gas Resources Appraisal	10.07	9.49	2.24
Environmental Investigations	3.93	4.50	1.37
Marine Geology Investigations	1.24	1.49	.35
Reimbursable Programs	25.46	23.12	7.36
State, counties, and municipalities	1.55	1.48	.38
Miscellaneous non-Federal sources	3.75	5.24	1.12
Other Federal agencies	20.16	16.40	5.86
Alaska Pipeline Related Investigations	.34	.31	.08

United States in terms of existing public policies for the mineral industries.

- Studies of Landsat images for lineaments, structural zones, and hydrothermal alteration of rocks and soils that have proven effective in focusing attention on potential ore deposits in Alaska, Arizona, Nevada, Mexico, Brazil, and Pakistan.
- Completion of geologic maps for about 2,590 square kilometers (1,000 square miles) of an area bearing low-sulfur coal in Wyoming, Montana, Kentucky, Virginia, and West Virginia.
- Initiation of a 5-year program with the Energy Research and Development Administration to evaluate and characterize black shales in the Appalachian and Illinois Basins.
- Continuation of geologic studies in Alaska that resulted in significant discovery of a potential uranium-thorium deposit.

LAND RESOURCE SURVEYS

Earthquake Hazards

The goal of the earthquake prediction and hazard-mitigation program is to reduce casualties, damage, and social and economic disruption caused by earthquakes. The social, economic, and political actions that can be taken to attain this goal are based on technological capabilities that require development through research. The primary objectives of this research are to develop capabilities to:

- Predict the time, place, magnitude, and effects of earthquakes so that effective preparatory action can be taken.
- Control or alter seismic phenomena to make them less hazardous.
- Assess seismic risk and evaluate earthquake hazards so that appropriate construction and land-use plans can be implemented.
- Improve economically feasible design and construction methods for building earthquake-resistant structures of all types and for upgrading existing structures.
- Understand the factors that influence public utilization of earthquake-mitigation methods and information.

Responsibility for research on these objectives is shared between the Survey and the National Science Foundation, which is responsble for the last two objectives.

Highlights of the program during fiscal year 1976 included:

- Discovery of an anomalous uplift of up to 25 centimeters (12 inches) in southern California (Castle and Yerkes, 1976). This uplift, which began about 1960 and has grown to include an area of more than 12,000 square kilometers (4,600 square miles), clearly seems to represent an episode of anomalous crustal deformation in the region and may be the precursor of a large earthquake in the region (fig. 39).
- Investigation of the Chinese methods used in predicting earthquakes. China has suffered greatly from earthquakes. The greatest earthquake disaster known occurred there in 1556 when over 800,000 people died. About 100,000 died in 1920 from a magnitude 8.6 shock in Kansu and Shansi Provinces, and in 1927 about 200,000 were killed by a tremor of magnitude 8.3 near Nanshan. Two additional disastrous earthquakes in 1966 (casualties unknown) prompted the government of the People's Republic of China to launch an intensive effort to predict earthquakes. Surprisingly, more than 10,000 trained workers and many amateurs are engaged in the program, which utilizes much modern equipment. In 1976, a delegation of Survey scientists visited the Liaoming region to study the Chinese methods of predicting earthquakes, just prior to the magnitude 8.0 earthquake in Hopeh Province on July 27–28, 1976, that may have killed approximately 500,000 people.
- Investigation, at the request of the Guatemalan Government, into the geologic, seismologic, and engineering effects of and hazards resulting from the February 4, 1976, earthquake. The results of the investigations (Espinosa, 1976) should aid in the reduction of hazards from future earthquakes in Guatemala (fig. 40) and should also contribute measurably to the body of scientific information that will aid in the reduction of earthquake hazards in the United States.
- Demonstration of the feasibility of seismic zonation for the San Francisco Bay region (Borecherdt, 1975). Seismic zonation is a necessary basis for development of regional land-use policies aimed at minimizing future losses during earthquakes.

Volcano Hazards

The Volcano Hazards program is designed to mitigate the hazards posed by the active volcanoes in Hawaii and in the Cascade Range of the Western United States. During fiscal year 1976, considerable

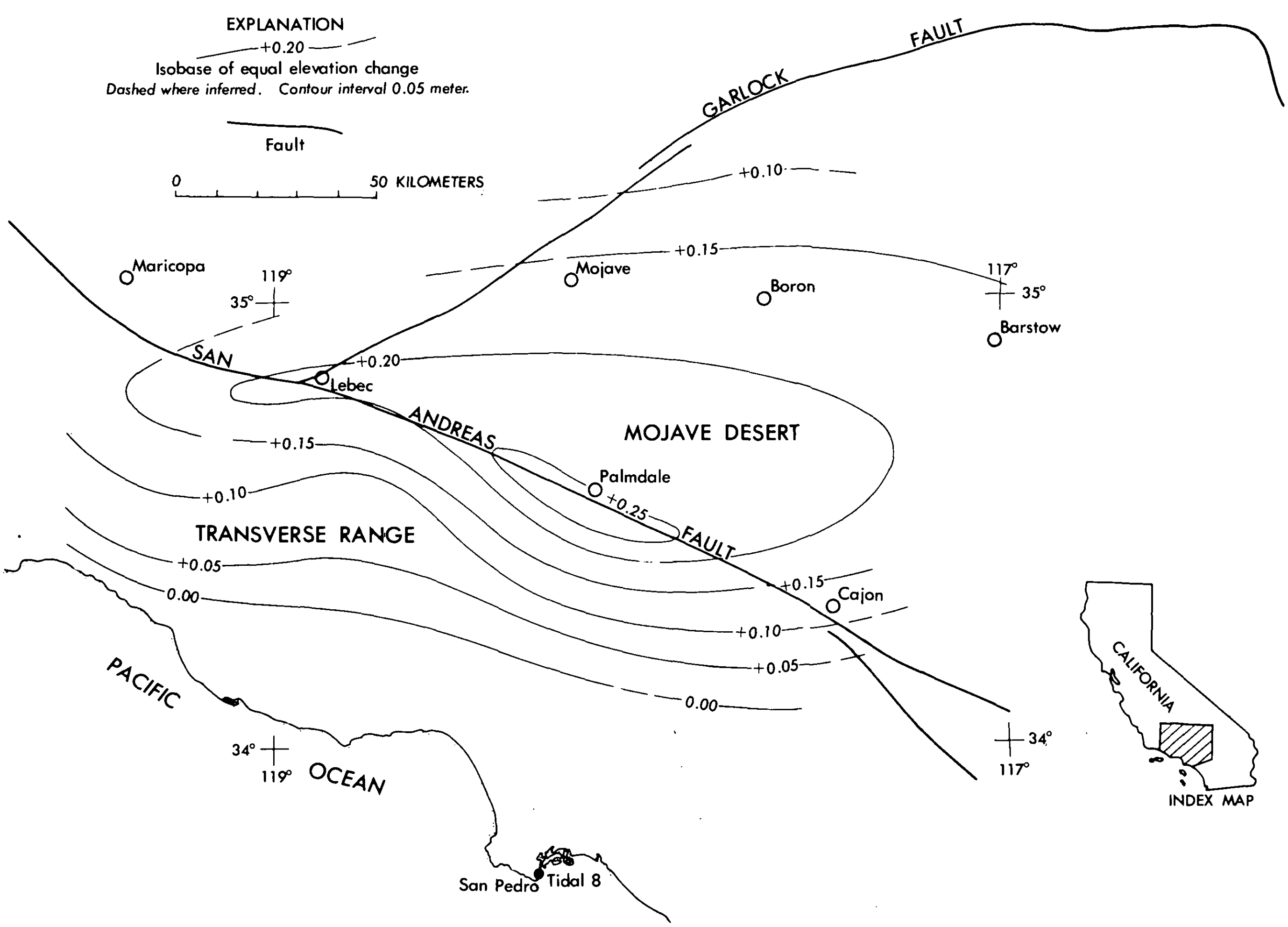


FIGURE 39.—Minimum uplift in the Transverse Range and adjacent parts of the Mojave Desert, California, during the period 1959–74 relative to benchmark Tidal 8 at San Pedro.

attention was devoted to the July 4–5, 1975, vigorous eruption of Mauna Loa after a 25-year period of quiescence; the November 29, 1975, Kalapana earthquake, tsunami, and eruption, the largest seismic event in Hawaii since 1868; and the continued high level of thermal activity at Mount Baker, Wash.

Significant accomplishments of fiscal year 1976 activities included:

- Prediction of a major eruption of Mauna Loa Volcano before the summer of 1978, based on analyses of the volcano's past eruptive history and continuing inflation trend.
- Determination that the increased thermal activity at Mount Baker has not signaled an impending major eruption but that potential hazards of avalanches and mudflow remain.
- Preliminary evaluation of the feasibility of using bombs to divert potentially destructive lava flows in Hawaii.
- Establishment of a precisely measured triangle linking Mauna Kea, Mauna Loa, and Hualalal Volcanoes to provide baselines for long-term, large-scale crustal changes of the Hawaiian Island chain.
- Provision of expertise in monitoring eruptive activity at Cotopaxi Volcano, Ecuador, and Soufriere Volcano, Guadeloupe.

Environmental Aspects of Energy

The Environmental Aspects of Energy program acquires, interprets, and distributes geologic, hydrologic, geophysical, geochemical, and related information, which is required in analyzing and solving environmental problems associated with energy-resource extraction and utilization and the planning, siting, and construction of facilities for energy conversion and distribution.

ENERGY LANDS

Studies conducted in the energy lands on the basis of environmentally oriented earth-science data seek to assist in the orderly, safe, and efficient develop-

FIGURE 40.—Photographs of earthquake damage to structures in Guatemala towns of *A*, Joyabai, *B*, Compala, *C*, Tecpan, and *D*, San Martin Jilotepeque.

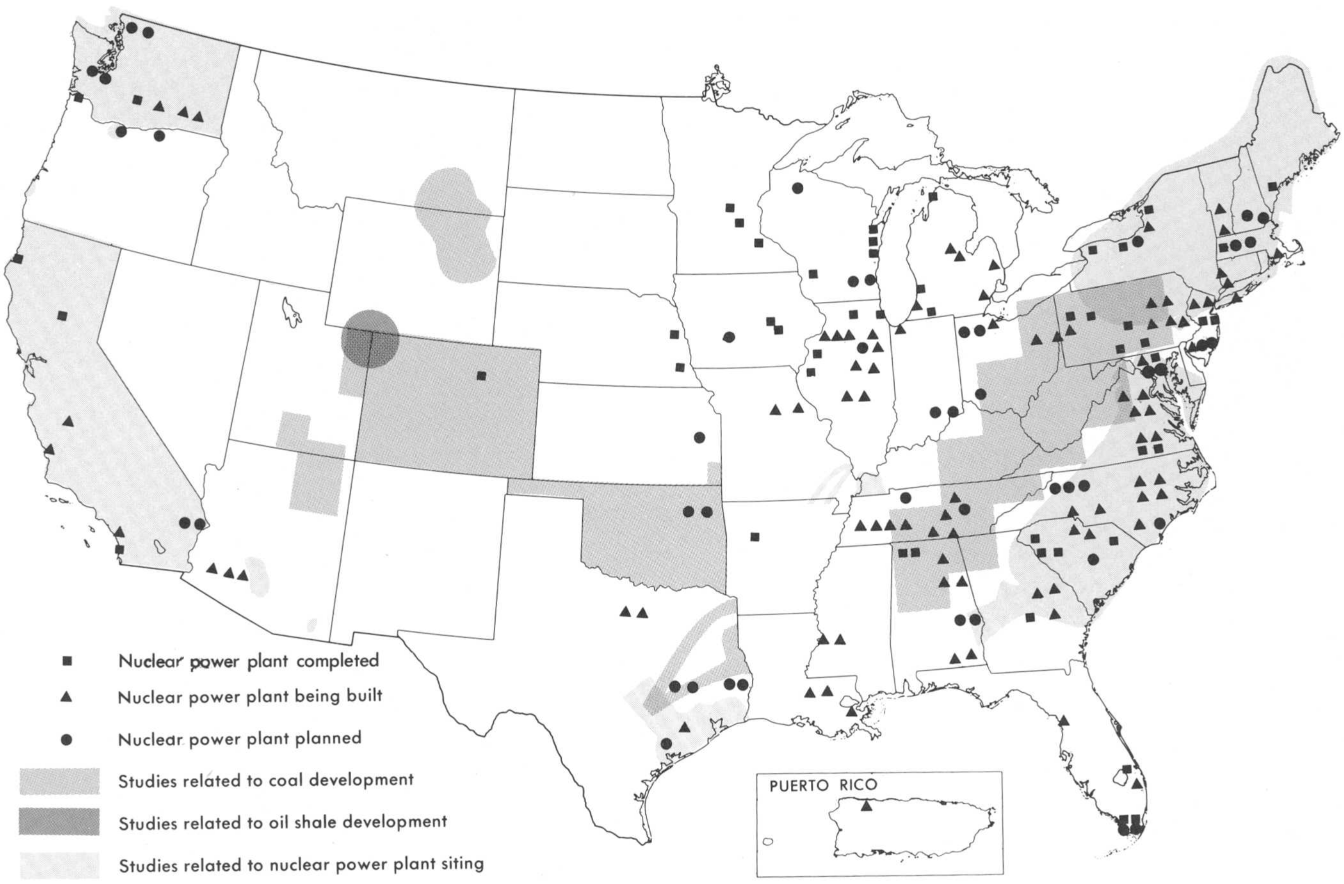


FIGURE 41.—Geologic investigations relating to environmental aspects of energy resource development.

ment of the Nation's energy resources. These contributions include the integration of large amounts of information on bedrock and surficial geology, geomorphology, geochemistry, quality and quantity of coal and overburden, ground- and surface-water conditions, and erosional and weathering patterns. They aid in making decisions on leasing of Federal lands, preparation of environmental impact statements, efforts by States in enforcement of health, safety, and environmental laws, and enactment of legislation to regulate and control mining and siting of energy facilities.

Program accomplishments during fiscal year 1976 included:

- Landslide-hazard maps of Washington, Butler, and Beaver Counties, Pa., emphasizing landslide deposits and their statistical density, landslide susceptibility, and areal quantitative distribution of landslides.
- Geologic maps of the northern part of the Powder River Basin showing areas of alluvial valley floors that are important for agriculture.
- A report of landslide occurrence and susceptibility in the western Powder River Basin.
- An energy-resources map of Colorado showing coal, oil and gas, uranium, oil shale, and geothermal areas and energy conversion and distribution facilities.

Future energy lands investigations include: studies of environmental factors associated with mining of coal in Alaska; mapping of surficial and bedrock geologic units in the San Juan basin, New Mexico; compilation of geologic studies of the coal region in North Dakota; environmental aspects of uranium mining; environmental disturbance caused by mining coal in the Eastern United States; and erodibility of surficial material as a constraint on the use of off-road vehicles.

REACTOR SAFETY RESEARCH

Accelerated construction of nuclear power reactors is part of most strategies for meeting the expanding demand for electrical power in the United States; about 100 have now been built or are under construction (fig. 41). The operational safety of these reactors is sensitive to geologic hazards such as fault movement, earthquake, volcanic eruption, ground deformation induced by man's activities, and other failures due to foundation and construction materials. These hazards are evaluated through the Reactor Hazards Research program and through a companion program sponsored by the Nuclear Regulatory Commission to meet specific needs arising from applications for reactor licenses. The Reactor Hazards Research program continues to look beyond immediate licensing of nuclear reactors to delineate regional geologic hazards that may pose constraints on reactor siting and to develop techniques needed in regional studies.

Program accomplishments during fiscal year 1976 included:

- Investigating the Charleston, S.C., earthquake of 1886 by studying the various structures in the Cenozoic Coastal Plain sediments and the underlying basement rock.
- Finding evidence of apparent tectonic quiescence in southeastern California where seismicity and late Quaternary faulting are rare.
- Documenting a major offshore fault that dominates the central California coast.
- Locating reverse faults near the Fall Line in Virginia and Georgia that suggest extensive faulting associated with older extensional structures.
- Evaluating the extent of Quaternary deformation in central Washington and along the east side of the Great Valley in California.

NATIONAL ENVIRONMENTAL OVERVIEW

As land development increases and as more of our natural resources are being extracted, it is important to have data on the constraints imposed by our physical environment. A series of U.S. maps at a scale of 1:7,500,000 are providing basic geologic data useful for management of energy, land, and mineral resources at the national level.

During fiscal year 1976, the following maps were completed:

- A preliminary landslide map (fig. 42).
- A map showing areas of sinkholes in limestone (karst topography).
- A map showing the location of nuclear reactor sites with a tabulation of the geologic setting at each site.
- A map showing the volcanic hazards within the United States.

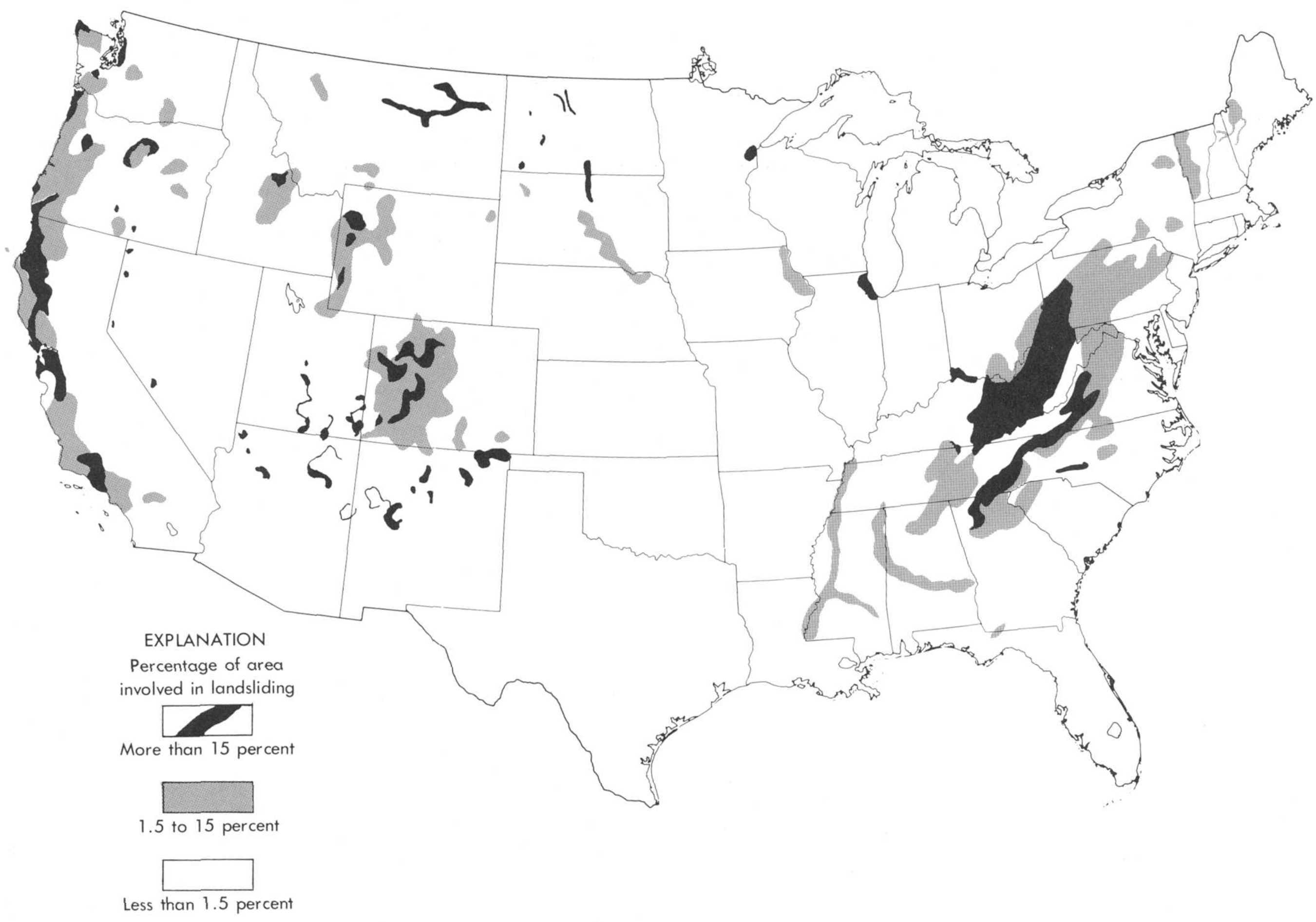


FIGURE 42.—Generalized map of areas affected by landsliding in the conterminous United States.

Additional maps scheduled for preparation will cover the following topics: active faults, density of faults, surficial materials, water availability for cooling powerplants, swelling clays, radioactive-waste disposal sites, bedrock lithology, impact structures, coal strip mines, and strippable coal deposits.

Arctic Environmental Studies

The arctic and subarctic regions of Alaska pose special geologic problems in the development of natural resources, transportation systems, and urban areas, primarily because of the unusual environmental-geologic conditions of permafrost or perennially frozen ground (fig. 43) along the routes of the trans-Alaska oil pipeline from Prudhoe Bay to Valdez and the arctic gas pipeline from Prudhoe Bay to Canada.

Accomplishments of the program during fiscal year 1976 included:

- Completion of reconnaissance engineering-geologic investigations of the Arctic Coastal Plain between Prudhoe Bay and the Canadian border.
- Completion of about two-thirds of the surficial engineering-geologic mapping of the central Brooks Range.
- Initiation of a seismic study in northeastern Alaska.
- Completion of an exchange program with Soviet scientists and engineers on pipelines, permafrost, and environmental protection.
- Collection of geotechnical data made available during construction of the trans-Alaska pipeline.

FIGURE 43.—An example of the dramatic effects of differential settlement caused by the thawing of permafrost, a serious engineering-geologic problem in Alaska.

Engineering Geology

Engineering geology is the application of geologic knowledge to civil engineering practice in order to achieve a better understanding of the effects of geologic processes and materials on man's use of the land and on the design and construction of manmade structures. As the emphasis on efficient use of available land becomes more intense, engineering-geologic knowledge will become more important in planning and developing our limited natural Earth resources.

Major accomplishments in fiscal year 1976 included:

- Participating in a program to evaluate earthquake-induced landslides in Guatemala and predicting subsequent failure of slopes weakened by the earthquake.
- Revising the standard classification chart of landslides and slope movement for use by engineers.
- Recognizing massive downslope movements in the Rocky Mountain area of Colorado that cause entire mountainsides to be unstable and establishing laser-beam instrumentation to measure the rate of movement.
- Continuing studies to appraise potential landslide and mudflow hazards at dormant volcanoes in the Western United States as a basis for land-use planning, disaster response, and mitigation when eruptions occur in the future.

The Survey continues to assist other government agencies, as requested, by providing technical services and advice in the applications of engineering geology. For example, support is given to the Energy Research and Development Administration on problems of radioactive-waste disposal and on conducting nuclear tests. A treaty between the United States and the U.S.S.R. provides that, when one country conducts a peaceful nuclear explosion, the other country is to be represented at the site to verify certain aspects of the project. The Survey is training a geologic team to be ready to travel to the U.S.S.R. to observe the construction of explosive emplacement holes and to verify the geologic data of the site.

Regional Mapping and Analysis

The Regional Mapping and Analysis program provides baseline geological, geophysical, and geochemical information. Its objective is to increase and refine fundamental knowledge about the geologic framework of the Nation as necessary to support the current applied-research programs and help in the early recognition of future earth-science problems and resource opportunities. The program determines the distribution and properties of rocks and other geologic materials, investigates the relative and absolute ages of earth materials, and investigates the processes responsible for the formation, modification, and distribution of materials within the Earth and on its surface.

REGIONAL GEOLOGY

An understanding of the regional geologic framework of the Nation is fundamental to assessing the country's land, mineral, and energy resources. The Regional Geology program is designed to provide this foundation and is therefore one of the most vital programs of the Survey. The program provides regional synthesis and scientific studies that, in the long run, may be of greater significance than short-range mission objectives. The program provides a broad perspective on geologic processes and conditions, permitting early recognition of potential resources and impending environmental problems that can then be pursued in detail by specific applied-research programs; it also provides the necessary continuity in scientific expertise, including regional and topical specialists whose knowledge is drawn upon to carry out the goals of specific applied-research projects; and finally, this program also provides the main impetus in exploring unknown or little known regions.

The geologic problems attacked by this program demand a variety of stratigraphic, structural, and other techniques. The most powerful tool for solution of geologic problems is the geologic map. A geologic map displays the general character, distribution, age, and spatial relationships between rock units and/or surficial deposits exposed at the Earth's surface or at depth below the surface. It is a clear and concise statement of what is known about the geology of an area. Inferences can be drawn from it regarding the geologic history, the three-dimensional form and extent of rock bodies, and the physical and chemical processes that have shaped and modified them. A geologic map can be used directly for land-use planning and for the studies of mineral and energy resources. Geologic maps ranging in scale from 1:2,500,000 to 1:20,000 and related reports are major products of this program.

The selection of geologic problems attacked by the program is guided by relevance to environmental and resource problems, by the needs of other Federal and State agencies, and by scientific importance. Through cooperative agreements with several States, the program furnishes Statewide geologic mapping and analysis.

Program accomplishments for fiscal year 1976 included:

- Recognition that the inner limit of coastal plain sediments along the middle Atlantic seaboard may be a zone of faulting.
- Publication of an analysis of the tectonic history of southwestern New England.
- Interpretation of the bends in the Appalachian Mountain chain as resulting from opening of the early Atlantic Ocean 600–800 million years ago.
- Development of a hypothesis that a hot spot below the crust explains the presence of young volcanoes and faults in Idaho, Nevada, Utah, Wyoming, and western Oregon.
- Identification of active faults, volcanic hazards, and landslide and rockfall hazards in Idaho and California.
- Discoveries of oil, gas, coal, limestone, gravel, copper, and titanium occurrences. Data from the program served as the basis for discovery of a major coal field in Kentucky and a major oil province in Idaho and Wyoming.
- Provision of background regional-geologic information for investigation of the Teton Dam failure on June 5, 1976.

GEOPHYSICAL SURVEYS

The Geophysical Surveys program is concerned with supplying the vertical subsurface dimension needed to complement geologic mapping of the ground surface. Research activities in 1976 emphasized investigations of broad regions using gravity, magnetic, electrical, and heat-flow methods and studies of the Earth's present and past magnetic field.

Significant accomplishments in fiscal year 1976 included:

- Integration of geophysical data from offshore and onshore regions into a synthesis of the tectonic evolution of an area where three plates of the Earth's crust are converging.
- Interpretation of stripe-shaped aeromagnetic anomalies of the California coast as resulting from a plate of the Earth's crust plunging beneath a large mass of sheared rocks.
- Development of computer programs for efficient analysis of electrical-resistivity survey data from regions of ground-water and geothermal resources.

- Confirmation that self-potential electrical anomalies are sometimes associated with local eruptive centers of volcanoes in Hawaii.
- Determination, based on magnetic studies of ancient lake sediments, that the Earth's magnetic field was only one-tenth as strong as the present-day field during a brief period 700,000 years ago when the magnetic field reversed its direction.
- Identification, based on geomagnetic observatory data, of large 25-year variations of the Earth's magnetic field caused by processes active within the Earth's core.

GEOCHEMICAL SURVEYS

Geochemical Surveys provide data on variations of chemical elements in rocks, soils, and vegetation. This information establishes baselines against which to compare future observations and is used in pollution control, environmental health research, and mineral resource evaluations. Continuing activities are the development of statistical anaytical methods, compilation of rock-analysis data, operation of a geochemical-data system, investigation of trace elements in the human food chain, and studies of urban-area geochemistry.

Accomplishments during fiscal year 1976 included:

- Publication of reports on trace-element concentrations in the plants and soils of the State of Missouri.
- Demonstration that natural vegetation is a pollution indicator. Studies of phosphate-processing plants and coal-burning powerplants indicate that trace metals from the industrial facilities are being concentrated in the surrounding vegetation.
- Confirmation of the presence of anomalous levels of plutonium in surface soils downwind from the Rocky Flats Nuclear Weapons Plant, Colorado. These studies, in cooperation with the Colorado Department of Health, have resulted in public reexamination of the State standard for plutonium in soil.

DATING AND CORRELATION—PALEONTOLOGY AND STRATIGRAPHY

The Paleontology and Stratigraphy program compiles and interprets basic data on the distribution of fossils (fig. 44) within the stratigraphic column. The data are used to analyze the age, correlation, and paleoenvironment of sedimentary rocks, to study evolutionary trends of species, and to provide a framework for interpretation of geologic history. Research activities are directed toward developments of new principles and techniques. The stratigraphic and paleontologic information directly supports mission programs throughout the Survey and provides a base on which to respond to future missions that require an understanding of the history and geologic framework of the Earth.

Highlights of the program during fiscal year 1976 included:

- Developing a method of petroleum exploration using the color of fossil conodonts, a small toothlike or platelike structure composed of apatite, to tell the degree to which sedimentary rocks have been heated.
- Showing that sediments in the lakes of Minnesota have changed in response to human settlement and the introduction of pollutants.
- Refining the dates and history of delta building and shoreline retreats and advances in the Atlantic Coastal Plain to aid in the search for offshore energy resources.

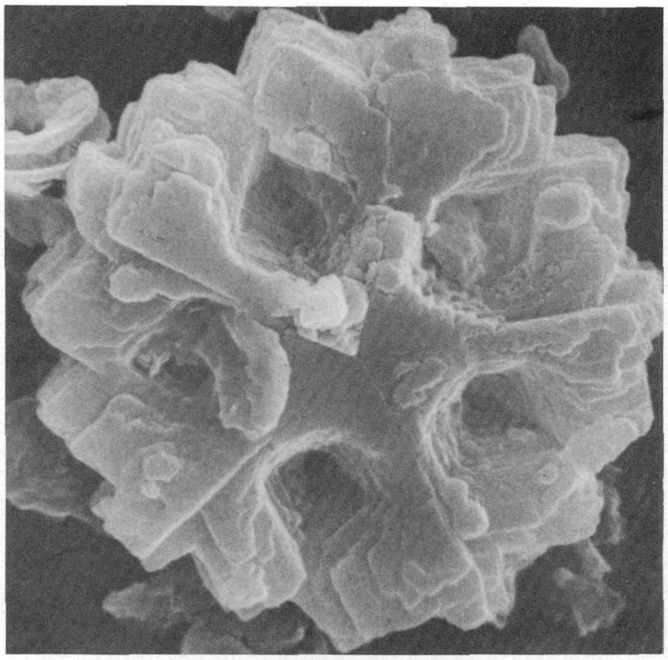
DATING AND CORRELATION—ISOTOPE GEOLOGY

The Isotope Geology program investigates, develops, and utilizes methods for determining ages of rocks and minerals, geochemical methods for studying geological processes, and neutron-activation methods of field chemical analysis for mineral exploration. This work provides the basic data necessary for understanding Earth history and the geologic processes that have been active in shaping the Earth for the last 4.5 billion years and for solving a great variety of problems, ranging from mineral exploration to nuclear-plant site evaluation, in which knowledge of the age of rocks or geologic events is essential.

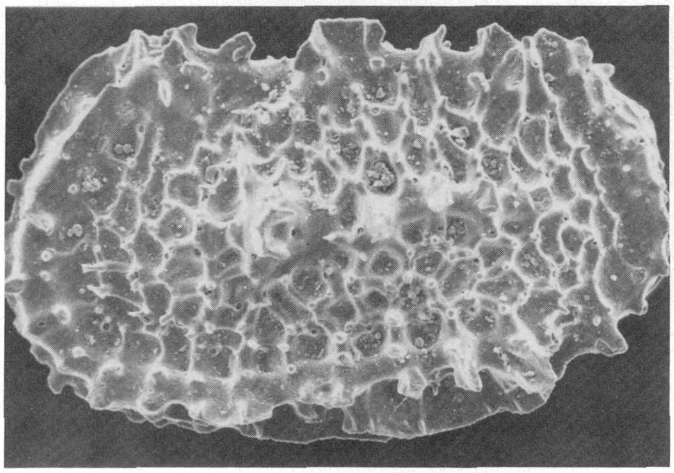
Highlights of the program during fiscal year 1976 included:

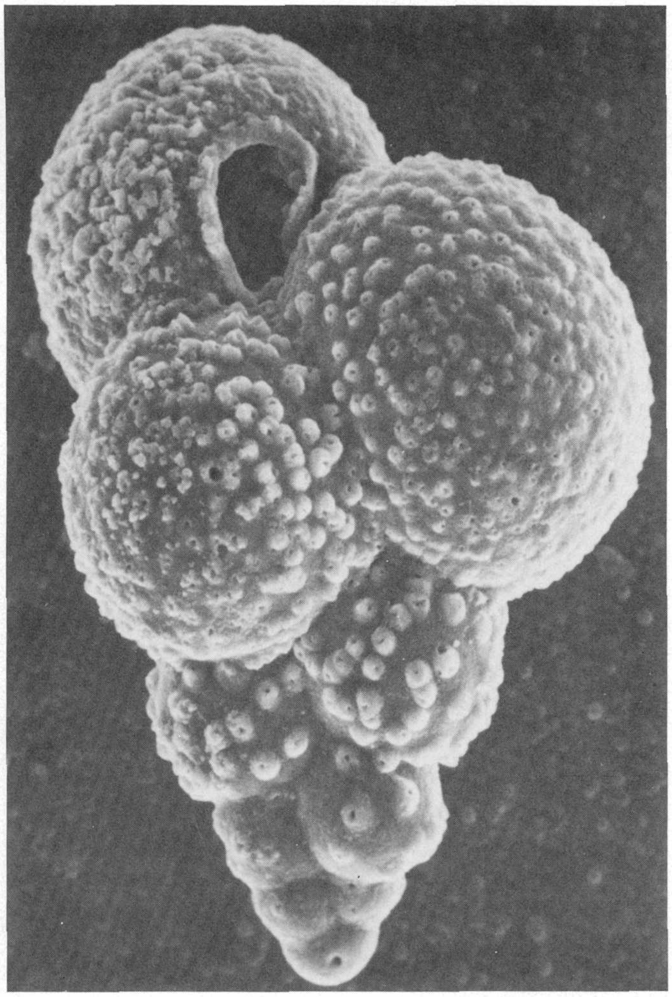
- Determining that the age of the beginning of pitchblende mineralization in a mine near Gallup, N. Mex., is probably 159,000±30,000 years ago, by far the youngest age for known uranium mineralization in the United States.
- Initiating the use of thermoluminescence on carbonate minerals. This technique, which has already been shown useful in dating volcanic rocks 5,000 to 500,000 years old, should prove invaluable in studies of geothermal resources, reactor hazards, earthquake hazards, and radioactive-waste disposal.
- Exploring the potential of using the isotopes of hydrogen and oxygen in well water near the Oroville Dam, Calif., in the prediction of earthquakes. Anomalies of deuterium, a heavy isotope of hydrogen, were observed starting about 3 days before two earthquakes in September 1975 and at the same time as three earthquakes in January 1976.

A



B





C

FIGURE 44.—Three scanning electron photomicrographs representing three important groups of microfossils: *A*, a platelet from a planktic calcareous alga subspecies, *Pemma basquense basquense*; *B*, an ostracode (a microscopic crustacean) female of *Acetoleberis plummeri*; and *C*, a foraminifer (shelled protozoan), *Guembelitria cretacea*.

- Developing a field radioactive activation probe for drill holes that permits hydrogen and aluminum analysis of coal in the ground.
- Dating a diamond-bearing kimberlitic pipe in southern Wyoming at 377±36 million years old.
- Dating gneiss in the Upper Peninsula of Michigan at 3,500 million years old. Previously rocks of this age in the Lake Superior region had been found only in southwestern Minnesota.

GEOLOGIC PROCESSES

The Geologic Processes program studies the fundamental properties of rocks and minerals and the fluids associated with them in nature. When these properties are related to the temperatures and pressures at the time of the rocks' and minerals' origin, useful geologic thermometers and barometers result. Current studies of the relationship of volcanic activity to plate tectonics, the significance of chemical differentiation in igneous rocks and in ground water, and the mechanisms of mineral formation in rocks will contribute to future resource evaluations of many types of mineral deposits. Some criteria for the selection of appropriate sites for the disposal of radioactive wastes, the nature of the release of toxic chemicals into mine drainage, and a basis for economical solution mining may be forthcoming from studies in progress.

Accomplishments for fiscal year 1976 included:

- Using a sulfate-water isotope geothermometer to calculate subsurface temperatures for many geothermal systems. This work resulted in a considerable increase in indicated reserves of geothermal energy and a better estimate of the importance of the mixing of subsurface waters.

- Measuring the volume of complex brine systems in geothermal reservoirs to gain useful information for engineering purposes and model studies.
- Continuous monitoring of the chemistry and temperature of fumaroles on Mount Baker, Wash., by using electrochemical sensors and radiotelemetry.

MINERAL RESOURCE SURVEYS

Mineral Resource Assessment—Land

During 1976, the Survey conducted mineral resource assessments of Federal lands administered by the Department of the Interior and other agencies, lands for which congressional actions require evaluation of mineral potential before their reclassification, and non-Federal lands having high potential for discovery of mineral resources. Lands under study as a result of congressional actions include those proposed for withdrawal from mineral or other development as wilderness areas or under Section 17(d)(2) of the Alaskan Native Claims Settlement Act (Alaskan D–2 lands). Studies of Department of the Interior lands were conducted in Indian reservation lands and in the California desert areas. Areas judged to have high mineral potential were under study in Alaska (fig. 45) and the conterminous United States (fig. 46) as part of continuing systematic investigations of the mineral resource endowment of the Nation.

WILDERNESS AREAS

Areas of wild unspoiled beauty are recognized as a national heritage worthy of preservation, but some of these areas also may host future supplies of critically needed mineral resources. More than 12.5 million hectares (31 million acres) have been proposed for wilderness status by Federal agencies since passage of the Wilderness Act in 1964. The Congress requires an assessment of the resource potential of proposed wilderness areas before granting wilderness status and the concomitant prohibition of mining activity. To date, the Survey, in cooperation with the Bureau of Mines, has completed mineral surveys of 7.5 million hectares (18.5 million acres) of land proposed for designation as wilderness areas.

Accomplishments for fiscal year 1976 included:

- Publication of five wilderness area assessments (Scapegoat Wilderness additions, Montana; Scotchman Peak study area, Montana-Idaho; South Warner Wilderness, California; Cloud Peak additions, Wyoming; and Bradwell Bay-Sopchoppy, Florida).
- Location of significant mineralization in the Scotchman Peak Wilderness area, Montana-Idaho. This mineralization has a surface geochemical expression and geologic setting that suggest the possible presence of a strata-bound copper deposit similar to the one now being developed 3.2 kilometers (1.9 miles) to the east.

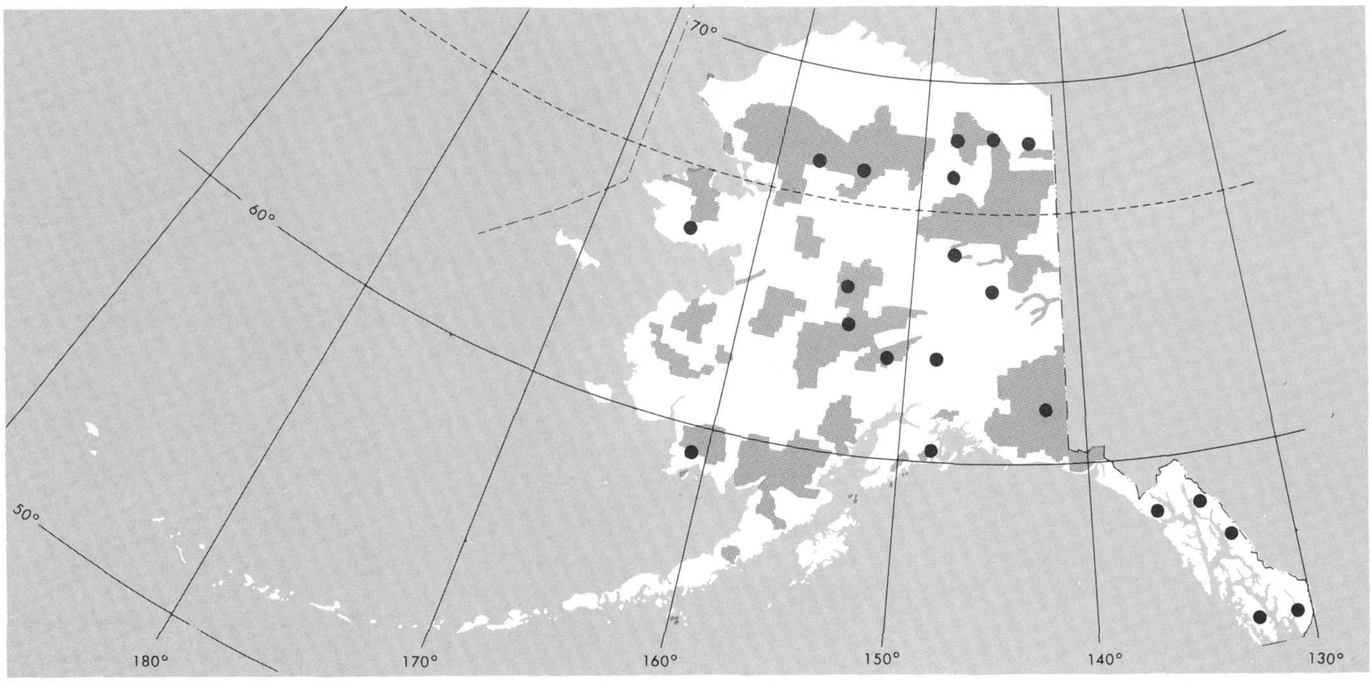


FIGURE 45.—Map of Alaska showing D–2 lands (shaded) and location of current Mineral Resource Survey projects.

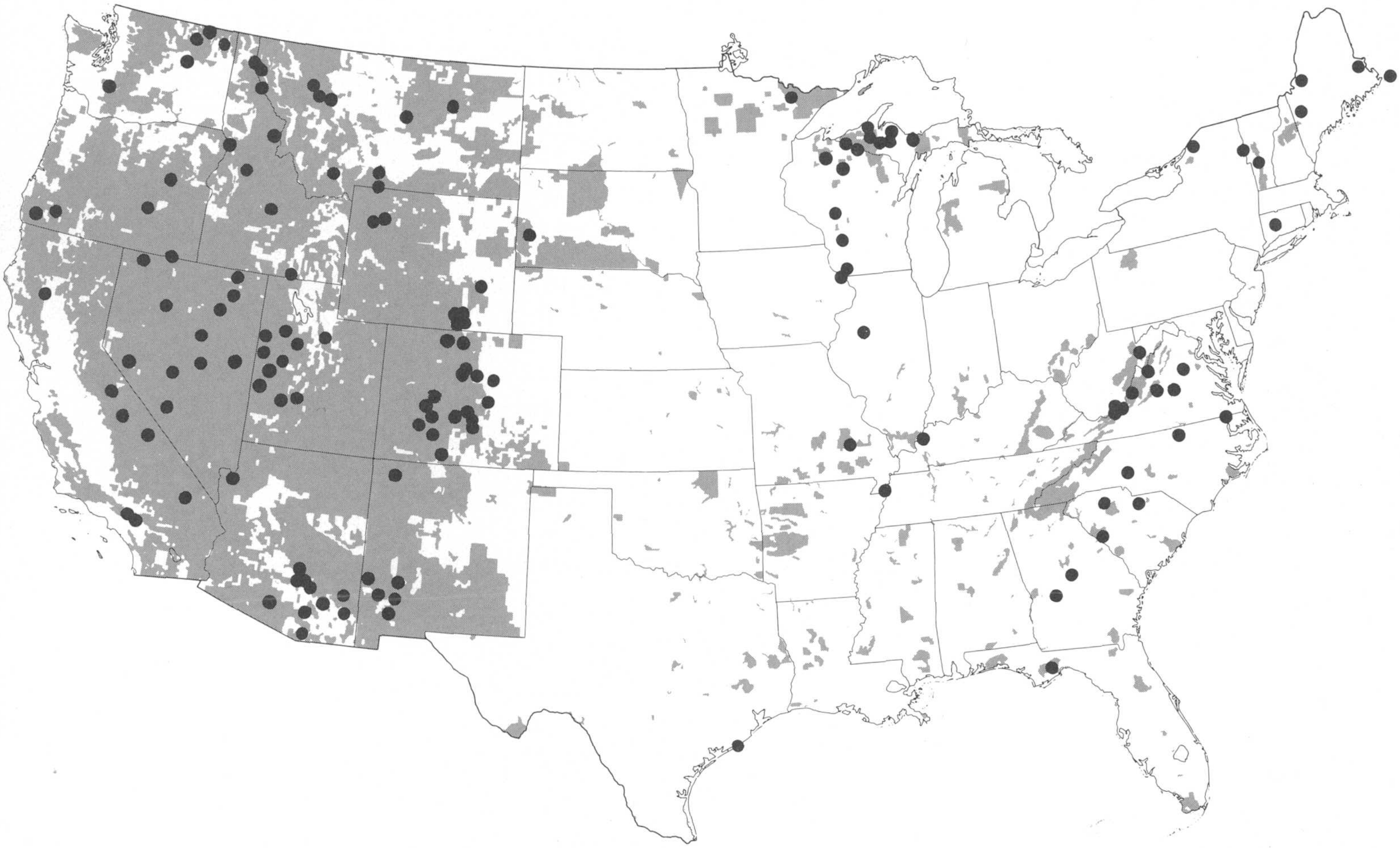


FIGURE 46.—Map of the conterminous States showing Federal lands and Indian reservations (shaded) and location of fiscal year 1976 Mineral Resource Survey projects.

ALASKA D–2 LANDS

The D–2 lands of Alaska are specified in the Alaska Native Claims Settlement Act as national interest lands for the National Parks, National Wild and Scenic Rivers, National Forest, and National Wildlife Refuge systems. Mineral assessment studies of these lands, which total 33.6 million hectares (83 million acres), are being conducted in cooperation with the Bureau of Mines under the Survey's regional Alaska Mineral Resource Assessment program. Final determination of the classification and possible inclusion of the D–2 lands in the four national systems is scheduled to be made by Congress in December 1978.

The accomplishment for fiscal year 1976 was:

- Completion of mineral resource assessment for approximately one-third of the Alaska D–2 lands area.

ALASKA

An intensive systematic study of Alaska's mineral potential is being conducted under the Survey's Alaska Mineral Resource Assessment program. This program (Cobb, 1976) involves systematic mapping, field sampling, geostatistical compilations, and mineral economic modeling of 1:250,000-scale quadrangle areas covering an average of about 17,000 square kilometers (6,500 square miles) and publication of the resulting information and data in resource map folios containing a text and geologic, geochemical, and geophysical maps, interpretive maps based on Landsat satellite imagery, and maps showing the location of known and potential mineral resources.

Highlights of the program during fiscal year 1976 included:

- Completion of the fieldwork for four quadrangles. Fieldwork is in progress in 12 additional quadrangles and is scheduled in 18 others.
- Publication of the Nabesna quadrangle folio.

INDIAN AND DESERT LANDS

Joint Survey and Bureau of Mines mineral resource assessments of Indian lands include studies made from compilations and interpretations of published and unpublished reports and records and from reconnaissance field examinations. Studies of California desert lands consist of mineral resource summaries made from existing maps and records of areas administered by the Bureau of Land Management.

Accomplishments for fiscal year 1976 included:

- Compilation of 12 reports, from existing information, on the mineral resources of 23 Indian reservations totaling 3.2 million hectares (7.9 million acres) in Colorado, Michigan, Nevada, New Mexico, Utah, and Wisconsin.
- Completion of a mineral resource assessment of the East Mojave and Mojave Basin areas for the Bureau of Land Management.

CONTERMINOUS STATES

To meet the need for comprehensive information and data on the mineral resources of the Nation, mineral resource assessments of 2° (1:250,000-scale) quadrangles are being conducted in areas having a high probability for mineral deposits and in other areas where information on the mineral potential is required. These assessment studies provide information on the present and possible future availability of mineral commodities and give Federal, State, and local governments a basis for making decisions on land-use planning. In 1976, studies were being conducted in twelve 2° quadrangles in Arizona, Colorado, Missouri, Montana, North Carolina, Oregon, Utah, and Washington. Detailed geologic mapping at larger scales is being done to support resource assessment investigations and to provide an improved understanding of the origin and occurrence of mineral resources. Geophysical mapping, in mineral resource study areas, provides data on gravity, magnetic, and electrical properties of rocks to outline structures and mineral deposits below the Earth's surface.

Highlights and accomplishments of the program in fiscal year 1976 included:

- Publication of a map showing potential for copper mineralization in the Tucson urban area. This map adds to previously published contributions resulting from the Survey's mineral resource studies that provide Arizona State and local agencies with information for land-use planning.
- Publication of a map outlining the occurrence of platinum-group metals in the Medford-Coos Bay, Ore., 2° quadrangle. Studies of mineral potential in this area are contributing information on scarce mineral commodities.
- Geophysical mapping in southwest New Mexico that indicates that Basin and Range structures of tilted fault blocks unexpectedly persist northwestward and northward beneath the cover of the high volcanic plateaus. The alinement of fluoride mineralization and thermal springs in the area supports this interpretation.
- Geophysical surveying over the southeastern Coastal Plain that suggests the presence of local placer deposits of heavy minerals in six areas. These may be favorable targets for surface exploration of ilmenite, zircon, and monazite.
- Geophysical studies in Montana that have identified a buried horizon of high electrical conductivity in Precambrian sedimentary rocks which may represent a pyrrhotite zone associated with mineral deposits.
- Studies of Landsat imagery that show areas of hydrothermally altered rock in Alaska, Arizona, Nevada, northern Mexico, Brazil, and Pakistan. The presence of altered rock is an indication of potential mineralization.

Mineral Resource Assessment—Commodity

The objective of the Mineral Resource Commodity Assessment program is to collect data worldwide on the geologic occurrences and availability of mineral commodities and to develop new geologic concepts useful in the assessment of and exploration for mineral resources. Information on location, quantity, quality, and geologic characteristics of deposits of 43 mineral commodities is analyzed by mineral resource specialists. New trends in exploration by industry are of particular interest to the specialist as mineral potential is being assessed in new regions and in new geologic settings.

An important group of mineral commodities (aluminum, chromium, cobalt, nickel, manganese, and platinum) is presently imported. Mineral commodity specialists provide resource estimates and long-range forecasts of supply of these critical minerals. Emphasis is given to the study of alternative domestic sources of materials that may provide future options for domestic production in the event of disruption of foreign supplies, nationalization, or international cartel actions and attendant large price increases.

Another important group of minerals (copper, lead, zinc, molybdenum, fluorspar, and iron) is available domestically, but known deposits are being depleted and must be replaced by new discoveries. These mineral commodities and others, such as barite, bentonite, niobium, and silver, are essential in energy production, and the demand for them will increase greatly in the next decade as the United States strives for self-sufficiency in energy. Specialists provide resource estimates, long-range projections of mineral supply from known deposits, and an estimate of future discovery requirements for these commodities.

The Mineral Resource Commodity Assessment program has been greatly expanded during the past year: studies of geostatistical approaches to copper, nickel, zinc, and chromium resources are providing new concepts; the program staff has been increased to provide long-term continuity in chromium, nickel, and mercury studies; and an investigation into the origin of sea-floor manganese-copper-nickel-cobalt occurrences has been initiated.

Knowledge of the mineral resources of other nations is becoming increasingly important as world competition for mineral supplies grows. During the past year, Survey geologists visited major deposits of chromium in Greenland and South Africa; copper, manganese, and platinum in South Africa; nickel in New Caledonia and Canada; niobium in Brazil; tin in Southeast Asia; and zinc in Poland. Close communication has been established between Survey specialists and the Department of State Resources Attaché and Reporting Program in South Africa, Brazil, Venezuela, Australia, Japan, and India.

Accomplishments of the program during fiscal year 1976 included:

- Estimating the iron-ore resources of the Marquette Range, Mich., with the aid of a computer program that calculates the number of tons of iron formation within specific limits of grade, mineralogy, grain size, thickness, and depth below the surface.
- Correlating the fluorspar districts in the Rocky Mountain region with a large rift zone that extends from Mexico to Canada. This correlation indicates that the rift zone may contain undiscovered fluorspar deposits.
- Describing the geologic character, age, and origin of U.S. ball clay and fireclay deposits used for making high-grade refractories.
- Determining from studies of domestic copper resources that, by the year 2000, output, based on projected production rates, will supply only one-half of the probable annual demand. The study also indicates that additional supply will have to come from new discoveries or imports.
- Compiling a report on the mineral and water resources of the State of Wisconsin.
- Finding that important amounts of the platinum-group metals are present in the Brady Glacier, Alaska, nickel-copper deposit.
- Developing computer-generated contour maps showing the thickness and grade of the kaolinite and bauxite deposits in Georgia. These maps are useful in determining the kaolin and aluminum resources of the State.

Mineral Resource Information Systems and Analysis

The Mineral Resource Information Systems and Analysis program assists national mineral policy decisionmaking and Survey resource programs by improving methods of assessing and locating mineral resources as well as methods for the storage, retrieval, manipulation, and display of geologic and commodity information for mineral resource evaluation and prediction.

Highlights of the program for fiscal year 1976 included:

- Developing a method for calculating a resource target based on the area of influence from an exploratory drill hole or sample. This method can provide maps showing how much and to what extent a region has been explored, graphs evaluating the possibility that undiscovered resource targets of specific size and shape may exist in a region, and estimates of the undiscovered resources in that region.
- Analyzing the tonnages and grades of nickel deposits. The results suggest that average grade is independent of total tonnage for sulfide- and laterite-type deposits and that very large tonnage low-grade deposits are as rare as very large tonnage high-grade deposits.
- Comparing and contrasting the efficiency of resource programs in terms of existing public policies for the mineral industries of Canada and the United States.
- Assessing the available supplies of materials required by the energy industries. Demand shows that significant increases in aluminum, barite, bentonite, iron, and tungsten production above 1975 levels will be needed to satisfy the demands of the energy industries.
- Developing a computer program called Geologic Retrieval and Synopsis Program (GRASP) that now permits interactive access to earth-science data banks.

Resource Processes Research

The Resource Processes Research program develops knowledge of the fundamental mechanisms by which minerals are deposited in concentrations large enough to become resource materials. This knowledge is essential for success in the assessment of, or exploration for, minerals. Observation, measurement, and analysis of the geologic, geochemical, and geophysical characteristics of known mineral occurrences aid in identifying resource exploration targets. Data obtained from a variety of field and laboratory studies range from the documentation of mining districts and mineral belts and the collection of relevant geologic observations, maps, and samples to experimental studies of the physical and chemical properties of minerals and mineralized rocks. An important goal of the program is a working model that permits predicting as well as pinpointing and evaluating such mineral concentrations.

The scientific insights and technology of the Resource Processes Research program provide the basis for resource assessment of domestic lands; evaluation of global availability of critical mineral commodities; and development and use of computerized resource-information files and resource-analysis capability.

Highlights and accomplishments of the program for fiscal year 1976 included:

- Resource evaluation, based on geologic mapping near Tucson, Ariz., that shows that an intrusive rock is the source of the base metal deposits formed in adjacent rocks.
- Age determinations of alunite from the Cordero mining district, Nevada-Oregon, that show that eruptive and tectonic features developed in a caldera fracture system that preceded ore deposition by as much as 4 million years. Late hydrothermal solutions made use of the caldera ring fractures as conduits and the adjacent sediments as the host for mercury deposition.
- Geologic, mineralogic, and stratigraphic studies at Kennecott, Alaska, that strongly suggest that the copper lodes were formed in sediments of the salt-flat type underlying impervious shallow marine limestone. Copper was leached from subjacent greenstones by meteoric water that migrated into the salt-caliche aquifer where the copper was precipitated.
- Discovery that the ore minerals in organic sediments include sphalerite (ZnS) found in substantial amounts in the Illinois Basin coal beds. U.S. zinc production could be increased by 25 percent if this sphalerite were recovered as the coal is mined. Another discovery is manganese enrichment in carbonate-cemented rocks overlying petroleum reservoirs. These manganese materials luminesce and can be detected by airborne technology when present in excess of 1,500 parts per million manganese.
- Identification of oxygen stable isotopes in fluid inclusions in sphalerite crystals (ZnS) at Creede, Colo., that indicate that a very complex plumbing system formed this ore deposit. This information may provide guides for a search for extensions of the deposit.

Resource Techniques in Geochemistry and Geophysics

A fully effective Mineral Resource Assessment program depends, in part, on improved geochemical and geophysical information and methods, which augment geologic information and assist in identifying surface mineral anomalies and buried or low-grade mineral concentrations. Until recently, worldwide efforts to discover mineral deposits have concentrated on deposits exposed at the surface or concealed by only a thin veneer of surficial material. Consequently, geochemical techniques for the detection of buried mineral deposits are just beginning to be developed. As the more easily found, near-surface ore bodies are depleted in the relatively near future, the hard-to-find concealed deposits become the necessary targets of exploration. The surface parameters characterizing an exposed ore deposit differ from those describing concealed or new types of mineral deposits. Yet, established and well-proven geochemical techniques employed in the detection of exposed deposits are still being used in this country in the search for concealed deposits. New innovative approaches leading to the discovery of concealed deposits are imperative if the United States is to remain viably independent of foreign sources for mineral commodities. An intensive research program is needed to assure that adequate exploration methods will be available to find concealed deposits for future reserves.

Program highlights and accomplishments for fiscal year 1976 included:

- Reconnaissance geochemical surveys in mountainous areas of Alaska. The surveys have shown that heavy mineral concentrates, secondary manganese-iron oxide, and organic-rich materials are effective sample media to test stream-drainage headwater areas of 5 to 13 square kilometers (1.9 to 5 square miles).
- Determination that oxalic acid leachates of rocks, soils, and stream sediments from arid climates of the Southwest have proven effective in detecting mineral-bearing environments underlying volcanic rocks.
- Studies of 23 elements in cores and drill cuttings from the Kalamazoo porphyry copper deposit, Arizona, that delineated five geochemical zones spatially related to the ore deposit. The extent of the outermost zone, at least 1,000 meters (3,280 feet), suggests that concealed deposits can be detected at the surface even though buried to that depth.
- Demonstration, using computer techniques and data on the Coeur d'Alene district, Idaho, that several volatile elements (antimony, arsenic, sul-

fur, tellurium, cadmium, and lead) formed substantial halos around the stock that intruded a preexisting mineral belt. Production data show that 85 percent of the Coeur d'Alene ores were derived from the halo area but that only one-half of the reconstructed halo area has thus far been prospected.

- Analyses of galena from Leadville, Colo. These analyses have shown that molybdenum, tin, tungsten, and indium increase toward the center of mineralization and that radiogenic lead, silver, and gold decrease.
- Analyses of soil and rock samples from northeastern Minnesota that show a 29-km-long (18-mile) linear nickel-copper anomaly within the Duluth gabbro. The lineament is believed to lie along a major fracture zone having large displacement.
- Development of new chemical methods to determine trace elements of oxalic acid leachates. A quantitative determination method for phosphorus oxide (P_2O_5), and a new sequential fractionation procedure to determine trace elements in manganese oxides, amorphous iron oxides, crystalline iron oxides, sulfides, and silicates are among recent advancements in geochemical research.
- Computer interpretation of satellite data that resulted in defining a high-amplitude negative anomaly of probable crustal origin in western Africa, possibly related to mineral deposits.
- Establishment of a modern physics laboratory in Denver to make experimental and theoretical studies of electric, dielectric, and elastic properties of rocks and soils to lead to a better understanding of the physical processes involved in mineral deposition and to assist in interpretation of geophysical data.

ENERGY RESOURCE SURVEYS

Coal

The Coal Resources Investigation program appraises the amount and quality of coal resources by conducting research to determine the physical and chemical characteristics of coal; by collecting, analyzing, and evaluating geologic, geochemical, and mining data to provide information for the selection of future mine sites; by developing and utilizing geophysical techniques to aid in assessing the thickness, depth, and composition of coal beds; by determining the geologic processes that partly or wholly control the selection, development, and operation of existing and future mines; by studying the organic, metallic, and mineral contaminants in coal as related to depositional environments, diagenesis, and complete geologic history; and by continuing expansion of the computerized National Coal Resources Data System (NCRDS).

Accomplishments for fiscal year 1976 included:

- Collecting 2,250 samples of coal for chemical analyses of 60 elements.
- Estimating the remaining coal resources of the United States to be 3.58 trillion tons.
- Investigating 12 potential coal-mine sites on Federal land in cooperation with the Bureau of Land Management, Bureau of Reclamation, and Montana Bureau of Mines and Geology.
- Geologically mapping about 2,590 square kilometers (1,000 square miles) of lands containing low-sulfur coal in Wyoming, Montana, Kentucky, Virginia, and West Virginia.

Oil and Gas

The Oil and Gas Resources Investigation program improves resource appraisal techniques and estimates by gathering and interpreting geological and geophysical data; provides up-to-date technical expertise; develops new geological and geophysical data through ongoing topical investigations; and designs and develops resource information which can be used in planning national energy policies.

Accomplishments for fiscal year 1976 included:

- Completion of a study, for the Federal Energy Administration, to develop new methods for assessing future oil and gas finding rates in different regions of the United States. Finding rates are important in determining the contribution of exploration activity to future oil and gas production rates.
- Location of several areas in New Mexico and Colorado which may be highly prospective for oil and gas from fractured Cretaceous shales.
- Location, in a sparsely explored part of Wyoming, of an area that may contain oil and gas stratigraphic traps.
- Completion of a small-diameter borehole gravity meter that will be especially useful in evaluating fractured shale and tight gas-sand reservoirs.
- Initiation of a program in cooperation with the Energy Research and Development Administration to evaluate and characterize black shales. These shales may be an important source of future gas production in the United States.

Oil Shale

The ultimate aim of the Oil Shale Resources Investigation program is to inventory the oil shale resources of the United States and to understand the geologic setting in which the shale exists. The present work is concentrated on the Green River Formation of the central Rocky Mountain area, probably the thickest and richest oil shale in the world.

Highlights of the program during fiscal year 1976 included:

- Assessment of the equitability of a proposed exchange of land between Superior Oil Company and the Federal government.
- Determination of the optimum resource characteristics for the Bureau of Mines deep-shaft pilot mine in the Piceance Creek basin, Colorado.
- Comparison of the geologic characteristics and mineral potential of tracts of land nominated for in-situ oil shale leases in Colorado and Utah.
- Appraisal of the data-gathering procedures used by the lessees on Federal oil shale lease tracts.

Uranium and Thorium

The Uranium and Thorium Investigations program consists of research on the theories of origin of uranium; on the paleomagnetic properties of uranium deposits; and on the source-rich areas. Geochemical exploration techniques include gaseous emanation studies and analyses of stream and spring waters and their associated sediments and precipitates. Geophysical exploration techniques include a variety of radiometric and non-nuclear techniques that measure the physical properties associated with uranium deposits.

Fiscal year 1976 accomplishments included:

- Studies of Paleozoic rocks in the Eastern United States that have led to renewed interest in the potential of undiscovered uranium deposits.
- Development of new thorium reserve and resource figures for the Lemhi Pass district, Idaho.
- Studies of hard-rock uranium occurrences that indicate new areas for exploration, particularly in the Northeastern and Eastern United States.
- Studies of natural waters and modern sediments that resulted in improved geochemical techniques and in the identification of several favorable uranium exploration areas.
- Constructing a mobile helium-detection instrument for uranium exploration.
- Constructing a nuclear borehole tool for inhole uranium analysis.
- Studies in Alaska that resulted in significant discovery of a potentially large rare-earth uranium-thorium deposit.

Geothermal Energy

The Geothermal Energy Investigations program assesses the magnitude of regional and national geothermal resources. Promising target areas are identified, and regions for further exploration and development are studied. The program also develops a scientific basis for improving assessment and exploration methodology and assists the Energy Research and Development Administration in technologic research.

Significant results and accomplishments for fiscal year 1976 included:

- Geologic mapping of the San Francisco volcanic field, Arizona. The results indicate that there is a reasonable prospect for finding hot igneous rock in the subsurface east of the San Francisco Mountains.
- Geologic mapping of the Collayomi fault zone, south of Clear Lake, Calif. The mapping indicates that the zone is probably active and has experienced right-lateral slip as well as normal displacement. This zone may be a major control of the northeast extent of The Geysers geothermal field.
- Modification and update of the Geothermal Computer Data File (GEOTHERM) that has added information from the U.S. hot spring file and the international geothermal field data.
- Indications that the thermal anomaly at Roosevelt Hot Springs in southeastern Utah is magmatic in origin and large in size.
- Determination that the two deep geothermal wells at Raft River, Idaho, are producing from a common aquifer, suggesting that the geothermal reservoir is large and potentially productive. It has a 170°C water temperature and a shut-in pressure of about 10,546 grams per square centimeter (150 pounds per square inch).
- Geologic mapping at Mount Shasta, Calif. The mapping has revealed that the volcano is a compound feature consisting of four separate but overlapping cores. The youngest core is only a few thousand years old. The youth of the volcano has considerable significance in evaluating the geothermal potential of the volcanic system.

Energy Resource Data

The Geological Survey is building and maintaining computerized files of energy resource data to use in preparing accurate resource estimates and to meet public needs for such data for independent appraisals.

The National Coal Resources Data System (NCRDS) contains 30,000 records of coal resources by area. It will contain additional information on individual mines and boreholes, and it will include software for computing resources and overburden volume.

The Petroleum Data System (PDS) includes information on 68,000 oil and gas fields and pools in the United States. The data cover geologic occurrence, engineering information on the reservoirs, and analyses of crude oil, brine, and natural gas. Annual and cumulative production is given as well as size in acres or number of wells. Enhanced recovery prospects are identified. Center locations and outlines of the fields are now being digitized to permit graphic display of the fields, together with information selected from the data file.

The United Nations Seabed Data file contains a summary of petroleum and selected mineral statistics for 120 countries, including offshore areas. The software associated with the file allows the user to make limited retrievals of information for the purpose of generating summary reports.

The Oil Shale Data Storage and Retrieval System is designed to store oil shale Fischer assay and saline mineral data and to compute oil-yield thicknesses and resource estimates.

The Computerized Resources Information Bank (CRIB) contains the basic information needed to characterize one or more mineral commodities, a mineral deposit, or several related deposits and consists of text, numeric data, and codes.

The Geothermal Resources Computer File (GEOTHERM) is made up of 1,000 records relating to the location, exploration, evaluation, and use of geothermal energy and resources. Data are included on boreholes, water analyses, and heat values.

The Well History Control System (WHCS) contains basic information on oil and gas wells, including location, production tests, formations, cores, drill-stem tests, depths, and log runs. It is composed of 800,000 records.

The Uranium-Thorium Data Bank is being built to link a variety of existing computerized files to precise deposit locations. Nonproprietary portions of the file will be selected and reformatted for input into CRIB.

OFFSHORE GEOLOGIC SURVEYS

Oil and Gas Resource Appraisal

The objectives of the Oil and Gas Resource Appraisal program are:

- To provide estimates of the oil and gas resource potential of the Outer Continental Shelf areas.
- To help define areas having significant petroleum potential.
- To provide geological and geophysical data and analysis of the areas that have potential petroleum resources.

The most effective method of assessing the resources in offshore sedimentary basins is by the widespread use of geophysical data with the available geological information. The geophysical data consist of common depth point seismic reflection for deep-penetration, single-channel seismic reflection for intermediate-depth recording, high-resolution seismic reflection for shallow and near-surface horizons, seismic refraction, shipborne gravity and magnetics, and aeromagnetics. The geologic information is derived from sea-floor samples collected by water-bottom coring equipment and dredge. Additional geologic information is obtained from shallow core holes, deep stratigraphic test wells, and nearby onshore wells.

The accomplishments and results during fiscal year 1976 included:

- Collecting and analyzing various geophysical data.
- Analyzing 1,937 dredge samples of rock and bottom sediments.
- Conducting a shallow core drilling program on the Atlantic Outer Continental Shelf. This project consisted of drilling (fig. 47) and retrieving 1,030 meters (3,380 feet) of core from 20 sites ranging in depth from about 20 to 300 meters (66 to 985 feet). The holes were located from the Georgia Embayment to Georges Bank. Water depths at the locations were from 20 to about 1,000 meters (66 to 3,280 feet). Preliminary shipboard analyses detected methane in shallow sediments, and large amounts of freshwater were found in the deeper strata offshore from the northeast coastal States.

Environmental Investigations

The Environmental Investigations program assesses the potential impacts of geologic hazards on the development of offshore oil and gas resources. Hazards to drilling structures and/or pipelines may occur in areas of active faulting, unstable sediment masses, and excessive erosion of sedimentation. Field studies which compile this information for leasing decisions and baseline data were conducted during fiscal year 1976 in the north and mid-Atlantic Outer Continental Shelf areas, in the central and western Gulf of Mexico, off the southern California coast, and in the Alaska area.

The activities and highlights for fiscal year 1976 included:

- Completion of 2,900 kilometers (1,800 miles) of high-resolution geophysical surveys in the Georges Bank area. The area is a complex network of channels, which appear to be cutting into the bank surface, and large sand dunes.
- Recovery of cores from Georges Bank containing material identified as glacial till. This work has

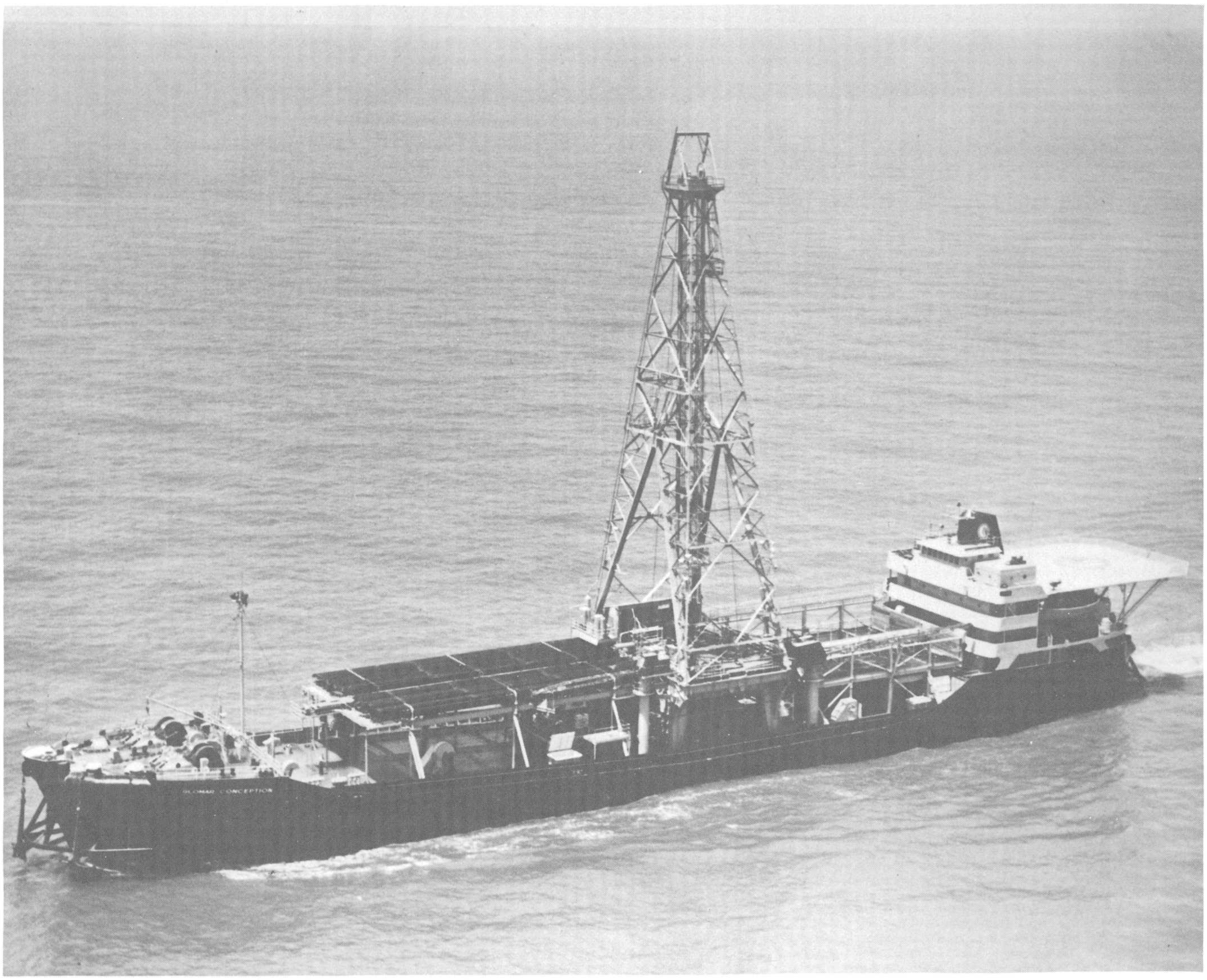


FIGURE 47.—The *Glomar Conception* was used by the Survey in a 60-day scientific expedition to increase the geologic knowledge of the Atlantic Outer Continental Shelf. (Photograph courtesy of Global Marine, Inc.)

extended the known limit of continental glaciation several hundred kilometers into the Atlantic Ocean.

- Photographing sand waves at a depth of 80 meters (262 feet) during the passing of a surface storm.
- Observations by manned submersible in the north and mid-Atlantic Outer Continental Shelf. The observations were made to calibrate the instrument packages containing current, pressure, temperature, and suspended sediment sensors.
- Completion of 2,000 kilometers (1,243 miles) of high-resolution geophysical surveys in the south Atlantic Outer Continental Shelf. These surveys show active cut and fill sediment transport. Deep core material documents a change in position of the Gulf Stream.
- Mapping in the Gulf of Alaska and off the southern California coast revealed submarine landslides and sea-floor faults. Tracts that had potentially unstable sea floors were subsequently withdrawn from the lease sales schedule.

Marine Geology Investigations

The Marine Geology Investigations focus on topics necessary to the development of applied programs. Geochemical studies of deep-sea manganese nodules and the development of deep-ocean remote-sensing geophysical instruments are two examples of future major programs as the Nation develops its Outer Continental Shelf areas for mineral and hydrocarbon resources. Other research activities not directed specifically toward Outer Continental Shelf development include research on coastal-zone processes, minable minerals on the shelf, and engineering properties of sea-floor sediments.

The highlights of the program for fiscal year 1976 included:

- Mapping the faults in the offshore area to the west of the extension of onshore faults in the Puget Sound area.
- Mapping, using geophysical methods, the offshore and north of the Diablo Canyon nuclear power-plant site in central California.
- Studying the triggering of large submarine landslides by cycle loading of storm waves in the Mississippi River Delta area.

ASTROGEOLOGY

The exploration of the Moon and planets by the National Aeronautics and Space Administration has provided an opportunity to compare geologic materials, processes, and histories of other planets with those of Earth. The Astrogeology program is designed to exploit the geologic potential of space exploration.

The lunar part of the program has evolved from an earlier emphasis on geologic mapping to a current emphasis on studies of processes and on integration of the vast amounts of geologic, geochemical, and geophysical data generated by the Apollo program. The long history of impact cratering on the Moon has led to studies of cratering processes including shock effects on lunar rocks, studies of impact and explosive craters on Earth, and stratigraphic investigations of material thrown out of the enormous lunar basins.

The planetary studies are focused mainly on Mars and Mercury. The Survey is coordinating an effort to map geologically both planets at a scale of 1:5,000,000. Studies of Martian processes are aimed at wind erosion, volcanoes, and water erosion (fig. 48). Mercury offers another perspective on the history of impact cratering and the distribution and source of impacting bodies. Radar techniques are being developed for application to the study of Venus.

Highlights of the program for fiscal year 1976 included:

- Completion of topographic maps of Mars (from photographs taken from orbit) near the Viking Lander I landing site prior to its successful landing.
- Completion of a topographic map of Mars.
- Completion of a shaded-relief map of Mercury.
- Completion of a true-color mosaic of Nevada from Landsat imagery.
- Preparation of a geologic map of the entire Moon and a new geologic map of Mars.

INTERNATIONAL ACTIVITIES

International Activities form a significant part of the Survey's research and investigations. These activities include technical assistance to earth-resources institutions in foreign countries, scientific cooperation and exchange of knowledge with counterpart agencies, and participation in international commissions and scientific programs.

Technical assistance is conducted at the request of, and is funded by, international organizations and other U.S. Government agencies and foreign governments and is authorized by the Agency for International Development, Department of State. This assistance, which involved 25 countries during 1976, provides a mechanism for using Survey scientific expertise in achieving the objectives of the Foreign Assistance Act. It also affords an opportunity for the Survey to develop contacts, study geologic phenomena, and test geologic concepts with counterpart agencies abroad.

Scientific cooperation and exchange are conducted partly on behalf of other Federal agencies and partly as an extension of the Survey's domestic geologic research. In 1976, cooperative research on geological and resources problems was conducted with 15 foreign countries. In addition, Survey scientists participated in seven major international scientific programs and participated in several international commissions during the year.

Resources Attaché and Reporting Program

The Survey continued to cooperate with the Department of State and the Bureau of Mines in developing an expanded Resources Attaché and Reporting program to collect, organize, and synthesize international mineral and energy resource data. At the end of fiscal year 1976, 11 resources attaché positions had been established in U.S. embassies abroad.

Transfer of Technology

Transfer of remote-sensing technology to foreign countries continued to receive special emphasis. Training courses or seminars were conducted by Survey personnel in Thailand, Nepal, Saudi Arabia, and Iran. The multidisciplinary remote-sensing project in Thailand, sponsored by the Agency for International Development, was completed during the year. This 4-year project assisted the resource agencies and institutions of Thailand in applying data derived from Landsat imagery in their ongoing effort to provide improved information for development and management of earth resources. Twenty-two organi-

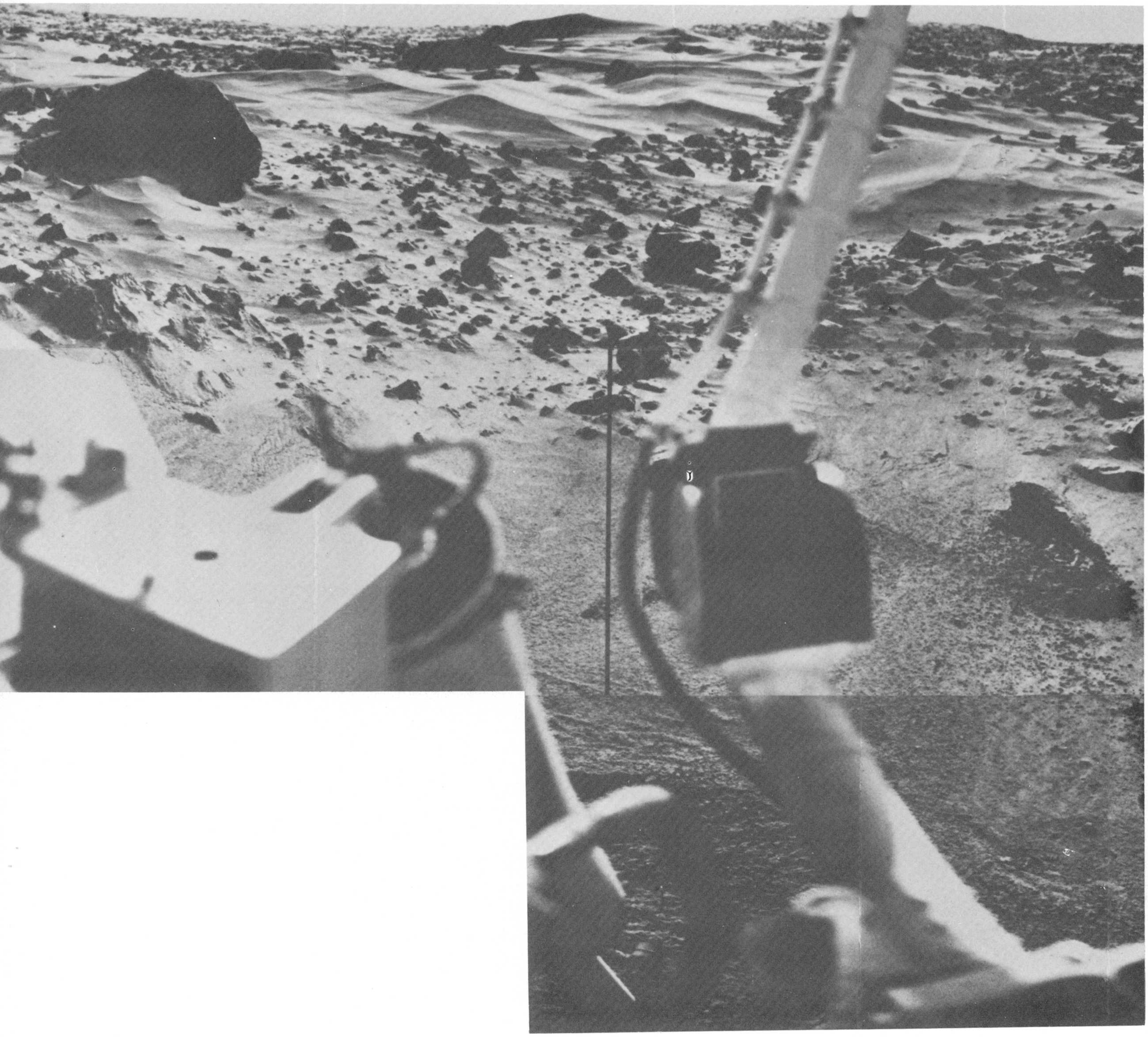
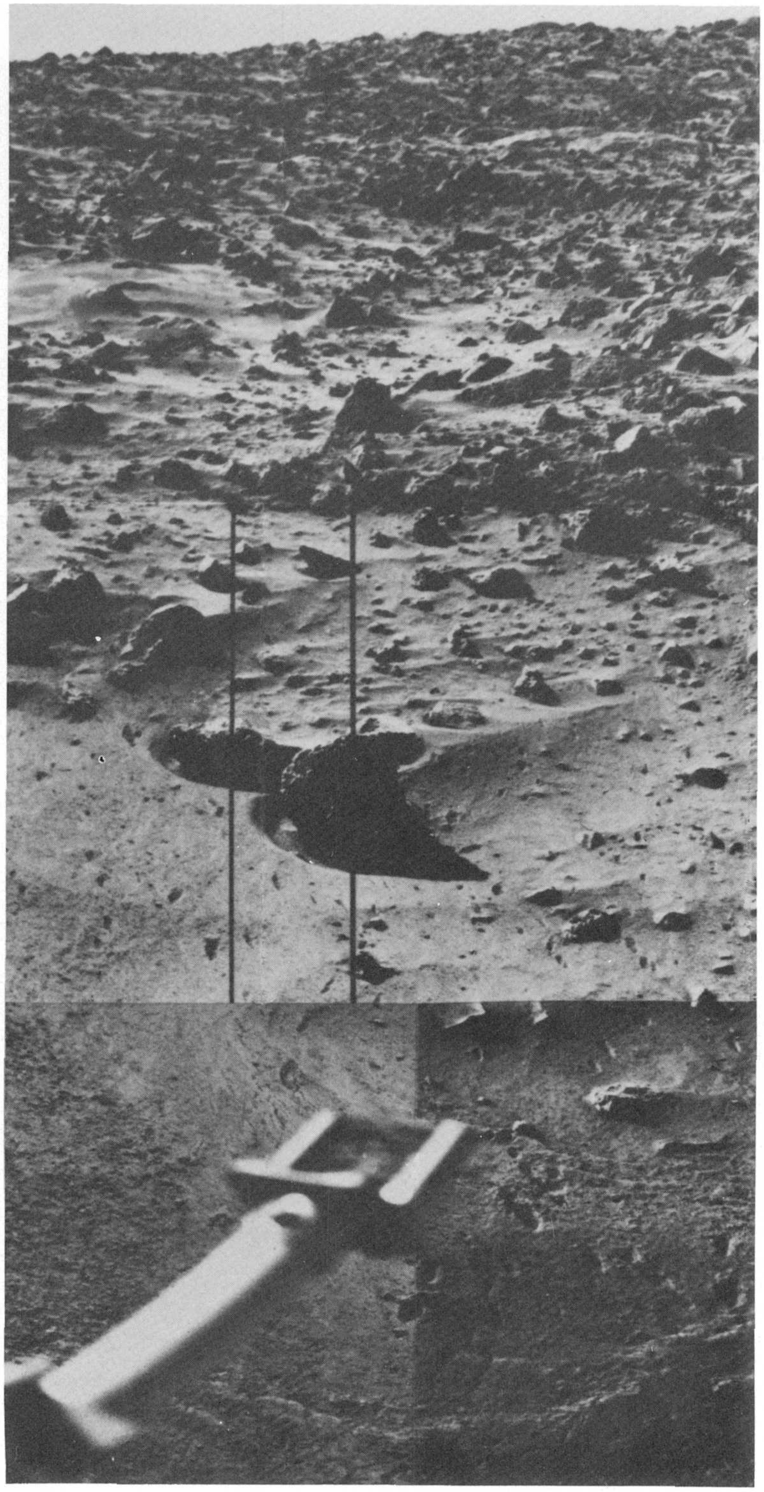


FIGURE 48.—This panorama of the Martian surface is a composite of high-resolution pictures taken by Viking Lander I cameras. A sample of soil was obtained from the trench in the center of the picture. The surface is strewn with a variety of angular rocks, and fine material has formed tails on the lee side of the rocks by winds.



zations participated in the project, which was coordinated by the National Research Council of Thailand.

Major highlights for the International Activities in fiscal year 1976 included:

- Investigation into the geologic, seismologic, and engineering effects of and hazards resulting from the February 4, 1976, Guatemala earthquake.
- Assistance in the establishment of a Center for Earthquake Hazard Reduction in Nicaragua.
- Investigation of the volcanic activity at Cotopaxi Volcano, near Quito, Ecuador, during July 1975.
- Consultation on slope stability studies in La Paz, Bolivia, ground-water development proposals in Assam, India, and resource development and remote-sensing programs in Central America.

ALASKA PIPELINE AND RELATED INVESTIGATIONS

The Alaska Pipeline and Related Investigations activity collects geologic and hydrologic information. This information is used as the basis for safeguards against possible pollution and environmental damage that might result from the construction and use of the trans-Alaska pipeline. The Arctic Environmental Studies program augments the pipeline investigations by conducting engineering geologic studies.

Principal accomplishments and highlights of the program during fiscal year 1976 included:

- Continuation of mapping and investigation of engineering-geologic conditions critical to proper construction and safe operation of the pipeline.
- Continuation of monitoring channel erosion, streamflow, and water quality at 35 sites along the pipeline route and monitoring glacial and river icing at selected locations.
- Continuation of earthquake monitoring at several locations to evaluate possible hazards. A resurvey was made where the pipeline crosses the Denali fault in order to determine if fault movement has occurred in that area during the past few years.

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Water Resources Investigations

Introduction—Functions and Authority

The availability of water in usable form is a major determinant in defining the quality of life. As the demand for water increases, decisions regarding its allocation and use become more difficult and more critical. In 1976, the expanding search for new energy sources, the droughts in California and Great Britain, the disastrous flood on Big Thompson River in Colorado were striking examples of the vital need for understanding and judiciously assessing our water resources.

Managing the Nation's water resources is a major concern at all levels of government, but the Water Resources Division of the Geological Survey has the principal responsibility at the Federal level for appraising this vital resource. The Survey's program, through its numerous cooperative efforts with State and local governments, is uniquely structured to gather and evaluate water information. The Water Resources Division's role is that of a scientific organization concerned with presenting impartial, factual information and analyses on which decisionmakers can rely. It publishes the data which are used by other Federal agencies, State, and local governments and by all groups charged with managing or developing water resources. Water reports and maps are made available to the public in Federal, State, and local publications and in technical journals (tables 46 and 47). In 1976, more than 1,000 such water reports and approximately 1,400 maps were issued. Some reports were released to the open file and made available for public use at selected depositories.

In the Water Resources Division's Federal-State Cooperative program, 583 State and local agencies cooperate with financial support and services, matching in equal amount the funds provided by congressional appropriation. For many years this arrangement has assured responsiveness to water-information needs at all levels of government. It has enabled the Federal Government to be aware of urgent State and local problems and has contributed to valuable information exchange. Although studies conducted within the Federal-State Cooperative program are usually linked to State and local water problems, they are of substantial national interest because the information developed is applicable in other areas or forms a part of the information base for larger areas. Therefore, one of the benefits of the cooperative program has been the elimination of more costly multiplicity of effort. Through a network of offices in all 50 States, as well as Puerto Rico and Guam (fig. 49), the Water Resources Division works closely with State and local agencies. The addresses of the Division's District Offices are listed in the chapter on organization and statistical data.

A broad category of responsibility for water data was assigned to the U.S. Geological Survey when, in 1964, 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 function has effectively minimized duplication of data-collection activities among Federal agencies and has strengthened the overall data base and the accessibility of these data to users.

◀ Stream gaging by cable car.

Highlights

- The comprehensive Madison Limestone Ground-Water Study was begun to assess the adequacy of ground-water supplies for coal development in Wyoming, Montana, South Dakota, and Nebraska. The first test well of 1,323.1 meters (4,341 feet) has been completed. Preliminary pumping tests indicate the well yield is about 1,477.0 liters per minute (700 gallons per minute).
- Studies on radioactive-waste disposal as they relate to ground-water contamination are in progress at four State-owned, commercially operated sites and at two Federally operated solid-waste burial sites.
- The ever-increasing concern for clean water in the environment and pure water for drinking has led to more than 50 studies in progress within the Federal-State Cooperative program which relate to the potential for pollution of ground water.
- Results of the Intensive River Quality Assessment of Oregon's Willamette River basin demonstrated that methodology for assessing river basins must be tailored carefully to the particular basin under study. This tailoring is necessary because there are cause-effect relationships that are unique to each basin.
- A 4,553.8 square-meter (49,000 square-foot) laboratory complex in Denver, Colo., was completed. Eighty-five percent of the building houses an analytical-services laboratory, which emphasizes the increased importance of an expanded water-quality program in monitoring the impact of nature and man on the Nation's water resources.

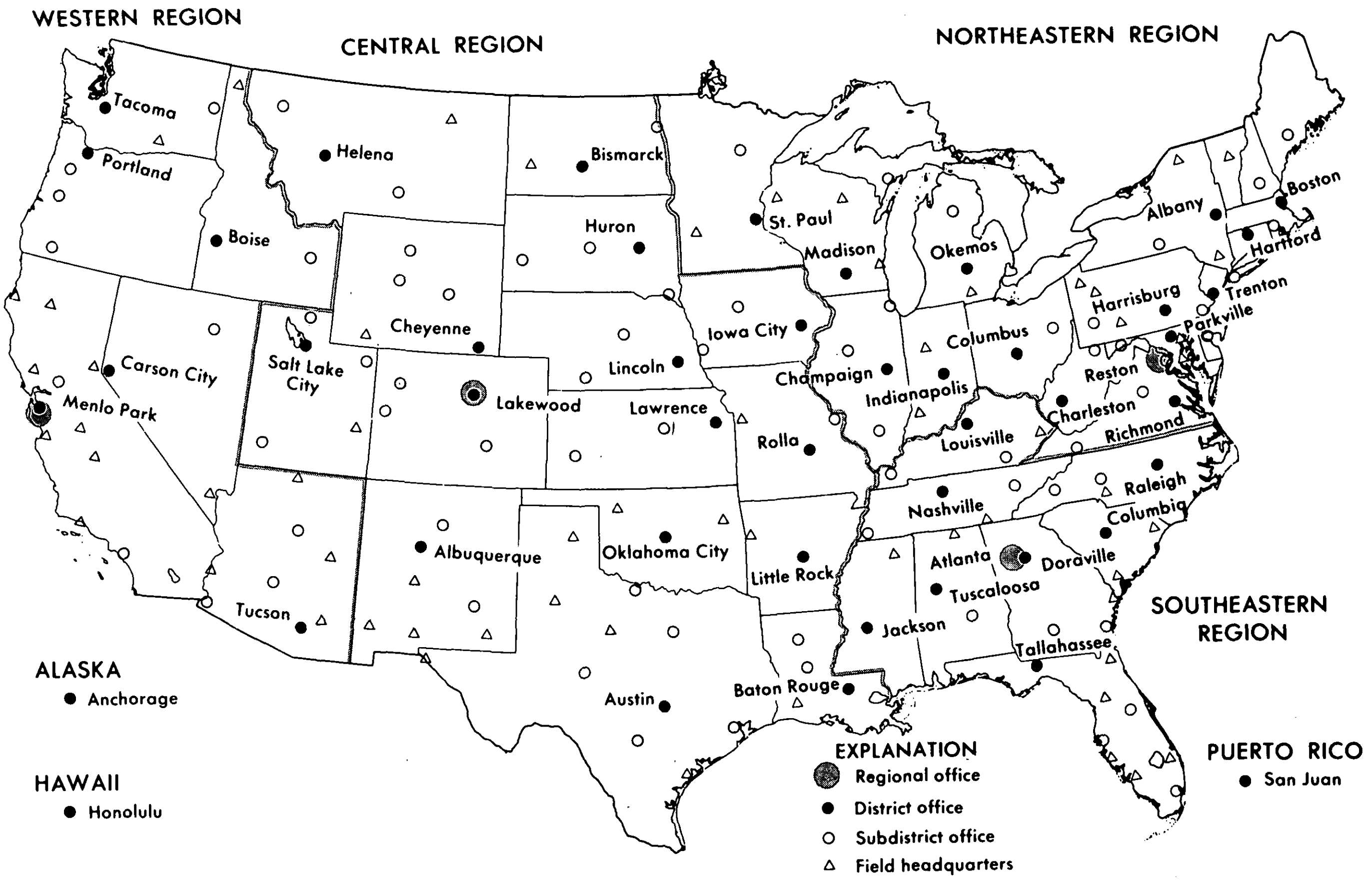


FIGURE 49.—Location of principal offices of the Geological Survey's Water Resources Division in the conterminous United States. Cities named are those where regional and district offices are located. In addition to the subdistrict offices noted on the map, there are two subdistrict offices in Alaska, three in Hawaii, and one on Guam, all in the western region.

- In cooperation with other Federal agencies, the Osceola National Forest project was begun to predict the potential impacts of strip mining for phosphate on surface- and ground-water resources.
- Preliminary interpretations of data gathered at Redwood National Park, Calif., indicate that timber harvesting outside the park boundaries has had identifiable effects on the hydrologic environment of the park. The lumber companies involved have voluntarily changed their timber-harvest practices. Investigations on the hydrology of the area are continuing in cooperation with the National Park Service.
- The Federal-State Cooperative program placed special emphasis on water investigations related to the development of new energy sources, such as the availability of water for coal mining and processing. Other high-priority activities of the program included water quality, urban-area problems, and other matters related to environmental improvement.
- Seventeen Hydrologic Investigations Atlases were released which delineate the inundated areas and maximum water-surface elevations resulting from failure of the Teton Dam in southeastern Idaho. A formal report is in preparation.
- Professional papers were published on three disastrous floods: those caused by Hurricane Agnes in June 1972, record floods of 1973 on the Mississippi River, and the severe floods of March-April 1973 in the Southeastern United States.
- Regional flood-frequency reports were prepared for 14 States. They describe results of analyses and the various techniques for estimating the magnitude and frequency of floods at ungaged sites.
- The National Water Data Exchange (NAWDEX) was established. It maintains two computerized data bases (a Water Data Sources Directory and a Master Water Data Index) to assist data users in identifying, locating, and acquiring needed water data.

- WATSTORE, the computerized data storage and identifying, locating, and acquiring needed water Data System, was made available for direct on-line use by other Federal and non-Federal organizations.
- Under the sponsorship of the Office of Water Data Coordination, two chapters of the "National Handbook of Recommended Methods for Water-Data Acquisition" on chemical and physical quality of water and hydrometeorological observations were completed.

Budget and personnel

In fiscal year 1976, the $112.5 million obligated for the Water Resources Investigations activity came from three sources (fig. 50 and table 11):

1. Direct Congressional appropriations for the Federal program.
2. Joint congressional and State and local appropriations for the Federal-State Cooperative program.
3. Funds transferred from other Federal agencies and State and local agencies for reimbursable programs.

The work funded by these three sources is divided into a number of subactivities and programs. (See table 11.)

Approximately 2,900 full-time personnel carried out the many water-resources studies and data-collection activities of the Water Resources Division. In 1976, the Division employed 1,287 hydrologists, 168 engineers and other scientists, 989 technical specialists and aids, and about 450 persons who provided administrative, secretarial, and clerical services. In addition, at the end of the fiscal year, approximately 700 persons were employed in a variety of capacities on a part-time basis.

FEDERAL PROGRAM

The Federal program, amounting to $29.3 million[1] in fiscal year 1976 (approximately 26 percent of the Geological Survey's total water program), is designed to provide nationwide resource data for planning and management and to improve the scientific basis of hydrologic investigations and techniques. Water-data collection, resources investigations, and research activities support that segment of the National Water Data System in which the Federal interest is paramount, including the public domain, interstate river basins and aquifers, and other areas of international or interstate concern.

The Federal program supports the operation of more than 700 surface-water measurement stations—stage and/or discharge—throughout the Nation, including nearly 650 sites where stream discharge is measured continuously. The program also includes the operation of the National Stream Quality/Quantity Accounting Network (fig. 51), hydrologic research, and the publication of water reports.

FEDERAL-STATE COOPERATIVE PROGRAM

The Federal-State Cooperative program consists of projects funded on an equal matching basis by the Geological Survey and State and local agencies—583 in fiscal year 1976 (table 12). The cooperative program totaled $56 million. These projects contribute to the solution of urgent national and State problems and complement the federally funded part of the National Water Data System. Once the Federal interest in a proposed project is identified, cooperative projects are jointly planned at State or local levels and by Federal representatives.

Efficient and effective conservation, development, and utilization of the Nation's water resources are dependent upon an adequate data base. The Federal-State Cooperative program provides more than half of that base and is a continuing program which directly responds to the changing mutual needs of Federal, State, and local governments for data.

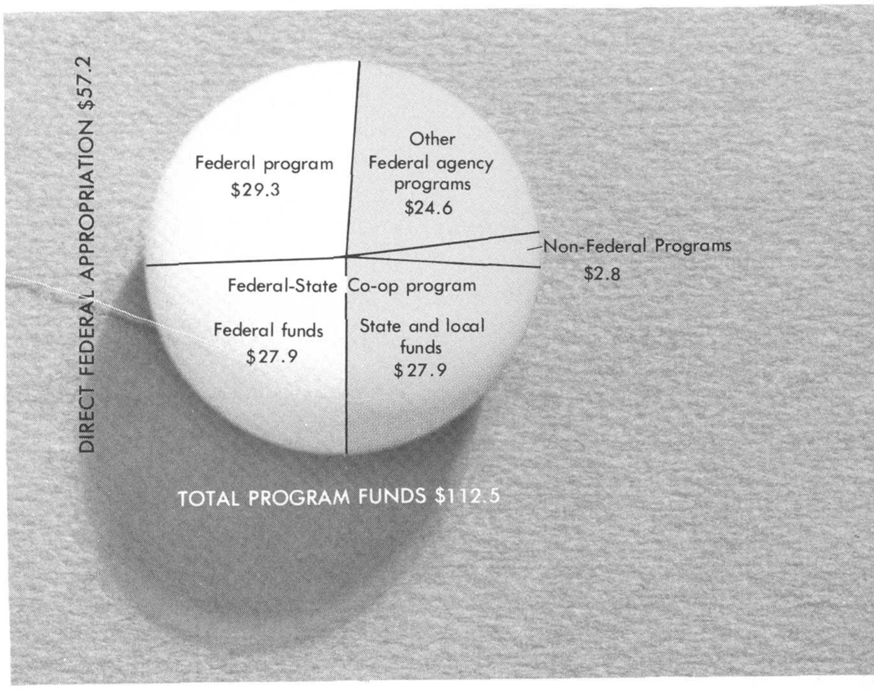


FIGURE 50.—Sources of fiscal year 1976 funds for Water Resources Investigations (dollars in millions).

[1] In fiscal year 1976, $58.1 million was appropriated for the Water Resources Investigations activity, $28.0 million of which was used to match State and local agency funds (table 36). The balance, $30.1 million, is referred to here as the Federal program.

TABLE 11.—*Water Resources Investigations activity obligations for fiscal year 1976, by program (dollars in millions)*

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

Program	Source of funds: Federal program [1]	Federal-State Cooperative program [2]	Other Federal agency programs [3]	Non-Federal programs [4]	Total	Percent change relative to fiscal year 1975
TOTAL	$29.26	$55.92	$24.63	$2.67	$112.48	+12
National Water Data System	20.58	55.92	24.63	2.67	103.80	+ 9
Collection, analysis, and dissemination of streamflow, water-quality, ground-water, and sediment data [5]	10.95	27.94	11.42	1.81	52.12	
Regional and areal resource appraisals	.74	14.93	6.72	.33	22.72	
Studies related to critical water problems	-----	6.05	4.16	.16	10.37	
Core program of hydrologic research	5.39	-----	-----	----	5.39	
Other data collection and applied research	-----	7.00	2.33	.37	9.70	
Hydrologic investigations on public lands (soil and moisture conservation)	.14	-----	-----	----	.14	
Publications and other supporting services	3.36	-----	-----	----	3.36	
Critical National Water Problems	8.68	-----	-----	----	8.68	+66
Accelerated energy research and development programs	6.15	-----	-----	----	6.15	
Coal hydrology	2.72	-----	-----	----	2.72	
Oil-shale hydrology	2.21	-----	-----	----	2.21	
Underground heat storage	.11	-----	-----	----	.11	
Nuclear energy hydrology	1.11	-----	-----	----	1.11	
Ground-water recharge	.95	-----	-----	----	.95	
Subsurface waste storage	1.03	-----	-----	----	1.03	
Flood-hazard mapping	.37	-----	-----	----	.37	
Estuarine and coastal studies	.18	-----	-----	----	.18	
Percent change relative to fiscal year 1975	+11	+4	+30 (Other Federal and Non-Federal combined)		+12	

[1] Federal funds excluding those used to match funds from State and local agencies.
[2] Includes Federal funds used to match State and local agency funds on a 50–50 basis.
[3] Funds from 23 other Federal agencies transferred to the Geological Survey, Water Resources Division.
[4] Includes unmatched funds from State and local agencies, funds from permittees and licensees of the Federal Power Commission, and funds from minor miscellaneous sources.
[5] Federal funds include support of coordination of national water data and the National War Data Exchange.

Activities in the Federal-State Cooperative program in 1976 included:

- Data collection, analysis, and dissemination.
- Areal resource appraisals and problem-related studies, including urban hydrology, sedimentation, lakes, hydrobiology, stream-system modeling, aquifer modeling, water-quality modeling, saline waters, flood frequency and magnitude, floods and droughts, waste disposal, and others.
- Studies related to critical problems including relation of coal and oil development to water resources, surface- and ground-water contamination, estuarine problems, artificial recharge, and flood-hazard mapping.
- Applied research on hydrologic problems, principles, and techniques.

Activities under the Federal-State Cooperative program have provided most of the information required for wise use of the Nation's water. Local water problems have the potential for becoming national or regional problems. Examples are floods, land droughts affecting several States, or problems of one area which may be analogous or similar to those found elsewhere. The accumulation of water information from the cooperative-program studies has increased the reliability of predictive methods and generated many new techniques.

In fiscal year 1976, the Federal-State Cooperative program placed special emphasis on water investigations related to the accelerated development of new energy sources as, for example, in studies involving the availability of water for coal mining and processing. Other high-priority activities included intensified work in water quality, urban-area problems, and environmental improvement.

Reports published in the past year include, among others:

- Plan of study of the hydrology of the Madison Limestone and associated rocks in parts of Montana, North Dakota, South Dakota, and Wyoming.
- Geothermal investigations in Idaho.
- Effects of urbanization on streamflow and sediment transport in the Rock Creek and Anacostia River basins, Montgomery County, Md.

FIGURE 51.—Location of stations in the National Stream Quality/Quantity Accounting Network in operation as of January 1, 1976.

- Ground-water quality at the site of a proposed deep-well injection system for treated wastewater, West Palm Beach, Fla.
- Geochemical effects of recharging the Magothy aquifer, Bay Park, N.Y., with tertiary-treated sewage.
- Chemical quality of ground water in the Tehama-Colusa Canal Service Area, Sacramento Valley, Calif.

NON-FEDERAL PROGRAM

Non-Federal reimbursable funds are unmatched funds received by the Geological Survey from State

TABLE 12.—*State and local agencies, by State, with which the Geological Survey had a written agreement for fiscal cooperation (Federal-State Cooperative program) in Water Resources Investigations in fiscal year 1976*

State	Number of agencies				
	State	County	City	Other	Total
Alabama	2	1	0	---	3
Alaska	6	---	2	2	10
Arizona	6	3	4	5	18
Arkansas	4	---	---	---	4
California	4	36	9	23	72
Colorado	5	7	8	11	31
Connecticut	1	---	4	5	10
Delaware	2	---	---	---	2
District of Columbia	1	---	---	---	1
Florida	5	24	26	12	67
Georgia	4	2	2	---	8
Hawaii	2	---	2	---	4
Idaho	2	---	---	1	3
Illinois	5	5	1	4	15
Indiana	3	---	3	1	7
Iowa	7	1	3	---	11
Kansas	4	---	1	1	6
Kentucky	3	---	---	---	3
Louisiana	3	---	---	1	4
Maine	7	---	---	---	7
Maryland	3	0	1	0	4
Massachusetts	6	---	---	---	6
Michigan	2	---	---	---	2
Minnesota	5	---	1	0	6
Mississippi	5	2	1	3	11
Missouri	4	1	2	1	8
Montana	7	2	---	2	11
Nebraska	5	5	---	5	15
Nevada	4	---	---	---	4
New Hampshire	2	---	---	1	3
New Jersey	3	2	---	4	9
New Mexico	4	---	3	4	11
New York	9	17	5	8	39
North Carolina	3	---	6	---	9
North Dakota	2	1	---	---	3
Ohio	3	---	3	2	8
Oklahoma	5	---	1	---	6
Oregon	3	7	7	5	22
Pennsylvania	6	1	4	4	15
Rhode Island	2	---	1	---	3
South Carolina	4	---	1	---	5
South Dakota	2	---	2	2	6
Tennessee	6	2	5	1	14
Texas	2	1	4	2	9
Utah	2	1	---	1	4
Vermont	1	---	1	---	2
Virginia	3	1	5	---	9
Washington	4	1	5	12	22
West Virginia	3	---	2	---	5
Wisconsin	5	2	2	0	9
Wyoming	6	1	1	---	8
American Samoa	---	---	---	1	1
Guam	---	---	---	1	1
Puerto Rico	3	---	---	1	4
Trust Territories	---	---	---	1	1
Virgin Islands	2	---	---	---	2
Total	202	126	128	127	583

and local agencies ($2.7 million) in situations where there is both Federal and State interest in investigation of water resources but where matching Federal funds are inadequate for cost sharing.

OTHER FEDERAL AGENCY PROGRAMS

Other Federal agency programs, amounting to $24.6 million in fiscal year 1976, consisted of work carried out by the Geological Survey at the request of other Federal agencies to provide them with information for use in support of their missions. Examples of work performed for other Federal agencies are:

Department of Agriculture	Hydrologic studies on small watersheds. Sediment studies. Stream discharge and quality.
Department of Housing and Urban Development.	Flood-plain delineation, flood profiles, flood frequency related to flood insurance.
Department of Transportation.	Stream-discharge and flood-frequency data; hydrologic studies on small watersheds, scour, and bank erosion.
Energy Research and Development Administration.	Hydrologic and water-supply exploration studies at test sites; research in field of radiohydrology related to interaction between radioactive materials and the environment, both above and below ground.
Environmental Protection Agency.	Waste-disposal site studies; study of relationship of ground water to lakes; collection of water-quality information.
National Aeronautics and Space Administration.	Applications of remote sensing to problems concerning ground water, estuaries, water temperature, lakes, glaciology, snow-cover mapping.
Tennessee Valley Authority	Stream-discharge and flood-frequency data; hydrologic studies on watersheds, including sedimentation.
Department of Defense—Corps of Engineers.	Tidal flows in estuaries, subsidence studies; streamflow data, ground-water studies, sedimentation, and water-quality studies.

In cooperating with other Federal agencies, the U.S. Geological Survey plays a significant role in undertaking studies which affect the preservation of environmental quality in our national parks and public lands. In 1976, two typical water-related studies were underway:

Redwood National Park

Changing patterns of rainfall runoff and of sediment transport and deposition in Redwood National Park, Calif., have been the subject of intensive study by Water Resources Division scientists since early 1973. The work, performed in cooperation with the National Park Service, is intended to try to segregate changes resulting from heavy timber harvest in adjacent lands from changes that reflect natural events, such as major floods. The studies have included measurements of stream discharge; physical, chemical, and biological characteristics of the streams; mapping of landslides and other areas of unstable ground; and detailed examination of geomorphic phenomena throughout the drainage basins of Mill Creek and Redwood Creek, the two principal streams in the park. Special emphasis has been given to a comparison of logged versus unlogged basins tributary to Redwood Creek.

Osceola National Forest

At the direction of the Secretary of the Interior, the Geological Survey is presently evaluating the hydrogeology of the Osceola National Forest in northern Florida to predict the potential impacts of strip mining for phosphate on the surface and subsurface water resources. The Bureau of Mines, Fish and Wildlife Service, and the Bureau of Land Management in Interior, and the Forest Service (U.S. Department of Agriculture) are participating in the study, which must be completed by December 1977.

ACTIVITIES

The Water-Resources Investigations activity consists of two subactivities: *The National Water-Data System* and *Critical National Water Problems*, both augmented by the Federal-State Cooperative program.

The objectives of the *National Water-Data System* are to appraise the Nation's water resources and to provide the water data and information needed to develop and manage these resources efficiently. Investigations include collecting basic information at hydrologic-data stations, making areal studies, and conducting supportive research. The programs comprise more than 90 percent of the water-resources studies carried out by the Geological Survey and constitute a major part of the government-wide water-data-collection activities. For example, in 1974, the Geological Survey operated more than 70 percent of all surface-water stations (streamflow, lake level, and water stage) reported by 17 Federal agencies and

Studying flood photographs to aid in flood-prone mapping.

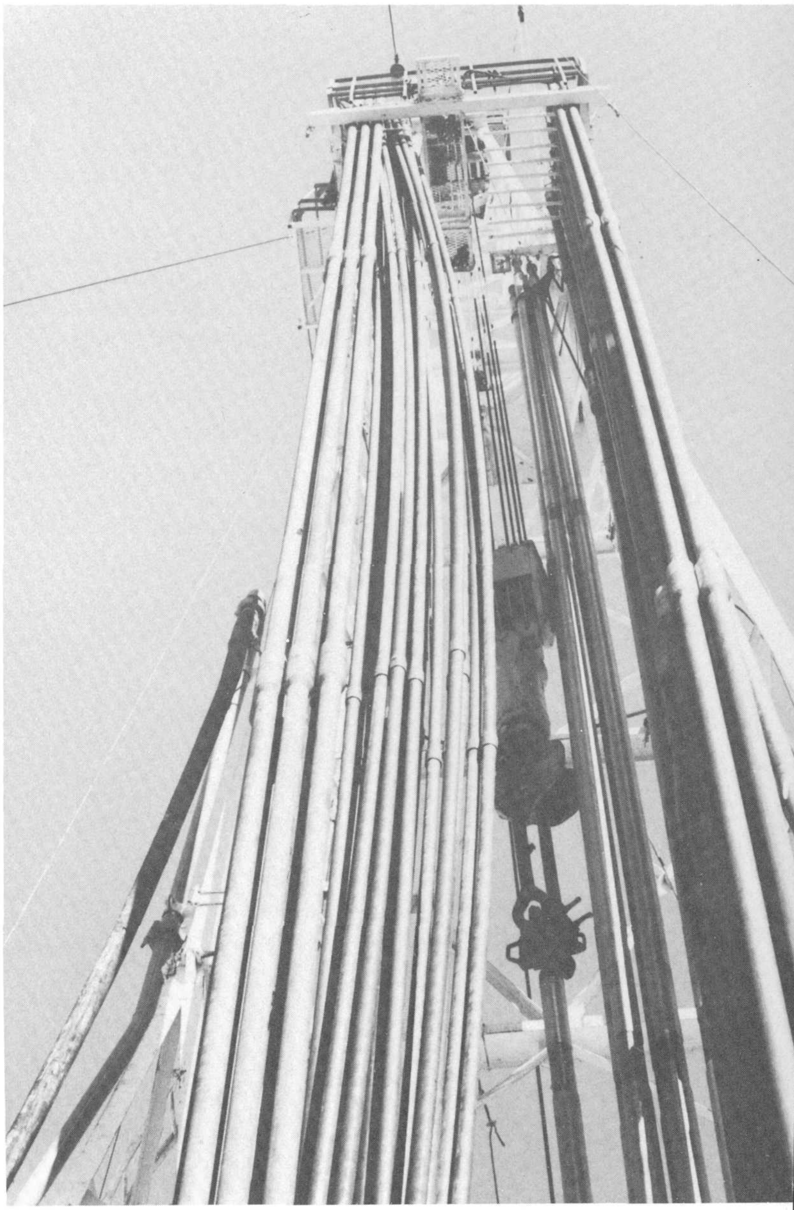
approximately 200 non-Federal agencies. The Survey was also responsible for 35 percent of all sites at which the quality of ground and surface water was measured.

The *Critical National Water Problems* activity focuses on two principal areas: (1) water availability for energy development, conversion, and storage, and (2) impact on the hydrologic regime from the above or associated energy activities.

The availability of an adequate water supply is paramount to the development of all major forms of energy. Moreover, environmental concerns dictate that such use should not be detrimental to those hydrologic systems involved. These two requirements have guided the water-resources effort conducted under the program, Critical National Water Problems. The program involves:

1. Determination of water-supply availability for coal and oil-shale mining, conversion and reclamation, transportation of coal, and nuclear-power-plant cooling-water requirements;
2. Establishment of baseline hydrologic conditions in areas where mining and conversion industries exist, or are imminent, to permit assessment of environmental impacts;
3. Site-specific studies and modeling of actual or possible impacts of energy developments such as delineation of potential areas of waste storage, including radioactive waste; and
4. Studies of ground-water recharge, mapping of flood-prone areas, and investigations of estuaries and water resources of coastal areas.

In addition to the nationwide monitoring programs in fiscal year 1976, 29 studies were in progress to determine water-supply availability, 36 to establish baseline hydrologic conditions, and 38 on predictive modeling. Many such studies serve multiple needs with a total of 81 projects specified as energy-related.



Massive drill at Madison Limestone Ground-Water Project.

Elements of the National Water-Data System

INTERAGENCY WATER-DATA COORDINATION

The Survey's Office of Water-Data Coordination continued during fiscal year 1976 to work closely with a large number of Federal and non-Federal agencies, organizations, and individuals in the planning, design, and documentation of water-data networks and in the planning and development of standards for water-data acquisition (table 13). This coordination effort, mandated by Office of Management and Budget Circular A–67, involves about 20 Federal agencies and approximately 200 non-Federal agencies that collect water data. It affects about 50 Federal agencies and more than 600 non-Federal agencies that use water data.

A major function of the interagency coordination activity during fiscal year 1976 was the preparation and release of "Regional Plans for the Acquisition of Water Data" for each of the 21 major water-resources regions of the United States. The field information was summarized and expanded to include national water-data activities and was released as the "Federal Plan for the Acquisition of Water Data—Fiscal Year 1977." A new edition of the 21-volume "Catalog of Information on Water Data" also was released.

Emphasis was placed during the year on work-group activities related to production of the 10 chapters for the "National Handbook of Recommended Methods for Water-Data Acquisition," an update of a preliminary report issued in 1972. Two chapters, Chapter 5 on "Chemical and Physical Quality of Water" and Chapter 10 on "Hydrometeorological Measurements," were completed and have been under review by Federal and non-Federal experts in these data fields. Another interagency activity resulted in the release of the report, "Development of a Catalog of Information for Surface Meteorological Data." The report discusses the needs for such data and their availability. It also proposes a systematic means of communicating the information.

Another major activity during the year was preparation and publication of 27 maps in the new nationwide series of four-color State Hydrologic Unit maps (scale 1:500,000), leaving only six State maps to be completed (fig. 52).

COLLECTION, ANALYSIS, AND DISSEMINATION OF BASIC WATER DATA

The collection and analysis of basic water records, such as stream discharge, lake stage, water levels in wells, the chemical and biological characteristics and sediment loads of streams, and water-use statistics are basic aspects of water-resources investigations. These kinds of measurements are necessary first steps in determining how much and what kind of water is available when and where. Comparisons can then be made of the water used and water needed. Basic water data are essential not only in determining the adequacy of water supplies but also in designing culverts, bridges, dams, and other public works, in planning for actions to prevent or lessen the damages and

TABLE 13.—*Participation in water-data coordination activities with the Geological Survey's Office of Water Data Coordination, fiscal year 1976*

Activity	Participants
Federal:	
1. Coordination of Federal water-data programs through the Interagency Advisory Committee on Water Data.	32 Federal agencies.
2. Development of recommended methods for collecting water data; includes Coordinating Council for Water-Data Acquisition Methods (18 Federal agencies).	25 Federal agencies and 170 scientists in 10 working groups.
3. Design and development of national system for handling water data through Federal Interagency Water Data Handling Work Group.	13 Federal agencies.
4. Design of small-watershed network for data on water quality; Ad Hoc Working Group on Water-Quality Data Needs for Small Watersheds.	8 Federal agencies.
5. Develop improved communication for interagency coordination, through the Interagency Working Group on Improved Communications Mechanisms.	8 Federal agencies.
6. Field coordination and development annually of 21 regional plans and a Federal plan for water-data acquisition.	28 Federal agencies and 140 field officials.
Non-Federal:	
1. Consultation with non-Federal community of data users through the Advisory Committee on Water Data for Public Use.	25 Members.
2. Review and consultation with the Ad Hoc Working Group on "National Handbook of Recommended Methods for Water-Data Acquisition."	10 Members.
3. Assessment of river quality through an Ad Hoc Working Group of the Advisory Committee on Water Data for Public Use.	9 Members.
4. Develop improved communications for coordination activities through an Ad Hoc Working Group on Improved Communications Mechanisms.	9 Members.

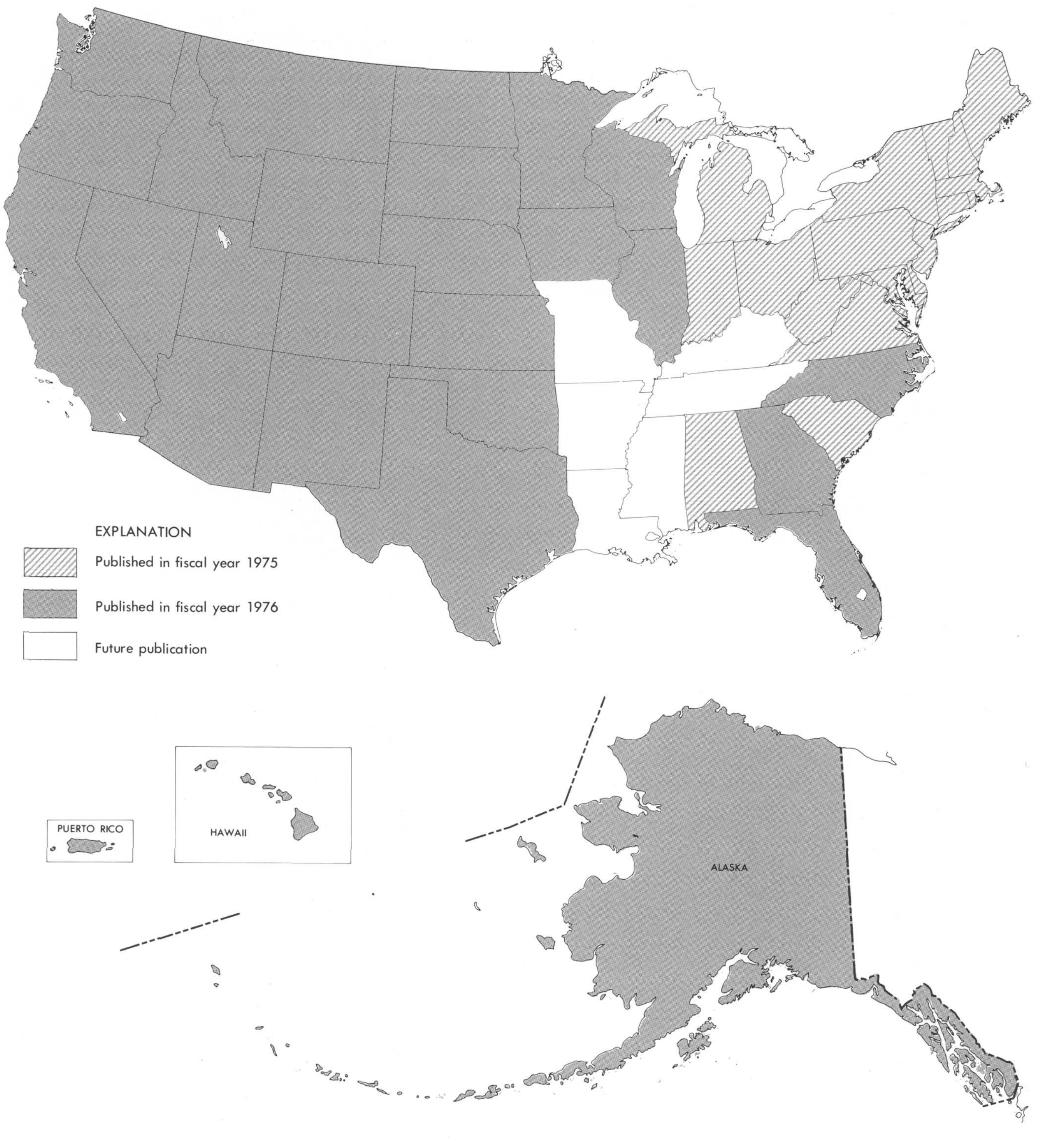


FIGURE 52.—Location of areas covered by maps published in the Survey's series of State Hydrologic Unit maps (scale 1:500,000).

impacts of floods and droughts, in determining the feasibility of water-power and irrigation developments, and to some extent in planning projects for water-pollution control, navigation, and outdoor recreation. About 40 percent of the water funds that the Geological Survey receives from all sources supports basic-data activities—the largest single major element of the National Water-Data System.

In 1976, the Survey maintained continuous discharge records at 7,820 stream sites, analyzed water quality at more than 5,000 stream sites, and measured water levels or other parameters periodically in more than 21,000 wells (table 14).

TABLE 14.—*Number and type of measurement sites (stations) of the Geological Survey, July 1976*

Type of station	Federal program	Federal-State Cooperative program	Other Federal agency programs	Non-Federal program [1]	Total
SURFACE-WATER FLOW OR CONTENTS					
TOTAL	792	12,728	2,483	591	16,594
Continuous discharge	713	4,891	1,827	389	7,820
Partial discharge (high flow and/or low flow)	54	7,395	472	42	7,963
Lake reservoir and contents	25	442	184	160	811
SURFACE-WATER QUALITY					
TOTAL	745	4,216	1,230	39	6,230
Surface-water stations (excluding temperature only)	504	3,510	955	38	5,007
Sediment stations	241	706	275	1	1,223
GROUND WATER					
Sites at which water levels and/or pumpage are collected annually or more frequently			21,400 (total)		
Approximate number of sites at which well or spring records are maintained by computer file			300,000(total)		

[1] Includes permittees and licensees of the Federal Power Commission.

Most of the streamflow and stream-quality data that the Survey collects and analyzes are published not only in various Federal and State reports but are also filed in computer storage. WATSTORE, the data storage and retrieval system for the National Water-Data System, now contains approximately 70 percent of the streamflow and water-stage data and 35 percent of the quality of ground- and surface-water data collected by the Federal sector.

Two major files in WATSTORE were made available to outside users in 1976, and several Federal and State agencies have registered as users. Those files are the Daily Values File and Station Header File. The enormous volume of surface-water data collected by the U.S. Geological Survey's Water Resources Division and other agencies may be accessed directly by users nationwide through their own computer terminals. These two files plus others in the WATSTORE system are available through more than 50 terminals in U.S. Geological Survey field offices.

In 1976, WATSTORE was augmented by the addition of the Ground Water Site Inventory (GWSI) data base. This data base contains basic physical, geohydrologic, and geologic data about wells, springs, test borings, and other sources of ground water. By the end of the year, the GWSI data base contained records for more than half a million sites. By 1980 it is expected to grow to a million records.

The National Water Data Exchange (NAWDEX) was established in 1976 to assist users of water data to identify, locate, and acquire needed data. It provides a nationwide service for indexing and describing the characteristics of data available from the entire spectrum of data-collection activities throughout the Federal and non-Federal sectors of the water-data community. Requests for needed water data are received by a central program office and referred to those organizations that can best respond to the request. NAWDEX maintains two computerized data bases: (1) a Water Data Sources Directory, which identifies and describes more than 300 organizations that collect water data, and (2) a Master Water Data Index, which currently identifies and describes the water data available from more than 61,500 sites nationwide. The contents of the Index are expected to triple in 1977. As of October 1976, the NAWDEX organization was composed of four Federal and three non-Federal members.

During the year, major emphasis was placed on "baseline water quality." The baseline surface-water-quality concept involves a system of continuing multipurpose measurements of stream quality designed to be the factual base for waste-management and water-supply studies by all concerned levels of government. During fiscal year 1976, 345 stream sites were operated as part of the National Stream Quality/Quantity Accounting Network (NASQAN).

More than 40 chemical, physical, and biological characteristics (table 15) are being measured at each of the 345 NASQAN stream sites (fig. 51); in addition to these analyses, radiochemical determinations are being made at 50 sites, and pesticide-residue determinations are being made at 153 of the network sites. The NASQAN program provides balanced and unbiased information for evaluating stream-quality conditions and changes. In terms of Federal interest, NASQAN is designed to respond to the stream-information requirements of agencies such as the Water Resources Council, the Council on Environmental Quality, and the U.S. Army Corps of Engineers and of special groups such as the National Commission on Water Quality. The NASQAN network complements the efforts of the Environmental Protection Agency in fulfilling the information requirements specified under Section 104(a)(5) of the Federal Water Pollution Control Amendments of 1972 (Public Law 92–500), which calls for the establishment of a nationwide water-quality surveillance system.

Increasing implementation of the Federal Water Pollution Control Amendments of 1972 (PL 92–500) and the added impetus of the Safe Drinking Water Act (PL 93–523) directed more attention to the quality of ground water. In addition to more than 50 studies in the Federal-State Cooperative program concerned with waste-disposal sites such as landfills, industrial-waste ponds, and unsewered urban areas, federally sponsored subsurface waste studies are increasing.

Current-meter measurement of flow of Susquehanna River at Harrisburg, Pa.

TABLE 15.—*Characteristics measured at NASQAN stations*

[Frequencies: C, continuous; D, daily; M, monthly; Q, quarterly]

Characteristic	Frequency
Field determinations:	
Water temperature	[1]C, D, or M
Specific conductance	[1]C, D, or M
pH	M
Discharge	C
Coliform, fecal	M
Streptococci, fecal	M
Common constituents (dissolved):	[2]M or Q
(Bicarbonate, carbonate, total hardness, noncarbonate hardness, calcium, magnesium, fluoride, sodium, potassium, dissolved solids, silica, turbidity, chloride, and sulfate).	
Major nutrients:	
Phosphorus, total as P	M
Nitrite plus nitrate, total as N	M
Nitrogen, total Kjeldahl as N	M
Trace elements (total and dissolved):	Q
(Arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, selenium, and zinc).	
Organics and biological:	
Organic carbon, total	Q
Phytoplankton, total, cells/ml	M
Phytoplankton, identification of 3 codominants	M
Phytoplankton, 3 codominants, percent of total	M
Periphyton, biomass, dry weight g/m^2	Q
Periphyton, biomass, ash weight g/m^2	Q
Periphyton, chlorophyll *a*	Q
Periphyton, chlorophyll *b*	Q
Suspended sediment:	
Suspended sediment concentration	M
Percent finer than 0.062-mm sieve diameter	M

[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] Quarterly or monthly, depending upon whether relationships have been established between conductance and concentrations of various common constituents.

The subjects include pollution from feedlots, mine waste, and the residuals of chemical-warfare manufacture, research in seismic effects of deep-well injection, development and use of borehole geophysical tools for evaluating injection aquifers, and the impacts of disposal of treated municipal wastewater in pits on Long Island.

The Survey is conducting a pilot program of river-quality assessments. The first study was completed in 1976 on the Willamette River basin of Oregon. Results of the study have had a significant impact on decision-making processes for the basin, and nationally as well. The study found that further waste treatment, in addition to existing basin-wide treatment, would produce insignificant improvement in the dissolved-oxygen concentrations in the river and that augmentation of the low flows from headwater streams was necessary for maintaining the State's high dissolved-oxygen standards.

SUPPORTING SERVICES

In addition to the publishing of reports and maps, this support program includes management of the

Water Resources Division Training Center at Lakewood, Colo. In 1976, 38 courses in hydrology were given to 850 scientific and technical personnel. Participants included not only Survey personnel but also representatives of cooperating State agencies and foreign hydrologic organizations. Some training courses were held at other locations that provided either a hydrologic setting or the laboratory facilities essential to the presentation of the course material.

The subject matter of the courses ranged from instructions on the operation of hydrologic instruments to the programming of sophisticated hydrologic computer models. The classroom training is coupled to a video-tape production system that provides video tapes of courses for loan to all offices.

Another supporting service is the Central Laboratory System of the Water Resources Division. The newly constructed laboratory complex in Denver, Colo., and the Atlanta, Ga., and Albany, N.Y., facilities, together, have the capacity for determining virtually all the physical, chemical, and biological characteristics of water samples for the national program. During fiscal year 1976, about 114,000 analyses were made by the Central Laboratory System (fig. 53). The Denver laboratory also houses 16 project offices concerned with methods development and applied research in water resources.

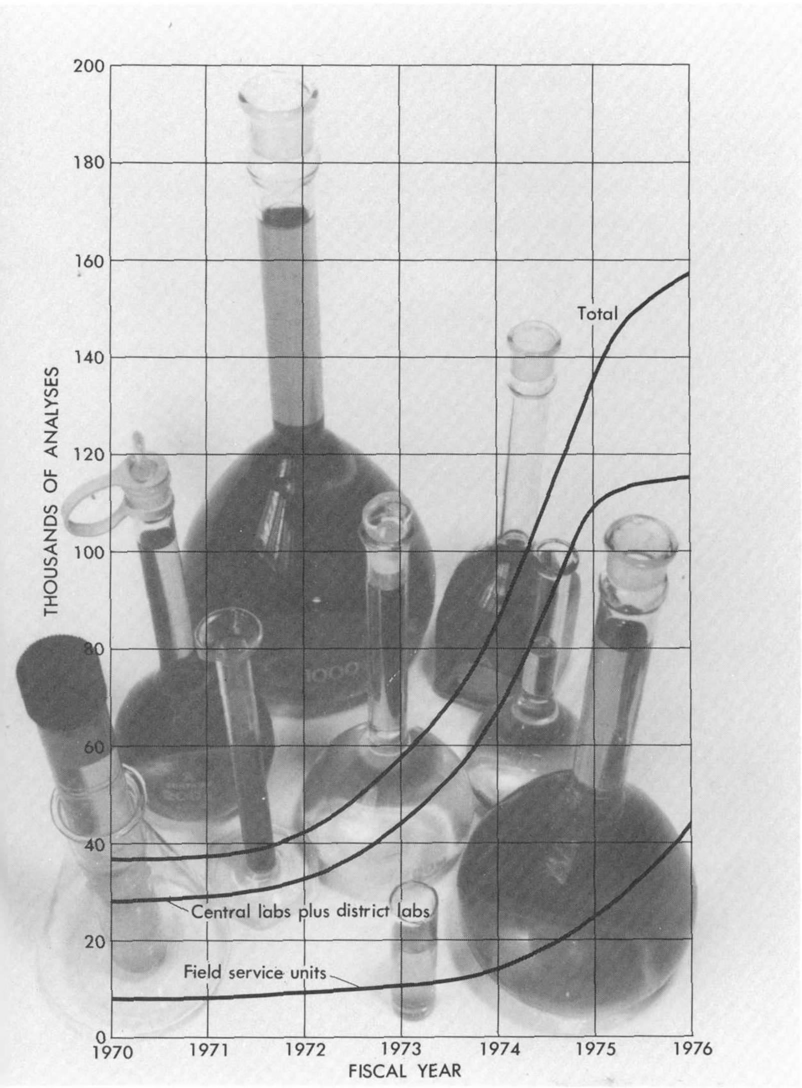


FIGURE 53.—Number of water-quality analyses performed by the Water Resources Division, 1970–76.

INTERNATIONAL ACTIVITIES

For more than two decades, the Water Resources Division has been active in technical assistance programs under the United States Foreign Assistance Act, sponsored mostly by the Agency for International Development and its predecessors in the Department of State. In the last few years, however, much of the technical-assistance activity has been funded by reimbursable agreements with the Department of State.

The Division has been appointed by the Department of State as the lead agency for the U.S. National Committee on Scientific Hydrology and provides its Secretariat. The Committee represents the hydrologic community of the United States primarily for the International Hydrological Program, under the aegis of UNESCO, but it also concerns itself with the Commission for Hydrology of the World Meteorological Organization. Highlights of the 1976 program of technical assistance included:

- Provision of technical advice on water resources to the Kingdom of Saudi Arabia. Comparative studies were made of alternative sources of water to supply Ar Riyad area.
- Improvement of existing geologic maps by interpretation of Landsat imagery of the Yemen Arab Republic. Test drilling and monitoring produced new information on occurrence and fluctuations of ground water.
- Planning and supervision of test and production drilling programs in water-short areas of Kenya.

Critical National Water Problems

COAL HYDROLOGY

Many of the coal-hydrology projects are concerned wholly or partly with the adequacy of water supply for direct mining use, coal gasification, cooling and processing use, or transport via slurry pipelines. In the latter case, 1976 saw increased concern on the part of the States and the Congress with plans to utilize ground water from the deep Madison aquifer, underlying parts of Wyoming, Montana, South Dakota, and Nebraska, for transport of coal in a slurry pipeline. These concerns prompted Congress to direct the U.S.

Geological Survey to make a 5-year study of the Madison aquifer and the availability of water, as well as possible impacts through its use. Exploratory drilling began in 1976, with the first test well in northeastern Wyoming. Additional sites may be selected in Wyoming, Montana, and South Dakota; drilling to depths as great as 3,050 meters (10,000 feet) may be required. The resulting improved model of the Madison acquifer is expected to permit a quantitative assessment of the water supply available from the regional system.

Coal-hydrology studies involve the concurrent determination of available water supplies and baseline water-quality data reflecting pre-mining or current mining and reclamation conditions. Such information is essential to the assessing of any future impacts caused by additional mining and by new conversion industries. It is expected that baseline-monitoring needs will increase as coal-leasing restrictions are eased and reclamation standards are adopted.

OIL-SHALE HYDROLOGY

Water problems, and potential environmental impacts related to mining, waste disposal, and refining of oil shale, are major constraints to oil-shale development. The oil-shale program is providing the data on the surface- and ground-water hydrology needed to: (1) predict the amount and quality of ground water present in the oil shale and how it will affect underground mining, surface mining, and in-situ oil-extraction processes; (2) predict the effects on ground and surface water of the disposal of a tremendous volume of spent shale; and (3) provide baseline data to enable the Department of the Interior to evaluate the long-term impacts of oil-shale development on water quantity and quality both in the oil-shale region and on the Colorado River basin.

The area under immediate study covers about 64,750.1 square kilometers (25,000 square miles) in Colorado, Utah, and Wyoming and includes four Federal prototype leases, as well as several developments on private lands. In addition to baseline monitoring of the surface- and ground-water quantity and quality, basic hydrogeologic data on aquifer properties and the relation of surface water to ground water are being obtained by core drilling and aquifer testing and are being used to develop predictive models of the hydrologic system to simulate the effects of mining. Geochemical and geomorphic research is determining the pollution risks of the wastes that are associated with mining and surface processing.

NUCLEAR HYDROLOGY

One method for managing nuclear waste is to store the waste on or in the Earth's crust where the characteristics of the geologic formations at the disposal site are such as to isolate the waste from the environment until radionuclides in the waste decay to a safe emission level. The length of retention time required is dependent on the half-lives of radionuclides in the waste, and retention time may be more than tens of thousands of years.

Water is the principal medium in which waste products can be moved away from a disposal site. Current research, therefore, is aimed at understanding the transport of waste in water. This research includes studies in geochemistry, ground-water movement, and solute transport. Geochemical studies include sorption, solubility of radionuclides, and interaction between waste and geological formations. Such studies are performed both in laboratories and in the field at waste burial sites. Ground-water tracer studies are in progress in the Amargosa Desert of Nevada to develop a methodology for determination of local ground-water movement. Development of theoretical two- and three-dimensional ground-water solute-transport models, used to predict concentration, travel time, and pathways of migrating radionuclides, are also in progress. The results of this research will be used to develop hydrogeologic criteria for locating future low-level radioactive-waste burial sites and for designing the hydrologic monitoring systems for such sites. Research on the use of hydrofracturing as a tool to dispose of liquid waste, by mixing it in a slurry and injecting it into bedded shale, is also in progress at Oak Ridge National Laboratory, Tenn.

Radioactive wastes are classified according to their form, either liquid, gas, or solid, and are further classified as high-level wastes or other wastes according to the level of radioactivity of their source. High-level wastes, by definition, result only from reprocessing irradiated reactor fuels. Other wastes include spent ion-exchange resins and filter sludges resulting from treatment of contaminated liquids, contaminated air filters, clothing, laboratory equipment, and so forth.

To support the Energy Research and Development Administration in its search for repositories for disposal of high-level wastes, hydrologic and geologic investigations by the Survey are in progress at various locations and involve different geologic formations. Site-feasibility investigations are in progress at Carlsbad, N. Mex., at salt domes in Louisiana, in bedded salt in the Paradox Basin, Utah, the Eleana Shale in Nevada, and the Pierre Shale in Colorado, South and North Dakota, and adjacent States. Also underway is a study of seismicity, a part of the investigation of bedded salt in New Mexico associated with the injection of oil-field brine in the Central Basin Platform in the area of Texas and New Mexico.

GEOTHERMAL PROGRAM

Hydrologic investigations are an integral part of the Survey's multidisciplinary Geothermal program. The hydrologic-research activities are intimately related to the geological, geochemical, and geophysical phases of the program, and the projects of the hydrologic specialists involve most of the fields into which the Geothermal program is divided. Resource-assessment projects with emphasis on hydrogeology are being carried out on both regional reconnaissance levels and detailed site-investigation levels.

Hydrologic modeling; water chemistry and physics; techniques of drilling, logging, and hydrologic testing; and environmental effects are other important fields of geothermal research. The hydrologic-modeling research is being done on both a theoretical and a site-related basis. The main regions being modeled are the Gulf coast, the Salton Trough, Calif., and the Raft River area of Idaho.

The water-chemistry studies are coordinated with the regional and site investigations, and they include research and analysis on the geochemistry of geopressured systems and trace elements in support of the Federal leasing program of the Conservation Division.

UNDERGROUND HEAT STORAGE PROGRAM

The feasibility of repetitively cycling large amounts of thermal energy in the form of heated ground water is being evaluated, including the theoretical analysis of thermal diffusion in ground water and of thermal conductivity of aquifer materials.

Field tests are presently being performed near Mobile, Ala., by the Water Resources Institute at Auburn University, Ala., jointly funded by the Survey and the Energy Research and Development Administration through the Office of Water Research and Technology. The U.S. Geological Survey is serving as technical monitor. Field data from such tests will permit verification of digital aquifer-system models. These models are kindred to models being developed for geothermal studies and waste-heat disposal studies, all of which are complementary.

GROUND-WATER RECHARGE

Studies on ground-water recharge include the use of both spreading basins and injection wells. Studies in the semiarid High Plains of Texas and New Mexico are developing methods to predict the amount of water that can be returned to aquifers by examining the fundamental properties that control movement of water into aquifers, the rock-water interactions that occur during storage, and the diffusion-dispersion phenomena accompanying water movement after emplacement. In another area, a report has been completed on the relative merits of various mensuration techniques of the parameters related to the design of pits for artificial recharge on Long Island, N.Y.

Accomplishments to date in these studies on ground-water recharge include:

- Demonstration under experimental field conditions that recharge is technically feasible at selected locations on the southern High Plains.
- Development of a method for determining the permeability of the unsaturated materials above the water table by monitoring air-pressure changes at depth.
- Development of unique instrumentation for extraction of water samples from the unsaturated zone to depths greater than 30.5 meters (100 feet) below land surface. This instrumentation makes feasible the routine monitoring of quality changes in percolating water deep in the unsaturated zone beneath spreading sites.
- Demonstration of the utility of water-quality modeling techniques to predict water-quality changes at depth beneath spreading sites.
- Improvement of core-barrel sampling equipment that has resulted in increased core-sample recovery from unconsolidated or poorly consolidated aquifers.
- Development of geophysical-logging techniques that relate the logged parameters of gamma radiation, neutron response, resistivity, and natural gamma radiation to the movement of recharge water.
- Development of a methodology for visual examination of pore space and demonstration of clogging mechanisms through use of the scanning electron microscope and microanalysis.

MAPPING IN FLOOD-PRONE AREAS

The mapping program in flood-prone areas, begun in 1969, is directed toward rapid identification of areas subject to inundation. The program has received a high priority to meet flood-plain management and land-use planning needs as expressed in recommendations of the Task Force on Federal Flood Control Policy (House Document 465, 89th Congress) and the National Flood Insurance Act of 1968. During 1973 and 1974, the Federal Flood Insurance Administration (Department of Housing and Urban Development) provided substantial funding to accelerate the program.

The Geological Survey published about 700 maps of flood-prone areas in 1976. Since the beginning of the program in 1969, the Survey has prepared and printed more than 12,500 maps and 1,000 descriptive pamphlets and has printed 220 maps prepared by the Soil Conservation Service. The maps identify the flood-prone areas of virtually all the developed and developing parts of the Nation. Yet to be mapped are many areas of potential future development, public lands for which management and planning decisions are needed, and recreational lands.

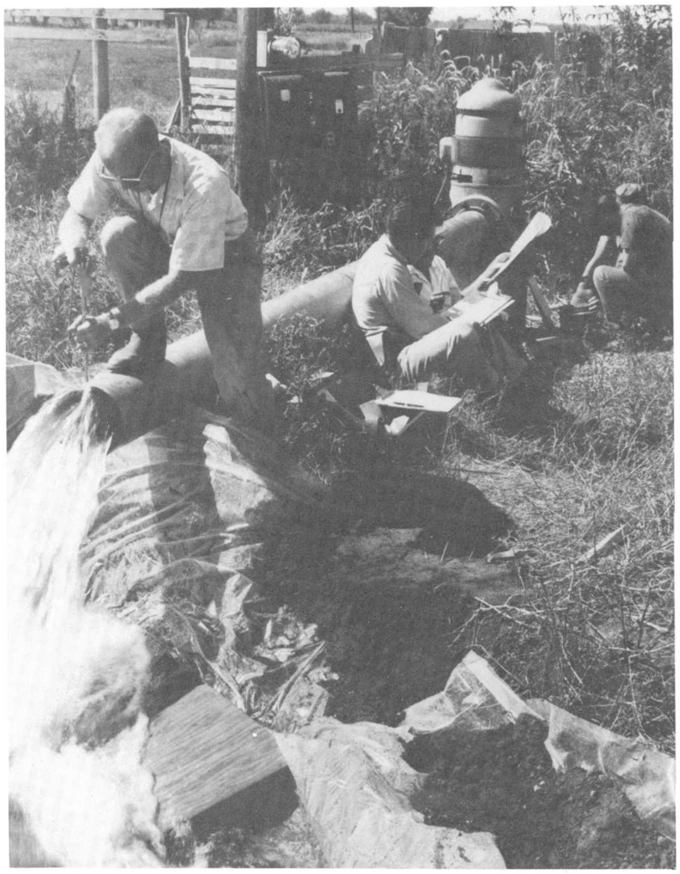
Flood-prone-area maps show on a 7.5-minute quadrangle topographic map base (scale 1:24,000, 1 centimeter on the map equals 240 meters) the approximate boundaries of areas having a 1-percent chance of being flooded in any given year. The maps are used extensively to meet local planning needs and to meet objectives of the National Flood Insurance Act of 1968 and the National Disaster Protection Act of 1973.

The flood-prone-area maps are stocked in field offices of the Water Resources Division for general distribution to the public without charge. As many as 200 separate requests each month are received in some of the field offices.

In addition to conducting reconnaissance flood mapping, the Geological Survey is one of several agencies that are conducting flood-insurance studies for the Department of Housing and Urban Development. These studies include flood-profile information and delineation of 100-year floods on city or community maps of scales such as 1:4,800 (1 centimeter on the map equals 48 meters). Since 1970, such studies have been undertaken by the Survey in about 400 communities.

Documentation of major flood events that occur every year in the United States provides flood information required for the prudent management of flood-plain land. In 1976 the U.S. Geological Survey and the National Weather Service (National Oceanic and Atmospheric Administration) published joint reports on investigations of three large floods. Cooperative reports on disastrous floods during February and July 1976 in Maine and Colorado, respectively, are in preparation. In addition, during 1976, the Geological Survey released to the open file investigative reports for five severe floods covering parts of six States. The flood caused by the failure of Teton Dam, Idaho, in June 1976, was documented by the publication in August 1976 of 17 hydrologic atlases of the area affected (HA 565–HA 581). A formal report on the Teton Dam flood is in progress.

The National Water Data Storage and Retrieval System (WATSTORE) maintains a Peak Flow File of flood records for more than 12,000 surface-water sites and contains more than 325,000 peak observations. In 1976, this file of annual maximum streamflow (peak discharge) values and gage-height (stage) values was released for public use through the Survey's WATSTORE system.



Measuring rate of flow in pumping well.

SUBSURFACE WASTE STORAGE

The Survey's subsurface-waste-storage program consists of: (1) regional delineation and description of deep saline-aquifer systems that are potentially useful for waste storage, (2) assessment of the degradation of ground-water quality that has been caused, or may be caused, by waste disposal or other existing activities, (3) determination of the field values of hydrodynamic dispersion of waste in ground water, and (4) other fundamental studies in geology, hydrology, chemistry, and physics related to the movement of waste in aquifers. The purpose of the program is to define the hydrologic principles and techniques relevant to the use and management of subsurface space for storage of waste to prevent endangering usable water resources. The pressures to store wastes underground keep building because of increasing legal restraints on surface discharge and disposal practices. The impact of contamination on ground water is long lasting, although usually limited in area. Each year, however, many new points of pollution are created and few are eliminated.

Studies related to potential waste-disposal sites or to impacts of existing waste-disposal activities on ground-water quality in 1976 include: development and testing a method of measuring tectonic stress in boreholes to evaluate the potential of injection-pressure-induced seismic events; characterizing the impact and quality of water reaching the water table beneath recharge basins utilized for the disposal of treated municipal sewage on Long Island; mapping potential waste-injection aquifers on the Atlantic and Gulf Coastal Plains; and investigating the generation and movement of leachate from oil-shale and coal strip-mine wastes.

Only part of the subsurface-waste-storage program is directly concerned with the impacts of potential ground-water degradation from energy-related activities such as mine-waste disposal. However, data on industrial waste-injection problems and potential disposal horizons (porous rock formations), or on the percolation from surface disposal sites, industrial-waste lagoons, and spray irrigation of wastewater, all find applications in energy developments. Many of the studies that yield data and insights into waste movement involve areas where waste disposal was practiced for many years before pollution was observed or before the public became concerned. Studies of these sites will show the long-term effects of waste movement, dispersion, dilution, retention, and diminution and will provide information that can be used in the planning of all kinds of waste-disposal developments, including those that are energy related.

ESTUARINE AND COASTAL STUDIES

Estuarine and coastal studies determine the substances entering estuaries and coastal waters, their movement in the waters, their effect on the environment, and their subsequent fate; they determine factors and impacts affecting present and future usability of freshwater supplies in coastal areas. Man-induced stresses on estuarine ecosystems frequently result from increased urbanization. These stresses are manifested in the need for disposal of sewage and storm runoff, improved navigation facilities, expanded water supplies, and increased energy requirements. The primary purpose of the Geological Survey's water-related projects in estuaries is to provide data for design and to evaluate the hydraulic, chemical, and biological changes induced by human activities.

During 1976, estuarine and coastal studies continued on the biogeochemistry and circulation patterns in San Francisco Bay. A comparative study of major estuaries on the west coast was undertaken. Studies continued on the impact of waste disposal in the Rhode River estuary, a tributary to Chesapeake Bay, and in the Duwamish River estuary of Washington. Digital flow models of estuarine dynamics are being developed to appraise some of the present and future effects and interrelationships of natural and manmade impacts on estuaries. Two-dimensional models of water circulation and solute transport are currently being used in studies of Tampa Bay in Florida and Port Royal Sound in South Carolina. Research into the development of three-dimensional models is continuing. Studies to evaluate the flow patterns, freshwater-saltwater balances, sediment transport, and ecologic composition of estuaries are currently being conducted in California, Delaware, Florida, Maryland, North Carolina, Oregon, South Carolina, Texas, and Washington. Many of these studies are cooperative efforts with other Federal, State, and local agencies that are attempting to define the consequences of planned changes in estuarine water balances.

Stream gaging.

Destruction caused by flash flood on Big Thompson River, Loveland, Colo. (Photograph courtesy of United Press International, Inc.)

Research and Development

Mission: to understand hydrologic systems sufficiently well to predict quantitatively the response of hydrologic systems to stress—both natural and manmade.

Water Resources Division research supports the programs of the Division by (1) providing operational products (analytical methods, instrumentation for data collection, and predictive models), and (2) making available to the Division a group of consultants and instructors to spend up to 30 percent of their time in district consultation and in-house teaching. The research program accounts for about 17 percent of the Division's total appropriation. It has been divided into a number of subdiscipline areas:

Water Chemistry research is concerned with understanding the behavior of constituents which can be measured. An understanding of these controls assists in the design of appraisal studies by providing a guide indicating where and when to sample and how to interpret the results.

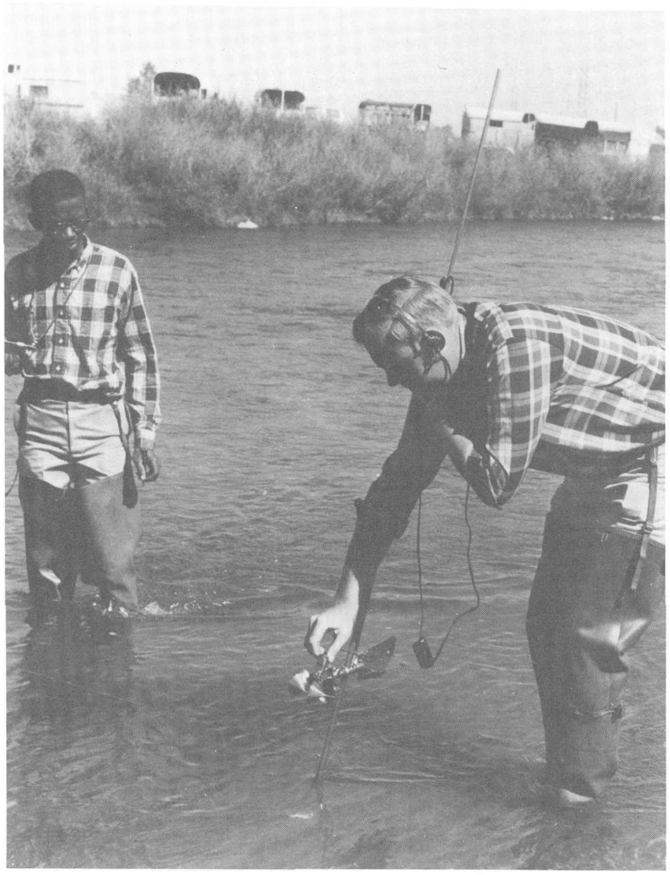
In *Geochemistry* the goal is to understand the relation of mineralogy and geologic structure to water chemistry in various aquifer systems and to understand the regional paleoclimatic effects on isotopic hydrology.

The *Solute Transport* research group shares its interest in the solutes of surface and subsurface waters with several of the other groups. Their objectives are to increase the understanding of the factors which determine the concentrations of particular solutes and to develop methods for identification of the most relevant processes affecting the concentrations and for measuring the parameters controlling these processes.

The objective of the *Hydrogeology* discipline is to obtain the maximum useful information possible from a point source (a borehole, for example) and surface mapping and combine that data with geologic insight to extrapolate the data for regional interpretations.

The *Groundwater Physics* research objectives are to develop techniques for evaluating and managing ground-water systems using mathematical models and for conducting field studies to understand fundamental principles of movement of fluids through porous media.

In the *Surface Water* discipline, emphasis is placed on developing and improving flow models that simulate natural rainfall and runoff situations. The models can then be used for estimating flood peaks, determining effects of temperature on winter runoff, making step-regression studies of inflow to reservoirs to develop flow forecasting for low-flow periods, and



Measuring and recording streamflow, velocity, and depth information.

determining reservoir-yield and bank-storage relations.

Surface Water Physics is involved in numerical simulation of one-, two-, and three-dimensional flow and transport models.

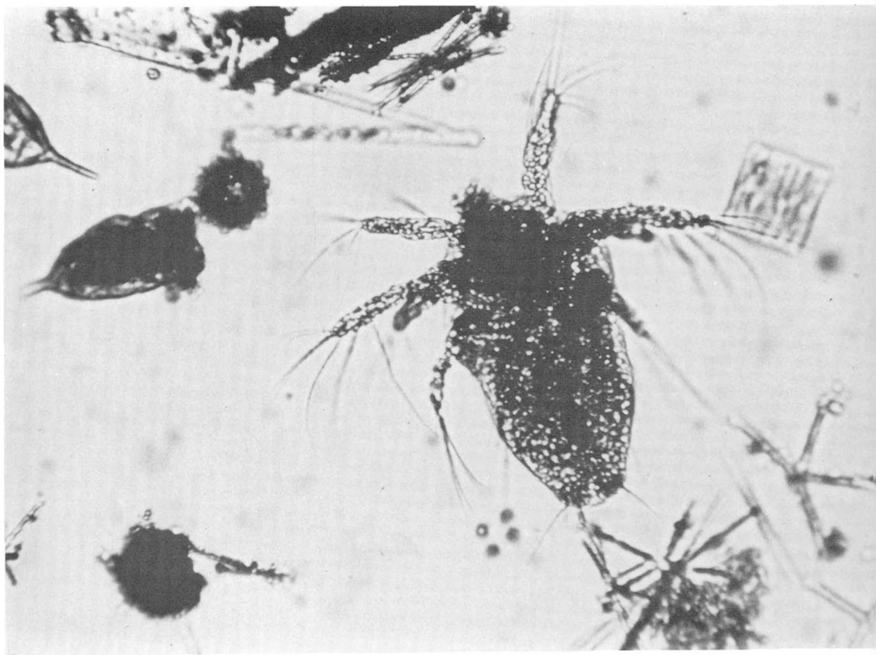
The *Sediment* research discipline is working to develop deterministic and stochastic models of sediment-transport processes. These models should aid in assessing the causal factors involved in changing stream-sediment loads with time, the rates at which rivers change their morphologic features, particularly as to catastrophic events and sources, pathways, and sediment sinks in rivers.

The *Snow and Ice* research group is concerned with defining the hydrologic cycle of major basins in the western mountains where as much as 90 percent of the runoff is thought to be derived from snowmelt. As some glaciers respond in a very sensitive way to slight, long-term changes in climate, the group is also studying the response of glaciers to changes of input (snowfall) and output (melting), the meteorological factors which determine input and output, and the climatic change as recorded by glaciers, glacier runoff, and glacier hazards.

Unsaturated Zone and Evapotranspiration research involves studies of evapotranspiration and flow in the unsaturated zone to evaluate the feasibility of such water-management techniques as: artificial ground-water recharge, clearing phreatophytes or lowering the water table to salvage evapotranspiration from ground water, modification of upland vegetation to increase runoff, and evaluation of radioactive-waste burial grounds.

Ecology research has varied objectives and approaches. They are mainly problem- or environment-oriented and all are water related. The environments studied range from mountains to estuaries, from the arctic tundra to deserts, and from lakes and streams to wetlands and ground-water reservoirs. Living organisms receive most emphasis in all projects and range in type from bacteria to fish and from microscopic algae to giant cacti and forest trees.

The basic objective of *Hydrologic Systems* research is to develop mathematical techniques and digital computer programs to solve complex hydrologic problems.



Sample of river water seen through a microscope; both aquatic plants and animals are visible.

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Above, a bucket wheel excavator being used to strip overburden above coal seam at a strip mine. Bottom, offshore oil and gas platforms in the Santa Barbara Channel, California. The USGS Conservation Division supervises operations such as these on Federal and Indian lands.

Conservation of Lands and Minerals

OVERVIEW

The Conservation of Lands and Minerals activity has three major missions:

- Classification of public lands according to their content of leasable minerals and their value for water-power and water-storage purposes.
- Evaluation of mineral tracts that are subject to competitive leasing.
- Supervision and regulation of exploration, development, and production of minerals on Federal, Indian, and Outer Continental Shelf lands authorized by lease, license, and prospecting permits, including the collection of royalties and certain rentals that result from those operations.

From data acquired in the pursuit of these missions, the Geological Survey provides technical advice and information on the leasing or disposal of mineral rights, as well as resource-management information, to land-management agencies, including the Bureau of Land Management, the Bureau of Indian Affairs, the Bureau of Reclamation, the Forest Service, the General Services Administration, and the Department of Defense. The Geological Survey also implements and enforces all lease stipulations and operating regulations and certain leasing regulations that are issued by the Bureau of Land Management and the Bureau of Indian Affairs.

The importance of Federal and Indian lands to the Nation's domestic supply of energy and mineral resources is illustrated in figure 54. In fiscal year 1976, 8 percent of the coal, 9 percent of the uranium, 18 percent of the oil, and 23 percent of the natural gas produced in the United States came from leased Federal and Indian lands. The share of the Nation's coal that was produced on Federal and Indian leases has increased about 300 percent since 1970, uranium has increased nearly 100 percent, and gas produced has increased almost 44 percent; oil has remained essentially unchanged. In fiscal year 1976, the value of all energy and mineral commodities produced

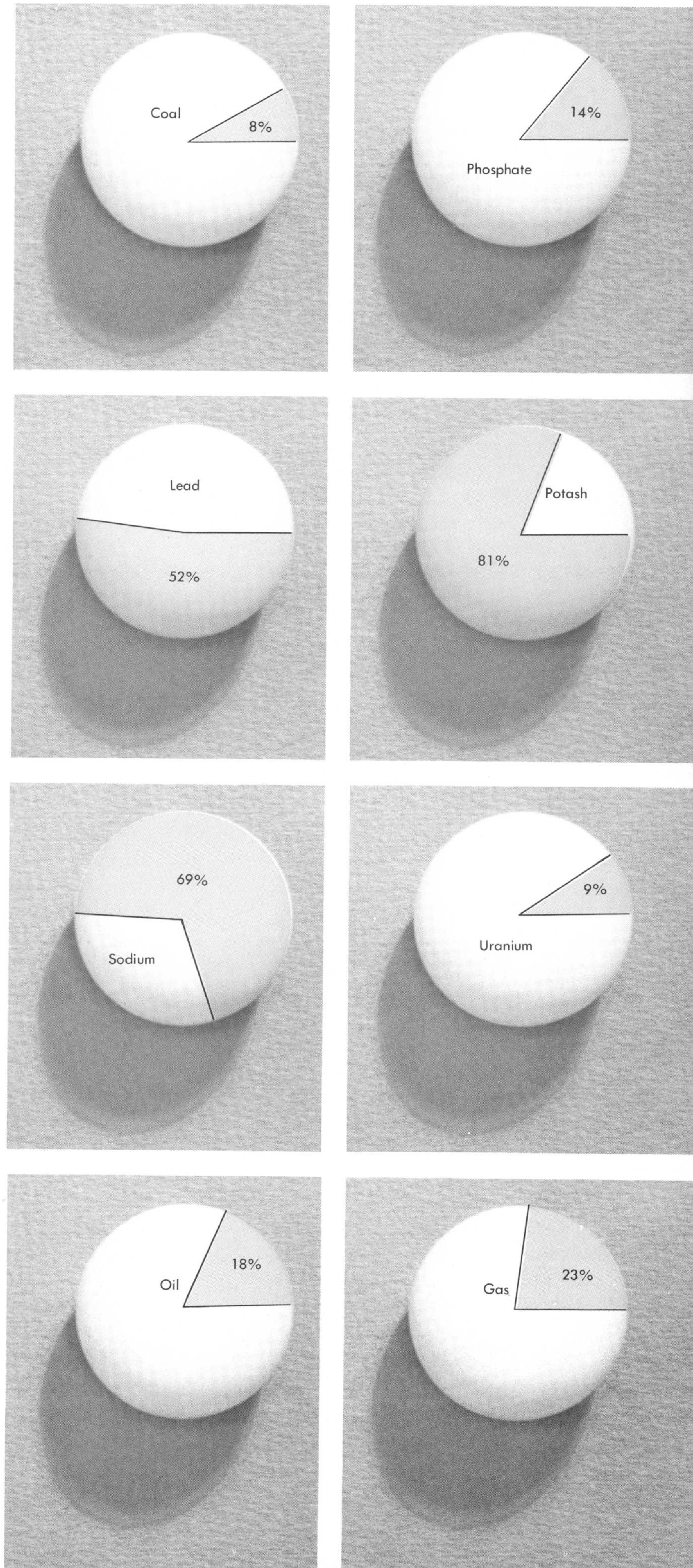


FIGURE 54.—Production from Federal and Indian lands as ▶ percentage of total U.S. production in fiscal year 1976.

from leased Federal and Indian lands amounted to about $6.8 billion. Royalties collected by the Survey during the same period totaled more than $931 million.

Highlights

Accomplishments of the Conservation of Lands and Minerals activity in 1976 included the following:

- Completion of tract evaluations for four Outer Continental Shelf lease sales covering 2.8 million hectares (6.9 million acres) in fiscal year 1975, four sales covering 1.9 million hectares (4.7 million acres) in fiscal year 1976, and one sale covering more than 300,000 hectares (800,000 acres) in the transition quarter. During these two fiscal years, 700,000 and 500,000 hectares (1.8 million and 1.2 million acres) were leased for bonuses of $2.0 billion and $1.3 billion, respectively; during the transition quarter, more than 200,000 hectares (500,000 acres) were leased for cash bonuses of $1.1 billion.
- Revision and updating of Outer Continental Shelf Orders for the Gulf of Mexico and Pacific areas.
- Supervision of 1,683 offshore oil and gas leases covering 3.1 million hectares (7.7 million acres) in fiscal year 1975 and 1,886 leases covering 3.6 million hectares (8.8 million acres) in fiscal year 1976.
- Supervision of 125,718 onshore oil and gas leases covering 37.5 million hectares (92.7 million acres) in fiscal year 1975 and 125,847 leases covering 37.2 million hectares (92.0 million acres) in fiscal year 1976.
- Supervision of 2,557 mineral leases covering 3.7 million hectares (9.1 million acres) in fiscal year 1976.
- Collection of $950 million in royalties and rentals from all sources during fiscal year 1976.
- Tract evaluation for 12 geothermal lease sales during fiscal year 1976. More than 51,000 hectares (126,000 acres) in 65 tracts were leased, for a total bonus of $987,256.

BUDGET AND PERSONNEL

Fiscal year 1976 was a period of continued growth for the Conservation of Lands and Minerals activity. The appropriation for this activity increased by 20.3 percent to $43.3 million in fiscal year 1976, of which $41.4 million was obligated during fiscal year 1976 (table 16). The Outer Continental Shelf land subactivity increased $3.0 million (12.9 percent) to $26.2 million, representing 63.1 percent of the total direct program funding (fig. 55). The increase in the Outer Continental Shelf subactivity, 54.9 percent of the total increase, reflects (1) the administration's decision to select and evaluate an increased number of Outer Continental Shelf tracts so as to encourage domestic energy production and (2) the need to inspect more drilling and production operations on recently leased tracts and increased activity on older tracts. The increased funds covered additional staffing, several large contracts for helicopter service to transport inspectors offshore to monitor operations, and the acquisition of geophysical data with which to select and evaluate tracts for lease sales.

TABLE 16.—*Conservation of Lands and Minerals activity obligations for fiscal year 1976 and the transition quarter by program (dollars in millions)*

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

Program	Fiscal year 1976	Percent change relative to FY 1975 in current dollars	Transition quarter 1976
Total [1]	$41.4	+15	$13.4
Outer Continental Shelf Lands	26.2	+13	9.2
Regulation of OCS oil and gas	12.2		3.4
Research on OCS safety devices	.5		.1
OCS oil and gas tract selection and evaluation	13.5		5.7
Federal and Indian Lands	15.2	+19	4.2
Regulation of operations	10.8		3.0
Oil and gas	7.0		1.9
Energy minerals (coal and uranium)	1.0		.3
Oil shale	.4		.1
Geothermal	1.0		.3
Nonenergy minerals	1.4		.4
Resource classification and evaluation	4.4		1.2
Oil and gas	.3		.1
Coal	2.2		.6
Oil shale	.3		.1
Geothermal	1.0		.2
Nonenergy minerals	.2		.1
Water-resource development	.4		.1

[1] Total direct program. Reimbursable program amounted to $187,000, bringing the total program to $41,632,000 (table 26).

Increased workload in resource classification and evaluation and supervision of development and production operations also resulted in a budget increase of $2.5 million (45.1 percent) for the Federal and Indian Lands subactivity.

Staffing of the activity increased from 926 permanent full-time employees at the end of fiscal year 1975 to 1,135 in fiscal year 1976 (table 45). Most of the increased positions were filled by geophysicists, geologists, and petroleum and mining engineers.

PROGRAMS AND ACTIVITIES

The operating environments, logistics, and technologies for exploration and development of offshore resources are completely different from those onshore. The Outer Continental Shelf Lands and onshore Federal and Indian Lands subactivities, however, both comprise: (1) resource evaluation and (2) supervision of operations. Both subactivities involve prelease responsibilities for supervision of exploration, development, and production operations and the computation and collection of royalty and certain rental payments. The onshore program also includes the classification of Federal lands for leasable mineral and water-resource development potential.

Outer Continental Shelf lands

Outer Continental Shelf leases are issued by the Bureau of Land Management, but the operating regulations are implemented and enforced by the Geological Survey. The Bureau of Land Management and the Geological Survey consult closely on the significant actions that take place before each lease sale (Adams and others, 1975). The Survey provides the Bureau of Land Management with:

- Petroleum-resource assessments and other technical information used to identify areas for leasing and to schedule lease sales.
- Environmental baseline data and geologic-hazards information for use in preparing environmental impact statements for each lease sale.
- Resource evaluations for use in jointly selecting tracts for each lease sale and in establishing fair market value for each tract.

RESOURCE EVALUATION

On the Outer Continental Shelf, resource evaluation activities are concentrated on identifying target areas for future lease sales, advising the Bureau of Land Management on the selection of tracts to offer for sale, estimating the value of oil and gas on each tract offered, determining the fair market value for each tract, and determining geologic hazards on specific tracts.

Between 1954 and 1966, Outer Continental Shelf tracts were selected for lease sales without an evaluation of their hydrocarbon potential. In 1967, the Geological Survey established a mineral-resource evaluation program to improve methods of selecting and evaluating shelf tracts for leasing. The Survey has since much expanded its geological, geophysical, and engineering capability to map, select, and evaluate the potential resource of the Outer Continental Shelf (fig. 56).

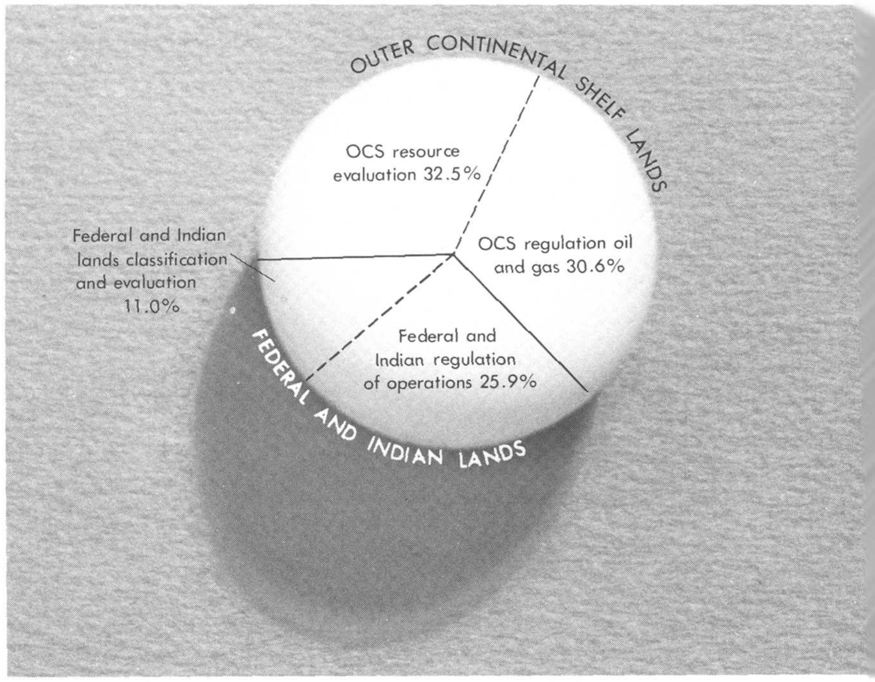


FIGURE 55.—Distribution of Conservation of Land and Minerals direct program funds by subactivity and program.

During fiscal year 1976, four Outer Continental Shelf lease sales were held: two in the Gulf of Mexico, one in the frontier area off of southern California, and one in the frontier Gulf of Alaska area. The southern California sale was the first to offer tracts in the outer banks region. The sale of eastern Gulf of Alaska tracts was the first Federal lease sale for offshore Alaska. The first lease sale in the Baltimore Canyon area of the mid-Atlantic Outer Continental Shelf, drawing $1,127,936,425 from successful bidders, was held during the transition quarter.

Tract evaluations were begun during fiscal year 1976 for Sales 44 and 47 in the Gulf of Mexico, Sales 40, 42, and 43 in the Atlantic Shelf, and Sales C–1, 45, and 46 in the Alaskan Outer Continental Shelf.

The Department of the Interior continued in 1976 to authorize deep off-structure stratigraphic test drilling in frontier shelf areas, begun in 1974. During fiscal year 1976, one test well was completed in the eastern Gulf of Alaska, one in the Pacific (southern California), and two in the Atlantic shelf (mid-Atlantic and north Atlantic). Drilling depths ranged from 1,510 meters (5,150 feet) in the Gulf of Alaska to 4,900 meters (16,071 feet) in the north Atlantic shelf. In the transition quarter, one test well was being drilled in the Bering Sea off Alaska.

Shallower off-structure test drilling was also authorized during fiscal year 1976 for holes ranging in depth from 150 to 1,200 meters (500 to 4,000 feet) in the frontier shelf areas of Alaska.

FIGURE 56.—Geologist studying well logs of oil and gas wells in the Gulf of Mexico.

During fiscal year 1976 and the transition quarter, the Survey purchased 41,013 kilometers (25,490 miles) of common-depth-point seismic data to help locate potential hydrocarbon-bearing structures, 61,338 kilometers (38,122 miles) of high-resolution seismic data to help detect the presence of shallow geological hazards, and 45,271 kilometers (28,136 miles) of gravity data and 48,249 kilometers (29,987 miles) of magnetic data for specialized studies. The total cost was $7.1 million.

SUPERVISION OF OPERATIONS

After leases are issued by the Bureau of Land Management, the Geological Survey supervises oil and gas exploratory, development, and production operations of the lease operator on Outer Continental Shelf lands to assure that operations conform with Department of the Interior operating regulations and orders and that royalties paid to the Government are correct and represent a fair market value for its share of the resources produced. Supervision of lessee operations involves:

- Review and approval of plans to conduct operations (fig. 57).
- Inspection of operations (fig. 58) and computation and collection of rents and royalties.

In fiscal year 1976, considerable activity was directed toward updating the Outer Continental Shelf Orders. A list of all the orders and their status as of the end of fiscal year 1976 are shown in table 17.

The Survey supervised oil and gas operations on 1,792 leases covering 3.4 million hectares (8.3 million acres) of the Outer Continental Shelf during calendar year 1975. Most of these operations were in the Gulf of Mexico; 74 leases were located offshore California. Total production from these leases amounted to 44.6 million tonnes[1] (330 million barrels) of oil and 98 billion cubic meters (3,459 billion cubic feet) of natural gas. The total value of all petroleum products produced on Outer Continental Shelf lands was $3.9 billion.

During calendar year 1975, Survey personnel for the Gulf of Mexico made 2,218 inspections of drilling rigs, 2,593 inspections of production platforms, and many overflights of other sites, while flying between inspections, in order to check for oilspills. As a result of these inspections, the Survey issued 1,700 warnings on individual items found not to comply with regulations and ordered 1,107 zones and 117 platforms shut-in until violations of orders and regulations were corrected. The oilspills and fires and explosions associated with Outer Continental Shelf oil and gas operations during the last 6 years are summarized in tables 18 and 19.

[1] A conversion factor of 7.4 barrels=1 tonne was used in this report.

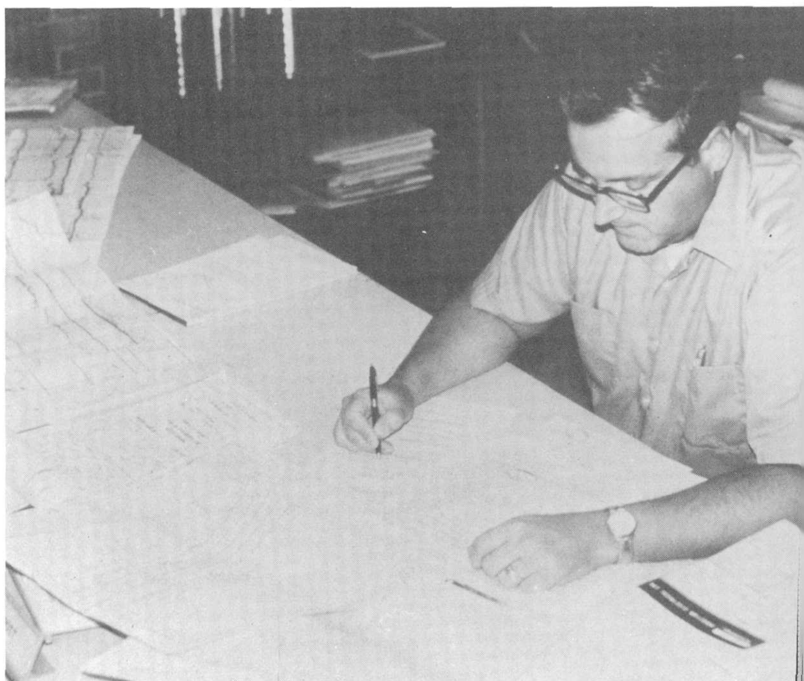


FIGURE 57.—Geologist reviews geologic information for potential geologic hazards in an area before approval of drilling plans.

TABLE 17.—*Status of Outer Continental Shelf Orders at the end of fiscal year 1976*

Order number and title	Gulf of Mexico area	Pacific area	Gulf of Alaska area	Atlantic OCS area
1. Marking of Wells, Platforms, and Fixed Structures	Effective 8/28/69.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
2. Drilling Procedures	Effective 1/1/75.	Effective 5/1/76.	Effective 3/1/76.	Effective 7/1/76.
3. Plugging and Abandonment	Effective 8/28/69.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
4. Suspensions and Determination of Well Producibility	Effective 8/28/69.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
5. Subsurface Safety Devices	Effective 6/5/72.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
6. Completion of Oil and Gas Wells	Effective 8/28/69; being revised.	Effective 6/1/71.	----------------	----------------
7. Pollution and Waste Disposal	Effective 8/28/69; being revised.	Effective 6/1/71.	Effective 3/1/76.	Effective 7/1/76.
8. Platforms and Structures	Effective 10/30/70; being revised.	Effective 6/1/71.	----------------	----------------
9. Oil and Gas Pipelines	Effective 10/30/70.	Effective 6/1/71.	----------------	----------------
10. Sulphur Drilling Procedures	Effective 8/28/69.	Effective 6/1/71.	Not Applicable.	Not Applicable.
11. Oil and Gas Production Rates, Prevention of Waste, and Protection of Correlative Rights	Effective 5/1/74.	Effective 5/1/75.	----------------	----------------
12. Public Inspection of Records	Effective 2/1/75.	Effective 12/1/74.	Effective 3/1/76.	Effective 7/1/76.
13. Production Measurement and Commingling	Effective 10/1/75.	----------------	----------------	----------------
14. Approval of Suspensions of Production	First draft in *Federal Register* 12/19/75.	----------------	----------------	----------------
U.S. Geological Survey Standard GSS–OCS # 1	Effective 2/1/76	Effective 2/1/76	Effective 2/1/76	Effective 2/1/76

In calendar year 1975, royalty revenue from the sale of petroleum and sulfur products amounted to $616 million, an increase of $56 million over calendar year 1974 and $215 million over calendar year 1973.

Oil production from the Outer Continental Shelf has been declining since 1971 (fig. 59) because discoveries have not kept pace with the declining production from older fields.

Production of natural gas increased yearly from 1953 until 1975, the first year that has shown a decline. The value of the produced gas, however, increased 50 percent because of higher prices. Production is expected to continue to decrease over the next few years unless significant discoveries are made and brought on production.

Inasmuch as production usually trails lease sales by 3–10 years, the impact of the accelerated leasing program has not yet been fully felt, but requests for approval of exploration plans and notices of intent to drill have increased.

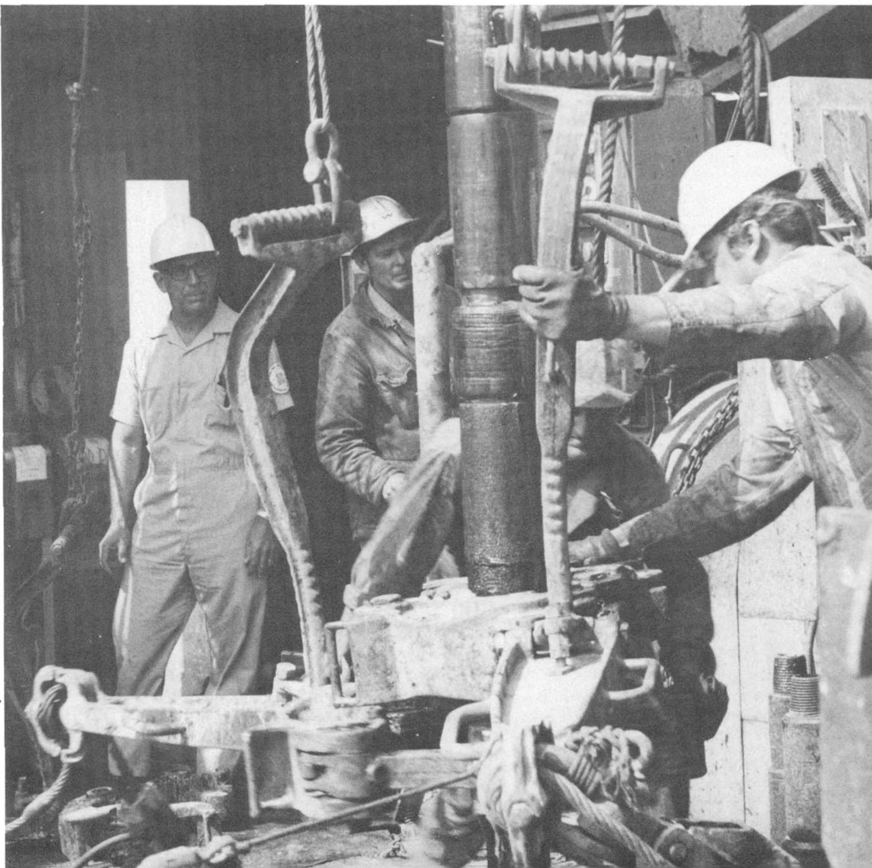


FIGURE 58.—Engineer technician inspecting drilling operation▶ on offshore platform.

TABLE 18.—*Hydrocarbon spills on Outer Continental Shelf, calendar years 1971–75*

Calendar year	Spills of 50 barrels or more		Spills of less than 50 barrels	
	Number	Barrels spilled	Number	Barrels spilled
1971	11	1,285	1,245	1,493
1972	2	150	1,159	1,032
1973	4	[1] 22,175	1,171	921
1974	8	[2] 22,721	1,129	667
1975	2	266	1,126	711

[1] 9,935 barrels spilled from a ruptured storage tank (1/9/73) and 7,000 barrels spilled from a leaking barge (1/26/73).
[2] 19,850 barrels spilled from a pipeline broken when a ship's anchor dragged on the seabed (4/17/74).

TABLE 19.—*Fires and explosions on the Outer Continental Shelf, calendar years 1970–75*

Calendar year	Number of events	Injuries	Fatalities
1970	12	31	17
1971	19	16	1
1972	31	9	0
1973	30	9	2
1974	22	15	0
1975	27	11	[1] 10

[1] A tanker collided with a platform. Oil escaping from the tanker ignited and set the ship afire. Six men died in the blaze (8/15/75).

Federal and Indian lands

The Geological Survey classifies and evaluates the mineral and waterpower and reservoir-site resources on Federal lands onshore and supervises exploration, development, and production operations on both Federal and Indian land leases. Public land laws provide for the leasing of specific minerals such as oil and gas, coal, oil shale, asphaltic minerals, sodium, potash, phosphate, and geothermal resources and of sulfur in New Mexico and Louisiana only. The laws pertaining to Indian and acquired lands authorize the leasing of all metalliferous and nonmetalliferous minerals.

The Survey in fiscal year 1976 continued to provide the Department of the Navy with technical advice on Naval Petroleum Reserve lands and supervised operations for the drilling and production of oil and gas on Naval Petroleum Reserve No. 2 (Buena Vista) in California.

RESOURCE EVALUATION AND CLASSIFICATION

The purpose of resource-classification actions by the Geological Survey is to retain for the Federal Government the title to leasable minerals and water-resource development sites that otherwise might be lost with disposal of the surface rights. Basic geologic, geophysical, and engineering data are compiled and

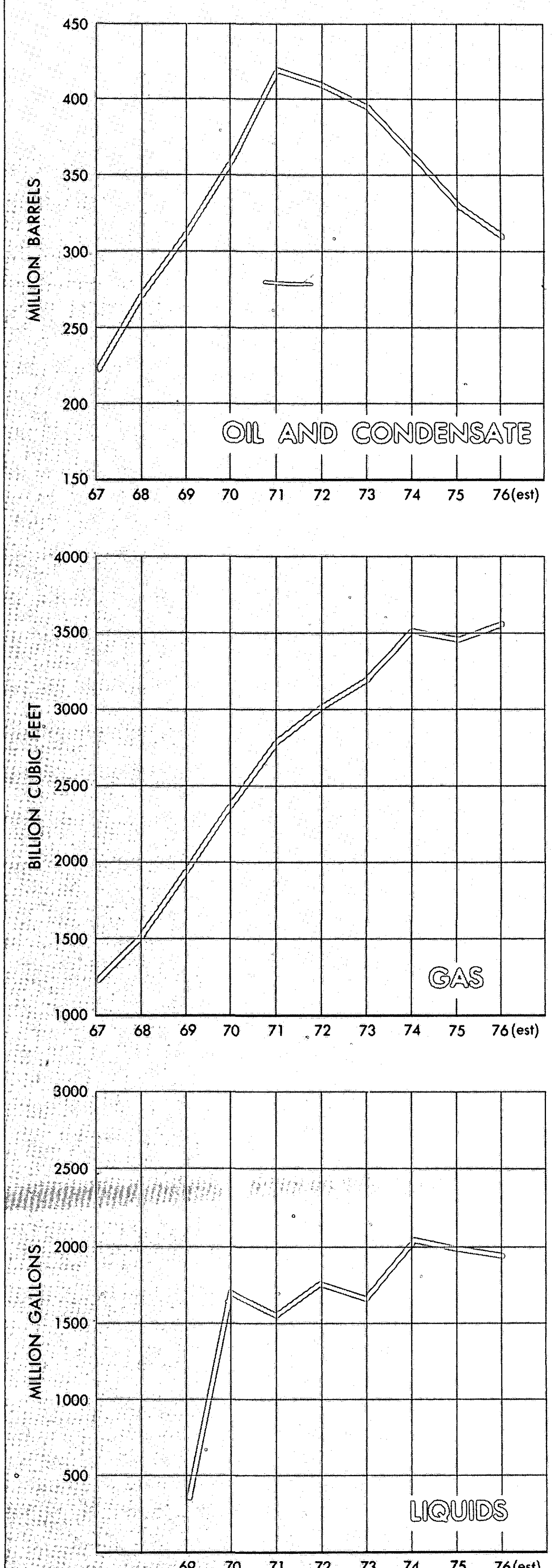


FIGURE 59.—Oil and gas production from Outer Continental Shelf lands, calendar years 1966–76. ▶

used (1) to classify Federal mineral lands and waterpower and reservoir sites, (2) to delineate prospectively valuable mineral areas, and (3) to modify or eliminate outstanding mineral withdrawals and waterpower- and reservoir-site classification or withdrawals.

At the end of fiscal year 1976, 17.2 million hectares (42.5 million acres) of withdrawn land had been classified as mineral land, and 18.5 million hectares (45.7 million acres) remained to be classified (table 20).

In complying with requests for 15,000 mineral reports by other Federal agencies during fiscal 1976, the Survey designated 950 million hectares (2.35 billion acres) of land as prospectively valuable for leasable minerals.

Once it has been classified as mineral land, Federal land must be evaluated to determine whether or not it is subject to competitive leasing or noncompetitive leasing (coal land is subject only to competitive leasing).

The Survey recommends lands for leasing whenever there is reason to believe that sufficient competitive interest exists or that leasing would be in the best interests of the United States. For lands designated as subject to competitive leasing, the Geological Survey makes a presale evaluation of each parcel of Federal land offered competitively for leasing in order to establish a fair market value for their sales.

Leasing procedures and regulations differ with each commodity. Lands within the boundaries of Known Leasing Areas are subject to competitive leasing and are not subject to lease by application. For example, when a new oil and gas field is discovered, the Survey establishes an undefined Known Geologic Structure and informs the Bureau of Land Management. This action prevents any further noncompetitive leasing of the area until the boundaries of the Known Geologic Structure can be more accurately determined and its description can be published in the *Federal Register*.

Most Indian lands are leased by competitive bidding, and the Bureau of Indian Affairs has usually relied on the Survey to parcel the tracts for sale, to recommend stipulations to be included in the leases to protect other uses, to prevent environmental damage through supervision, and to recommend acceptance or rejection of high bids offered. Complete presale evaluations for Indian land lease sales are made only when requested by the Bureau of Indian Affairs.

- *Oil and gas.*—Lands containing oil and gas are leased competitively if they are located on Known Geologic Structures of producing oil and gas fields as defined from analysis of well logs, core sampling data, production records, and maps that are required to be submitted to the Geological Survey by lessees and operators. During calendar year 1976, approximately 460 tracts covering 35,500 hectares (87,600 acres) were sold in 28 competitive oil and gas lease sales of Federal lands (table 50). During the same period, the Survey classified more than 74,000 hectares (183,000 acres) in undefined Known Geologic Structures.
- *Geothermal resources.*—Since 1971, Federal lands have been put into Known Geothermal Resources Areas on the basis of geological, geophysical, or geochemical indicias (fig. 60) or on the basis of overlapping noncompetitive lease applications. As of the end of fiscal year 1976 and transition quarter, 1,286,050 hectares (3,176,542 acres) have been placed in 133 Known Geothermal Resources Areas in 11 Western States. These lands have been available for competitive leasing since the beginning of the geothermal leasing program in 1974. As of the end of fiscal year 1976 and the transition quarter, 800 leases covering 690,000 hectares (1.7 million acres) of Federal lands have been leased.

TABLE 20.—*Status of Federal land classifications, fiscal year 1976*
[Acres in thousands]

Commodity	Mineral lands withdrawn	Classified lands		Prospectively valuable lands [1]	Known leasing areas	
		Nonmineral	Mineral		Undefined	Defined
Total	45,708	38,145	42,486	2,348,563	5,953	25,253
Oil and gas	-----	-----	4	1,476,001	5,335	11,864
Oil shale	14,206	98	-----	14,372	-----	-----
Asphaltic minerals	-----	-----	-----	17,941	-----	-----
Coal	20,471	33,445	48,560	350,800	-----	9,654
Geothermal resources	-----	-----	110,560	102,544	-----	3,029
Phosphate	1,620	4,625	414	30,601	2	40
Potash	9,411	-----	-----	80,928	49	378
Sodium	-----	-----	625	267,442	567	288
Sulfur	-----	-----	-----	5,593	-----	-----

[1] These figures represent the total acreage for each leasable mineral commodity and, because some acreage contains more than one mineral commodity, do not reflect total acreage prospectively valuable.

FIGURE 60.—Geologist sampling the water near a geothermal spring.

- *Coal.*—The coal-resource evaluation program has been providing basic geologic and engineering data and analyses for use in the Bureau of Land Management's Energy Minerals Activity Recommendation System and the coal leasing program. Basic data collected for the program include field mapping and core drilling. During fiscal year 1976 and the transition quarter, 81 primary coal projects and 10 projects involving coal of the Conservation of Lands and Minerals activity on Federal land were in progress in seven Western States (fig. 61). Drilling and coring were conducted in Colorado, New Mexico, Montana, North Dakota, Utah, and Wyoming. The data derived from these activities contributed to the definition of five new Known Recoverable Coal Resource Areas (formerly Known Coal Leasing Areas) covering 160,800 hectares (397,183 acres) (fig. 62).

To facilitate the reporting of the quality and quantity of coal deposits on Federal land and to assess the potential of that coal for commercial development, a series of coal-resource occurrence maps and coal-development-potential overlays are being prepared for submittal to the Bureau of Land Management's Energy Minerals Activity Recommendation System program. The maps are restricted to areas within defined and proposed Known Recoverable Coal Resource Areas. As of the end of the transition quarter, the equivalent of 100 quadrangles had been completed.

Thirty-nine leasable mineral and waterpower land-classification maps at a scale of 1:250,000 were completed and placed in the open file by the end of the transition quarter. Eight of these maps are scheduled for publication during fiscal year 1977. Fifty-eight additional maps are in various stages of completion. These maps provide an overall picture of land classification by the Geological Survey useful in showing resource relationships for the coal-leasing program and for land-use planning.

Five coal-investigation maps were published during fiscal year 1976.

In anticipation of the lifting of the moratorium on leasing of Federal coal lands, the Geological Survey established a task force during the first half of fiscal year 1976 to speed development of procedures for evaluating coal tracts and to determine their fair market value.

On January 26, 1976, the Secretary of the Interior lifted the moratorium, clearing the way for resumption of coal leasing and the processing of pending preference-right leases. The Bureau of Land Management subsequently published regulations for their

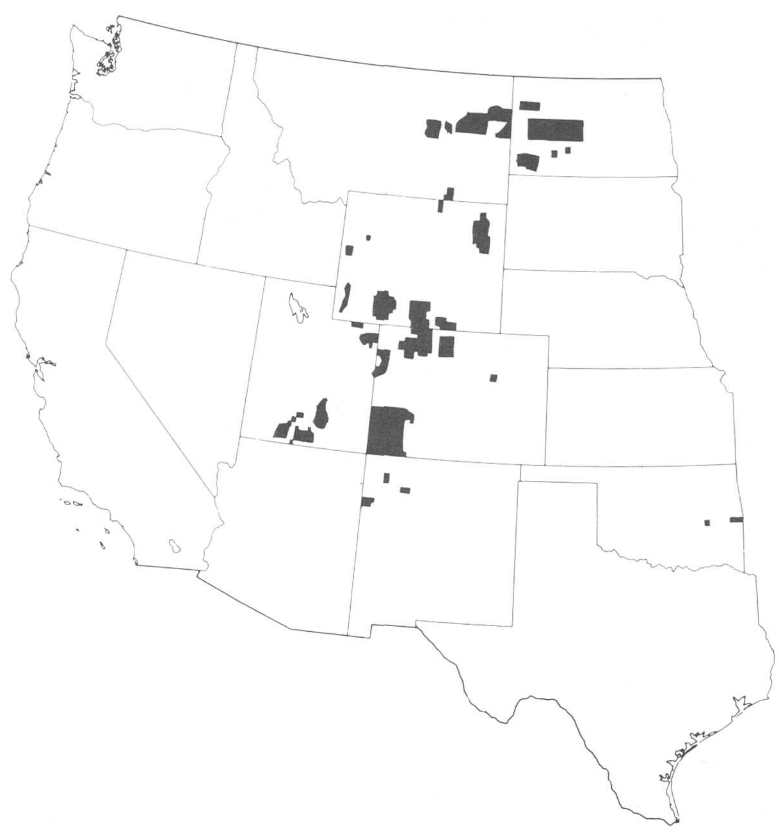


FIGURE 61.—Areas of active coal projects of the Conservation of Lands and Minerals activity on Federal lands during fiscal year 1976.

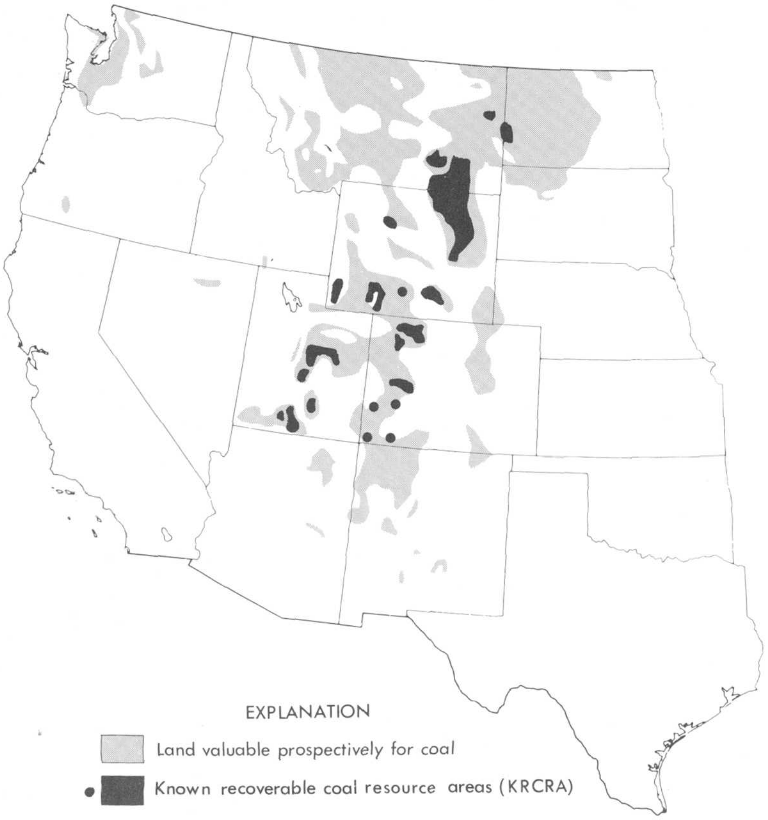


FIGURE 62.—Status of coal classification on Federal and Indian lands in the Western United States.

program, which affects both the coal leasing process and the regulatory functions of the Geological Survey's Conservation Division. The Bureau's reconsideration of these coal leasing regulations and their Energy Minerals Activity Recommendation System has been prompted by the enactment into law on August 4, 1976, of the Federal Coal Leasing Amendments of 1975. The Geological Survey will continue to be responsible for (1) the identification of Known Recoverable Coal Resource Areas as principal leasing target areas, (2) preparation of coal-resource occurrence maps and coal-development-potential overlays, and (3) participation in the selection and evaluation of proposed coal lease tracts for future lease sales. Other provisions of the Federal Coal Leasing Amendments Act of 1975 will require further study before they can be fully implemented.

- *Waterpower.*—Potential water-power and water-storage sites on Federal lands are classified as valuable or not valuable for development in order to retain the Government's right to authorize or license hydroelectric or water-storage development on such lands. Of the 5.7 million hectares (14 million acres) so withdrawn, 2,040 hectares (5,050 acres) were classified or reclassified in fiscal year 1976 and 2,200 hectares (5,450 acres) during the transition quarter. About 3.6 million hectares (9 million acres) of the total are withdrawn for possible use at the Ramparts Reservoir site on the Yukon River, Alaska.
- *Other leasable minerals.*—During fiscal year 1976, about 28,220 hectares (69,710 acres) were classified in Known Potash Leasing Areas in New Mexico. Field mapping was in progress in 10 quadrangles for phosphate deposits.

SUPERVISION OF OPERATIONS

After leases are issued by the Bureau of Land Management or the Bureau of Indian Affairs, the Geological Survey is responsible for supervising oil, gas, and mining operations on Federal and Indian lands and geothermal operations on Federal lands. In this regulatory program, oil, gas, geothermal, and mining operations are treated separately because of the different technologies and engineering disciplines used by each type of operation. The major program requirements, however, are basically the same, and they are similar to those of the Outer Continental Shelf subactivity: (1) review and approval of exploration and development plans; (2) supervision of exploration, development, and production operations (fig. 63); and (3) computation and collection of royalties and certain rentals.

Related activities such as unitization, method-of-production measurement, transportation allowances, commingling of products, off-lease storage, and sales contracts also require the prior approval or concurrence of the Survey.

Oil, Gas, and Geothermal Operations

At the end of calendar year 1976, there were 125,900 oil and gas leases covering 38.2 million hectares (94.4 million acres) (table 50). These leases were located in 33 States. During calendar year 1976, total oil and gas production from these leases amounted to 25.9 million tonnes (192 million barrels of oil), a decrease of nearly 4 percent from calendar year 1975, and 34 billion cubic meters (1,200 billion cubic feet) of natural gas, an increase of 8 percent over calendar year 1975. Survey personnel made over 19,200 inspections of oil and gas lease operations, prepared 2,551 environmental analyses of proposed new wells, approved 2,246 new wells (both exploratory and development wells), and processed 5,700 other types of applications.

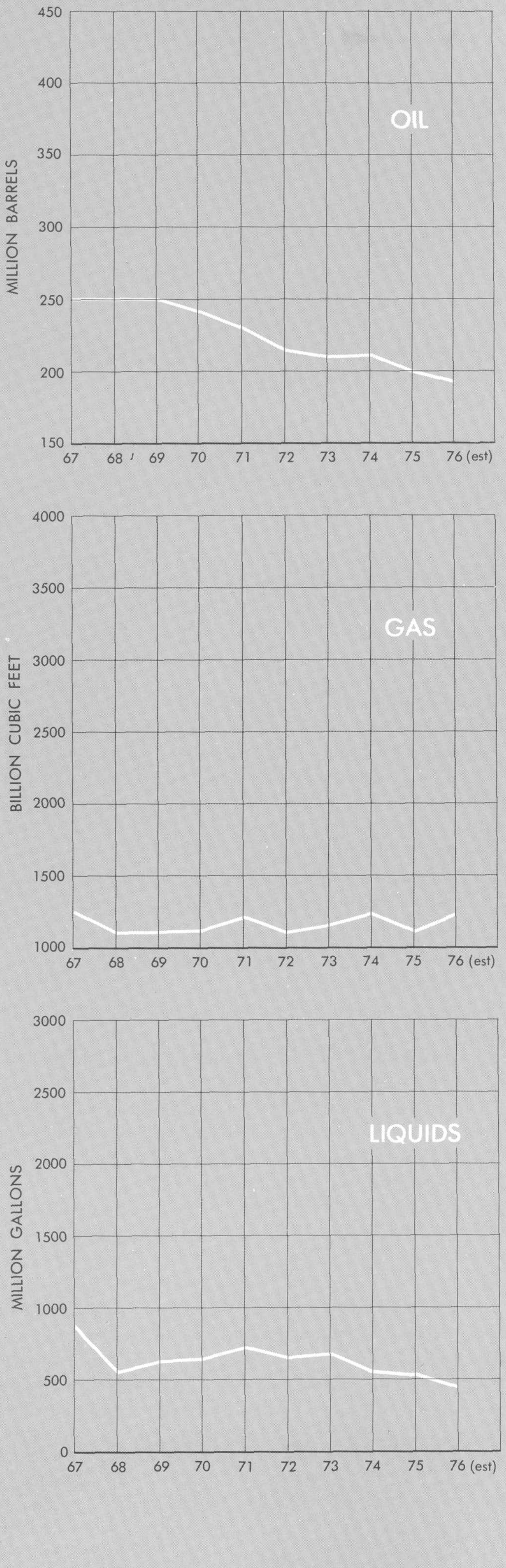
At the end of fiscal year 1976, the Geological Survey was maintaining 14,726 producing oil and gas lease accounts, an increase of 5.7 percent over fiscal year 1975, and at that time the Survey also had under its jurisdiction 2,129 rental accounts for Federal land

FIGURE 63.—Engineer taking noise readings near geothermal well at The Geysers, California.

leases. Total royalty revenue from the sale of oil, gas, and liquid products in calendar year 1976 amounted to $266 million; the increase of $21 million over calendar year 1975 reflects increased prices for those commodities.

About 6.4 percent of the Nation's domestic production of oil and 6.0 percent of its production of natural gas came from onshore Federal and Indian lands. Oil production from these lands, however, has been declining since 1968 (fig. 64) because new discoveries have not kept pace with the decline in production from older fields. The increasing demand for natural gas, which has caused greater effort to be directed toward finding new gas reserves, may account for some of the decline in oil production as well as the small increase in gas production. Liquid hydrocarbon products, which are extracted from natural gas produced from gas wells and from casing-head gas produced in association with oil, increased slightly during the year despite the decline in oil production.

The Geothermal Leasing program began in 1974 when the Department of the Interior published regulations governing the leasing of geothermal resources. By the end of fiscal year 1976, 24 wells had been drilled under lease; 18 of the wells were considered to be producible or usable, 4 were still being drilled, and 2 were abandoned. Most of the wells were located in The Geysers geothermal field in northern California, the only commercially producing field in the United States; the others were in the East Mesa and Mono-Long Valley in southern California and in the Roosevelt Hot Springs in Utah, where the first Federal Geothermal Unit was formed and approved in April 1976. During the transition quarter, one additional well was drilled, and one well was considered producible or usable. The completed wells on Federal lands that are capable of producing hot water and/or steam remain shut-in because of the lack of facilities necessary to convert the geothermal resources into usable energy.



Mining Operations

During fiscal year 1976, the Survey supervised 2,557 mineral leases covering 3.6 million hectares (9 million acres) of Federal and Indian lands in 32 States. The number of leases under supervision has increased over the previous fiscal year by 78 leases. Total production of solid mineral commodities under lease during the year, for example, increased 6.8 percent to 81.5 million tons valued at $813 million as a result of continuing increases in the demand for energy minerals (such as coal and uranium), fertilizer minerals (such as potash), and metallic minerals (such as lead, zinc, and copper).

Survey personnel made more than 2,000 producing lease and permit inspections, reviewed and approved new or modified exploration and mining plans, prepared environmental analyses, and assisted in the preparation of 27 environmental impact statements; four environmental impact statements cleared the Council on Environmental Quality. Royalties from 184 producing lease accounts totaled $36 million, an increase over 1975 of 16 percent. Revenues from 801 rental accounts provided an additional $3 million.

The importance of Federal and Indian lands to the Nation's domestic production of solid minerals is shown by figure 54.

- *Coal.*—Eight percent of the Nation's coal production in fiscal year 1976 came from leases on Federal and Indian lands in Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. It is estimated that production from existing leases could be increased from 52 million tons in 1976 to 213 million tons in 1980, an increase of nearly 310 percent. At the end of the fiscal year, 189 preference-right leases covering approximately 175,000 hectares (432,000 acres) were pending a decision by the Secretary of the Interior on future coal leasing policy, and the coal leasing and operating regulations were revised. One preference-right lease covering approximately 6,000 hectares (15,000 acres) in Wyoming was issued during fiscal year 1976.
- *Oil shale.*—In 1971, the Department of the Interior initiated the Prototype Oil-Shale Leasing program to encourage private industry to develop oil-shale mining and processing technology on a commercial scale, to insure the environmental integrity of the affected areas, to develop environmental safeguards and land-restoration techniques, and to develop management expertise in leasing and supervising oil-shale development. After the preparation of an environmental impact statement, the Department competitively leased four tracts of land in Utah and Colorado em-

◀FIGURE 64.—Oil and gas production from Federal and Indian lands, calendar years 1966–76.

bracing 8,300 hectares (20,400 acres) for a bonus of $449 million. The lease terms require each lessee to file a detailed development plan with the Survey for review and approval on or before the third anniversary date of the lease. Furthermore, the lease terms require the bonus payments to be paid in five annual installments and permit the lessee to credit against the fourth and fifth payments any expenditures incurred prior to the third anniversary of the lease that are directly attributable to operations for the development of the lease. The Survey's mining supervisor is responsible for determining that such expenditures credited by the lessee are properly attributable to development operations.

During 1975, four companies submitted their initial exploration plans for evaluation and approval by the Survey. Initial work also began on projects involving collecting baseline environmental data, monitoring air and water quality, and developing guidelines for future operations.

- *Fertilizer minerals.*—A large increase in the demand for fertilizer minerals has accelerated the production and leasing activities for potash and phosphate during the past few years. Eighty-one percent of the Nation's potash is produced from Federal lands, and 14 percent of phosphate comes from Federal and Indian lands. In Idaho, the principal western phosphate-producing State, 117 phosphate prospecting-permit applications and 15 lease applications are pending.

REVIEW OF ISSUES IN FISCAL YEAR 1976

During this fiscal year, several issues continued to have significant impact on the Conservation of Lands and Minerals activity.

Regulation of Outer Continental Shelf lease operations

On January 28, 1969, a well being drilled in the Santa Barbara Channel off southern California blew out. Although the flow of fluids from the well was effectively controlled by closing the blowout preventer, oil and gas continued to flow for 11 days through subsurface fractures to the ocean floor and subsequently to the water surface. The Santa Barbara oilspill drew national attention to the potential of damage from offshore oil and gas installations if adequate safety and environmental controls are not maintained. Public concern was further heightened when a fire broke out on an oil and gas platform in the Gulf of Mexico on February 19, 1970. This fire destroyed the platform and damaged equipment to the extent that oil and gas flowed uncontrolled for several weeks after the fire was extinguished. Although no injuries or environmental damage was reported, the potential for such damage existed.

These incidents prompted several major studies of oil and gas operations on the Outer Continental Shelf:

- *National Aeronautics and Space Administration (1971).*—A study, made at the request of the Geological Survey, to review the applicability of National Aeronautics and Space Administration contract-quality management and failure-mode effect analysis procedures to the Outer Continental Shelf oil and gas lease-management program.
- *U.S. Geological Survey (1972).*—An in-house study of the Survey's inspection program and procedures for enforcement of regulations.
- *National Academy of Engineering (1972).*—A study done at the request of the Survey, by the Marine Board of the National Academy of Engineering, which reviewed the technology and recommended regulatory practices that would minimize pollution of the Outer Continental Shelf from oil and gas operations.
- *Kash and others (1973).*—An exhaustive study, conducted under the aegis of the University of Oklahoma's Science and Public Policy program through a grant from the National Science Foundation, which resulted in a technological assessment of Outer Continental Shelf oil and gas operations.
- *Council on Environmental Quality (1974).*—A study which assessed the environmental impact of oil and gas production on the Atlantic Outer Continental Shelf and in the Gulf of Alaska.

Soon after the Santa Barbara blowout, the Survey reviewed and revised its operating procedures and regulations. Revised regulations and Outer Continental Shelf orders which implemented the regulations were issued August 28, 1969. Subsequently, the Survey commissioned three of the studies cited above (National Aeronautics and Space Administration, 1971; U.S. Geological Survey, 1972; and National Academy of Engineering, 1972) and established a work group on Outer Continental Shelf safety and pollution control, chaired by the Survey's Associate Director, to review the studies' findings and recommendations. This work group issued its first report and recommendations in May 1973 (U.S. Geological Survey, 1973). Supplemental studies (U.S. Geological Survey, 1974a, b) evaluated the two other reports listed above (Kash and others, 1973; Council on Environmental Quality, 1974).

These recommendations and their status in fiscal year 1976 are listed in table 21.

TABLE 21.—*Status of Outer Continental Shelf recommendations*

Work group recommendation	Implementation in fiscal year 1976 or before
1. Failure reports and corrective actions.	A system was established for operators to report, quarterly, failures of subsurface safety valves. The system can be expanded to include other types of equipment failures. Failure-reporting forms are being designed.
2. Accident investigation and reporting.	Accident-reporting procedures were revised to define better causes and effects of accidents. Geological Survey reports of accidents are available for public inspection.
3. Information exchange.	Reports on failures of subsurface safety valves are distributed quarterly to all operators. A safety alert system has been established to inform operators of the causes of accidents and pollution events.
4. Research and development.	American Petroleum Institute-sponsored committees have been formed to encourage industry research on sand-probe development and testing, orifice coefficients, and oil detection and removal. The Survey contracted with the Harry Diamond Laboratories to assess industry research and development concerning safety and pollution control, development of communications equipment and flow meters, fire suppression, and subsea inspections.
	Aerospace Corp. completed a study for verification of new offshore structures, as well as a design review of Shell's Cognac platform in 1,100 feet of water.
5. Standards and specifications.	The American Petroleum Institute established standards and specifications for: design, installation, and operation of subsurface safety valve systems; analysis, design, installation, and testing of surface safety systems on offshore platforms; wellhead surface safety valves; design and installation of production-platform piping systems.
	The American National Standards Institute has agreed to form committees to review standards.
6. Systems analysis --	The Geological Survey contracted for pilot studies on the analysis of the design of platform facility systems. The Survey also provided a research grant to Rice University to draft standards on platform-systems design analysis.
7. Engineering documentation.	The revision of OCS Order No. 8 (Platforms and Structures) requires extensive documentation of construction design and safety systems.
8. Wearout prevention.	The revision of OCS Order No. 8 requires the monitoring of sand erosion of valves and lines. Industry is conducting research on sand-erosion detectors.
9. Training and certification.	OCS Order No. 2 (Drilling Procedures) (Pacific Area) requires well-control training for supervisory and drilling personnel. OCS Order No. 8 requires training for all personnel working with safety devices. Procedures have been established to insure that minimum training standards are met. Training of inspectors is to be evaluated on an individual basis. Training sources are (1) on-the-job training, (2) technical schools, and (3) indoctrination sessions.
10. Motivation -------	As a result of work group recommendations, industry published a bulletin (American Petroleum Institute, 1974) on ways to motivate employees to be concerned with safety and pollution prevention.
11. Lease Management program.	This program on the OCS has been buttressed to provide adequate staff and funds to mount an optimum effort.
12. Inspection procedures.	Uniform inspection and enforcement procedures have been established. A computerized platform inspection system has been developed.
13. OCS order development.	Procedures were established for development of new OCS orders and revision of existing orders.
	Public participation (including affected States) in the development of OCS Orders is provided through the placing of notices of proposed rulemaking in the *Federal Register*.
	The technical adequacy of OCS Orders was assured by providing for review by the American National Standards Institute.
14. Standardization of forms.	Forms have not yet been standardized.

TABLE 21.—*Status of Outer Continental Shelf recommendations* —Continued

Work group recommendation	Implementation in fiscal year 1976 or before
15. Safety and advisory committees.	The Marine Board of the National Academy of Engineering established a committee to review OCS operations (National Academy of Engineering, 1974a, b; National Research Council, 1975a, b). The Geological Survey established safety committees in field operations offices. Oil companies have established internal safety and anti-pollution groups.
16. Memorandum of understanding with the Occupational Safety and Health Administration.	Negotiations failed to produce a procedural memorandum of understanding.
17. Memorandum of understanding on pipelines.	A memorandum of understanding is in effect with the Bureau of Land Management.
	A memorandum of understanding is in effect with the Department of Transportation (Office of Pipeline Safety).
18. Memorandum of understanding on standards for discharge from platforms and rigs.	The Environmental Protection Agency has begun to establish discharge criteria.
19. Subsea production systems.	A task force was assembled to assess the current state of the art, and comments were solicited through a notice in the *Federal Register*.
	Two reports on subsea systems were prepared.

Regulation of Federal and Indian lease operations

In December 1973, the Geological Survey began an intensive review of the onshore regulatory program in order to define deficiencies in the program and to recommend corrective actions. The National Aeronautics and Space Administration, assisted by the Martin Marietta Corporation, was requested to study the Conservation Division's responsibilities, authority, and procedures for supervising leases on Federal and Indian lands, to define techniques for measuring program performance and industry compliance, to recommend ways of improving leasehold inspections, and to suggest general management improvements. The Geological Survey also requested that the Department of the Interior's Office of Audit and Investigations undertake a study of the onshore-royalty accounting system.

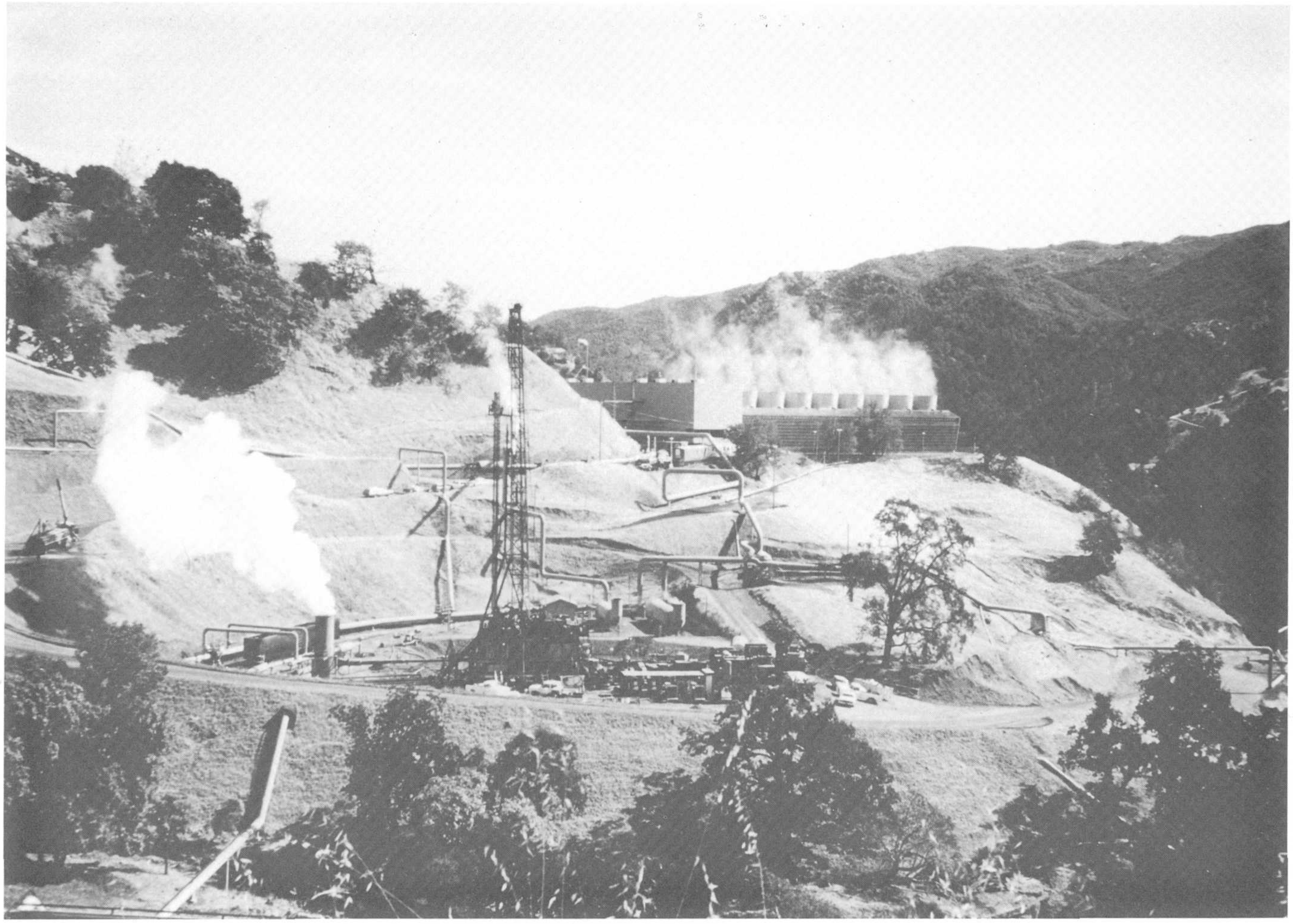
The National Aeronautics and Space Administration's component of the study was completed in December 1974 (National Aeronautics and Space Administration and Martin Marietta Corporation, 1974). Their report contained 79 numbered recommendations, many of which had subparts. The study recommendations addressed overall program management and contained various suggestions for clarifying and interpreting Department regulations governing onshore operations. These regulations provide guidelines but do not explicitly define the criteria which lessees or operators must meet in conducting operations on leases. In the past, it has been left to local Survey officials to interpret and enforce these regulations, and, as a result, there has been a lack of uniformity in the application of standards and procedures.

Subsequent to the completion of the National Aeronautics and Space Administration's study, the Survey established a task force to review the onshore-lease management report. After extensive review by the managers responsible for the various operations, in May 1975, the Survey adopted nearly all the recommendations as presented or as slightly modified (U.S. Geological Survey, 1975). Implementation of certain of the recommendations was commenced in fiscal year 1976, and further corrective actions will be undertaken in fiscal year 1977.

The Office of Audit and Investigations report on accounting procedures (Office of Audit and Investigations, 1975) concluded that improvements were needed in several areas and that increased staff was needed to handle the work load. The areas identified for improvement were:

- Lessee reporting procedures.
- Royalty accounting procedures.
- Determination of value and volume of oil and gas production.

The Geological Survey generally agreed with the findings of the study and immediately took steps to implement them. With the additional people provided in fiscal year 1976, the Survey has restructured the chief accountant's responsibilities to provide for overall systems management and policy development. Positive action has also been taken to streamline accounting operations through such means as requiring uniform reporting, eliminating duplicative reporting, and making more extensive use of automation to handle accounting data and audit reporting. Coupled with these modifications is an aggressive effort to in-



Well being drilled for geothermal steam in California.

sure prompt and accurate royalty reporting and payment. The Geological Survey expects to have fully implemented all recommendations early in fiscal year 1977.

Royalty oil

The Mineral Leasing Act of 1920, the Acquired Lands Leasing Act of 1947, and the Outer Continental Shelf Lands Act of 1953 authorize the Secretary of the Interior to sell royalty oil accruing to the United States under oil and gas leases issued under those acts. In order to assist small business enterprise, the Congress has authorized and directed the Secretary, when he determines that supplies of crude oil are not sufficient in the open market for refineries not having their own source of crude oil, to grant a preference to such refineries in the sale of royalty oil for processing or use in such refineries but not for resale in kind. The Act of July 13, 1946, provides that the sale of royalty oil to such refineries may be a private sale at not less than the market price and that in selling such oil the Secretary may at his discretion prorate such oil among such refineries in the area in which the oil is produced.

During fiscal year 1976, 3.8 million tonnes (28.4 million barrels) of royalty oil from operations conducted on the Outer Continental Shelf (Gulf of Mexico and Pacific) were taken by oil refineries under 45 separate contracts, and 1.3 million tonnes (9.8 million barrels) of royalty oil from Federal onshore leases were taken by oil refineries under 24 separate contracts. The royalty oil was allocated pursuant to the regulations contained in Title 30, Parts 225 and 225a, of the Code of Federal Regulations as they apply to onshore and OCS royalty oil, respectively. It is anticipated that the total volume of royalty oil distributed during fiscal year 1977 will increase substantially.

Shut-in wells

Still of major concern during fiscal year 1976 was the question of shut-in oil and gas wells. The Geological Survey defines a "shut-in well" as any well which at some time in the past was a producing well, is not currently producing, and is physically in such mechanical condition that the former producing interval could be opened for production if any production capability exists. As of June 30, 1976, 182 leases were shut-in and not producing.

A Congressional subcommittee contends that some oil companies deliberately shut-in producible wells and reservoirs (particularly gas wells and reservoirs) until higher prices will make production more profitable. Industry's response was that reserve figures include behind-the-pipe reserves in wells with multiple sands which could not be produced concurrently. Where multiple horizons occur, the productive sands are produced sequentially. In January 1975, the Survey asked 10 companies that appeared to have the most questionable cases of shut-in wells on leases either to start producing immediately or to submit reasons and data explaining why shut-in status should be permitted. Subsequently, in March 1975, 3 of these 10 lessees were required to submit additional data supporting the shut-in status of their wells. As a result of these actions, two lessees chose to terminate one lease each in fiscal year 1975. Then, in fiscal year 1976, one other lessee chose to terminate two leases. However, in general, the inquiries disclosed that the wells and leases were shut-in because transportation facilities did not exist, or production equipment was ordered but not yet delivered and installed, or the gas reserves had been depleted to the point where further production was not economical.

Geological and geophysical regulations regarding exploration

On June 11, 1976, the Secretary of the Interior signed regulations governing prelease geological and geophysical exploration of the Outer Continental Shelf. These regulations standardize prelease exploration procedures on the outer shelf and provide for protection of the marine environment. They cover the conduct of exploration operations such as gravity, magnetic, and seismic surveys; shallow test drilling; and deep "off-structure" drilling to determine geological conditions in a particular area. One especially significant provision of the regulations requires that the exploratory data acquired under a permit must, upon request, be submitted to the Geological Survey. Other provisions call for the ultimate public release of submitted data. An environmental impact statement on the regulations was published in April 1976.

Implementation of the regulations will:

1. Revoke various notices and agreements governing exploration on the Outer Continental Shelf.
2. Institute uniform policies by the Director of the Geological Survey through the Chief of the Conservation Division for the conduct of geological and geophysical exploration.
3. Establish a requirement that the exploration on the Outer Continental Shelf will not cause undue harm to aquatic life, cause pollution, create hazardous or unsafe conditions, endanger operations under a lease, interfere with other uses of the area, or disturb any sites, structures, or objects of historical or archeological significance.
4. Provide ready access for the Geological Survey to a reliable data base for use in Outer Continental Shelf tract-selection and evaluation program and in the geological hazards analysis program.
5. Decrease the cost of marine geophysical data previously purchased from industry.
6. Schedule the release to the public of all geological and geophysical data submitted to the Geological Survey.

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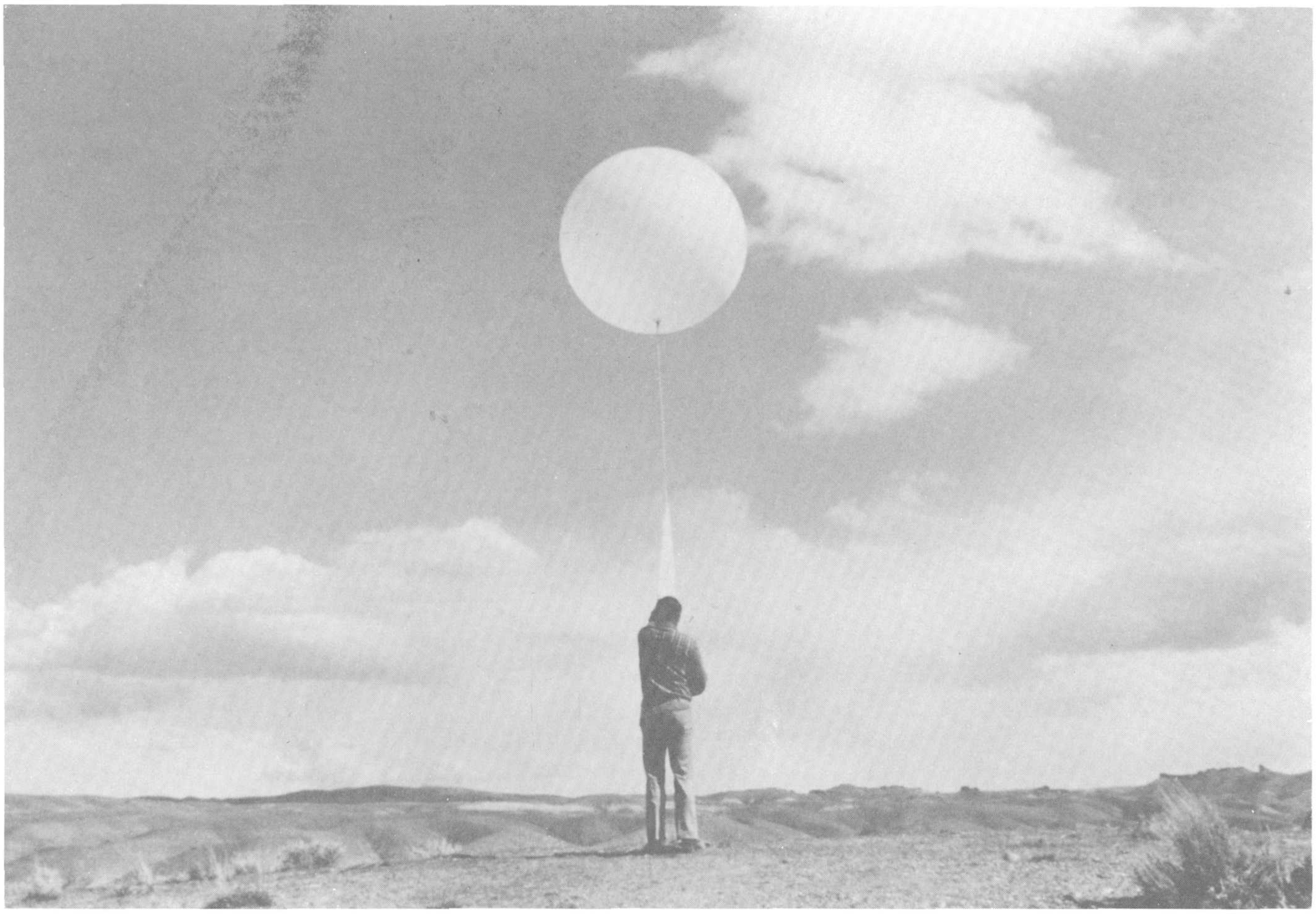
———1975, Conservation Division Task Force Report on the Onshore lease management study for the U.S. Geological Survey by National Aeronautics and Space Administration and a support team from Martin Marietta Corporation: U.S. Geological Survey, Reston, Va., 120 p.



Meteorologist preparing to release a pilot balloon as part of an upper-air-quality study to facilitate monitoring the environmental impact of future oil-shale development in Utah.

Geological Survey Warns About Constant Danger of Landslides
This is a critical period in the earthslide danger zone.
That was the warning this week from the U.S. Geological Survey.
Experts from that technical agency are in Pacific Palisades cooperating with the U.S. Corps of Engineers, forming a slide-fighting plan of action.
are urged to watch closely for signs that the earth is beginning to slip.
Reporting telltale signs to building and safety officials is essential, according to the survey.
—Doors that stick or jam for the first time.
—New cracks in plaster, tile, brickwork or foundations.
widening cracks in the ground or paved areas.
Mining-Ar
Planners are sticking by their original idea that intense development should be banned from areas where there is a potential for mining copper.
SAN JOSE, CALIF., FRIDAY MORNING, JANUARY 26, 1973
Portola Valley Okays Earthquake Ordinance
PORTOLA VALLEY — The Portola Valley Town Council has approved an earthquake ordinance that
TUCSON DAILY C
PAGE 6
Public hearing on Pima slope
By THOMAS P. LEE
Citizen Staff Writer
Pima County's proposed "slope ordinance," a controversial proposal to limit housing along mountainsides, will undergo another public hearing Monday.
After about a dozen revisions since the idea first was outlined nearly two years ago, the latest version is to be discussed during the Board of Supervisors' meeting Monday.
The supervisors' meeting begins at 9:30 a.m. in the first floor hearing room of the new County Courts Building. It has not been decided at what time during the meeting the slope ordinance will be discussed.
NEW CITY POLICY
Quake Study Required For Building Project
ACTIVE FAULTS AND PRELIMINARY EARTHQUAKE
1970) IN THE SOUTHERN PART OF
AN FRANCISCO BAY REGION
FIELD STUDIES MAP MF-30
Brown, Jr., and W. H. K. Lee
1971
SAN FRANCISCO BAY REGION ENVIRONMENT AND RESOURCES PLANNING STUDY
U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
OFFICE OF THE ASSISTANT SECRETARY FOR POLICY DEVELOPMENT
Earthquakes to

Land Information and Analysis

OVERVIEW

Growing concern about the quality of our environment and the adequacy of our Nation's land and water resources to meet present and future needs, and concern about worldwide shortages of energy and mineral resources, have awakened the widespread interest of officials at all levels of government, and of the general public, to the need for and usefulness of earth-science information for problem solving—especially for solving problems related to the wise use of the Nation's land resources.

Most of the earth-science information required to evaluate alternative uses of the land and to facilitate related planning and decisionmaking is multidisciplinary in the sense that the information is derived from more than one of the U.S. Geological Survey's core disciplines—geology, hydrology, topographic mapping, and geography. In the past, the Geological Survey responded to the need for multidisciplinary information on a case by case basis, but during the past decade it became apparent that a more formally structured approach to conducting multidisciplinary land-resource and environmental studies was necessary. It also became apparent that closer interaction between the compilers of earth-science data and users of the data, such as land-resource planners and decisionmakers, was needed to produce map and book reports and other products that are readily understandable by those users. There was, in other words, a need to bridge the gap between the earth scientist and the planner and decisionmaker. The Land Information and Analysis Office was established in fiscal year 1975 to help serve that purpose. The Land Information and Analysis Office provides scientific and engineering data developed by the Geological Survey and the Department of the Interior to support environmental planning and decisionmaking for land use and land resources at all levels of government and in the private sector. Explicit in this mission is the translation of scientific and engineering information on activities involving land and other natural resources into readily understandable language and formats so as to encourage its use by

◄Increasing use of earth-science information in the solution of land-use problems by environmentally aware citizens is reflected by this sampling of news articles and USGS publications.

elected officials, planners, public interest groups, the legal profession, social scientists, and the general public. The task of achieving these objectives is carried on by five multidisciplinary programs:

- Earth Sciences Applications (ESA).
- Resource and Land Investigations (RALI).
- Geography.
- Earth Resources Observation Systems (EROS).
- Environmental Impact Analysis (EIA).

Principal issues

The principal issues faced by the Land Information and Analysis Office in fiscal year 1975 carried on into fiscal year 1976. These issues basically fall within two categories.

1. The recent rapid growth of Federal and State legislation responding to concerns such as energy development, coastal-zone management, hazards reduction, environmental impact, and water quality has greatly stimulated need for earth-science information to plan and manage land and water resources. Examples are the demands on the research and data-collection activities of the Geological Survey from recently mandated Federal programs such as the Department of Housing and Urban Development Community Block Grants/Entitlement Grants and Comprehensive Planning Assistance Program, National Flood Insurance Program, Disaster Relief Act, EPA–208 Program, the Department of Commerce Coastal Zone Management Program, and related State and local legislation and regulations.
2. The increasing concentration of the Nation's population in urban areas and the need for greater and more efficient use of land have focused attention on the opportunities and constraints the Earth poses to growth and development. For example, Kansas City is developing subsurface space for factories and warehousing; Chicago is excavating vast underground cavities for storage of storm-water runoff; and cities throughout the United States are placing utilities, communication, and transportation networks in tunnels. These trends, along with the increase in high-density, major structures in urban areas, have escalated the requirements for accurate earth-science data in support of planning and decisionmaking.

Although the Survey has already done much to foster the integration of earth-science information into the planning process through urban-area studies and other means, much research is still needed to address issues of data content and interpretation and to apply the results of Survey work to a broad spectrum of resource and environmental managers. The Survey is hopeful of strengthening this effort to meet national needs for earth-science information.

Highlights

- Completion of five urban-area study projects in the Baltimore-Washington area, the Connecticut Valley area, the greater Pittsburgh area, the San Francisco Bay region, and the Tucson-Phoenix area.
- Publication of "A Guide to State Programs for the Reclamation of Surface Mined Areas" (U.S. Geological Survey Circ. 731, by Imhoff and others, 1976) which provides an inventory of each State's programs requiring reclamation of surface mined areas.
- Production of land-use and land-cover maps for 1,170,000 square kilometers (450,000 square miles), including the entire States of Kansas, Florida, and Pennsylvania, bringing the total area mapped to 1,950,000 square kilometers (750,000 square miles) since the nationwide land-use mapping program started in fiscal year 1975.
- Publication of "ERTS–1, A New Window on Our Planet" (U.S. Geological Survey Prof. Paper 929, by Williams and Carter, 1976) which presents 85 case histories on the use and application of ERTS–1 (now Landsat–1) data to earth-resource mapping, monitoring, and inventory.
- Preparation, with lead or joint-lead responsibility, of 20 environmental impact statements and participation in a nonlead capacity in the preparation of 15 statements; 29 of the total number were energy related. Review of 2,812 impact statements and related documents.

Budget and personnel

Obligations for Land Information and Analysis Office activities in fiscal year 1976 amounted to $17.28 million, an increase of 4 percent over fiscal year 1975 (table 22 and fig. 65). The EROS Program transition quarter obligations of $4.84 million included $2.93 million for the procurement of a digital image-processing system for installation at the EROS Data Center to provide higher quality Landsat imagery on a production basis.

Cooperative programs with State agencies were carried on by the Geography program for land-use and land-cover mapping.

TABLE 22.—*Land Information and Analysis Office obligations for fiscal year 1976 and the transition quarter (dollars in millions)*

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

Program	Fiscal year 1975	Fiscal year 1976	Percent change	Transition quarter
Total	$16.99	$17.28	+ 2	$8.92
Total obligations	15.46	14.91	— 4	7.79
Earth Sciences Applications program	1.60	1.63	+ 2	.41
Resource and Land Investigations program	.96	.74	— 23	.49
Geography program	2.01	2.34	+ 16	.75
Earth Resources Observation Systems program	8.28	8.16	— 1	4.84
Environmental Impact Analysis program	2.61	2.04	— 22	1.30
Reimbursable programs	1.31	1.90	+ 45	.64
State, counties, and municipalities	.03	.13	+333	.02
Miscellaneous non-Federal sources	1.09	1.50	+ 38	.47
Other Federal agencies	.18	.27	+ 50	.15
Working funds	.23	.47	+104	.49
Ozark Regional Commission	.05	.03	— 40	------
National Aeronautics and Space Administration	.18	.44	+144	.06
National Park Service	------	------	------	.04
Environmental Protection Agency	------	------	------	.21
Department of Transportation	------	------	------	.18

The work of the Land Information and Analysis Office is partly accomplished through private contracts and research grants. Of fiscal year 1976 funds, $5.0 million (24 percent) was expended on contracts and $0.16 million on research grants. Contract services were the major source of support for operations at the EROS Data Center.

The programs of the Land Information and Analysis Office were carried out by 195 full-time career employees in 1976; at the end of the year 157, were assigned to the Office's programs (table 45), and 38 were assigned to other Survey offices in support of the work of the Land Information and Analysis Office. In addition, contract support services at the EROS Data Center amounted to 296 man-years. Personnel of the Topographic, Computer Center, and Administrative Divisions were also assigned to the EROS Data Center.

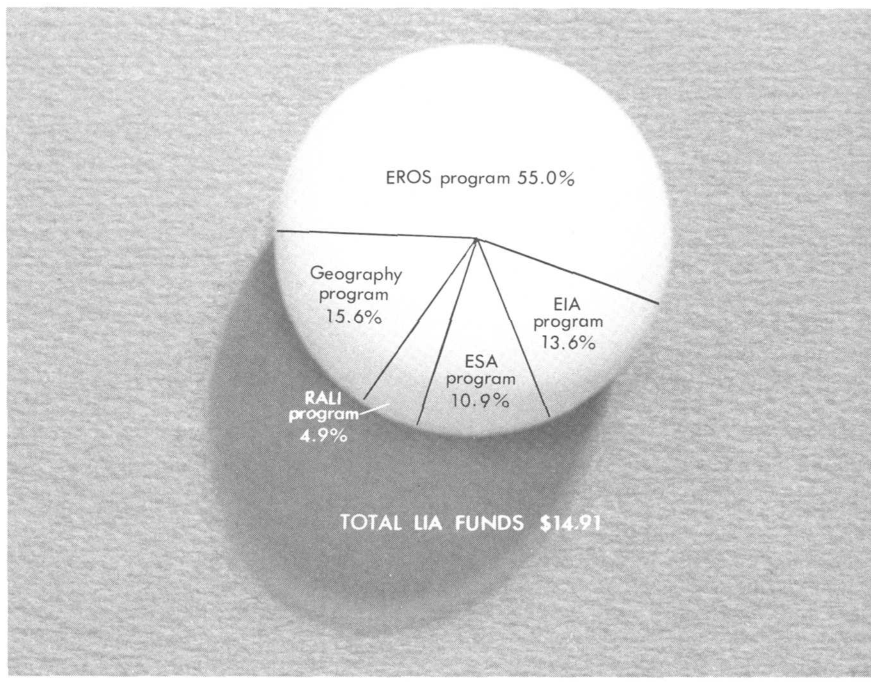


FIGURE 65.—Distribution of Land Information and Analysis funds in fiscal year 1976 (dollars in millions).

EARTH SCIENCES APPLICATIONS PROGRAM

Programs and activities

The Earth Sciences Applications program was established to provide a unit within the U.S. Geological Survey to direct and coordinate multidisciplinary Geological Survey projects specifically concerned with disseminating earth-science data to land-resource decisionmakers in readily usable forms. The program's objectives are threefold: (1) to interpret, demonstrate, and encourage the use of earth-science information for land-resource decisionmaking through specially designed projects, interaction with users, technical assistance, publication of specially designed map and book reports, and project evaluation; (2) to stimulate development of multidisciplinary studies in the Survey through coordination and integration of activities; and (3) to serve as the focal point within the Survey for multidisciplinary studies to support the work of other Federal, State, and local agencies.

In the course of addressing these objectives, the Earth Sciences Applications program has undertaken the study of eight selected urban and adjoining areas. Five of these studies—those located in the Baltimore-Washington area, the Connecticut Valley area, the greater Pittsburgh area, the San Francisco Bay region, and the Tucson-Phoenix area—were completed at the end of fiscal year 1976 as scheduled. Three ongoing studies in Puget Sound, Wash., Denver, Colo., and Fairfax County, Va., will be greatly strengthened in fiscal year 1977 and will build on experiences gained in the other urban studies.

The Earth Sciences Applications program initiated three new projects in fiscal year 1976. Two tunneling-feasibility studies for rapid transit systems, funded by the Department of Transportation through the Earth Sciences Applications program, were undertaken in the central business districts of Minneapolis-St. Paul, Minn., and Los Angeles, Calif. The main objective of these projects, which are to be completed in fiscal year 1977, is to assess the need for, and the availability of, hydrologic and geologic data relevant to the construction, maintenance, and operation of an underground transit system.

A third project initiated in fiscal year 1976 and scheduled for competion in fiscal year 1977 entails the preparation of an atlas which demonstrates the applicability of earth-science information to land and water planning.

Earth Sciences Applications program studies are staffed by personnel from the Geologic, Water Resources, and Topographic Divisions supported by allocations of personnel and funds from the Earth Sciences Applications and Geography programs. In fiscal year 1976, approximately $1.6 million was allocated specifically to the urban-area studies; in addition, these studies were able to build upon about $0.4 million of related research in the project areas conducted by other divisions of the Geological Survey. An additional $0.2 million was available from the Department of Transportation.

The urban areas selected for study are characterized by their geologic and geographic diversity and by rapidly growing populations accompanied by an attendant increasing demand on land and water resources. By carefully collating, documenting, and interpreting data on geologic and hydrologic constraints on certain land uses, these projects have provided a basis for assessing unforeseen social and economic costs. The variety of earth-science input into this evaluation process is great. To date, the total number of releases from the eight urban-area studies has exceeded 350 maps and reports dealing with such diverse information as the character, thickness, and erodibility of soils; quantity and quality of surface and ground water; definition of hazards associated with floods, earthquakes, landslides, subsidence, and poor foundation materials; and distribution of mineral resources, landforms, slopes, and watercourses. Publications have also dealt specifically with techniques of applying earth-science data to land-use planning.

One of the goals of these experimental studies has been to foster a desire and capability on the part of local governments to continue the development and application of earth-science data long after the studies are terminated. This objective has been reached by a variety of techniques, each unique to the political structure, resource capability, and interests of individual urban areas. For example, in the Connecticut Valley Urban Area Project, several innovative programs were developed to stimulate dissemination of information. Most notably in this respect, the project office worked with the Connecticut State Geological Survey, Cooperative Extension Service, and Department of Environmental Protection in establishing a series of land-use workshops to inform potential local users—town planning, zoning, and conservation commission members in all 169 Connecticut towns—of the types of earth-science data available and their applicability to the planning process. The success of this endeavor was measured both by the local users' receptive attitude towards the workshops and the data presented and by the interest and participation of several Federal agencies, among them the Soil Conservation Service, Environmental Protection Agency, and regional agencies.

In the San Francisco Bay Region Environment and Resources Planning Study, a quite different approach resulted in a significant degree of success in working with county and regional organizations to design highly usable products and achieve their assimilation into the planning process. A close working association with the Association of Bay Area Governments, which functioned as both a user and producer, was designed into the project.

As a user, the Association of Bay Area Governments applied San Francisco Bay Region Study results extensively in its capacity as an A–95[1] and environmental impact statement and report review agency and through its involvement in many area planning programs. As an initial step in the association-sponsored San Mateo Coast Corridor Study, products from the bay study project were used to identify areas of critical environmental concern and those parts of the corridor with limited development

[1] The A–95 review process was established by the Federal Office of Management and Budget, pursuant to its revised Circular A–95. It requires that all requests for Federal aid be reviewed by designated State and regional governmental agencies.

potential because of natural hazards. The Association then used basic data and interpretive maps from the bay study project in developing a new and imaginative methodology for assessing the capability and costs of land to support various types and degrees of land use (fig. 66).

The success of the San Francisco Bay project in producing usable information is demonstrated by its ready acceptance by the local governments. All eight counties in the San Francisco Bay region have made extensive use of project material in their planning studies, plans, ordinances, and other planning activities (Kockelman, 1976). Of particular interest are the uses of bay region study results in the preparation of ordinances and other types of legislation, for they demonstrate the application of land information as major development determinants. Several counties have developed ordinances which deal with geologic studies and natural hazards and rely in large part on the project products for implementation (for example, Santa Clara County Ordinance No. NS–1203.31).

The continued application of earth-science data to the legislative process seems assured as the Federal and State governments become increasingly aware of the vital importance of this information to the planning process. Examples of this awareness are already manifest in the California State mandates restricting developments in active fault zones and requiring all jurisdictions to prepare seismic safety planning elements. Similarly, recent Federal rules and guidelines—such as the 1974 Federal Insurance Administration guidelines for mandatory purchase of flood insurance and the 1975 Department of Housing and Urban Development Comprehensive Planning Assistance Program requiring counties to collect, analyze, and apply earth-science information—recognize the need for the acquisition and application of such data to land-use decisions.

Despite these encouraging signs of increasing acceptance, persistent danger exists that the momentum generated by these studies will be lost without developing stronger Federal support of local and State efforts. This would be a critical loss, indeed, when so much remains to be accomplished in terms of refining earth-science output and insuring integration of this information into the planning process. Failure to recognize the constraints certain geologic and hydrologic conditions place on development can result in tragedy (fig. 67). On the other hand, certain geologic and economic conditions can provide opportunities, aesthetic as well as economic, for better planning. As concluded by A. D. Little, Inc. (1975), in their evaluation of the San Francisco Bay Region Study on behalf of the Department of Housing and Urban Development, "... the consequences of not following through with the urban studies program can be more costly—in terms of dollars, lives, and resources wasted—than the costs of fulfilling the potential of this concept."

Accomplishments

Fiscal year 1976 was a successful and productive year for the Earth Sciences Applications program. Accomplishments of project activities during fiscal year 1976 included:

- Publication of "Geologic Conditions Related to Waste-Disposal Planning in the Southern Hood Canal Area, Washington" (Carson and others, 1975). The Puget Sound Urban Area Study also completed an analysis of the effects on water quality of recent increased volcanic activity at Mount Baker.
- Completion of two evaluations of the San Francisco Bay Region Environment and Resources Planning Study (A. D. Little, Inc., 1975; Kockelman, 1976).
- Completion of Association of the (San Francisco) Bay Area Governments' study, "Land Capability Analysis." The study develops and demonstrates a methodology for the application of earth-science information to land-use planning and decisionmaking. This approach grew out of the San Francisco Bay Region Study and relies heavily on products from the study.
- Publication of maps showing land-use and flood-prone areas in the Denver area, Front Range Urban Corridor, Colo. (Driscoll, 1976; McCain and Hotchkiss, 1975).
- Completion of seven maps delineating hydrologic and geologic conditions in Prince Georges County, Md., and the District of Columbia.
- Publication (by the Appalachian Regional Commission) of the results of a study concerning the dissemination of geological information generated by the Greater Pittsburgh Region Study to local officials involved in making land-use decisions (Wissel and others, 1976).
- Publication of "Landsliding in Allegheny County, Pennsylvania" (Briggs and Pomeroy, 1976), which discusses geologic factors affecting landsliding and ramifications for engineering considerations and land-use control.
- Publication of three resource identification maps: "Occurrences of Commercially Important Nonmetalliferous Minerals in the Phoenix Area, Arizona" and "Mineral Construction Materials in the Phoenix Area, Arizona," prepared by authors from the Arizona Bureau of Mines (Moore and Varga, 1976), and "Map Showing Potential for Copper Deposits" (U.S. Geol. Survey, 1976).

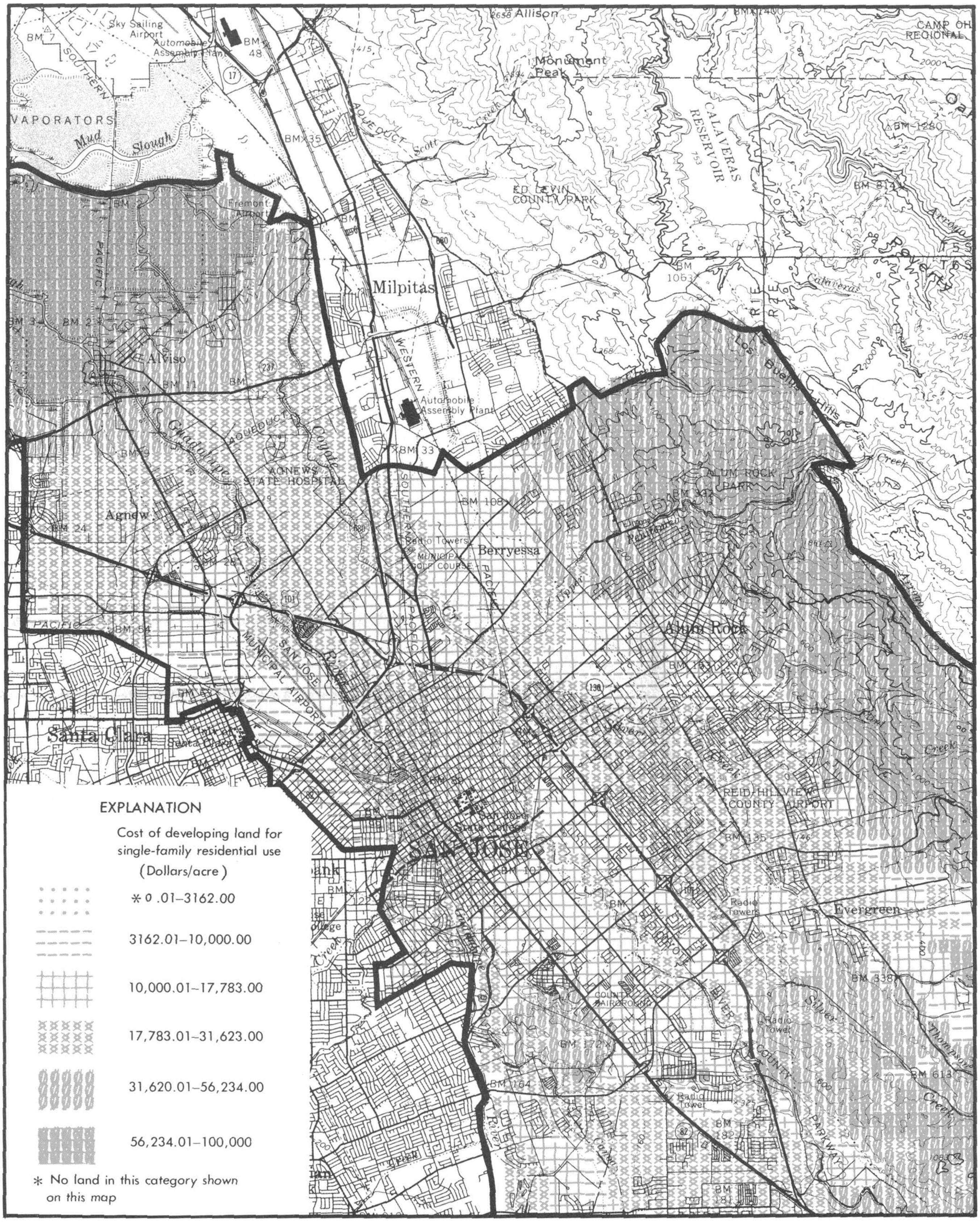


FIGURE 66.—Cost of developing land for single-family residential use.

FIGURE 67.—Landslide largely in landfill, Lawnwood Avenue, Brentwood and Baldwin Boroughs, greater Pittsburgh area, Pennsylvania. Warped wall of partly dismantled house in right foreground resulted from movement of footings that were not set in bedrock. House in right background is set on bedrock and apparently is not distressed structurally even though side and back yards have slipped away.. Note large trees inclined strongly downslope behind car and house, evidence of a history of movement in the area. (Photographed in April 1975.)

RESOURCE AND LAND INVESTIGATIONS PROGRAM

Program and activities

The Resource and Land Investigations (RALI) program is a Department of the Interior program, administered by the Geological Survey, whose purpose is to improve technical communication between the collectors and analysts of resource and land information and the planners, managers, and decisionmakers in government, industry, and the public sector. This goal is accomplished by coordinating the activities of the several bureaus in the Department of the Interior in those cases where a multidisciplinary perspective would improve the Department's ability to communicate with the planning community and by coordinating the Department's technical response to complex issues relating to land-resource analysis. To improve the transfer of technical information in the planning community, directories, catalogs, and bibliographies are compiled and distributed that describe the information products, services, and research. The program also provides for technical assistance to planners in the acquisition and interpretation of information and in the development, selection, and application of planning tools.

Accomplishments

The Resource and Land Investigations program accomplishments in fiscal year 1976 included the following activities:

- Identification and assessment of the utility of selected information products, geographic data systems, and data sources to State and local planning communities.
- Development and distribution of directories of data holdings and special information products of the Department of the Interior.
- Identification of technical expertise in the Department needed by regional, State, and local planning communities and development of ad-

ministrative procedures to make appropriate personnel available for consultation.

- Support and coordination of the preparation of guidebooks for planning methodologies.
- Publication of "A Guide to State Programs for the Reclamation of Surface Mined Areas" (Imhoff and others, 1976).
- Publication of a "Directory to U.S. Geological Survey Program Activities in Coastal Areas, 1974–76" (Marcus, 1976).
- Development of a computer program to automate the preparation of onshore facility scenarios, given various levels and rates of oil and gas production (publication in review, scheduled for release as a Survey open-file report in February 1977).
- Completion of an agreement with Department of the Interior Library (Office of Library Services) to produce a "Directory to the U.S. Department of the Interior Information Sources," to be published in 1977.
- Completion of an agreement with the Colville Indian Tribe, the Washington State University, and the American Society of Planning Officials to conduct a natural-resource management study utilizing a computerized land-use analysis system.
- Sponsorship of a series of five regional workshops around the country, attended by delegates appointed by the Governors of every State, to transfer the results of the Resource and Land Investigations studies on Critical Environmental Areas and Land Use Information Systems.
- Completion of an agreement with the Council on Environmental Quality to produce a bi-annual "Environmental Indicators" publication and an annual "Compendium of Environmental Statistics."
- Completion of an agreement with the Environmental Protection Agency to conduct workshops to transfer to State and local agencies the methodology and information to be used for the assessment of onshore impact of oil and gas development on the Outer Continental Shelf.

The Resource and Land Investigations program was named the coordinator of Geological Survey responses to States' requests for technical assistance under the provisions of the Coastal Zone Management amendment (Public Law 94–370) which formally links Outer Continental Shelf development and coastal-zone planning.

The reports, bibliographies, and assistance on planning techniques have been well received, and user responses have identified the need for more coordination between Federal and State data-collection and dissemination programs and for closer cooperation within the planning community to provide specific information for land-use information systems, critical environmental area planning, and assessment of the utility of information products for planning needs.

GEOGRAPHY PROGRAM

Programs and activities

The Geography program links and integrates social-science information and the techniques of geographic analysis with earth-science information collected by the Geological Survey. Activities include:

- Mapping land use and land cover on a nationwide basis.
- Developing and demonstrating techniques of land-use and land-cover mapping using remotely sensed data and a geographic-information system.
- Conducting field investigations and participating in multidisciplinary studies that contribute to solutions of problems arising from interactions of land-use practices and environmental factors.
- Contributing to the National Atlas project.

Planning and implementing programs designed to promote wise use of the land depend in part on a knowledge of the present distribution of and temporal changes in different types of land use and land cover and on a knowledge of where urbanization and other types of development are occurring. The location, area, and percentages of land use and land cover are among the types of statistical data used by Federal and State legislators and local officials to determine land-use policy, to project demands for different types of land use, to predict where future development pressures will occur, and to formulate plans for regional development. Current land-use and land-cover data also support Federal and State planning for developing energy resources, managing public lands, siting facilities, developing recreational areas, managing water resources, and assessing potential and actual natural disaster damages.

National land-use and land-cover mapping and data compilation

In fiscal year 1976, the Geography program continued the nationwide land-use and land-cover mapping and data-compilation effort, established by the Geological Survey in fiscal year 1975 as the Land Use Data and Analysis program and designed to alleviate or remedy many of the shortcomings of various types of existing data (fig. 68). Maps of current land use

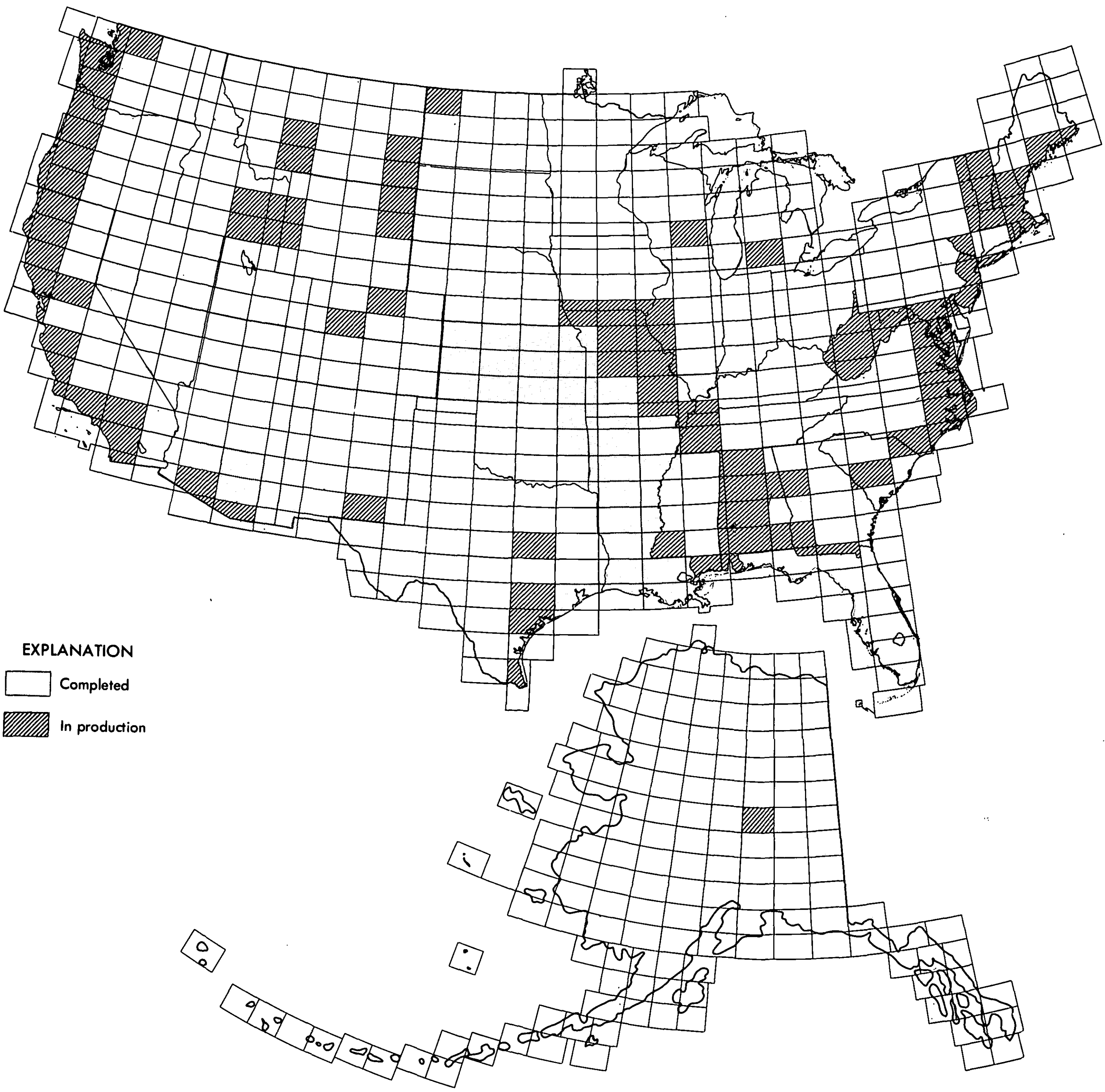


FIGURE 68.—Status of land-use and land-cover mapping, September 1976.

and land cover for the entire Nation are being compiled at a scale of 1:250,000 and at a scale of 1:100,000 where such new intermediate-scale maps are available. Additional maps of federally owned lands, political units, census county subdivisions, and hydrologic units are being prepared in overlay format to relate to the current land-use and land-cover data.

The classification system being employed to map land use and land cover was developed after consultation with many Federal and State agencies. It incorporates common terminology and can accommodate land-use and land-cover data gathered in greater detail (Anderson and others, 1976).

A computerized geographic-information system has been developed to store and retrieve the data compiled under the national land-use and land-cover mapping program and related research projects. The system includes: (1) entry of digitized land-use and land-cover maps and other related data; (2) editing and updating of the data base; and (3) retrieval and manipulation of the data for area measurement, comparative analysis with other data, and other analytic applications. Statistical summaries are prepared that present land-use and land-cover data for counties, watersheds, census county subdivisions, and federally owned land.

Experimental and demonstration land-use and land-cover maps are produced to test various mapping techniques, remotely sensed data applications, regional applications, classification variation, computer applications, and combinations of map scale and minimum mapping unit.

The Geography program has provided technical assistance to users of Geological Survey land-use and land-cover data and maps and to those who desire to use the data in conjunction with computer software developed by the Geography program or who need the data converted to use with other systems. For example, the Geography program is cooperating with and assisting the U.S. Fish and Wildlife Service, the Bureau of Outdoor Recreation, the Bureau of Land Management, the Environmental Protection Agency, the Soil Conservation Service, the Forest Service, the Appalachian Regional Commission, the Ozarks Regional Commission, the Pacific Northwest Regional Commission, the Four Corners Regional Commission, and many State and local agencies to utilize the Survey's land-use and land-cover data in their resource management and planning.

Accomplishments

Accomplishment of the Geography program during fiscal year 1976 included:

- Compilation of land-use and land-cover maps and data for approximately 1,170,000 square kilometers (450,000 square miles) during fiscal year 1976, the second year of the national land-use mapping effort, bringing the total area completed for such mapping to 1,950,000 square kilometers (750,000 square miles). As in fiscal year 1975, the emphasis continued on mapping coastal areas, energy-production areas, other areas for which such mapping was desired by other U.S. Geological Survey units and other Federal agencies, and areas for which cooperative agreements for land-use and land-cover mapping had been made. Map and overlay sets for sixty 1:250,000-scale quadrangles were released to the open file in fiscal year 1976, which brings the total released to 86 sets.
- Mapping was completed under cooperative agreements for the States of Kansas (funded by the Ozarks Regional Commission), Florida, and Pennsylvania and the Atlanta (Georgia) Metropolitan Region. Cooperative agreements were entered into for land-use and land-cover mapping for the States of West Virginia, Alabama, Missouri, and North Carolina. Arkansas and Louisiana were previously mapped under cooperative agreements.
- Compilation of land-use and land-cover maps at regional (1:250,000), intermediate (1:100,000), and large scale (1:24,000) for the Atlanta Metropolitan Region and adjacent quadrangles in fulfillment of cooperative agreement obligations, in support of Atlanta Regional Commission activities, and in support of data needs for the Water Resources Division's Chattahoochee River Quality Assessment Study.
- Compilation of land-use-change maps at land-use and land-cover classification system Levels II and III for urban and regional settings in the southeastern Idaho area, in support of an Environmental Impact Analysis program study on monitoring capability following the release of the southeast Idaho environmental impact statement on phosphate-resource development.
- Completion of a test, in cooperation with the Publications Division, demonstrating the feasibility of lithographic printing of land-use and land-cover maps from polygon digital information stored on magnetic tape.
- Initiation of research activities directed toward creating operational land-use and land-cover maps from Landsat digital data for the northern Great Plains and the southern Alaskan coastal region.
- Completion of final reports for the Central Atlantic Regional Ecological Test Site Project dealing with land-use climatology, regional analysis, and geographic-information system development.
- Completion of research on the development of the oil and gas industry on the Louisiana coast dealing with impacts on land use and land cover of canal system expansion, maritime facilities siting, and labor force changes since 1947.
- Land-use and land-cover data for thirty-five 1:250,000-scale quadrangles (620,000 square kilometers or 240,000 square miles) and data from 215 related overlays comprising 20 million bytes of information were digitized through a contract for automated laser line-following digitizing and entered into the Geography program information system.
- Completion of implementation of a Geography program information system in the State of Louisiana and initiation in several other States.
- Development of the capability to convert polygon maps to grid cells of any selected size.

- Design and implementation of a data base having land-use and land-cover data as the central elements.
- Implementation of a highly efficient data-compaction routine.
- Provision of the initial impetus and partial funding for the seminar series conducted by the International Geographical Union, Commission on Geographical Data Sensing and Processing, for the purpose of studying spatial data bases within the Geological Survey.
- Publication of a map of land-use change, 1970–72, for the Washington urban area (U.S. Geol. Survey, 1975) and release of maps of land use and land-use change for Boston, Cedar Rapids, New Haven, Phoenix, Pontiac, Pittsburgh, San Francisco, and Tucson.
- Completion of a demonstration of land-use and land-cover classification of the Puget Sound region from Landsat digital data in collaboration with the Pacific Northwest Regional Commission, local planning agencies, National Aeronautics and Space Administration, and the Earth Resources Observation Systems program. Initiation of steps to incorporate machine processing of satellite data for use in the nationwide land-use and land-cover mapping and data-compilation program.
- Completion of studies of the use of Skylab sensors in analysis of urban land use and land-use change in urban areas. Also continued research in spatial analysis of digital land-use and land-cover data, as distinguished from spectral analysis, in the search for semiautomated techniques to detect land-use and land-cover change.
- Publication of "A Land Use and Land Cover Classification System for Use With Remote Sensor Data" (Anderson and others, 1976). This system is being applied in the nationwide land-use and land-cover mapping and data-compilation program.

EARTH RESOURCES OBSERVATION SYSTEMS PROGRAM

Program and activities

The Earth Resources Observation Systems (EROS) program, administered by the Geological Survey for the Department of the Interior, develops techniques to obtain and analyze remotely sensed data and promotes the use of these techniques in fulfilling the resource and environmental inventory and management responsibilities of the Department. This objective is accomplished in cooperation with the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and other Federal agencies.

Program personnel work closely with representatives of the Department's bureaus and offices to coordinate and jointly sponsor applications of remote-sensing technology. Much of the research, which has resulted in the demonstration of numerous new applications, has been made possible by the experimental data acquired through the National Aeronautics and Space Administration's Landsat and Skylab programs and their aerial remote-sensing research program. Other research draws on data collected by other systems, such as the environmental satellites of the National Oceanic and Atmospheric Administration and aerial remote-sensing activities sponsored by Department of the Interior bureaus and other Federal and State agencies.

EROS Data Center

The EROS Data Center in Sioux Falls, S. Dak., maintains an extensive archive of aerial and space photography, processes and distributes photographic and digital products, and provides extensive user training and technical assistance in the use of remotely sensed data. The Data Center's archive is a major component of the Survey's National Cartographic Information Center.

TRAINING AND ASSISTANCE

A major function of the Data Center is to communicate the results of remote-sensing research to potential users. Technical training programs, ranging in length from a few days to 1 month, stress the use of remotely sensed data to particular applications such as forest inventories or mineral exploration (fig. 69).

During fiscal year 1976, the Data Center sponsored 9 orientation courses, 17 discipline- or technique-oriented workshops, 3 structured courses, 2 international training courses, and 1 technical symposium. Courses and workshops were attended by 720 people.

In addition to formal courses, the Data Center operates a laboratory that provides visiting scientists with access to sophisticated equipment for processing digital imagery. This equipment is used for research, demonstration projects, and training. Data Center scientists also assist individual Federal, State, and local agencies in applying remotely sensed data to specific problems. In 1976 more than 600 scientists and resource managers attended demonstrations of the methods or conducted research analyses of Landsat data in the laboratory.

FIGURE 69.—A specialist in remotely sensed data shows students an interpretation technique at a technical training course.

DATA PRODUCTION AND DISSEMINATION

The EROS Data Center produces and distributes materials from data collected by satellites and aircraft. Data archived at the center, as of June 30, 1976, totaled over 6.5 million images, including over 800,000 frames of Landsat images and Landsat data in the form of computer compatible magnetic tapes. Aerial and space imagery holdings increase at an average rate of 38,000 frames per month, of which 20,000 are Landsat imagery.

The demand for reproductions of the data increased rapidly in fiscal year 1976 (tables 23 and 24). The Data Center distributed 25 percent more frames of Landsat imagery than in 1975, and, in addition, sales of computer compatible tapes increased from 879 to 2,289, an increase of 160 percent. This indicates an increased trend toward use of digital processing of Landsat data. Landsat and other satellite

TABLE 23.—*Demand for remotely sensed data*

Fiscal year	Thousands of dollars
1973	$0.4
1974	.9
1975	1.6
1976	2.5

TABLE 24.—*EROS Data Center customer profile*

Customer	Percentage of Landsat computer compatible magnetic tapes	Percentage of image data produced
Federal Government	38	37
State/local government	0	3
Academia	14	10
Industry	26	21
Individuals	2	12
Non-United States	20	17

products constituted 67 percent of the dollar-value data produced by the center during fiscal year 1976.

Procurement actions are in progress for a digital image-processing system at the EROS Data Center which will supply superior data products to customers in a shorter time. The new capability that is being implemented by Goddard Space Flight Center and the EROS Data Center will provide for: (1) shorter data delivery times for the digital tapes and film products; data will be available about 2 weeks after acquisition at ground stations instead of the 6 to 7 weeks using the present system; (2) high-quality film products derived directly from the archival high-density digital tape, which will retain over 50 percent of the information content lost by the present photographic-film archival system; and (3) geometrically corrected tape and film products.

Environmental monitoring

Landsat data were used for mapping and classification of lands in southeast Idaho to aid in preparation of an environmental impact statement on the effects of phosphate mining.

Remote-sensing education

The Survey aided in establishing a remote-sensing capability at the Washington Technical Institute, the District of Columbia Land Grant College, under the U.S. Geological Survey Committee on Minority Education in Earth Science. Two courses of one semester each were taught in 1976. A diazo printer and color-additive viewer, for analysis of Landsat images, were acquired and used in the courses.

Subsurface analysis

The integration of remote-sensing techniques into subsurface geologic analysis has been described in a report by Taranik and Trautwein (1976). Examples included are an exploration model for ground water in the Tucson, Ariz., area and an exploration model for mineralization in southeast Idaho.

Accomplishments

- Distribution of over 400,000 frames of imagery valued at more than $2 million.
- An increase in distribution of computer compatible magnetic tapes of Landsat data from 879 in fiscal year 1975 to 2,289 in fiscal year 1976.
- Initiation of a major digital image-processing system to provide higher quality image data for customers from Landsat–C and later satellites.
- Visits of over 17,000 persons to the EROS Data Center to become acquainted with applications of satellite data.
- In October 1975, the first W. T. Pecora Memorial Symposium was held in Sioux Falls, S. Dak., under the sponsorship of the American Mining Congress. The symposium was on the application of remote-sensing techniques to mineral and fuel exploration. Thirty of the papers will be published as a U.S. Geological Survey professional paper.
- Publication of "ERTS–1, A New Window on Our Planet" (Williams and Carter, 1976). It consists of 85 case histories on the use and application of ERTS–1 (now Landsat–1) data to earth resource mapping, monitoring, and inventorying.

ENVIRONMENTAL IMPACT ANALYSIS PROGRAM

Program and activities

The Environmental Impact Analysis (EIA) program provides an integrated Geological Survey response to the requirements of the National Environmental Policy Act through:

- Direction, coordination, and expertise in the preparation of environmental impact statements for which the Survey has lead or joint responsibility.
- Scientific and technical support of the preparation of statements for which the Survey has contributing responsibility.
- Technical analyses and review of statements and related documents prepared by other agencies.
- Manuals, guidelines, and training courses on the preparation and review of statements.
- Environmental research.

The National Environmental Policy Act requires that a Federal agency contemplating a major action that could significantly affect the quality of the environment must prepare a detailed statement of the possible environmental impacts. The Act further requires that statements must be reviewed by other Federal agencies having pertinent jurisdiction or expertise. In final form, the statement plays an essential role in an agency's decisionmaking process.

The Geological Survey becomes involved as a lead agency in the preparation of statements through the Conservation Division's supervision of mineral-resource exploration, development, extraction, and reclamation operations on Federal lands. The Survey becomes involved as a participating agency, in a nonlead role, both through its supervisory function, as described above, and through its special expertise in the areas of geology, hydrology, and mining and petroleum engineering.

In accordance with guidelines set by the Council on Environmental Quality, Federal agencies submit environmental impact statements to the Department of the Interior for review. The statements are assigned by the Department to one or more bureaus, primarily on the basis of legal jurisdiction or special expertise.

The principal objectives of the Environmental Impact Analysis program are to:

- Provide a core group of multidisciplinary specialists to assure the continuity of quality standards through acquired expertise in the preparation and review of environmental impact statements and through associated research and training.
- Reduce the time required for preparation and review of environmental impact statements.

The Environmental Impact Analysis program is organized functionally into three branches:

The Preparation Branch directs, coordinates, and reviews the work of the task forces preparing environmental impact statements throughout the United States. The task-force approach provides great flexibility through its rapid utilization of experienced scientists with topical and areal knowledge of the resource under study. During fiscal year 1976 and the transition quarter, the workload associated with preparing environmental impact statements increased about 30 percent; 70 percent of the total effort was for coal-related statements.

The Review Branch provides technical analyses and review of statements and related documents prepared by the Geological Survey task forces, the Department of the Interior, and other Federal agencies. The level of effort required to review environmental statements increased by about 10 percent this year.

The Research and Training Branch supports and improves the activities of the other two branches by training new members, by preparing guidelines and manuals for task-force leaders and members, and by encouraging, sponsoring, and developing new methodologies for environmental statement preparation and impact monitoring. During the year the workload associated with these branch activities increased approximately 50 percent.

The growing participation of Federal, State and local agencies in the preparation of environmental impact statements has led to a wider range of jurisdictional concerns and a greater variety of related actions to be addressed in a single statement. This increasing complexity strains the current methods of task-force management and organization and the present format of the statements. Innovations in managerial techniques and imaginative restructuring of the statements, including increased use of computers, are required to meet the present problems and challenges.

The preparation of environmental impact statements is immensely expensive in terms of time and cost. Research concerned with reducing the bulk, time, and cost involved in the preparation of the environmental impact statements was started during fiscal year 1976. The first step concentrates on an overall reduction in bulk by restructuring the statements by stringent editing, use of summarization, use of highly structured supporting materials for ease of reference, and maximum use of charts, matrices, and graphics. Subsequent improvements will include use of improved analytical methods such as computer-modeling techniques for analyzing alternative actions and their impacts.

Accomplishments

During the fiscal year 1976 and the transition quarter, the Survey:

- Took lead or joint-lead responsibility for the preparation of 20 environmental impact statements. Seventeen statements concerned the development of onshore coal, uranium, oil and gas, and offshore oil and gas operations. The other three concerned critical minerals, leasing, and regulations (fig. 70 and table 25). Five of these statements were completed during the year.
- Participated in a nonlead capacity in the preparation of 15 impact statements for which other Federal agencies had lead responsibility. Twelve of these statements were energy related, involving principally coal and oil and gas-leasing operations and projects involving mine-mouth electric generating plants and related transmission lines, pipelines, and water supply. The remainder dealt with critical minerals. One of these statements was completed during the year (fig. 70 and table 25).
- Provided technical information, gathered by other Survey programs, to the U.S. Forest Service for 7 impact statements on geothermal energy resources and to the Bureau of Land Management for 12 impact statements on leasing of the U.S. Outer Continental Shelf.
- Reviewed and commented on 2,812 impact statements and related documents.
- Prepared guidance manuals to aid in the management and administration of task forces and in the writing of environmental impact statements.
- Conducted training seminars for personnel assigned to task forces.
- Initiated research for reduction of bulk, time, and cost of preparing environmental impact statements.

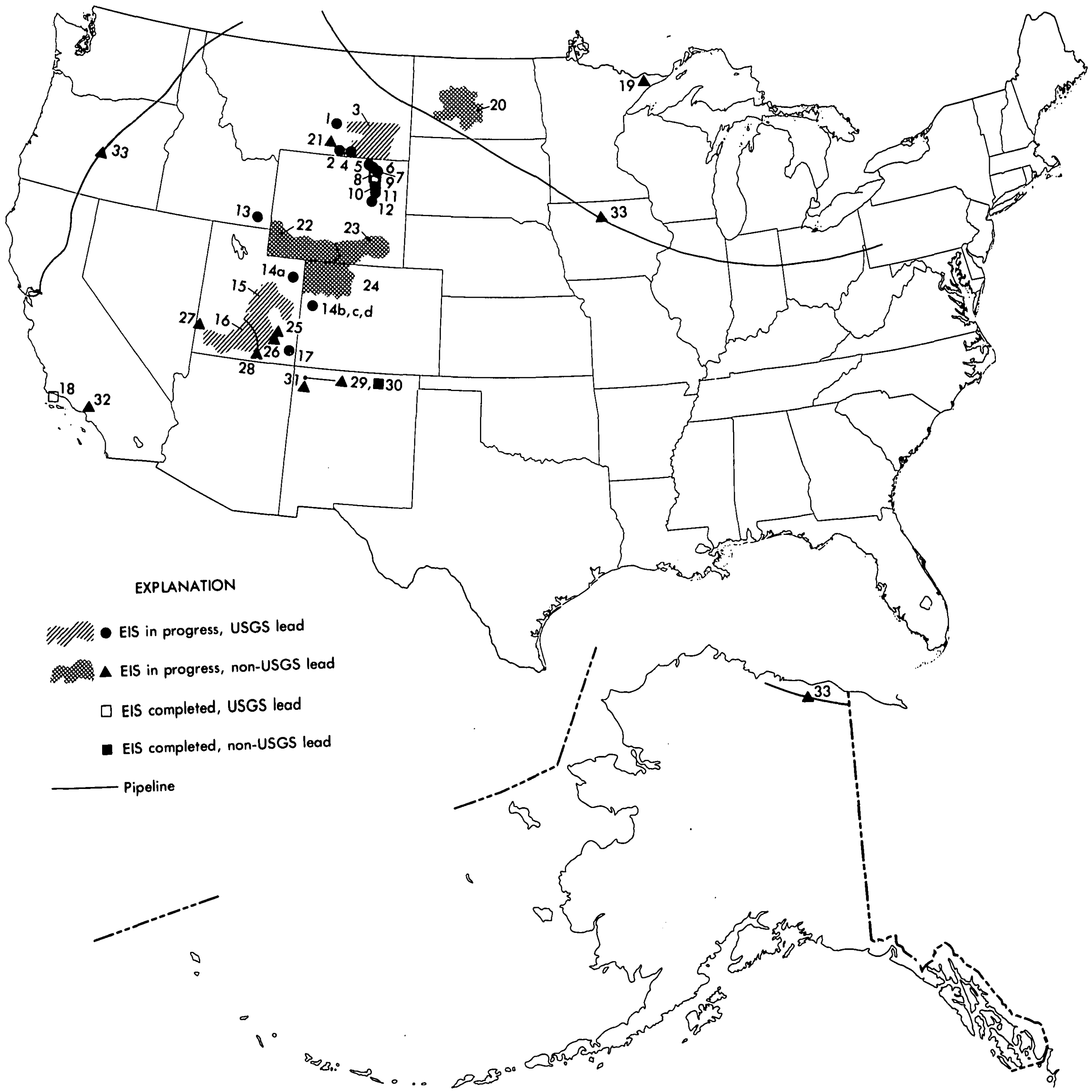


FIGURE 70.—Locations for which environmental impact statements (EIS) were in progress or completed during fiscal year 1976 and transition quarter. (Locality numbers are keyed to table 25.)

- Initiated research concerned with developing methodologies for delineating, measuring, and monitoring environmental impacts of phosphate strip mining in southeastern Idaho (fig. 70). These methodologies, developed in cooperation with other Federal agencies and State and local governments, can be used by the local or State agencies who will assume the monitoring costs and responsibilities.

TABLE 25.—*Environmental impact statements completed or in progress during fiscal year 1976 and transition quarter (locality numbers are keyed to fig. 70)*

Title	State	Locality number	Project description
GEOLOGICAL SURVEY LEAD OR JOINT-LEAD RESPONSIBILITY			
Westmoreland coal mine	Montana	1	Determine impacts of proposed mining and reclamation plan in the Crow-ceded area in south-central Montana.
Crow Shell (Youngs Creek) coal mine[1]	do	2	Evaluate impacts of mine and transportation system on Crow Indian Reservation.
Northern Powder River regional coal leasing and mining	do	3	Evaluate individual and cumulative regional impacts of leasing and mining in south-central Montana.
Decker coal mines	do	4	U.S. Geological Survey and State of Montana project to determine impact of proposed mining and reclamation plan.
Eagle Butte coal mine	Wyoming	5	Determine impacts of Amax Coal Co.'s proposed mine north of Gillette.
East Gillette coal mine	do	6	Determine impacts of Kerr-McGee Co.'s proposed mine north of Gillette.
Caballo coal mine	do	7	Determine impacts of Carter Oil Co.'s proposed mine southeast of Gillette.
Belle Ayr South coal mine[2]	do	8	Determine impacts of mining and reclamation plan for expanded Amax Coal Co.'s mine.
Cordero coal mine[2]	do	9	Determine impacts of Sun Oil Co.'s proposed mining and reclamation plan south of Gillette.
Coal Creek coal mine	do	10	Determine impacts of Atlantic Richfield Co.'s proposed mining and reclamation plan south of Gillette.
Rochelle coal mine	do	11	Evaluate impacts of Peabody Coal Co.'s project in eastern Powder River Basin.
Bear Creek uranium mine and mill	do	12	Determine impacts of Rocky Mountain Energy Co.'s mining and milling operation in the national grasslands south of Gillette.[3]
Phosphate leasing and development	Idaho	13	Determine separate and collective impacts of 16 mining plans on Federal leaseholds in southeastern Idaho.
Oil-shale tract leasing	Colorado-Utah	14	Evaluate impacts of leasing 4 tracts for in situ production of shale oil.
Central Utah regional coal leasing and development	Utah	15	Evaluate individual and cumulative regional impacts of leasing and mining.
Southern Utah regional coal leasing and development	do	16	Do.
Glen Canyon National Recreation Area fireflood project[1]	do	17	Evaluate impacts of Oil Development Co. of Utah's pilot fireflood project to extract oil from bituminous sandstone.
Santa Barbara Channel development[2]	California	18	Examine impacts of further oil and gas development in channel.
Coal operating regulations (30 CFR, part 211)[2]	Nationwide[4]		Examine impact of proposed revised regulations on lessees, permittees, and licensees during discovery, testing, development, mining, and reclamation.[5]
Geological and geophysical regulations[2]	do[4]		Examine impacts of proposed regulations governing Outer Continental Shelf geological and geophysical exploration.

See footnotes at end of table.

TABLE 25.—*Environmental impact statements completed or in progress during fiscal year 1976 and transition quarter*—Continued

Project	State	Locality number	Lead agency
GEOLOGICAL SURVEY PARTICIPATION			
INCO copper-nickel open-pit mine[1]	Minnesota	19	Forest Service.
West-central North Dakota regional coal leasing and development	North Dakota	20	Bureau of Land Management.
Westmoreland coal leasing	Montana	21	Bureau of Indian Affairs.
Sweetwater-Kemmerer regional coal leasing and development	Wyoming	22	Bureau of Land Management.
Hanna Basin-Atlantic Rim regional coal leasing and development	do	23	Do.
Regional coal leasing and development	Northwest Colorado	24	Do.
Emery coal mine and power-generation plant	Utah	25	Do.
Allen-Warner Valley coal mining, power generation, and slurry pipeline	do	26	Do.
Alunite mining and processing	do	27	Do.
Kaiparowits coal mine and power-generation plant[1]	do	28	Do.
El Paso coal mine and gasification plant[2]	New Mexico	29	Bureau of Reclamation.
WESCO coal mine and gasification plant	do	30	Do.
Exxon uranium exploration leasing	do	31	Bureau of Indian Affairs.
Los Padres phosphate leasing	California	32	Bureau of Land Management.
Natural gas transportation system	Alaska, Canada, and conterminous United States	33	Bureau of Land Management and State of Alaska.

[1] Inactive.
[2] Completed.
[3] Joint-lead responsibility with Nuclear Regulatory Agency and Forest Service.
[4] Not shown in figure 70.
[5] Joint-lead responsibility with Bureau of Land Management.

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Two of the program support activities: Top, Public Inquiries Offices throughout the country distribute USGS maps and books to the public; bottom, the Computer Center Division maintains a nationwide computer network.

Program Support Activities

OVERVIEW

Four organizational units of the Geological Survey provide essential managerial, administrative, and technical services to support the Survey's scientific and regulatory programs:

- *Office of the Director*, through the Director, the Associate Director, the Assistant Directors, and their respective staffs (excluding the Land Information and Analysis Office), provides executive direction, coordinates interagency and intrabureau activities, and guides program development.
- *Administrative Division* supplies the Survey's programs with budgetary, financial, procurement, personnel, and other administrative services and manages the Survey's National Center in Reston, Virginia.
- *Computer Center Division* operates a nationwide computing system and provides Survey scientists with a wide range of automatic data-processing services.
- *Publications Division* edits the Survey's scientific and technical publications, as well as its nontechnical booklets; prints maps; distributes maps and monographs; and answers inquiries from the public about the Survey's work and reports.

Although the Geological Survey Library is operated and funded for the most part by the Geologic Division, it is also described in this section because of its importance to the research activities of all Survey programs.

Program support activities are financed by direct appropriations ("General administration" and "Facilities" budget activities, table 26), assessments on direct and reimbursable program funds of other budget activities (table 26), and reimbursements from other agencies ("Miscellaneous services to other accounts," table 26).

GENERAL ADMINISTRATION

General administrative expenses include the executive direction and coordination of Survey programs by the Director's Office and the provision of financial, procurement, personnel, and other administrative services by the Administrative Division.

During fiscal year 1976 and the transition quarter, general administrative expenses (table 26) amounted to $15.1 million. These expenses were funded from three sources: (1) The "General administration" budget activity, about $4.9 million; (2) assessments on the directly appropriated activities, $7.2 million; and (3) assessments on the reimbursable programs, $3.0 million. No assessments are made on cooperative funds from State and local governments. Despite the Geological Survey's larger budget, greater number of employees, and increased use of grants and contracts, general administrative expenses continued to represent only about 3.0 percent of the total Survey budget and have increased less than one-half of one percent over the past 5 years (table 26).

Significant events and accomplishments during the year included:

FLEXITIME TEST

The successful completion of a 1-year experiment with flexible working hours for all Survey employees in the Washington, D.C., area resulted in implementation of the policy. Although several Federal organizations are now studying or testing the Flexitime concept, the Survey, whose 10,000 employees now enjoy flexible hours, is one of the first—and the largest—Federal establishments to adopt the concept.

In accordance with the Flexitime policy, employees are permitted to work an 8-hour day any time between 7:00 a.m. and 5:30 p.m., provided that they are present for the "core time," 9:00 a.m. to 3:30 p.m., minus the lunch break. Employees may vary their starting times each day to conform to their personal needs and individual lifestyles. The enthusiasm of both employees and supervisors for the concept was supported by responses to questionnaires sent to all employees before the policy was adopted permanently. Among the findings of the survey were:

- *Reductions in absenteeism*—During the experiment, short-term leave usage decreased by more than 20 percent, probably because employees were able to schedule personal activities outside of working hours.

- *Tardiness*—71 percent of all supervisors felt that tardiness declined.
- *Employee morale*—Substantial increases were noted, and Flexitime has also been a recruitment incentive. It is also believed that Flexitime has helped reduce personnel turnover, particularly among students and working mothers.
- *Productivity*—27 percent of all supervisors felt that the amount of work accomplished increased as a result of Flexitime; only 5 percent felt that there had been a decrease.
- *Overtime usage*—Decreases in the amount of paid overtime required under Flexitime were reported by 62 prcent of all supervisors.
- *Utilization of specialized equipment*—Offices were able to make greater use of specialized equipment because of the longer operating day.
- *Quiet time*—73 percent of all supervisors felt that they and their employees benefited from "quiet time" periods before and after core time.
- *Traffic and transportation*—Morning and evening traffic congestion around the National Center was eased, and 56 percent of all employees reported some reduction in their commuting time.

No major problems were experienced. Communications might have worsened slightly in some areas, but improvements have also been cited, since the longer workday enables the Survey to provide better service to the public and to communicate more easily with other agencies.

NEW USGS CENTER IN ROLLA, MISSOURI

May 19, 1976, marked the dedication of a Geological Survey Center in Rolla, Missouri. All Survey activities in the Rolla area, previously located in four different buildings, were consolidated under one roof. The largest of these activities is the Mid-Continent Mapping Center, whose area of responsibility comprises 14 States. Particular consideration was given to developing a facility with suitable equipment and space to help the mapping center satisfy the Nation's needs for products such as orthophotomaps, slope maps, regional and county maps, and land use maps. Construction began in 1974 on the 8,825-square-meter (95,000-square-foot) single-story brick and cinder block building. Special features include a computer room with a recessed floor and a photographic laboratory with vibration-isolating pads in the concrete floors under the cameras. This 930-square-meter (10,000-square-foot) laboratory also has special plumbing with a filtered water supply and interceptor tanks to remove chemicals before wastewater enters the sewer system. The first emergency system in the building features smoke detectors, sprinklers, battery-powered emergency lights, and alarms connected to the city's fire department. Nearly $2,000,000 was spent on the project. Approximately 340 employees work at the Rolla Center.

PROCUREMENT AND CONTRACTING ACTIVITIES

Increases in the Survey's programs, especially those related to energy resources, and personnel ceilings have led the Survey to depend more frequently on the private sector for services. Over the past 7 fiscal years, the Survey's procurement and contracting program has increased tenfold, from $9 million in fiscal year 1970 to $99 million in fiscal year 1976 (fig. 71).

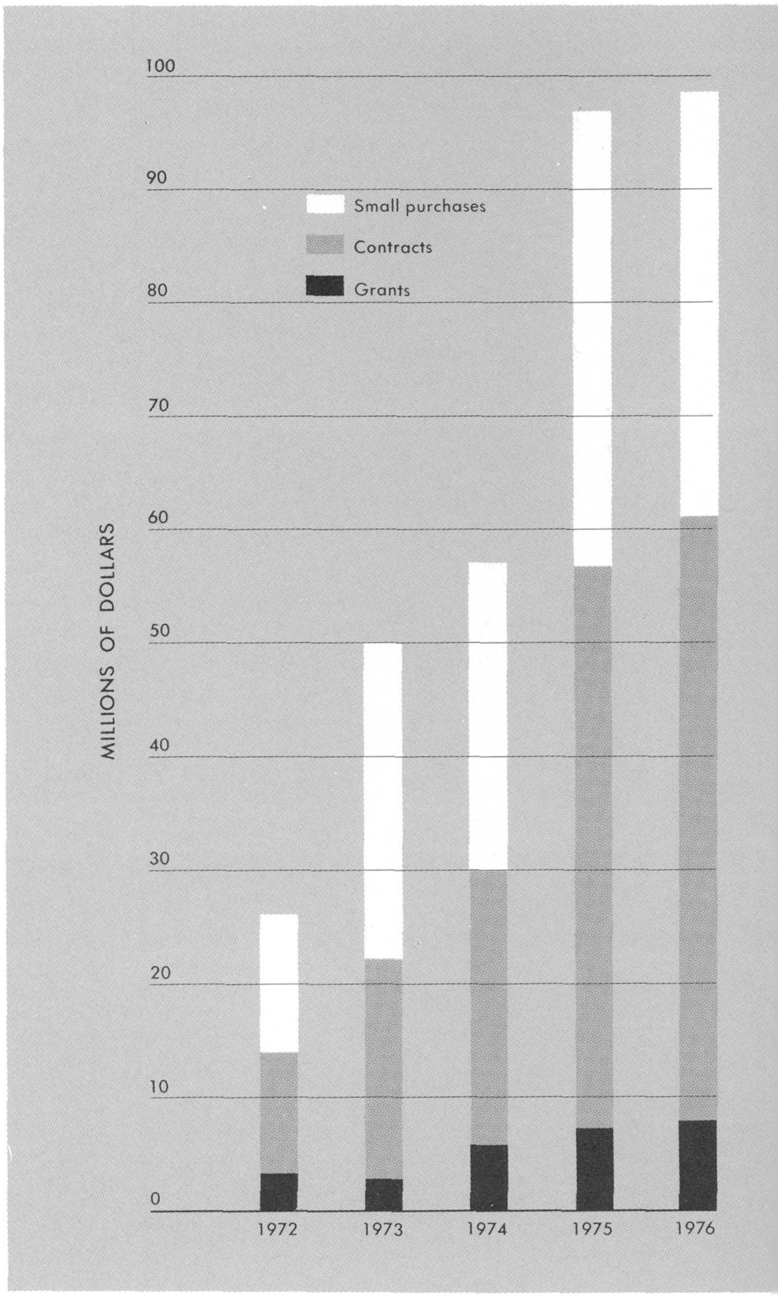

FIGURE 71.—Geological Survey expenditures on grants, contracts, and small purchases, fiscal years 1972–76.

During this period, personnel responsible for procurement and contracting increased from 34 to 67. Also, the type of procurement has changed substantially. At the start of the decade, practically all of the Geological Survey's procurement actions were for low-cost, commercially available equipment. Now the procurement program includes research and development contracts, grants for research, complex service contracts, and contracts for sophisticated equipment whose performance characteristics and specifications are often not available on the commercial market.

CONSUMER REPRESENTATION PLAN

As part of the increasing emphasis in the Executive Branch on responsiveness to consumer concerns, the Survey contributed to the preparation of the first Department of the Interior Consumer Representation Plan; initiated development of a Consumer Representation Plan for the Survey; and designated individuals to act as contact on consumer affairs for headquarters, divisional, and regional offices.

FIRE AT THE CENTRAL REGION HEADQUARTERS

In March 1976, a fire in the two-story building that houses the Survey's Central Region offices in Denver, Colo., destroyed six major laboratories, nine smaller laboratories, and supporting office space. In addition, there was smoke and water damage and extensive structural damage to the building. The cost of reconstructing the building was estimated at $4.5 million; repair and replacement costs of critical items, as cited in a budget supplemental request, totaled $2.4 million. Disruption of normal operations was minimized through implementation of an existing Emergency Preparedness Plan. In accordance with the plan, regional managers established priority actions and provided direction and liaison to facilitate those actions. The General Services Administration furnished valuable technical assistance, and plans were initiated immediately to build or relocate the affected laboratories and offices and the library, which suffered water damage.

The existence of a large quantity of combustibles, particularly chemicals, made the fire difficult to suppress. Controls on combustibles and ignition sources have since been expanded, and other preventive actions have been taken to (1) limit amounts of combustibles stored; (2) properly store all equipment, materials, and supplies; and (3) provide adequate staffing to guard buildings outside of normal working hours.

FACILITIES

The "Facilities" activity covers the operation of the National Center, which consists of office, laboratory, industrial, and warehouse space in Reston, Virginia. Funds appropriated for facilities management in fiscal year 1976 and the transition quarter amounted to $12 million (table 26). These funds were maintained in a separate account under the control of the Assistant Director for Administration.

COMPUTER TECHNOLOGY

The Computer Center Division operates a nationwide system of computer facilities and terminals to provide automatic data-processing services for the Geological Survey. The primary computer installation, located at the National Center, consists of two interconnected large-scale IBM 370/155 computers. Together, these computers provide high-speed magnetic core memory for 8 million characters of information and on-line magnetic disk storage for 6.6 billion characters of information. During fiscal year 1976 and the transition quarter, more than 800 users from 84 remote locations (fig. 72) submitted approximately 423,000 jobs to these computers.

In addition to the Reston computer facility, the Survey operates a number of other computers:

- Burroughs Corporation Model B–6700 computer at the Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota.
- Digital Equipment Corporation Model 1070 computer at Denver, Colorado.

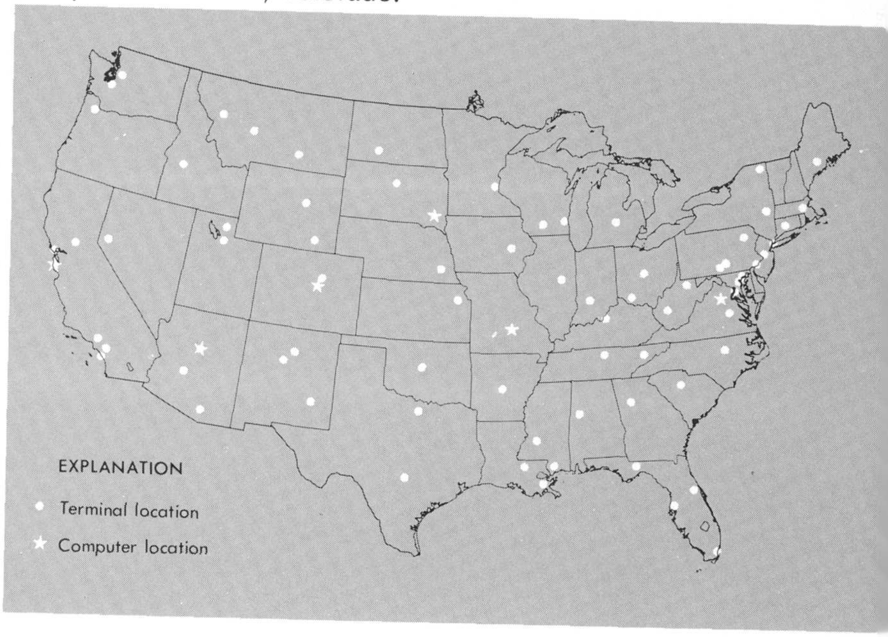

FIGURE 72.—Geological Survey computing network. A terminal site in Alaska is currently under construction.

- Systems Engineering Laboratories, Inc., Model 86 computer at Rolla, Missouri.
- Digital Equipment Corporation Model 11/20 and Model 11/45 computers at Flagstaff, Arizona.
- A number of special-purpose computers and minicomputers for use in field and laboratory investigations.

The Survey is increasingly charged with providing direction to both Government and industry in all phases of energy-related exploration, development, and production. Concomitantly, Survey requirements for increased computation capacity accelerated in fiscal year 1976. This growth is reflected in the following statistics:

- 55 terminals were connected to the National Center computers for remote entry and time-sharing, an increase of 24 percent.
- $13.9 million was spent on in-house data processing and related services, and $2.5 million was spent on contracts for commercial data-processing services.
- On-line storage capacity was increased by 1,600 million bytes by the addition of 16 units of double-density disk drives.
- A $15 million contract was awarded to the Honeywell Corporation for three Series 60-Level 68 Multics time-sharing computers to be installed in Reston, Virginia; Denver, Colorado; and Menlo Park, California.

Much of this activity can be attributed to the continued expansion of Survey activities in energy research and development, resource evaluation, lease supervision, and information dissemination and to the transition from routine batch-processing techniques to more sophisticated interactive processing methods that make use of time-sharing systems and software for data-base management. Program managers, faced with stringent personnel ceilings and increasing workloads, are using automatic data processing techniques to improve the productivity of their staffs. For example, remote terminals give Survey scientists rapid access to information about the availability of maps, aerial photographs, and space imagery, bibliographies of scientific literature, and a variety of data files.

In many cases, the time required to assemble data for research or to answer requests for information has been significantly shortened. Although much still remains to be learned about how to use these tools to greatest advantage, their potential for improving the productivity and quality of Geological Survey programs appears to be great.

Some examples of computer applications in operation or under development during 1976 are listed below:

- Development of a number of geologic data bases dealing with mineral resources, energy resources, and geochemical analyses.
- Operation of a real-time seismic monitoring and earthquake detection network.
- Expansion of the National Water Data Storage and Retrieval System to include ground-water data.
- Simulation of surface-water and ground-water behavior in areas expected to be mined for coal and oil shale.
- Development of automated cartographic methods to produce maps from spatial digital data.
- Royalty accounting.
- Tracking and development of Outer Continental Shelf oil and gas leases.
- Processing of remote-sensing data.
- Provision of custom enhancements to Landsat pictures containing areas of special geologic interest.

Highlights of computed support activities included:

- An RFP was issued on August 8, 1975, asking industry to bid on specifications for three compatible time-sharing computers, one each at Menlo Park, California; Denver, Colorado; and Reston, Virginia. The specifications for the three computers met long-term Geological Survey requirements at the three locations. Benchmark testing, technical evaluation, and cost evaluation of equipment proposed by vendors was completed during fiscal year 1976. A contract was awarded to the Honeywell Corporation on August 10, 1976, with installation scheduled for the three locations early in fiscal year 1977.
- The Flagstaff Computation Center provided computer support for the Viking Mars landing mission. The Flagstaff computer was used to provide cartographic digital image enhancements of the photographs sent back to Earth. The selection of the final landing site for Viking I was based on the calculations made by the Flagstaff computer.

PUBLICATIONS PROGRAM

Results of research and investigations conducted by the Geological Survey are made available to the public through increasingly diverse information services and publications. Developing mechanisms to assure timely release of data and maps is a formidable challenge.

The number of reports approved for publication by the Geological Survey continues to increase (fig. 73). About 64 percent of the 4,300 reports prepared in fiscal year 1976 and the transition quarter were designated for publication in professional journals and monographs outside the Survey; about 23 per-

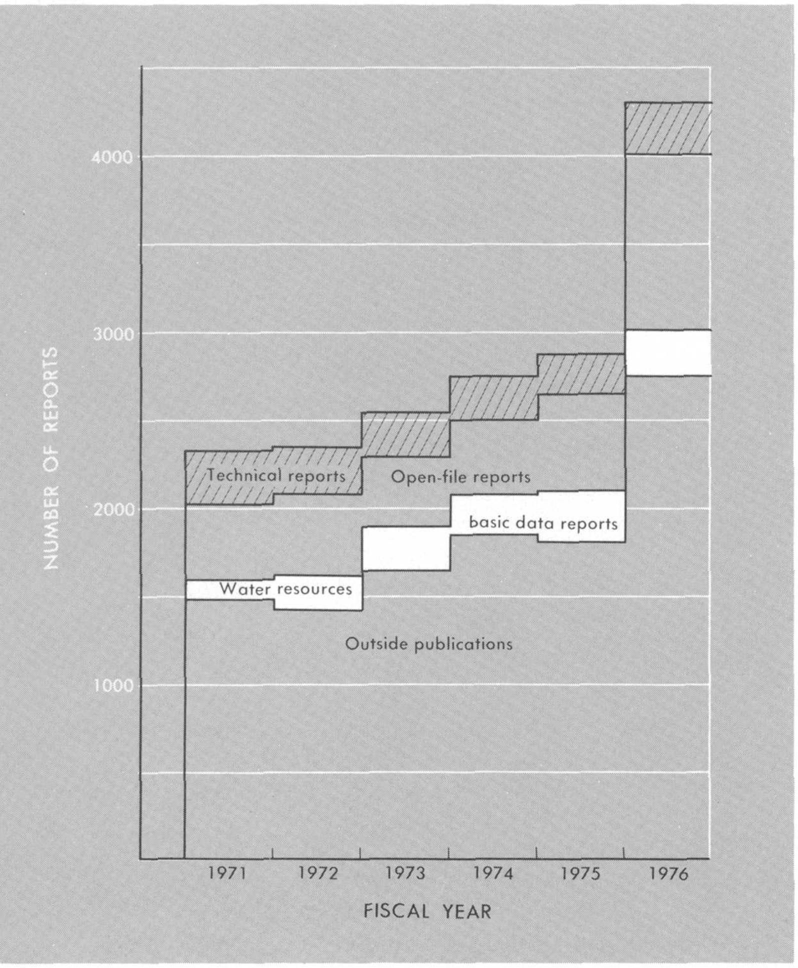

FIGURE 73.—Number of reports approved for publication, fiscal years 1971–76. (1976 figures include transition quarter.)

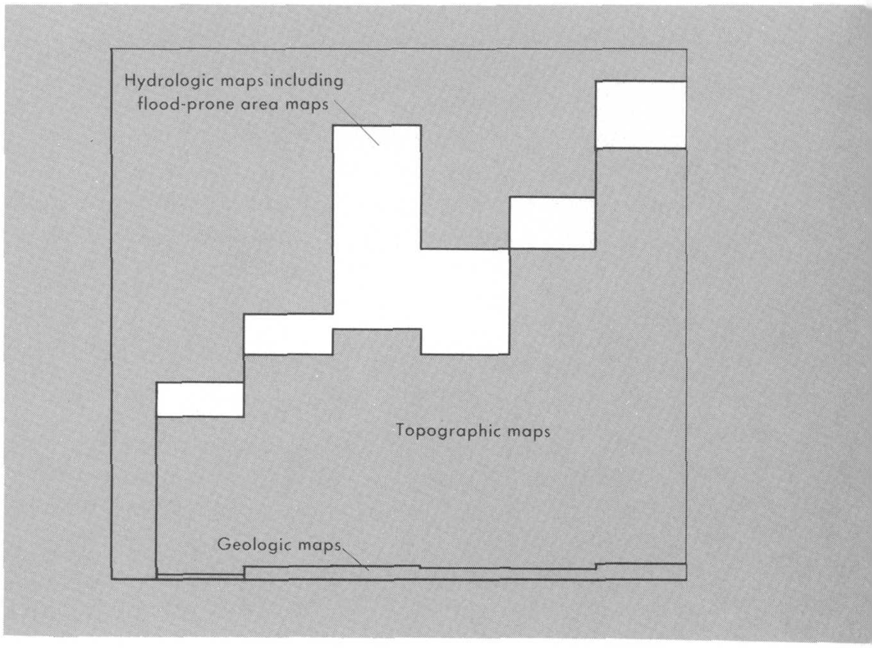

FIGURE 74.—Number of maps produced, fiscal years 1971–76. (1976 figures include transition quarter.) (Does not include maps produced by the Conservation Division and the Director's Office.)

cent were placed in open file; and the remainder were scheduled for publication by the Survey (table 46). The Survey also produced over 11,000 topographic, hydrologic, and geologic maps in fiscal year 1976 and the transition quarter (fig. 74 and table 47).

The Publications Division edits the Survey's scientific and technical publications printed by the Government Printing Office, prepares nontechnical booklets, produces reproduction material for geologic and hydrologic maps, and prints and distributes all Survey maps. Most of the maps are printed at the National Center, but in recent years a substantial number have been printed by commercial firms under contract.

The Publications Division also operates nine Public Inquiries Offices throughout the country that answer queries about the Survey's work and sell maps and books over the counter as agents of the Government Printing Office.

Highlights of the Publications Division's program in fiscal year 1976 included:

- Installation in fiscal year 1975 of a five-color printing press enabled the Publications Division to reduce the average cost of printing new maps by more than 25 percent. This 60-inch press accommodates approximately 80 percent of the maps printed with one pass-through, as opposed to three passes on the older two-color press. In addition, the acquisition of an automated imposition machine reduced the time required for making printing plates by 50 percent.
- To make urgently needed results of scientific investigations available to the public on a timely basis, the Publications Division, through the Government Printing Office, established a commercial-contracts system for printing books. This system has reduced the printing time of book reports from an average of 5 months to an average of 4½ weeks.
- In April 1975, the Publications Division's Branch of Distribution of the Eastern Region became an agent of the Superintendent of Documents of the Government Printing Office for the sale of Survey book publications. These publications are sold over the counter and by mail. Many Survey books were not stocked by the Superintendent of Documents because their subject matter was

of interest only to a specialized clientele and were low in sales. Current indications are that, since the Branch of Distribution has become an agent of the Superintendent of Documents, sales from these reports will match those of reports stocked by the Superintendent of Documents. Thus, a service was provided to users of the Survey's book reports that formerly was not available. Also, the order-processing time for books was reduced from several weeks to an average of 2 or 3 days.

Guide to publications

Throughout this report, reference has been made to information services and publications of the Geological Survey. This section describes how and where the public may acquire information and obtain products.

To buy Survey book publications; to buy maps of areas east of the Mississippi; or to request Survey circulars, catalogs, pamphlets, and leaflets (limited quantities free), write or visit:

U.S. Geological Survey
Branch of Distribution
1200 S. Eads St.
Arlington, Virginia 22202

Include check payable to U.S. Geological Survey.

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

U.S. Geological Survey
Branch of Distribution
Box 25286, Bldg. 41, Federal Center
Denver, Colorado 80225

Include check payable to U.S. Geological Survey.

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 Dr.
Reston, VA 22092

To start a subscription to the "Journal of Research of the U.S. Geological Survey," the "Earthquake Information Bulletin," or the "Preliminary Determination of Epicenters", write:

Superintendent of Documents
Government Printing Office
Washington, DC 20402

"Journal of Research": $18.90 per year (plus $4.75 for foreign mailing)
"Earthquake Bulletin": $3.00 per year (plus 75¢ for foreign mailing)
"Preliminary Determination of Epicenters": $4.35 per year (plus $1.10 for foreign mailing)

Include check payable to U.S. Geological Survey.

To buy books and maps of local areas and general interest, visit the Public Inquiries Offices in the following states:

Alaska:
108 Skyline Bldg., 508 2d Ave.
Anchorage, Alaska 99501
California:
7638 Federal Bldg., 300 N. Los Angeles St.
Los Angeles, California 90012

504 Customhouse, 555 Battery St.
San Francisco, California 94111
Colorado:
1012 Federal Bldg., 1961 Stout St.
Denver, Colorado 80294
Texas:
1-C-45, Federal Bldg., 1100 Commerce St.
Dallas, Texas 75202
Utah:
8105 Federal Bldg., 125 S. State St.
Salt Lake City, Utah 84138
Virginia:
1-C-402, National Center, 12201 Sunrise Valley Dr.
Reston, Virginia 22092
Washington:
678 U.S. Courthouse, W. 920 Riverside Ave.
Spokane, Washington 99201
Washington, D.C.:
1028 General Services Bldg., 19th and F Sts., NW.
Washington, D.C. 20244

To obtain information on cartographic data, write or visit:

U.S. Geological Survey
National Cartographic Information Center
507 National Center
12201 Sunrise Valley Dr.
Reston, Virginia 22092

To obtain information on satellite and space photography, write or visit:

U.S. Geological Survey
EROS Data Center
Sioux Falls, South Dakota 57198

GEOLOGICAL SURVEY LIBRARY

The Geological Survey Library is one of the largest earth-science libraries in the world. The main library is located at the Survey's National Center in Reston, Virginia; branches are located at major research centers in Denver, Colorado; Menlo Park, California; and Flagstaff, Arizona. These libraries collectively contain more than 1.9 million items, including books, monographs, serials, pamphlets, single-sheet maps, photographs and negatives, aerial photographs, microforms, field record notebooks, and related materials. Although these holdings are intended primarily to support the research of the Geological Survey, the library also serves other Government agencies, State geological surveys, academic institutions, and research organizations throughout the country.

The main library at Reston currently is involved in developing a computerized cataloging manual for maps. Hopefully, the system, which will be housed at and operated by the Ohio College Library Center, will be fully operational by early 1977. Cooperative cataloging of single-sheet maps by those repositories having significant collections will give earth-science libraries easier access to the thousands of geoscience maps produced annually. All map-cataloging data will be put on magnetic tape, the ultimate aim being to generate a book catalog of the library's map collection and to produce a monthly list of current map acquisitions.

A fire at the Denver Federal Center in March 1976 disrupted library services and resulted in the relocation of all library operations in new facilities outside the Denver Federal Center. One result of this disruption is that public-service statistics (users, circulation, interlibrary lending/borrowing, and reference queries) are lower than might otherwise be expected. (See table 55.)

USGS editors and illustrators work together to produce publications resulting from Survey programs.

- **DIRECTOR**
- **ASSOCIATE DIRECTOR**
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    - LAND RESOURCES
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    - ENVIRONMENTAL CONSERVATION
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    - WESTERN REGION
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    - ASSOCIATE CHIEF, PROGRAM MANAGEMENT
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      - EARTH SCIENCES APPLICATIONS PROGRAM
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      - ENVIRONMENTAL IMPACT ANALYSIS PROGRAM
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          - Photogrammetry
          - Cartography
          - Aerial Photography and Image Technology
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          - National Cartographic Information Center
          - International Activities
      - MAPPING CENTERS
        - Eastern—Reston, Va.
        - Mid-Continent—Rolla, Mo.
        - Rocky Mountain—Lakewood, Colo.
        - Western—Menlo Park, Calif.
        - Special Mapping Center—Reston, Va.
  - **GEOLOGIC DIVISION**
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    - DEPUTY CHIEF GEOLOGIST, OPERATIONS
    - DEPUTY CHIEF GEOLOGIST, PROGRAM AND BUDGET
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          - Special Projects
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          - Paleontology and Stratigraphy
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          - Exploration Research
          - Office of Resource Analysis
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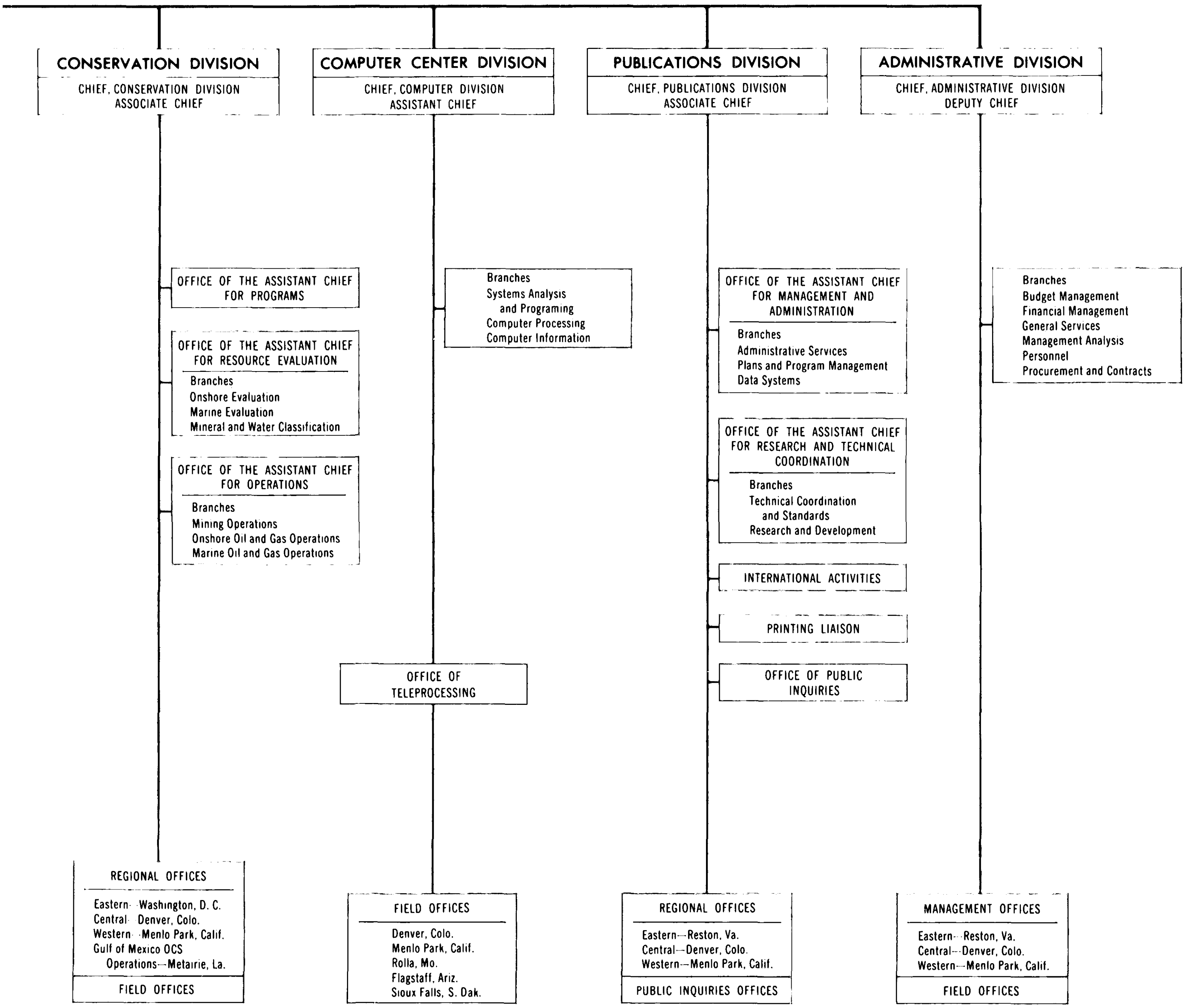
          - Seismicity and Earth Structure
          - Earthquake Mechanics and Prediction
          - Earthquake Hazards
      - OFFICE OF GEOCHEMISTRY AND GEOPHYSICS
        - Branches
          - Experimental Geochemistry and Mineralogy
          - Field Geochemistry and Petrology
          - Isotope Geology
          - Regional Geochemistry
          - Analytical Laboratories
          - Petrophysics and Remote Sensing
          - Electromagnetism and Geomagnetism
          - Regional Geophysics
      - OFFICE OF ENERGY RESOURCES
        - Branches
          - Oil and Gas Resources
          - Coal Resources
          - Chemical Resources
          - Uranium and Thorium Resources
      - OFFICE OF INTERNATIONAL GEOLOGY
        - Branches
          - Latin American and African Geology
          - Middle Eastern and Asian Geology
      - OFFICE OF MARINE GEOLOGY
        - Branches
          - Pacific—Arctic Geology
          - Atlantic—Gulf of Mexico Geology
      - REGIONAL OFFICES
        - Eastern—Reston, Va.
        - Central—Denver, Colo.
        - Western—Menlo Park, Calif.
  - **WATER RESOURCES DIVISION**
    - CHIEF HYDROLOGIST
    - ASSOCIATE CHIEF HYDROLOGIST
      - OFFICE OF INTERNATIONAL ACTIVITIES
      - OFFICE OF WATER DATA COORDINATION
      - OFFICE OF THE ASSISTANT CHIEF FOR RESEARCH AND TECHNICAL COORDINATION
        - DEPUTY ASSISTANT CHIEF FOR RESEARCH
          - Branches
            - Surface Water
            - 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
        - Northeastern—Reston, Va.
        - Southeastern—Atlanta, Ga.
        - Central—Denver, Colo.
        - Western—Menlo Park, Calif.
        - DISTRICT OFFICES

Organizational and Statistical Data



U.S. GEOLOGICAL SURVEY OFFICES
HEADQUARTERS OFFICES

12201 Sunrise Valley Drive
National Center, Reston, VA 22092

OFFICE OF THE DIRECTOR

Official	Name	Telephone number	Address
Director	V. E. McKelvey	(703) 860–7411	National Center, STOP 101.
Associate Director	W. A. Radlinski	(703) 860–7412	National Center, STOP 102.
Washington Liaison Officer	George W. Whetstone	(202) 343–3888	National Center, STOP 103. Rm. 4441, Interior Bldg., Washington, DC 20240.
Assistant Director—Land Resources	James R. Balsley	(703) 860–7488	National Center, STOP 104.
Assistant Director—Energy and Mineral Resources	Montis R. Klepper	(703) 860–7481	National Center, STOP 171.
Assistant Director—Environmental Conservation	Henry W. Coulter	(703) 860–7491	National Center, STOP 106.
Assistant Director—Administration	Edmund J. Grant	(703) 860–7201	National Center, STOP 201.
Assistant Director—Program Analysis	Dale D. Bajema	(703) 860–7435	National Center, STOP 105.
Assistant Director—Eastern Region	William B. Overstreet	(703) 860–7414	National Center, STOP 109.
Assistant Director—Central Region	Alfred Clebsch, Jr., Acting	(303) 234–4630	Denver Federal Center, Box 25046, STOP 101, Denver, CO 80225.
Assistant Director—Western Region	George E. Robinson, Acting	(415) 323–8111	345 Middlefield Rd., Menlo Park, CA 94025.
Information Officer	Frank H. Forrester	(703) 860–7444	National Center, STOP 119.

LAND INFORMATION AND ANALYSIS OFFICE

Official	Name	Telephone number	Address
Chief	James R. Balsley	(703) 860–7488	National Center, STOP 104.
Associate Chief, Research and Technical Coordination	Philip Cohen	(703) 860–7471	National Center, STOP 703.
Earth Resources Observation Systems Program, Chief	John M. DeNoyer	(703) 860–7881	National Center, STOP 730.
Geography Program, Chief	James R. Anderson	(703) 860–6344	National Center, STOP 710.
Resource and Land Investigations Program, Chief	J. Ronald Jones	(703) 860–6717	National Center, STOP 750.
Environmental Impact Analysis Program, Chief	Daniel B. Krinsley	(703) 860–7455	National Center, STOP 760.
Earth Sciences Applications Program, Chief	Donald R. Nichols	(703) 860–6961	National Center, STOP 720.

TOPOGRAPHIC DIVISION

Official	Name	Telephone number	Address
Chief	Robert H. Lyddan	(703) 860–6231	National Center, STOP 516.
Associate Chief	Rupert B. Southard	(703) 860–6232	National Center, STOP 516.
Office of Research and Technical Standards, Chief	Roy R. Mullen	(703) 860–6291	National Center, STOP 519.
Office of Plans and Program Development, Chief	Doyle G. Frederick	(703) 860–6281	National Center, STOP 514.
National Cartographic Information Center, Chief	John R. Swinnerton	(703) 860–6187	National Center, STOP 507.
Special Mapping Center, Chief	Roy E. Fordham	(703) 860–7760	National Center, STOP 560, 1925 Newton Square East, Reston, VA 22090.

GEOLOGIC DIVISION

Official	Name	Telephone number	Address
Chief Geologist	Richard P. Sheldon	(703) 860–6531	National Center, STOP 910.
Deputy Chief Geologist, Operations	Robert E. Davis	(703) 860–6532	National Center, STOP 910.
Deputy Chief Geologist, Program and Budget	Donald H. Dow	(703) 860–6544	National Center, STOP 910.
Office of Scientific Publications, Chief	George E. Becraft	(703) 860–6575	National Center, STOP 904.
Office of Environmental Geology, Chief	John C. Reed, Jr.	(703) 860–6411	National Center, STOP 908.
Office of Earthquake Studies, Chief	Robert M. Hamilton	(703) 860–6471	National Center, STOP 905.
Office of Energy Resources, Chief	Charles Masters	(703) 860–6431	National Center, STOP 915.
Office of Marine Geology, Chief	Charles Masters, Acting	(703) 860–6431	National Center, STOP 915.
Office of Mineral Resources, Chief	George E. Becraft, Acting	(703) 860–6562	National Center, STOP 913.
Office of Geochemistry and Geophysics, Chief	Robert Tilling, Acting	(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	Joseph S. Cragwall, Jr.	(703) 860-6921	National Center, STOP 409.
Associate Chief Hydrologist	O. Milton Hackett	(703) 860-6921	National Center, STOP 408.
Assistant Chief Hydrologist, Scientific Publications and Data Management	Vacant	(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	Edward A. Moulder	(703) 860-6971	National Center, STOP 414.
Office of Water Data Coordination, Chief	R. H. Langford	(703) 860-6931	National Center, STOP 417.
Office of International Activities, Chief	James R. Jones	(703) 860-6548	National Center, STOP 470.

CONSERVATION DIVISION

Official	Name	Telephone number	Address
Chief	Russell G. Wayland	(703) 860-7524	National Center, STOP 600.
Associate Chief	Robert F. Evans	(703) 860-7524	National Center, STOP 600.
Assistant Chief, Resources Evaluation	Robert L. Rioux	(703) 860-7571	National Center, STOP 640.
Assistant Chief, Operations	John Duletsky	(703) 860-7515	National Center, STOP 620.
Assistant Chief, Programs	Harold L. Pumphrey	(703) 860-7581	National Center, STOP 630.

COMPUTER CENTER DIVISION

Official	Name	Telephone number	Address
Chief	Carl E. Diesen	(703) 860-7106	National Center, STOP 801.
Assistant Chief	Charles H. Tyler	(703) 860-7109	National Center, STOP 801.
Office of Teleprocessing	Ralph N. Eicher	(703) 860-7119	National Center, STOP 805.

PUBLICATIONS DIVISION

Official	Name	Telephone number	Address
Chief	Harry D. Wilson, Jr.	(703) 860-7181	National Center, STOP 341.
Associate Chief	Melvin E. Hanes	(703) 860-7181	National Center, STOP 341.
Assistant Chief, Management and Administration	Van M. Rayburn	(703) 860-7181	National Center, STOP 341.
Assistant Chief, Research and Technical Coordination	Bernard J. Thien	(703) 860-7183	National Center, STOP 341.
Office of Public Inquiries	Robbie S. Ritchey	(703) 860-7185	National Center, STOP 341.
Printing Liaison Officer	Jesse R. Upperco	(703) 860-7622	National Center, STOP 330.
International Activities	A. L. Dilonardo	(703) 860-6791	National Center, STOP 341.

ADMINISTRATIVE DIVISION

Official	Name	Telephone number	Address
Chief	Edmund J. Grant	(703) 860-7201	National Center, STOP 201.
Deputy Chief	Lewis Menen	(703) 860-7203	National Center, STOP 202.
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

LAND INFORMATION AND ANALYSIS OFFICE

EARTH RESOURCES OBSERVATION SYSTEMS DATA CENTER

Location	Official in charge	Telephone number	Address
South Dakota	Allen H. Watkins	(605) 594-6123	EROS Data Center, Sioux Falls, SD 57198.

TOPOGRAPHIC DIVISION

REGIONAL MAPPING CENTERS

Mapping Center	Chief	Telephone number	Address
Eastern	Peter F. Bermel	(703) 860-6352	National Center, STOP 567.
Midcontinent	Lawrence H. Borgerding, Acting	(314) 364-3680, ext. 111	1400 Independence Rd., Rolla, MO 65401.

SELECTED FIELD OFFICES—CONTINUED

Mapping Center	Chief	Telephone number	Address
Rocky Mountain	Albert E. Letey	(303) 234–2351	Box 25046, STOP 510, Denver Federal Center, Denver, CO 80225.
Western	Rob M. Collier, Acting	(415) 323–8111, ext. 2411	345 Middlefield Rd., Menlo Park, CA 94025.

GEOLOGIC DIVISION

REGIONAL OFFICES

Region	Regional Geologist	Telephone number	Address
Eastern	Eugene H. Roseboom, 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	George Gryc	(415) 323–8111	345 Middlefield Rd., Menlo Park, CA 94025.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Region	Regional Hydrologist	Telephone number	Address
Northeastern	Joseph T. Callahan	(703) 860–6985	National Center, STOP 433.
Southeastern	Leslie B. Laird	(404) 881–4395	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	William H. Robinson	(415) 323–8111	345 Middlefield Rd., Menlo Park, CA 94025.

DISTRICT OFFICES

State	District Chief	Telephone number	Address
Alabama	William J. Powell	(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	Horace M. Babcock	(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	Lee R. Peterson	(415) 323–8111, ext. 2326	855 Oak Grove Ave., Menlo Park, CA 94025.
Colorado	James E. Biesecker	(303) 234–5092	Box 25046, STOP 415, Denver Federal Center, Denver, CO 80225
Connecticut	Frederick H. Ruggles, Jr.	(203) 244–2528	P.O. Box 715, 235 Post Office Bldg., 135 High St., Hartford, CT 06101
Delaware	Walter F. White, Jr.	(301) 828–1535	See Maryland District Office.
District of Columbia	Walter F. White, Jr.	(301) 828–1535	See Maryland District Office.
Florida	Clyde S. Conover	(904) 386–1118	325 John Knox Rd., Suite F–240, Tallahassee, FL 32303.
Georgia	John R. George	(404) 526–4858	6481 Peachtree Industrial Blvd., Doraville, GA 30340.

WATER RESOURCES DIVISION DISTRICT OFFICES—CONTINUED

State	District Chief	Telephone number	Address
Hawaii	Frank T. Hidaka	(808) 955–0251	1833 Kalkaua Ave., 5th Floor, Honolulu, HI 96815.
Idaho	Edwin E. Harris	(208) 384–1750, ext. 2537	Box 036, 365 Federal Bldg., 550 W. Fort St., Boise, ID 83724.
Illinois	Lawrence A. Martens	(217) 359–3918	P.O. Box 1026, 605 N. Neil St., Champaign, IL 61820.
Indiana	James L. Cook	(317) 269–7101	1819 N. Meridian St., Indianapolis, IN 46202.
Iowa	Sulo W. Wiitala	(319) 338–0581, ext. 521	P.O. Box 1230, 269 Federal Bldg., Iowa City, IA 52240.
Kansas	J. 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) 387–0181, ext. 281	P.O. Box 66492, 6554 Florida Blvd., Baton Rouge, LA 70896.
Maine	John A. Baker	(617) 223–2822	See Massachusetts District Office.
Maryland	Walter F. White, Jr.	(301) 828–1535	208 Carroll Bldg., 8600 La Salle Rd., Towson, MD 21204.
Michigan	T. Ray Cummings	(517) 372–1910, ext. 561	2400 Science Parkway, Red Cedar Research Park, Okemos, MI 48864.
Minnesota	Charles R. Collier	(612) 725–7841	1033 Post Office Bldg., St. Paul, MN 55101.
Mississippi	Lamar E. Carroon	(601) 969–4600	430 Bounds St., Jackson, MS 39206.
Missouri	Anthony Homyk	(314) 361–3680, ext. 185	1400 Independence Rd., Rolla, MO 65401.
Montana	George M. Pike	(406) 449–5011, ext. 5263	P.O. Box 1696, 421 Federal Bldg., Helena, MT 59601.
Nebraska	Kenneth A. Mac Kichan	(402) 471–5082	406 Federal Bldg. and U.S. Courthouse, 100 Centennial Mall North, Lincoln, NE 68503.
Nevada	John P. Monis	(702) 882–1388	227 Federal Bldg., 705 N. Plaza St., Carson City, NV 89701.
New Hampshire	John A. Baker	(617) 223–2822	See Massachusetts District Office.
New Jersey	Harold Meisler	(609) 599–3511, ext. 212	P.O. Box 1238, 420 Federal Bldg., 402 E. State St., Trenton, NJ 08607.
New Mexico	William E. Hale	(505) 766–2246	P.O. Box 26659, Western Bank Bldg., Rm. 815, 505 Marquette NW., Albuquerque, NM 87125.
New York	Robert J. Dingman	(518) 472–3107	P.O. Box 1350, 343 U.S. Post Office and Courthouse Bldg., Albany, NY 12201.
North Carolina	Ralph C. Heath	(919) 755–4510	P.O. Box 2857, 436 Century Station P.O. Bldg., Raleigh, NC 27602.
North Dakota	Walter R. Scott	(701) 255–4011, ext. 227	P.O. Box 778, 332 New Federal Bldg., 3d St. and Rosser Ave., Bismarck, ND 58501.

WATER RESOURCES DIVISION DISTRICT OFFICES—CONTINUED

State	District Chief	Telephone number	Address
Ohio	James F. Blakey	(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 97208.
Pennsylvania	Norman H. Beamer	(717) 782–3468	P.O. Box 1107, 4th Floor, Federal Bldg., 228 Walnut St., Harrisburg, PA 17108.
Puerto Rico	Ernest D. Cobb	(809) 783–4660	P.O. Box 34168, Bldg. 652, Ft. Buchanan, PR 00934.
Rhode Island	John A. Baker	(617) 223–2822	See Massachusetts District Office.
South Carolina	John S. Stallings	(803) 765–5966	2001 Assembly St., Suite 200, Columbia, SC 29201.
South Dakota	John E. Powell	(605) 352–8651, ext. 258	P.O. Box 1412, 231 Federal Bldg., Huron, SD 57350.
Tennessee	Stanley P. Sauer	(615) 749–5424	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 S. State St., Salt Lake City, UT 84138.
Vermont	John A. Baker	(617) 223–2822	See Massachusetts District Office.
Virginia	William E. Forrest	(804) 782–2427	200 W. Grace St., Rm. 304, Richmond, VA 23220.
Washington	John E. McCall	(206) 593–6510	1305 Tacoma Ave. S., Rm. 300, Tacoma, WA 98402.
West Virginia	David H. Appel	(304) 343–6181	3303 Federal Bldg. and U.S. Courthouse, 500 Quarrier St. E., Charleston, WV 25301.
Wisconsin	William W. Barnwell	(608) 262–2488	1815 University Ave., Rm. 200, Madison, WI 53706.
Wyoming	Samuel W. West	(307) 778–2220, ext. 2111	P.O. Box 2087, 4015 Warren Ave., Cheyenne, WY 82001.

CONSERVATION DIVISION

REGIONAL OFFICES

Region	Conservation Manager	Telephone number	Address
Eastern	George Brown	(202) 254–3137	1725 K St., NW., Suite 213, Washington, DC 20244.
Central	George H. Horn	(303) 234–2855	Box 25046, STOP 609, Denver Federal Center, Denver, CO 80225.
Gulf of Mexico Outer Continental Shelf Operations	A. Dewey Acuff	(504) 837–4720, ext. 9381	P.O. Box 7944, 434 Imperial Office Bldg., 3301 N. Causeway Blvd., Metairie, LA 70011.
Western	Willard C. Gere	(415) 323–8111, ext. 2563	345 Middlefield Rd., Menlo Park, CA 94025.

PUBLICATIONS DIVISION

REGIONAL OFFICES

Region	Official in charge	Telephone number	Address
Eastern	Lewis D. Brown	(703) 860–6761	National Center, STOP 328.
Central	John L. Heller	(303) 234–4974	Box 25046, STOP 303, Denver Federal Center, Denver, CO 80225.
Western	Fred Kunkel	(415) 323–8111, ext. 2537	345 Middlefield Rd., Menlo Park, CA 94025.

PUBLIC INQUIRIES OFFICES

Location	Official in charge	Telephone number	Address
Alaska	Margaret I. Erwin	(907) 277–0577	108 Skyline Bldg., 502 2d Ave., Anchorage, AK 99501.
California:			
Los Angeles	Lucy E. Birdsall	(213) 688–2850	7638 Federal Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012.
San Francisco	Jean V. Molleskog	(415) 556–5627	504 Custom House, 555 Battery St., San Francisco, CA 94111.
Colorado	Alice M. Coleman	(303) 837–4169	1012 Federal Bldg., 1961 Stout St., Denver, CO 80294.
District of Columbia	Bruce A. Hubbard	(202) 343–8073	1028 GSA Bldg., 19th and F Sts. NW., Washington, DC 20244.
Texas	Jimmie L. Wilkinson, Acting	(214) 749–3230	1C45 Federal Bldg., 1100 Commerce St., Dallas, TX 75202.
Utah	Wendy R. Hassibe	(801) 524–5652	8105 Federal Bldg., 125 S. State St., Salt Lake City, UT 84138.
Virginia	A. Ernestine Jones	(703) 860–6167	1C402 National Center, STOP 302, 12201 Sunrise Valley Dr., Reston, VA 22092.
Washington	Eula Thune	(509) 456–2524	678 U.S. Courthouse, W. 920 Riverside Ave., Spokane, WA 99201.

BRANCH OF DISTRIBUTION OFFICES

Location	Official in charge	Telephone number	Address
Alaska	Natalie Cornforth	(907) 452–1951	310 First Ave., Fairbanks, AK 99701.
Colorado	Dwight F. Canfield	(303) 234–3832	Box 25286, STOP 306, Denver Federal Center, Denver, CO 80225.
Virginia	John J. Curry	(703) 557–2781	1200 S. Eads St., Arlington, VA 22202.

ADMINISTRATIVE DIVISION

REGIONAL MANAGEMENT OFFICES

Region	Regional Management Officer	Telephone number	Address
Eastern	Roy Heinbuch	(703) 860–7691	National Center, STOP 290.
Central	Thomas J. Lyons	(303) 234–3736	Box 25046, STOP 202, Denver Federal Center, Denver, CO 80225.
Western	Avery W. Rogers	(415) 323–2211	345 Middlefield Rd., Menlo Park, CA 94025.

COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL FINANCIAL YEAR 1976 AND TRANSITION QUARTER

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for financial cooperation in fiscal year 1976 and the transition quarter, cosigned by responsible officials of the Geological Survey and the cooperating agency. Agencies with whom the Geological Survey had research contracts and to whom it supplied funds for such research are not listed. Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency]

FEDERAL COOPERATORS

Department of Agriculture:
- Agricultural Research Service
- Forest Service
- Saudi Joint Commission
- Soil Conservation Service
- Statistical Reporting Service

Department of the Air Force:
- AFWL/PRP Kirtland AFB
- Air Force Academy
- Air Force Headquarters, Washington, D.C.
- Headquarters (AFTAC/AC)
- Headquarters Pacific Air Forces
- Headquarters 321st Combat Support Group (SAC)
- Homestead Air Force Base
- Vandenburg Air Force Base

Department of the Army:
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Construction Engineering Research Laboratory
- Corps of Engineers
- Rocky Mountain Arsenal
- White Sands Missile Range

Department of Commerce, National Oceanic and Atmospheric Administration:
- Economic Development Administration
- Environmental Research Laboratories
- National Ocean Survey
- National Weather Service
- Old West Regional Commission

Department of Defense:
- Advanced Research Projects Agency
- Defense Intelligence Agency
- Defense Nuclear Agency
- U.S. Arms Control and Disarmament Agency

Department of Health, Education and Welfare, Public Health Service

Department of Housing and Urban Development

Department of the Interior:
- Alaska Power Administration
- Bonneville Power Administration
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Outdoor Recreation
- Bureau of Reclamation

Department of the Interior—continued
- Fish and Wildlife Service
- National Park Service
- Office of Land Use and Water Planning
- Office of Saline Water
- Office of the Secretary
- Office of Water Policy Coordination
- U.N. Geothermal Symposium
- Water Resources Council

Department of the Navy:
- Marine Corps, Camp Pendleton
- Naval Facilities Engineering Command
- Naval Weapons Center
- Underwater Systems Center

Department of State:
- Agency for International Development
- International Joint Commission

Department of Transportation, Federal Highway Administration

Department of the Treasury, U.S. Customs Service

Energy Research and Development Administration:
- Albuquerque Operations Office
- Division of Applied Technology
- Division of Administrative Services
- Division of Geothermal Energy
- Division of Reactor Research and Development
- Grand Junction Office
- Idaho Operations Office
- Nevada Operations Office
- Oak Ridge Operations Office
- Richland Operations Office
- San Francisco Operations Office
- Savannah River Operations Office

Environmental Protection Agency:
- Enforcement Division
- National Environmental Research Center
- Office of Energy, Minerals, and Industry
- Office of Radiation Programs
- Office of Research and Development
- Office of Water Programs
- Pacific Northwest Environmental Research Laboratory
- Technical Services Branch
- Upper Mississippi River Basin Commission

Federal Energy Administration

General Services Administration

National Aeronautics and Space Administration

National Science Foundation

Nuclear Regulatory Commission

Office of Emergency Preparedness

Pacific Northwest River Basins Commission

Tennessee Valley Authority

Veterans Administration

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Development Office
- Alabama Highway Department
- Commission of Jefferson County
- Geological Survey of Alabama

Alaska:
- Alaska Department of Fish and Game
- Alaska Department of Highways
- Alaska Geological and Geophysical Survey
- Alaska Pipeline Coordination Office
- City of Anchorage
- Department of Environmental Conservation
- Greater Anchorage Area Borough
- Kenai Borough
- North Star Borough

Arizona:
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Water Commission
- City of Flagstaff
- City of Nogales
- City of Safford
- City of Tucson
- Department of Health Services
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Pima County Board of Supervisors
- Salt River Valley Water User's Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company
- University of Arizona

Arkansas:
- Arkansas Department of Pollution Control and Ecology
- Arkansas Division of Soil and Water Resources
- Arkansas Geological Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley-East Kern Water
- California Department of Conservation, Division of Mines and Geology
- California Department of Transportation
- California Department of Water Resources
- California Water Resources Control Board

California—continued
- Casitas Municipal Water District
- City and County of San Francisco:
  - Hetch Hetchy Water Supply
  - Water Department
- City of Lompoc
- City of Merced
- City of Modesto, Public Works Department
- City of San Diego
- City of San Rafael
- City of Santa Barbara, Public Works Department
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Fresno
- County of Madera, Flood Control and Water Conservation Agency
- County of Modoc, Public Works Department
- County of San Diego, Department of Sanitation and Flood Control
- County of San Mateo, Engineer and Road Commissioner
- Desert Water Agency
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Humboldt County, Department of Public Works
- Imperial County Department of Public Works
- Imperial Irrigation District
- Indian Wells Valley County Water District
- Kern County Water Agency
- Lake County Flood Control and Water Conservation District
- Livermore Amador Valley Water Management Agency
- Los Angeles County, Department of County Engineers
- Los Angeles County Flood Control District
- Los Angeles Department of Water and Power
- Madera Irrigation District
- Marin County Department of Public Works
- Merced Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- North Marin County Water District
- Orange County Environmental Management Agency
- Orange County Water District
- Oroville-Wyandotte Irrigation District
- Pacheco Pass Water District
- Paradise Irrigation District
- Riverside County Flood Control and Water Conservation District

California—continued
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Luis Obispo County:
  - Engineering Department
  - Flood Control and Water Conservation District
- Santa Barbara County Flood Control and Water Conservation District
- Santa Clara Valley Water District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Margarita and San Luis Rey Watershed Planning Agencies
- Santa Maria Valley Water Conservation District
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Terra Bella Irrigation District
- Tulare County Flood Control District
- Turlock Irrigation District
- Twentynine Palms Water District
- United Water Conservation District
- University of California, School of Forestry and Conservation
- Ventura County Flood Control District, Riverside County
- Western Municipal Water District
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- Boulder City-County Department of Health
- City and County of Denver, Board of Water Commissioners
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs, Department of Public Utilities
- City of Fort Collins
- Colorado City Water and Sanitation District
- Colorado Department of Local Affairs
- Colorado Department of Natural Resources:
  - Division of Water Resources
  - Division of Wildlife
  - Geological Survey
- Colorado Department of Public Health, Water Pollution Control Commission
- Colorado River Water Conservation District
- Colorado Water Conservation Board
- Denver Regional Council of Governments
- Eagle County Commissioners
- El Paso County:
  - Board of Commissioners
  - Water Association
- Jefferson County Health Department
- Kiowa-Bijou Groundwater Management District
- Metro Denver Sewage Disposal District No. 1
- Park County Board of County Commissioners
- Pikes Peak Area Council of Governments
- Pitkin County Board of County Commissioners
- Rio Grande Water Conservation District
- Southeastern Colorado Water Conservancy District
- Southern Ute Indian Tribe
- Southwestern Water Conservation District
- State of Colorado, Department of Highways
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works

Connecticut—continued
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Department of Environmental Protection
- Town of Fairfield
- Town of Farmington
- Town of Manchester
- Town of Newton
- Town of South Windsor
- Town of Wilton

Delaware:
- Delaware Geological Survey, University of Delaware
- Department of Highways and Transportation, Division of Highways

District of Columbia, Department of Environmental Services

Florida:
- Brevard County
- Broward County
- Broward County Air and Water Pollution Control Board
- Central and Southern Florida Flood Control District
- City of Boca Raton
- City of Boyntin Beach
- City of Clearwater
- City of Cocoa
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Fort Myers
- City of Gainesville
- City of Hallandale
- City of Hollywood
- City of Jacksonville
- City of Juno Beach
- City of Miami-Dade Water and Sewer Authority and the City of Miami Beach
- City of Pensacola
- City of Perry
- City of Pompano Beach
- City of Riviera Beach
- City of St. Petersburg
- City of Sarasota
- City of Tallahassee
- City of Tampa
- City of West Palm Beach
- Charlotte County
- Collier County Water Management District No. 1
- Collier County Water Management District No. 7
- Department of Environmental Regulations
- Department of Pollution Control
- Division of State Planning
- Englewood Water District
- Escambia County
- Florida Department of Natural Resources:
  - Bureau of Geology
  - Division of Parks and Recreation
- Florida Department of Transportation
- Florida Keys Aqueduct Authority
- Hendry County
- Hillsborough County
- Jacksonville Area Planning Board
- Lake County
- Lake Worth Drainage District
- Lee County

Florida—continued
- Loxahatchee River Environmental Control District
- Manasota Basin Board
- Manatee County, Board of County Commissioners
- Marion County
- Martin County
- Metropolitan Dade County
- Northwest Florida Water Management District
- Old Plantation Drainage District
- Orange County
- Palm Beach County
- Pinellas County
- Reedy Creek Improvement District
- Sarasota County
- Seminole County
- Southwest Water Management District
- St. Johns River Water Management
- Sunshine Drainage District
- Suwanee River Authority
- Suwanee River Water Management District
- Town of Highland Beach
- Village of Tequesta
- Volusia County
- Walton County

Georgia:
- Chatham County
- City of Brunswick
- City of Valdosta
- Dekalb County
- Department of Natural Resources:
  - Earth and Water Division
  - Environmental Protection Division
- Department of Transportation

Hawaii:
- City and County of Honolulu
- Honolulu Board of Water Supply
- Maui County, Department of Public Works
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- Idaho Department of Transportation
- Idaho Department of Water Resources
- Mann Creek Irrigation District

Illinois:
- Bloomington and Normal Sanitary District
- City of Springfield
- Cook County, Forest Preserve District
- DuPage County Highway Department
- Environmental Protection Agency
- Fountain Head Drainage District
- Fulton County-East Liverpool Drainage and Levee District
- Kane County Highway Department
- Lake County Highway Department
- McHenry County Regional Planning Commission
- Sanitary District of Bloom Township
- State Department of Registration and Education, Illinois State Water Survey
- State Department of Transportation, Division of Water Resources Management
- The Metropolitan Sanitary District of Greater Chicago
- University of Illinois at Urbana-Champaign, Board of Trustees

Indiana:
- City of Indianapolis
- City of Logansport
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission
- Town of Carmel

Iowa:
- City of Cedar Rapids
- City of Des Moines
- City of Fort Dodge
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State Highway Commission, Highway Research Board
- Iowa State University:
  - Department of Agricultural Engineering
  - Department of Science and Technology, Agricultural Experiment Station

Kansas:
- City of Wichita
- Kansas State Department of Health
- Kansas State Water Resources Board
- Kansas-Oklahoma Arkansas River Commission
- State Geological Survey of Kansas
- State Highway Commission of Kansas

Kentucky:
- Bureau of Highways, Department of Transportation
- Department of Natural Resources and Environmental Protection:
  - Division of Conservation
  - Division of Water Quality
- Kentucky Geological Survey, University of Kentucky

Louisiana:
- Capital Area Ground Water Conservation Commission
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Compact Administration

Maine:
- Department of Environmental Protection
- Greater Portland Council of Governments, Androscoggin Regional Planning Agency
- Maine Department of Transportation
- Maine Public Utilities Commission
- South Kennebec Regional Planning Commission
- South Maine Regional Planning Agency

Maryland:
- City of Baltimore, Bureau of Engineering, Water Supply Division
- Maryland Department of Health and Mental Hygiene
- Maryland Department of Transportation, The State Highway Administration
- Maryland Geological Survey

Massachusetts:
- Department of Public Works:
  - Division of Research and Materials
  - Division of Highways
  - Division of Waterways
- Metropolitan District Commission

Massachusetts—continued
- State Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources

Michigan:
- Michigan Department of Agriculture, Soil and Water Conservation Division
- Michigan Department of Natural Resources:
  - Environmental Protection Branch
  - Geological Survey Division

Minnesota:
- City of Lakeville
- Minnesota Department of Natural Resources, Division of Natural Waters
- Minnesota State Planning Agency

Mississippi:
- City of Jackson
- Harrison County Development Commission
- Jackson County Port Authority
- Marine Research Council
- Mississippi Air and Water Pollution Control Commission
- Mississippi Board of Water Commissioners
- Mississippi Geological Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pat Harrison Waterway District
- Pearl River Valley Water Supply District

Missouri:
- Curators of the University of Missouri
- Department of Natural Resources:
  - Division of Environmental Quality, Clean Water Commission
  - Division of Geology and Land Survey
  - Division of Research and Technical Information
- Metropolitan St. Louis Sewer District
- Missouri Office of Administration
- Missouri State Highway Commission
- Springfield Sanitary District
- St. Louis County

Montana:
- Endowment and Research Foundation-Montana State University
- Flathead Drainage 208 Project
- Lewis and Clark County, Board of County Commissioners
- Missoula and Powell Counties
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana Department of Natural Resources, Environmental Protection Branch
- Montana State Fish and Game Department
- Montana State Highway Commission
- Yellowstone-Tongue Area Planning and Organization

Nebraska:
- Blue River Association of Ground Water Conservation Districts
- Clay County Ground Water Conservation District
- Filmore County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Kansas-Nebraska Big Blue River Compact Administration
- Lower Elkhorn Natural Resources District
- Lower Platte South Natural Resources District

Nebraska—continued
- Nebraska Department of Water Resources
- Nebraska Natural Resources Commission
- Seward County Ground Water Conservation District
- State Department of Roads
- University of Nebraska, Water Resources Institute
- Upper Big Blue Natural Resources District
- York County Ground Water Conservation District

Nevada:
- Department of Human Resources (Environmental Protection Services)
- Nevada Bureau of Mines and Geology
- Nevada Department of Conservation and Natural Resources
- Nevada State Highway Department

New Hampshire:
- New Hampshire Department of Resources and Economic Development
- New Hampshire Water Resources Board
- New Hampshire Water Supply and Pollution Control Commission
- Strafford-Rockingham Regional Council

New Jersey:
- Bergen County
- Camden County Board of Freeholders
- Delaware River Basin Commission
- Morris County Municipal Utilities Authority
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers State University
- Township of Cranford

New Mexico:
- Albuquerque Metropolitan Arroyo Flood Control Authority
- City of Las Cruces
- Costilla Creek Compact Commission
- Interstate Stream Commission
- New Mexico Bureau of Mines and Mineral Resources
- New Mexico State Engineer
- New Mexico State Highway Commission
- Pecos River Commission
- Rio Grande Compact Commission
- State Planning Office

New York:
- Board of Hudson River-Black River Regulating District
- Central New York State Parks Commission
- City of Albany
- City of Auburn
- City of New York:
  - Board of Water Supply
  - Environmental Protection Administration
- City of Rochester, Water Bureau
- County of Chautauqua
- County of Cortland
- County of Dutchess, Department of Planning
- County of Nassau, Department of Public Works

New York—continued
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Orange, Department of Public Works
- County of Putnam, Highway Department
- County of Rockland Drainage Agency
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster, Ulster County Legislature
- County of Westchester, Department of Public Works
- County of Wyoming
- Department of Environmental Conservation:
  - Bureau of Monitoring and Surveillance
  - Facilities and Construction Management
  - Office of Program Development
- Department of Transportation
- Monroe County Water Authority
- Nassau-Suffolk Regional Planning Board
- New York State Department of Health
- New York State Education Department, Museum and Science Service
- Oswegatchie-Cranberry Reservoir Commission
- Power Authority of the State of New York
- State University of New York, College of Environmental Science and Forestry
- Susquehanna River Basin Commission
- Town of Waterford Commissioners

North Carolina:
- Board of Transportation
- City of Asheville, Public Works Department
- City of Burlington
- City of Charlotte
- City of Durham, Department of Water Resources
- City of Greensboro
- City of Winston-Salem
- North Carolina Department of Natural and Economic Resources, Office of Earth Resources
- State Department of Transportation
- University of North Carolina, Water Resources Research Institute

Ohio:
- City of Canton
- City of Columbus, Department of Public Service
- City of Toledo
- Miami Conservancy District
- Ohio Department of Natural Resources
- Ohio Department of Transportation
- Ohio Department of Transportation, Division of Highways
- Ohio Environmental Protection Agency
- Ohio River Valley Water Sanitation Commission
- Three Rivers Watershed District
- Toledo Metropolitan Area Council of Governments

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geologic Survey
- State Pollution Control Coordinating Board
- Oklahoma Water Resources Board
- State Department of Health, Environmental Health Service

Oregon:
- Burnt River Irrigation District
- City of Corvallis
- City of Eugene, Water and Electric Board
- City of McMinnville, Water and Light Department
- City of Portland:
  - Bureau of Water Works
  - Department of Public Utilities
- Columbia Region Association of Governments
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of the Warm Springs Reservation
- Coos Bay-North Bend Water Board
- Coos County, Board of Commissioners
- Department of Fish and Wildlife
- Douglas County, Board of Commissioners
- Lakeside Water District
- Land County, Board of Commissioners
- Multnomah County, Board of County Commissioners
- Oregon State Highway Commission
- Oregon State Water Resources Department
- Rogue Valley Council of Governments

Pennsylvania:
- Chester County Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia, Water Department
- Department of Environmental Management
- Pennsylvania Department of Environmental Resources:
  - Bureau of Topographic and Geologic Survey
  - Bureau of Water Quality Management
  - Office of Planning and Research
  - Office of Resource Management
- Pennsylvania Department of Transportation
- Slippery Rock State College

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works
- Department of Health and Environmental Control, Bureau of Waste Water and Stream Quality
- State Highway Department
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- City of Watertown
- East Dakota Conservancy Subdistrict
- South Dakota Department of Natural Resource Development
- South Dakota Department of Transportation and Board of Transport
- South Dakota Department of Transportation and State Geological Survey

Tennessee:
- Chickasaw Basin Authority
- City of Franklin
- City of Lawrenceburg
- City of Manchester
- City of Memphis, Board of Light, Gas, and Water Commissioners
- Lincoln County Public Utilities Board
- Metropolitan Government of Nashville and Davidson County, Department of Public Works

Tennessee—continued
- Murfreesboro Water and Sewer Department
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Public Health, Division of Water Quality Control
- Tennessee Department of Transportation
- Tennessee Wildlife Resources Agency
- University of Tennessee Water Resources Research Center

Texas:
- City of Austin
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- Sabine River Compact Administration
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- State Department of Natural Resources, Division of Water Rights
- Utah Geological and Mineralogical Survey

Vermont:
- City of Springfield
- State Department of Highways
- State Department of Water Resources, Planning and Development Division

Virginia:
- City of Alexandria
- City of Newport News, Department of Public Utilities
- City of Norfolk
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Virginia Department of Conservation and Economic Development, Division of Mineral Resources
- Virginia Department of Highways
- Virginia State Water Control Board

Washington:
- Chehalis Tribal Council
- City of Port Angeles
- City of Seattle, Department of Lighting

Washington—continued
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Clark County:
  - Department of Public Works
  - Public Utility District
- Cowlitz County Public Utility District
- Kilsap County Board of Commissioners
- Lower Elwah Tribal Council
- Makah Tribal Council
- Municipality of Metropolitan Seattle
- Nisqually Indian Community Council
- Pacific County Board of County Commissioners
- Port Gamble Tribal Council
- Quilente Tribal Council
- Quinault Tribal Council
- Suquamish Tribal Council
- Swinomish Tribal Council
- The Evergreen State College
- Tulalip Tribe Board of Directors
- University of Washington
- Washington State Department of Ecology

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- City of Madison
- City of Middleton
- Dane County Regional Planning Commission
- Douglas County Soil and Water Conservation District
- Southeastern Wisconsin Regional Planning Commission
- State Department of Natural Resources
- State Department of Transportation, Division of Highways
- State Soil and Water Conservation Districts
- The University of Wisconsin-Extension, Geological and Natural History Survey

Wyoming:
- City of Cheyenne, Board of Public Utilities
- Geological Survey of Wyoming
- State Highway Commission of Wyoming
- University of Wyoming, Water Resources Institute
- Wyoming Department of Economic Planning and Development
- Wyoming State Department of Agriculture
- Wyoming State Department of Environmental Quality
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Appalachian Regional Commission

Coastal Plains Regional Commission

Government of Algeria

Government of Saudi Arabia

Ozarks Regional Commission

Permittees and licensees of the Federal Power Commission

Puerto Rico:
- North Metropolitan 208 Area Wide Planning Commission
- Puerto Rico Aqueduct and Sewer Authority
- Puerto Rico Department of Natural Resources
- Puerto Rico Environmental Quality Board

United Nations

Virgin Islands:
- College of Virgin Islands
- Department of Public Works

ORGANIZATIONAL AND STATISTICAL DATA

[Data in these statistical tables may differ slightly from data in the individual division chapters because of rounding]

TABLE 26.—*Geological Survey budget, by activity and sources of funds, fiscal years 1971–76 and transition quarter*

[In thousands of dollars. Detail may not add to totals because of rounding]

Budget activity	1971	1972	1973	1974	1975	1976	Transition quarter (estimated)
Total	$173,243	$188,996	$211,944	$249,437	$338,764	$353,970	$102,816
Direct program	114,080	130,951	149,971	171,983	253,605	264,434	77,756
Reimbursable program	59,163	58,045	61,973	77,454	85,159	89,536	25,060
States, counties, and municipalities	24,687	25,857	28,011	32,443	35,124	35,006	9,114
Miscellaneous non-Federal sources	3,240	3,383	3,620	4,695	6,399	7,923	2,264
Other Federal agencies	31,236	28,805	30,342	40,316	43,636	46,607	13,682
Alaska Pipeline Related Investigations	1,401	1,401	1,239	890	344	287	112
Direct program	1,336	1,339	1,239	890	344	287	112
Reimbursable program	65	62	-------	-------	-------	-------	-------
Other Federal agencies	65	62	-------	-------	-------	-------	-------
Topographic Surveys and Mapping	37,426	38,737	40,271	43.664	52,597	52,220	13,393
Direct program	31,153	34,545	35,172	37,161	45,350	45,354	11,553
Reimbursable program	6,273	4,192	5,099	6,503	7,247	6,866	1,840
States, counties, and municipalities	3,901	3,204	3,719	4,942	4,995	3,675	940
Miscellaneous non-Federal sources	355	357	600	643	594	501	160
Other Federal agencies	2,017	631	780	918	1,658	2,690	740

See footnotes at end of table.

TABLE 26.—*Geological Survey budget, by activity and sources of funds, fiscal year 1971–76 and transition quarter*—Continued

Budget activity	1971	1972	1973	1974	1975	1976	Transition quarter (estimated)
Geologic and Mineral Resource Surveys and Mapping [1]	49,015	51,529	57,979	73,563	114,477	115,554	32,997
Direct program	31,919	34,244	42,895	49,877	89,018	92,322	24,837
Reimbursable program	17,096	17,285	15,084	23,686	25,459	23,232	8,160
States, counties, and municipalities	1,322	1,359	1,556	1,681	1,550	1,467	392
Miscellaneous non-Federal sources	2,280	2,317	2,306	2,684	3,751	4,936	1,323
Other Federal agencies	13,494	13,609	11,222	19,321	20,158	16,829	6,445
Water Resources Investigations [2]	66,084	71,324	78,103	88,352	101,437	112,480	29,726
Direct program	34,581	37,446	40,185	45,433	53,420	57,176	15,922
Reimbursable program	31,503	33,878	37,918	42,919	48,017	55,304	13,804
States, counties, and municipalities	19,464	21,294	22,736	25,820	28,546	29,735	7,730
Miscellaneous non-Federal sources	571	679	664	721	901	940	270
Other Federal agencies	11,468	11,905	14,518	16,378	18,570	24,629	5,804
Conservation of Lands and Minerals [3]	9,704	13,467	14,748	18,213	36,082	41,677	13,487
Direct program	9,670	13,441	14,700	18,172	36,032	41,489	13,440
Reimbursable program	34	26	48	41	50	188	47
Miscellaneous non-Federal sources	2	1	3	-------	4	1	1
Other Federal agencies	32	25	45	41	46	187	46
Land Information and Analysis [4]	3,539	7,289	13,125	13,003	16,994	17,278	8,859
Direct program	2,373	6,714	11,876	11,458	15,461	14,908	7,806
Reimbursable program	1,166	575	1,249	1,545	1,533	2,370	1,053
States, counties, and municipalities	-------	-------	-------	-------	33	130	52
Miscellaneous non-Federal sources	-------	-------	-------	593	1,093	1,496	498
Other Federal agencies	1,166	575	1,249	952	407	144	503
General Administration [5]	3,048	3,187	3,217	3,517	3,671	3,398	1,493
Direct program	3,048	3,187	3,217	3,517	3,671	3,398	1,493
Facilities [6]	-------	35	687	5,475	10,309	9,500	2,593
Direct program	-------	35	687	5,475	10,309	9,500	2,593
Miscellaneous services to other accounts	3,026	2,027	2,575	2,760	2,853	1,576	156
Reimbursable program	3,026	2,027	2,575	2,760	2,853	1,576	156
Miscellaneous non-Federal sources	32	29	47	54	56	49	12
Other Federal agencies	2,994	1,998	2,528	2,706	2,797	1,527	144

[1] Funds include: Mineral Discovery Loan Program activity for fiscal years 1971–75; and parts of Geothermal Investigations, Minerals Policy, and Arctic Environmental Studies components of the Special Resource and Environmental Projects activity for fiscal years 1971–75. Funds exclude the Land Resource Analysis program for fiscal years 1973–75.

[2] Funds exclude Employee Compensation Payments subactivity for fiscal years 1971–1975.

[3] Funds include parts of Geothermal Investigations component of the Special Resource and Environmental Projects activity for fiscal years 1972–75.

[4] Budget activity funds are reconstructed for fiscal years 1971–75 and include: Earth Resources Observation System activity for fiscal years 1971–75; Urban Area Studies and Energy Impact Evaluation components of the Special Resource and Environmental Projects activity for fiscal years 1971–75; Land Resources Analysis program of the Geologic and Mineral Resource Surveys and Mapping activity for fiscal years 1974–75; and the Land Use Data and Analysis activity for fiscal year 1975.

[5] Funds include Employee Compensation Payments subactivity of the Water Resources Investigations activity for fiscal years 1971–75.

[6] Budget activity began in fiscal year 1972.

TABLE 27.—*Geological Survey Federal-State Cooperative program funds, by State, fiscal years 1971–76 and the transition quarter*

[In thousands of dollars]

State	1971	1972	1973	1974	1975	1976	Transition quarter
Total [1]	$49,274	$50,651	$55,633	$65,256	$70,151	$68,219	$ 2,584
Total State share [2]	24,687	25,857	28,011	32,443	35,124	35,037	1,265
Alabama	846	839	928	1,094	1,212	1,106	6
State share	467	461	514	554	623	553	3
Alaska	411	619	838	897	1,162	772	------
State share	203	330	399	410	410	410	------
Arizona	869	1,021	1,001	1,144	1,248	1,267	------
State share	444	540	510	576	646	682	------
Arkansas	492	506	596	857	887	797	28
State share	239	250	288	455	410	371	14
California	4,014	3,893	4,115	4,789	4,690	4,778	102
State share	1,951	1,936	2,053	2,280	2,337	2,446	69
Colorado	944	995	1,128	1,484	2,445	2,089	158
State share	477	507	575	837	1,324	1,150	79
Connecticut	619	617	687	814	1,069	850	115
State share	302	304	292	374	523	416	43
Delaware	112	111	121	130	194	214	------
State share	73	75	81	74	106	119	------
District of Columbia	12	2	3	3	3	3	------
State share	6	1	1	1	1	2	------
Florida	3,119	3,398	3,643	5,083	5,575	5,653	76
State share	1,539	1,719	1,858	2,552	2,781	2,851	38
Georgia	751	799	2,008	3,239	3,083	2,482	244
State share	400	437	1,041	1,611	1,531	1,241	122
Hawaii	649	622	653	691	697	865	------
State share	334	314	337	339	341	492	------
Idaho	633	619	675	718	749	837	------
State share	308	307	344	353	366	419	------
Illinois	650	653	646	544	645	816	8
State share	316	341	333	277	323	450	4
Indiana	906	994	1,107	1,363	1,288	1,496	2
State share	439	491	590	678	632	782	1
Iowa	442	517	525	608	617	807	64
State share	214	255	259	299	302	405	32
Kansas	1,324	1,362	1,358	1,402	1,424	1,511	104
State share	645	675	676	686	716	757	52
Kentucky	1,900	2,033	2,212	2,451	2,728	2,809	481
State share	939	1,008	1,039	1,122	1,229	1,301	210
Louisiana	1,167	1,212	1,240	1,900	1,740	1,660	22
State share	621	655	674	980	902	862	11

See footnotes at end of table.

TABLE 27.—*Geological Survey Federal-State Cooperative program funds by State, fiscal years 1971–76 and the transition quarter*—Continued

State	1971	1972	1973	1974	1975	1976	Transition quarter
Maine	158	163	168	175	248	334	20
State share	84	89	91	96	127	196	10
Maryland	580	620	695	851	1,011	1,005	2
State share	295	321	356	435	530	522	1
Massachusetts	1,126	1,159	1,379	1,346	1,618	1,615	122
State share	595	614	625	656	810	779	66
Michigan	865	859	947	930	1,054	1,068	45
State share	407	417	425	436	505	525	19
Minnesota	1,434	1,369	1,420	1,903	1,639	1,171	------
State share	707	681	727	966	817	624	------
Mississippi	551	592	593	645	743	634	------
State share	316	357	340	325	415	317	------
Missouri	863	792	732	657	678	629	76
State share	420	413	375	322	337	315	38
Montana	393	401	402	505	587	549	------
State share	212	221	223	255	287	283	------
Nebraska	502	553	588	705	731	769	------
State share	246	274	298	344	358	396	------
Nevada	513	578	640	689	846	933	35
State share	234	271	288	304	332	378	19
New Hampshire	113	100	139	177	172	224	13
State share	55	50	67	97	73	98	3
New Jersey	785	822	856	1,051	977	1,073	------
State share	390	418	433	530	501	569	------
New Mexico	888	963	1,107	1,332	1,439	1,500	2
State share	462	509	601	662	714	779	2
New York	1,989	2,224	2,395	2,796	2,977	2,770	12
State share	973	1,111	1,229	1,415	1,585	1,610	6
North Carolina	938	946	1,038	1,586	1,885	1,442	124
State share	437	457	492	771	942	725	62
North Dakota	661	714	899	763	998	980	10
State share	325	361	461	369	489	490	5
Ohio	979	990	1,028	978	1,093	1,237	38
State share	521	518	520	481	563	672	19
Oklahoma	664	614	634	702	748	777	36
State share	359	333	340	344	368	388	18
Oregon	606	727	828	896	902	886	24
State share	307	372	432	439	443	454	12

See footnotes at end of table.

TABLE 27.—*Geological Survey Federal-State Cooperative program funds by State, fiscal years 1971–76 and the transition quarter*—Continued

State	1971	1972	1973	1974	1975	1976	Transition quarter
Pennsylvania	2,178	2,167	2,047	2,357	2,415	2.489	32
State share	1,088	1,092	1,042	1,195	1,209	1,282	16
Rhode Island	97	92	90	97	110	123	------
State share	52	50	50	52	54	61	------
South Carolina	374	403	574	546	574	540	------
State share	196	212	301	279	284	270	------
South Dakota	409	424	423	471	515	518	28
State share	226	236	230	227	251	259	14
Tennessee	546	538	589	851	952	1,017	------
State share	292	294	321	422	470	509	------
Texas	3,835	3,717	3,794	4,046	4,261	4,315	170
State share	1,922	1,925	1,949	2,027	2,100	2,177	85
Utah	868	967	1,069	1,068	1,361	1,299	47
State share	421	486	530	534	838	746	25
Vermont	124	125	129	144	130	139	------
State share	62	64	66	73	64	69	------
Virginia	1,119	797	793	905	858	726	14
State share	577	420	421	466	442	378	7
Washington	1,774	1,800	1,988	2,121	2,208	2,028	17
State share	856	881	962	1,037	1,104	1,020	9
West Virginia	457	482	620	946	775	705	43
State share	249	263	332	521	448	418	30
Wisconsin	1,229	1,285	1,354	1,563	1,706	1,864	222
State share	584	619	638	775	883	1,007	108
Wyoming	626	589	612	698	853	752	4
State share	315	316	310	328	514	402	2
American Samoa	65	72	64	63	70	40	------
State share	32	36	32	31	32	20	------
Guam	25	36	43	62	65	66	------
State share	12	18	21	31	32	33	------
Puerto Rico	964	1,042	1,347	1,303	1,293	1,002	38
State share	484	494	557	682	585	463	11
Trust Territories	93	105	125	117	170	170	------
State share	45	52	62	58	84	85	------
Virgin Islands	23	12	(3)	(3)	33	18	------
State share	12	6	(3)	(3)	31	9	------

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

TABLE 28.—*Geological Survey reimbursable program funds from other Federal agencies, by agency, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976 [3]	Transition quarter (estimated)[3]
Total	$31,236	$28,805	$30,342	$40,316	$43,636	$46,607	$13,682
Appalachian Regional Commission	------	------	------	189	179	------	------
Department of Agriculture	310	268	273	356	891	2,008	460
Department of Commerce	233	85	73	(1)	154	2,205	95
Department of Defense	7,863	9,123	8,443	13,351	11,247	11,965	3,470
Department of Housing and Urban Development	713	1,202	2,095	3,581	3,069	4,624	1,480
Department of the Interior	3,408	1,714	2,208	2,312	9,361	6,290	1,821
Bonneville Power Administration	------	101	118	136	105	130	30
Bureau of Indian Affairs	------	------	149	340	697	759	222
Bureau of Land Management	166	205	207	251	5,114	3,682	1,208
Bureau of Mines	------	80	------	------	1,735	148	------
Bureau of Reclamation	2,358	656	855	676	721	790	180
Bureau of Sports Fisheries	12	11	------	------	------	------	------
Fish and Wildlife Service	------	101	256	380	372	205	45
National Park Service	647	508	459	529	617	576	136
Office of Saline Water	------	31	156	------	------	------	------
Office of Territories	225	21	8	------	------	------	------
Department of State	2,697	2,789	2,756	2,177	1,698	949	278
Department of Transportation	------	------	------	------	4	470	115
Energy Research and Development Administration [2]	3,072	3,112	3,011	4,029	3,501	4,466	1,898
Environmental Protection Agency	579	627	916	1,127	1,389	1,921	598
Federal Energy Administration	------	------	------	------	353	238	44
National Aeronautics and Space Administration	7,029	6,017	6,507	5,672	3,449	3,584	1,194
National Oceanographic and Atmospheric Administration	------	------	------	2,001	434	1,513	517
National Science Foundation	1,279	906	333	1,375	1,928	1,650	548
Nuclear Regulatory Commission	------	------	------	------	1,195	1,439	373
Ozark Regional Commission	------	------	------	60	49	------	------
Tennessee Valley Authority	204	198	255	212	252	216	62
Miscellaneous Federal Agencies	855	766	944	1,168	1,686	1,542	585
Miscellaneous services to Other accounts	2,994	1,998	2,528	2,706	2,797	1,527	144

[1] Included in miscellaneous Federal agencies.
[2] Includes Atomic Energy Commission funds for fiscal years 1971–74. See also funds from the Nuclear Regulatory Commission in fiscal year 1975.
[3] Information is as of September 15, 1976.

TABLE 29.—*Alaska Pipeline Related Investigations, reimbursable program funds from other Federal agencies, by agency, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976	Transition quarter
Total	$65	$62	----	----	----	----	----
Department of the Interior	65	62	----	----	----	----	----
Bureau of Commercial Fisheries	----	----	----	----	----	----	----
Bureau of Land Management	53	51	----	----	----	----	----
Bureau of Sports Fisheries	12	11	----	----	----	----	----

TABLE 30.—*Topographic Surveys and Mapping direct program funds, by subactivity, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Subactivity	1971	1972	1973	1974	1975	1976	Transition quarter [3]
Total direct program	$31,153	$34,545	$35,172	$37,161	$45,350	$45,354	11,553
Quadrangle Mapping and Revision [1]	29,090	32,710	33,433	35,046	41,148	38,266	9,401
Small Scale and Special Mapping	2,063	1,835	1,739	2,115	2,661	5,358	1,730
National Cartographic Information Center [2]	(150)	(300)	(675)	(1,043)	1,541	1,730	422

[1] Funds are reconstructed for fiscal years 1971–72 and include the Map Revision and Maintenance subactivity.

[2] National Cartographic Information Center funds included in the Quadrangle Mapping and Revision subactivity prior to fiscal year 1975.

[3] Actual obligations.

TABLE 31.—*Topographic Surveys and Mapping Federal-State Cooperative program funds, by State, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

State	1971	1972	1973	1974	1975	1976	Transition quarter
Total [1]	$7,802	$6,408	$7,438	$9,884	$9,990	$7,350	$1,764
Total State share [2]	3,901	3,204	3,719	4,942	4,995	3,675	882
Alabama	50	50	50	40	62	48	------
State share	25	25	25	20	31	24	------
Arkansas	50	46	54	58	72	74	28
State share	25	23	27	29	36	37	14
California	432	186	186	198	252	206	66
State share	216	93	93	99	126	103	33
Colorado	------	------	------	4	830	420	158
State share	------	------	------	2	415	210	79
Connecticut	40	40	40	120	124	110	56
State share	20	20	20	60	62	55	28
Florida	580	580	512	578	454	450	76
State share	290	290	286	289	227	225	38
Georgia	40	56	1,218	2,294	1,992	1,340	244
State share	20	28	609	1,147	996	670	122
Illinois	168	150	120	30	70	70	8
State share	84	75	60	15	35	35	4
Louisiana	136	136	134	136	136	108	2
State share	68	68	67	68	68	54	1
Iowa	44	------	------	------	------	176	64
State share	22	------	------	------	------	88	32
Kansas	266	266	248	286	268	266	104
State share	133	133	124	143	134	133	52
Kentucky	200	210	182	278	254	204	60
State share	100	105	91	139	127	102	30
Louisiana	60	60	50	152	120	90	22
State share	30	30	25	76	60	45	11
Maine	40	40	40	40	40	40	20
State share	20	20	20	20	20	20	10
Maryland	------	20	22	20	20	30	2
State share	------	10	11	10	10	15	1
Massachusetts	200	200	196	190	250	250	6
State share	100	100	98	95	125	125	3
Michigan	100	100	100	100	100	100	------
State share	50	50	50	50	50	50	------

See footnotes at end of table.

TABLE 31.—*Topographic Surveys and Mapping Federal-State Cooperative program funds, by State, fiscal years 1971–76 and transition quarter—Continued*

State	1971	1972	1973	1974	1975	1976	Transition quarter
Minnesota	884	734	708	1,092	840	246	------
State share	442	367	354	546	420	123	------
Missouri	226	184	130	134	134	110	44
State share	113	92	65	67	67	55	22
Nevada	36	40	40	58	54	58	32
State share	18	20	20	29	27	29	16
New Mexico	------	------	------	------	16	16	------
State share	------	------	------	------	8	8	------
New York	272	380	234	366	226	------	12
State share	136	190	117	183	113	------	6
North Carolina	220	220	172	670	890	502	124
State share	110	110	86	335	445	251	62
North Dakota	100	112	242	88	222	198	10
State share	50	56	121	44	111	99	5
Ohio	150	150	150	150	150	150	38
State share	75	75	75	75	75	75	19
Oklahoma	165	126	112	110	110	110	36
State share	83	63	56	55	55	55	18
Oregon	60	60	78	44	92	32	24
State share	30	30	39	22	46	16	12
Pennsylvania	700	550	326	392	312	224	32
State share	350	275	163	196	156	112	16
South Carolina	------	------	120	------	36	------	------
State share	------	------	60	------	18	------	------
South Dakota	38	50	50	50	50	50	28
State share	19	25	25	25	25	25	14
Tennessee	42	12	38	50	44	16	------
State share	21	6	19	25	22	8	------
Texas	1,162	694	742	726	686	682	170
State share	581	347	371	363	343	341	85
Utah	104	72	114	120	100	100	40
State share	52	36	57	60	50	50	20
Vermont	20	20	20	40	34	20	------
State share	10	10	10	20	17	10	------
Virginia	510	166	132	232	218	188	14
State share	255	83	66	116	109	94	7
Washington	50	32	32	34	6	28	6
State share	25	16	16	17	3	14	3
West Virginia	198	206	298	506	228	142	26
State share	99	103	149	253	114	71	13
Wisconsin	398	400	402	412	414	410	208
State share	199	200	201	206	207	205	104
Wyoming	10	10	10	10	10	10	4
State share	5	5	5	5	5	5	2
Puerto Rico	50	50	76	76	74	76	------
State share	25	25	38	38	37	38	------

[1] Includes Federal funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.

TABLE 32.—*Topographic Surveys and Mapping reimbursable program funds from other Federal agencies, by agency, fiscal years years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976 [1]	Transition quarter (estimated)[1]
Total	$2,017	$631	$780	$918	$1,658	$2,691	$740
Department of Agriculture	------	------	------	95	326	1,256	320
Department of Commerce	181	------	------	------	------	187	5
Department of Defense	------	------	35	92	183	151	50
Department of the Interior	1,125	21	68	238	441	284	150
Bureau of Indian Affairs	------	------	60	165	198	209	50
Bureau of Land Management	------	------	------	73	243	74	100
Bureau of Reclamation	900	------	------	------	------	1	------
Office of Territories	225	21	8	------	------	------	------
Department of Transportation	------	------	------	------	4	257	50
National Aeronautics and Space Administration	326	138	207	235	97	132	------
National Science Foundation	202	256	198	46	257	112	20
Miscellaneous Federal Agencies	183	216	272	212	350	312	145

[1] Information is as of September 15, 1976.

TABLE 33.—*Geologic and Mineral Resource Surveys and Mapping direct program funds, by subactivity, fiscal years 1971–76*

[In thousands of dollars]

Subactivity	1971	1972	1973	1974	1975	1976
Total direct program	$31,919	$34,244	$42,895	$49,877	$89,018	$92,322
Land Resource Surveys [1]	14,519	15,154	19,246	23,077	33,385	34,077
Mineral Resource Surveys [2]	13,424	13,524	14,026	14,971	18,017	19,775
Energy Resource Surveys	2,639	3,144	5,197	6,696	22,376	23,000
Offshore Geologic Surveys	1,337	2,422	4,426	5,133	15,240	15,470

[1] Funds adjusted for fiscal years 1971–73 to include geologic mapping in support of Mineral Resource Surveys.

[2] Funds adjusted for fiscal years 1971–73 to exclude geologic mapping and to include the Mineral Discovery Loan Program activity for fiscal years 1971–73.

TABLE 34.—*Geologic and Mineral Resource Surveys and Mapping Federal-State Cooperative funds, by State, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

State	1971	1972	1973	1974	1975	1976	Transition quarter
Total [1]	$2,825	$2,941	$4,270	$4,254	$4,541	$3,910	$782
State share [2]	1,322	1,359	1,556	1,681	1,550	1,479	364
Alabama	------	------	10	10	15	------	------
State share	------	------	10	5	5	------	------
Alaska	------	160	332	238	476	------	------
State share	------	80	135	93	75	------	------
Arkansas	50	51	85	125	165	110	------
State share	25	25	36	27	27	27	------
California	127	71	79	362	57	99	36
State share	63	33	22	80	21	66	36
Colorado	74	42	50	------	------	------	------
State share	41	20	30	------	------	------	------
Connecticut	150	141	235	208	258	200	59
State share	75	69	69	75	75	75	15
Georgia	------	2	------	6	10	------	------
State share	------	1	------	3	5	------	------

See footnotes at end of table.

TABLE 34.—*Geologic and Mineral Resource Surveys and Mapping Federal-State Cooperative funds, by State, fiscal years 1971–76 and transition quarter*—Continued

State	1971	1972	1973	1974	1975	1976	Transition quarter
Hawaii	------	------	------	------	------	------	------
State share	------	------	------	------	------	------	------
Idaho	------	------	------	------	------	------	------
State share	------	------	------	------	------	------	------
Iowa	------	------	------	16	------	------	------
State share	------	------	------	8	------	------	------
Kansas	------	------	------	------	------	------	------
State share	------	------	------	------	------	------	------
Kentucky	1,100	1,158	1,332	1,454	1,599	1,643	421
State share	550	575	600	630	675	718	180
Maryland	45	20	27	14	19	------	------
State share	23	10	10	7	9	------	------
Massachusetts	410	417	633	563	581	630	116
State share	205	205	205	228	205	205	63
Michigan	166	153	216	178	158	148	45
State share	68	65	65	65	65	65	19
Minnesota	------	------	------	------	------	------	------
State share	------	------	------	------	------	------	------
Nevada	173	192	249	254	384	396	3
State share	70	80	90	90	105	110	3
New Hampshire	24	25	31	59	50	53	13
State share	12	13	13	39	13	13	3
New Mexico	------	------	20	40	11	18	2
State share	------	------	10	20	------	18	2
New York	------	------	------	20	21	------	------
State share	------	------	------	10	10	------	------
North Carolina	51	35	99	40	18	------	------
State share	6	6	12	6	18	------	------
Pennsylvania	19	15	30	10	------	------	------
State share	8	8	15	5	------	------	------
South Carolina	------	------	------	------	5	------	------
State share	------	------	------	------	5	------	------
Texas	------	------	3	------	------	------	------
State share	------	------	3	------	------	------	------
Utah	------	11	18	7	6	37	7
State share	------	3	7	7	4	4	5
Washington	53	58	122	67	134	81	11
State share	25	20	30	20	30	35	6
West Virginia	------	------	20	20	21	3	17
State share	------	------	10	10	10	3	17
Wisconsin	50	55	82	76	68	121	14
State share	8	8	8	8	8	8	4
Wyoming	48	15	27	26	11	35	------
State share	4	2	2	2	2	2	------

See footnotes at end of table.

TABLE 34.—*Geologic and Mineral Resource Surveys and Mapping Federal-State Cooperative funds, by State, fiscal years 1971–76 and transition quarter*—Continued

State	1971	1972	1973	1974	1975	1976	Transition quarter
Puerto Rico	270	320	570	461	474	336	38
State share	131	136	174	243	183	130	11
Virgin Islands	15	------	------	------	------	------	------
State share	8	------	------	------	------	------	------

[1] Includes Federal funds from direct program.
[2] Includes reimbursable program funds from States, counties, and municipalities.

TABLE 35.—*Geologic and Mineral Resource Surveys and Mapping reimbursable program funds from other Federal agencies, by agency, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976 [2]	Transition quarter (estimated)[2]
Total	$13,494	$13,609	$11,222	$19,321	$20,158	$16,828	$6,261
Appalachian Regional Commission	------	------	------	189	179	------	------
Department of Defense	3,179	3,219	1,431	5,670	2,648	2,443	1,080
Department of Housing and Urban Development	------	281	294	224	817	------	------
Department of the Interior	------	134	156	------	5,719	2,330	867
Bureau of Indian Affairs	------	------	------	------	243	370	121
Bureau of Land Management	------	------	------	------	3,741	1,851	746
Bureau of Mines	------	80	------	------	1,735	109	------
Bureau of Reclamation	------	23	------	------	------	------	------
Department of Commerce	------	------	------	------	------	342	------
Office of Saline Water	------	31	156	------	------	------	------
Department of State	1,711	1,987	1,975	1,510	1,056	359	------
Energy Research and Development Administration [1]	1,858	2,090	2,134	3,125	2,542	3,324	1,578
Federal Energy Administration	------	------	------	------	353	77	44
National Aeronautics and Space Administration	5,454	5,038	4,708	4,745	2,938	2,800	1,049
National Oceanographic and Atmospheric Administration	------	------	------	2,001	434	1,513	517
National Science Foundation	1,077	650	135	1,329	1,604	1,538	528
Nuclear Regulatory Commission	------	------	------	------	1,195	1,439	373
Miscellaneous Federal Agencies	215	210	389	528	673	663	225

[1] Includes Atomic Energy Commission funds for fiscal years 1971–74. See also funds from the Nuclear Regulatory Commission in fiscal year 1975.
[2] Information is as of September 15, 1976.

TABLE 36.—*Water Resources Investigations direct program funds, by subactivity, fiscal years 1971–76*

[In thousands of dollars]

Subactivity	1971	1972	1973	1974	1975	1976
Total direct program [1]	$34,581	$37,446	$40,185	$45,433	$53,420	$57,176
National Water Data System	32,360	34,849	37,523	42,993	48,191	48,494
Federal program	13,177	14,841	16,334	17,695	21,183	20,577
Federal-State program [2]	19,183	20,008	21,189	25,298	27,008	27,917
Critical National water problems	2,221	2,597	2,662	2,440	5,229	8,682

[1] Direct program funds exclude the Employee Compensation Payments subactivity for fiscal years 1971–76.
[2] Federal share of Federal-State Cooperative program.

TABLE 37.—*Water Resources Investigations—Federal-State Cooperative program funds, by State, fiscal years 1971–76*
[In thousands of dollars]

State	1971	1972	1973	1974	1975	1976
Total [1]	$38,647	$41,302	$43,925	$51,118	$55,554	$56,709
State share [2]	19,464	21,294	22,736	25,820	28,546	29,753
Alabama	796	789	868	1,044	1,135	1,024
State share	442	436	479	529	587	512
Alaska	411	459	506	659	686	772
State share	203	250	264	317	335	410
Arizona	869	1,021	1,001	1,144	1,248	1,267
State share	444	540	510	576	646	682
Arkansas	392	409	457	674	650	613
State share	189	202	225	399	347	307
California	3,455	3,636	3,850	4,229	4,381	4,473
State share	1,672	1,810	1,938	2,101	2,190	2,277
Colorado	870	953	1,078	1,480	1,615	1,669
State share	436	487	545	835	909	940
Connecticut	429	436	412	486	687	540
State share	207	215	203	239	386	286
Delaware	112	111	121	130	194	214
State share	73	75	81	74	106	119
District of Columbia	12	2	3	3	3	3
State share	6	1	1	1	1	2
Florida	2,539	2,818	3,071	4,505	5,055	5,147
State share	1,249	1,429	1,572	2,263	2,521	2,593
Georgia	711	741	790	939	1,081	1,142
State share	380	408	432	461	530	571
Hawaii	649	622	653	691	697	865
State share	334	314	337	339	341	492
Idaho	633	619	675	718	749	837
State share	308	307	344	353	366	419
Illinois	482	503	526	514	575	746
State share	232	266	273	262	288	415
Indiana	770	858	973	1,227	1,152	1,388
State share	371	423	523	610	564	728
Iowa	398	517	525	592	617	631
State share	192	255	259	291	302	317
Kansas	1,058	1,096	1,110	1,116	1,156	1,245
State share	512	542	552	543	582	624
Kentucky	600	665	698	719	875	962
State share	289	328	348	353	427	481
Louisiana	1,107	1,152	1,190	1,748	1,620	1,570
State share	591	625	649	904	842	817
Maine	118	123	128	135	208	294
State share	64	69	71	76	107	176
Maryland	535	580	646	817	972	975
State share	272	301	335	418	511	507
Massachusetts	516	542	550	593	787	735
State share	290	309	322	333	480	449

See footnotes at end of table.

TABLE 37.—*Water Resources Investigations—Federal-State Cooperative program funds, by State, fiscal years 1971–76*—Continued

State	1971	1972	1973	1974	1975	1976
Michigan	599	606	631	652	796	820
State share	289	302	310	321	390	410
Minnesota	550	635	712	811	799	925
State share	265	314	373	420	397	501
Mississippi	551	592	593	645	743	634
State share	316	357	340	325	415	317
Missouri	637	608	602	523	544	519
State share	307	321	310	255	270	260
Montana	393	401	402	505	587	549
State share	212	221	223	255	287	283
Nebraska	502	553	588	705	731	769
State share	246	274	298	344	358	396
Nevada	304	346	351	377	408	479
State share	146	171	178	185	200	239
New Hampshire	89	75	108	118	122	171
State share	43	37	54	58	60	85
New Jersey	785	822	856	1,051	977	1,073
State share	390	418	433	530	501	569
New Mexico	888	963	1,087	1,292	1,412	1,466
State share	462	509	591	642	706	753
New York	1,717	1,844	2,161	2,410	2,730	2,770
State share	837	921	1,112	1,222	1,462	1,610
North Carolina	667	691	767	876	977	940
State share	321	341	394	430	479	474
North Dakota	561	602	657	675	776	782
State share	275	305	340	325	378	391
Ohio	829	840	878	828	943	1,087
State share	446	443	445	406	488	597
Oklahoma	498	488	522	592	638	667
State share	276	270	284	289	313	333
Oregon	546	667	750	852	810	854
State share	277	342	393	417	397	438
Pennsylvania	1,459	1,602	1,691	1,955	2,103	2,165
State share	730	809	864	994	1,053	1,120
Rhode Island	97	92	90	97	110	123
State share	52	50	50	52	54	61
South Carolina	374	403	454	546	533	540
State share	196	212	241	279	261	270
South Dakota	371	374	373	421	465	468
State share	207	211	205	202	226	234
Tennessee	504	526	551	801	908	1,001
State share	271	288	302	397	448	501
Texas	2,673	3,023	3,049	3,320	3,575	3,633
State share	1,341	1,578	1,575	1,664	1,757	1,836
Utah	764	884	937	941	1,255	1,162
State share	369	447	466	467	784	692

See footnotes at end of table.

TABLE 37.—*Water Resources Investigations—Federal-State Cooperative program funds, by State, fiscal years 1971–76*—Continued

State	1971	1972	1973	1974	1975	1976
Vermont	104	105	109	104	96	119
State share	52	54	56	53	47	59
Virginia	609	631	661	673	640	538
State share	322	337	355	350	333	284
Washington	1,671	1,710	1,834	2,020	2,068	1,919
State share	806	845	916	1,000	1,071	971
West Virginia	259	276	302	420	526	500
State share	150	160	173	258	324	314
Wisconsin	781	830	870	1,075	1,224	1,333
State share	377	411	429	561	668	794
Wyoming	568	564	575	662	832	707
State share	306	309	303	321	507	395
American Samoa	65	72	64	63	70	40
State share	32	36	32	31	32	20
Guam	25	36	43	62	65	66
State share	12	18	21	31	32	33
Puerto Rico	644	672	701	766	745	590
State share	328	333	345	401	365	295
Trust Territories	93	105	125	117	170	170
State share	45	52	62	58	84	85
Virgin Islands	8	12	([3])	([3])	33	18
State share	4	6	------	------	31	9

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

TABLE 38.—*Water Resources Investigations reimbursable program funds from other Federal agencies, by agency, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976 [3]	Transition quarter (estimated)[3]
Total	$11,468	$11,905	$14,518	$16,378	$18,570	$24,631	$ 5,804
Department of Agriculture	310	268	273	261	565	753	140
Department of Commerce	52	85	73	([1])	154	1,733	90
Department of Defense	4,659	5,879	6,953	7,554	8,391	9,367	2,340
Department of Housing and Urban Development	358	921	1,801	3,018	2,252	4,624	1,480
Department of Interior	2,218	1,497	1,984	2,026	3,190	3,668	804
Bonneville Power Administration	------	101	118	101	105	130	30
Bureau of Mines	------	------	------	------	------	39	------
Bureau of Indian Affairs	------	------	89	175	256	179	51
Bureau of Land Management	113	154	207	178	1,130	1,749	362
Bureau of Reclamation	1,458	633	855	676	721	790	180
Fish and Wildlife Service	------	101	256	367	361	205	45
National Park Service	647	508	459	529	617	576	136

See footnotes at end of table.

TABLE 38.—*Water Resources Investigations reimbursable program funds from other Federal agencies, by agency, fiscal years 1971–76 and transition quarter*—Continued

Agency	1971	1972	1973	1974	1975	1976 [3]	Transition quarter (estimated)[3]
Department of State	986	802	781	667	642	589	144
Department of Transportation	------	------	------	------	47	214	65
Environmental Protection Agency	579	627	916	1,127	1,389	1,921	342
Energy Research and Development Administration [2]	1,214	1,022	877	904	959	1,142	280
National Aeronautics and Space Administration	438	266	343	284	235	213	20
National Science Foundation	------	------	------	------	67	------	------
Tennessee Valley Authority	204	198	255	212	252	216	62
Miscellaneous Federal agencies	450	340	262	325	494	191	37

[1] Included with miscellaneous Federal agencies funds.
[2] Includes Atomic Energy Commission funds for fiscal years 1971–74.
[3] Information is as of September 15, 1976.

TABLE 39.—*Conservation of Lands and Minerals direct program funds, by subactivity, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Subactivity	1971	1972	1973	1974	1975	1976	Transition quarter
Total direct program	$ 9,670	$13,441	$14,700	$18,172	$36,032	$41,489	
Outer Continental Shelf Lands	4,234	7,626	8,114	10,957	23,196	26,194	------
Federal and Indian Lands	5,436	5,815	6,586	7,215	12,836	15,295	------

TABLE 40.—*Conservation of Lands and Minerals reimbursable program funds from other Federal agencies, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976 [1]	Transition quarter [1]
Total	$32	$25	$45	$41	$46	$186	$47
Department of Defense	25	25	24	25	25	25	6
Miscellaneous Federal agencies	7	---	21	16	21	161	41

[1] Information is as of September 15, 1976.

TABLE 41.—*Land Information and Analysis direct program funds, by subactivity fiscal years 1971–76*

[In thousands of dollars]

Subactivity	1971	1972	1973	1974	1975	1976
Total direct program	$ 2,373	$6 ,714	$11,876	$11,458	$15,461	$14,908
Earth Sciences Applications	452	970	1,519	1,580	1,600	1,629
Resource and Land Investigations	------	------	------	916	959	740
Geography	------	------	------	------	2,013	2,341
Earth Resources Observation Systems	1,921	5,744	10,357	8,962	8,284	8,158
Environmental Impact Analysis	------	------	------	------	2,605	2,040

TABLE 42.—*Land Information and Analysis reimbursable program funds from other Federal agencies, by agency, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Agency	1971	1972	1973	1974	1975	1976[1]	Transition quarter (estimated)[1]
Total	$1,166	$575	$1,249	$952	$407	$744	$503
Department of Defense	------	----	-----	10	----	----	----
Department of Housing and Urban Development	355	----	-----	339	----	----	----
Department of the Interior	------	----	-----	48	11	15	----
Bureau of Mines	------	----	-----	----	----	3	----
Bonneville Power Administration	------	----	-----	35	----	----	----
Fish and Wildlife Service	------	----	-----	13	11	4	----
Bureau of Land Management	------	----	-----	----	----	8	----
Environmental Protection Agency	------	----	-----	----	----	----	206
National Aeronautics and Space Administration	811	575	1,249	408	179	443	125
Ozark Regional Commission	------	----	-----	60	49	31	----
Miscellaneous Federal agencies	------	----	-----	87	168	255	172

[1] Information is as of September 15, 1976.

TABLE 43.—*Land Information and Analysis Federal-State Cooperative program funds, by State, fiscal years 1971–76 and transition quarter*

State	1971	1972	1973	1974	1975	1976	Transition quarter
Total[1]	------	------	------	------	66	250	38
Total State share[2]	------	------	------	------	33	130	19
Alabama	------	------	------	------	--	34	6
State share	------	------	------	------	--	17	3
Florida	------	------	------	------	66	56	--
State share	------	------	------	------	33	33	--
Missouri	------	------	------	------	--	---	32
State share	------	------	------	------	--	---	16
Pennsylvania	------	------	------	------	--	100	--
State share	------	------	------	------	--	50	--
West Virginia	------	------	------	------	--	60	--
State share	------	------	------	------	--	30	--

[1] Includes Federal funds from direct program.
[2] Includes reimbursable funds from States, counties, and municipalities.

TABLE 44.—*Program support funds, by activity, fiscal years 1971–76 and transition quarter*

[In thousands of dollars]

Program support activity	1971	1972	1973	1974	1975	1976	Transition quarter (estimated)
General Administrative Expenses [1]	$ 5,335	$ 6,422	$ 7,173	$ 8,197	$10,806	$11,451	$ 3,675
General Administration [2]	3,048	3,187	3,217	3,517	3,671	3,398	1,492
Direct program assessments [3]	962	1,669	2,352	2,770	5,126	5,766	1,466
Reimbursable program assessment [4]	1,325	1,566	1,604	1,910	2,009	2,287	717
Electronic data processing and related services [5]	5,582	4,862	6,168	6,987	8,425	7,432	1,922
Funded by Survey programs [6]	3,068	3,351	4,177	4,828	6,129	6,700	1,908
Funded by miscellaneous accounts [7]	2,514	1,511	1,991	2,159	2,296	732	14
Publication services	9,615	10,667	11,656	11,932	13,004	15,468	3,608
Funded by Survey programs [6]	9,248	10,297	11,147	11,432	12,488	14,662	3,469
Funded by miscellaneous accounts [7]	367	370	509	500	516	806	139

[1] Obligations of the Director's Office for executive direction and of the Administrative Division for management services.
[2] Direct program funds of the General Administration budget activity. Obligations reconstructed for fiscal years 1971–75 to include Employee Compensation Payments.
[3] Assessments made on direct program funds of other budget activities.
[4] Assessments made on reimbursable program funds of other budget activities. No assessments are made on cooperative funds from State and local governments.
[5] Obligations of the Computer Center Division.
[6] Obligations charged to Survey program activities.
[7] Obligations charged to the Miscellaneous Services to Other Accounts activity for reimbursable work done for other agencies.

TABLE 45.—*Geological Survey end-of-year employment, by organizational unit, fiscal years 1971–76*

Organizational unit	1971	1972	1973	1974	1975	1976
Total	9,192	9,224	9,387	9,921	10,435	10,872
Permanent employment	8,173	8,002	8,089	8,357	8,999	9,142
Other than permanent employment	1,019	1,222	1,298	1,564	1,436	1,730
Topographic Division	2,079	2,045	2,020	1,956	1,877	1,876
Permanent employment	1,893	1,828	1,758	1,762	1,719	1,693
Other than permanent employment	186	217	262	194	158	183
Geologic Division	2,048	2,060	2,147	2,406	2,572	2,709
Permanent employment	1,765	1,706	1,766	1,888	2,135	2,119
Other than permanent employment	283	354	381	518	437	590
Water Resources Division	3,427	3,409	3,419	3,611	3,610	3,632
Permanent employment	2,965	2,876	2,900	2,910	2,957	2,924
Other than permanent employment	462	533	519	701	653	708
Conservation Division	492	549	568	647	990	1,218
Permanent employment	475	529	547	612	926	1,135
Other than permanent employment	17	20	21	35	64	83
Land Information and Analysis Office	------	51	72	85	114	157
Permanent employment	------	39	52	68	89	116
Other than permanent employment	------	12	20	17	25	41

See footnotes at end of table.

TABLE 45.—*Geological Survey end-of-year employment, by organizational unit, fiscal years 1971–76*—Continued

Organizational unit	1971	1972	1973	1974	1975	1976
Director's Office[1]	94	64	57	64	66	64
Permanent employment	79	51	55	62	57	54
Other than permanent employment	15	13	2	2	9	10
Administrative Division	362	360	382	408	441	491
Permanent employment	336	326	341	366	398	426
Other than permanent employment	26	34	41	42	43	65
Facilities[2]	------	------	------	15	30	37
Permanent employment	------	------	------	15	30	37
Other than permanent employment	------	------	------	------	------	------
Computer Center Division	153	170	174	182	198	146
Permanent employment	142	150	153	159	178	130
Other than permanent employment	11	20	21	23	20	16
Publications Division	537	516	548	547	537	542
Permanent employment	518	497	517	515	510	508
Other than permanent employment	19	19	31	32	27	34

[1] Includes Land Information and Analysis Office personnel for fiscal year 1971.
[2] Administrative Division personnel assigned to the operation of the Survey's Headquarter facilities.

TABLE 46.—*Number of Geological Survey reports approved for publication, by organizational unit, fiscal years 1971–76 and transition quarter*

Organizational unit	1971	1972	1973	1974	1975	1976	Transition quarter
Total	2,320	2,351	2,548	2,755	2,888	3,418	883
Book reports[1]	183	163	147	155	144	146	29
Journal of Research articles[2]	126	106	107	90	85	101	19
Open-file reports	399	447	380	440	570	781	215
Basic data reports	131	196	255	230	256	------	------
Outside publications	1,481	1,439	1,659	1,840	1,833	2,183	576
Topographic Division	53	42	53	53	33	36	6
Book reports	------	------	------	------	------	0	0
Journal of Research articles	------	------	2	1	----	0	0
Open-file reports	------	------	------	------			
Outside publications	53	42	51	52	33	36	6
Geologic Division	1,311	1,329	1,419	1,546	1,811	2,209	578
Book reports	93	102	91	96	90	101	16
Journal of Research articles	90	78	79	69	70	62	14
Open-file reports	189	258	216	245	379	499	145
Outside publications	939	891	1,033	1,136	1,272	1,547	403
Water Resources Division	865	875	953	1,002	926	1,061	245
Book reports	88	59	54	56	50	42	11
Journal of Research articles	36	28	26	20	15	38	5
Open-file reports	200	180	149	181	152	264	55
Basic data reports	131	196	255	230	256	207	44
Outside publications	410	412	469	515	453	510	130
Conservation Division	11	15	17	18	44	28	15
Book reports	------	1	------	2	1	0	1
Open-file reports	5	8	13	11	32	13	10
Outside publications	6	6	4	5	11	15	4

See footnotes at end of table.

TABLE 46.—*Number of Geological Survey reports approved for publication, by organizational unit, fiscal years 1971–76 and transition quarter*—Continued

State	1971	1972	1973	1974	1975	1976	Transition quarter
Director's Office [3]	80	90	106	136	74	84	39
Book reports	2	1	2	1	3	3	1
Open-file reports	5	1	2	3	7	5	5
Outside publications	73	88	102	132	64	75	33
Journal of Research	------	------	------	------	------	1	0

[1] Book reports include U.S. Geological Survey Professional Papers, Bulletins, Water-Supply Papers, Circulars, and other report series.
[2] Before January 1973 articles were published as part of the annual "Geological Survey Research" Professional Paper.
[3] Includes reports of the Land Information and Analysis Office, Administrative Division, Computer Center Division, and Publications Division.

TABLE 47.—*Number of maps produced by the Geological Survey, by organizational unit, fiscal years 1971–76 and transition quarter*

Organizational unit	1971	1972	1973	1974	1975	1976	Transition quarter
Total [1]	4,553	6,094	10,304	7,361	8,722	9,099	2,310
Topographic Division	3,541	4,817	5,313	4,938	7,288	7,339	2,080
Quadrangle maps	3,346	4,641	5,117	4,780	7,087	6,757	1,970
New standard quadrangles	1,692	2,544	2,347	2,052	2,016	1,405	237
Orthophotoquads	------	------	49	15	2,869	3,197	730
Revisions	953	1,223	1,118	966	923	656	165
Reprints	701	874	1,603	1,747	1,279	1,499	838
Small scale and special maps	135	112	148	121	171	582	114
1:250,000 series	19	26	57	50	52	37	5
Antarctica	10	------	5	------	4	6	------
State bases	6	8	2	------	2	34	1
Other	13	20	25	8	24	112	6
Reprints	87	58	59	63	80	73	54
Intermediate scale	------	------	------	------	9	259	32
Topographic maps indexes	60	64	48	37	30	61	16
Geologic Division [2]	119	315	320	215	229	285	71
Water Resources Division	876	952	4,650	2,192	1,198	1,358	109
Hydrologic maps	49	47	84	52	58	653	70
Flood-prone area maps	827	905	4,566	2,140	1,140	705	39
Conservation Division [3]	17	10	8	9	5	14	------
Director's office [3]	------	------	13	7	2	103	46

[1] Additional maps are produced for inclusion in book reports.
[2] Geologic and geophysical maps.
[3] Miscellaneous maps and charts.

TABLE 48.—*Oil and gas operations on the Outer Continental Shelf lands, calendar years 1971–76*

Activity	1971	1972	1973	1974	1975	1976 (estimated)
Number of exploration permits issued	254	254	350	400	517	550
Lease sales:						
Number of sales	1	2	6	5	4	4
Tracts offered:						
Number	18	210	276	1,006	1,374	536
Area (acres in thousands)	56	971	1,515	5,006	7,248	2,827
Tracts sold:						
Number	11	178	187	356	321	241
Area (acres in thousands)	37	826	1,033	1,762	1,680	1,276
Percentage of tracts sold	61.1	84.8	67.8	35.4	23.4	45.9
Bonus (dollars in thousands)	$96,304	$2,251,348	$3,082,463	$5,022,861	$1,088,133	$2,242,899

See footnotes at end of table.

TABLE 48.—*Oil and gas operations on the Outer Continental Shelf lands, calendar years 1971–76*—Continued

Activity	1971	1972	1973	1974	1975	1976 (estimated)
Status of leases:						
Total number of leases supervised	1,083	1,023	1,266	1,590	1,792	2,200
Total area (acres in thousands)	4,603	4,339	5,614	7,247	8,322	10,300
Number of producing leases	649	698	726	748	790	850
Area (acres in thousands)	2,710	2,915	3,039	3,147	3,253	3,500
Percentage	59.9	68.2	57.3	47.0	44.0	38.6
Number of non-producing leases	434	325	540	842	1,002	1,350
Area (acres in thousands)	1,893	1,424	2,575	4,100	5,069	6,800
Percentage	40.1	31.8	42.7	53.0	56.0	61.4
Lease operations:						
Number of platforms	1,856	1,963	2,016	2,059	2,084	2,100
Number of new well starts	841	847	820	816	892	900
Number of new wells completed	407	338	420	310	392	405
Number of new zones completed	640	496	600	398	515	520
Oil zones	393	306	304	226	225	210
Gas zones	240	180	288	155	277	295
Service zones	7	10	8	17	13	15
Total number of completed wells	5,718	6,032	6,421	6,218	6,104	5,990
Total number of completed zones	9,348	9,716	10,187	8,750	9,074	9,465
Oil zones	6,657	6,740	6,868	4,418	4,519	4,600
Gas zones	2,474	2,680	2,987	2,403	2,765	3,110
Service zones	217	296	332	416	325	340
Other zones [1]	------	--------	--------	1,513	1,465	1,415
Miles of pipeline under supervision (estimated)	5,000	6,000	6,450	6,700	7,150	7,400
Production:						
Oil and condensate (barrels in millions)	419	412	395	361	330	310
Percentage of domestic production	12.1	11.9	11.8	11.2	10.8	10.6
Gas (cubic feet in millions)	2,777	3,038	3,212	3,515	3,459	3,363
Percentage of domestic production	12.6	13.5	14.0	16.0	17.2	18.7
Gasoline and LPG (gallons in millions)	1,551	1,737	1,635	2,032	1,983	1,920
Percentage of domestic production	5.9	6.5	6.1	7.9	7.9	8.0

[1] New classification since 1974.

TABLE 49.—*Revenues from bases on Outer Continental Shelf lands, calendar years 1971–76*

[Dollars in thousands]

Source of revenue	1971	1972	1973	1974	1975	1976 (estimated)
Total revenue	$ 456,012	$2,624,958	$3,494,981	$5,598,758	$1,723,325	$2,913,039
Bonuses	96,304	2,251,347	3,082,462	5,022,861	1,088,133	2,242,899
Minimum royalties	1,891	2,020	2,391	2,048	2,086	2,100
Rentals	7,742	7,985	8,949	13,533	17,522	21,000
Number of accounts	(735)	(529)	(647)	(1,036)	(1,203)	(1,430)
Shut-in-gas payments	32	50	53	32	40	40
Totals:						
Royalties	350,042	363,556	401,126	560,284 [1]	615,545	647,000
Production value	(2,135,677)	(2,229,179)	(2,486,865)	(3,570,054) [1]	(3,924,915)	(4,102,000)
Number of accounts	(754)	(912)	(1,158)	(2,260) [1]	(2,468)	(2,850)
Oil and condensate:						
Royalties	253,229	247,689	271,491	384,367	399,527	401,000
Production value	(1,481,681)	(1,453,968)	(1,620,732)	(2,398,794)	(2,428,849)	(2,459,000)
Gas:						
Royalties	87,406	105,892	118,245	142,257	195,198	228,000
Production value	(549,648)	(663,648)	(736,878)	(881,634)	(1,205,678)	(1,409,000)

See footnotes at end of table.

TABLE 49.—*Revenues from bases on Outer Continental Shelf lands, calendar years 1971–76*—Continued

Source of revenue	1971	1972	1973	1974	1975	1976 (estimated)
Gasoline and LPG:						
Royalties	5,944	6,525	7,768	19,797	16,376	18,000
Production value	(80,563)	(89,214)	(105,437)	(254,744)	(216,043)	(234,000)
Salt:						
Royalties	11	11	11	10	8	(2)
Production value	(67)	(65)	(69)	(62)	(54)	--------
Sulfur:						
Royalties	3,452	3,439	3,611	3,853	3,738	(2)
Production value	(23,718)	(22,287)	(23,749)	(34,820)	(69,738)	--------

[1] Includes $3,950,000 of lost oil and gas.
[2] Productive leases transferred to Louisiana by Supreme Court decree of June 16, 1975.

TABLE 50.—*Oil, gas, and geothermal operations on Federal and Indian lands, calendar years 1971–76*

Activity	1971	1972	1973	1974	1975	1976 (estimated)
Competitive oil and gas lease sales:						
Federal lands:						
Tracts offered:						
Number of tracts	418	464	339	421	420	480
Area acres	121,962	130,546	86,681	98,064	102,397	96,900
Tracts sold:						
Number of tracts	206	279	311	295	356	460
Area acres	52,102	88,326	89,315	65,247	92,967	87,600
Percentage of tracts sold	49.3	60.1	91.7	70.1	84.8	95.8
Bonus (dollars in thousands)	$1,163	$1,118	$2,203	$2,296	$6,399	$6,710
Status of oil and gas leases:						
Total number of leases supervised	112,784	113,158	115,761	123,652	125,720	125,900
Total area (acres in thousands)	70,628	75,213	79,116	89,829	93,717	94,425
Number of producing leases	11,285	11,640	11,953	12,386	12,961	13,400
Area (acres in thousands)	5,629	5,741	5,902	6,349	6,564	6,700
Percentage	10.0	10.3	10.3	10.0	10.3	10.6
Number of non-producing leases	101,499	101,518	103,808	111,266	112,759	112,500
Area (acres in thousands)	64,999	69,472	73,214	83,480	84,153	87,725
Percentage	90.0	89.7	89.7	90.0	89.7	89.4
Oil and gas lease operations:						
Number of new well starts	1,651	1,956	1,848	2,312	2,277	1,830
Number of new wells completed	883	1,045	1,132	1,280	1,569	1,215
Number of new zones completed	907	1,081	1,172	1,341	1,646	1,234
Oil zones	589	660	507	701	923	761
Gas zones	271	374	601	579	606	420
Service zones	47	47	64	61	117	53
Total number of completed wells	36,936	37,441	38,199	38,372	38,218	37,465
Total number of completed zones	38,686	39,159	39,991	40,251	40,292	39,374
Oil zones	23,366	23,282	23,139	22,791	21,868	21,034
Gas zones	10,159	10,421	11,083	11,487	12,272	12,203
Service zones	5,161	5,456	5,769	5,973	6,152	6,137
Oil and gas production:						
Oil and condensate (barrels in millions)	228	217	208	208	200	192
Percentage of domestic production	6.6	6.3	6.2	6.4	6.3	6.6
Gas (cubic feet in billions)	1,173	1,124	1,153	1,234	1,111	1,200
Percentage of domestic production	5.2	5.0	5.1	5.6	5.3	6.3
Gasoline and LPG (gallons in millions)	713	641	669	567	521	450
Percentage of domestic production	2.7	2.4	2.5	2.2	2.1	1.9
Status of geothermal leases:						
Total number of leases in effect	------	------	------	------	552	800
Total area (acres in thousands)	------	------	------	------	1,270	1,704

TABLE 51.—*Royalties from oil and gas leases on Federal and Indian lands, calendar years 1971–76*

[Dollars in thousands]

Commodity	1971	1972	1973	1974	1975	1976 (estimated)
Total royalties	$115,997	$115,204	$134,568	$219,630	$245,345	$266,200
Total production value	(938,276)	(918,360)	(1,074,758)	(1,728,536)	(1,915,768)	(2,067,200)
Oil and condensate:						
Royalties	90,753	87,594	100,963	176,566	193,608	197,500
Production value	(714,767)	(678,085)	(783,149)	(1,349,656)	(1,459,088)	(1,486,000)
Gas:						
Royalties	23,449	25,905	31,263	39,798	47,508	65,000
Production value	(187,032)	(206,625)	(248,768)	(315,490)	(374,785)	(515,000)
Gasoline and LPG:						
Royalties	1,771	1,686	2,323	3,238	3,789	2,800
Production value	(35,921)	(33,226)	(42,398)	(62,758)	(76,632)	(61,400)
All others:						
Royalties	24	19	19	28	440	900
Production value	(556)	(424)	(443)	(632)	(5,263)	(4,800)

TABLE 52.—*Mining operations on Federal and Indian lands by commodity, fiscal years 1971–76 and transition quarter*

Activity and commodity	1971	1972	1973	1974	1975	1976	Transition quarter
Total number of leases supervised	2,566	2,647	2,579	2,488	2,479	2,557	2,575
Total area (acres in thousands)	5,873	5,924	7,566	7,830	7,977	9,096	9,167
Total number of producible mines	405	343	338	377	435	450	450
Total commodity production (tons in thousands)	36,101	39,004	42,028	54,978	76,113	81,554	21,000
Coal:							
Number of leases supervised	558	560	561	563	565	570	573
Area (acres in thousands)	903	934	1,038	977	1,023	1,057	1,060
Production (tons in thousands)	17,263	18,966	24,247	32,139	43,590	52,491	14,000
Percentage of domestic production	3.1	3.2	4.1	5.4	7.2	7.9	8.5
Phosphate:							
Number of leases supervised	243	226	219	194	194	279	280
Area (acres in thousands)	145	136	131	100	100	114	114
Production (tons in thousands)	3,256	3,124	3,156	6,258	5,772	6,937	1,500
Percentage of domestic production	8.4	7.7	7.4	14.0	11.8	13.9	12.0
Potash:							
Number of leases supervised	159	164	163	158	161	163	163
Area (acres in thousands)	250	249	246	238	237	237	237
Production (tons in thousands)[1]	3,913	3,345	3,442	3,551	3,302	3,576	1,000
Percentage of domestic production	81.6	72.0	75.5	79.2	87.8	81.3	83.0
Sodium:							
Number of leases supervised	91	87	84	84	84	89	90
Area (acres in thousands)	138	133	132	132	132	136	138
Production (tons in thousands)	2,230	2,606	2,336	2,092	2,826	3,311	950
Percentage of domestic production	62.5	66.5	50.5	45.4	58.9	69.2	79.4
Oil shale:							
Number of leases supervised	------	------	------	4	4	4	4
Area (acres in thousands)	------	------	------	20.4	20.4	20.4	20.4
Production (tons in thousands)	------	------	------	------	------	------	------
Other:							
Number of leases supervised	1,515	1,610	1,552	1,485	1,471	1,452	1,465
Area (acres in thousands)	4,437	4,472	6,019	6,363	6,465	7,532	7,598
Production (tons in thousands)	9,439	10,963	8,847	10,938	20,623	15,239	3,550

[1] Converted to refined tons, 1976 estimated in part.

TABLE 53.—*Revenues from mining leases on Federal and Indian lands by commodity, fiscal years 1971–76 and transition quarter*

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

Commodity	1971	1972	1973	1974	1975	1976 [2]	Transition quarter (estimated)
Total revenue	$21,851	$14,841	$16,484	$470,464	$31,596	$36,479	$11,012
Bonuses	7,627	------	34	449,192[1]	4	50	12
Total royalties	14,224	14,841	16,450	21,272	31,560	36,429	11,000
Total production value	(293,983)	(301,665)	(335,282)	(463,811)	(681,281)	(813,221)	(240,000)
Coal:							
Royalties	2,654	3,119	4,044	5,535	8,335	10,949	3,000
Production value	(70,552)	(78,256)	(93,307)	(140,307)	(224,947)	(337,312)	(97,000)
Phosphate:							
Royalties	838	811	842	1,618	1,538	1,868	500
Production value	(9,669)	(9,674)	(11,314)	(31,158)	(28,383)	(25,769)	(6,000)
Potash:							
Royalties	3,695	3,104	3,270	3,962	5,565	6,321	1,800
Production value	(83,521)	(72,227)	(75,872)	(96,897)	(132,518)	(144,693)	(40,000)
Sodium:							
Royalties	1,960	2,531	2,547	2,439	5,046	7,364	2,600
Production value	(47,680)	(59,728)	(58,179)	(56,240)	(109,590)	(155,612)	(51,000)
Copper:							
Royalties	198	153	158	563	1,331	1,328	328
Production value	(4,137)	(2,995)	(2,691)	(6,087)	(7,140)	(7,347)	(1,750)
Fluospar:							
Royalties	40	70	86	31	------	11	5
Production value	(485)	(698)	(865)	(322)	------	(180)	(100)
Lead and zinc:							
Royalties	1,765	1,695	2,192	3,241	5,109	3,677	950
Production value	(44,017)	(42,195)	(54,640)	(75,319)	(115,340)	(81,564)	(22,000)
Limestone:							
Royalties	4	3	4	6	10	------	------
Production value	(75)	(20)	(54)	(86)	(83)	------	------
Sand and gravel:							
Royalties	614	886	623	633	842	505	125
Production value	(6,879)	(9,713)	(6,846)	(7,430)	(18,774)	(12,431)	(3,200)
Silica—pumice:							
Royalties	------	------	1	------	------	------	------
Production value	------	------	(14)	------	------	------	------
Uranium:							
Royalties	2,176	2,205	2,303	2,224	2,664	3,191	800
Production value	(18,370)	(18,394)	(18,822)	(22,014)	(16,938)	(23,912)	(6,000)
Zinc:							
Royalties	206	214	336	936	1,006	1,001	350
Production value	(5,119)	(5,219)	(8,207)	(22,806)	(24,413)	(22,240)	(8,000)
Other:							
Royalties	75	50	42	84	56	214	542
Production value	(3,478)	(2,546)	(4,490)	(5,146)	(3,155)	(2,161)	(4,950)

[1] Includes bonuses of $448,797,000 from four competitive oil-shale lease sales.
[2] 1976 estimated in part.

TABLE 54.—*Information products ordered from the EROS Data Center, fiscal years 1974–76 and transition quarter*

[Dollars in thousands] [1]

Product	1974 Images	1974 Value	1975 Images	1975 Value	1976 Images	1976 Value	Transition quarter Images	Transition quarter Value
Totals	284,097	$ 837	414,084	$1,610	407,395	$2,589	104,414	$ 718
Landsat images	157,178	529	195,125	760	246,449	1,238	50,804	274
Landsat computer-compatible data tapes	228	36	879	169	2,289	404	1,010	178
Gemini, Apollo, and Skylab images and photographs	17,201	34	28,049	113	9,664	86	1,405	15
Aerial photographs	109,490	237	190,031	567	148,993	735	51,195	221
Miscellaneous custom and special products	------	----	------	------	------	125	------	30

[1] Dollar amounts may not total due to rounding.

TABLE 55.—*U.S. Geological Survey Library Operating Statistics, fiscal years 1971–76* [1] *and transition quarter*

[N.A., not applicable]

Activity	1971	1972	1973	1974	1975	1976	Transition quarter	Estimated total holdings
Library acquisitions:								
Total number of items	80,401	94,445	84,208	91,047	136,106	116,927	25,077	2,006,004
Bound and unbound issues of periodicals and serials	47,194	50,322	45,499	48,095	49,775	58,360	14,890	658,250
Books and monographs	10,189	7,693	7,183	11,600	12,891	11,796	1,666	328,462
Pamphlets and reprints	5,221	2,660	2,425	2,901	2,798	6,927	1,863	358,790
Single-sheet maps	14,091	19,817	20,653	19,439	21,777	20,873	3,102	373,975
Photographs and negatives	2,568	12,558	7,121	7,818	3,485	15,387	3,222	218,609
Aerial photographs	77	1,100	1,019	812	45,000	1,888	125	54,013
Field record notebooks and related materials	361	295	308	382	380	1,104	209	13,313
Microforms	-----	-----	-----	-----	------	592	------	592
New serial titles (number of titles)	542	959	650	434	657	631	204	N.A.
Library users:								
Total number of visits	42,497	47,744	45,526	43,948	52,092	49,849	------	N.A.
Geological Survey users	35,897	39,141	37,211	37,327	46,210	44,110	------	N.A.
Other users	6,600	8,603	8,315	6,621	5,882	5,739	------	N.A.
Library circulation:								
Total number of items	78,075	69,302	66,327	61,656	80,991	95,814	24,575	N.A.
Books and periodicals	75,850	66,627	63,980	59,402	76,658	87,611	23,058	N.A.
Maps	2,225	2,675	2,347	2,254	4,333	8,203	1,517	N.A.
Interlibrary loans:								
Total number of items	18.548	19,156	16,308	15,252	20,356	18,977	4,767	N.A.
Items loaned	15,272	16,138	13,818	13,073	16,965	15,144	3,407	N.A.
Items borrowed	3,276	3,018	2,490	2,179	3,391	3,833	1,360	N.A.
Reference queries	13,302	13,093	11,358	14,047	14,774	17,765	3,836	N.A.

[1] Statistics include the operations of the Survey's main library in Reston, Va., and branch libraries in Denver, Colo., Menlo Park, Calif., and Flagstaff, Ariz.

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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.

On the cover: USGS Building I, housing offices of the Administrative and Geologic Divisions, in Menlo Park, California.