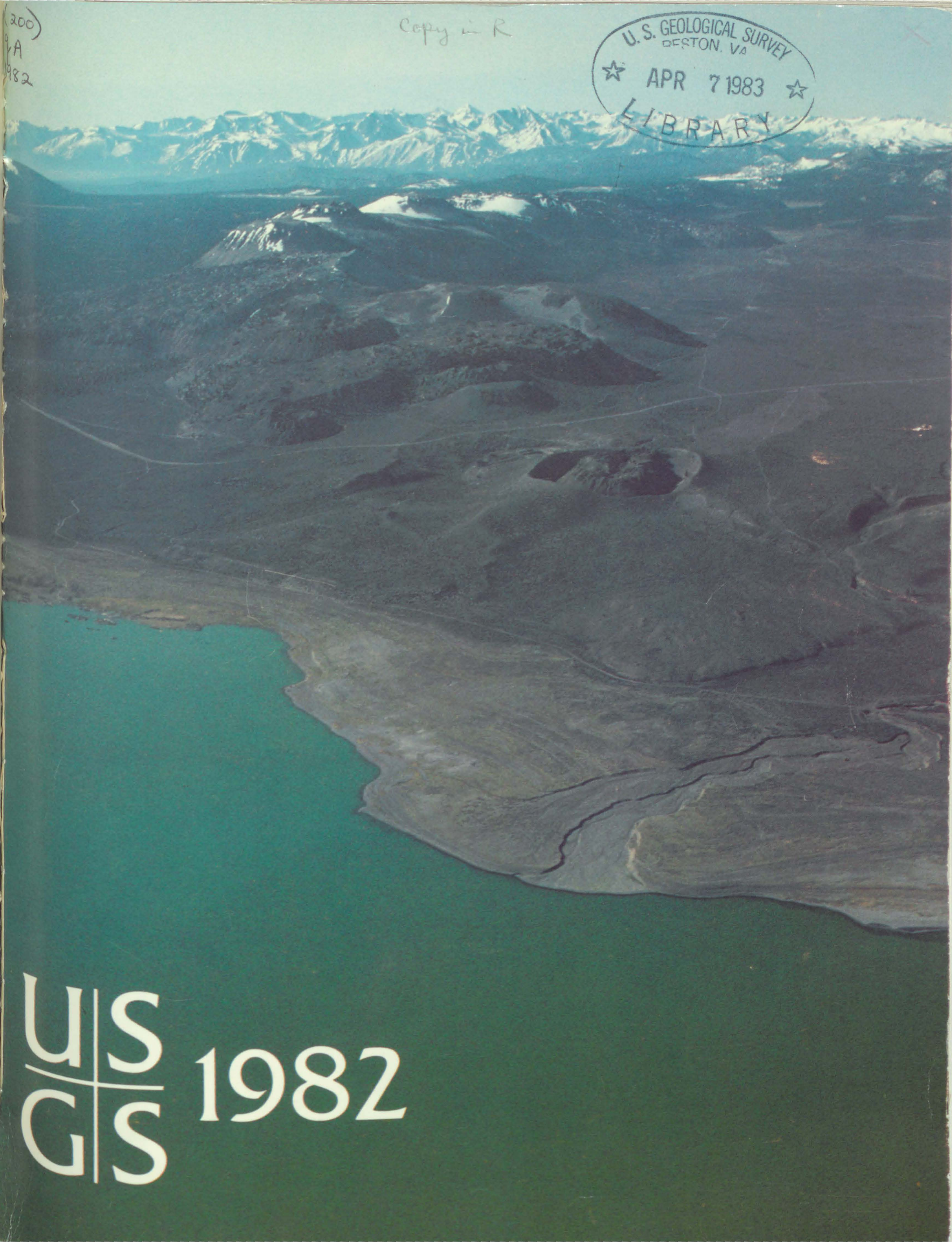

USGS 1982

Cover: *Oblique aerial view southward of the Mono Craters in eastern California. Mono Lake is in the foreground; Long Valley Caldera and the Sierra Nevada are in the distant background. The Mono Craters are an arcuate chain of rhyolite volcanic domes that have formed by eruptions during the past 40,000 years.*

United States Geological Survey Yearbook, Fiscal Year 1982

UNITED STATES DEPARTMENT OF THE INTERIOR
JAMES G. WATT, Secretary

GEOLOGICAL SURVEY
Dallas L. Peck, *Director*

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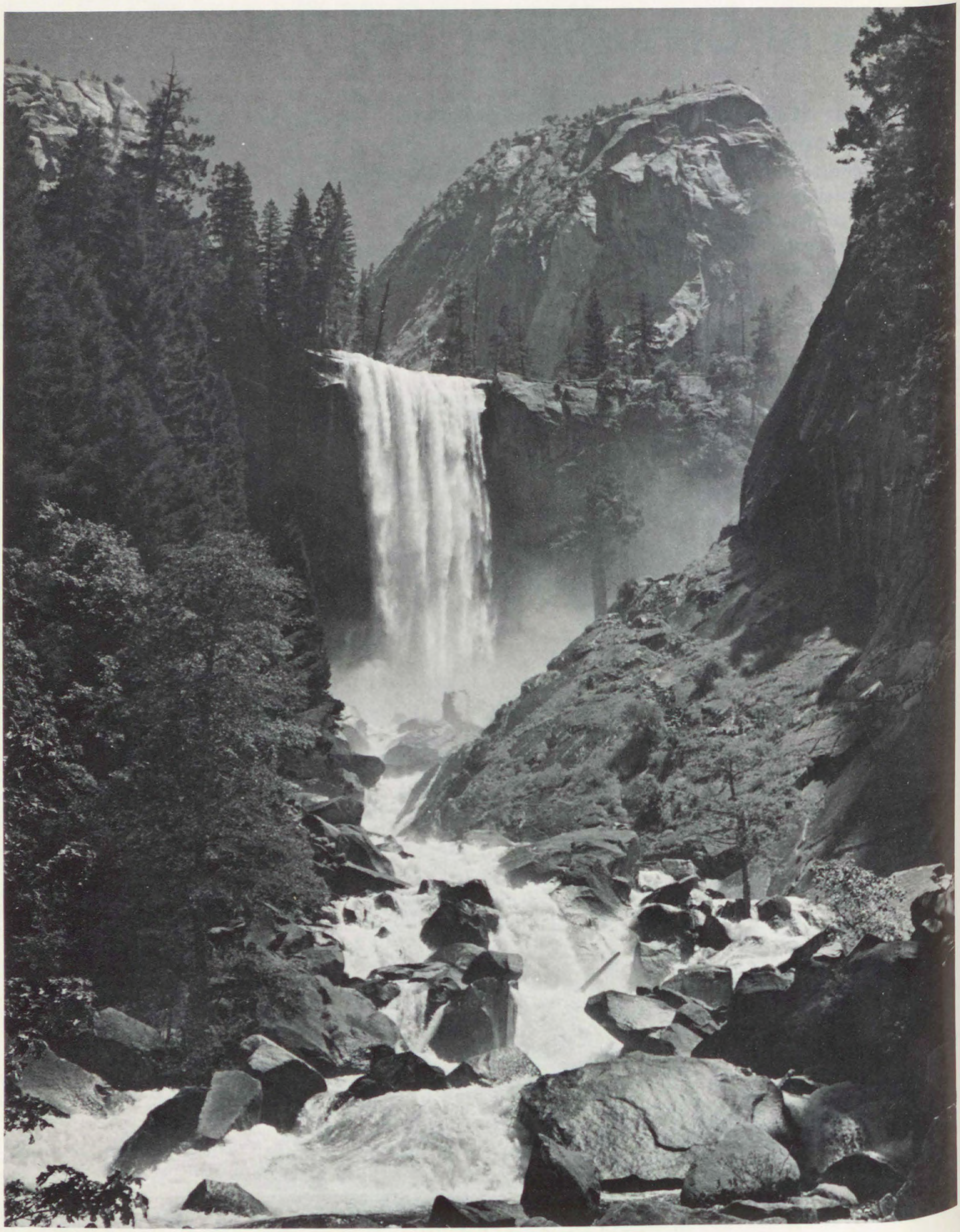


A YEAR OF CHANGE, A YEAR OF CHALLENGE

During the past 100 years of service as the Nation's earth science agency, the U.S. Geological Survey has faced numerous changes and challenges. We have taken on functions that our founding fathers never dreamed of, and we have spun off agencies and offices that now perform vital services to the public. That they perform these well is in no small part due to their initial nurturing and shaping by the Survey. We have faced challenges in the past that range from the harsh natural conditions at the South Pole and along the North Slope to the harsh management realities of necessary budget restraints; today, we must learn to do more with less.

Our 103d year probably brought as much change and challenge as any other single year in our history. Approximately one-quarter of our staff and operating budget was reassigned through the transfer of our Conservation Division and support personnel in other Divisions to the new Minerals Management Service. As part of the Executive Branch of the Federal Government, we have been asked to aid the Nation's economic recovery by limiting our use of people and dollars.

We continue to be involved in helping to understand and provide solutions to problems that need scientifically sound resolutions: acid rain, underground storage of toxic and nuclear wastes, increased dependence on foreign supplies of critical minerals and energy resources, and future water supplies. Perhaps even more challenging than the conduct of science is the important task of making people aware of the problems, and providing on a timely basis the best information on possible mitigation measures. This basic and applied research effort must be effective today if there are to be scientifically sound solutions tomorrow. In essence, we must not only be the best possible scientists and managers of the Nation's earth science needs, but we must also be the best possible communicators.

I believe that we have met these challenges during the past year and have made significant new contributions to the Nation's store of scientific and technical knowledge. We also have increased our scientific productivity in innovative ways. We have and will continue to provide the best in earth science for the public good.

The *Yearbook* provides a more detailed summary of the changes, challenges, and accomplishments of fiscal year 1982. I am pleased to summarize some of those accomplishments here.

The Survey's record of accurate predictions at Mount St. Helens Volcano continued in 1982 with advance warnings issued for each eruption. These warnings of continuing activity provided notice for the safe evacuation of people potentially threatened by an eruption. Seismic activity at Long Valley, California, led the Survey to issue a notice of potential volcanic activity hazard for that area. The detailed story of this geologic hazard is the subject of a major essay in this volume. In a broader contribution, the National Earthquake Information Center designed and implemented an efficient new technique for automatically summarizing digital data collected at stations worldwide and quantitatively describing the physical nature of earthquake sources. This technique greatly increases the accuracy of earthquake descriptions and facilitates recognition of long-term seismic patterns.

Significant advances in mineral resource research during the year include the initiation of a new program to assess the adequacy of U.S. and world resources of nonfuel minerals for the defense and industrial needs of the nation, the completion of mineral resource assessments for 44,000 square miles in nine States under the Conterminous U.S. Mineral Appraisal Program, and the publication of a highly useful new guide for the discovery and evaluation of metallic ore deposits. In addition, the second flight of the space shuttle *Columbia* included in its scientific payload the Shuttle Multispectral Infrared Radiometer, which successfully distinguished important mineral and rock types in a geologically diverse terrain. The results of this experiment by scientists from the Survey and the California Institute of Technology represent a major advance in the use of remote sensing for

Vernal Falls, Yosemite National Park.

mineral exploration. The experiment is described further in one of the *Yearbook* articles.

In 1982, the Survey reevaluated the Nation's undiscovered recoverable oil and gas resources in onshore and offshore basins. Survey Circular 860 lists these resource estimates for 15 regions, which comprise 137 provinces. Mean values of the estimates were 82.6 billion barrels of oil and 593.8 trillion cubic feet of gas. Survey marine geologists produced informative reports on the geology of petroleum basins in Alaskan and other offshore waters. In addition, our scientists made pioneering discoveries concerning the occurrence of polymetallic sulfides and metal-rich crusts on the sea floor. The sulfides offer a pristine natural laboratory for the study of ore-forming processes. The sea-floor crusts contain manganese, cobalt, and nickel, three strategic commodities, and are found at less than one-half the depth of the well-known manganese nodules.

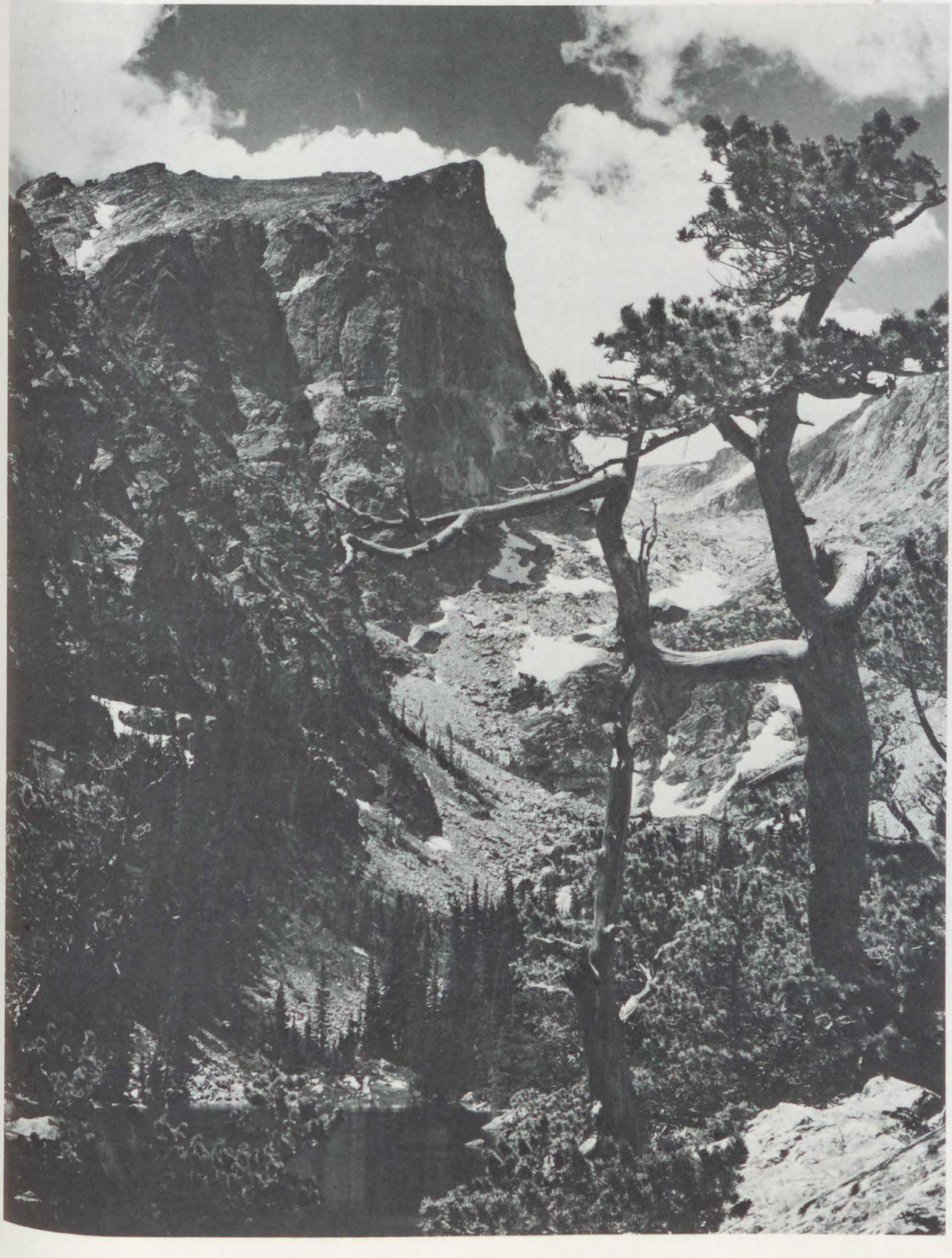
The Survey's hydrologic investigations in 1982 focused on major national problems. Many studies were carried out in cooperation with more than 850 Federal, State, and local agencies. The Survey continues to investigate long-term changes in the environment caused by acid precipitation using data from several sources including its Benchmark Network. The Benchmark Network, established in 1958, is the only long-term water-quality network in the Nation. Studies provide fundamental information for Federal and State agencies involved in efforts to understand and mitigate the effects of substances from the atmosphere on the Nation's water resources. In an investigation of the Potomac tidal river and estuary, Survey scientists have increased our understanding of chemical, physical, and biological processes that occur in the river so that future development in the river basin can be quantitatively evaluated. The isolation of high-level radioactive waste continues to be a subject of major national concern. In cooperation with the Department of Energy, we have established a systematic approach to screening regions for repository sites that can best isolate such waste from the rest of the environment. In 1982, the Regional Aquifer Systems Analysis Program produced new information on the availability of ground-water supplies and variations in ground-water quality. Such information is critical in planning for irrigation and public and industrial water supplies. The program in fiscal year 1982 focused primarily on hydrologic analyses of fifteen of the Nation's most important aquifer systems, including the Atlantic and Southeastern Coastal Plains, Southeastern Carbonates, Northern Great Plains, High Plains, Snake River Plain, and the Central Valley of California.

Management of vital water resources information collected by the Survey was improved with the implementation of a new decentralized computer network that will provide field and research offices across the country with an integrated system for analyzing and distributing hydrologic information.

Increased concern regarding the balanced use of our lands and resources have placed heavy demands on our topographic mapping efforts. The Survey has responded with a number of innovative mapping products. In 1982, we made available to the public new provisional maps for the 1:24,000-scale series on a much more rapid production schedule than is normally achievable. We have also successfully developed and produced a major new computerized data base for regional and national small-scale maps. The new digital data base at 1:2,000,000 scale has been produced in response to a need for an information source that can be applied to problems of all kinds and updated rapidly. Cultural and physiographic data are digitized and can be obtained as computer tapes from the National Cartographic Information Center. A new milestone in the map-making process was achieved with the completion of the first computer-generated topographic map. Each item of information on the map is digitized with photogrammetric instruments specially equipped to record features appearing on aerial photographs. The recorded digital information is then processed through a series of computer programs which format and edit the data for producing maps on a high-speed automatic plotter. The new process, although still in the experimental stage, offers the potential for large increases in efficiency, speed of production, and flexibility of data presentation. In a new application of cartographic data, a small-scale digital framework has been established for assessment of natural resources on federally owned lands. These data, when merged with geologic information and with petroleum production data from adjoining lands, can be used to develop accurate estimates of petroleum reserves in wilderness areas and on other Federal lands.

As the Federal Government continues to increase its efficiency and economy of operation, we must plan new efforts so that our research programs continue to effectively meet the natural resource needs of the nation. I am confident that our dedicated staff is fully capable of accomplishing this very worthwhile goal.

Charles L. Peck



Hallett Peak, Colorado.

Oblique aerial view southeastward of the south moat of the Long Valley Caldera (left middle ground) and the Sierra Nevada (right middle ground). Mammoth Mountain and the resort town of Mammoth Lakes are in the left foreground. Since May 1980, repeated earthquake swarms in the area (arrow) between the town of Mammoth Lakes and Lake Crowley (Left center) have increased concern for earthquake and volcanic hazards in the area.

Mammoth Lakes Earthquakes and Ground Uplift: Precursor to Possible Volcanic Activity?

By Roy A. Bailey

Prior to the eruption of Mount St. Helens, few Americans were aware or could have been persuaded that volcanoes posed a serious hazard to life and property in this country. And understandably so, for as far back as most people can remember, most of the volcanoes have been deceptively quiet. Even since the tragedy of Mount St. Helens, a common misconception seems to be that the danger of eruptions in the near future, both from Mount St. Helens and other Cascade volcanoes, is now past. A careful look at the historic record for the Cascade Range volcanoes suggests otherwise.

During the mid-1800's, when Mount St. Helens was last active, several other Cascade volcanoes were also active. Historic accounts indicate that, between 1830 and 1880, ash or steam eruptions occurred repeatedly at Mount Baker, Mount Rainier, Mount Hood, and possibly Mount Shasta, as well as at Mount St. Helens; and, in 1851, a cinder cone and lava flow, not unlike that of Parícutin Volcano which erupted through a Mexican cornfield in 1945, erupted in what is now Lassen Volcanic National Park. On more than one occasion in the mid-1800 period, as many as three volcanoes were active during a single year. That these eruptions caused little public concern is due to the sparse population and the undeveloped state of the region at that same time. Similar eruptions today would probably have considerably greater social and economic impact.

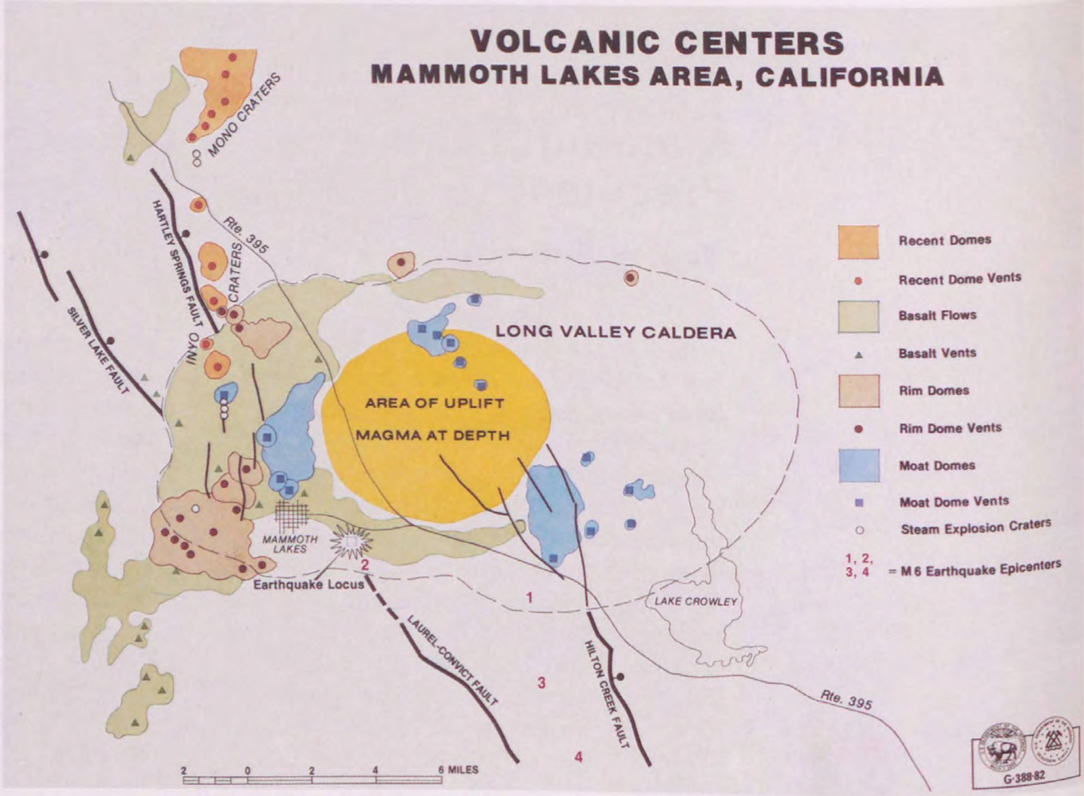
For the past 100 years, the Cascade volcanoes have been unusually quiet, but, since 1975, seismicity and apparent precursory volcanic activity in the Cascade Range have increased significantly enough to suggest that we may be on the threshold of another period of more frequent eruptions similar to that of the mid-1800's.

In 1975, Mount Baker suddenly began steaming vigorously and still continues, although considerably abated. In 1978, earthquake swarms accompanied by unusual ground rifting occurred in volcanic terrain east of Mount Shasta. In 1980, 3 months after Mount St. Helens burst to life, earthquake swarms shook the slopes of Mount Hood. In 1981, swarms were again recorded east of Mount Shasta. And, of course, Mount St. Helens continues its restless course, pumping new lobes of lava onto its crater floor every few months. In 1982, additional signs of restlessness have been observed and (or) felt further south in California. Unfelt, but instrumentally recorded, seismic activity at Lassen Volcanic National Park increased significantly during early 1982, and a similar increase in seismicity has been noted beneath the Coso Range volcanoes in the southern Owens Valley. However, the most unsettling activity of 1982 has been that in the vicinity of Mammoth Lakes, California, where apprehensions akin to those that preceded the Mount St. Helens outburst have been rekindled.

The Mammoth Lakes Earthquake Sequence of 1980

The activity at Mammoth Lakes began in 1980, but its implications were not fully understood until 2 years later in early 1982. On May 25, 1980, coincidently on the same day that Mount St. Helens erupted explosively for the second time, Mammoth Lakes, a resort town nestled at the eastern foot of the Sierra Nevada, was shaken by an historically unprecedented sequence of earthquakes. During a 48-hour period, the area was jolted by four magnitude 6 earthquakes, tens of magnitude 4 and 5 earthquakes, and literally hundreds of earthquakes of lesser intensity. Avalanches and rockfalls cascaded down slopes in the surrounding Sierras; the ground over an extensive area fissured and buckled; foundations, walls, and chimneys cracked; and the contents of cupboards and grocery store shelves tumbled to floors. Fortunately, most of the damage was superficial, and few serious injuries were reported. As a consequence of

Sketch geologic map of the Long Valley Caldera showing the location of the south moat earthquake epicentral locus and its relation to other young volcanic centers and major faults in the Mammoth Lakes area.

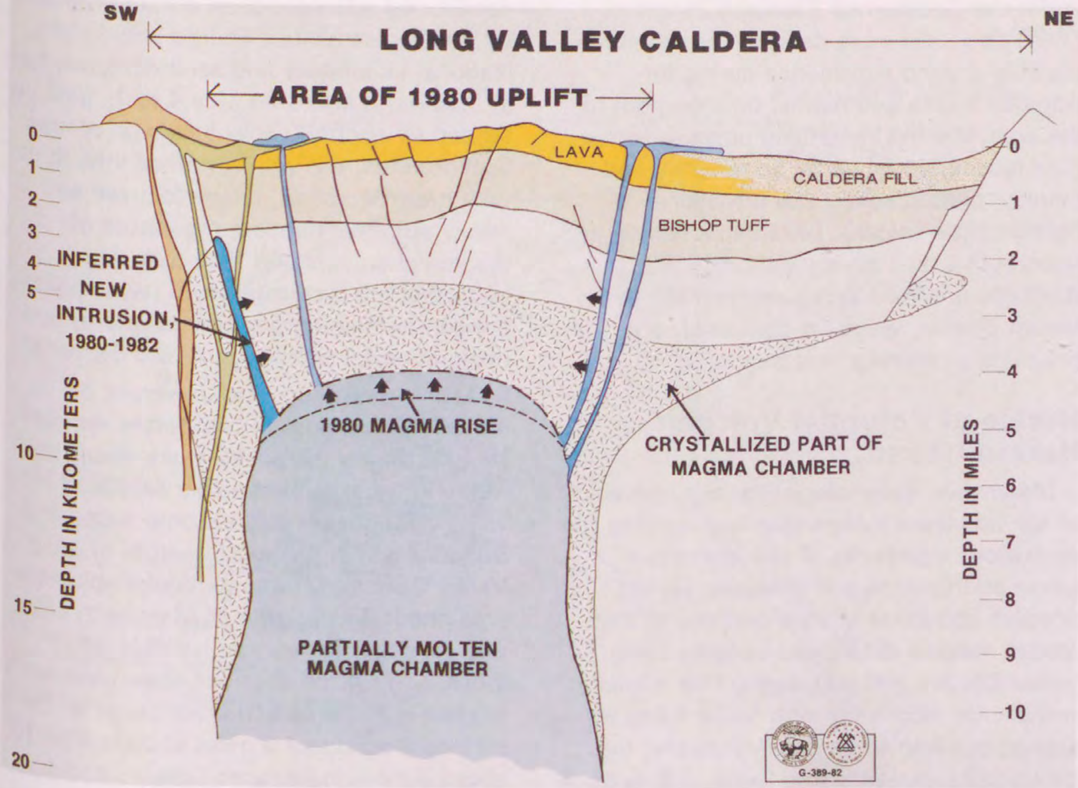


that earthquake sequence and on the basis of knowledge of the historic pattern of seismicity in the area, the U.S. Geological Survey issued an earthquake hazard watch on May 27, 1980, warning of possible continued severe earthquakes in the area. That earthquake hazard watch has remained in effect to the present time.

The town of Mammoth Lakes, which has a permanent population of about 4,000 and a transient residency of as many as 20,000 during the height of the winter ski season, lies on the active fault zone bounding the eastern front of the Sierra Nevada, a region long noted for its earthquake activity. The nearby Owens Valley was rocked by a magnitude 8.2 earthquake in 1872, and sporadically, every decade or so the region experiences magnitude 5 and 6 earthquakes. Geologists generally agree that this earthquake activity has been predominantly, if not entirely, tectonic in nature—probably related to the continuing uplift of the Sierra Nevada and possibly to regional extension at the western edge of the Basin and Range province, which is fundamentally caused by interaction between the Pacific and North American crustal plates that abut and grind together along the San Andreas rift 300 miles west of Mammoth Lakes. However, over the past 2 years, continuing events in the Mammoth Lakes area and recent discoveries concerning the nature of the unusually prolonged aftershock activity following the May 1980 earthquake sequence have raised concern that other natural forces of a different nature may be stirring in the area. This likelihood has prompted the Geological Survey to add a notice of potential volcanic hazard to the 1980 earthquake hazard watch and to mount a major monitoring effort in the area.

Long Valley Magma Chamber, Potential Source for Eruptions

Mammoth Lakes, in addition to being along the tectonically active eastern Sierran front, also lies in the southwestern corner of Long Valley Caldera, a large oval volcanic depression, 20 miles long and 10 miles wide, which formed about 700,000 years ago during colossal pyroclastic eruptions that spread volcanic ash over most of the Western United States. Since that time, lesser eruptions have occurred repeatedly within the caldera. The last major eruption occurred about 100,000 years ago, but smaller eruptions have occurred as recently as 50,000 years ago. Although these eruptions are sufficiently old as to not cause great concern about imminent future eruptions, geophysical and seismological studies undertaken between 1973 and 1974 as part of the



Northeast-southwest cross section through the Long Valley Caldera showing inferred subsurface relations of the Long Valley magma chamber and the tonguelike offshoot of magma in the south moat ring-fracture zone.

Geological Survey's Geothermal Research Program indicate that Long Valley Caldera is still underlain by a large residual magma chamber (a subterranean pool of molten rock). Its existence alone poses a special hazard, particularly in a region frequently shaken by large earthquakes.

Since the colossal eruptions of 700,000 years ago, the Long Valley magma chamber has been slowly cooling and solidifying inward from its margins; initially 12 miles in diameter and about 3 miles below the surface, it is now about 6 miles in diameter and 5 miles deep. Although diminished in size, it is still a large molten mass within the crust, potentially capable of producing future volcanic eruptions. Recent developments accompanying and following the Mammoth Lakes earthquake sequence of May 1980 suggest that the magma is indeed moving and that the potential for an eruption from it may be greater than the rather long past eruption intervals might otherwise suggest.

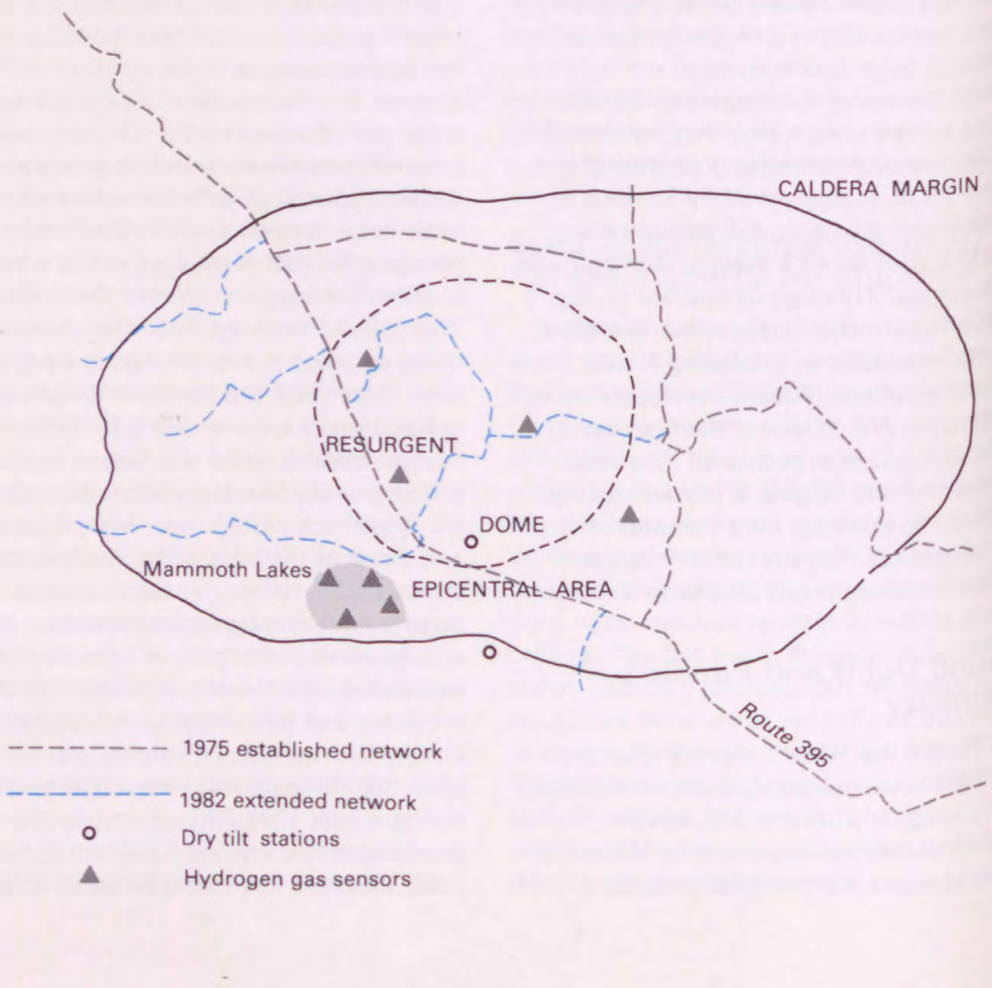
Ground Uplift and Puzzling Seismicity

In September 1980, 3 months after the May 1980 earthquake sequence, a releveling survey along U.S. Route 395, which parallels the Sierran front east of Mammoth Lakes, showed that the ground surface along the 22-mile segment between Tom's Place and Crestview had bulged upward as much as 10 inches since the previous survey in 1975. At first, as with the earthquakes, this ground deformation was thought to be related to tectonic mountain-building forces, but further analysis in the summer of 1981 showed that the center of this bulge coincided with the center of the known residual magma chamber beneath Long Valley Caldera, as well as with the center of an older bulge formed as a result of magma pressure 650,000 years ago, which was shortly after the formation of the caldera. This coincidence suggested that recently renewed magma pressure rather than tectonic forces was the cause of this present bulge. During summer 1981, Geological Survey volcanologists also began to notice puzzling similarities between seismograms of the aftershock activity near Mammoth Lakes and those of the continuing volcanic activity at Mount St. Helens. These observations suggested that magma movement was involved in the ground deformation associated with the May 1980 earthquake sequence and even may have triggered the quakes themselves. To confirm this possibility, the Geological Survey made plans during winter 1981-82 to reoccupy the geodimeter and leveling networks in summer 1982; they had been established in 1975 under the Geothermal Research Program. These networks were designed to monitor possible ground subsidence during anticipated future geothermal development of the area, but the immediate purpose for their reoccupation would be to verify and monitor ground uplift. The advisability of conducting a volcanic hazards workshop in Mammoth Lakes during summer 1982, similar to one held in November 1981 at Mount Shasta, was also discussed, and preliminary planning was begun.

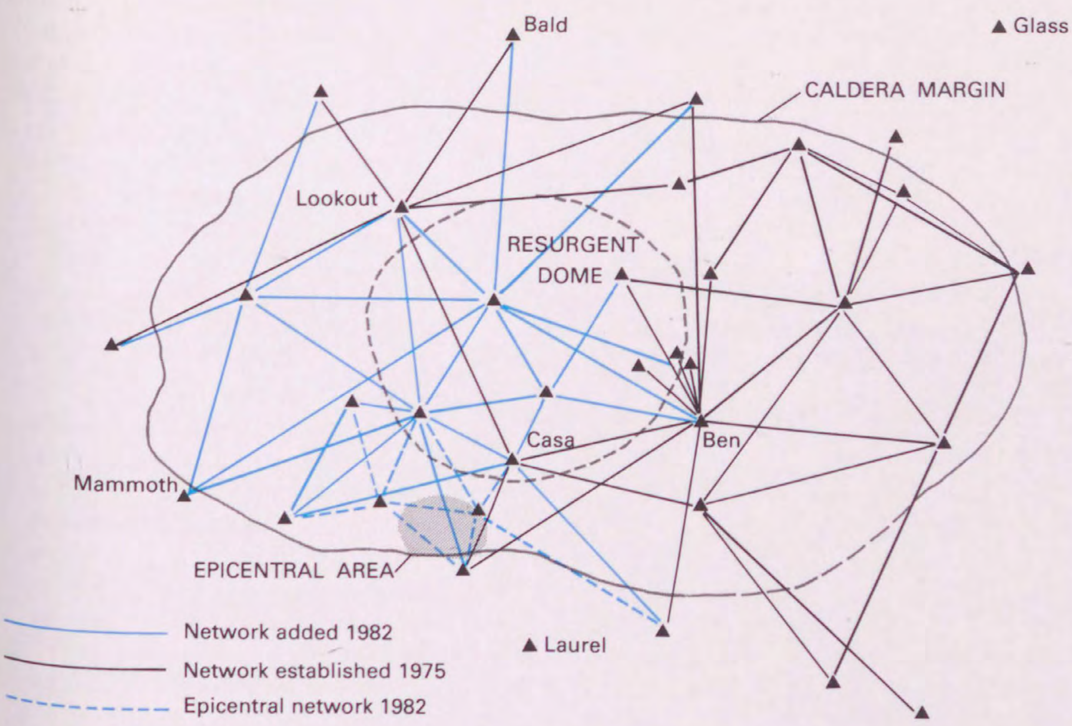
Notice of Potential Volcanic Hazard Issued

Meanwhile, seismologists at the University of Nevada were independently observing the anomalous signatures of the Mammoth Lakes earthquakes and amassing an impressive collection of data confirming that molten magma did indeed underlie Long Valley Caldera and suggesting that it was sufficiently mobile not only to be rising en masse, but also to be locally injecting the cauldron block at shallow levels. Although the results of these investigations were first presented at a meeting of the Seismological Society of America held in March 1982, the implications were not fully appreciated until presented a second time at a workshop on continental scientific deep drilling organized by the Department of Energy and Sandia National Laboratory and serendipitously held in Mammoth Lakes on May 4 to 7, 1982. Attended by about 60 scientists with diverse backgrounds, the workshop had little to do with hazards; rather, it was focused primarily on understanding the nature of magma chambers and their associated hydrothermal systems, which have applications in harnessing geothermal energy and exploration for volcanogenic ore deposits.

At this workshop, the University of Nevada Seismological Laboratory revealed that (1) during the past 2 years since the Mammoth Lakes earthquake swarm of May 1980, earthquakes had become increasingly frequent within the south margin of Long Valley Caldera, (2) one particular epicentral area about 2 miles east of Mammoth Lakes was persistently more active than other areas, and (3) the depth of shallowest earthquakes in this area had crept closer to the surface from about 5 miles in June 1980 to about 3 miles in October 1981. In addition, it was reported that during winter 1981-82, new fumaroles had broken out at Casa Diablo, a nearby solfaric area. Furthermore, they noted that the earthquakes in this particular area were accompanied by



Sketch map of Long Valley Caldera showing the location of geodimeter lines measured to detect horizontal changes in distance between stations on and around the resurgent dome.



Sketch map of Long Valley Caldera showing the location of surveyed level lines used to detect changes in ground elevation associated with uplift of the resurgent dome.

"spasmodic tremors," a seismic phenomena commonly associated with active volcanoes and considered to be the result of rock fracture caused by the pressure of intruding magma or of gas released from it. These revelations prompted considerable concern among Geological Survey volcanologists present, particularly those from the Cascades Volcano Observatory familiar with the activity at Mount St. Helens. That concern was dramatically heightened on May 7, the last day of the workshop, when departing scientists were awakened by a swarm of moderate earthquakes. A telephone call from the University of Nevada Seismological Laboratory indicated that the quakes were located at the persistently active epicentral area just east of Mammoth Lakes and were now at a depth of only 2 miles! A second swarm of earthquakes, including one of magnitude 4.2, later that evening precipitated a meeting of Geological Survey volcanologists and University of Nevada seismologists at the U.S. Forest Service's Visitor Center where careful reviews of seismograms and prolonged discussions led to concurrence that a small offshoot, or tongue of magma, was intruding fractures beneath the southern edge of the caldera and that it could potentially reach the surface and produce an eruption within the foreseeable future. This conclusion was reinforced by the knowledge that the earthquakes in the Mammoth Lakes area tended to be seasonal; earthquakes are relatively infrequent during the winter months and increased to a maximum during the summers. That the May 7-8 swarm was the first of the 1982 summer season and one of the strongest in the previous 2-year interval lent some urgency to beginning additional monitoring activities, as well as to the need to provide some form of warning of the potential hazard to the local inhabitants.

During the following 2 weeks, a succession of meetings and review sessions were held at Geological Survey centers in Menlo Park, California, Vancouver, Washington, Denver, Colorado, and Reston, Virginia, during which time a formal *notice of potential volcanic hazard*, the lowest level of warning issued by the Geological Survey, was prepared and finally released on May 27, 1982.

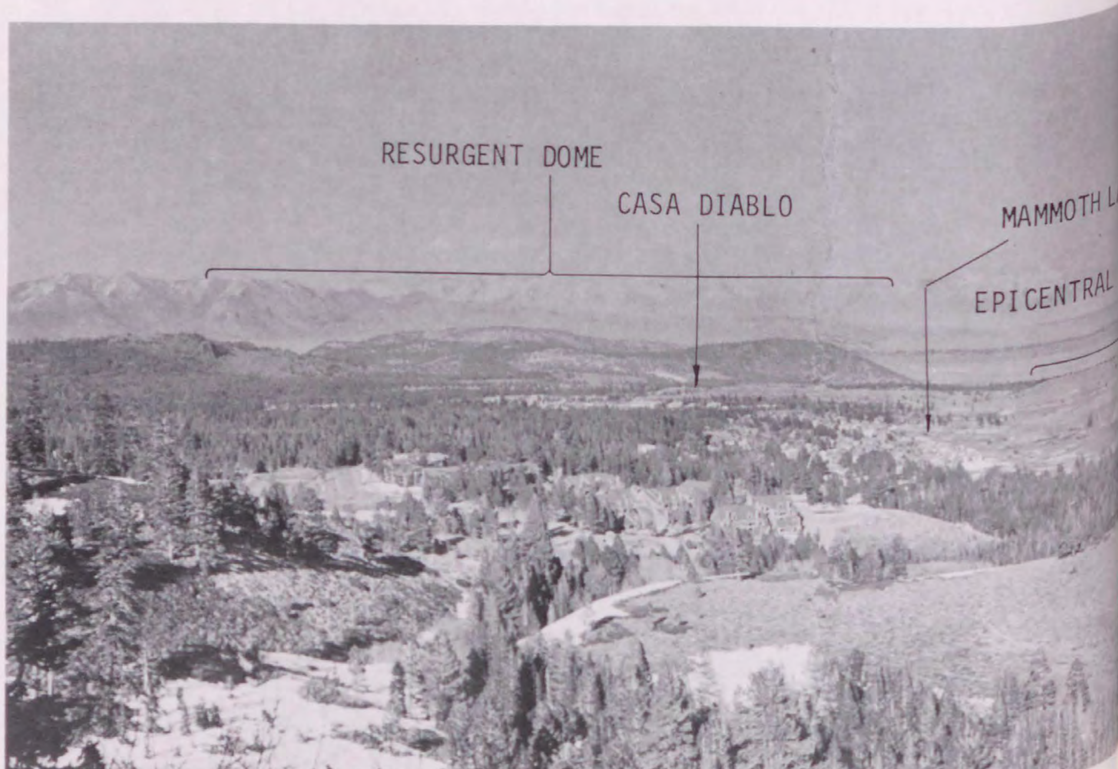
View southeastward of the south moat of the Long Valley Caldera from a hill on the resurgent dome overlooking the Casa Diablo epicentral area (bracketed by arrows) where frequent earthquakes have occurred since May 1980. The steep slope rising to the high Sierra Nevada peaks of Mount Morgan, Mount Morrison, Laurel Mountain, and Bloody Mountain (from left to right on the skyline) forms the south wall of the caldera. U.S. Route 395 arcs through the left center of the photograph.

Monitoring Activities Expanded

Even before release of the volcanic hazards notice, the Geological Survey began intensifying its monitoring activities in the Long Valley-Mammoth Lakes area. The seismic network deployed by the University of Nevada Seismological Laboratory, with funding from the Geological Survey, was reconfigured to better determine the location and depth of earthquakes in the Mammoth Lakes epicentral area, and, over the following several weeks, additional seismic stations were added to the network. Arrangements were also made at the Geological Survey's Menlo Park Center to automate seismic computations so that analysis of the data from all the stations could be done in real time (that is, at the actual instant the data were being measured).

Within days after the shallow May 7-8 earthquake swarm, a crew from the Cascades Volcano Observatory established four dry-tilt stations on the flanks of the Long Valley resurgent dome and a fifth station near the Mammoth Lakes epicentral area to supplement the leveling and geodimeter trilateration surveys that were to be undertaken in June. Later in July, four additional tilt stations were added in the vicinity of the epicentral area by the University of California, Santa Barbara. In addition, hydrogen gas sensors were immediately installed, one on the resurgent dome and another on the southern edge of the caldera, to detect changes in hydrogen emissions that might foretell of further rise of the magma. Data from these continuously recording sensors are radiotelemetered to the Forest Service's Mammoth Lakes Visitor Center and thence relayed via GOES satellite to the National Oceanic and Atmospheric Administration-National Environmental Satellite Service's Wallops Island, Virginia, receiving station, where it can be retrieved by telephone from any Geological Survey center in the country. In the near future, data from continuously recording borehole tiltmeters will be similarly transmitted via satellite to Geological Survey centers.

By early June, a surveying crew from the Geological Survey's National Mapping Division was in the field beginning the long painstaking task of remeasuring the 60 miles of level lines established in 1975 and adding 40 miles of new lines across the resurgent dome and elsewhere within the caldera to better define the pattern of uplift since 1980. Before the end of the summer, they were joined by a Los Angeles Department of Water and Power surveying crew, which greatly speeded the work. At the same time, the Geological Survey's Water Resources Division Subsidence Research Group began



View of the southern margin of the Long Valley Caldera showing the location of Mammoth Lakes, the Casa Diablo fumarole area, the epicentral area of the 1980–82 seismic activity, and the resurgent dome of the caldera.

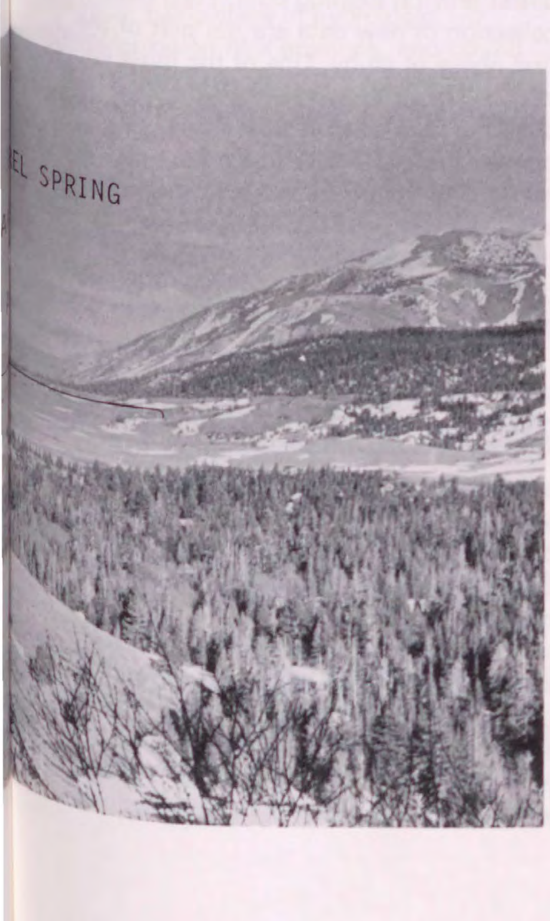
reoccupying the 1975 trilateration (geodimeter) network previously occupied in 1978 and adding additional stations to provide better coverage of horizontal changes accompanying uplift of the resurgent dome. In late August, they returned to reoccupy the network a second time, aided by helicopter support provided by Los Angeles Department of Water and Power.

During the course of the summer, previously established Geological Survey gravity and magnetic surveys were expanded within the caldera and elsewhere in the region to help substantiate measured elevation changes and to detect other possible physical changes accompanying the rise of the magma.

In addition to these Geological Survey monitoring activities, many other organizations, including the California Division of Mines and Geology, and many university teams joined in the monitoring and research effort to better understand the causes and possible consequences of the rising and quaking landscape.

Uncertainties About the Future Affect Scientists and Local Citizens Alike

By the end of summer 1982, a clearer, but still incomplete, picture of the activity began to emerge. By late August, it was clear that uplift of the resurgent dome was continuing but at a slower rate than in the previous 2 years. Lateral spreading of the dome, however, seemed to be going on at about the same or even somewhat faster rate. At the same time, the uplift, which initially extended well beyond the margins of the caldera, was now confined within the caldera. Most puzzling was a sudden decline in frequency of earthquakes at the Mammoth Lakes epicentral area and the complete cessation of spasmodic tremor. However, small earthquakes continue in a diffuse zone peripheral to the resurgent dome along what is most likely the caldera ring fracture.



Has the tongue of magma beneath the epicentral area ceased rising toward the surface, or is it only taking a "breather"? Is the decline in seismicity a comforting sign, or is it just "the calm before a storm"? Is the magma chamber responding to regional tectonic forces, or are independent chemical and physical processes going on within causing it to rise and generate earthquakes? All are critical questions that will be answered by continued monitoring. However, it is a very slow and painstaking process. The hope is that the results obtained will provide enough insight to give adequate warnings, if more serious activity should develop.[1]

Meanwhile, the citizens and public officials of Mammoth Lakes and neighboring communities are taking no chances. Spurred by the admonition to "Prepare for the worst, and hope for the best" voiced at a volcanic hazards workshop, which was held in Mammoth in late August and was jointly organized by the California Office of Emergency Services, the California Division of Mines and Geology, and the U.S. Geological Survey, they are going about business as usual in the midst of their winter ski season.

[1]From January 6 to 9, 1983, an unusually large earthquake swarm in the south moat of the Long Valley Caldera included three successive shocks of magnitude 5.1, 5.6, and 5.0 and was interspersed among thousands of quakes of lesser magnitude. This swarm indicates that earthquake and potential volcanic hazards are a continuing concern in the Mammoth Lakes area.

Use of the Geohydrologic Environment for High-Level Radioactive Waste Disposal

By George Dinwiddie

Deeply buried repositories in specially constructed mines offer several properties suitable for disposal of high-level radioactive waste. Principal among these properties are adequate shielding, isolation from the accessible environment, absorption and dispersion of heat generated by the radioactive waste, and protection from intrusion by man. The potential for migration of high-level radioactive wastes from the repository demands that attention be given not only to selection of a suitable host material for the waste—the rock in which the respository is to be constructed—but also to selection of the geohydrologic environment of the repository. Ideally, the geohydrologic environment best suited for a high-level radioactive waste disposal site would have all of the natural barriers to waste movement. These barriers include the following:

- Rock through which water moves very slowly (low permeability);
- Ground-water flow away from the biosphere;
- Slow rates of ground-water movement;
- Long flow paths to points readily accessible to humans;
- Deep water table;
- Low rainfall;
- Strong host rock with few fractures;
- Small probability of seismic or volcanic activity;
- Slow rate of erosion;
- Ground-water chemistry favoring low radionuclide solubility; and
- High capacity for adsorption (sorption) or ion exchange of waste radionuclides.

In view of the numerous combinations that are possible among the various natural barriers, the identification of suitable geohydrologic environments dictates that site selection for a high-level radioactive waste repository be approached using systems analysis. The process used by the U.S. Geological Survey is described below.

The Geological Survey's program for identifying environments potentially suitable for locating acceptable repository sites was an outgrowth of a plan developed jointly with the U.S. Department of Energy, which has the responsibility for selecting, building, and operating the repositories. The Geological Survey's effort, one of its most important applied studies, is aimed at assisting in solving the Nation's dilemma in selecting high-level radioactive waste disposal sites. Although this is a Geological Survey study, there is active participation by earth scientists from the particular States involved.

The screening process consisted initially of identifying 11 provinces in the conterminous United States (see fig. 1) for evaluation. According to the plan, a province is successively divided into smaller land units which are ranked: first, regions (10^3-10^5 square miles); second, areas (10^2-10^3 square miles); and, ultimately, potential sites (about 10 square miles). At each stage, the screening process involves geologic and hydrologic description and evaluation of the land units with respect to preestablished guidelines for radioactive waste isolation.

Initial screening, province evaluation, is based only on existing data. Field work and collection of new data are not part of the first phase of study. One of the most important criteria in the screening process is the occurrence of suitable host rocks. The primary factors in selecting a host rock are mineability, thermal conductivity, frequency and extent of permeable fractures, permeability, thickness, areal extent, depth of burial, homogeneity, sorption capacity, and other geochemical properties.

The principal candidates presently being considered are crystalline rocks, such as granite and gneiss; salt formations, either bedded salt or salt domes; basalt; tuff; argillaceous (clayey) formation; and unsaturated valley-fill sediments. These candidate host rocks are distributed widely, though unevenly, throughout the conterminous United States.

The other most significant factor considered in characterizing a province is ground-water flow systems. Assuming that a repository will be located in an area unlikely to be affected by earthquakes, volcanoes, and so forth, and that the risk of exhuma-

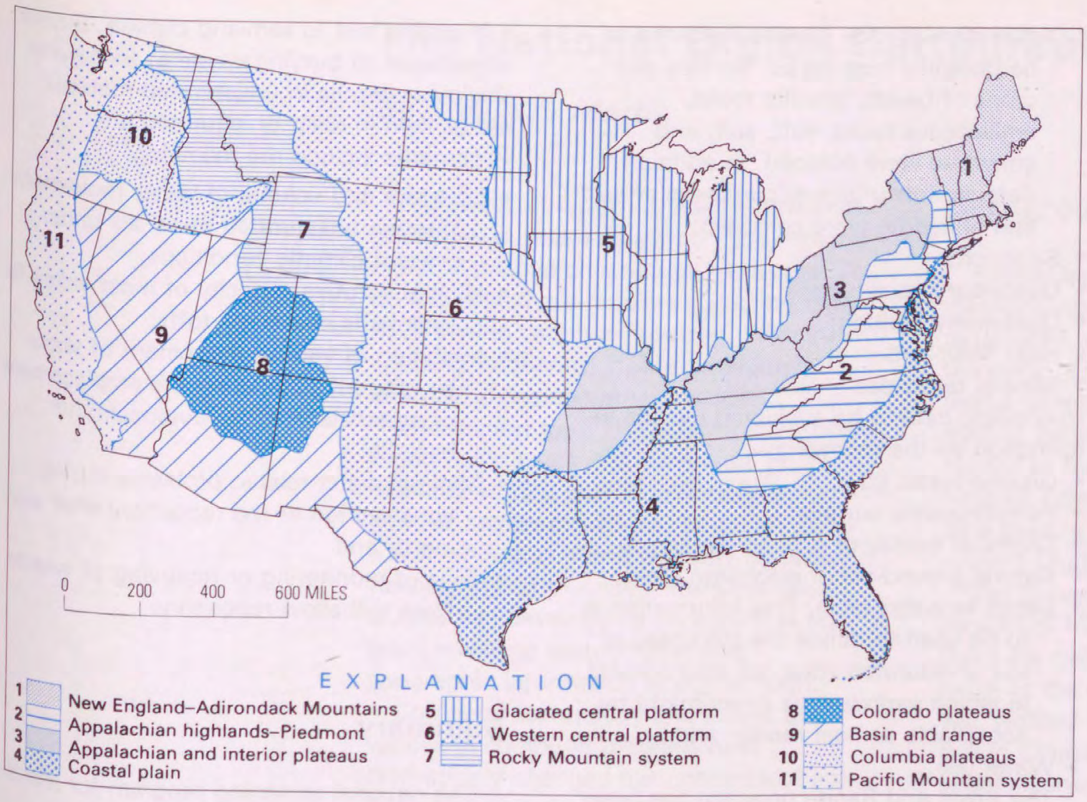


Figure 1.—*Provinces of the conterminous United States selected for screening.*

tion of wastes by erosion, catastrophic event (for example, meteorite impact), or intrusion by man is minimal, it is generally acknowledged that the single most likely means by which radionuclides could reenter the biosphere is by way of ground water. Definition of these flow systems is one of the most basic steps in hydrologic characterization of a province, and boundaries between the various flow systems are the basis for the division of a province into regions.

The components most basic to delineating ground-water flow systems are potentiometric head (the level to which water will rise in a tightly cased well that taps a particular rock unit), geology, geochemistry and temperature of ground-water recharge and discharge zones, and water quantities of water inflow, storage, and outflow. Potentiometric head is usually the most significant of these factors in defining ground-water flow within a system and in delineating system boundaries. Geology is necessary to defining ground-water flow systems because the rocks are the framework within which the system operates. Geochemistry and temperature of the ground water are indicators of the history of the ground water before it reaches the observation point; they may also control leaching and chemical reactions of waste nuclides.

The Basin and Range province (province 9 in fig. 1) was selected for a prototype study to determine the feasibility of the screening procedure. This province appeared to be suitable for such a study because it offered a large variety of geologic conditions and because the Geological Survey has been studying the geology of the province for many years.

A Province Working Group, composed of earth scientists from the Geological Survey and the States, was established. The States that are formally participating in the province screening program are Arizona, Idaho, Nevada, New Mexico, Texas, and Utah. Oregon is kept informed of progress, and California is participating informally.

Province screening was based initially on information available from published reports and files. It was recognized that availability of data would be inconsistent throughout the province and that lack of information might preclude evaluation of some parts of the province. Coincidentally, it was recognized that all available geologic and hydrologic data could not be compiled and assimilated during the first phase of province evaluation.

Basic factors selected for province evaluation were the distribution of potential host rocks, tectonic stability, and ground-water hydrology. Geologic data to be evaluated include information on the following:

- Distribution of rock types considered to be potential host rocks. Surface outcrops of basalt, granitic rocks, argillaceous rocks, tuff, salt, and anhydrite were mapped. In addition, data on subsurface occurrences of salt and anhydrite were compiled;
- Seismicity;
- Quaternary volcanism;
- Quaternary faulting;
- Heat flow; and
- Mineral resources.

Hydrologic data to be evaluated include information on the following:

- Ground-water flow;
- Potentiometric surface;
- Chemical quality of ground water;
- Natural ground-water discharge areas;
- Depth to water table. This information is to be used to define the thickness of the unsaturated zone, an environment in which various rock types might be acceptable as host media; and
- Water use.

The Basin and Range province has been subdivided into regions, and those considered most suitable will be described and evaluated. Initial evaluation of characteristics of the Basin and Range indicates that about 40 percent of the province appears to be worthy of further attention. The second phase of evaluation will focus more on the identification and evaluation of specific geohydrologic barriers in the subsurface. This effort will result in identification of areas where further more intensive study appears warranted.

As mentioned earlier, depth to water (or thickness of the unsaturated zone) is one factor considered in screening the Basin and Range province. Disposal of high-level radioactive waste in thick and relatively dry unsaturated rock units, principally valley fill and volcanic tuff, appears to offer an economical and workable alternative to burial in deep or saturated geologic formations. The Basin and Range province has some of the thickest accumulations of unsaturated materials in the United States and a favorable arid to semiarid climate. Several advantages of burying waste at somewhat shallower depths in unsaturated material rather than in deep or saturated environments include the following:

- Low rate and volume of water movement through unsaturated materials under present climatic conditions;
- High absorptive capacity of most valley-fill sediments and some tuffs;
- Inhibition of vertical movement of water by properly enginering the emplacement of materials used for overpack and backfill;
- Minimal water-related problems during construction of the repository after sealing it; and
- Ease of monitoring or removing of wastes from a shallow repository.

Summary

The national screening program for identifying potentially suitable disposal sites allows for a systematic consideration of the effects of waste disposal by focusing geologic and hydrologic expertise on the problem at the primary stage. This type of systematic approach assures not only that the most suitable areas will be considered but also that potentially suitable areas are not likely to be overlooked. Although the systematic nature of the screening program probably precludes its contributing significantly to selection of the site for the first repository, the ongoing program and the program methodology should be useful in the selection of subsequent sites. A screening program based on nongeologic factors, such as socioeconomic considerations, is also important in choosing areas for further study to select a site for disposal of radioactive waste. Such a program will be managed by the U.S. Department of Energy and its contractors for the Basin and Range province.

The National Digital Cartographic Data Base

By Sheila E. Martin

Digital cartography provides a new computer-based means to support the management of the Nation's natural resources. To do this effectively requires collecting data from a wide variety of sources. With increasing frequency, this information is analyzed using computer models.

Information from U.S. Geological Survey topographic maps is fundamental in resource studies that require geographic control, terrain elevations, boundary portrayal, and stream and highway patterns. Responding to this need, the Geological Survey has developed a considerable program involving cartographic and geographic information in digitial form.

Computer technology and recent advances in computer graphics have dramatically changed our concepts of collecting and communicating map information. Digital cartography will soon surpass the major advances in mapping that resulted from developments in printing and photography during the late 19th century and in aerial photographic surveying and photogrammetry in the early 20th century. Maps produced by automatic plotters using digitial data are equal or superior in accuracy and graphic quality to those produced by manual techniques. Automated techniques can use the same data at varying graphic scales and formats and can provide for a wide variety of applications. Automation is less expensive.

Although the method of portraying terrain information in the form of a topographic map will still be used for many decades, the format and portrayal of map information are changing. Images presented on the cathode ray tube, where scale and viewing direction can be rapidly changed, have already replaced traditional printed maps for many applications. In applications such as weather reporting, where up-to-the-minute data are necessary, high-resolution images can be obtained instantly through commands to an orbiting satellite.

Background

Recognizing that traditional cartographic methods would someday be replaced by automated techniques, the Survey began in the early 1970's to conduct research in digital cartography and automated mapmaking techniques. By 1977, the Survey had started to focus on the development of a national cartographic and geographic digital data base, a major component of the present Digital Cartography Program.

The Survey has digitized considerable data from 1:24,000-scale maps, but, because there are over 54,000 different 1:24,000-scale maps of the conterminous United States, it was realized that digitizing all these maps would exceed the resources available. (In addition, many requirements appeared for data covering large areas that could not be satisfied by existing small-scale data bases.) Therefore, the decision was made in 1978 to proceed with a national small-scale digital cartographic data base.

The first phases of the project have recently been completed. The 21 sectional maps of the *National Atlas of the United States of America*, at a scale of 1:2,000,000 (1 inch equals about 32 miles) portray a relatively high level of detail for this small scale (fig. 1). These maps are now available in digital form through the National Cartographic Information Center. Applications of the data for automated map production and computer analysis have begun.

Earlier Data Bases

Four earlier small-scale digital cartographic data bases have been used extensively. The Dahlgren data base was developed in the early 1960's. It is a global data base of coastlines and international boundaries digitized mostly from 1:12,000,000-scale maps using 8,300 coordinate points. The coastlines and the State boundaries of the United States were obtained from

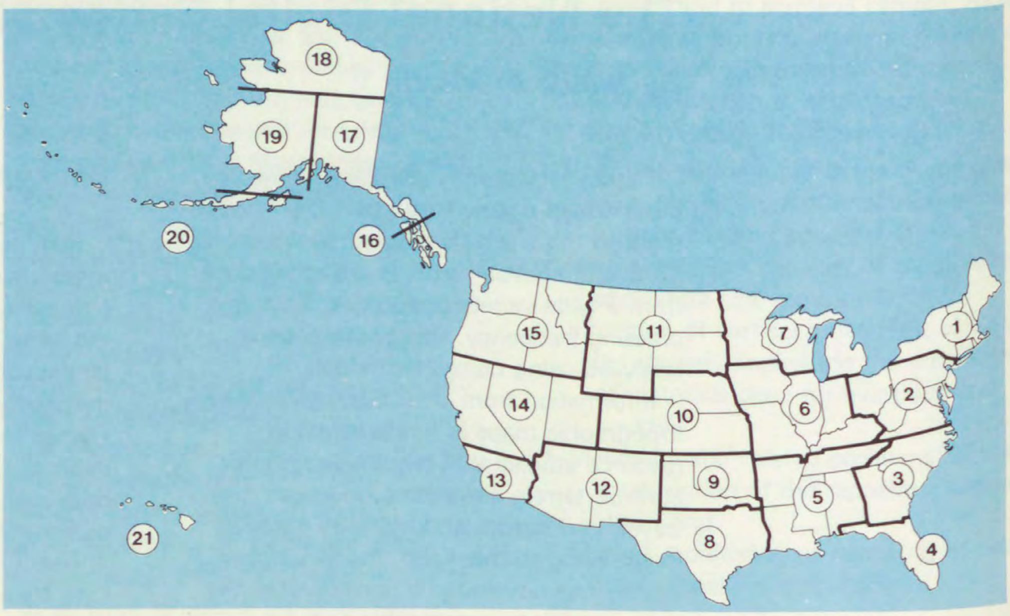


Figure 1.—*Index map showing location of 21 areas of 1:2,000,000-scale digital cartographic data available on computer tapes for the United States.*

1:1,000,000-scale maps. The data provide a general portrayal of the coastlines, countries, and States.

Another data base was developed in the mid-1960's by the Department of Transportation as a county boundary file of the United States. County and State boundaries, together with the coastline, were digitized from 1:5,000,000-scale maps using 115,000 coordinate points.

The World Data Bank I was developed by the Central Intelligence Agency in 1966. It contains world coastlines and international boundaries digitized from 1:12,000,000-scale maps using 100,000 coordinate points; the United States coastline is described by 20,000 points.

A second World Data Bank was completed in 1977 using source maps which ranged from 1:4,000,000 to 1:1,000,000 in scale. This data base contains country and State boundaries, coastlines, islands, lakes, rivers, and selected roads and railroads. The number of digitized points increased dramatically to 6 million. Source materials for the United States were digitized from 1:3,000,000-scale maps using 1.5 million points.

Some of the limitations associated with these earlier data bases are:

- The very small scale of the source maps used for digitization;
- The limited range of features digitized;
- The lack of current information;
- Data formats designed primarily for graphic applications;
- Limited flexibility for combining these data with other thematic data available in digital form.

Experience with these earlier data bases has shown that, while they meet their objectives, their content is not sufficient for all user applications (fig. 2).

The U.S. Geological Survey Small-Scale Data Base

The Survey's small-scale digital cartographic data base was prepared from an updated *National Atlas of the United States of America*. For comparison, World Data Bank I contained about 100,000 points and World Data Bank II had about 6 million points to describe the entire globe, while the Survey's small-scale data base has some 7 million points to describe the United States alone.

The content of the data base includes political boundaries (State and county level), Federal lands, transportation networks (roads and railroads), hydrographic features (streams and water bodies), and populated places. These data were entered into the computer in a format that records both the location of a feature and its relations with similar features on the source map. This format allows graphic applications, such as drawing streams and roads for automatic map plotting, as well as analytical applications, such as area calculations and verifying the data for consistency and accuracy. The format also permits automatic smoothing to produce maps at scales ranging from 1:2,000,000 to 1:10,000,000.

The data are available on computer tape in two formats. The standard format provides a useful geographic reference system for displaying a wide range of various types of data. It also supports producing color maps and performing area calculations. The second format is a less complex organization of data corresponding to the 21 areas of the *National Atlas* source maps. Information on boundaries, transportation, and hydrography is available for each area (fig. 3).

An important feature is that these small-scale data are ranked from the "most significant" feature to the "least significant." This scheme allows the user to select a minimal amount of data and gradually to increase this amount to the level of detail needed to support the theme and scale of the particular map. For instance, a user producing a map of 1:5,000,000 scale can exclude all rivers and streams less than 30 miles long. The data can also be grouped together in various ways to produce logical sets of information; an interstate highway system can be represented either by only those road segments actually classified as interstate roads or as a complete highway system made up of interstate roads and other roads which act as connectors.

Political boundary data are organized into international boundaries, State boundaries, and city and county boundaries. Federally administered lands, such as national forests, national parks, national wildlife refuges, and others, are classified by the length of their longest dimension. This allows the user to select the types of federally administered lands to be displayed and to control the amount of detail for each type selected.

Road and trail data are organized to display densities of connected networks,

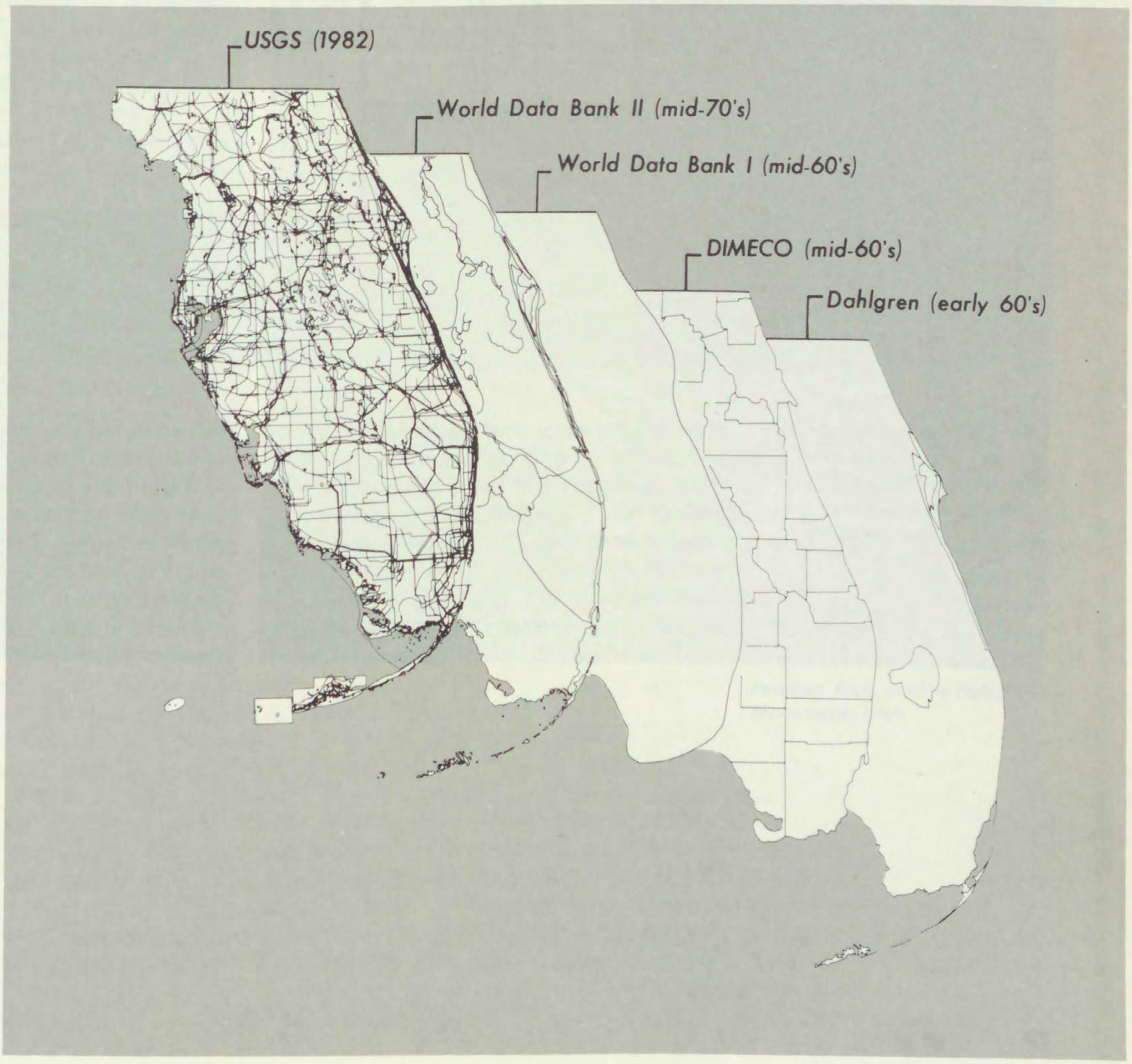


Figure 2.—*Comparison of level of detail contained in existing small-scale digital data bases for part of Florida, shown here at about 1:5,000,000 scale.*

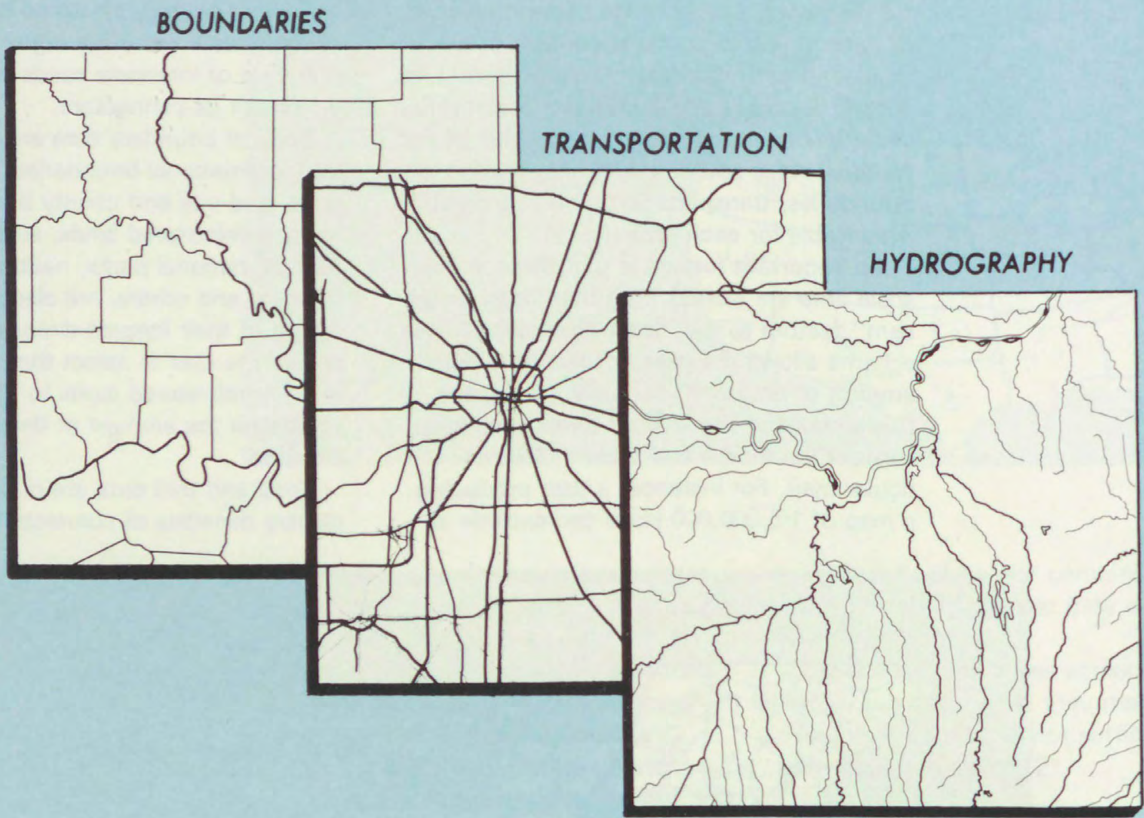


Figure 3.—*Comparison of the kinds of small-scale information available on computer tapes for each of the 21 areas shown in figure 1.*

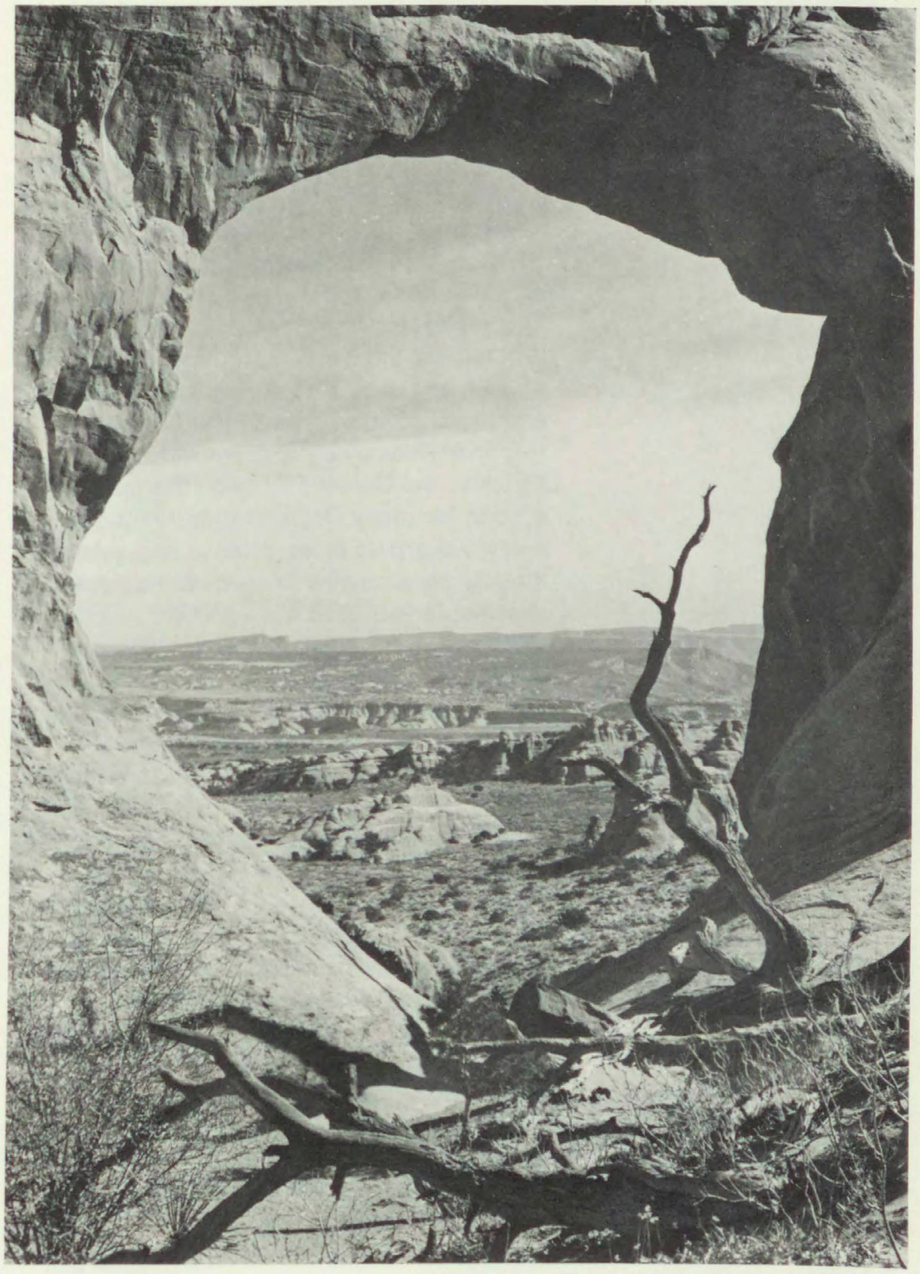
starting with major limited-access highways and continuing through major national and State routes to other roads and trails. The railroad data are organized by annual tonnage, starting with a connected network of the primary rail routes. Stream data are organized by length, beginning with the longest stream drainage for an area. Stream segments are also identified as perennial, intermittent, or canal.

Water-body features are organized in a way similar to that used for federally administered lands. They are classified by length so that the user may select from the different types of water bodies to be displayed and also control the detail for the types of water bodies chosen.

Potential Petroleum Reserves

An assessment of potential petroleum reserves in existing or designated wilderness areas of the Western United States is being assisted through the use of small-scale digital cartographic data. Map data portraying the boundaries of these wilderness areas, underlying geological formations, and previously delineated resource areas have been digitized and correlated by using computer techniques. These data, merged with data on petroleum production on adjoining lands, will enable petroleum geologists to develop meaningful estimates of potential reserves in the wilderness lands.

The promising results from this petroleum study show that small-scale digital cartographic data provide an important framework for the analysis of natural resources of federally owned lands. Because of this, the Geological Survey is giving high priority to the development of a national Digital Cartographic Data Base covering all Federal lands. The data formats are designed to provide the capability of analyzing a variety of data on other natural resources.



Partitian Arch, Arches National Monument, Utah.

Missions, Organization, and Budget

Missions

The U.S. Geological Survey was established by an act of Congress on March 3, 1879, to answer the need for a permanent government agency at the Federal level to conduct, on a continuing, systematic, and scientific basis, the investigation of the "geological structure, mineral resources and products of the national domain." A number of laws and executive orders have expanded and modified the scope of the Survey's responsibilities over its 100-year history. Notably, the Survey has been the nurturing ground for many Departmental functions that have grown in importance and subsequently became new bureaus to address specific Federal land management responsibilities. The Bureau of Mines, Bureau of Reclamation, and, most recently (1982), the Minerals Management Service are prominent examples of major organizations in the Department of Interior that have had their origins in the Survey. With these organizational changes, the Survey has served to add a scientific dimension to the performance of many major Department responsibilities. The Survey remains the principal source of scientific and technical expertise in the earth sciences within Interior and, beyond that, within the Federal government. This *Yearbook* provides highlights of the wide range of earth science research and services in the fields of geology, hydrology, and cartography. Together they represent the continuing pursuit of the long-standing scientific missions of the Survey.

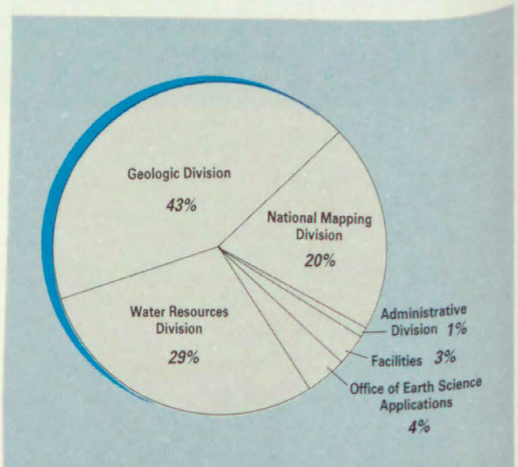
Organization

The U.S. Geological Survey is headquartered in Reston, Virginia. Its activities are administered through three major program divisions (National Mapping, Geologic, and Water Resources). These program operations are serviced by two major support divisions (Administrative and Information Systems). The Survey conducts its functions through an extensive field organization of offices located throughout the 50 States and Puerto Rico. At the national level, the functions of the Survey are coordinated through six Assistant Directors acting in the area of administration, program analysis, research, information systems, intergovernmental affairs, and engineering geology.

Budget

In fiscal year 1982, the U.S. Geological Survey had obligational authority (including the Minerals Management Service) of $661.8 million, of which $510.0 million came from direct appropriations and $151.8 million from reimbursements. The Survey received funds under two congressional appropriations, "Exploration of National Petroleum Reserve in Alaska" ($2.2 million), and "Surveys, Investigations, and Research," which is the traditional source of direct funding for all other Survey activities ($507.8 million, including the Minerals Management Service). The Survey also received funds for reimbursements for work performed under agreements with Federal agencies, State and local governments, international organizations, and foreign governments. The Survey performs services under these agreements when earth science expertise is

Percentage allocation of funds, by Division.



U.S. Geological Survey obligations for fiscal year 1982, by activity

[Dollars in thousands]

Activity/Subactivity/Program Element	Fiscal year 1982[1] enacted
Surveys, Investigations, and Research—National Mapping, Geography and Surveys	**77,687**
Primary Quadrangle Mapping	**38,178**
Primary Quadrangle Mapping	34,202
Modernization of Mapping Technology	3,976
Map Revision and Orthophotoquads	**16,396**
Revision	10,146
Orthoquads	6,250
Digital Mapping	**3,873**
Small, Intermediate, and Special Mapping	**15,388**
Intermediate-Scale Mapping	6,804
Land Use and Land Cover Mapping	3,461
Airborne Profiling of Terrain System	2,592
Small-Scale and Other Special Mapping	2,531
Cartographic and Geographic Information	**3,852**
Geologic and Mineral Resource Surveys and Mapping	**163,731**
Geologic Hazards Surveys	**48,547**
Earthquake Hazards Reduction	32,992
Volcano Hazards	9,664
Ground Failure and Construction Hazards	2,785
Reactor Hazards Research	3,106
Land Resource Surveys	**16,476**
Geologic Framework	13,320
Geomagnetism	2,139
Climate Change	1,017
Mineral Resource Surveys	**39,302**
Alaska Mineral Surveys	8,924
Conterminous U.S. Mineral Surveys	5,131
Wilderness Mineral Surveys	8,583
Strategic-Critical Minerals	4,542
Development of Assessment Techniques	12,017
Mineral Discovery Loan Program	105
Energy Geologic Surveys	**38,148**
Coal Investigations	12,901
Onshore Oil and Gas Investigations	7,032
Oil Shale Investigations	2,304
Geothermal Investigations	8,064
Uranium-Thorium Investigations	6,878
World Energy Resource Assessment	969
Offshore Geologic Surveys	**21,258**
Offshore Oil and Gas Resources	11,350
Energy-Related Environmental Investigations	8,448
Marine Geology Investigations	1,460

U.S. Geological Survey obligations for fiscal year 1982, by activity—Continued

Activity/Subactivity/Program Element	Fiscal year 1982[1] enacted
Water Resources Investigations	**108,637**
National Water Data System—Federal Program	**48,100**
Data Collection and Analysis	14,833
National Water Data Exchange	1,257
Regional Aquifer Systems Analyses	14,872
Coordination of Water Data Activities	898
Core Program Hydrologic Research	5,996
Improved Instrumentation	1,944
Subsurface Waste Storage	1,461
Flood Hazards Analysis	460
Water Resources Assessment	337
Supporting Services	3,599
Toxic Wastes-Ground Water Contamination	958
Acid Rain	1,485
Federal-State Cooperative Program	**45,012**
Data Collection and Analysis, Areal Appraisals and Special Studies	38,541
Water Use (Cooperative)	3,334
Coal Hydrology (Cooperative)	3,137
Energy Hydrology	**15,525**
Coal Hydrology	7,564
Nuclear Energy Hydrology	6,673
Oil Shale Hydrology	1,288
Earth Sciences Applications	**14,359**
Earth Resources Observation Systems	12,058
Environmental Affairs	1,457
Land Resources Data Applications	844
General Administration	**3,407**
General Administration	2,525
Employee Compensation Payment	882
Facilities	**10,098**
National Center—Standard Level Users' Charge	8,467
National Center—Facilities Management	1,631
TOTAL, Surveys, Investigations, and Research	**[2]377,919**
Exploration of National Petroleum Reserve in Alaska	**2,196**
Barrow Area Gas Operation, Exploration and Development	**2,196**
Operation and Maintenance	—
Exploration and Development	—
TOTAL, U.S. Geological Survey	**$380,115**

[1] Funding shown represents appropriations under "Surveys, Investigations, and Research" only and does not include other sources of funding such as reimbursements from other Federal or State organizations.

[2] Excludes $129,868 for Minerals Management Service.

required by other agencies and their needs complement its program objective. Work done for State, county and municipal agencies is almost always done on a cost-sharing basis.

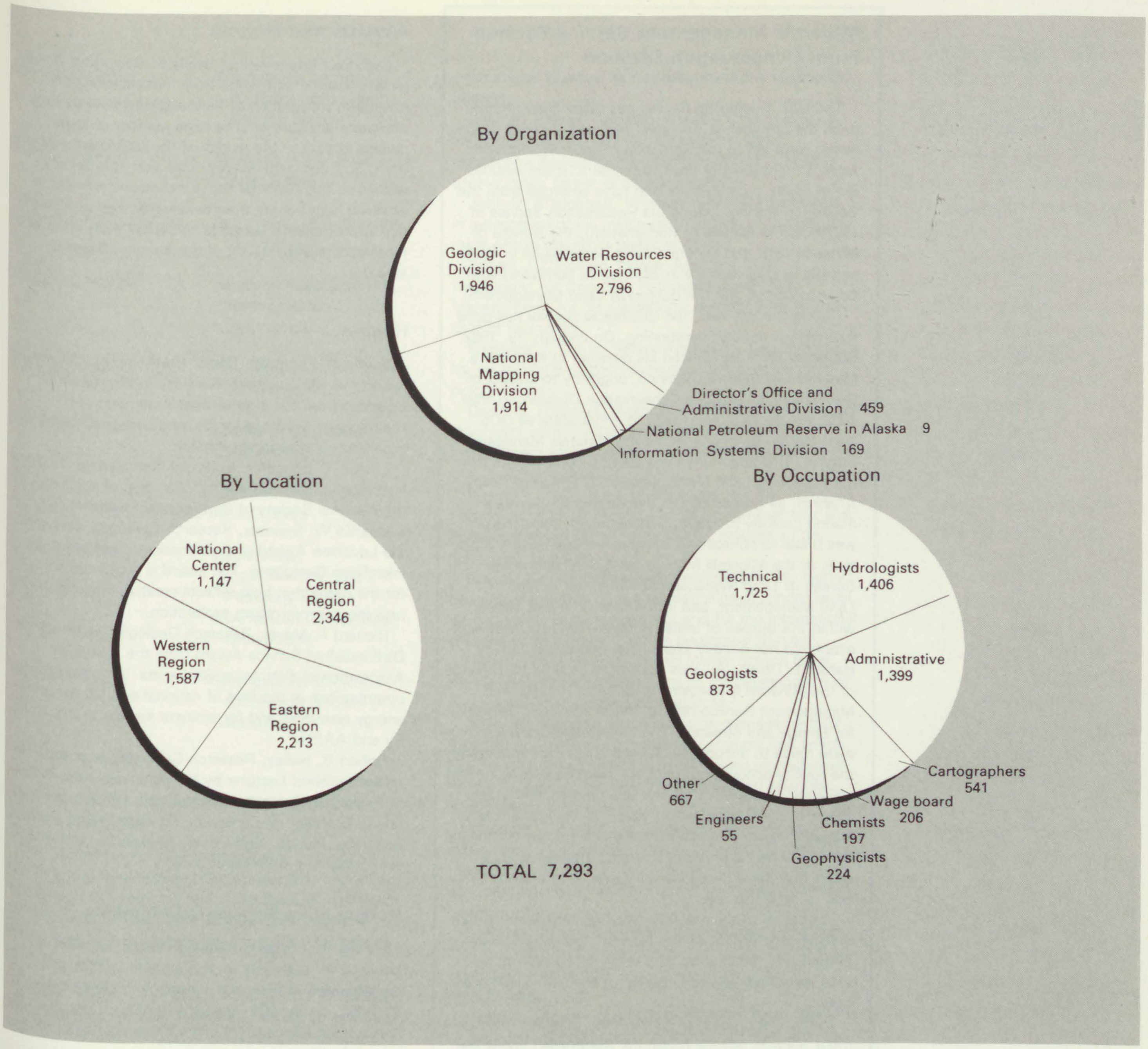
Most of the funds received by the Survey in fiscal year 1982, both appropriations and reimbursements, are distributed through budget activities that roughly correspond to its mapping, geologic, hydrologic, information transfer, administration, facilities, and regulatory areas of responsibility. During fiscal year 1982, the "Conservation of Lands and Minerals" activity ($129.9 million) in the "Surveys, Investigations, and Research" account functioned under the name "Minerals Management Service." In fiscal year 1983, portions of Offshore Geology and the support organizations will be transferred to the new Minerals Management Service which will have, given Congressional approval, its own appropriation account.

Personnel

At the end of fiscal year 1982, the U.S. Geological Survey had 7,293 permanent full-time employees on board, a decrease of 2,145 from fiscal year 1981. Most of this decrease was associated with the transfer of personnel to the Minerals Management Service. More than one-half of the Survey's permanent full-time staff are professional scientists, and approximately one-fourth are technical specialists. Hydrologists and geologists predominate among the professional group, which includes members of more than 30 other disciplines, such as geophysicists, cartographers, chemists, and engineers.

The Survey's work has been accomplished with a virtually level full-time work force since 1973; moderate increases in the Geologic Division and the support Divisions have been offset by decreases in the National Mapping and Water Resources Divisions. The additional workload on these scientifically oriented components has been supported in part by the rapid expansion in the use of grants and contractual services and, in part, by the extensive use of temporary and part-time personnel.

The number of these other-than-full-time permanent employees has more than doubled since 1973 and includes many students and faculty members from colleges and universities and summer hires from various categories. The Survey has profited greatly from its association with the academic community. The expertise of many eminent specialists has become available to the Survey in this manner and has given it great flexibility in solving problems and meeting surges in its workload, especially during the field season. The relationship also has been an invaluable channel for recruiting young professionals of demonstrated ability for permanent full-time positions upon the completion of their studies.



Permanent full-time U.S. Geological Survey employees.

Minerals Management Service Formed From Conservation Division

The U.S. Geological Survey has often been referred to as the "Mother of Bureaus" because many of its activities have led to the formation of new organizations when a managerial or developmental function evolved. Some of the organizations that have emerged from the Geological Survey include the Reclamation Service in 1901(now the Bureau of Reclamation), the Bureau of Mines in 1910, the Federal Power Commission in 1920, and the Grazing Service in 1934 (since combined with other functions into the Bureau of Land Management).

During the last year, the Geological Survey has gone through yet another partitioning. On January 19, 1982, Secretary Watt announced his decision to establish a Minerals Management Service, originally to consist of the Geological Survey's Conservation Division. In May 1982, the decision was made to consolidate all OCS lease-related functions within the Minerals Management Service. This action involved moving components from the Bureau of Land Management and Office of Policy Analysis, as well as part of the Geological Survey's marine geology program. Subsequently, the decision was made to consolidate onshore mineral-leasing functions of the Minerals Management Service and the Bureau of Land Management within the Bureau of Land Management, and in the case of Indian Lands, within the Bureau of Indian Affairs. However, this later action did not directly impact the Geological Survey. Harold E. Doley, Jr., was appointed as the first Director of the Minerals Management Service. The Minerals Management Service reports to the Assistant Secretary for Energy and Minerals. The Secretary's decisions were made to accomplish several objectives: strengthen the royalty-accounting function; streamline lease-related activities; and strengthen the scientific capability and image of the Geological Survey. The Secretary has stated on several occasions his desire for the Geological Survey to be his principal scientific advisor. It is his belief that these decisions will place us in a better position to fulfill this role.

Formation of the Minerals Management Service had a significant impact on the Survey. The total Survey budget was reduced by 29 percent ($150 million) and total personnel was reduced by 23 percent (2,400 positions).

During the process of forming the Minerals Management Service, several questions were raised about the division of responsibilities. The marine geology question has been specifically addressed, and the decision was made that the Geological Survey will retain the responsibility for marine geologic research to include, among other things, regional geologic studies and hazards evaluation and assessment of potential seabed mineral resources.

Formation of the Minerals Management Service should permit the Geological Survey to focus more clearly on its principal mission as defined in the Organic Act of 1879, which is "to classify the public lands, examine the geologic structure, mineral resources, and products of the national domain. . . ." The Geological Survey looks forward to fulfilling this traditional role as well as to cooperating with the Minerals Management Service and the Bureau of Land Management in their new undertaking.

Awards and Honors

Each year employees of the U.S. Geological Survey receive awards that range from modest monetary awards to recognition of their achievements by large professional societies. The large number of these awards attests to the quality of the individuals who are the U.S. Geological Survey. This year, the Survey wishes to acknowledge those individuals who either received high honors from or were elected to high office in professional societies and those individuals who received the Department of the Interior's highest award.

Honors

Walter B. Langbein, Senior Staff Hydrologist, received the 1982 International Prize in Hydrological Sciences from the International Association of Hydrological Sciences for his long career of scientific excellence and accomplishment.

Francis T. Schaefer, Assistant Northeastern Regional Hydrologist, was named the "Engineer of the Year" by the National Society of Professional Engineers.

Charles W. Spencer, Research Geologist, was given the Levorsen Award of the American Association of Petroleum Geologists. The award is presented annually for the paper that best reflects creative thinking toward new ideas in petroleum exploration.

Richard F. Meyer, Research Geologist, received the Distinguished Service Award from the American Association of Petroleum Geologists "for outstanding contributions in the field of national and international energy resources and for eminent service to this country and AAPG."

Robert B. Halley, Research Geologist, was appointed a Distinguished Lecturer by the American Association of Petroleum Geologists. His lecture, which was entitled "Evolution of Carbonate Porosity During Burial—Bahamas, Florida, Gulf Coast, Jurassic to Holocene," was presented at 10 institutions.

Honors From Foreign Governments

George E. Ericksen, Research Geologist, was honored for this work in geology and institutional development in Peru at a ceremony in Lima on March 22, 1982, on the 80th anniversary of the Cuerpo do Ingenieros de Minas, Peru's first national geological/mining institute.

Presidents of Professional Societies

Service in professional societies is one of the important professional contributions a scientist can make. Societies play a fundamental role in the distribution of new knowledge, in addition to providing a forum in which new ideas are tested. The active participation of Survey scientists in professional societies attests to the scientific vitality of the Bureau. The Bureau is particularly proud of those individuals who have been elected to society presidencies by their professional peers. They includes the following:

Bruce R. Doe	Geochemical Society of America;

Frederick J. Doyle	International Society for Photogrammetry and Remote Sensing;
Philip E. Greeson	American Water Resources Association;
J. Howard McCarthy, Jr.	Association of Exploration Geochemists;
Douglas J. Nichols	American Association of Stratigraphic Palynologists;
Edwin D. Roedder	Mineralogical Society of America; and
Donald E. White	Society of Economic Geologists.

Presidents (or chairmen) of sections in large interdisciplinary societies include the following:

G. Brent Dalrymple	Volcanology, Geochemistry, and Petrology Section (American Geophysical Union); and
Leonard A. Wood	Hydrogeology Division (Geological Society of America).

Department of the Interior Distinguished Service Awards

The highest honor given by the Department of the Interior is the Distinguished Service Award. This award for careers in challenging and difficult assignments was given to 13 U.S. Geological Survey employees this year. These individuals and the bases for their awards were as follows:

Paul B. Barton, Jr., Deputy for Scientific Programs in the Office of Mineral Resources, for his imaginative scientific research on the mineralogy, chemistry, and origin of hydrothermal ore deposits, the inspiration and source of ideas he has provided his coworkers, and the international prestige he has brought to the Geological Survey;

Peter F. Bermel, Assistant Division Chief for Plans and Operations (NMD), for his exemplary and resourceful leadership, his scientific integrity, and his distinguished career as an administrator;

John D. Bredehoeft, Western Regional Hydrologist, in recognition of his major contributions to the development of this country's water resources;

Robert J. Dingman, former Assistant Chief Hydrologist for Scientific Publications and Data Management, for his exceptional contributions to the field of hydrology;

Frederick J. Doyle, Senior Adviser for Cartography, for his exceptional contributions to the National Mapping Program;

Doyle G. Frederick, Associate Director, for his many significant contributions in the development and management of cartographic and earth sciences programs of the Geological Survey;

Wayne E. Hall, Research Geologist, for his many contributions as a scientist and as an administrator and in recognition of the prestige he has brought to the Geological Survey;

Warren Hamilton, Research Geologist, for his highly innovative research on the relationships of fundamental geologic processes to tectonics and for the international prestige he has brought to the Geological Survey;

Gerald Meyer, former Ground Water Branch Chief, for his exceptional contributions to the development of ground-water programs and resources;

Avery W. Rogers, Western Region Management Officer, in recognition of his essential support role which has contributed so significantly to the accomplishment of the Geological Survey's Western Region scientific and research programs;

Hansford T. Shacklette, Research Botanist, in recognition of his eminent career as a scientist and of his exceptional contributions to the important fields of environmental geochemistry and mineral exploration geochemistry;

Norman F. Sohl, Chairman of the Bureau's Geologic Names Committee, in recognition of his outstanding accomplishments and the excellence of his scientific reports; and

David B. Stewart, Research Geologist, in recognition of his outstanding research in experimental studies of rock-forming minerals and his contributions to the national program to manage nuclear wastes.

National Mapping, Geography, and Surveys

Mission

The National Mapping Division conducts the United States National Mapping Program to make cartographic and geographic information available in graphic and digital form. A family of general-purpose maps in various formats and scales, as well as basic cartographic data, is being produced in four regional Mapping Centers to meet the expanding mapping needs of the Nation. The Division prints Survey map products and stores and distributes all Survey map, text, and photography products. The Division operates the National Cartographic Information Centers, the Earth Resources Observation Systems Data Center, and the Public Inquiries Offices.

Major Activities

- Primary quadrangle mapping and revision. About 1,135 revised and 950 new standard topographic maps were published. Most were in the 7.5-minute 1:24,000-scale series (fig. 1), Alaska being the exception where the 1:63,360-scale series is the primary quadrangle map coverage. Currently, 15 States have complete published topographic map coverage at 1:24,000 scale, and, overall, 79 percent of the conterminous United States is available in published form at this scale.
- Small-scale and special mapping. Complete topographic coverage is available for the United States in the 1:250,000 small-scale map series. The intermediate-scale (1:50,000 and 1:100,000) series (fig. 2) is available for more than 70 percent of the conterminous United States. More than 70 topographic/bathymetric maps were published for coastal area planning. Land use and land cover maps are complete for 2.1 million square miles.
- Information and data services; acquisition and dissemination of information about U.S. maps, charts, and aerial and space photographs and imagery; geodetic control, cartographic and geographic digital data, and other related information; distribution of earth science information to the public; and sale of map and map-related products through more than 2,500 private retailers.
- Advanced development and engineering; to improve the quality of standard products; to provide new products, such as digital cartographic data, that make maps and map-related information more useful to users; to reduce costs and to increase productivity of mapping activities; to acquire innovative and more useful equipment; and to design and develop techniques and systems to advance the mapping of important high-priority areas of the country.
- Cartographic and geographic research; with particular emphasis on spatial data techniques for studies using modern geographic analysis with new and improved cartographic concepts and techniques.
- Digital mapping to produce base categories of cartographic data at common standards of content, accuracies, and formats suitable for computer-based analysis.

Budget and Personnel

For fiscal year 1982, National Mapping Division available funding amounted to about $87 million. Included are funds from 34 States, which, together with matching Federal funds, amounted to about $6 million for joint funding agreements for mapping. These joint funding projects mutually benefit the State and national programs by ensuring completion of map coverage sooner than would otherwise be possible.

The permanent full-time personnel strength of the Division at the end of fiscal year 1982 was 1,840, encompassing a variety of professional skills incuding geography, cartography, data processing, engineering, physical science, and photographic and remote-sensing technology.

Figure 1.—*Status of standard topographic mapping and revision.*

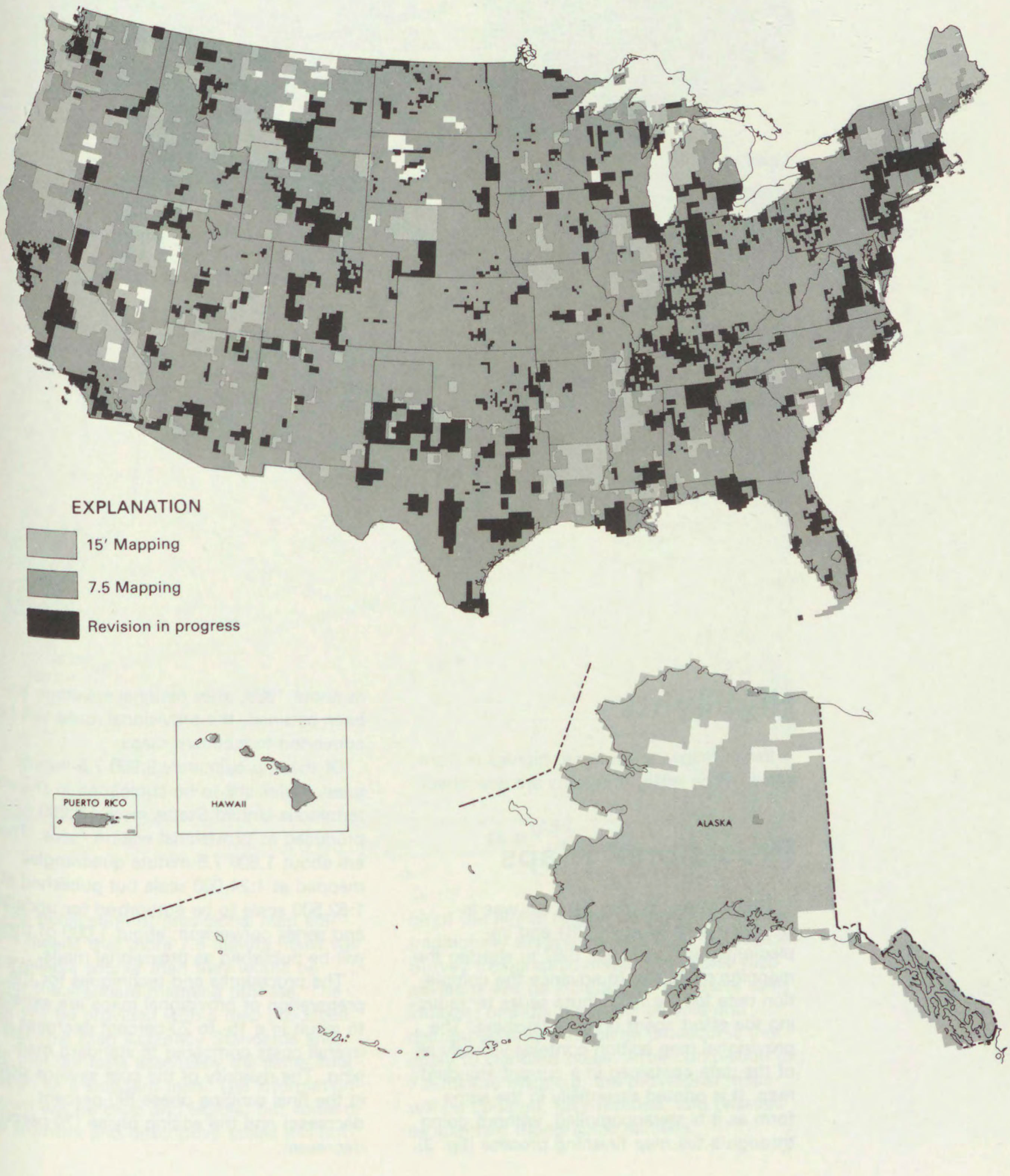
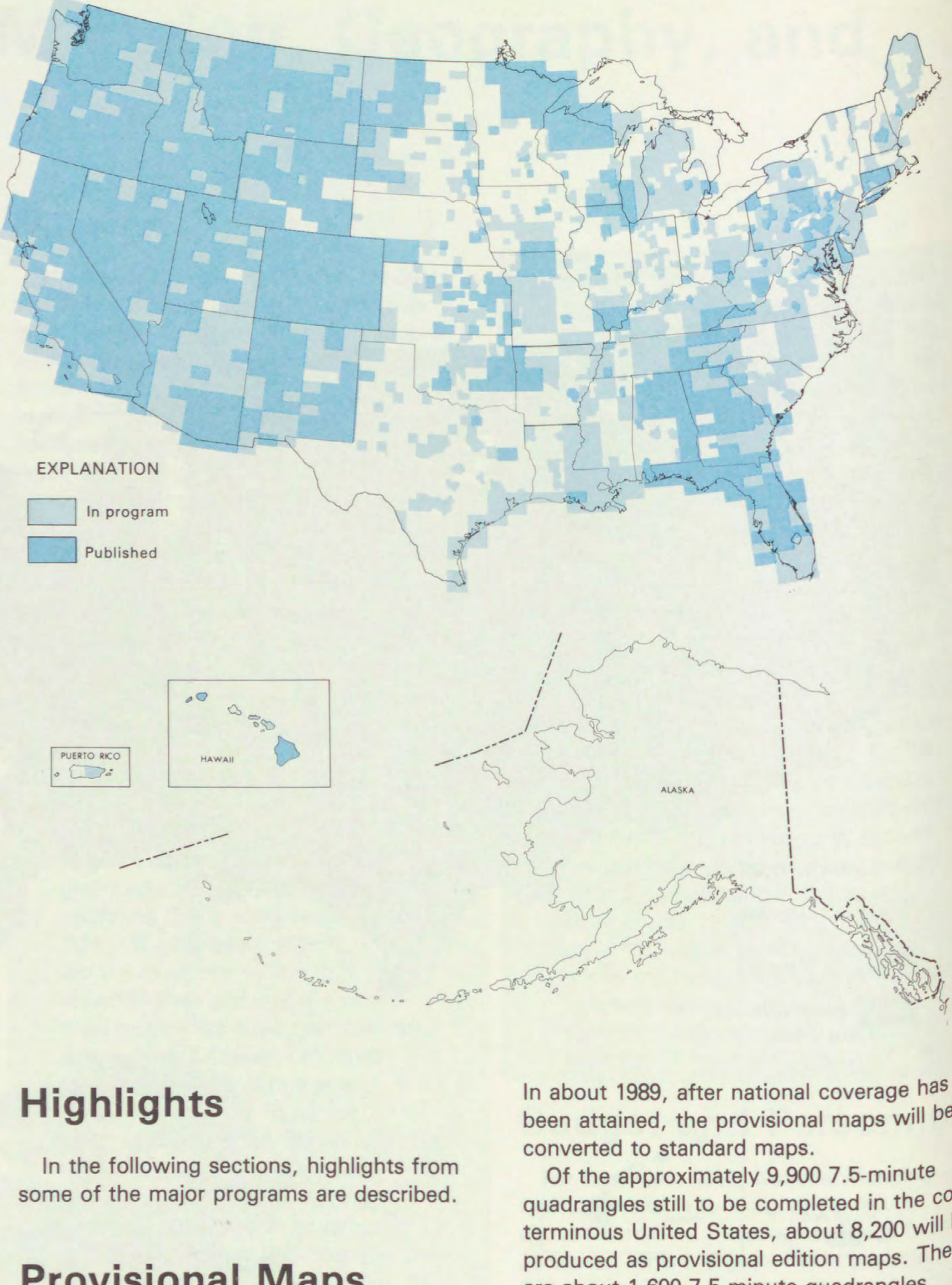


Figure 2.—*Status of the intermediate-scale mapping program.*



Highlights

In the following sections, highlights from some of the major programs are described.

Provisional Maps

The provisional map concept was introduced in fiscal year 1981 and implemented in fiscal year 1982 to shorten the mapping cycle and to advance the completion date for the 7.5-minute series by reducing the effort spent on map finishing. The provisional map edition contains virtually all of the data contained in a current standard map. It is printed essentially in the same form as it is stereocompiled, without going through a full map finishing process (fig. 3). In about 1989, after national coverage has been attained, the provisional maps will be converted to standard maps.

Of the approximately 9,900 7.5-minute quadrangles still to be completed in the conterminous United States, about 8,200 will be produced as provisional edition maps. There are about 1,600 7.5-minute quadrangles mapped at 1:24,000 scale but published at 1:62,500 scale to be authorized for updating and series conversion; about 1,000 of these will be published as provisional maps.

The procedures and techniques for the preparation of provisional maps are expected to result in a 15- to 20-percent decrease in overall costs compared to standard mapping. The majority of the cost savings occur in the final scribing phase (90-percent decrease) and the editing phase (70-percent decrease).

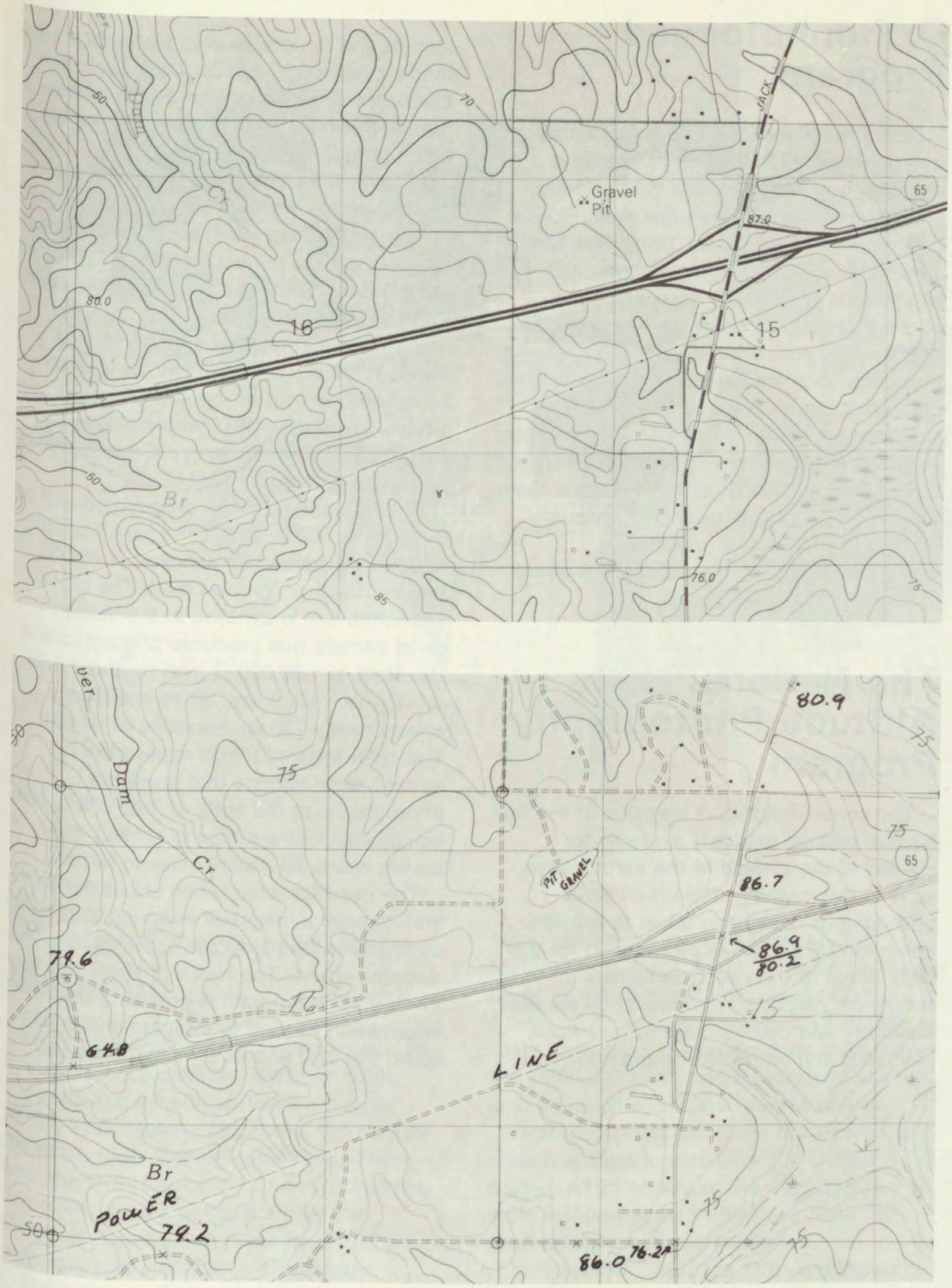


Figure 3.—*Portion of a standard 1:24,000-scale topographic map (above) compared with a portion of a provisional edition map at the same scale (below).*

The publication of provisional map editions means that more 7.5-minute maps will be available sooner than they would be under the standard mapping process. The user will be provided with a map produced at National Map Accuracy Standards and one that contains essentially the same information as a standard map. The information shown will be clear and legible, but some of the linework and descriptive tables will not be of the highly refined cartographic quality traditionally associated with U.S. Geological Survey topographic maps. Provisional map coverage will be included on the State sales indexes, and the maps will be sold and distributed under the same procedures that apply to standard maps. After completion of 7.5-minute mapping, the provisional maps will be updated, fully finished, and reissued as standard topographic editions.

Orthophotoquad Program

Orthophotoquads are one-color distortion-free photographic products produced in standard quadrangle format with selected place names added. Basic marginal information such as the Universal Transverse Mercator grid, scale, quadrangle name, and survey date are shown. Standard orthophotoquads do not show contour lines, but they may be added for special purposes. Orthophotoquads are used primarily as interim map products for unmapped areas or as supplements to line maps. Produced mainly at 1:24,000 scale in the conterminous United States and at 1:63,360 scale in Alaska, they have proven valuable to engineers, surveyors, foresters, and scientists.

Orthophotoquads are available for about 44 percent of the 48 States.

The National High-Altitude Photography Program

The aerial photograph was one of the first remote sensing products available for studies of the surface of the Earth. Since early in this century, millions of aerial photographs have been taken to provide geographical and other information for a wide range of uses such as military intelligence, mapping, environmental studies, inventory and development of resources, planning, and education. Improvements in aircraft and remote sensing technology have made it economically possible to acquire black-and-white and infrared-color photographs from 40,000 feet above the terrain being photographed.

In 1978, the Geological Survey began coordinating a National High-Altitude Photography Program specifically designed to maximize the annual coverage contracted with Federal funds and thus to better satisfy Federal and State needs.

By 1982, contracted coverage totaled about 1,767,000 square miles, or approximately 59 percent of the conterminous United States (fig. 4). Complete coverage is anticipated by 1986, when a 6-year cyclic rephotography program will begin.

Photographs from the program consist of 9- by 9-inch black-and-white panchromatic and color-infrared film exposed at 40,000 feet above mean ground level. The black-and-white film is exposed in a precision aerial camera that produces photographs at the scale of 1:80,000 (1 inch to about 1.25 miles); each black-and-white exposure covers nearly 130 square miles of terrain. The color-infrared film is exposed in a second aerial camera that produces photographs at the scale of 1:58,000 (1 inch equals about nine-tenths of a mile) and covers nearly 68 square miles of terrain.

The need for information about the Earth and its environment will continue to grow as competition for resources accelerates in the decades ahead. The National High-Altitude Photography Program is providing the basic information needed to evaluate and understand the land and its temporal changes.

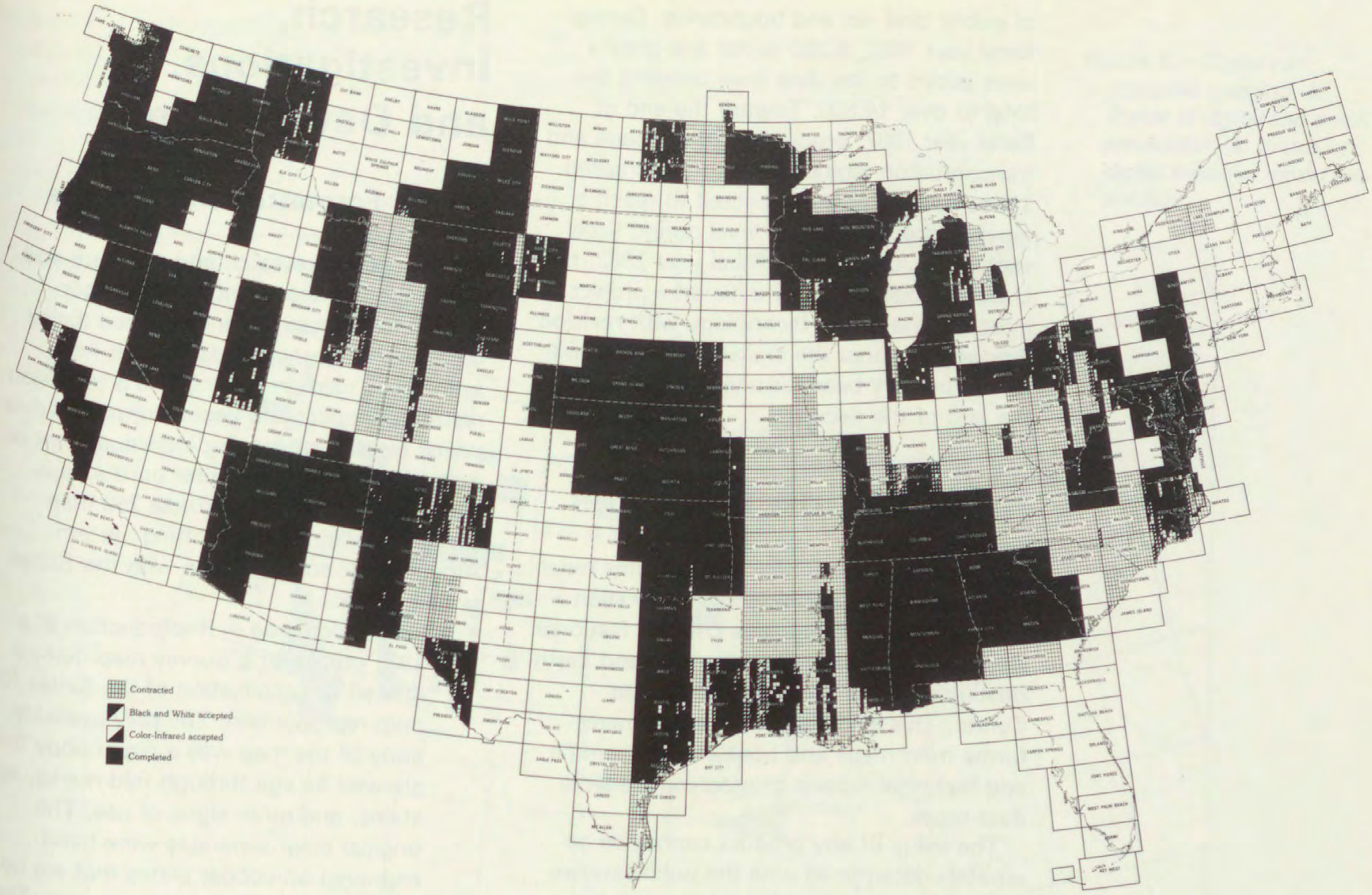


Figure 4.—*Status of National High-Altitude Photography coverage.*

Digital Cartographic Mapping

Maps have traditionally played a key role in earth science analysis. Because earth scientists and other map users are automating their analysis processes, the map information must also be automated. Therefore, the U.S. Geological Survey is building and maintaining a national digital cartographic data base to make its published-map data also available in digital form.

The primary effort is devoted to the building of a data base containing the basic data categories shown on 7.5-minute published topographic quadrangle maps (fig. 5). Work is authorized on the basis of needs expressed by users. The data, available in two forms, are the digital line graphs and digital elevation models. The digital line graphs are graphic data digitized from published maps. The digital elevation models are digitized elevations collected at regularly spaced intervals throughout a quadrangle. Other data being collected include the planimetric features from the 1:2,000,000-scale sectional maps of the *National Atlas of the United States of America* and selected 1:500,000-scale State base maps, elevation data from the 1:250,000-scale map series, land use and land cover data, and geographic names.

Digital elevation data from the 1:250,000-scale maps are available for the United States. All 21 sheets of the 1:2,000,000-scale *National Atlas* series have been digitized and are available to users.

In fiscal year 1982, the U.S. Geological Survey added 1,176 digital elevation models to the data base for a total of about 8,000. Each model describes one 7.5-minute quadrangle area.

Currently, there are five categories of digital line graphs: public land net, boundaries, drainage, transportation systems, and other culture. Any one or all of these categories may be digitized from an existing 7.5-minute quadrangle map. Based on user requests through fiscal year 1982, nearly all digital line graph production has been that of public land net and boundaries. During fiscal year 1982, 5,250 digital line graphs were added to the data base bringing the total to over 14,800. Toward the end of fiscal year 1982, production of drainage and transportation digital line graphs increased. Those categories are expected to reach a much higher production level during fiscal year 1983. Also, during fiscal year 1982, the U.S. Geological Survey initiated a project to integrate the digital technology with revision processes so that the digital line graphs will be the primary base for revision mapping by the end of the decade.

Information Services

The Geological Survey disseminates much of the Nation's earth science information through its Public Inquiries Offices, National Cartographic Information Centers, and Earth Resources Observation Systems Data Center. This information comes in many forms from maps and booklets to scientific and technical reports to machine-readable data tapes.

The value of any product cannot be accurately determined until the public knows its availability and application to their particular needs and has used it. Market research techniques are being used to identify the many different user publics. A prime example is the market study of the digital spatial data industry, which was created from the merging of the cartographic and computer sciences. This market study will help to answer questions about the best way to disseminate this new type of information: Who are the users? what are their needs? how can the Survey best serve them? Many of the potential users are other Federal and State agencies.

State map indexes portray available 7.5-minute topographic map coverage. The current single-sheet index shows only a few selected map series. A new booklet format will show the entire range of available map series from the standard topographic quadrangle to the ecological inventories of the coastlines, cooperative Federal products, and special maps prepared for particular needs. Other indexes reflecting Survey special-product availability also help to expand the availability of Survey cartographic products to the public.

Research, Investigations, and Development

Raster-Formatted Digital Data

Applications research and software and techniques development are being conducted to address raster-formatted digital data. Raster-formatted data result from scanning a map area (similar to a television raster) as opposed to vector-formatted data which result from tracing individual lines on a map. These efforts center on the capabilities of the Scitex RESPONSE 250 map scanning, editing, and plotting system. Among 1982 achievements with the Scitex system were:

- *Map Reproduction.*—Reproduction of a 1931 edition of a Survey map demonstrated the application of the Scitex for map reproduction. The only available copy of the map was a paper copy that showed its age through fold marks, age stains, and other signs of use. The original color separates were hand engraved on copper plates that are no longer usable for reprint purposes. The paper copy was scanned, and, using the editing functions of the Scitex electronic design console, the age stains, fold lines, and other blemishes were erased from the digital copy. Lines and symbols were retouched and repaired, and the map was rescaled to more modern dimensions. The laser printer was then used to generate reproduction-quality color separates for printing. The entire process reduced to a few hours a task that previously would have required months of manual labor.
- *Shaded-Relief Graphics.*—Digital elevation data are used to produce graphics representing topographic relief, based on slope aspect and Sun elevation and azimuth. The elevation data are coded to represent colors or shades of gray and the laser plotter is used to produce a film transparency that can be combined with other map separates to print a shaded-relief map of the terrain. Before these procedures were developed, shaded-relief graphics could only be prepared manually by personnel having special artistic skills.

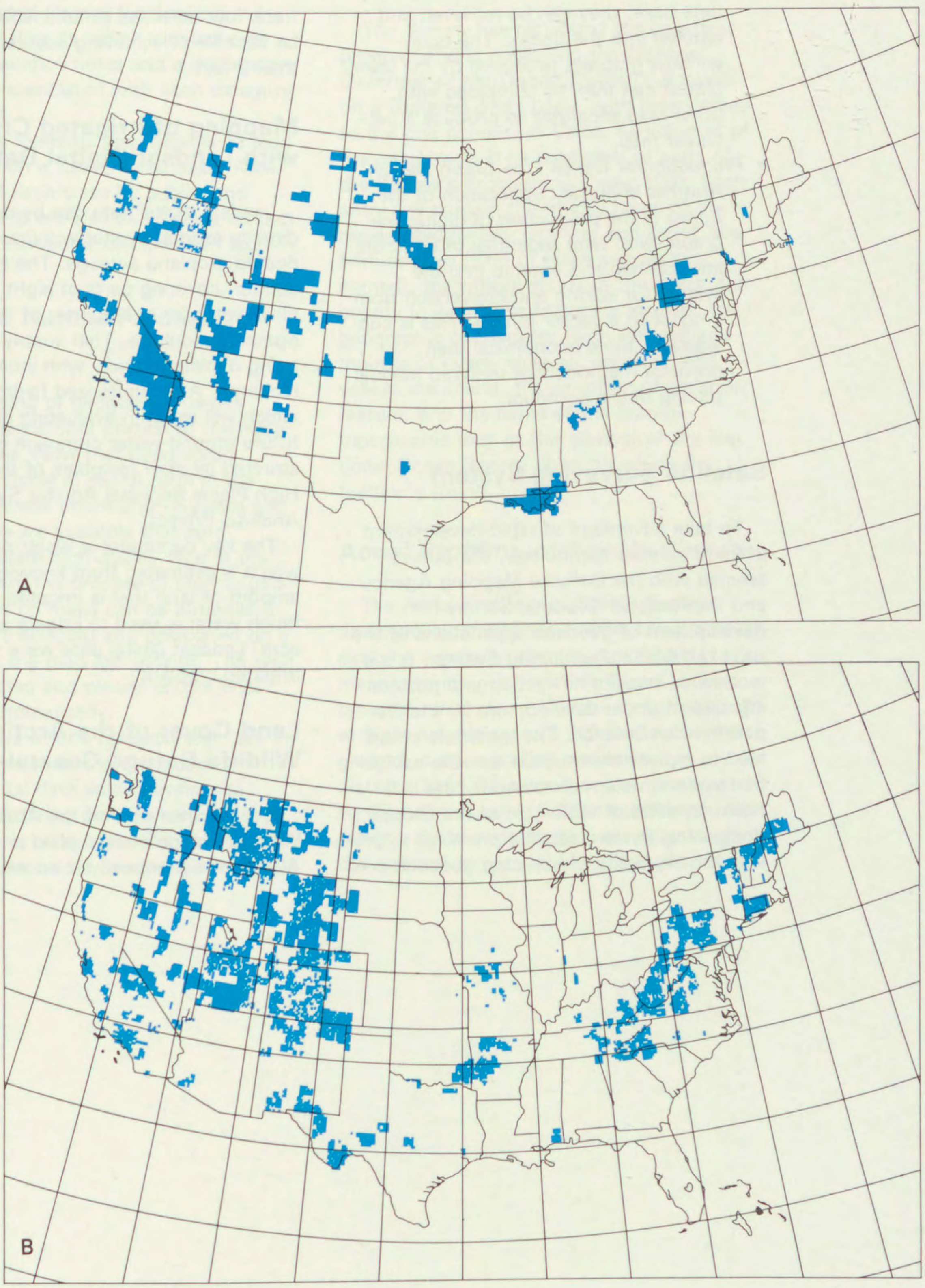


Figure 5.—*Digital cartographic mapping.* A, *Status of digital line graph production.* B, *Status of digital elevation model production.*

- *Open-Window Graphics.*—Thematic maps often contain thousands of areas. Manually etching and peeling an open-window color separate for just one classification is a labor-intensive and time-consuming task. Because a large quantity of the data exist in a digital data base, they can be retrieved and entered into the Scitex. The open-window graphics produced by the laser plotter can then be combined with other map separates to produce a particular map.
- *Production of Digital Line Graph Data.*—Another important application of the Scitex is the production of digital line graph data. Map separates of contours are scanned and entered into the system for editing and conversion from a raster to a vector format. This is considerably more economical than previous methods that required manual tracing of the contours.

Satellite Surveying System

To take advantage of rapid development in Earth satellite technology, the Survey teamed with the Defense Mapping Agency and the National Geodetic Survey for development of geodetic applications of the NAVSTAR Global Positioning System. It is a worldwide satellite navigation and positioning system under development by the Department of Defense. The system is scheduled to replace the TRANSIT satellite navigation system, now maintained by the U.S. Navy, by 1986 or 1988. Use of the Global Positioning System satellite promises to provide the capability of attaining geodetic positional data with much less effort and in less time than is required for current landbased techniques.

The results of this activity have led to a contract awarded to the University of Texas, Applied Research Laboratory, to develop an Advanced Geodetic Receiver which will track four satellites simultaneously and will be capable of achieving accuracies to less than 3 feet.

Mapping of Irrigated Cropland with Landsat Digital Data

Landsat digital data can be used to indirectly estimate water withdrawal from irrigated cropland acreage. The High Plains aquifer, covering parts of eight States, supplies water for one-quarter of the Nation's irrigated agriculture. That supply of water is being depleted rapidly with little natural recharge. A computerized hydrologic model which will assist in evaluating effects of future ground-water pumpage is being constructed by staff members of the Survey's High Plains Regional Aquifer Systems Analysis Project.

The key parameter is water pumpage, which is estimated from knowing the amount of land that is irrigated and how much water is used to irrigate an average acre. Landsat digital data were used to map irrigated cropland.

Land Cover of the Arctic National Wildlife Refuge Coastal Area

A land cover map of the Arctic National Wildlife Refuge coastal plain in northern Alaska was produced for an environmental impact statement regarding proposed oil and gas exploration that was being prepared with Geological Survey support by the U.S. Fish and Wildlife Service. Three Landsat scenes were selected for analysis using knowledge of sites mapped in the field along with computer clustering techniques to establish spectral classes for the land classification. Results were validated with field reconnaissance notes and a description of vegetation associated with each category was compiled.

This unique thematic map depicts 12 land cover classes on a topographic base. Area tabulations of each class by public land survey township are also included, a distinct advantage of computer classification techniques.

Automated Names Processing Research

The processing of geographic names constitutes a significant portion of the map-making process. Now that geographic names are available in digital form in the Geographic Names Information System and output devices are available that automatically generate high-quality type in the correct position, the process of placing geographic names on maps can be automated. The names are selected and positioned on a proof copy of the map manuscript. The type is then generated and placed on the final manuscript automatically.

The members of one research team are investigating the use of the computer-controlled digital data editing system to prepare map lettering plates where the type in both the map border and the map interior is rapidly and accurately positioned using a video screen. In most instances, the type style and size are automatically selected for the operator, thus eliminating many errors that occur in conventional type placement.

National Gazetteer Series

The Survey has reinstated the gazetteer program and is publishing the *National Gazetteer of the United States of America* on a State-by-State basis, with New Jersey as the first completed State. All volumes of the gazetteer will be published as parts of the Survey's Professional Paper 1200. Each entry will contain the official name of the geographic feature (spelling and form), the feature class (kind of place and feature named), the official status of the name, the county in which the feature is located, the geographic coordinates (with sources and mouths of rivers, streams, canyons, and valleys identified), the elevation of place or feature, and the name of the Survey topographic map or the number of the National Ocean Survey chart on which the feature is found.

Aerial Profiling of Terrain System

The Aerial Profiling of Terrain System, under development since 1974, is a precision airborne surveying system capable of measuring elevation profiles across various types of terrain from a relatively light aircraft at flight heights up to 3,000 feet above the ground. A laser profiler measures the distance from the aircraft to the terrain, and an inertial measuring unit and a laser tracker provide the aircraft position by measuring the distance to ground-based reflectors.

Geologic and Mineral Resource Surveys and Mapping

Mission and Outlook

During fiscal year 1982, the Geologic Division conducted programs to assess energy and mineral resources onshore and offshore, to identify and investigate geologic hazards, and to evaluate the Nation's geologic framework, the geologic processes that have shaped it, and their relationship to long-term climatic changes. The mission of the Division was essentially unchanged from that of previous years, with the exception of the departmental decision on January 19, 1982, to transfer all direct suppport functions of the Outer Continental Shelf Leasing Program to the newly created Minerals Management Service. Although the Department's action to strengthen the Outer Continental Shelf Leasing Program resulted in a loss to the Geologic Division of mission responsibilities, the action simultaneously clarified and strengthened the Division's responsibilities in basic earth science research.

Fiscal year 1982 was a year of change as well as accomplishment in the Geologic Division with several implications for the future. In addition to its traditional basic research and factfinding role, the Division will be increasingly called upon to emphasize its data dissemination and public information activities in support of such diverse mission objectives as land use planning, energy and mineral development, and geologic hazard mitigation. These increased responsibilities will require closer collaboration with agencies at the Federal, State, and local levels.

The articles in this section of the *Yearbook* describe some of the most significant accomplishments of the Geologic Division during fiscal year 1982. We believe that these articles, while representing only a select few of the activities of the Division, show how geologic research simultaneously opens new avenues in geoscience and provides the basic information to serve missions central to the national welfare.

Major Programs

The Geologic Division budget is presented to Congress under five major program headings. A discussion of accomplishments under these subactivities during this last fiscal year follows:

Geologic Hazards Surveys

In addition to the work described in the articles regarding the Los Angeles, California, urban areas earthquake hazards assessment and the studies of subsidence near Houston, Texas, the Geologic Division continued to monitor and assess the potential for the imminent renewal of volcanic activity at Mount St. Helens, Washington, and Mammoth Lakes-Long Valley, California. Because of the threat to human life and the major economic impacts that would be associated with an earthquake, volcanic eruption, or major landslide, the Geologic Division recognizes its Hazards Program responsibilities as among the most challenging that it must address in the next several years. The Division will continue to emphasize increasing its capability to identify and understand geologic hazards while also providing products that will enable Federal, State, and local governments to make informed land use, zoning, and engineering design decisions that will enhance the Nation's capability to avoid and mitigate these potential hazards.

Land Resource Surveys

During fiscal year 1982, the Geologic Framework Program continued to provide new insights into the fundamental geologic structure of the United States. The publication of numerous maps and reports resulting from these studies translate directly into new understanding of geologic hazards and the Nation's energy and mineral resources. A following article on the evolution of the Pacific Coast is illustrative of the nature of the research provided by the Geologic Framework Program. In addition, observations from the 11 geomagnetic observatories produced data that supported the preparation of topographic, nautical, and aeronautical maps and charts. The Geologic

Division will continue to place considerable emphasis on the maintenance of this basic research capability because of its importance, not only to the Division's other programs, but also to a large and growing user community.

Mineral Resource Surveys

In addition to the completion and publication of the results of the mineral resource appraisal of the Rolla, Missouri, quadrangle, which are described in a following article, the Geologic Division completed similar work in 11 other 2-degree quadrangles in the United States; maps and reports dealing with the results of these appraisals are either in press or in final compilation. Field investigations are underway in five additional quadrangles. The Division produced its first annual report under the Alaska National Interest Lands Conservation Act of 1980, approached completion of mineral resource assessments of Forest Service wilderness lands, and accelerated assessments of Bureau of Land Management wilderness lands. The Division completed a compendium of 48 mineral occurrence models while also continuing work on the use of space shuttle technology, described below, and other innovative approaches to mineral resource exploration.

Future long-term directions for the minerals programs include placing high priority on the identification of unconventional sources of strategic and critical minerals while continuing the systematic appraisal of the Nation's mineral resources through the Alaska Mineral Resource Appraisal Program and Conterminous United States Mineral Appraisal Program. The Division will also be challenged to address the short- to mid-term requirements of the Wilderness Programs of the Bureau of Land Management and the Forest Service.

Energy Resource Surveys

During fiscal year 1982, the Geologic Division successfully completed a prototype project in using digital cartographic techniques to produce both quantitative and qualitative assessments of the oil and gas potential of land units within oil and gas basins. The Division also moved closer to completion of a major study of the occurrence of uranium in the San Juan Basin, New Mexico, which contains the largest known uranium reserves and resources in the United States.

The Division completed an additional 10 coal folios at 1:100,000 scale in support of the Bureau of Land Management's land use planning requirements. Of the 110 quadrangles identified for the preparation of the folios, 14 are now completed, and an additional 22 will be completed in the near future based on efforts underway during fiscal year 1982.

Following the oil embargo of 1973 and the ensuing energy crisis, the Geologic Division recognized a rapidly evolving responsibility to provide a central repository for the vast amounts of data that were collected, not only by the Survey, but also by other Federal agencies, regarding the Nation's coal, oil and gas, oil shale, and uranium resources. To meet this responsibility, the Geologic Division began in 1974 to design and implement the National Coal Resources Data System, a computer-based capability to store and provide both quantity and quality analyses of the Nation's coal resources. During fiscal year 1982, an additional 30,000 drillholes were entered into the system bringing the total to 80,000, leaving an estimated 320,000 to be entered. This system, which is now operational, is available to support land use planning at the Federal, State, and local levels and has, in fact, been built with substantial participation by the coal-bearing States. Work will continue to complete data entry in the data system while other efforts are already underway to similarly address other energy commodities.

Offshore Geologic Surveys

During fiscal year 1982, all functions in direct support of the Department of the Interior's Outer Continental Shelf Leasing Program were transferred from the Geologic Division to the newly created Minerals

Management Service. The Division continued its efforts in indirect support of the Outer Continental Shelf Leasing Program by providing resource appraisals of offshore basins where future Outer Continental Shelf lease sales may be held. These offshore resource appraisals were incorporated in revised estimates of the undiscovered recoverable petroleum resources in the United States, which was published in fiscal year 1982 as U.S. Geological Survey Circular 860. Compared to the 1975 assessment, Circular 860 confirms the same amount of oil remaining to be discovered but reflects a 22-percent increase in the amount of gas. The Secretarial Order clarified the Geologic Division's research mission to perform work similar to that which is described in the article entitled "Oceans and Oil." This type of basic research will provide the Nation with the capability to discover and assess new areas of petroleum potential as conventional sources are depleted.

The refocusing of the Geologic Division's offshore mission provided impetus for new activities in areas of polymetallic sulfides in the Juan de Fuca and Gorda Ridges, which contain commercial amounts of zinc, sulfur, iron, copper, lead, cadmium, and silver; in the newly identified cobalt-rich manganese crusts off the coast of Hawaii and the Trust Territories; and in the planning for surveys offshore Antarctica in anticipation of the treaty renegotiation, which may occur in 1991.

Highlights

In the following sections, highlights from some of the major programs are described.

Devil's Tower, Wyoming.

The Evolution of the Pacific Coast of North America

New geological, geophysical, and paleontological data obtained during the past 10 years or so have dramatically changed our ideas concerning the geologic history of western North America. It has long been known that the stable central shield region of the continent is very old—some rocks are known to have formed at least 3.8 billion years ago. These ancient rocks do not extend continuously westward to the Pacific Coast, however, but end along a line running northward from about central Nevada. On the basis of the new data, we now believe this line, which can be defined both on geologic and geochemical bases, marks the edge of the North American Continent about 250 million years ago. Since that time, the western edge of the continent has grown through the addition of new material. We now recognize that a belt averaging over 370 miles in width and extending from Mexico north to Alaska—nearly 25 percent of the total land area—represents new crust that has been added to the continent through a process that involved collision between the continent itself and separate oceanic blocks.

This growth of new continental crust has been piecemeal, resulting in new crust that is highly variable in composition and character. Much effort has been expended lately in an attempt to identify these separate accreted blocks, now called terranes, and to determine the following:

- Where they originated;
- How much and by which path they moved;
- When they collided with North America; and
- What mechanical processes, such as folding, faulting, and compositional changes in buried rocks caused by in depth fluctuation of temperature, stress, and chemical environment, were involved in the collision process.

Nearly 200 terranes have now been identified in western North America, but sufficient information to permit answering all the above questions for all these terranes is not yet available. Despite this, we do know that some terranes have traveled a very long distance and can be realistically described as exotic elements because they are displaced from their place of origin. A good example of a far-traveled terrane is Wrangellia (see fig. 1), which extends from southern Alaska to eastern Oregon. Combined geologic and paleontologic data suggest that Wrangellia originated far to the south of its present position, perhaps near to the equator. This hypothesis has been substantiated by geophysical studies, such as paleomagnetism, that show that some rocks in Wrangellia did indeed form at low latitudes, near the equator, and probably in the Southern Hemisphere. Thus, Wrangellia has moved northward relative to North America by nearly 60 degrees of latitude, the equivalent of about 3,600 miles, or one-sixth of the circumference of the Earth. This terrane was added to the continental margin of North America about 100 million years ago, and, since then, its distribution has been further affected by younger lateral movement along faults that have dispersed fragments of Wrangellia along the Pacific Coast.

Geologic and geophysical research carried out by scientists of the U.S. Geological Survey has been critical to the development of this new concept of continental growth by accretion of exotic terranes. Because this new concept touches almost all areas of the earth sciences from paleontology to seismology, it has tended to draw together specialists from disciplines that hitherto had little in common into closely coordinated research teams. Only in this way can questions about the accretionary process be answered. And these answers are important.

For example, the crustal properties of separate terranes is closely related to metallic mineral resources. Some mineral deposits were clearly formed before the host terrane arrived in North America; some deposits were formed in suture zones where terranes collided; others formed after accretion to North America, but their very existence is genetically related to previously accreted rocks. Thus, understanding the distribution, character, and history of each terrane will provide critical data for mineral resource evaluations and the design of exploration strategies that will enable us to develop these resources.

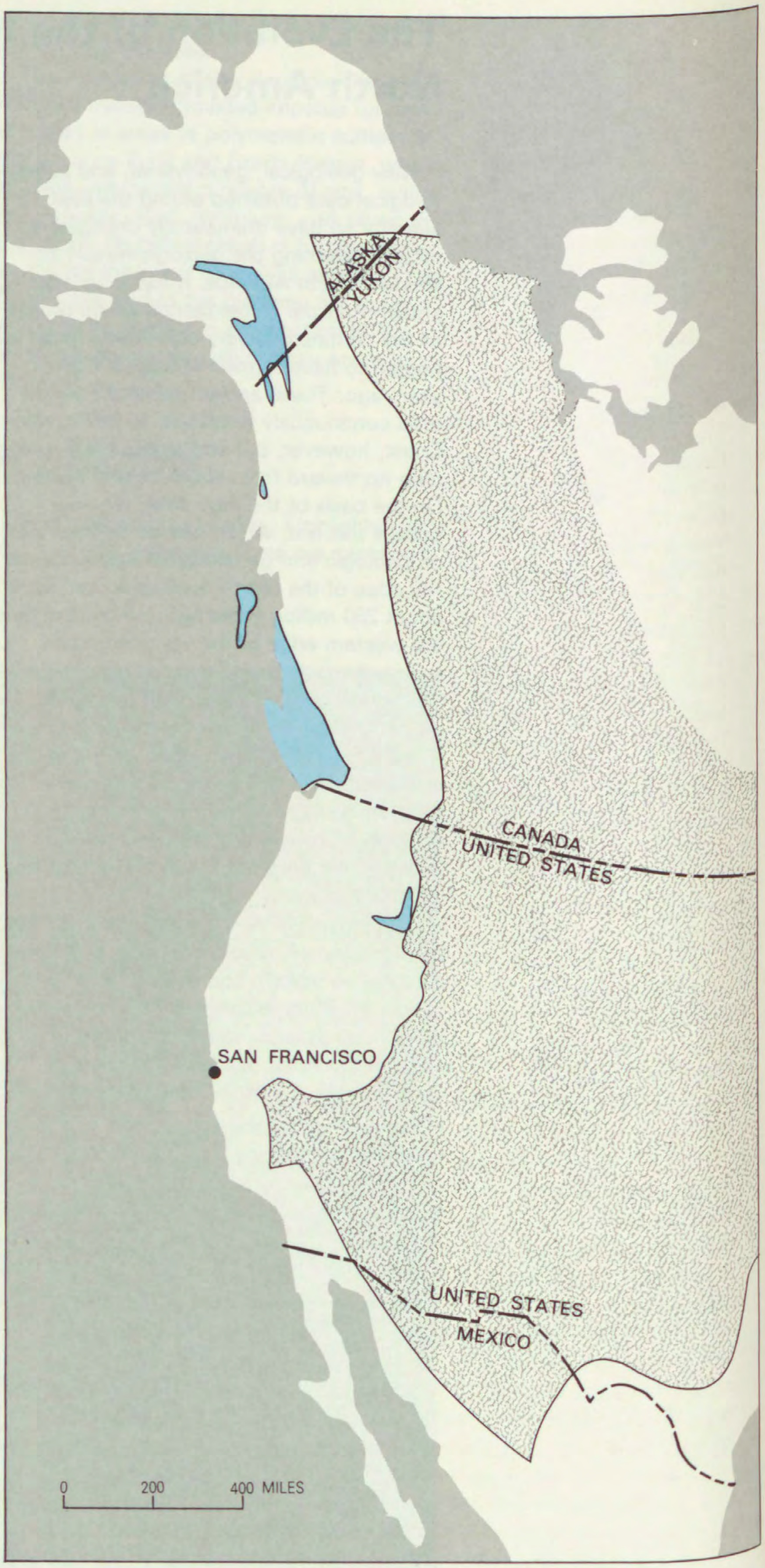


Figure 1.—*This map shows the original configuration of the western boundary of the North American Continent (patterned area); the blue area indicates approximate location of Wrangellia; and the white area shows other accreted terrains.*

Oceans and Oil

The traditional emphasis in the exploration for oil has been on reservoir rocks; that is, the rocks from which the oil is pumped. However, as the larger reservoirs are depleted and we have begun to search for smaller and smaller reservoirs, it has become important to understand the distribution of so-called "source rocks," the rocks in which the oil originates before it migrates to and pools in the reservoirs. Exploration for oil has also moved into "frontier" areas; that is, areas that have not been previously explored. Oil and gas research within the U.S. Geological Survey is designed to develop models and techniques that will guide industry to these new petroleum resources in a manner that gives maximum value for each exploration dollar.

One of the techniques being used at the U.S. Geological Survey for promoting the understanding of source-rock distribution involves modeling and producing maps of ancient ocean currents. The work aimed at producing the ocean models and predicting the locations of oil source rocks is exciting because it combines knowledge derived from a large number of scientific endeavors.

Most oil is composed of material originating from the bodies of single-celled marine plants that were deposited on the ocean floor. Vast numbers of these tiny plants are needed to create significant amounts of oil. Some environments are favorable for the preservation of any plants that fall to the sea bottom. In other environments, the plants are so numerous that, even though large numbers decay or are eaten, many are buried in the sediments, and they eventually create large amounts of oil. It is to these environments that ocean modeling studies are directed.

We know that certain ocean currents create the conditions favorable for the continued and rapid growth of marine plants. These currents, which are called upwelling zones, occupy less than 1 percent of the ocean surface. The currents are driven by strong winds that are part of very large scale wind patterns, the components of which cover areas as large as the Pacific Ocean north of the equator. The overall global pattern of circulation seen today is dependent on the present positions of the continents and seas. We know that, in the geologic past, the continents were not in their present positions; for example, 200 million years ago, world geography was very different from that of today. This is why past circulation patterns must be modeled theoretically; simply superimposing modern circulation on past geography does not produce a valid model.

Once we know the worldwide patterns of ancient winds, we can predict the probable locations of ancient upwelling zones. The potential for source areas for oil can then be assessed. For example, U.S. Geological Survey geologists predicted that, from the viewpoint of ocean models, the source rock potential for Baltimore Canyon (located about 90 miles offshore from Atlantic City, New Jersey) was not favorable and that the potential for Georges Bank (located about 100 miles offshore from Nantucket Island, Massachusetts) was good. Since that time, dry holes have been drilled in Baltimore Canyon, and oil has been found on Georges Bank. Like any exploration technique, the ocean modeling studies do not guarantee oil discoveries, but, even in the early stages of their development, they have proved a valuable tool.

Conodonts Aid Oil and Gas Investigations in the Western United States

Conodonts are the microscopic (generally 0.004 to 0.039 inch in size) phosphatic hard parts of an extinct group of marine animals that are common to abundant in Cambrian through Triassic rocks (rocks deposited from 570 to 205 million years before present). Conodonts evolved and spread rapidly throughout most of their geologic range, and species distributions show a relation to paleogeography, particularly to seawater temperature and chemistry. Conodonts contain trace amounts of organic matter that undergo visible color changes from pale yellow to brown to black with increasing temperature as a result of a carbon-fixing process in the range of 60° to 300°C.; above 400°C., conodonts change from black to gray to opaque white and finally to crystal clear as a result of carbon loss, release of water of crystallization, and recrystallization. Thus, conodonts are useful chronologic, ecologic, and geothermal indicators.

Conodont research in the U.S. Geological Survey has led to the use of conodonts for determining several stratigraphic, structural, and organic-metamorphic aspects of oil and gas in the Western United States. The color changes in conodonts are used to create color-alteration maps that identify areas where past temperature conditions were favorable for generating and preserving oil and gas. In addition, conodont-based color-alteration maps for areas of proven oil and gas potential, such as the Western overthrust belt in Wyoming, can be used as comparative tools when evaluating similar color-alteration patterns found in other regions.

Figure 2*A* shows the main area of the U.S. Geological Survey conodont research in the Western United States. In Arizona, preliminary age-based conodont color-alteration (thermal assessment) maps were compiled. Figure 2*B* shows generalized areas of oil and gas potential in Paleozoic rocks (rocks deposited from 570 to 240 million years before present) that were derived from these maps; however, many local thermal highs related to extensive post-Paleozoic igneous activity are present in southeastern Arizona that complicate the simple pattern shown. A preliminary conodont-alteration map for southwestern Montana (fig. 2*C*) shows a marked change in thermal maturity across the Medicine Lodge thrust indicating that this thrust may involve relatively large movement that placed more thermally mature (more deeply buried) western rocks above and adjacent to less thermally mature eastern rocks. This pattern is similar to that of the Absaroka thrust in the overthrust belt in Wyoming and suggests that both thrusts possibly formed at the same time and involve transport of similar magnitude. This similarity allows tenative correlation of these structures across the Snake River Plain in Idaho.

Conodont-based stratigraphic studies in southwestern Montana show that deposition of the Quadrant Sandstone within the thrust belt was initiated well before similar sandstone deposition on the craton to the east (approximately 10 million years earlier). This age difference, together with subtle changes in sedimentary facies, implies a late Paleozoic structural basin. The Quadrant Sandstone is a potential reservoir rock, and its distribution and depositional history, among other things, affect potential oil and gas preservation and migration.

The maps for assessing thermal maturity (conodont color-alteration index maps) in Ordovician through Triassic rocks in Nevada and Utah and adjacent parts of Idaho and California (Geological Survey Miscellaneous Investigation Map I-1249) are being updated and expanded to include hundreds of new localities in these States and in parts of Arizona, Colorado, Idaho, Montana, New Mexico, and Wyoming and to serve as oil and gas exploration guides. In addition, an outcrop map of the Phosphoria Formation (a major potential Paleozoic petroleum source rock) throughout the overthrust belt in Wyoming and Idaho and the thrust belt in southwestern Montana has been compiled using conodont-based thermal-maturity assessments for preliminary oil and gas assessment.

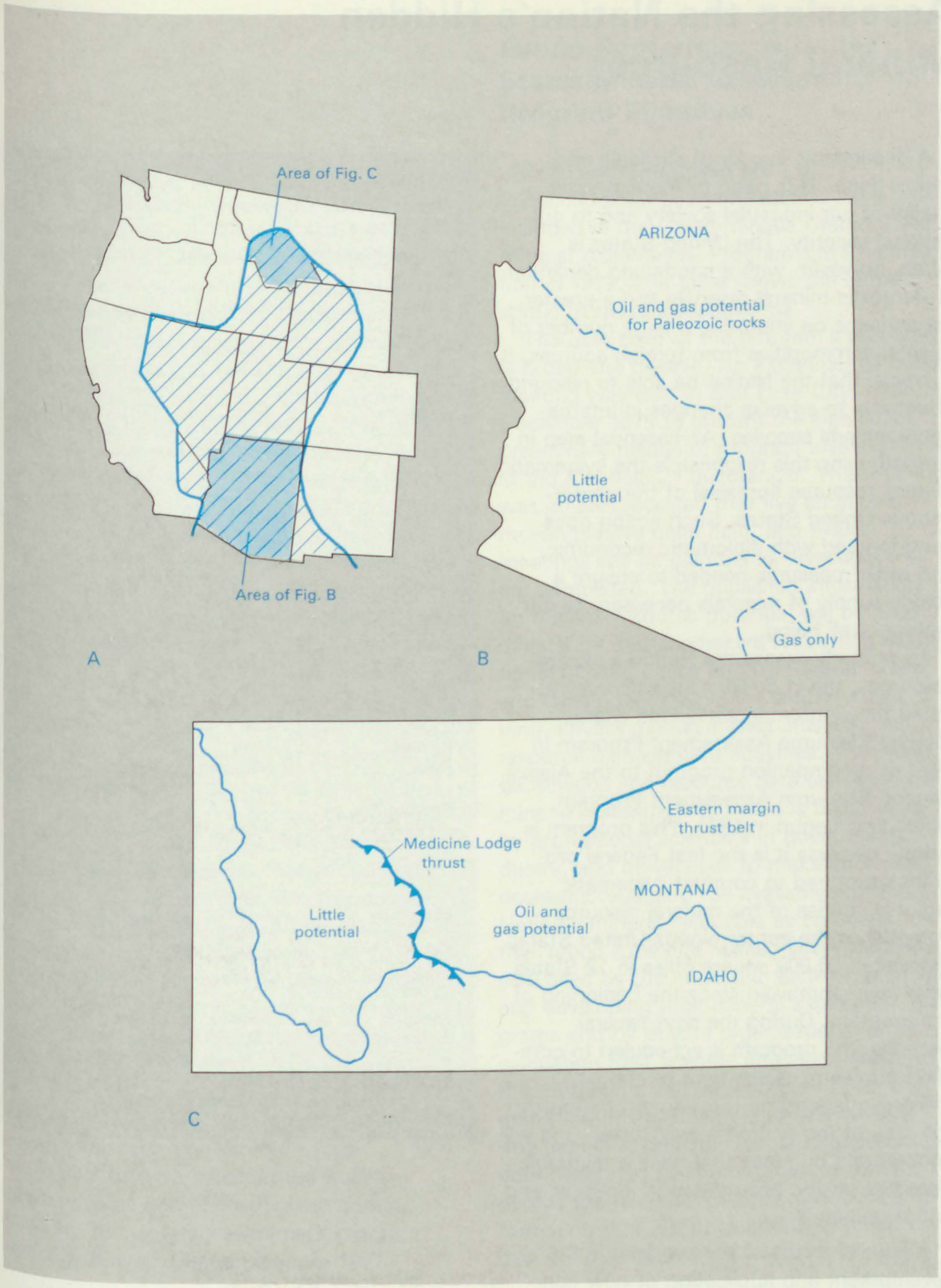


Figure 2.—*Conodont research in the Western United States.* A, *Area of the Western United States being studied for conodont-based thermal assessment of Paleozoic-Triassic rocks; also shown are the locations of* B *and* C. B, *Map of Arizona showing generalized areas of relative oil and gas potential as assessed by conodont color alteration in Paleozoic rocks.* C, *Map of southwestern Montana showing Medicine Lodge thrust and eastern margin of the thrust belt; most Paleozoic and Triassic rocks east of the Medicine Lodge thrust are within the thermal window for oil and gas preservation.*

Assessing the Nation's Hidden Mineral Resources

A dependable supply of strategic and critical minerals is basic to the economic vitality of our industrial society and to our national security. The United States is faced, however, with a continuing depletion of domestic mineral reserves and a greater dependence on importing a large number of mineral commodities from foreign sources. It is crucial that the Nation be able to respond effectively to adverse changes in international mineral supplies. An essential step in strengthening this response is the systematic mineral resource appraisal of the conterminous United States. Such action goes hand-in-hand with diplomatic, economic, and other measures needed to ensure a steady supply of minerals necessary to our national well being.

To properly assess the Nation's mineral resources, the U.S. Geological Survey initated the Conterminous United States Mineral Resource Assessment Program in 1977 as a companion program to the Alaska Mineral Resource Assessment Program, which was begun in 1974. This program is unique because it is the first Federal program structured to conduct systematic regional studies of the mineral resource potential of the conterminous United States. More than 66,000 square miles in 12 States have been appraised since the beginning of the program. During the next several decades, the program is scheduled to complete a mineral assessment of almost 1 million square miles, more than one-fourth the area of the entire United States, and will concentrate on areas that have a favorable potential for the occurrence of strategic and critical minerals.

A parallel thrust of the program is the development and application of new con-

Current status of the Conterminous United States Mineral Assessment Program Investigations

Quadrangle	State(s)	Status
Ajo	Arizona	Reports and maps in preparation.
Butte	Montana	Do.
Challis	Idaho	Field work in progress.
Charlotte	North Carolina; South Carolina.	Reports and maps in press.
Choteau	Montana	Reports and maps published.
Dillon	Idaho; Montana.	Reports and maps in preparation.
Glen Falls	New York; Vermont; New Hampshire.	Field work in progress.
Iron River	Michigan; Wisconsin.	Reports and maps in press.
Medford	Oregon	Do.
Pueblo	Colorado	Reports and maps in preparation.
Richfield	Utah	Do.
Rolla	Missouri	Reports and maps published.
Sherbrooke-Lewiston	Vermont; New Hampshire; Maine.	Fieldwork in progress.
Silver City	Arizona; New Mexico.	Reports and maps in press.
Springfield	Missouri	Fieldwork in progress.
Tonopah	Nevada	Do.
Walker Lake	California; Nevada.	Reports and maps in press.
Wallace	Idaho; Montana.	Do.

cepts in the identification of significant mineral potential in heretofore untested, but possibly mineralized, areas. Traditional exploration methods used to identify and appraise mineral occurrences exposed at the surface are of limited value in those areas of the conterminous United States where overburden conceals a significant amount of bedrock which, in places, may be significantly mineralized. It is estimated that two-thirds to three-quarters of the bedrock in the Western United States are concealed; even larger proportions of covered areas occur in other parts of the conterminous United States. An example is the midcontinent region where, until recent times, the only known mineral deposits were those outcropping at the surface. The potential for discovery of additional very large and economically significant mineral deposits in this region is excellent. At present, the State of Missouri alone produces 90 percent of the Nation's lead, 20 percent of its zinc, and minor, but significant, amounts of copper, silver, cobalt, nickel, and cadmium from vast stratabound deposits that are buried from 800 to 1,200 feet beneath the surface. However, this productive and promising region has received less than adequate attention because known exploration methods have offered little promise for discovery of concealed ore deposits existing in this environment except by inefficient and expensive "wildcat" drilling. It was for these reasons that the U.S. Geological Survey, in cooperation with the Missouri State Geological Survey, selected the Rolla quadrangle as one of the highest priority areas for the mineral assessment program investigations and began work in 1977.

Future Conterminous United States Mineral Assessment Program Initiatives

Rolla and Springfield are 2 of 18 1:250,000-scale quadrangles that have been included in the Conterminous United States Mineral Assessment Program since its inception in 1977. The table shows the current status of these investigations.

The user base of the program's products is broad and diverse. An experimental public meeting was held in Salt Lake City, Utah, in December 1979 to present the significant preliminary results of program investigations in the Richfield 2° quadrangle. This meeting was so well received that five additional meetings have been held, and future meetings will be planned as investigations are completed. The published information on mineral resource potential will be used directly by decisionmakers for setting national mineral policy and by Federal, State, and local governments for land use planning, environmental impact analysis, and resource management activities. The basic geoscience and resource data on which the mineral assessment is based is being used by professional scientists in government, industry, and universities to make informed decisions regarding the availability of the Nation's mineral resources as compared to the Nation's mineral needs. These data are also used by the mineral industry in planning and developing their mineral exploration programs and by private organizations for evaluating their specific interests relative to the protection, conservation, and prudent utilization of the Nation's mineral wealth. The geologic, geochemical, and geophysical data generated by the program become a part of the reservoir of basic geoscience information that will be available to guide these critical decisions.

Applications of Space Shuttle Technology to Mineral Resource Appraisal

On November 12, 1982, the second flight of the Space Shuttle *Columbia* was launched, carrying the first scientific payload in its cargo bay. Included in the seven experiments was the Shuttle Multispectral Infrared Radiometer, which is a nonimaging instrument designed and built at the Calfornia Institute of Technology's Jet Propulsion Laboratory, Pasadena, California. This experiment is a cooperative project among the Jet Propulsion Laboratory, the U.S. Geological Survey, and the National Aeronautics and Space Administration.

The radiometer measures the spectrum of light reflected from areas on the ground that are 300 feet in diameter. The spectral reflectance thus recorded is divided by wavelength into 10 channels that are positioned so that certain minerals are conveniently identified. Five of these channels that are in the wavelength range of 2.0 to 2.4 micrometers (far beyond the light wavelengths visible to the human eye) have proved to be particularly valuable for appraising mineral resources using these remote methods.

Approximately 400,000 spectra were acquired by the infrared radiometer in the 1981 shuttle flights along 17 orbits under cloud-free conditions over the Eastern and Southern United States, Mexico, Southern Europe, North Africa, the Mid-East, and China, in spite of the reduction of the shuttle flight to 2.5 days from a planned 5-day flight. Storm systems over the Western United States prevented the radiometer from collecting data over most of that region, although it was a primary target area. Planned coverage of Australia, South America, and South Africa was precluded by unfavorable lighting conditions because of a 2-hour launch delay.

Selection of the 10 wavelength channels for the radiometer was based on analyses of more than 1,000 laboratory and field measurements of the spectral reflectance of rocks and soils. These analyses indicated that determination by remote methods of the mineral content of rocks could be improved substantially beyond that possible using Landsat data by making measurements in the 10 wavelength channels shown in figure 3. Landsat 1, 2, and 3 recorded reflectance in four channels located between 0.5 and 1.1 micrometers. The wavelength region between 2.0 and 2.5 micrometers is of particular interest because absorption of light by rocks and soils in this region allow identification of several minerals; some of these are associated with mineralogically altered rocks in potentially metallized areas. Although Landsat 4 measures reflectance in a broad channel in the 2.10- to 2.36-micrometer region, narrower wavelength channels are needed for mineral identification.

The importance of the five radiometer channels between 2.0 and 2.5 micrometers is illustrated by the two laboratory curves in figure 4 showing subtle, but significant, differences in brightness as the wavelength changes. In the curve representing calcite, the principal constituent in limestone, the brightness decreases to a minimum at 2.33 micrometers. The other curve (fig. 4) is typical of kaolinite, a clay mineral used in the ceramic industry and commonly associated with some metal deposits. The kaolinite spectrum is characterized by a brightness minimum centered near 2.20 micrometers and a less intense depression at 2.17 micrometers. The marked decreases in brightness in the calcite and kaolinite spectral curves are related to absorption of light by vibrations in the molecules. The wavelength position and intensity of the absorption features depend on the composition and molecular structure of the mineral and, hence, the analytical value of the spectral curves.

Each radiometer spectrum consists of brightness measurements made in the 10 channels for a 300-foot-diameter spot on the ground. The measurements were made at a rate of 128 individual 10-channel spectra per second and recorded on a digital tape recorder onboard the spacecraft. Photographs recorded during the operation of the radiometer are used for precisely locating the line of 300-foot spots on the ground.

Analysis of the data was initiated in southern Egypt because of the presence of excellent exposures of sedimentary rocks and a general lack of vegetation and rugged topography, except for a few steep escarpments. Figure 5 shows the radiometric data line superimposed on a generalized geologic map of the area. Eight spectra, each based on reflectance measurements made in the 10

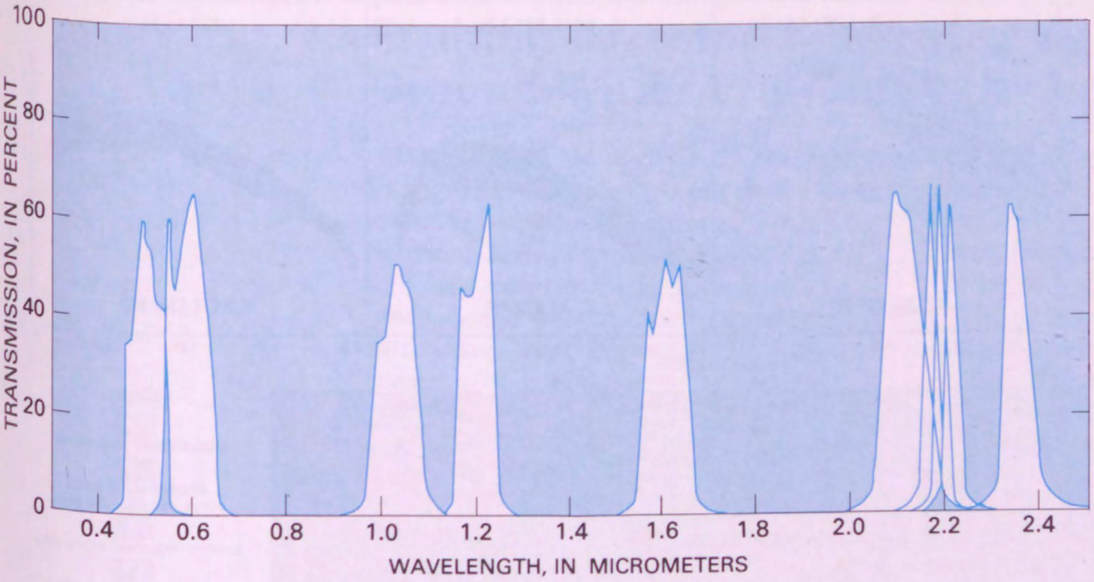


Figure 3.—*Ten wavelength channels used in the Shuttle Multispectral Infrared Radiometer.*

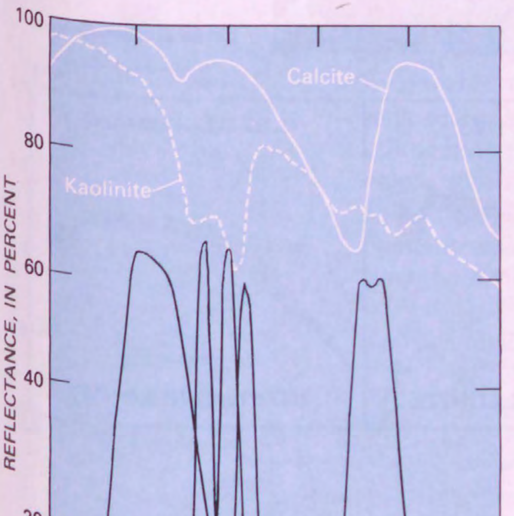


Figure 4.—*Laboratory reflectance spectra for calcite and kaolinite in the 2.0- to 2.5-micrometer region where five Shuttle Multispectral Infrared Radiometer channels (solid line) are located.*

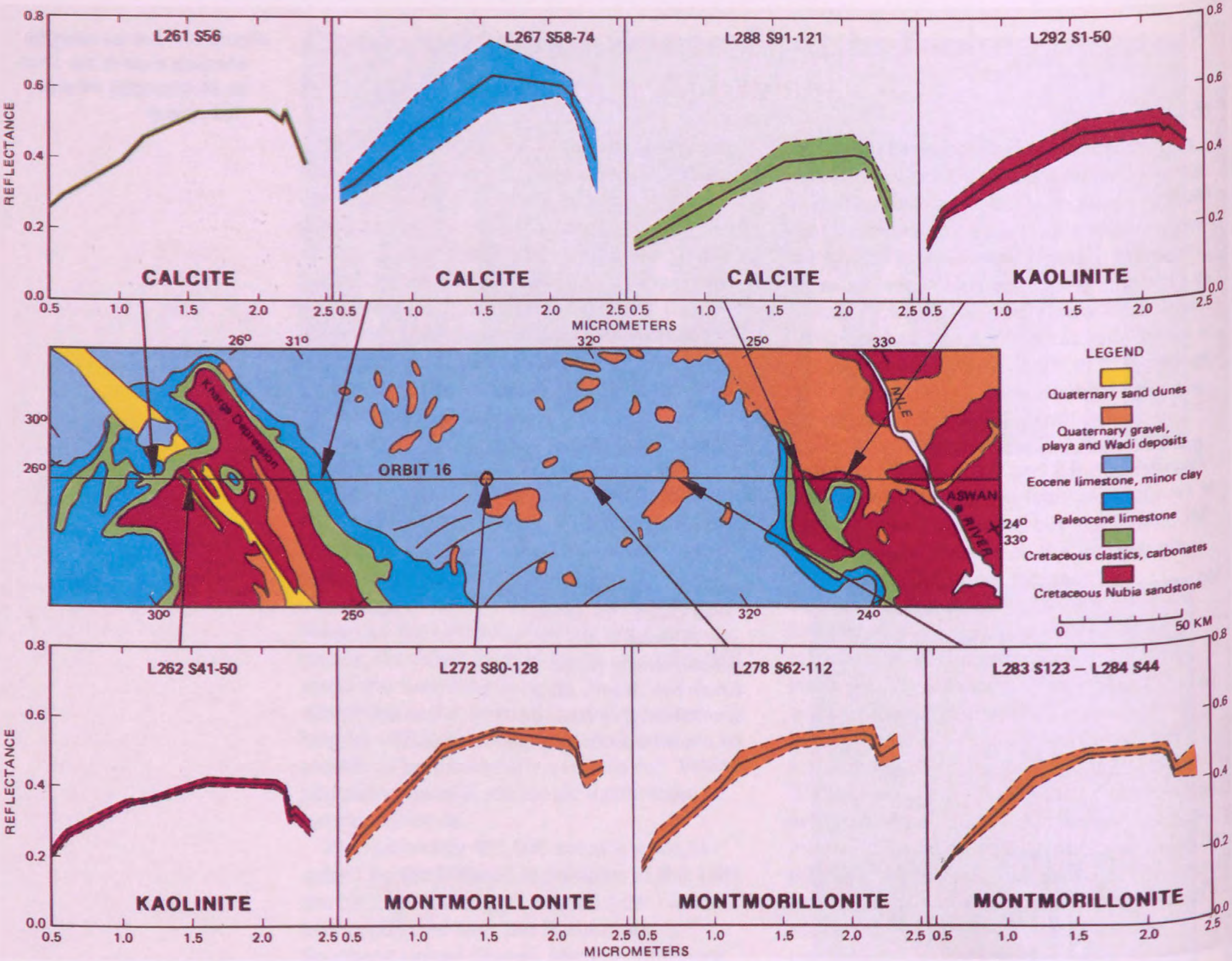


Figure 5.—*Geologic map of the Kharga-Aswan region of Egypt. The colors of the Multispectral Infrared Radiometer spectra indicate rock types. Gravel and sandstone contain two different clay materials. The solid line shows the average spectrum, and the dashed line indicates variation.*

channels, are keyed to the map using colors to indicate the rock type measured in each area. The solid dark line is the average of several spectra, and the color envelopes bounded by dashed lines express the variation. The spectrum located in the upper left corner is a single spectrum.

Mineralogical determinations are made by comparing the radiometer spectra acquired during the shuttle flight with 10-channel radiometer spectra made in the laboratory prior to the flight for a large number of rocks and minerals. Only the most conspicuous absorption features are evident in the radiometer spectra. Nevertheless, the shapes of the radiometer spectra can be used for identifying certain important minerals. The radiometer spectra, shown in dark blue and green in figure 5, have the shape that is characteristic of limestone, particularly the marked decrease in reflectance in the 2.35-micrometer channel that is caused by intense absorption in calcite (fig. 4). The other radiometer spectra indicate the presence of two types of clay minerals, one shown as red and the other as orange. The spectra shown in red indicate the presence of kaolinite in the sandstone.

The radiometer spectra shown for the rock units in figure 5 characterize the particular units for great distances; the spectra change abruptly at lithologic contacts. Although the radiometer collected spectra along narrow tracks, these results suggest that many lithologic units could be differentiated over large areas on the basis of specified mineralogical differences in high-spectral resolution images recorded from a satellite platform. Realization of this goal would permit mapping of mineralogical differences that require years of laboratory and field work using conventional methods. Such systems are already in the developmental and initial evaluation stages.

Faulting Arrested by Control of Ground-Water Withdrawal in Houston, Texas

More than 86 historically active faults with an aggregate length of 150 miles have been identified within and adjacent to the Houston, Texas, metropolitan area (fig. 6). Although scarps of these faults grow gradually and without causing damaging earthquakes, historical fault offset has caused millions of dollars in damage to houses and other buildings, utilities, and highways that were built on or across the faults (fig. 7). The historical fault activity results from renewed movement along pre-existing faults and appears to be caused principally by withdrawal of ground water for municipal, industrial, and agricultural uses in the Houston area. Approximately one-half of the area's water supply is obtained from local ground water. Monitoring by the U.S. Geological Survey of heights of fault scarps indicates that many of the scarps have recently stopped increasing in height. The area where faulting has ceased coincides with the area where ground-water pumping was cut back in the mid-1970's to slow the damage caused by land subsidence along Galveston Bay and the Houston Ship Channel. Thus, it appears that efforts to halt land subsidence in the coastal area have provided the additional benefit of arresting damaging surface faulting.

The Houston area is the largest metropolitan area in the United States dependent chiefly on local ground water for its municipal and industrial water supply. Not surprisingly, water levels in the freshwater-bearing sediments beneath the area have declined significantly since the beginning of the 20th century. These declines, in turn, have caused the water-bearing sediments to compact and the land surface to subside or sink over an area of more than 4,700 square miles. Maximum historical subsidence in the region exceeds 9 feet. The subsidence is particularly acute near Galveston Bay and along the Houston Ship Channel, where more than 31 square miles of low-lying coastal land has been permanently inundated. In addition, as the land sinks, the area susceptible to tidal flooding by tropical storms and hurricanes is increased greatly.

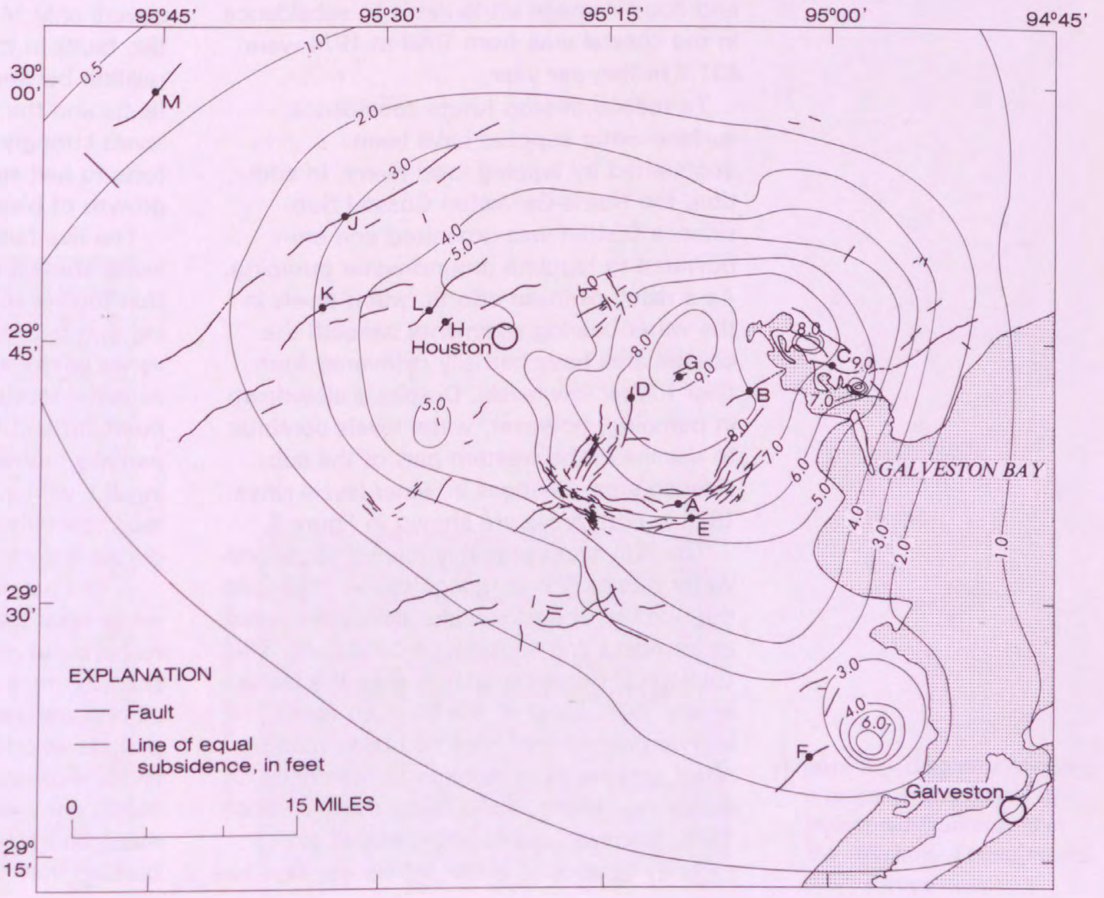


Figure 6.—*Map of surface faults and approximate land subsidence from 1906 to 1978 in the Houston, Texas, metropolitan area.*

Figure 7.—*Photograph of house damaged by a fault in northwest Houston. Fault has deformed garage and has required patch in road.*

For example, C. W. Kreitler of the Texas Bureau of Economic Geology estimated that Hurricane Carla, which struck the area in 1961, would have flooded at least 21 percent more land, a total of 146 square miles, if it had occurred in 1976. Today, more than 300,000 people would be affected by a similar event in an area where, in 1900, the worst natural disaster in United States' history occurred when a hurricane made landfall near Galveston Bay and killed more than 6,000 people. Even without a major hurricane, a study by L. L. Jones of Texas A & M University revealed property losses and flood damage attributable to subsidence in the coastal area from 1969 to 1974 were $31.7 million per year.

To reduce or stop future subsidence, surface-water supplies have been augmented by tapping local rivers. In addition, the Harris-Galveston Coastal Subsidence District was organized and empowered to regulate ground-water pumping. As a result of these efforts, water levels in the water-bearing sediments beneath the coastal area have partially recovered from their former low levels. Despite a slowdown in pumping, however, water levels continue to decline in the western part of the subsidence area. Changes in water levels since 1977 in both areas are shown in figure 8.

The first scarp probably related to ground-water pumping was recognized in 1936, and the number of active faults slowly increased as pumping and subsidence continued. The Geological Survey began to map the faults in late 1974. Most of the 50 or so faults known prior to that time had been recognized as a result of damage to manmade structures. Many of the faults mapped since 1974, however, are in undeveloped or recently developed areas, where damage has not yet occurred and could, in principle, be avoided or minimized. Today, more than 160 faults are known, ranging up to 10 miles in length and 3 feet in height. Historical scarp growth has been confirmed on at least 86 of them, and many others are suspected to be active. The fault scarps increase in height at rates that range from 0.2 to 1.1 inches per year, and the average rate of growth is 0.4 inch per year. Because the faults grow gradually and without earthquakes, they generally go unnoticed during construction unless special site investigations are conducted. Thus, houses, utilities, and roads built on a fault are subjected to cumulative structural damage as the slow steady movement continues.

In 1978, the U.S. Geological Survey began to monitor scarp growth of 12 selected faults in the subsidence area. Their measurements revealed that all seven of the monitored faults in the area of water-level recovery (fig. 8) have either completely stopped growing or slowed to rates of less than 0.05 inch per year, rates well below their average during historical time (fig. 9). By contrast, all five faults in the area where water levels have continued to drop have continued to grow at their former annual rates. Although this monitoring program covers only 14 percent of the recognized active faults in the area, the perfect areal correlation between stable or slow-moving faults and the recovery of ground-water levels strongly suggests that continuing efforts to halt subsidence will also halt the growth of historically active faults.

The five faults in the area of falling water levels show annual patterns of movement that further support the link between pumping and faulting. Movement on all five faults varies seasonally; rates of faulting increase as water levels drop rapidly during summer pumping and then decrease as water levels partially recover when pumping declines during the winter. As can be seen in figure 9, fault movement sometimes stops entirely during the winter months.

The response of the Houston faults to water-level changes is similar to the response of monitored surface faults in subsidence areas in Arizona and California. In all of these areas, faulting ceases during periods when pumping declines and water levels recover. Although the fault displacements can never be reversed, it appears that man can at least arrest the subsidence and faulting that he has initiated.

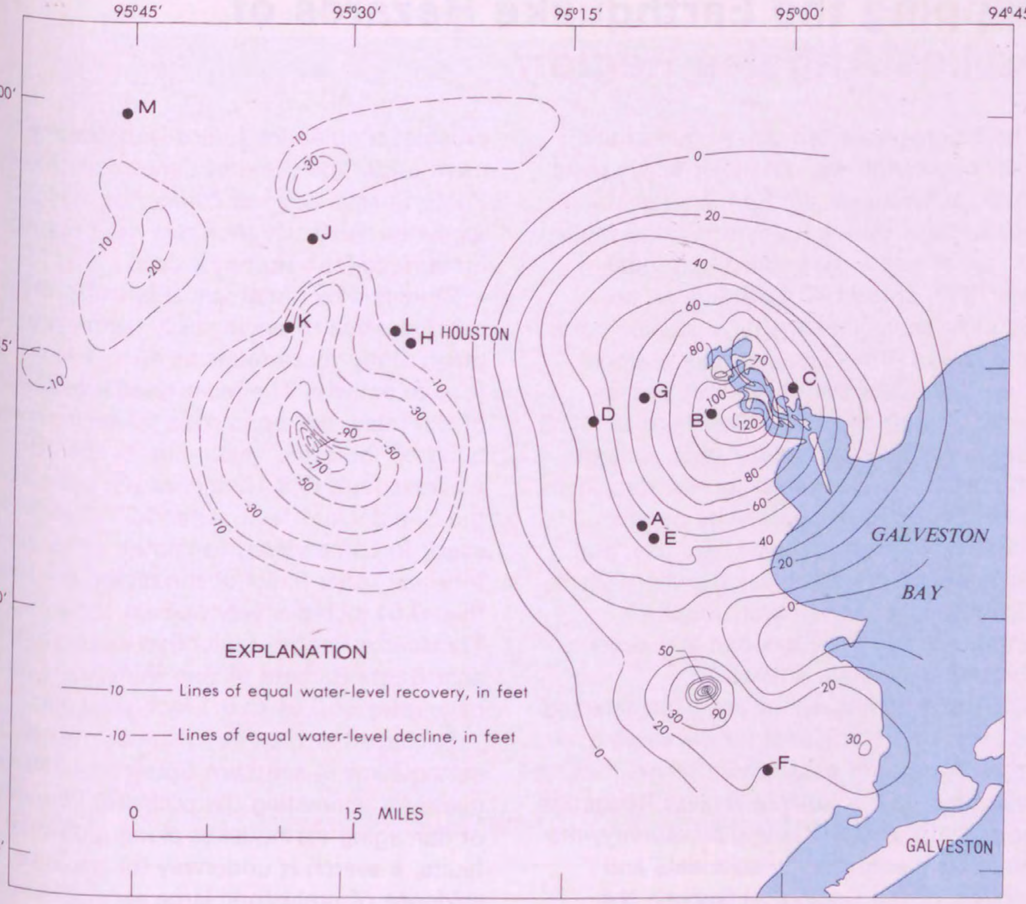


Figure 8.—*Map of changes of water level in Houston, Texas, aquifer, 1977 to 1982.*

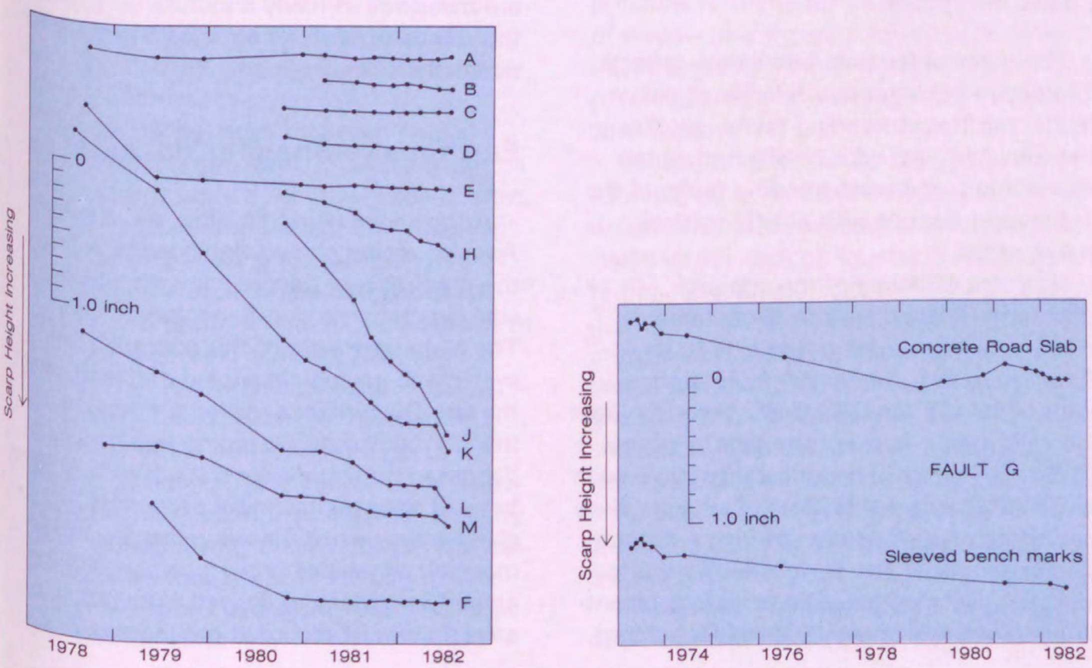


Figure 9.—*Diagrams showing changes in the height of monitored fault scarps in the Houston, Texas, metropolitan area.*

Mapping the Earthquake Hazards of the Los Angeles Region

The highly populated Los Angeles region is near one of the world's major active plate tectonic boundaries, the San Andreas fault zone, and lies astride numerous other faults that can generate destructive earthquakes. Since 1800, at least 40 earthquakes large enough to cause damage have shaken parts of the region. It is estimated that a single future earthquake could result in losses ranging as high as 21,000 casualities and $62 billion in property damage. Although large earthquakes are inevitable, losses from them can be reduced substantially by careful engineering design, by wise land use, and by emergency preparedness planning. These mitigating actions, however, require estimates of the likely location and severity of hazardous seismic effects.

The Los Angeles region has been selected as a prototype study area for developing earthquake hazard assessment techniques. Funded by the Earthquake Hazard Reduction Program of the U.S. Geological Survey, the research is conducted by scientists and engineers of the Geological Survey, the California Division of Mines and Geology, various universities, and private consulting firms.

These studies are providing an improved basis for delineating geographic variations in the earthquake hazards; specific examples are discussed below.

Fault Hazards

The regional tectonic framework reflects interaction between two families of active faults: northwest-trending faults, such as the San Andreas, with chiefly horizontal movements, and west-trending faults of the Transverse Ranges with chiefly vertical movements.

Geologic evidence of the age and geometry of latest surface displacement along a fault provides a first clue to its future behavior. Nearly 100 fault strands with offsets in late Quaternary time (the past 700,000 years), in Holocene time (the past 11,000 years), or in historical time have been identified in the region. Such faults are likely candidates for generation of future destructive earthquakes and surface-fault rupture (fig. 10). Detailed geologic mapping, recently completed for many of these fault zones, provides a guide for future land development under the State of California's Alquist-Priolo Special Studies Zones Act, which regulates construction where the potential for surface-fault rupture exists.

Studies now underway emphasize the determination of geologically recent rates of offset along these faults as an index of their relative activity. The most reliable estimates of slip rates, averaged over the past several hundred thousand years, are for the San Andreas fault (0.8-1.2 inches per year) and the San Jacinto fault zone (0.3-0.5 inch per year). In comparison, estimated offset rates for most other faults of the region are less than 0.04 inch per year, except for a belt of Transverse Ranges faults that extend from near Santa Barbara to San Bernardino and have rates of 0.04 to 0.1 inch per year.

Because the 200-year historical record of earthquakes in southern California is inadequate for estimating the probable frequency of damaging earthquakes along individual faults, a search is underway for geologic evidence of prehistoric large earthquakes in disturbed late Quaternary sedimentary deposits preserved along many of the faults. The findings suggest that parts of the San Andreas and San Jacinto fault zones have generated major earthquakes in intervals of several decades to a few centuries. In contrast, the repeat times of seismic events large enough to disturb the ground surface are measured in many hundreds to several thousands of years at points along other active faults in the region.

Earthquake Shaking Hazards

A technique being developed in the Los Angeles region should significantly improve the prediction of geographic variation in shaking response due to geologic factors. The major elements of this approach are (1) systematic geologic mapping and analysis of the late Quaternary sedimentary deposits of the alluvial basins, (2) regrouping of these deposits into seismically distinct units on the basis of their geotechnical properties and shear-wave-velocity measurements, and (3) mapping of relative ground response using amplification factors derived from comparative studies of recorded ground motions.

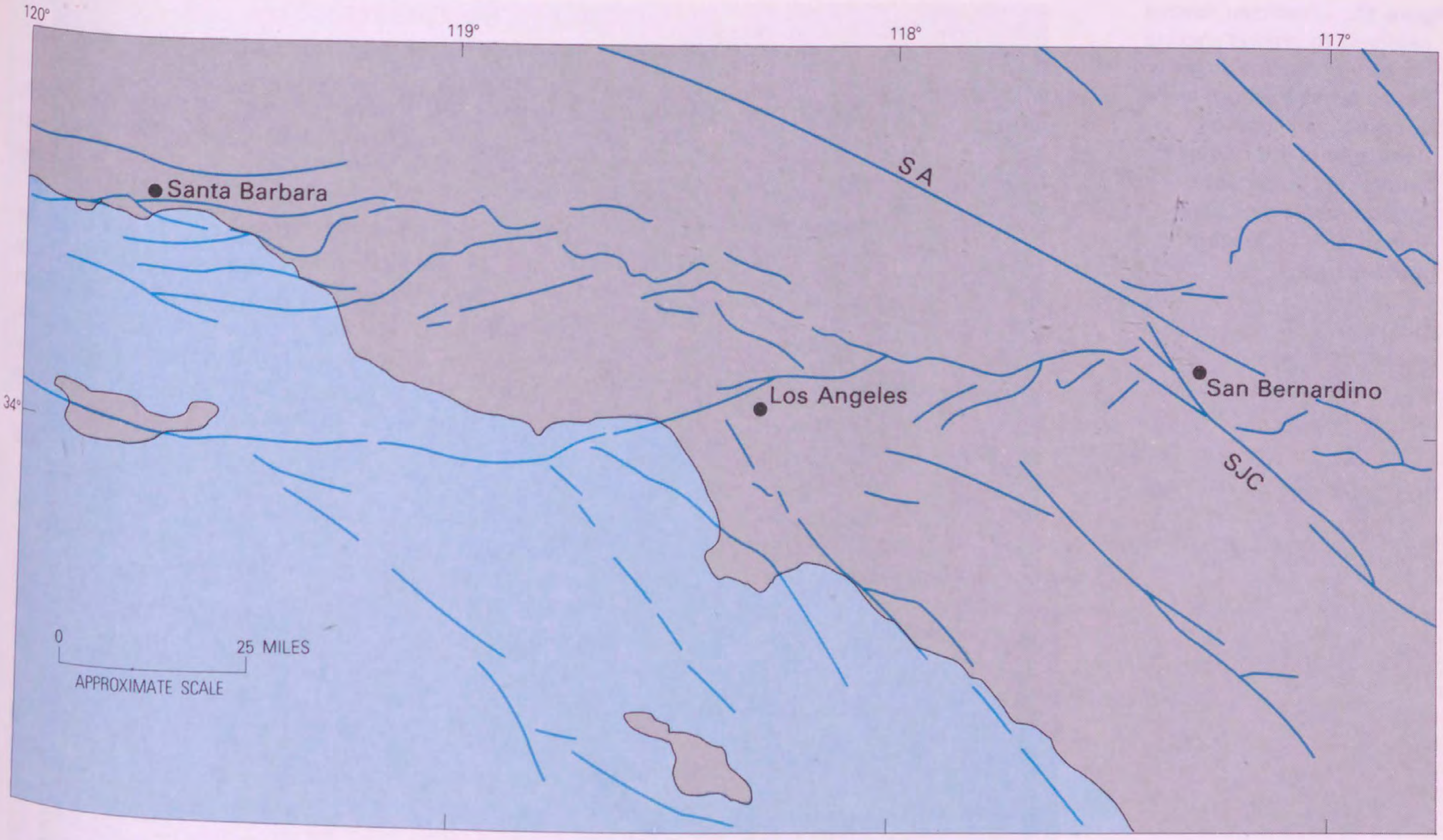


Figure 10.—*Faults in the Los Angeles region that may generate damaging earthquakes and associated surface-fault rupture. Major faults identified are SA, San Andreas, and SJC, San Jacinto.*

Ground motions from nuclear test explosions in Nevada measured at about 100 sites throughout the Los Angeles region show marked variations in amplitude that result from local geologic factors. For example, levels of shaking on alluvium are three to six times greater than on granite. The most pronounced differences in site response are correlated with differences in the amount of pore space in sediments, the thickness of surficial deposits, and the depth to hard basement rocks.

Several of the most important geologic factors that control levels of shaking can be grouped to identify distinctive types of sites. These site types are the basis for mapping future relative shaking response. Figure 11, an example of such a map for part of the Los Angeles basin, shows expected levels of response to ground shaking, relative to granite, that is of significance to 6- to 30-story buildings. Because this method uses information obtained from geologic maps, well borings, and geotechnical measurements gathered in the course of ordinary urban development, it is a versatile and easily transferable means of predicting geographic variations in shaking response from future earthquakes.

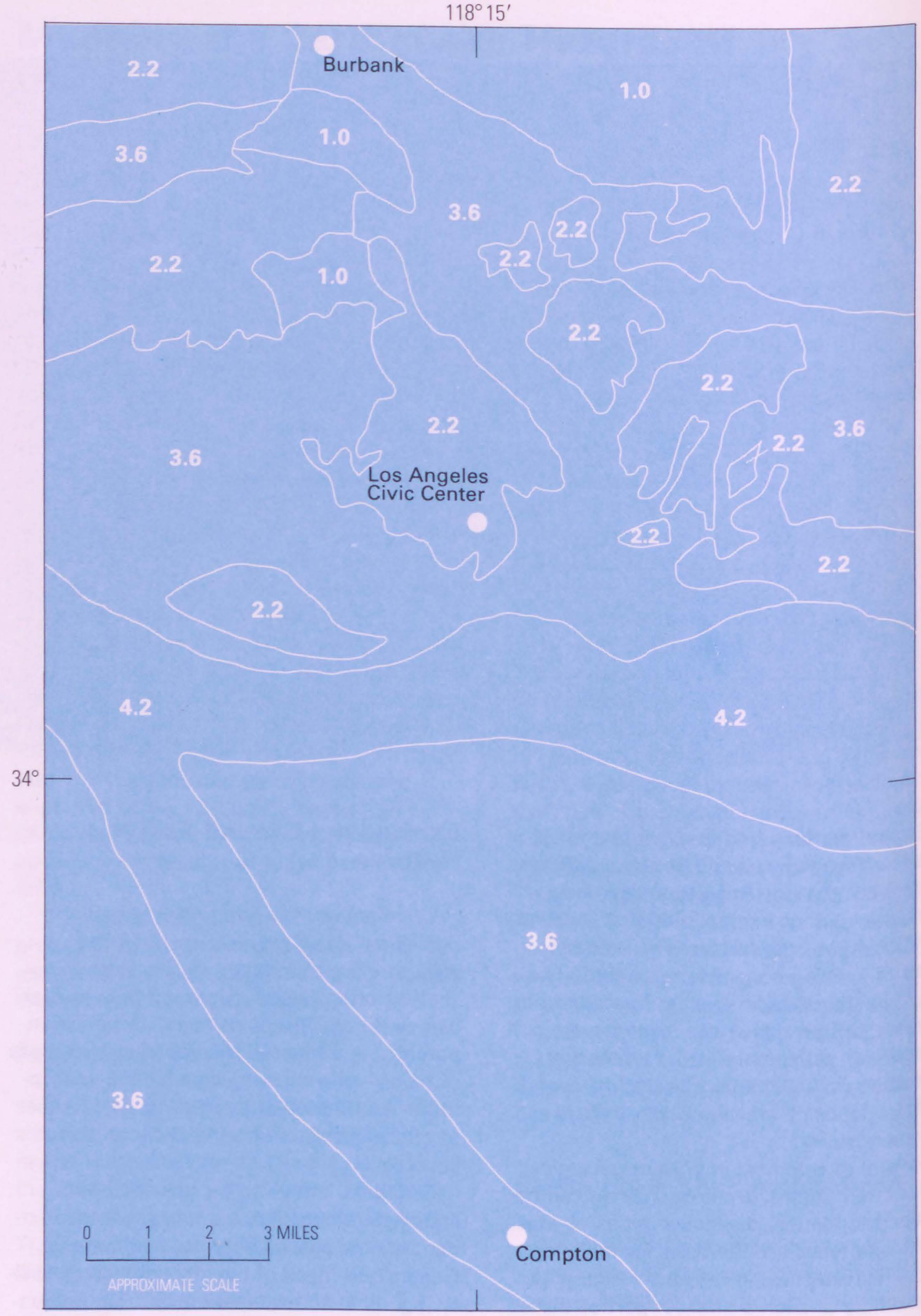
Earthquake Ground-Failure Hazards

Liquefaction, the temporary transformation of saturated granular material from a solid to a liquefied state, during seismic shaking often results in ground failures that can cause significant damage. Liquefaction potential is evaluated by preparing two types of maps—one showing liquefaction susceptibility and the other expressing the chances of critical levels of shaking likely to induce liquefaction.

Sediment known to be susceptible to liquefaction constitutes a narrow range of depositional and hydrologic environments. Generalized maps of liquefaction susceptibility (fig. 12 is an example for the San Fernando Valley northwest of Los Angeles) are prepared by analyzing the physical properties of the late Quaternary alluvial units, by grouping these according to their probable content of liquefiable material such as clay-free sand, and by considering whether these units are saturated with ground water at depths of less than 50 feet beneath the ground surface.

Alluvial materials most likely to contain clay-free sand are those deposited during

Figure 11.—*Predicted relative response to ground shaking for part of the Los Angeles basin. Numbers indicate the expected amplification, compared to sites on hard granite, for earthquake ground motions of significance to 6- to 30-story buildings.*



Holocene time (the past 11,000 years) and especially those deposited during the past few hundred years. These can be recognized and mapped on the basis of soil-profile development, geotechnical properties, and geomorphic expression.

Maps are being prepared that show contours of repeat times of shaking intensities strong enough to generate liquefaction in highly susceptible sediments (approximately VII or greater on the Modified Mercalli Intensity Scale). Preliminary studies, for example, suggest that such levels of shaking occur about every 45 years within the San Fernando Valley.

Implications

Progress is being made in the Los Angeles region toward mapping the areal potential for damaging earthquake effects. The improved methods of hazard evaluation being developed in this pilot area can be applied to other earthquake-prone metropolitan areas of the Nation. Substantial savings in lives and dollars can be anticipated as this information is used by planners and engineers to avoid or accommodate the effects of future earthquakes.

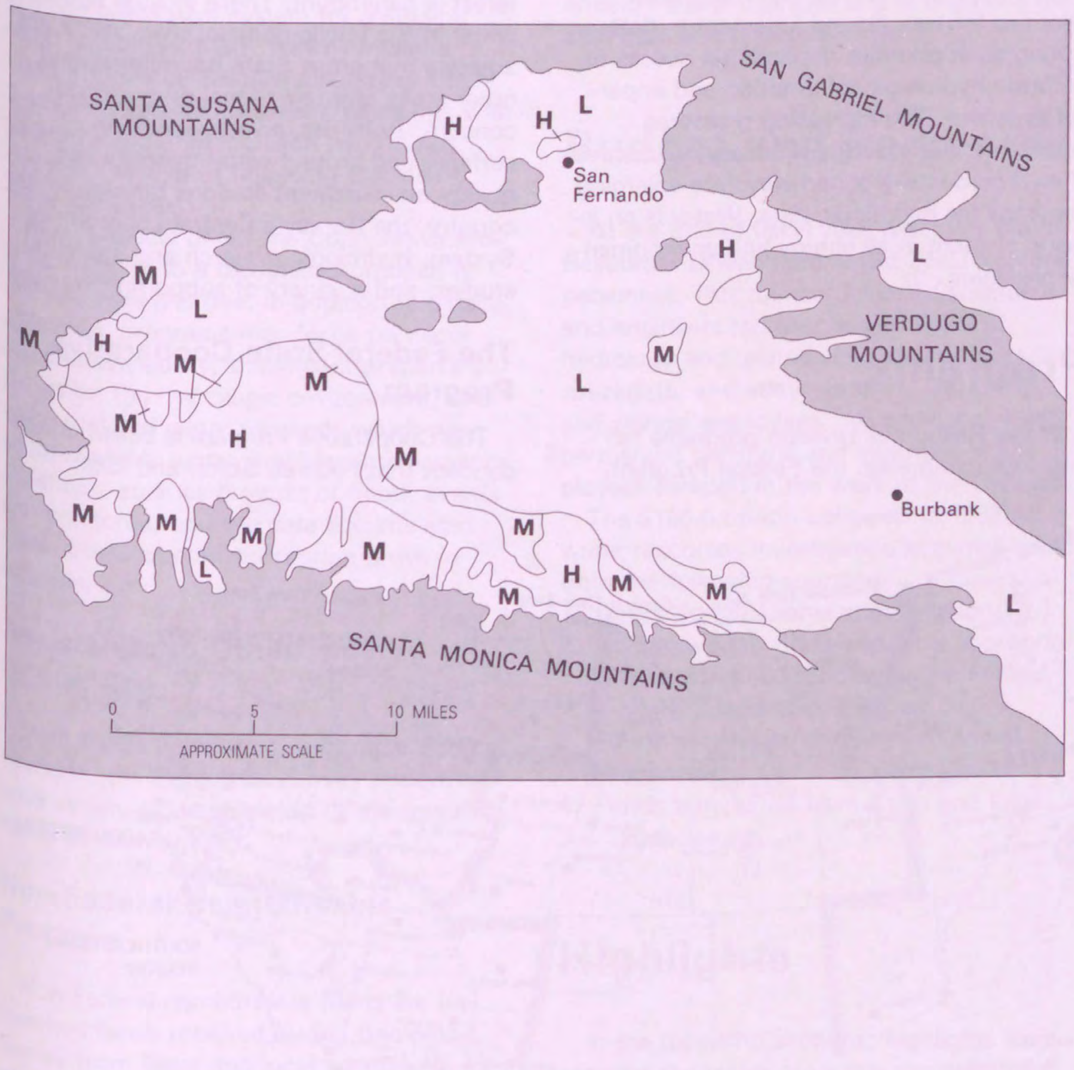


Figure 12.—*Susceptibility of alluvial sediments of the San Fernando Valley to earthquake-induced liquefaction. H = high, M = moderate, and L = low susceptibility in areas where clay-free sand layers are present.*

Water Resources Investigations

Mission and Organization

The U.S. Geological Survey has the major responsibility within the Federal Government for assessing the Nation's water resources. It collects basic data and conducts special investigations to provide background information for planners and managers. Demands for water from a wide variety of users increasingly require that planners at Federal, State, and local levels establish priorities for use. Sound judgment in determining such priorities depends on access to accurate hydrologic information and impartial expertise. The increasing pressures associated with developing energy resources in environmentally sound ways are enlarging demands for hydrologic data. Water is an integral element in all energy and environmental problems.

Programs

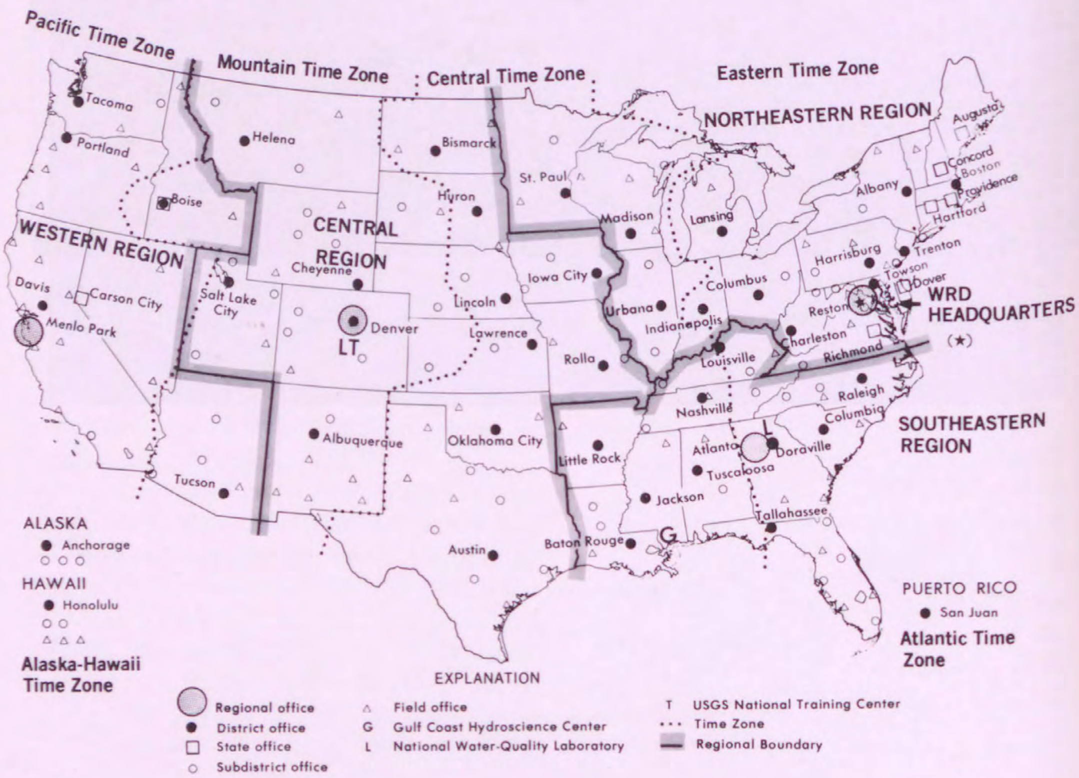
Water Resources Division programs fall into four categories: the Federal Program, the Federal-State Cooperative Program, Assistance to Other Federal Agencies, and the Non-Federal Reimbursable Program.

The Federal Program

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

The Federal-State Cooperative Program

The Cooperative Program is based on the concept that Federal, State, and local



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

governments have a mutual interest in evaluating, planning, developing, and managing the Nation's water resources. The immense size of the task of appraising the Nation's water resources precludes accomplishment by Federal efforts only. Similarly, State and local agencies working independently cannot relate to the sizable regional aspects of the hydrologic system. Cooperation though this Program, under which the Survey matches funds provided by State agencies, provides an economical and comprehensive system for assessing water resources. Many water problems begin at the local level. Recognizing this, the Survey has cooperative agreements with all States under which each party funds one-half the cost of financing studies of water resources.

Most projects under the Cooperative Program respond to a recognized problem or define a potential one. In addition to data collection, programs may focus on water use and availability, the impact of man's activities on the hydrologic environment, and energy-related water demands which may strain available water supplies. In emergency situations, such as drought or flood, events are monitored, and the data accumulated under the Cooperative Program prove invaluable.

Assistance to Other Federal Agencies

With funds transferred from other Federal agencies, the Geological Survey performs a wide variety of work related to the specific needs of each agency.

Non-Federal Reimbursable Program

Non-Federal reimbursable funds are unmatched funds received by the Geological Survey from State and local agencies in situations where there is both Federal and State interest in investigation of water resources but where matching Federal funds are either unavailable or are not otherwise applicable to cost sharing.

Office of Water Data Coordination

A major responsibility was assigned to the Survey in 1964 when it was designated the lead agency for coordinating water-data acquisition activities of all Federal agencies; activities include those that produce information on streams, lakes, reservoirs, estuaries, and ground water. This coordination effort minimizes duplication of data collection among Federal agencies and strengthens the data base and ts accessibility.

Budget and Personnel

At the end of fiscal year 1982, the Water Resources Division employed 2,923 full-time personnel. This number included scientists and engineers representing all fields of hydrology and related sciences, technical specialists, and administrative, secretarial, and clerical employees. An additional 1,445 permanent part-time and intermittent employees assisted in the work of the Division.

The $186.6 million obligated in 1982 for water resources investigation activities came from the following sources:

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

Highlights

In the following sections, highlights from some of the major programs are described.

The Federal-State Cooperative Water Resources Program—Some Highlights From 1982

The Federal-State Cooperative Program, started in 1895, continues to be the largest part of the U.S. Geological Survey's water-resources activity. In fiscal year 1982, this working partnership with 750 State, regional, and local agencies totaled about $88 million for hydrologic investigations and data collection in every State, Puerto Rico, and several of the territories. Details of the work and funding, which call for 50-50 matching, are arranged at State and local levels by representatives of the Survey and the cooperating agencies. The work is directed by the Survey, principally by Survey staff, who are accountable to the cooperating partners.

The process of project selection is a mutual effort whereby the Geological Survey represents national interests, including the needs of other Federal agencies, and the cooperators represent State and local interests. Recognition of water problems as national issues occurs naturally from perspectives pieced together from widespread Cooperative Program activities. The program concentrates on producing water information of highest priority to the Nation; for example, current concerns regarding ground-water contamination, flood-plain management, and underground waste storage had, as forerunners, a multitude of individual cooperative investigations across the country.

In addition to analytical and interpretive work, the program provides for more than one-half the water resources data collected by the Survey. This includes most of the streamflow information used by the National Weather Service in its flood-forecasting responsibilities. Thus, the Cooperative Program is the foundation for much of the country's water-resources planning and management. It also serves as a headstart on developing approaches to individual water problems before they become national crises. A few of the accomplishments of 1982 are highlighted below.

Acid Mine Discharge in the Kansas-Missouri-Oklahoma Tri-State Area

Lead and zinc have been mined in the tristate (Kansas-Missouri-Oklahoma) area since the late 19th century. Peak production was reached in the 1920's and declined until 1958, when most mining operations were discontinued. Initially, mines were shallow and above the water table. As mining was extended to greater depths, as much as 300 feet below the water table, pumping was required to keep the mines dewatered. The mines became interconnected as the ore was removed so that, when mining and mine dewatering ceased in the mid-1960's, the entire group of mines flooded. Water levels rose in the mine shafts as water from the surrounding Boone aquifer and from surface streams flowed into the mines.

As the result of a cooperative investigation with the Oklahoma Geological Survey in the mid-1970's, the Geological Survey estimated that acid mine water would eventually begin discharging into Tar Creek. Subsequent monitoring of ground-water levels in the area indicated that this discharge could be expected to occur in the early 1980's. Overflow from the mines began in April 1980. In 1982, because of the extent of the contamination, the Tar Creek area was declared to be the Nation's number one hazardous-waste site by the Environmental Protection Agency.

In addition to discharge into Tar Creek, the Survey noted that there was potential for contamination of the shallow Boone aquifer which contains the mines. Furthermore, it might be possible for water from the mines to move downward to the underlying Roubidoux aquifer, the primary source of drinking water for communities in the area.

The Geological Survey, in cooperation with the Oklahoma Geological Survey, is currently investigating the Roubidoux aquifer to develop information on its hydraulic characteristics, geochemistry, and potentiometric surface. Other investigations, in cooperation with the Kansas Department of Health and Environment and the Oklahoma Water Resources Board, are geared to assess further the water quality and the extent of contamination from lead and zinc mines in the respective States. Additional work will be needed to understand fully the hydrologic system in the area, including the flow quantity and quality of water entering and discharging from the mines.

Digital Ground-Water Simulation, Portland, Oregon

The city of Portland, Oregon, derives its water supply from the Bull Run watershed high in the Oregon Cascade Mountains. The present system serves approximately 750,000 people in the greater Portland metropolitan area. Four aquifers near the Columbia River are being developed at a cost of $25 million to provide a supplemental and emergency ground-water supply.

The water in the highly permeable gravel surficial aquifer is nitrate-rich and is connected with the river. In addition, three artesian aquifers have been the target of an exploratory program and will be tapped by about 20 out of 30 production wells, 11 of which have been completed to date. Based on results of geophysical exploration, the Geological Survey believes that an ancient stream channel of considerable thickness lies buried near the eastern part of the Portland well field. If so, the potential for substantial recharge to the aquifers in this area is promising.

The first water delivery, in the amount of 50 million gallons per day, is scheduled for spring 1984. By summer 1985, the well field is expected to be fully developed and capable of producing 100 million gallons per day from both artesian and water-table aquifers. The well-field pumping station may be available for hydroelectric generation by reversing flow to use 100 million gallons per day directly from the Bull Run surface-water supply. Such a multiple use of facilities could prove cost-effective and, if successful, might enable the recharging of the artesian aquifers by cyclic injection.

The Geological Survey's cooperative program with the city of Portland calls for development of a three-dimensional mathematical model to project the effects of various pumping rates on water levels in the well field and vicinity. Preliminary model runs show that some interconnection between the Columbia River and the Portland well field exists and that, under sustained pumping, artesian pressures in the aquifer system would drop severely over a wide region. Without recharge, such stress could bring on adverse effects such as dewatering, land subsidence, and downward movement of nitrate-rich ground water from the gravel aquifer. Projections made by using the completed computer model could be used to indicate the most favorable locations for installation of large-capacity wells in these aquifers. Thus, the city of Portland regards the completion of these projections and the final calibration of the model as having considerable significance.

Ground Water in the Greater Atlanta Area, Georgia

The Piedmont physiographic province extends from Alabama to New Jersey east of the Appalachian Mountains and covers thousands of square miles. Because of the anticipated low yields of water to wells, communities and industry in the Piedmont have developed surface-water sources for supplies. The demand for water, however, is rapidly outstripping the available surface water. The need for an alternate source of supply for the greater Atlanta area led to a ground-water investigation of the Piedmont by the Geological Survey in cooperation with the Earth and Water Division of the Georgia Department of Natural Resources.

The investigation indicates that deep wells tapping the Piedmont crystalline rocks may produce sufficient ground water to serve as an alternate source of supply to cities and industry in the Atlanta area. These results, and the criteria developed on the basis of topographic analysis to indicate the possible location of horizontal fractures, may be of value throughout the Piedmont. It is possible that deep-lying horizontal fractures also exist in crystalline metamorphic rocks in other parts of the country. If so, the impact of this investigation may be even greater than anticipated.

The study area comprised 6,000 square miles and covered all or parts of 23 counties. The crystalline rocks underlying the Piedmont are generally considered to be poorly permeable and capable of yielding only small quantities of ground water to wells, usually in the range of 2 to 30 gallons per minute. Such yields are obtained from vertical to near-vertical fractures that are most numerous near the land surface, diminish rapidly in size and number with depth, and are practically nonexistent below depths of 300 feet.

During the investigation, however, many wells were reported to yield from 50 to nearly 500 gallons per minute, but these were unusually deep, some as much as 700 feet. A number of the wells have been producing several hundred gallons per minute for 20 years. Investigation of selected wells by geophysical downhole logging and television cameras revealed horizontal fractures at depth, with some openings seemingly as large as 8 inches. It may be that these horizontal fractures resulted from the release of stress in the crystalline rocks as overlying materials eroded away. The areal extent of individual fractures is still unknown; however, wells as far as 1,000 feet apart are known to tap the same horizontal fracture. There is also evidence that some fractures may extend under an intervening ridge, thus hyraulically connecting adjacent valleys.

Hydrologic Data Collection

Of the 8,000 continuous-record streamflow stations operated by the Geological Survey, some 5,100 were supported by the Cooperative Program in 1982. In addition, intermittent records of streamflow were collected at 6,700 sites, and water-level data were recorded at 680 lakes and reservoirs. Water-quality information was obtained at 6,600 surface-water sites and 7,700 ground-water sites. Ground-water levels, and sometimes pumpage or flow, were measured at 21,000 wells and springs.

The information produced by these activities and the results of similar work in years past are the foundation for analytical and interpretive hydrologic appraisals, water resources planning and management, and problem-oriented research. Activities have been discontinued at some sites and started at others in response to changing needs and priorities. The data are published annually in a series of reports, generally on a State-by-State basis.

Hydrologic data are often needed prior to report publication and sometimes more quickly than the 4 to 6 weeks required for the many operations involved in collection, analysis, and processing. Some of the requirements for real-time data include flood warnings, irrigation-water allocations, water-supply forecasting, reservoir management, water-quality monitoring, management of navigational waters, and allocation of urban water supplies. Telemetry of information from remote data-collection sites has been accomplished by telephone and microwave radio, and now advanced electronic and satellite systems are used. The Survey currently operates more than 250 stations from which data are relayed by the Geostationary Operational Environmental Satellite. This has proved to be a reliable and, in some instances, cost-effective tool for real-time data acquisition. Any significant expansion of this application depends on a more complete evaluation of the need for and the economic benefits of the system. Rather than collecting data on the basis of standard-time intervals, it may be possible to develop instrumentation that will call for data in response to preselected changes in river stage, water quality, or other hydrologic characteristics.

In addition to operational improvements at individual sites, the Survey is reviewing its networks of stream-gaging stations to indicate the most cost-effective means of collecting the necessary data within prescribed standards of accuracy. The techniques for these evaluations, which will be carried out on a State-by-State basis, are being modified to accommodate legislative, judicial, and administrative directives, as well as requirements for flood and water-supply forecasting, current-purpose water management, and input to other hydrologic investigations and research. As a result, in the 1980's, some data-collection sites may be discontinued, others will need to be established, and, at selected stations, the parameters measured and the frequency of measurement may be altered.

For 1983, selection of specific activities to be included in the Cooperative Program will consider as highest priority investigations of ground-water contamination, water supply and demand, stream quality, and hydrologic hazards. These topics were identified as being of major national concern through consultation with Federal, State, and local agencies and reflect the judgement of the Geological Survey regarding its role in the water resources field. Other issues, such as acid precipitation, urban hydrology, and assessment of lakes and estuaries, also are considered high priority for new work, but their importance may differ in various parts of the country. The need for additional data-collection sites, as well as improvements in efficiency and cost effectiveness of data networks, will likewise be given careful scrutiny.

The advantages of the program's cost-sharing arrangement are increasingly evident as funds become tighter. Clearly, the need for water-data and hydrologic investigations and research will be great in the 1980's. The Cooperative Program is one proven way to serve Federal, State, and local interests and to assure the availability of resulting information nationally to all users.

Regional Snow Chemistry Reconnaissance

Concern about the possible environmental effects of acid rain is in the public spotlight. Because the problem is not yet fully understood, it is important to move from the area of speculation into that of scientific research. The U.S. Geological Survey has been part of this effort and is conducting studies related to acid rain and the atmospheric transport and deposition of potentially toxic chemical constituents. A recent investigation by the Geological Survey involved the areal distribution of chemical constituents deposited from the atmosphere in the North-Central and Northeastern United States, an area severely affected by acid rain. To reduce high analytical and collection costs, which are generally associated with a more extensive and formal monitoring program, bulk precipitation collectors consisting of 6-foot-high, 18-inch-diameter fiber tubes fitted with collection bags were installed at the beginning of December 1980 at 189 sites from Maine to Minnesota and from the Canadian border south to the Ohio River valley. Samples were retrieved early in March 1981 from all but 10 sites, where the samples were lost.

Contaminants deposited from the atmosphere can be divided into two parts: the wet component, which includes rain, snow, dew, and hail, and the dry component, which includes large particles that settle out of the atmosphere by gravity, fine to intermediate particles that are deposited by impact on surfaces, and gases that are absorbed or adsorbed by surfaces. Bulk precipitation, which was selected as the collection method in this study, is composed of large particles or dustfall and wet deposition in an open container. Interpretation of the composition of bulk precipitation is difficult because substances borne in the wet component cannot readily be distinguished from those borne in the dustfall. This problem is particularly troublesome when the dustfall component is large and is derived locally. In an attempt to reduce the contribution from local dustfall, the samples were collected during the winter when frozen ground and snow cover minimized the amount of locally derived dustfall. The bulk precipitation during this period should, therefore, represent the regional atmospheric deposition. Considerable effort was also made to avoid potential sources of local contamination from highways, chimneys, barnyards, and vegetation. For the most part, the collectors were placed a considerable distance from other major sources of contamination such as cities, industrial plants and coal- and oil-fired powerplants.

Samples were filtered and analyzed for the following 29 constituents: arsenic (As), barium (Ba), beryllium (Be), total inorganic carbon (TIC), cadmium (Cd), calcium (Ca)*, chloride (Cl)*, cobalt (Co), copper (Cu), flouride (F)*, iron (Fe)*, hydrogen (H)*, mercury (Hg), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn)*, molybdenum (Mo), nitrogen as ammonium (NH_4)*, nitrate (NO_3)*, sodium (Na)*, nickel (Ni), lead (Pb)*, selenium (Se), silica (Si), strontium (Sr)*, sulfate (SO_4)*, vanadium (V), and zinc (Zn). The analytical techniques and sampling procedures produced results that were judged to be reliable to assess the regional deposition patterns for 12 of these constituents (denoted above by an asterisk). For each site, daily mass loadings (mass per unit area which is generally expressed as milligrams per square meter or micrograms per square meter) were calculated from constituent concentration and quantity of precipitation that fell during the collection period at adjacent National Weather Service stations. These daily loadings are more useful for delineating regional patterns in atmospheric deposition than the concentrations because the length of the collection period and quantities of precipitation varied from site to site.

Regional patterns displayed for pH on figure 1 show that the areas of highest acidity (pH less than 4.2) were centered in western Pennsylvania, western New York, and eastern Ohio. For the 3-month collection period, the area east of Lake Michigan, with the exception of a few collection sites, received acid precipitation with a pH less than 4.8. In Minnesota, on the other hand, pH's were greater than 4.8, and, in western Minnesota, they were greater than 7.0. The samples that had high pH's also had high concentrations of total inorganic carbon and calcium and were in the area that received the lowest amount of precipitation. These high pH's may, therefore, reflect acid neutralization by dustfall derived from the alkaline soils in the area. Patterns for nitrate, lead, and iron loading are similar to those of pH and may reflect some interrelationship.

Many constituents showed local anomalies, although it was not the original intent of this study to assess them. Local deviation from regional patterns is exemplified by fluoride deposition (fig. 2). High fluoride deposition generally occurred downwind from urban and industrial centers where the principal users of flouride are the iron and steel, electronics, and chemical industries.

Finally, the validity and usefulness of these data may be tested by comparing them to the distribution of atmospheric deposition reported from other networks. The deposition pattern of hydrogen ion (mass per unit area) from this study agrees with that for wet deposition (averaged for 1978) from the Canadian Network for Sampling Precipitation. Furthermore, during late fall 1979 and winter 1980, the regional pattern for wet deposition from the Geological Survey study is similar to that of the National Atmospheric Deposition Program, excluding Minnesota and western Wisconsin where, as mentioned previously, the acidic atmospheric deposition may have been neutralized by dustfall.

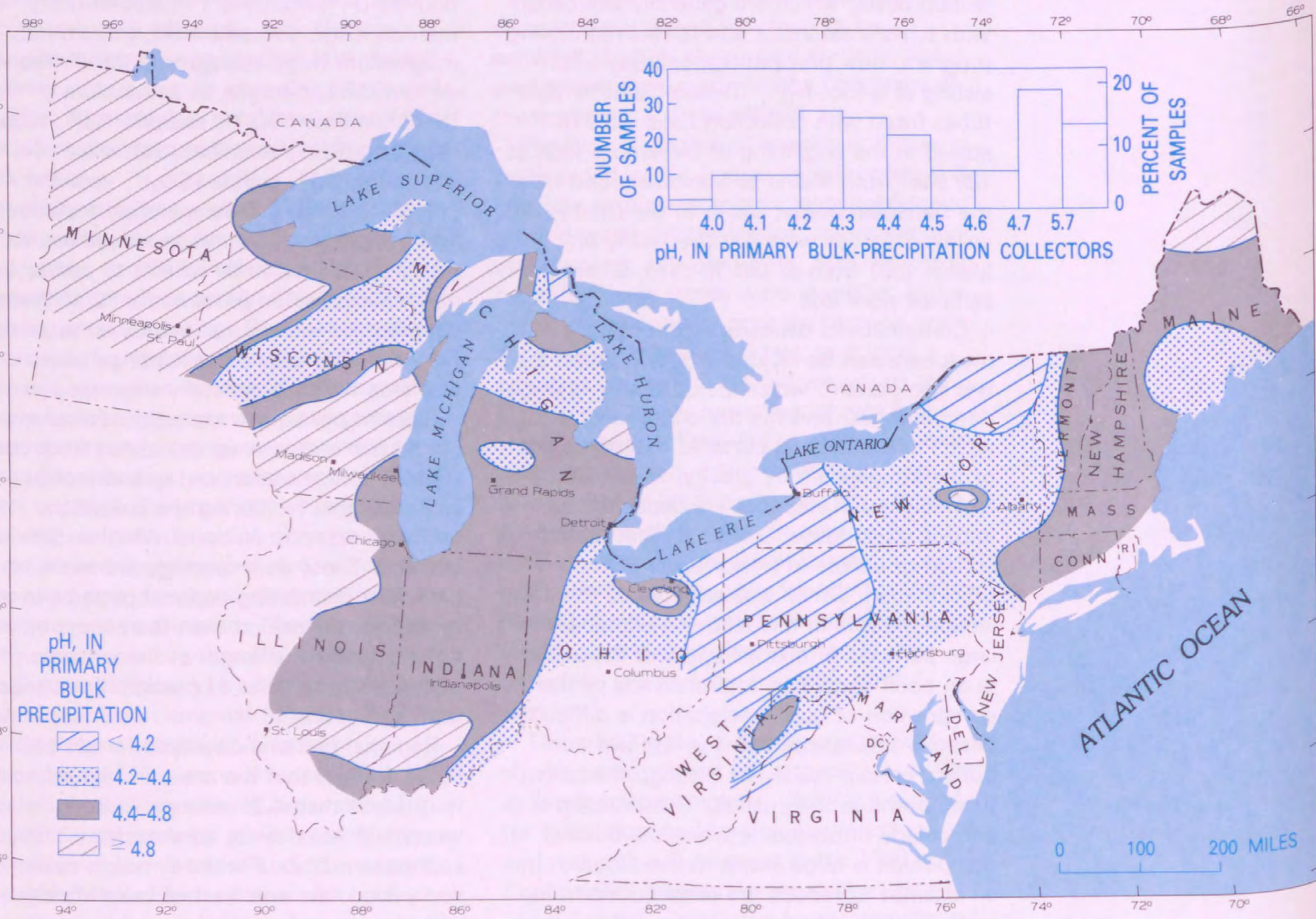


Figure 1.—*The spatial distribution of pH in bulk precipitation in the North-Central and Eastern United States during the 1980–81 winter. (Modified from fig. 14A, U.S. Geological Survey Circular 874.)*

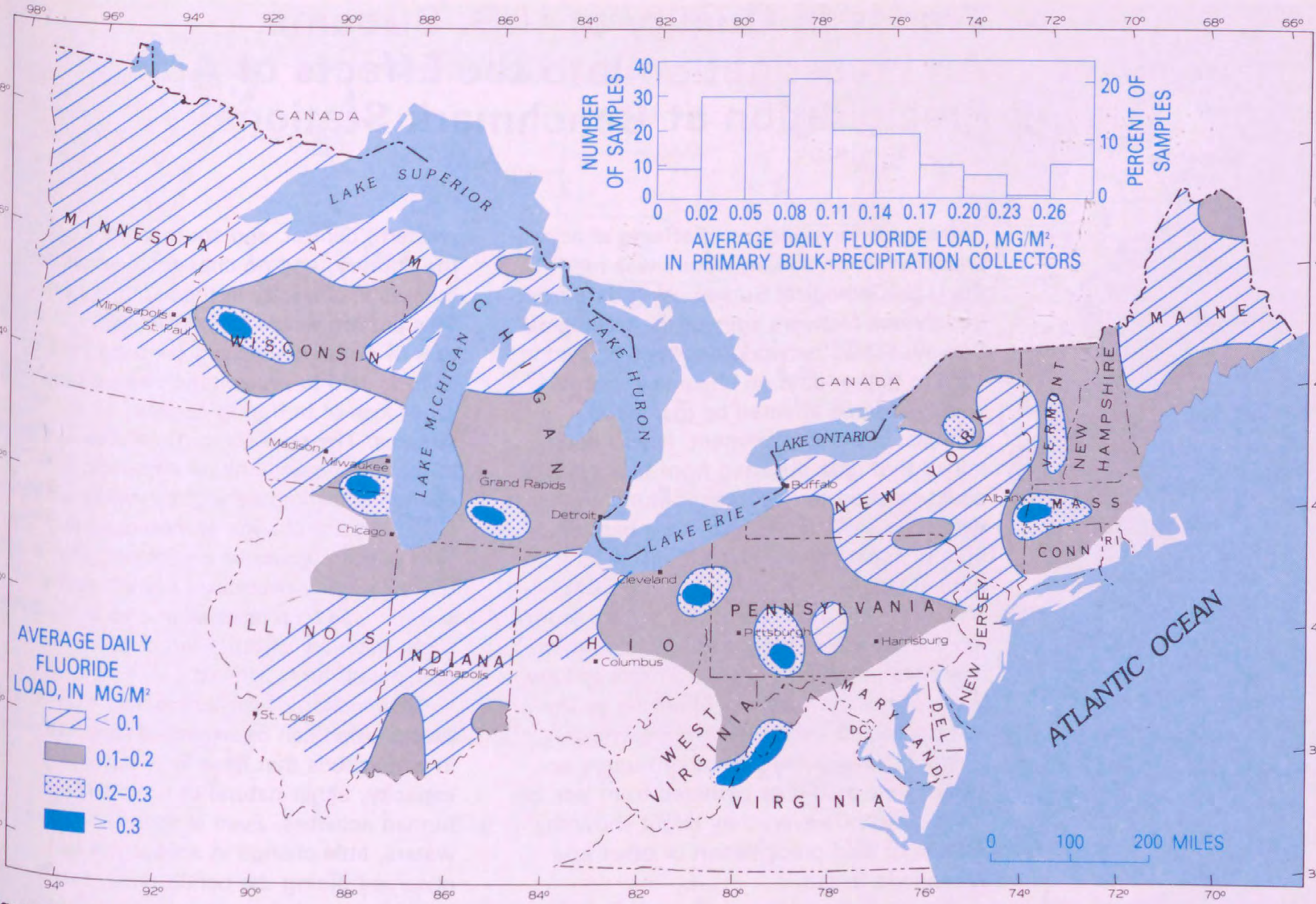


Figure 2.—*The spatial distribution of fluoride deposition in bulk precipitation in the North-Central and Eastern United States during the 1980–81 winter. (Modified from fig. 12B, U.S. Geological Survey Circular 874.)*

Trends in Quality of U.S. Streams: An Investigation into the Effects of Acid Precipitation at Benchmark Stations

A search for evidence of effects of acid precipitation on stream waters was made by the U.S. Geological Survey using data from Benchmark Network sites of the Geological Survey. (This "network" was established in 1958 to gather data on streams in basins which are little affected by manmade changes in the environment. It was determined that data obtained from these basins could be used to document natural changes with time and thereby provide a better understanding of the hydrologic structure of natural basins. In addition, the network could provide a comparative base for studying the effects of man on the environment.) The data gathered from the 51 streams and lakes of the network would not be as likely to be affected by population growth, industrial development, or other human activities as would data gathered from less isolated sites; however, they might show the effects of acid precipitation or other atmospheric fallout.

Although a number of the stream basins had high enough buffering capacity to mask the effects of precipitation acidity, evidence for small, but geographically, widespread changes in sulfate and alkalinity was noted (fig. 3). The pattern observed in streams expected to be sensitive to the effects of precipitation on water quality was that of no change or small increases in sulfate in the western, central, and southeastern parts of the country, and no change or small decreases in alkalinity in the same regions. This pattern would be consistent with a picture of slightly increased contributions of sulfuric acid to precipitation and a resulting slight loss of buffering capacity in the streams. The opposite pattern was exhibited in the Northeast—sulfate either did not change or decreased slightly, while alkalinity either did not change or increased slightly. This pattern would be consistent with a picture of slightly decreased contributions of sulfuric acid to precipitation and a resulting slight recovery of buffering capacity in the streams in the Northeast.

Acidification of surface waters due to acid precipitation can be expected to occur only in watersheds that have little buffering capacity, either natural or provided by human activities. Even in these sensitive waters, little change in acidity will be observed during the period when the buffering capacity of the watershed is being exhausted. When this has occurred, however, acidification of the water body will progress much more rapidly, even with precipitation acidity remaining the same. Measurement of alkalinity probably is the best way to detect a progressive change in the buffering capacity of a body of water.

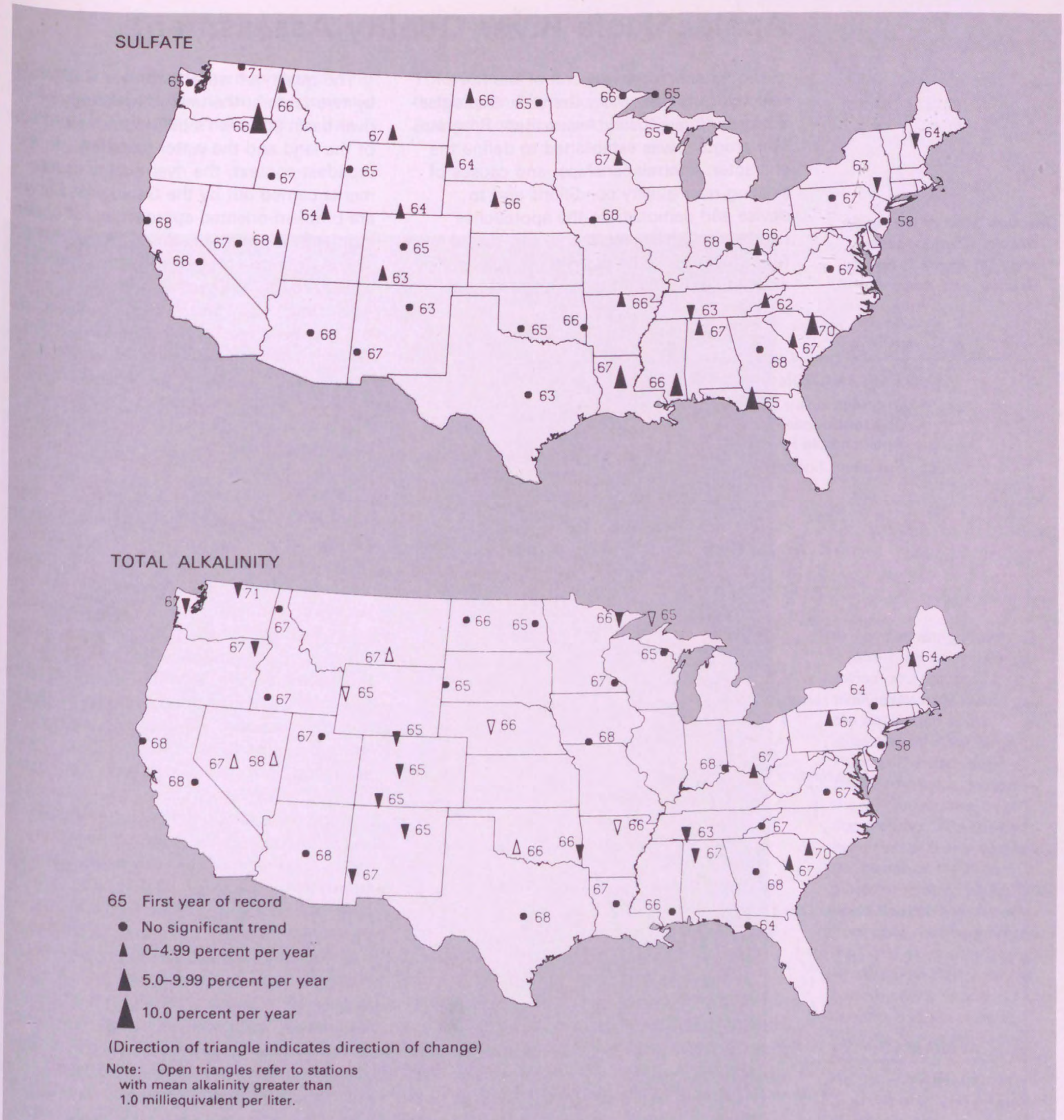


Figure 3.—Trends in sulfate and total alkalinity at hydrologic benchmark stations in the United States from 1963 to 1981.

Apalachicola River-Quality Assessment

The Apalachicola was one of the rivers selected for study under the U.S. Geological Survey's River-Quality Assessment Program. The program was established to define the character, interrelationships, and causes of existing river-quality conditions and to devise and demonstrate the approaches needed for developing technically sound information for use by planners to evaluate alternatives for river-quality management.

Drainage basin of the Apalachicola, Chattahoochee, and Flint Rivers in Florida, Georgia, and Alabama.

The quality of water in a river is affected by two factors: the unique hydrology of a river basin and man's development and use of the land and the water resources. In the broadest context, the river-quality assessments carried out by the Geological Survey are problem-oriented approaches for obtaining the needed information.

The Apalachicola River meanders 106 miles through northwestern Florida to Apalachicola Bay on the Gulf of Mexico. It is a good example of a multiuse waterway system. The area's principal commercial activities, barge traffic, timber harvest, land development, and commercial fishing in the Apalachicola Bay, often require different management practices for optimum returns in this river basin.

A flood-plain forest of 175 square miles borders the Apalachicola River in Florida. It has sustained a viable timber industry since the early 1800's. The bottom-land hardwood forest contains over 40 species of trees in a largely undisturbed wetland. This forest was an integral part of the broad interdisciplinary scientific investigation conducted as part of the Geological Survey's assessment. Statistical surveys of tree abundance and distribution were coupled with measurements of leaf production to provide estimates of total production of organic litter in the flood-plain environment.

Annual flooding overflows the natural levees and covers the flood plain. In many areas, the water velocities are sufficient to transport the decaying leaf litter into the river and ultimately to Apalachicola Bay. The nutrients and litter material form the basis for one of the most productive estuarine systems in North America. Oysters, shrimp, blue crab, and fish depend on the seasonal materials transported by the floods coming out of the Apalachicola River wetland system. The Apalachicola River-Quality Assessment developed methods and techniques to quantify the flood-plain contribution to the 1980–81 annual load of nutrients and detritus (organic particulate material) to the bay. Results obtained in the river were compared with estimates of litterfall transported in the flood plain. Such estimates were based on new methods developed during the study. During a 1-year period, approximately 30,000 tons of organic carbon entered the river from the flood plain.

The relation between the river system and the bay contributes directly to the economic welfare of the people surrounding the bay.

Their interest in preserving the natural productivity and hydrologic cycles of the Apalachicola River and bordering flood plain

This Landsat image, which is a false-color composite obtained on February 11, 1977, shows the extent of the flood plain in the Apalachicola River basin, Florida. The dark color of the flood plain is caused by the low reflectance from flood waters. The 656-foot-wide river is barely visible in the center of the 2- to 5-mile-wide flood plain. The Apalachicola River flows from Lake Seminole (at the top), 106 miles south, to Apalachicola Bay (near the bottom of the scene). The numerous white squares near the top of the scene are agricultural fields in Florida and Alabama. The large red area east of the river is pine forest (Apalachicola National Forest). The faint brown color on the bird's-foot delta at the river mouth is marsh. The light blue colors near the beaches at the bottom of the scene are a combination of shallow areas and areas with high suspended sediments caused by ocean currents.

Forested Apalachicola flood plain.

has at times been in conflict with the economic interests of people upstream in Alabama and Georgia, where navigability of the river has been a paramount concern. Private conservation and development groups, as well as county, State, and Federal agencies, have become involved.

The Geological Survey has played a role by developing new investigative techniques for this type of environment. The Survey collects and publishes data on the hydrodynamics of the river and ecological functions of the flood plain. Published reports on wetland hydrology and tree distribution and production and decomposition of forest litter fall have been key ingredients for information transfer workshops to acquaint all interested parties with the facts about river and flood-plain processes and their relationship to the fishing industry in Apalachicola Bay.

Potomac River Estuary Study

Estuaries are potentially the most productive as well as the most fragile and endangered areas of our Nation's coastal environment. Because they are the meeting place of saltwater and freshwater, estuaries are complex hydrodynamic, chemical, and biological environments. The fact that they are sinks for sediments further complicates the picture because nutrients, metals, and organic pollutants are often associated with sediments. These substances may become permanently or temporarily stored in the bottom sediments promoting eutrophication (enrichment of the food supply) and, in the case of metals and organics, sometimes concentrating in the life forms. Partly because of their complexity and partly because it is difficult, dangerous, and expensive to study them, estuarine environments are poorly understood. In light of increasing awareness of their importance and fragility, it becomes more and more imperative to make the extra effort to collect and interpret the data necessary to understand estuarine resources. It was in this vein that, in October 1977, the U.S. Geological Survey began its 5-year Interdisciplinary Potomac Estuary Study.

Acceleration of the natural filling process by increased sediment loads from upstream farms and the Washington, D.C., urban area is probably the most visible water-quality problem in the tidal Potomac River and marginal embayments. This process has been so rapid that the Lincoln and Jefferson Memorials now stand on what was described in 1711 as a harbor suitable for great merchant vessels.

Another persistent water-quality problem in the tidal river is the depletion of dissolved-oxygen associated with the disposal of municipal sewage and storm runoff from the Washington, D.C., metropolitan area. Following the installation of a water supply system for the District of Columbia in 1859, the problem of effluents and runoff was first apparent when large quantities of domestic sewage began entering the river by way of the storm sewers. Soon the loading was beyond the capacity of the river in the waterfront area of the city, and, by 1899, the river had become so obnoxious that President Benjamin Harrison appointed a board of sanitary engineers to find an outfall location where dilution was adequate and tidal action did not return the sewage to the edge of the city. The development of water-quality problems near the District of Columbia coincided with the growth of population. Improvements in water quality paralleled installation of and improvements in water-pollution-control technology used in the Blue Plains sewage treatment plant, the major treatment facility in the metropolitan

Research vessel Rockfish.

area. Some of the worst observed dissolved-oxygen conditions occurred in the mid- to late 1950's when carbonaceous biochemical oxygen demand loadings were at their peak. Today, the major problem has shifted from that of dissolved-oxygen depletion due to carbonaceous biochemical oxygen demand to one of eutrophication caused, at least in part, by the heavy nutrient loadings from the Washington, D.C., area municipal sewage treatment plants.

Because 72 percent of the 3.9 million people in the Potomac River basin are concentrated in a metropolitan area and because the primary business is government, the Potomac River, unlike many east coast estuaries and tidal rivers, is relatively free from the pollution problems associated with manufacturing and chemical industries. Therefore, the effects of sedimentation and eutrophication can be studied in the tidal Potomac River and Estuary independent of complications from those of other types of pollutants.

The Potomac Estuary Study is one of seven pilot River-Quality Assessments and the only one to concentrate on estuarine problems. Others have concentrated on problems in upland streams such as dissolved oxygen and excessive nutrient enrichment in the Willamette River-Quality Assessment or those associated with energy development and irrigation as in the Yampa Study.

The general objectives of the Potomac Study are (1) to conduct research into the physical, chemical, and biological mechanisms governing life cycles of phytoplankton, submerged vegetation, and benthic fauna in tidal rivers and estuaries, (2) to develop mathematical models necessary to support ecological models suitable for predicting the influence of phytoplankton on dissolved oxygen and nutrient levels (these models are designed to expedite water-quality management decisionmaking for the tidal Potomac River and Estuary), and (3) to develop, refine, and standardize efficient techniques for studying water quality of the Potomac and other tidal rivers and estuaries.

Examples of some of the many findings of the Potomac Estuary Study are summarized in the paragraphs below.

Low-Flow Dissolved-Oxygen Relationships

Nutrients associated with sediment discharged by the Potomac River during periods of high flow settle to the bottom. They become a major source of dissolved and particulate nutrients in the water column of the freshwater tidal river and estuarine transition zone (see fig. 4 for definition of these zones) during critical periods when river flow is low. During such periods, nutrients released through the 390-million-gallon-per-day discharge from the regional secondary sewage treatment plant cause a dissolved-oxygen sag for approximately 8 nautical miles in the upstream part of the tidal river. In the remainder of the tidal river and in the transition zone, the oxygen regime is dominated by biologic reactions fed by nutrients exchanged with the bottom. During extreme flood events, some of this material is moved to the transition zone. Therefore, the magnitude, frequency, and duration of flood events which transport most of the annual upland nutrient loads may be a major determinant of low-flow water quality in the downstream reaches of the tidal river and transition zone.

Tributary Loads

A sampling program was begun in 1979 to acquire data on monthly and major-storm

Percentage of material supplied during 1980 and 1981 water years and trapped in the various zones of the tidal Potomac River and Estuary.

[Negative numbers in parentheses indicate a net outflow of dissolved silica from the transition zone. This is included in the material trapped in the estuary and is, therefore, not subtracted from the total percentage. The percentage of material supplied to the Chesapeake Bay is 100 minus the number shown on the line labeled "Total percentage"]

Water year	Percentage trapped							
	Sediments		Dissolved silica		Total nitrogen		Total phosphorus	
	1980	1981	1980	1981	1980	1981	1980	1981
Segment:								
Tidal river	38	18	16	35	7	2	5	27
Transition zone	16	30	(−7)	(−9)	3	41	16	13
Estuary	46	43	19	42	51	4	40	40
Total percentage	100	91	35	77	61	47	61	80
Total supply in tons	2.38×10^6	783,000	127,000	43,000	41,700	19,400	2,710	1,490

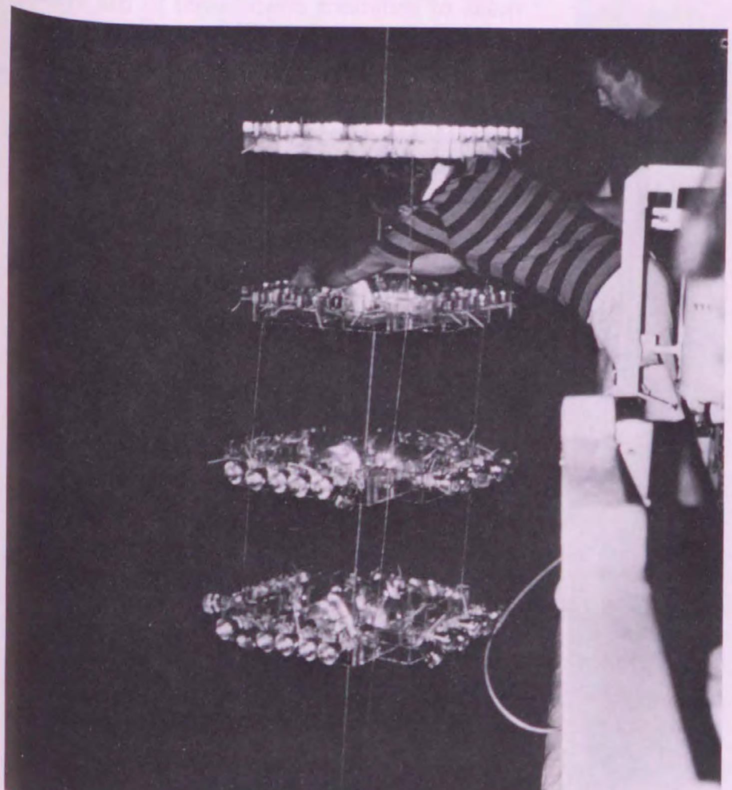
loadings of phosphorus, nitrogen, biochemical oxygen demand, dissolved silica, and sediment from nonpoint sources. Samples of the streamflow leaving four watersheds and from the Occoquan Reservoir in Virginia were collected. These data were correlated with discharge records and with reservoir characteristics so that pollutant loads could be estimated. Results from the three urban watersheds sampled indicate that suspended sediment is less than that measured 20 years ago. Data collected from the discharge of the reservoir were compared with available information on the amount of pollutants entering the reservoir. The results indicate that, during 1979 and 1980, most of the sediment and phosphorus was trapped, but most of the nitrogen passed through to the tidal Potomac River.

Bottom-Dwelling Life

Seasonal and spatial variability of bottom-dwelling animals was investigated at 59 stations located in 7 transects between Piney Point and Wilson Bridge from fall 1977 through summer 1979. Analysis of grab samples yielded 9 phyla composed of 123 species. The tidal river was partitioned into four zones: estuarine, transitional, tidal freshwater, and environmentally impacted. Analysis indicated that salinity is the predominant factor influencing infaunal distributions throughout most of the tidal river. Biological communities that characterize the four zones are primarily deposit-feeding resilient opportunists. Within the estuarine zone reside marine organisms that tolerate a wide range of salinities and that recolonize this area which is seasonally influenced by summer anoxic conditions. Estuarine endemics dominate the transitional zone where seasonal salinity fluctuations decrease diversity while supporting increased abundance. Freshwater species dominate the remaining reach of the river.

Nutrient and Sediment Budgets

During the 1980 and 1981 water years, twice-weekly samples of salt, sediment, and a variety of nutrients were collected at five stations along the 116-mile tidal reach between Washington, D.C., and the Chesapeake Bay. Computed nutrient and sediment loads passing each of the stations were used in combination with sewage treatment plant and local nonpoint source contributions to determine materials budgets for the major segments of the tidal river and estuary for



In-situ incubation of bottles for primary productivity measurements in the tidal Potomac River.

the 2 water years. Water discharge to the tidal river near Washington, D.C., during 1980 averaged 16,280 cubic feet per second, 43 percent above normal (51-year average is 11,400 cubic feet per second), while during 1981 the average discharge was 6,905 cubic feet per second, 39 percent below normal. The percentages of sediments and nutrients trapped in the various zones of the tidal river and estuary are shown in the table. For the 2 water years, 98 percent of supplied sediment was trapped in the tidal river and estuary. Corresponding figures for phosphorous, nitrogen, and dissolved silica were 68 percent, 57 percent and 46 percent.

Sampling submersed aquatic vegetation and substrate with modified oyster tongs.

Flow Modeling

The tidal Potomac River from the head-of-tide in the northwestern quadrant of Washington, D.C., to Indian Head, Maryland, was modeled mathematically using a general one-dimensional network-type flow-simulation model. Water-surface elevations and discharge can be computed at any desired location throughout the network of channels using the model. The flow model was calibrated using recorded water-surface elevations as well as measured discharges from throughout the network. The general model is a proven viable and economical flow-assessment tool that is applicable to a wide range of hydrologic conditions and varying field situations. Through the use of such techniques, water managers and scientists involved in similar comprehensive assessments can better understand the interrelationship of predominant riverine and estuarine processes.

Shoreline Erosion

Field studies, comparisons of historical maps, and photogrammetric measurements were carried out to identify erosion processes along the shores of the tidal Potomac River and Esturary, to measure rates of shoreline recession, and to estimate the mass of sediment contributed to the system by shore erosion. Results indicate that the average recession rate in the estuary (1.2 feet per year) is more than twice as high as the average recession rate in the tidal river and transition zone (0.5 foot per year). Of the total mass of sediment derived from shore erosion annually (670,000 tons), 35 percent originates in the tidal river and transition zone, and 17 percent and 48 percent are derived from the Maryland shore and from the Virginia shore of the estuary, respectively. About 40 percent of the sediment derived from shore erosion (262,000 tons) is in the silt- and clay-sized fraction. This is the same size of material as the suspended sediment in this area from other sources and represents 12 to 13 percent of the total mass of suspended sediment contributed to the tidal Potomac River.

Submersed Aquatic Vegetation

From 1978 through 1982, distribution and abundance of submersed aquatic vegetation in the tidal Potomac River and Estuary were studied with the assistance of the U.S. Fish and Wildlife Service. Of 16 identified species of submersed aquatic plants, 14 were vascular plants, and 2 were species of the algae *Chara*. The majority of the plants are located in the Potomac River transition zone and Wicomico River tributary, with a few isolated populations in the tidal river and lower estuary. Wildcelery, horned pondweed, widgeongrass, and redhead-grass were the most abundant and widespread species. The present distribution and abundance are very different from those of the early 1900's, when flats in the tidal river were covered with lush vegetation including wildcelery and pondweeds and the lower estuary had an abundance of eelgrass.

It is exceedingly difficult to isolate the factors responsible for the decline of submersed aquatic vegetation in the tidal Potomac River and Estuary. The most likely reasons for their almost complete disappearance from the tidal river include extensive storm damage in the 1930's, increasing nutrient enrichment with a shift in the relation or balance between submersed aquatic plants and phytoplankton, a change in availability of light, and grazing by predators before adequate rhyzome mats or minimum bed size is established. The wide variation of salinity concentrations in the transition zone may account for the relative abundance of vegetation and the diversity of species within this reach as compared to other reaches.

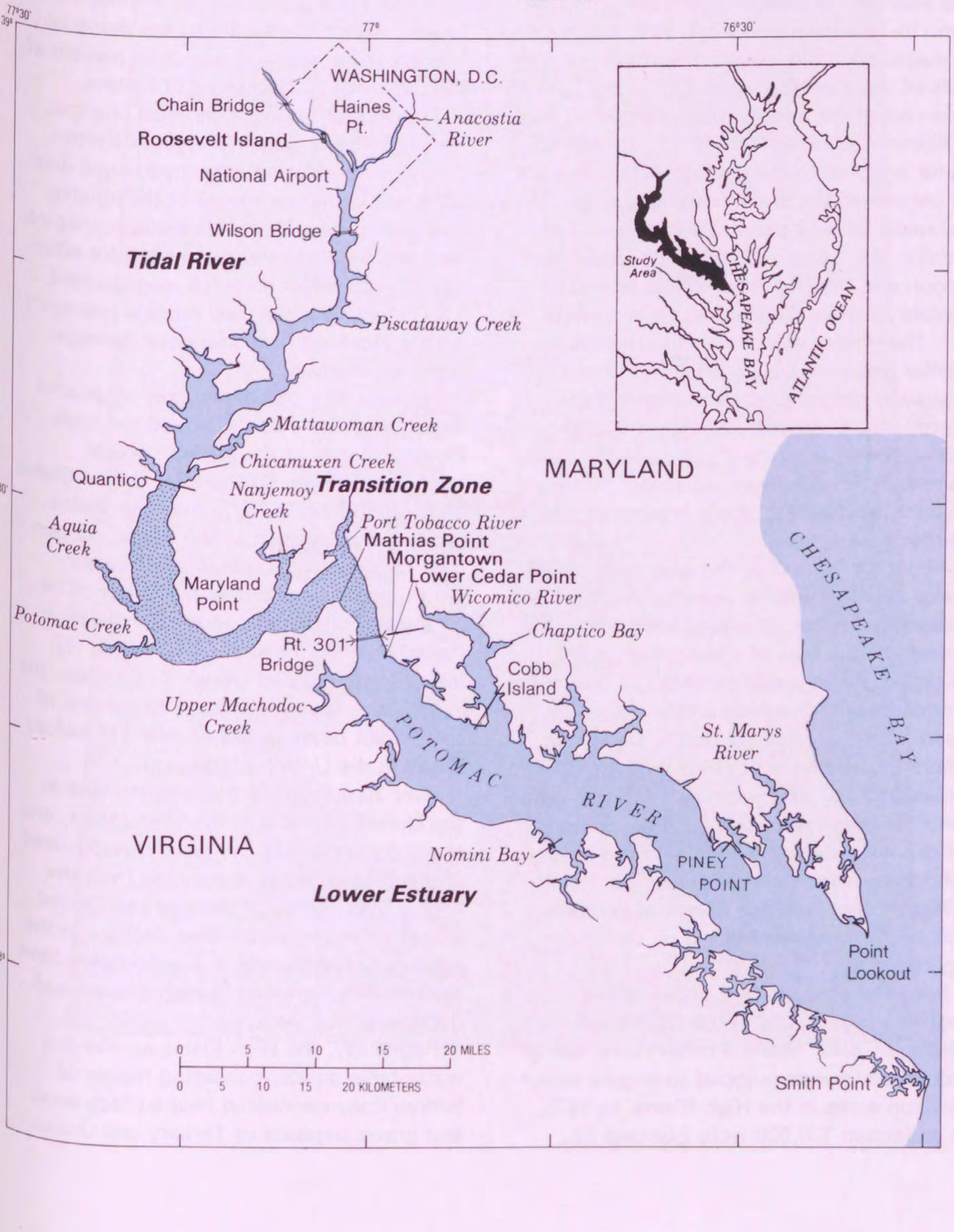


Figure 4.—*Potomac River study area map showing transport stations at Chain Bridge, Wilson Bridge, Quantico, Route 301 bridge, and Piney Point.*

High Plains Regional Aquifer-System Analysis

In 1978, the High Plains study was initiated in response to concern about the impact of declining water supplies on agriculture. This study is part of the Regional Aquifer-System Analysis Program of the U.S. Geological Survey, which was implemented to provide hydrologic information needed for effective management of the Nation's ground-water resources.

The High Plains aquifer underlies 174,000 square miles in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The region has abundant sunshine, moderate precipitation (16–18 inches annually), and high rates of evaporation (60–100 inches annually). The soils of the High Plains are highly productive when adequate water is available.

About 3.25 billion acre-feet of drainable water is stored in the aquifer. Approximately 66 percent of the water in storage is in Nebraska, and 12 percent is in Texas. New Mexico, the State with the smallest water resource in the High Plains, has only 1.5 percent of the volume of water in storage.

The quality of water in the High Plains aquifer generally is suitable for irrigation. However, the water does not satisfy Environmental Protection Agency drinking-water standards in many places. Excessive concentrations of dissolved solids, fluoride, chloride, and sulfate occur in parts of the aquifer in all States.

About 62 percent of the area of the High Plains aquifer contains water with 250 to 500 milligrams per liter dissolved solids; only 3 percent of the area of the aquifer (mostly in Texas) contains water exceeding 1,000 milligrams per liter dissolved solids. Generally, dissolved-solids concentrations are lowest where the aquifer is covered by dune sand because recharge is relatively high and the sand contains few highly soluble minerals. In most areas where the concentration of dissolved solids in the aquifer exceeds 1,000 milligrams per liter, the chemical composition of the water is affected by the underlying bedrock.

Irrigation development began in the southern High Plains in the 1930's and 1940's. In 1949, nearly 4 million acre-feet of ground water was pumped to irrigate about 2 million acres in the High Plains. In 1978, an estimated 170,000 wells pumped 23 million acre-feet of water to irrigate 13 million acres.

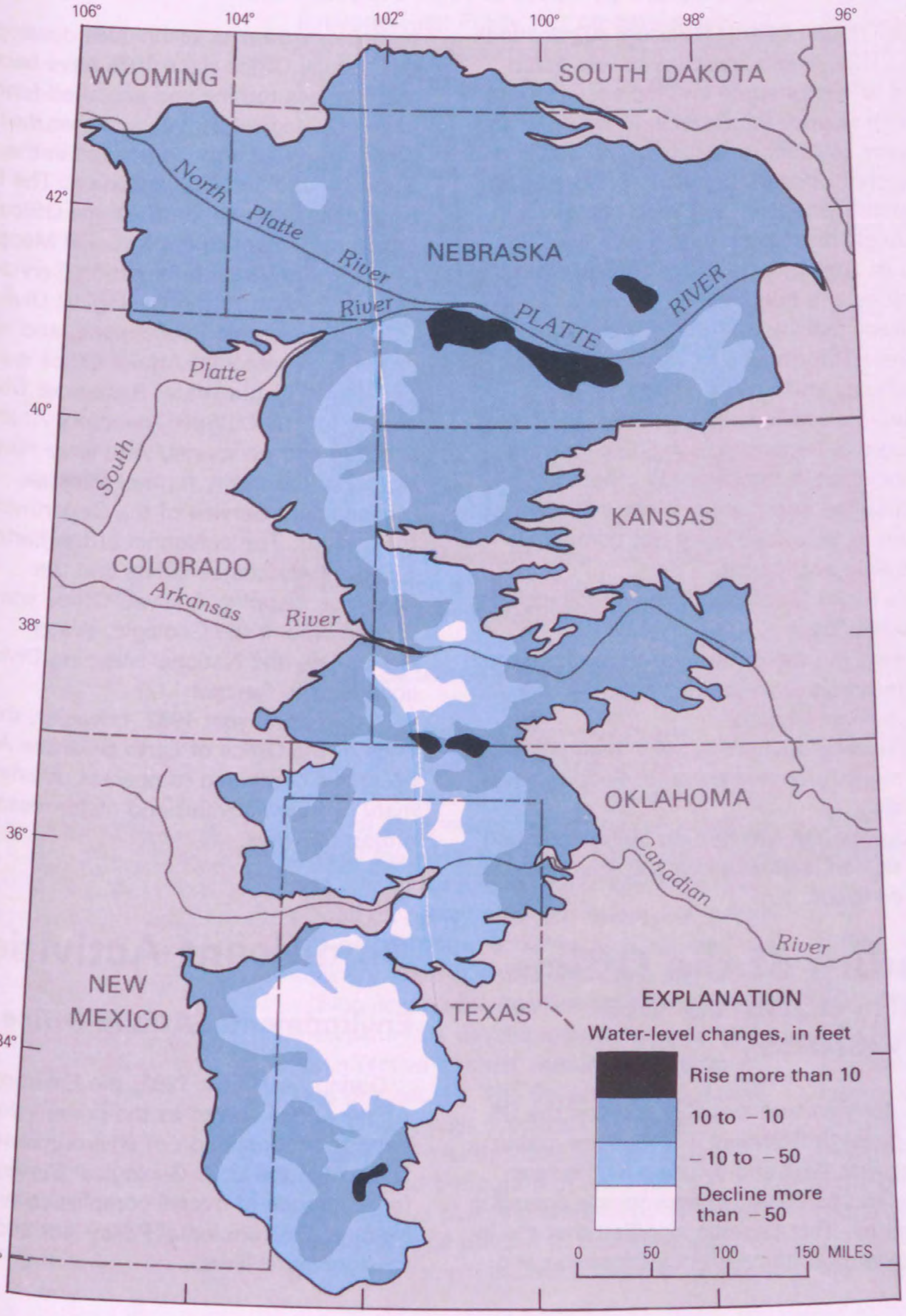
The rapid increase in pumpage since 1949 has resulted in extensive water-level declines in the High Plains aquifer. Since irrigation began, water levels have declined more than 10 feet in 50,000 square miles of the aquifer and more than 50 feet in 12,000 square miles of the aquifer. Water-level declines of as much as 200 feet have been reported in Texas since irrigation pumpage started. The volume of water in storage in the aquifer has decreased about 5 percent or 166 million acre-feet since ground-water development began. About 70 percent of the depletion has occurred in Texas; about 16 percent of the depletion has occurred in Kansas.

To forecast future water-level changes, the High Plains Regional Aquifer-System Analysis will develop a geohydrologic data base and computer model of the aquifer. The data base will provide water managers with regional information needed for effective ground-water resource management. The computer model will provide managers with a tool for evaluating water-management alternatives.

Because of a plentiful supply of ground water, irrigation has developed the High Plains into one of the Nation's major agricultural areas. Of the total United States crop production in 1977, the High Plains produced 16 percent of the wheat, 13 percent of the corn, 40 percent of the sorghum, and 25 percent of the cotton. The total value of crops produced in the High Plains in 1977 was about $4.6 billion ($2 billion from irrigated crops). In addition, the High Plains produced about 40 percent of the feedlot beef (valued at over $10 billion) raised in the United States.

Over 20 percent of the irrigated land in the United States is in the High Plains, and about 35 percent of the ground water used in the United States is pumped from the High Plains aquifer. Pumpage has caused areally extensive water-level declines in the aquifer. Consequently, many irrigators have experienced increased pumping costs and decreased well yields.

Regionally, the High Plains aquifer is a water-table aquifer consisting mainly of hydraulically connected near-surface sand and gravel deposits of Tertiary and Quaternary age. The Tertiary Ogallala Formation, which underlies about 80 percent of the High Plains, is the principal geologic unit in the aquifer. The maximum saturated thickness of the High Plains aquifer is about 1,000 feet and averages 200 feet. Ground water generally flows from west to east at an average rate of about 1 foot per day and discharges naturally to streams and springs and by evapotranspiration. Precipitation is the principal source of recharge to the aquifer. Estimated recharge rates range from about 0.03 inch per year in Texas to 6 inches per year in areas of dune sand in Kansas and Nebraska.



Predevelopment to 1980 water-level changes in the High Plains aquifer.

Office of Earth Sciences Applications

Mission

The Office of Earth Sciences Applications of the U.S. Geological Survey was established to demonstrate and increase the use of earth science information in land use and resource planning processes. The public and its elected officials, planners, policymakers, resource managers, and decisionmakers increasingly must cope with many issues, such as zoning, permitting, geologic hazard warnings and contingency plans, building-site selections, and so forth, that entail technical information at varying levels of complexity and from a diverse range of scientific disciplines. Many times, important geologic or hydrologic considerations are not included in the planning process because the information is not available, not known to be available, or not compatible to the needs of the user.

The major functions of the Office include the following:

- Enhancing the usefulness of earth science information in the planning-decision-making process.
- Reviewing environmental impact statements prepared by other Federal agencies.
- Applying remote-sensing technology and data in land resource and environmental analyses.

Return of the Office Functions to the Divisions

A decision was made to disband the Office of Earth Sciences Applications during fiscal year 1982 and to place all the functions and personnel in appropriate operating Divisions. This decision signified that the innovative layman-oriented information and technology transfer techniques developed by this special Office since 1975 have become more or less routine and accepted functions of the Geological Survey and that these functions could now be housed in the Survey's traditional organization. The Earth Resources Observation Systems Office was transferred intact to the National Mapping Division, the Visual Information Services Office went intact to the Geological Division's Office of Scientific Publications, and most of the Environmental Affairs Office was transferred to the Water Resources Division, except for the Oil Spill Trajectory Analysis function and personnel, who were reassigned to the newly formed Minerals Management Service of the Department of the Interior. The personnel of the Earth Sciences Assistance Office and the Resource Planning Analysis Office were divided among the Geologic, Water Resources, and National Mapping Divisions according to function.

During fiscal year 1982, however, the units of the Office of Earth Sciences Applications continued to operate. A brief summary of their activities and major research projects follows.

Significant Activities

Environmental Affairs Office

During fiscal year 1982, the Environmental Affairs Office served as the primary focal point for coordination of environmental matters within the U.S. Geological Survey and for assurance of overall compliance with the National Environmental Policy Act and other environmental laws.

Specific accomplishments during the year included a study to streamline the National Environmental Policy Act processes within the Survey, completion of studies summarizing natural resource and energy development policies and regulations for each of 40 States; completion of oilspill analyses for the Gulf of Mexico, Atlantic, and Norton Basin Outer Continental Shelf lease areas; and participation with approximately nine bureaus and agencies by providing Survey expertise and assistance in National Environmental Policy Act projects. Significant support during the year was provided to the Office of Surface Mining in the preparation of environmental impact statements and the review of mine reclamation plans, to the Bureau of Land Management in the preparation of environmental impact statements for various coal leasing projects, and to the Minerals Management Service for assistance in preparation of the Arctic National Wildlife Refuge environmental impact statement.

Earth Sciences Assistance Office

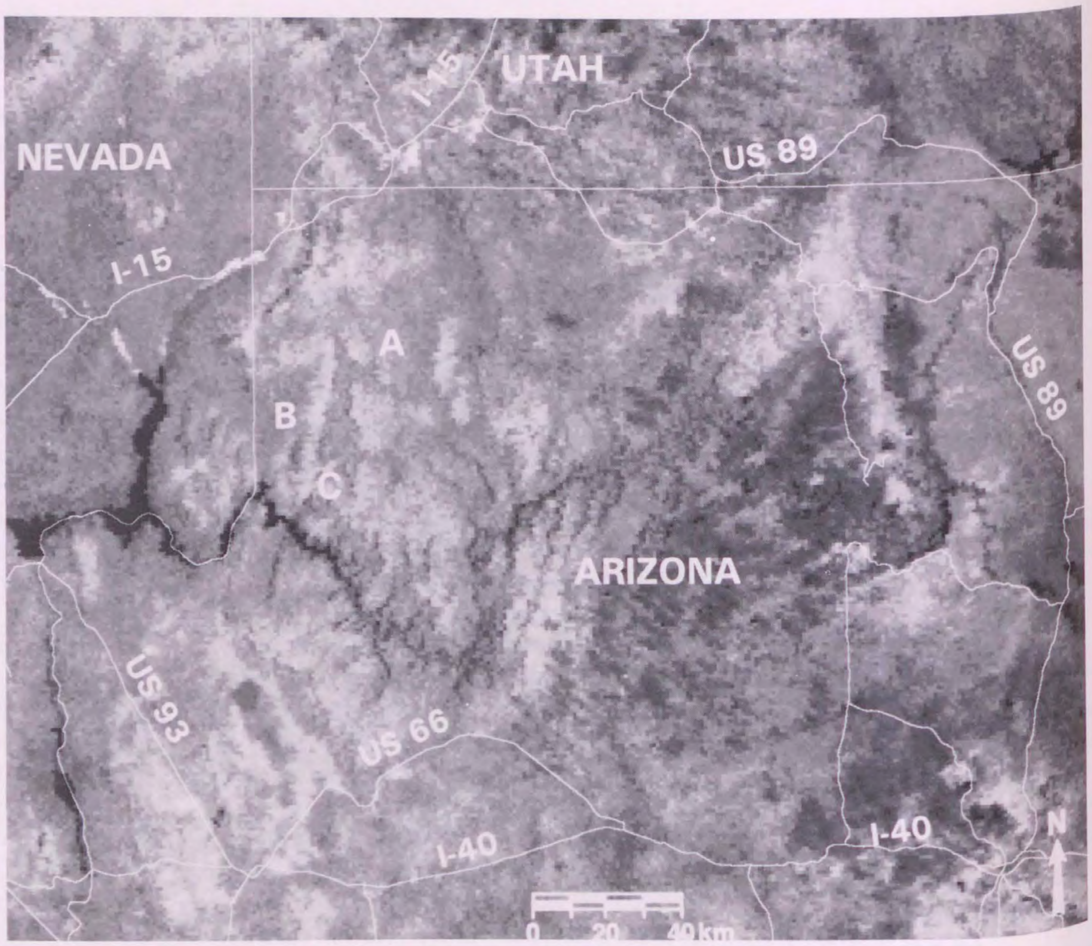
During fiscal year 1982, the Earth Sciences Assistance Office continued to develop, interpret, and demonstrate applications of earth sciences information in support of planning and decisionmaking for land and related resources. Major emphasis was placed on geologic related hazards warnings and preparedness activities and interdisciplinary earth sciences applications studies.

Significant advances were made during the year in the development of more positive and effective hazards warning and preparedness procedures. The Earth Sciences Assistance Office, with cooperation from a number of Federal, State, and local agencies, intiated a program of emergency response and planning workshops to assist State and local officials to deal with specific potential geologic hazards. The first of these workshops, held at Shasta, California, in November 1981, focused on potential hazards from future volcanic eruptions at Mount Shasta. Approximately 100 State and local officials attended the workshop to learn more about the specific nature of hazards to life and property that can be expected in the event of renewed eruptive activity at Mount Shasta, one of a number of active volcanoes in the Pacific Northwest. The specific information provided and the emergency planning initiated at workshops of this type are expected to stimulate and encourage early and effective response to imminent geologic threats as they are identified in the future.

Two major interdisciplinary projects supported by this Office and conducted by the Water Resources and Geologic Divisons were completed successfully in fiscal year 1982. The Puget Sound Project in Washington and the Culpeper Basin Project in northern Virginia together produced more than 120 basic and interpretive geologic and hydrologic maps and reports aimed primarily at describing the earth science constraints and opportunities for land and related resource use in the project areas.

Earth Resources Observation Systems Office

The Earth Resources Observation Systems Office, which was established in 1966 by order of the Secretary of the Interior and is administered for the Department by the U.S. Geological Survey, is the focal point for most of the Department's Earth resource-oriented remote-sensing activities. The mission of the Earth Resources Observation Systems Office is to develop, demonstrate, and encourage applications of techniques using remotely sensed data to the resource and environmental inventory and management responsibilities of the



This image of northwestern Arizona, acquired from NOAA-6 on April 7, 1982, has been processed to show greeness of vegetation in relative shades of gray. Brightness indicates higher levels of standing green vegetation, especially near sites A, B, and C. Digital Line Graph data (roads and State boundaries) from the National Mapping Division provide a geographic reference.

Department of the Interior. A realinement of functions during fiscal year 1982 has resulted in the transfer of this Office to the National Mapping Division.

Monitoring Vegetation Over Large Geographic Regions for Wildfire Management

A cooperative project with the Geological Survey's Earth Resources Observation Systems Office, the Bureau of Land Management, and the National Oceanic and Atmospheric Administration (NOAA) evaluated the use of Advanced Very High Resolution Radiometer data for monitoring areas of herbaceous vegetation. Bureau of Land Management fire managers require estimates of fire fuel and a means for monitoring vegetation growth, maturing, and curing (time of greatest fire potential).

The NOAA-6 and NOAA-7 satellites carry radiometer sensors that provide land cover information on a daily basis. These satellites are in sun-synchronous, near-polar orbits. Their images have a ground resolution of over 0.6 mile.

From March through April 1982, radiometer images were acquired for northwestern Arizona and registered to a digital geographic reference map base containing road patterns and State boundaries. The time intervals showed the spring growth cycle from dormancy through maturing of the annuals. Images were processed for five different days and analyzed to determine their usefulness in wildfire management decisions. The investigation showed that the data can be used to estimate the date when the vegetation becomes mature, document relative amounts of standing green vegetation for northwestern Arizona, and follow seasonal growth of annual grasses.

Land Cover and Terrain Mapping for the Kenai and Togiak National Wildlife Refuges, Alaska

A cooperative project between the Earth Resources Observation Systems Office and the U.S. Fish and Wildlife Service's Refuges Division has developed land cover and terrain digital data bases and maps for the Kenai and Togiak National Wildlife Refuges and surrounding areas.

The principal sources of raw data utilized to develop the land cover and terrain information to be incorporated in the comprehensive plans were digital Landsat multispectral scanner data and digital elevation model data. Digital terrain information was utilized to improve the overall representativeness and accuracy of the final classification. The results of this modeling activity are habitat maps that permit wildlife biologists to assess and inventory areas as suitable or critical for particular species. The methodology demonstrated in this project has been adopted as the approach that will be used in the development of plans for the remaining 14 National Wildlife Refuges in Alaska.

Digital Mapping of Drainage Basins and Drainage Lines

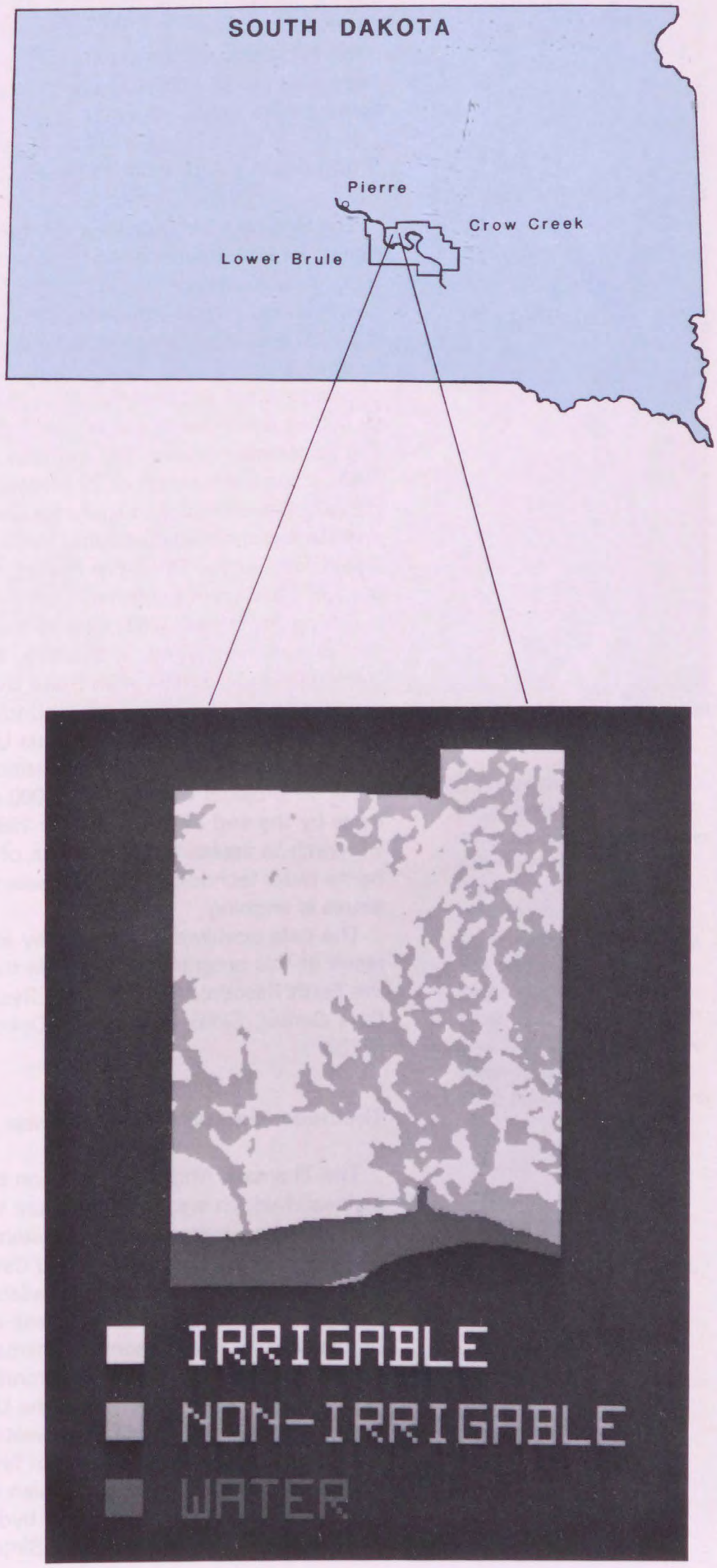
An Earth Resources Observation Systems Office project to describe the physical characteristics and hydrologic conditions of drainage basins within the Black Hills of South Dakota was initiated during 1982. A computer technique for mapping drainage lines and drainage basins was developed. Digital elevation data acquired from the Survey's National Mapping Division were the only data needed. Drainage basins are delineated by the highest elevation values above a predetermined location. The analyst indicates the point designated as the terminal location for the basin under consideration. Although the new technique has not been fully tested, it has provided a rapid accurate method of producing drainage lines and basin maps from digital elevation data. These maps are useful in studying basin parameters for gaged basins and for siting new stream gages to measure stream flow.

Determination of Irrigation Potential of the Lower Brule and Crow Creek Indian Reservations

The Bureau of Indian Affairs assists in the management of large Indian-owned acres that are used for agricultural cropping and grazing. Part of this responsibility is to be aware of existing resources, to plan and implement programs for their efficient utilization, and to monitor changes resulting from resource management.

For an Earth Resources Observation Systems Office and Bureau of Indian Affairs cooperative project, several types of data such as soil fertility, landslope, current land

Map of irrigation potential of the Joe Creek quadrangle, South Dakota.



uses, and landownership, were digitized, merged, and integrated to determine which reservation lands were most suitable for producing irrigated crops. Models were developed to estimate and map irrigation potential. These maps were used by the Bureau of Indian Affairs in planning and management decisionmaking.

Side-Looking Airborne Radar Program

The Survey's Side-Looking Airborne Radar, which was initiated in fiscal year 1980, involves evaluating this technology for geologic and cartographic applications. During 1980 and 1981, airborne radar data, including multilook and stereographic coverage, were acquired for approximately 60,000 square miles in the Alaska Peninsula and in northern Alaska. By the close of 1981, a summary report of 20 investigations ("Evaluation of Radar Imagery for Geologic and Cartographic Applications," U.S. Geological Survey Open-File Report 81-1358) had been published.

During fiscal year 1982, data of the Aleutian Arc were acquired. In addition, the Survey, in consultation with State Geologists, selected and has contracted to fly five project areas within the contiguous United States. Total airborne radar acquisition for these six projects will exceed 75,000 square miles by the end of calendar year 1982. Research to assess the application of the airborne radar technology to earth science issues is ongoing.

The data acquired by the Survey as a result of this program are available through the Earth Resources Observation Systems Data Center, Sioux Falls, South Dakota 57198.

Thematic Mapper Simulator Data

The Thematic Mapper, carried on board Landsat 4 which was launched July 16, 1982, is a new remote-sensing system designed for better resolution and data characteristics than previously available. In preparation for applications of these data, simulated data to approximate Thematic Mapper data were acquired by aircraft and evaluated for three areas within the Uinta Basin of eastern Utah and northwestern Colorado. The areas are composed of broad exposures of rocks of Pennsylvanian to Tertiary age and contain a variety of hydrocarbons. Initially, Thematic Mapper Simulator data were registered to a topographic map base to facilitate comparison with geologic maps. Several image processing techniques were applied to the data to enhance spectral differences so that the rock types could be identified.

The area covered by the 1:250,000-scale topographic quadrangle was one region for which specially processed false-color composite images were prepared. On two of these color composites, 17 of 18 sedimentary formations in this quadrangle were distinguishable. The increased spectral and spatial resolution of mapper data provides improved data from which specialists can discriminate the rock types in this hydrocarbon-rich area. As these results indicate, Thematic Mapper data may prove to be extremely useful for rapid mapping of potentially valuable areas containing minerals and energy resources.

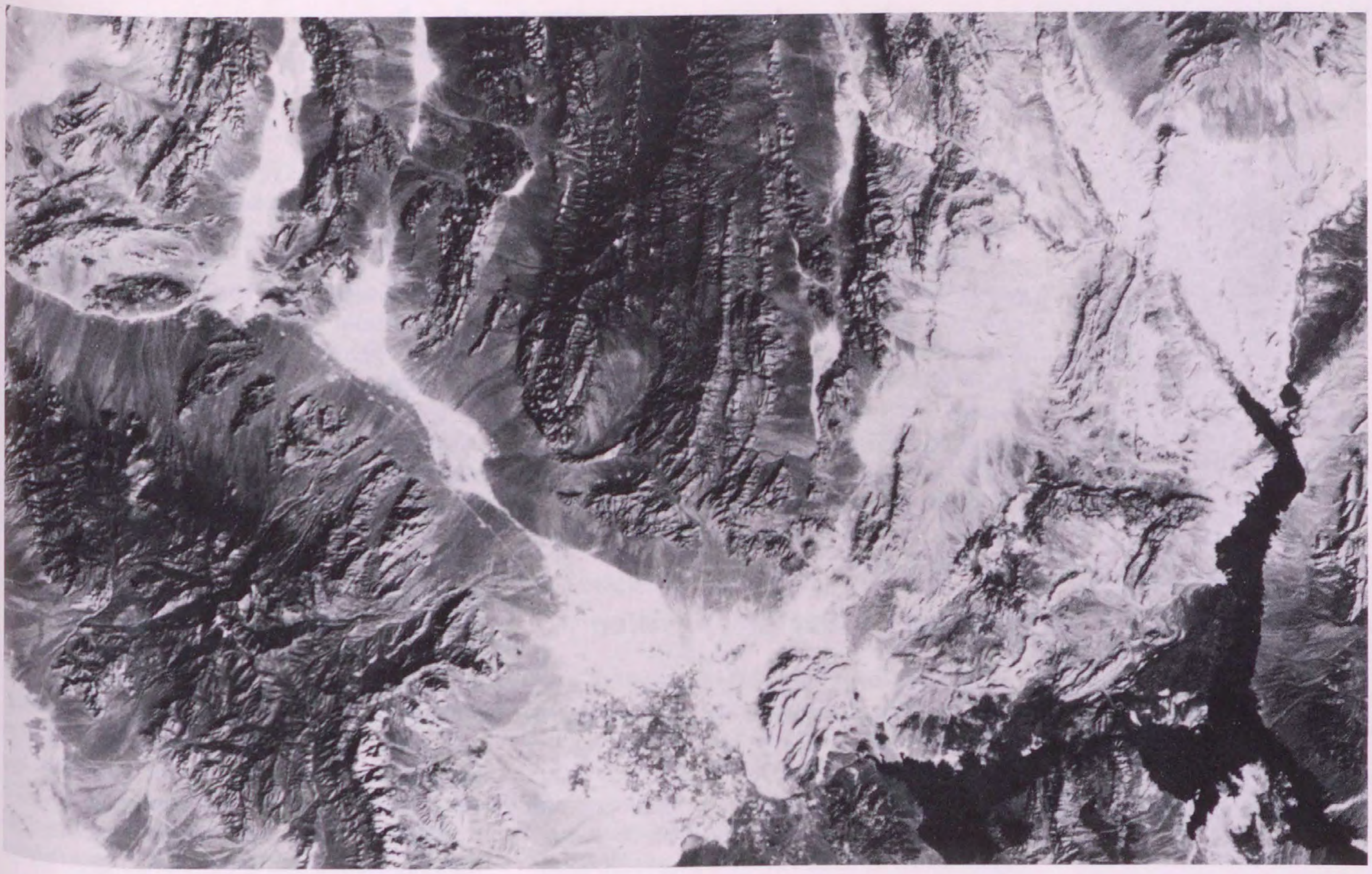
Digital Image Mapping

Spatial data, such as Landsat image data, can be combined with other types of data, such as cartographic information. Having both sets of data in digital form facilitates combinations by computer. The Earth Resources Observation Systems Office initiated a laboratory project in mid-1981 to develop a system that will register digital Landsat data to a digital cartographic data base and register one Landsat scene to another. This system was in the final stages of testing in early fiscal year 1982. The project includes the production of Landsat multispectral scanner false-color image maps compatible with and registered to 1:250,000-scale map quadrangles, such as the Las Vegas quadrangle.

The first step in registering the images was to select control points from the quadrangle maps and to generate a mapping grid. The images were then alined with corresponding map portions.

Once the four images used to produce the quadrangle were alined, they were merged to produce a digital mosaic. Individual photographic negatives for three wavelength bands were then generated, enlarged to the correct scale, and composited photographically to produce a final false-color mosaic.

The accuracy of the Las Vegas mosaic approaches established standards. The system will be useful for producing image mosaics of large areas for geologic interpretation and mapping and for other earth science investigations.



Remotely Sensed Data Base and Usage

The Earth Resources Observation Systems Data Center, Sioux Falls, South Dakota, added more than 130,000 satellite images of the Earth and more than 100,000 aircraft photographs of the United States to its archive this fiscal year. The archive now contains 6.8 million frames. Sales of satellite data exceeded $3.2 million, and sales of aerial photographs exceeded $1.4 million. Seventeen remote-sensing technology training courses were conducted at the center for 356 participants.

This image mosaic of Las Vegas area was produced using the digital processing system at the Earth Resources Observation Systems Data Center, Sioux Falls, South Dakota. The system will be useful for producing image mosaics of large areas for geologic interpretation and mapping and for other earth science investigations.

Information Systems Division

Organization and Mission

During fiscal year 1982, the U.S. Geological Survey made several organizational changes that are intended to increase the effective use of computers and information systems throughout the Survey. Among these were the restructuring of the Computer Center Division as the Information Systems Division, the establishment of an Assistant Director for Information Systems, and formation of a Bureau-level Information Systems Council.

Information Systems Division

The Information Systems Division was established in fiscal year 1982. Its functions incorporate those of the former Computer Center Division, including the operation of the Survey's general purpose computers and the provision of customer services to users nationwide. Offices within the new Division are Systems Policy and Management, Data Administration, ADP Services, Acquisition Management and Support, Program Support Services, and Operational Systems Support.

Assistant Director for Information Systems

The establishment of the Assistant Director for Information Systems created a focal point for management of Bureau information systems activities and placed the responsibility for developing Bureau Automated Data Processing policy and program leadership in one position.

Information Systems Council

An Information Systems Council, composed of policy-level representatives from each Division and from each field region, was instituted in fiscal year 1982. The purpose of this Council is to recommend policies, to coordinate research and technology, and to provide guidelines for major computer systems and information management programs and systems for the Geological Survey.

Earth Science Standards

The Office of Data Base Administration has established a comprehensive program for standardizing digital scientific data. In fiscal year 1980, a Memorandum of Understanding was signed with the National Bureau of Standards giving the Survey the responsibility for developing and maintaining earth science data standards for the Federal Government. To accomplish this, a U.S. Geological Survey Data Standards Committee was established to develop and maintain applicable standards. A Department of the Interior Earth Science Data Standards Council has also been established, chaired by the Survey, to coordinate earth science data standards throughout the Department. Standards for hydrologic unit codes have been published and other standards are in process. This program will benefit not only the Survey and the Federal Government but also various scientific, university, and local government groups.

Earth Science Information System

The U.S. Geological Survey is changing from an organization that stored its data in document form, such as tables, maps, charts, or photographs, to one that collects, processes, transmits, stores, and analyzes massive amounts of electronic digital data. To accomplish this, certain basic requirements are needed such as an inventory of data bases and a dictionary-directory of data elements, as well as a data management facility to support standardization and integration. The Earth Science Information System was designed for this purpose.

Acquisition Support

During fiscal year 1982, the Information Systems Division provided a broad spectrum of technical expertise to help process in excess of 3,200 requests from Survey project managers for Automated Data Processing hardware, software, and services. These resource acquisitions have ranged in technical complexity from simple off-the-shelf component "buys" to sophisticated processing networks and have resulted in expenditures exceeding $35 million. Representative programs supported during this period are earthquake studies, oil and gas operations, hydrologic data manipulation, automated cartography, digital image manipulation, and map printing and distribution.

Consolidation of Multics

The Information Systems Division implemented in fiscal year 1982 a plan to consolidate the present Multics (Multiplexed Information and Computing Service) computer systems from the present locations (Denver, Menlo Park, and Reston) to one central location at Denver. This consolidation will not be fully completed until fiscal year 1984.

Microcomputer Technology

One of the most frequent uses of microcomputers in the Geological Survey is the transfer of files from the microcomputer to the large Survey mainframe computers and minicomputers and vice versa. To assist our microcomputer users, the Information Systems Division obtained a data communications program in the public domain. Because the program was written primarily for communications and file transfer between microcomputers, the program was enhanced by tailoring it for use with many mainframes and minicomputers and by providing other useful features.

Telecommunications

The Information Systems Division implemented several management plans to help control increasing telecommunication costs. These activities included nationwide packet-switching services to support distributed data processing and to replace many fragmented services that were utilized and digital Private Area Branch Exchanges to replace obsolete costly systems. These acquisitions are predecessor activities leading to the ultimate merger of voice and data telecommunications over common facilities.

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As of September 30, 1982

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Assistant Division Chief for Plans and Operations	Peter F. Bermel	(703) 860-6281	National Center, STOP 514
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Office of Regional Geology, Chief	Douglas M. Morton	(703) 860-6411	National Center, STOP 908
Office of Earthquake Studies, Chief	John R. Filson	(703) 860-6471	National Center, STOP 905
Office of Energy Resources, Chief	Terry W. Offield	(703) 860-6431	National Center, STOP 915
Office of Marine Geology, Chief	Terence N. Edgar	(703) 860-7291	National Center, STOP 915
Office of Mineral Resources, Chief	A. Thomas Ovenshine	(703) 860-6561	National Center, STOP 913
Office of Geochemistry and Geophysics, Chief	Benjamin A. Morgan III	(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

Office	Name	Telephone number	Address
Chief Hydrologist	Philip Cohen	(703) 860-6921	National Center, STOP 409
Staff Assistant for Special Projects	Gary D. Cobb	(703) 860-6802	National Center, STOP 440
Associate Chief Hydrologist	R. Hal Langford	(703) 860-6921	National Center, STOP 408
Assistant Chief Hydrologist, Scientific Publications, and Data Management	James E. Biesecker	(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	Gordon D. Bennett	(703) 860-6971	National Center, STOP 414
Office of Water Data Coordination, Chief	Porter E. Ward	(703) 860-6931	National Center, STOP 417
Office of International Activities, Chief	Della Laura	(703) 860-6548	National Center, STOP 470

Office of Earth Sciences Applications (as of August 1, 1982)

Office	Name	Telephone number	Address
Chief	Gene A. Thorley	(703) 860-7471	National Center, STOP 516
Associate Chief	John J. Dragonetti	(703) 860-7811	National Center, STOP 109
Earth Resources Observations Systems Office, Chief	John W. Salisbury	(703) 860-7881	National Center, STOP 590
Resource Planning Analysis Office, Chief	Dennis R. Hood	(703) 860-6717	National Center, STOP 590
Environmental Affairs Office, Chief	James R. Burns	(703) 860-7455	National Center, STOP 423
Earth Sciences Assistance Office, Chief	Jerry C. Stephens	(703) 860-6961	National Center, STOP 406
Visual Information Services Office, Chief	Theresa M. Sousa	(703) 860-6162	National Center, STOP 790

Office	Name	Telephone number	Address
Information Systems Division			
Chief	R. Michael Gall	(703) 860-7108	National Center, STOP 801
Associate Chief	Carl E. Diesen	(703) 860-7106	National Center, STOP 801
Office of Systems Policy and Management	Carl E. Diesen (Acting)	(703) 860-7106	National Center, STOP 801
Office of ADP Services	Carl E. Dielsen (Acting)	(703) 860-7106	National Center, STOP 801
Office of Data Administration	Theodore M. Albert	(703) 860-6086	National Center, STOP 115
Office of Acquisition Management and Support	Virginia L. Thomas	(703) 860-7103	National Center, STOP 802
Office of Program Support Services	Rollin F. Nelson	(703) 860-7103	National Center, STOP 802
Office of Operational Systems Support	James S. Bregman	(202) 343-7981	Interior Building, Room 1743
Administrative Division			
Chief	Edmund J. Grant	(703) 860-7201	National Center, STOP 201
Deputy Chief	William F. Gossman, Jr.	(703) 860-7203	National Center, STOP 202
Administrative Operations Officer	George F. Hargrove, Jr.	(703) 860-7204	National Center, STOP 203
Personnel Officer	Maxine C. Millard	(703) 860-6127	National Center, STOP 215
Contracts Officer	Paul A. Denett	(703) 860-7261	National Center, STOP 205
Finance Officer	Posey B. Howell, Jr.	(703) 860-6181	National Center, STOP 270
General Services Officer	Robert E. Rogers	(703) 860-7206	National Center, STOP 207
Management Analysis Officer	Ronald E. DeMatteo	(703) 860-7211	National Center, STOP 206
Selected Field Offices			
National Mapping Division			
Regional Centers			
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Mid-Continent	Lawrence H. Borgerding	(314) 341-0880	1400 Independence Road, Rolla, MO 65401
Rocky Mountain	John D. McLaurin	(303) 234-2351	Box 25046, STOP 510, Denver, Federal Center, Denver, CO 80225
Western	John R. Swinnerton	(415) 323-8111, ext. 2411	345 Middlefield Road Menlo Park, CA 94025
Printing and Distribution	Charles D. Kuhler	(703) 860-6761	National Center, STOP 580
Public Inquiries Offices			
Alaska	Elizabeth C. Behrendt	(907) 277-0577	108 Skyline Bldg., 508 2d Ave., Anchorage, Ak 99501
California:			
Los Angeles	Lucy E. Birdsall	(213) 688-2850	7638 Fed. Bldg., 300 N. Los Angeles St., Los Angeles, CA 90012
Menlo Park	Bruce S. Deam	(415) 323-8111, ext. 2817	345 Middlefield Rd., STOP 33, Bldg. 3, Rm. 122, Menlo Park, CA 94025
San Francisco	Patricia A. Shiffer	(415) 556-5627	504 Customhouse, 555 Battery St., San Francisco, CA 94111
Colorado	Irene V. Shy	(303) 837-4169	169 Fed. 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	John P. Donnelly	(214) 767-0198	1C45 Fed. Bldg., 1100 Commerce St., Dallas, TX 75242
Utah	Wendy R. Mabey	(801) 524-5652	8105 Fed. Bldg., 125 S. State St., Salt Lake City, UT 84138
Virginia	A. Ernestine Jones	(703) 860-6167	1C402 National Center, STOP 503, 12201 Sunrise Valley Dr. Reston, VA 22092
Washington	Jean E. Flechel	(509) 456-2524	678 U.S. Courthouse W. 920 Riverside Ave., Spokane, WA 99201
Distribution Branch Offices			
Alaska	Natalie Cornforth	(907) 456-7535	101 12th Ave., Box 12 Fairbanks, AK 99701
Western	Dwight F. Canfield	(303) 234-3832	Box 25286, STOP 306, Denver Federal Center Denver, CO 80225

Office	Name	Telephone number	Address
Selected Field Offices—Continued			
Public Inquiries Offices—Continued			
Eastern	George V.DeMeglio	(703) 557-2781	1200 S. Eads St., Arlington, VA 22202
Geologic Division			
Regional Offices			
Eastern	Avery A. Drake, Jr.	(703) 860-6631	National Center, STOP 953
Central	Richard F. Mast	(303) 234-3625	Box 25046, STOP 911 Denver Federal Center Denver, CO 80225
Western	G. Brent Dalrymple	(415) 323-8111	345 Middlefield Rd., Menlo Park, CA 94025
Water Resources Division			
Regional Offices			
Northeastern	Stanley P. Sauer (Acting)	(703) 860-6985	National Center, STOP 433
Southeastern	James L. Cook	(404) 221-5174	Richard B. Russell Federal Bldg., 75 Spring St., SW, Suite 77, Atlanta GA 30303
Central	Alfred Clebsch, Jr.	(303) 234-3661	Box 25046, STOP 406, Denver Federal Center Denver, CO 80225
Western	John D. Bredehoeft	(415) 323-8111, ext. 2337	345 Middlefield Road, MS66, Menlo Park, CA 94025
District Offices			
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Alaska	Philip Emery	(907) 271-4138	733 W. 4th Ave., Suite 400, Anchorage, AK 99501
Arizona	Robert D. Mac-Nish	(602) 792-6671	Federal Bldg. 301 W. Congress St., Tucson, AZ 85701
Arkansas	Ector E. Gann	(501) 378-6391	2301 Federal Office Bldg., 700 W. Capital Ave., Little Rock, AR 72201
California	Timothy Durbin	(415) 323-8111, ext. 2326	855 Oak Grove Ave., Menlo Park, CA 94025
Colorado	James F. Blakey	(303) 234-5092	Box 25046, STOP 415, Denver Federal Center, Denver, CO 80225
Connecticut	David McCartney	(203) 244-2528	135 High St., Rm. 235 Hartford, CT 06103
Delaware	Herbert J. Freiberger	(301) 828-1535	See Maryland District Office
District of Columbia	Herbert J. Freiberger	(301) 828-1535	See Maryland District Office
Florida	Irwin H. Kantrowitz	(904) 386-7145	325 John Knox Rd., Suite F-240, Tallahassee, FL 32303
Georgia	Jeffrey T. Armbruster	(404) 221-4848	6481 Peachtree Industrial Blvd., Suite B, Doraville, GA 30360
Hawaii	Benjamin L. Jones	(808) 546-8331	P.O. Box 50166, Rm. 6110, Honolulu, HI 96850
Idaho	Ernest F. Hubbard, Jr.	(208) 334-1750	Box 036, Federal Bldg., Rm., 365, 550 W. Fort St., Boise, ID 83724
Illinois	Larry G. Toler	(217) 398-5353	Champaign County Bank Plaza, 102 E. Main St., 4th Floor, Urbana, IL 61301
Indiana	Dennis K. Stewart	(317) 269-7101	1819 N. Meridian St., Indianapolis, IN 46202
Iowa	John M. Klein	(319) 337-4191	P.O. Box 1230, 400 S. Clinton St., Iowa City. IA 52240
Kansas	Joseph S. Rosenshein	(913) 864-4321	1950 Ave. A, Campus West, University of Kansas, Lawrence, KS 66045

Office	Name	Telephone number	Address
Selected Field Offices—Continued			
Water Resources Division—Continued			
District Offices—Contined			
Kentucky	Alfred Knight	(502) 582-5241	572 Federal Bldg., 600 Federal Pl., Louisville, KY 40202
Louisiana	Darwin Knockenmus	(504) 390-0281	P.O. Box 66492, 6554 Florida Blvd., Baton Rouge, LA 70896
Maine	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
Maryland	Herbert J. Freiberger	(301) 828-1535	208 Carrol Bldg., 8600 La Salle Rd., Towson, MD 21204
Massachusetts	Ivan C. James II	(617) 223-2822	150 Causeway St., Suite 1001, Boston, MA 02114
Michigan	T. Ray Cummings	(517) 377-1608	6520 Mercantile Way, Suite 5, Lansing, MI 48910
Minnesota	Donald R. Albin	(612) 725-7841	1033 Post Office Bldg.. St. Paul, MN 55101
Mississippi	Garald G. Parker, Jr.	(601) 960-4600	Suite 710, Federal Bldg., 100 West Capitol St., Jackson, MS 39201
Missouri	Daniel P. Bauer	(314) 341-0824	1400 Independence Rd., STOP 200, Rolla, MO 65401
Montana	George M. Pike	(406) 449-5263	Federal Bldg., Drawer 10076 Helena, MT 59626
Nebraska	William M. Kastner	(402) 471-5082	406 Federal Bldg., and U.S. Courthouse, 100 Centennial Mall, North, Lincoln, NE 68508
Nevada	Ernest F. Hubbard, Jr.	(208) 334-1750	See Idaho District Office
New Hampshire	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
New Jersey	Donald E. Vaupel	(609) 989-2162	430 Federal Bldg., 402 E. State St., Trenton, NJ 08608
New Mexico	James F. Daniel	(505) 766-2246	P.O. Box 26659, Western Bank Bldg., Rm. 809, 505 Marquette, NW., Albuquerque, NM 87125
New York	Lawrence A. Martins	(518) 472-3107	P.O. 1350, 343 U.S. Post Office and Courthouse Bldg., Albany NY 12201
North Carolina	James F. Turner	(919) 755-4510	P.O. Box 2857, Rm. 436, Century Postal Station Raleigh, NC 27602
North Dakota	Grady Moore	(701) 255-4011, ext. 601	821 East Interstate Ave., Rm. 332, New Fed. Bldg., 3d St. and Rosser Ave., Bismark, ND 58501
Ohio	Steven M. Hindall	(614) 469-5553	975 West Third Ave., Columbus, OH 43212
Oklahoma	James H. Irwin	(405) 231-4256	Rm. 621, 215 Dean A. McGee St., Oklahoma City, OK 73102
Oregon	Stanley F. Kapustka	(503) 231-2009 ext. 4776	P.O. Box 3202, 830 NE Holladay St., Portland, OR 97232
Pennsylvania	David E. Click	(717) 782-3468	P.O. Box 1107, 4th Floor, Federal Bldg., 228 Walnut St., Harrisburg, PA 17108
Puerto Rico	Ferdinand Quinones-Marquez	(809) 783-4660	GSA Center, Bldg. 652, Ft. Buchanan, PR 00936
Rhode Island	Ivan C. James II	(617) 223-2822	See Massachusetts District Office

Office	Name	Telephone number	Address
Selected Field Offices—Continued			
Water Resources Division—Continued			
District Offices—Contined			
South Carolina	Rodney N. Cherry	(803) 765-5966	Strom Thurmond Federal Bldg., Suite 658, 1835 Assembly St., Columbia, SC 29201
South Dakota	Richard E. Fidler	(605) 352-8651, ext. 258	Rm. 317, Federal Bldg., 200 4th St., SW, Huron, SD 57350
Tennessee	Arthur Putnam	(615) 251-5424	A-413 Federal Bldg., U.S. Courthouse, Nashville, TN 37203
Texas	Charles W. Boning	(512) 397-5766	649 Federal Bldg., 300 E. 8th St., Austin, TX 78701
Utah	Theodore Arnow	(801) 524-5663	1016 Administration Bldg., 1745 W. 17th St., S., Salt Lake City, UT 84104
Vermont	Ivan C. James II	(617) 223-2822	See Massachusetts District Office
Virginia	Herbert J. Freiberger	(301) 828-1535	See Maryland District Office
Washington	Leslie B. Laird	(206) 593-6510	1201 Pacific Ave., Suite 600, Tacoma, WA 98402
West Virginia	David H. Appel	(304) 343-6181, ext. 310	3017 Federal Bldg. and U.S. Courthouse, 500 Quarrier St., E., Charleston, W VA 25301
Wisconsin	Vernon Norman	(608) 262-2488	1815 University Ave., Rm. 200, Madison, WI 53706
Wyoming	James F. Wilson, Jr. (Acting)	(307) 778-2220, ext. 2153	P.O. Box 1125, 2120 Capital Ave. Rm. 5017 Cheyenne, WY 82001
Office of Earth Sciences Applications			
Earth Resources Observation Systems Data Center			
South Dakota	Allen H. Watkins	(605) 594-7123	EROS Data Center, Sioux Falls, SD 57198
National Petroleum Reserve in Alaska			
District Offices			
NPRA Operations Office	Max Brewer	(907) 276-7422	2525 "C" St., Suite 400, Anchorage, AK 99503
Exploration Strategy Office	Arthur Bowsher	(415) 323-2917	345 Middlefield Rd. Menlo Park, CA 94025
Administrative Division			
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Western	Avery W. Rogers	(415) 323-2211	345 Middlefield Rd., STOP 11, Menlo Park, CA 94025

Guide to Information and Publications

Throughout this report, reference has been made to information services and publications of the U.S. Geological Survey. During fiscal year 1982, the Survey produced over 5,965 new and revised topographic, hydrologic, and geologic maps, printed 15,956,262 copies of 5,965 different maps, distributed 8,389,106 copies of maps, and sold 6,602,542 copies for $7,861,709. The number of reports approved for publication by the Geological Survey decreased —4,594 reports prepared in fiscal year 1982 with 64 percent designated for publication in professional journals and monographs outside the Survey with the remainder scheduled for publication by the Survey. In addition, 217,542 copies of technical reports were distributed of which 50,373 copies were sold for $271,145, and 1,007 open-file reports were released of which 58,288 copies were sold for $417,554.

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

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

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Western Distribution Branch
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Denver, CO 80225

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

To obtain information on the availability of microfiche or paper-duplicate copies of open-file reports, write:
U.S. Geological Survey
Open-File Services Section
Box 25425, Federal Center
Denver, CO 80225

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

To subscribe to the *Earthquake Information Bulletin,* write:
Superintendent of Documents
Government Printing Office
Washington, DC 20402

To obtain information on programs, publications, and services or to obtain copies or reports and maps, visit the U.S. Geological Survey Public Inquiries Offices at the following addresses:

Alaska:
108 Skyline Bldg.
508 2nd Avenue
Anchorage, AK 99501

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

122 Bldg. 3
345 Middlefield Rd.
Menlo Park, CA 94025

504 Customhouse
555 Battery St.
San Francisco, CA 94111

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

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

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

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

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

Washington, DC:
1028 General Services Bldg.
19th and F Sts., N.W.
Washington, DC 20244

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

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

Colorado:
Rocky Mountain Mapping Center
National Cartographic Information Center
Box 25046, Stop 501
Bldg. 25, Federal Center
Denver, CO 80225

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

Missouri:
Midcontinent Mapping Center
National Cartographic Information Center
1400 Independence Rd.
Rolla, MO 65401

Virginia:
National Cartographic Information Center
507 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

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

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

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

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

To obtain information on water resources in general and about the water resources of specific area of the United States, write:
U.S. Geological Survey
Water Information Group
420 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

To obtain information on geology topics such as earthquakes, energy and mineral resources, the geology of specific areas, and geologic maps and mapping, write:
U.S. Geological Survey
Geologic Inquiries Group
907 National Center
12201 Sunrise Valley Dr.
Reston, VA 22091

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[Cooperators listed are those whom the U.S. Geological Survey had a written agreement cosigned by Survey officials and the cooperating agency for financial cooperation in fiscal year 1982. Parent agencies are listed separately from their subdivisions whenever there are separate cooperative agreements for different projects with a parent agency and with a subdivision of it. Agencies with whom the Geological Survey has research contracts and to whom it supplied research funds are not listed.]

Cooperating office of the Geological Survey
c—Conservation District
e—Office of Earth Sciences Applications
g—Geological Division
n—National Mapping Division
w—Water Resources Division

State, County, and Local Cooperators

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Alabama Highway Department (w); Geological Survey of Alabama (e, n, w); Jefferson County Commission (w); Water Improvement Commission (w)

Alaska:

Alaska Department of—Environmental Conservation (w), Fish and Game (w), Natural Resources, Division of—(n)—Forests, Lands and Water Management (e), Geological and Geophysical Surveys (g, w), Transportation and Public Facilities (w); Alaska Power Authority (w) Anchorage, Municipality of—Department of Enterprise Activities, Sewer and Water Authority (w), Department of Health and Environmental Protection (w), Department of Planning (w); Fairbanks North Star Borough (w); Kenai Peninsula Borough (w); Matanuska Susitna Borough (w)

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Arizona Bureau of Geology and Mineral Technology (e); Arizona Department of—Game and Fish (w), Health Services, Bureau of Water Quality Control (w), Water Resources (w); Flagstaff, City of (w); Gila Valley Irrigation District (w); Maricopa County—Flood Control District (w), Municipal Water Conservation District No. 1 (w); Metropolitan Water District of Southern California (w); Navajo County Parks Commission (w); Pima County, Board of Supervisors (w); Salt River Valley Water Users Association (w); San Carlos Irrigation and Drainage District (w); Show Low Irrigation Company (w); Tuscon, City of (w); University of Arizona, Water Resources Research Center (w)

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Colorado:

Adams County, Board of Commissioners (w); Arapahoe, County of (w); Arkansas River Compact Administration (w); Aspen, City of (w); Aurora, City of (w); Central Yuma Ground Water Management District (w); Chapel Hills Water and Sanitation District (w); Cherokee Water District (w); Colorado Department of—Health, Water Pollution Control Division (w), Highways (w), Local Affairs (n), Natural Resources, Geological Survey (w); Colorado Division of Water Resources, Office of the State Engineer (w); Colorado River Water Conservation District (w); Colorado Springs, City of—Department of Public Utilities (w), Office of the City Manager (w); Colorado Water Conservation Board (w); Copper Mountain Water and Sanitation District (w); Delta County, Board of County Commissioners (w); Denver, City and County, Board of Water Commissioners (w); Denver Regional Council of Governments (w); Eagle County, Board of Commissioners (w); El Paso County Water Users Association (w); Englewood, City of (w); Frenchman Ground Water Management District (w); Glenwood Springs, City of (w); Grand County Board of Commissioners (w);

Larimer-Weld Regional Council of Governments (w); Longmont, City of (w); Marks Butte Ground Water Management District (w); Mesa, County of (w); Metropolitan Denver Sewage Disposal District No. 1 (w); Mineral County, Board of County Commissioners (w); Northern Colorado Water Conservation District (w); Northglenn, City of (w); Pitkin County, Board of Commissioners (w); Pleasant View Water and Sanitation District (w); Pueblo, City of, Board of Water Works (w); Pueblo Civil Defense Agency (w); Purgatoire River Water Conservancy District (w); Rio Blanco County, Board of County Commissioners (w); Rio Grande Water Conservation District (w); Sand Hills Ground Water Management District (w); Southeastern Colorado Water Conservancy District (w); Southwestern Colorado Water Conservation District (w); Trinchera Conservancy District (w); Uncompahgre Valley Water Users' Association (w); Upper Arkansas River Water Conservancy District (w); Upper Yampa Water Conservancy District (w); Urban Drainage and Flood Control District (w); Ute Mountain Ute Tribe (w); Yellow Jacket Water Conservancy District (w)

Connecticut:

Connecticut Department of Environmental Protection (g, n, w); Enfield, Town of (w); Fairfield, Town of, Conservation Commission (w); Manchester, Town of, Department of Public Works (w); Meriden, Town of, Department of Public Works (w); New Britain, City of—Board of Water Commissioners (w), Improvement Commission (w); New Haven Water Company (w); Northeast Connecticut Regional Planning Agency (w); Norwalk, Town of (w); Simsbury, Town of (w); Torrington, City of (w)

Delaware:

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

District of Columbia:

Department of Environmental Services (w)

Florida:

Big Cypress Basin Board (w); Boca Raton, City of (w); Bradenton, City of (w); Brevard County, Board of County Commissioners (w); Broward County—Environmental Quality Control Board (w), 208 Project (w), Water Management Division (w); Cape Coral, City of (w); Clearwater, City of (w); Collier, County of (w); Cocoa, City of (w); Coordinating Council on the Restoration of Kissimmee River Valley and Taylor Creek—Nubbins Slough Basin (w); Englewood Water District, Board of Supervisors (w); Escambia County—Board of County Commissioners (w), Utilities Authority (w); Flagler County, Board of County Commissioners (w); Florida Department of—Environmental Regulation—Bureau of Water Resources Management (w), Division of Recreation and Parks (w), Natural Resources (n), Transportation (n, w); Florida Institute of Phosphate Research (w); Florida Keys Aqueduct Authority (w); Fort Lauderdale, City of (w); Fort Walton Beach, City of (w); Gainesville, City of (w); Hallandale, City of (w); Hernando, County of (w); Highland Beach, Town of (w); Hillsborough County (w); Hollywood, City of (w); Jacksonville, Consolidated City of—Department of Public Works (w), Department of Health and Environmental Services (w); Jacksonville Electric Authority (w); Juno Beach, Town of (w); Jupiter Inlet District (w); Lake County—Board of County Commissioners (w), Pollution Control Department (w), Water Authority (w); Lee County, Board of County Commissioners (w); Leon County—Courthouse (w), Department of Public Works (w); Manatee County, Board of County Commissioners (w); Marion County, Board of County Commissioners (w); Metropolitan Dade County—Department of Environmental Resources Management—Environmental Planning Section (w), Water Management Division (w); Miami-Dade Water and Sewer Authority (w); Northwest Florida Water Management District (w); Old Plantation Water Control District (w); Orange County, Board of County Commissioners (w); Palm Beach County, Board of County Commissioners (w); Pensacola, City of (w); Perry, City of (w); Pinellas County, Board of County Commissioners (w); Polk County, Board of County Commissioners (w); Pompano Beach, City of, Water and Sewer Department (w); Quincy, City of (w); Reedy Creek Improvement District (w); Sarasota, City of (w); Sarasota, County of (w); South Florida Water Management District (w); Southwest Florida Regional Planning Commission (w); Southwest Florida Water Management District (w); St. Johns, County of (w); St. Johns River Water Management District (w); St. Petersburg, City of (w); Stuart, City of (w); Sumter County, Recreation and Water Conservation and Control Authority (w); Suwannee River Authority (w); Suwannee River Water Management District (w); Tallahassee, City of, Underground Utilities (w); Tampa, City of (w); Volusia, County of (w); Walton, County of (w); West Coast Regional Waters Supply Authority (w); Winter Haven Lake Region, Boat Course District (w); Winter Park, City of (w)

Georgia:

Albany, City of, Water, Gas, and Light Commission (w); Bibb County, Board of Commissioners (w); Brunswick, City of (w); Chatham County, Board of Commissioners (w); Clayton County, Water Authority (w); Consolidated Government of Columbus (w); Covington, City of (w); Georgia Department of—Natural Resources—Environmental Protection Division (w), Geological Survey (n, w), Transportation (w); Macon—Bibb County, Water and Sewage Authority (w); Valdosta, City of (w)

Guam: (See Hawaii)

Hawaii:

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

Idaho:

Big Lost River Irrigation District (w); Butte Soil Conservation District (w); Idaho Department of—Fish and Game (w), Health and Welfare, Bureau of Water Quality (w), Transportation, Division of Highways (w), Water Resources (w); Idaho Water Resources Board (w); Oakley Canal Company (w); Pullman Moscow Water Resources Committee (w); Salmon River Canal Company (w); The Shoshone Bannock Tribes, Fort Hall Indian Reservation (w); Water District No. 01—Idaho Falls (w); Water District No. 31—DuBois (w); Water District No. 33—Howe (w); Water District No. 37—Shoshone (w); Water District No. 37-N—Carey (w); Water District No. 65-K—Lake Fork (w)

Illinois:

Bloomington and Normal Sanitary District (w); Cook County, Forest Preserve District (w); Decatur, City of (w); Illinois Department of (w)—Conservation (n), Energy and Natural Resources, State Water Survey Division (w), Transportation, Division of Water Resources (n, w), Division of Highways (n, w); Illinois Environmental Protection Agency (w); Illinois State Geological Survey (e, n); Metropolitan Sanitary District of Greater Chicago (w); Springfield, City of (w)

Indiana:

Carmel, Town of (w); Elkhart, City of, Water Works (w); Indiana State Board of Health (w); Indiana Department of—Highways (w), Natural Resources (n, w), Indiana Geological Survey (e), Indiana University School of Public and Environmental Affairs (e)

Iowa:

Ames, City of (w); Cedar Rapids, City of (w); Charles City, City of (w); Clear Lake, City of (w); Des Moines, City of (w); Des Moines Water Works (w); Fort Dodge, City of (w); Harlan, City of (w); Iowa City, City of (w); Iowa Department of—Transportation—Highway Division (n, w); Iowa Geological Survey (e, n, w); Iowa Natural Resources Council (w); Iowa State University—Agricultural Experiment Station (w), Department of Agricultural Engineering (w); Marshalltown, City of (w); Ottumwa Water Works (w); Sewage Disposal Plant (w); Sioux City, City of (w); University of Iowa—Institute of Hydraulic Research (w), University Physical Plant (w); Waterloo, City of (w); West-Central Iowa Rural Water Association (w)

Kansas:

Arkansas River Compact Administration (w); Harvey, County of (w); Hays, City of (w); Kansas Department of—Health and Environment (w), Transportation (w); Kansas Geological Survey (n, w); Kansas State Board of Agriculture, Division of Water Resources (w); Kansas Water Office (w); Kansas-Oklahoma-Arkansas River Commission (w); Southwest Kansas GWMD No. 3 (w); Western Kansas GWMD No. 1 (w); Wichita, City of, Flood Control Maintenance (w)

Kentucky:

Elizabethtown, City of (w); Kentucky Department of—Natural Resources and Environmental Protection, Water Division (w), Transportation, Division of Design (w); University of Kentucky, Kentucky Geological Survey (e, n, w)

Louisiana:

Baton Rouge City-Parish Government (w); Capital-Area Groundwater Conservation Commission (w); Louisiana Department of—Natural Resources—Office of Conservation, Surface Mine Division (w), Office of Environmental Affairs, Water Pollution Control Division (w), Transportation and Development—Office of Highways (w), Office of Public Works (n, w); Louisiana Geological Survey (g); Rapides Area Planning Commission (w); Louisiana State Planning Office (n); Sabine River Compact Administration (w)

Maine:

Androscoggin Valley Regional Planning Commission (w); Cobbossee Watershed District (w); Maine Department of—Conservation, Geological Survey (n, w), Environmental Protection (w); Wilton, Town of (w)

Maryland:

Anne Arundel County Planning and Zoning Office (w); Baltimore County—Department of Permits and Licenses (w), Department of Public Works (w), Office of Planning and Zoning (w); Calvert County (w); Caroline County (w); Carroll County, Board of County Commissioners (w); Howard County, Department of Public Works (w); Maryland Department of—Health and Mental Hygiene, Office of Environmental Programs (w), Transportation, State Highway Administration (w); Maryland Energy Administration (w); Maryland Geological Survey (e, n, w); Maryland Water Resources Administration (w); Montgomery County—Department of Environmental Protection, Office of Environmental and Energy Planning (w), Division of Pollution Control (w); Poolesville, Town of (w); St. Marys County, County Commissioners (w); Upper Potomac River Commission (w)

Massachusetts:

Barnstable County, County Commissioners (w); Falmouth, Town of (w); Massachusetts Department of Public Works (g, n)—Division of Highways (w), Division of Research and Materials (w); Massachusetts State Water Resources Commission—Division of Water Pollution Control (w), Division of Water Resources (w); Metropolitan District Commission, Water Division (w); University of Massachusetts (e)

Michigan:

Ann Arbor, City of (w); Battle Creek, City of (w); Branch County (w); Clare, City of (w); Coldwater, City of, Board of Public Utilities (w); Dickinson County, Board of Road Commissioners (w); Elsie, Village of (w); Flint, City of, Water Supply and Pollution Control, Department of Public Works and Utilities (w); Genesee County Drain Commission, Division of Water and Waste Services (w); Huron-Clinton Metropolitan Authority (w); Imlay, City of (w); Kalamazoo, City of, Department of Public Utilities (w); Lansing, City of, Board of Water and Light, Water and Stream Division (w); Macomb County (w); Mason, City of (w); Michigan Department of—Agriculture, Soil and Water Conservation Division (w), Natural Resources—Geological Survey Division (e, w), Office of Budget and Federal Aid (w), Transportation (w); Oakland County, Drain Commission (w); Otsego County, Road Commission (w); Portage, City of (w); St. Johns, City of (w); Southeast Michigan Council of Governments (w); University of Michigan (e); Van Buren County, Board of Commissioners (w); Ypsilanti, City of (w)

Minnesota:

Bassett Creek Flood Control Commissioner (w); Coon Creek Watershed District (w); Egan, City of (w); Elm Creek Conservation Commission (w); Iron Range Resources Rehabilitation Board (w); Metropolitan Council of the Twin Cities Area (w); Middle River-Snake River Watershed District (w); Minnesota Department of—Energy, Planning and Development (w), Health (w), Natural Resources (w), Transportation (w); Minnesota Geological Survey (w); Minnesota Pollution Control Agency (w); Minnesota State Planning Agency (e); Minnesota Waste Management Board (w); Red Lake Watershed District (w); St. Louis Park, City of (w); University of Minnesota (w); Wesmin Resource, Conservation and Development Association (w)

Mississippi:

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

Missouri:

Little River Drainage District (w); Missouri Department of—Conservation (w), Natural Resources—Division of Environmental Quality, Lab Services Program (w), Division of Geology and Land Survey (n, w), Missouri Highway and Transportation Commission (w), Springfield, City of (w), St. Louis County, Department of Highways and Transportation (w)

Montana:

Montana Bureau of Mines and Geology (w); Montana Department of—Fish, Wildlife, and Parks (w), Health and Environmental Sciences (w), Highways (w), Natural Resources and Conservation (w), State Lands (w); Montana State University (w); State of Montana (w); Wyoming State Engineer (w)

Nebraska:

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

Nevada:

Carson City, Department of Public Works (w); Clark County, Department of Comprehensive Planning (w); Douglas County, Department of Planning (w); Las Vegas Valley Water District (w); Nevada Bureau of Mines and Geology (g, n, w); Nevada Department of—Conservation and Natural Resources—Division of Environmental Protection (w), Division of Water Resources (w), Human Resources (w), Transportation (w); Nevada Division of Forestry (w); Washoe County, Department of Planning (w)

New Hampshire

New Hampshire Water Resources Board (w)

New Jersey:

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

New Mexico:

Albuquerque, City of (w); Albuquerque Metropolitan Arroyo Flood Control Authority (w); Costilla Creek Compact Commission (w); New Mexico Bureau of Economic Development (w); New Mexico Bureau of Mines and Mineral Resources (w); New Mexico Environmental Improvement Division (w); New Mexico Department of Highways (w); Office of State Engineer (w); Pecos River Commission (w); Pueblo of Zuni (w); Rio Grande Compact Commission (w); Santa Fe Metropolitan Water Board (w)

New York:

Albany, City of, Department of Water and Water Supply (w); Auburn, City of (w); Brookhaven, Town of (w); Chautauqua, County of, Department of Planning and Development (w); Cornell University—Department of Natural Resources (w), Department of Utilities (w); Cortland, County of, Planning Department (w); Erie County, Division of Environmental Control, Department of Environment and Planning (w); Hudson River-Black River Regulating District (w); Irondequoit Bay Pure Waters District (w); Long Island Regional Planning Board (w); Monroe, County of, Water Authority (w); Nassau, County of, Department of Public Works (w); New York City—Department of Environmental Protection, Air Resources-Water Resources-Energy (w); New York State Department of—Education (w), Health, Division of Environmental Health (w), Environmental Conservation—Bureau of Monitoring and Assessment, Resource Monitoring Section (w), Bureau of Water Research (w), Division of Air (w), Division of Water (w), Hydrologic Services Section, PCB Project Unit (w), Water Research Bureau (w), Transportation, Bridge and Construction Bureau (n, w); New York State Geological Survey (e); New York State Power Authority (w); Nyack, Village of, Board of Water Commissioners (w); Onondaga, County of—Department of Drainage (w), Environmental Management Council (w), Water Authority (w); Oswegatchie River-Cranberry Reservoir Commission (w); Oswego, County of, Planning Board (w); Rochester, City of, Department of Public Works (w); Rockland, County of, Drainage Agency (w); Seneca Nation of Indians (w); Suffolk, County of—Department of Health Services (w), Water Authority (w); Susquehanna River Basin Commission (w); Ulster, County of, County Legislators (w); University of the State of New York, Regents Research Inc. (e, w); University of Virginia, Department of Environmental Sciences (w); Westchester, County of—Department of Health (w), Department of Public Works (w)

North Carolina:

Cary, City of (w); Charlotte, City of (w); Durham, City of, Department of Water Resources (w); Greensboro, City of (w); North Carolina State Department of—Natural Resources and Community Development (n, w), Transportation, Division of Highways (w); North Carolina Agricultural Research Service (w); Raleigh, City of (w); Rocky Mount, City of (w)

North Dakota:

North Dakota Geological Survey (w); North Dakota State University (e); Oliver County, Board of Commissioners (w); Public Service Commission (w); State Department of Health (w); State Water Commission (n, w)

Northern Mariana Islands: (See Hawaii)

Ohio:

Canton, City of, Water Department (w); Columbus, City of—Department of Public Service (w), Division of Water (w); Cuyahoga, County of (w); Geauga, County of (w); Miami Conservancy District (w); Northeast Ohio Areawide Coordinating Agency (w); Ohio Department of—Natural Resources—Division of Geological Survey (g, n), Division of Reclamation (w), Division of Water (w), Transportation (n)—Division of Highways (w); Ohio Environmental Protection Agency—Office of Planning Coordinator (w), Water Quality Planning and Assessment (w)

Oklahoma:

Ada, City of (w); Altus, City of (w); Central Oklahoma Master Conservancy District (w); Claremore, City of (w); Fort Cobb Reservoir Master Conservancy District (w); Foss Reservoir Master Conservancy District (w); Lawton, City of (w); Lugert-Altus Irrigation District (w); Oklahoma City, City of (w); Oklahoma Conservation Commission (w); Oklahoma Department of Transportation (w); Oklahoma Geological Survey (w); Oklahoma State Health Department (w); Oklahoma Water Resources Board (w); Sapulpa, City of (w); Tulsa, City of (w)

Oregon:

Benton County Emergency Services (w); Burnt River Irrigation District (w); Confederated Tribes of—Umatilla Indian Reservation (w), Warm Springs Indian Reservation (w); Coos Bay-North Bend Water Board (w); Douglas, County of, Department of Public Works (w); Eugene, City of, Water and Electric Board (w); Lane Council of Governments (w); Lane, County of, Office of the Chief Administrator (w); McMinnville, City of, Water and Light Department (w); Oregon Department of—Environmental Quality (w), Fish and Wildlife (w), Geology and Minerals (w), Water Resources (w); Oregon State Highway Division (w); Oregon State University (w); Portland, City of, Department of Finance and Administration (w); Salem, City of (w); Wasco County People's Utility District (w)

Pennsylvania:

Altoona City Authority (w); Bethlehem, City of (w); Chester, County of, Water Resources Authority (w); Delaware River Basin Commission (w); Harrisburg, City of, Department of Public Works (w); Letort Regional Authority (w); Millcreek, Township of (w); New York State Department of Environmental Conservation (w); Oley Township (w); Philadelphia, City of, Water Department (w); Pennsylvania Department of—Environmental Resources—Office of Resources Management (w), Surface Mine Reclamation Bureau (w), Topographic and Geologic Survey Bureau (n, w), Water Quality Management Bureau (w); Susquehanna River Basin Commission (w); Washington County Planning Commission (w)

Puerto Rico:

Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of—Agriculture (w), Health (w), Natural Resources (g, w), Transportation and Public Works (w); Puerto Rico Electric Power Authority (w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Land Authority (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Planning Board (w); Puerto Rico Sugar Corporation (w)—(See also Virgin Islands)

Rhode Island:

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

South Carolina:

Charleston Commission of Public Works (w); Georgetown, County of, Water and Sewer District (w); Grand Strand Water and Sewer Authority (w); Hilton Head Island, Public Service District No. 1 (w); Myrtle Beach, City of (w); North Myrtle Beach, City of (w); South Carolina State—Appalachian Council of Governments (w), Department of Highways and Public Transportation (w), Geological Survey (w), Health and Environmental Control (w), Public Service Authority (w), Water Resources Commission (w); Spartanburg Water Works, Commissioners of Public Works (w)

South Dakota:

Black Hills Conservancy Subdistrict (w); East Dakota Conservancy Subdistrict (w); Lower James Conservancy Subdistrict (w); Sioux Falls, City of (e, w); South Dakota Department of—Transportation (n, w), Water and Natural Resources—Geological Survey Division (w), Water Rights Division (w), South Dakota School of Mines and Technology (w), Watertown, City of (w)

Tennessee:

Franklin, City of (w); Lawrenceburg, City of (w); Lincoln County, Board of Public Utilities (w); Memphis, City of—Light, Gas, and Water Division (w), Public Works Division (w), Water Division (w); Metropolitan Government of Nashville and Davidson County, Department of Public Works (w); Shelby, County of (w); Tennessee Board of Public Utilities (w); Tennessee Department of—Conservation (e)—Geology Division (e, n, w), Water Resources Division (w), Public Health, Water Quality Control Division (w), Transportation, Bureau of Highways (w)

Texas:

Abilene, City of (w); Alice, City of (w); Arlington, City of (w); Athens Municipal Water Authority (w); Austin, City of (w); Bexar-Medina-Atascosa Counties, Water Improvement District No. 1 (w); Bistone Municipal Water Supply District (w); Brady, City of (w); Brazos River Authority (w); Cleburne, City of (w); Clyde, City of (w); Coastal Bend Council of Governments (w); Coastal Industrial Water Authority (w); Colorado River Municipal Water District (w); Corpus Christi, City of (w); Dallas, City of, Public Works Department (w); Dallas, County of, Public Works Department (w); Edwards Underground Water District (w); El Paso, City of, Public Service Board (w); Franklin, County of, Water District (w); Gainesville, City of (w); Galveston, County of (w); Garland, City of (w); Graham, City of (w); Greenbelt Municipal and Industrial Water Authority (w); Guadalupe-Blanco River Authority (w); Harris, County of, Flood Control District (w); Harris-Galveston Coastal Subsidence District (w); Houston, City of (w); Lavaca-Navidad River Authority (w); Lower Colorado River Authority (w); Lower Neches Valley Authority (w); Lubbock, City of (w); Mackenzie Municipal Water Authority (w); Nacogdoches, City of (w); North Central Texas Municipal Water Authority (w); Northeast Texas Municipal Water District (w); Nueces River Authority (w); Orange, County of (w); Palo Pinto, County of, Municipal Water District No. 1 (w); Pecos River Commission (w); Red Bluff Water Power Control District (w); Reeves, County of, Water Improvement District No. 1 (w); Sabine River Authority of Texas (w); Sabine River Compact Administration (w); San Angelo, City of (w); San Antonio, City of—Engineering Department (w), Public Service Board (w), Water Board (w); San Antonio River Authority (w); San Jacinto River Authority (w); Tarrant, County of, Water Control and Improvement District No. 1 (w); Texas A & M (e); Texas Department of Water Resources (w); Titus, County of, Fresh Water Supply District No. 1 (w); Tom Green, County of, Water Control and Improvement District No. 1 (w); Trinity River Authority (w); Upper Guadalupe River Authority (w); Upper Neches River Municipal Water Authority (w); Upper Trinity Basin Water Quality Compact (w); Velasco Drainage District (w); West Central Texas Municipal Water District (w); Wichita, County of, Water Improvement District No. 2 (w); Wichita Falls, City of (w); Wood, County of (w)

Trust Territory of the Pacific Islands: (See Hawaii)

Utah:

Bear River Commission (w); Salt Lake, County of—Board of County Commissioners (w), Division of Flood Control and Water Quality (w), Utah Department of—Natural Resources—Geological and Mineral Survey (g, n, w), Water Resources Division (w), Water Rights Division (w), Wildlife Resources Division (w)

Vermont:

Agency of Environmental Conservation (n); Springfield, Town of (w); Vermont Department of—Water Resources and Environmental Engineering (w)

Virginia:

Alexandria, City of, Department of Transportation and Environmental Services (w); James City, County of, Department of Public Works (w); Newport News, City of, Department of Public Utilities (w); Roanoke, City of, Utilities and Operations (w); Southeastern Public Service Authority of Virginia (w); Staunton, City of (w); University of Virginia, Department of Environmental Sciences (w); Virginia Department of Conservation and Development—Division of Mineral Resources (n); Virginia Department of Highways and Transportation (w); Virginia Polytechnic Institute and State University (e); Virginia State Water Control Board (w)

Virgin Islands:

Department of Public Works (w); Planning Office (w); Virgin Islands, College of (w)

Washington:

Bellevue, City of, Public Works Department (w); Chelan, County of, Public Utility District No. 1 (w); Cowlitz, County of, Department of Community Development (w); Everett, City of (w); Fircrest, Town of (w); Hoh Indian Tribe (w); Island, County of, Planning Department (w); King, County of, Department of Public Works (w); Lewis, County of, Board of Commissioners (w); Makah Tribal Council (w); Municipality of Metropolitan Seattle (w); Pend Oreille, County of, Public Utility District No. 1 (w); Puyallup Nation (w); Quinault Indian Business Council (w); San Juan County Board of County Commissioners (w); Seattle, City of—Department of Lighting (w), Water Department (w); Skagit, County of (w); Tacoma, City of—Public Utilities Department (w), Public Works Department (w); Tulalip Tribal Board of Directors (w); University of Washington (w); Washington Public Power Supply System (w); Washinton Department of—Ecology (w), Fisheries (w), Natural Resources (n), Transportation (n); Washington State University, Department of Agricultural Engineering (w); Whatcom, County of, Board of Commissioners (w)

West Virginia:

Interstate Commission Potomac River Basin (w); Morgantown, City of, Water Commission (w); West Virginia Department of—Highways (w), Natural Resources, Division of Water Resources (w); West Virginia Geological and Economic Survey (w)

Wisconsin:

Brown County Planning Commission (w); Dane, County of—Department of Public Works (w), Regional Planning Commission (w); Forest County Potawatomi Community (w); Green Bay Metropolitan Sewerage District (w); Green Lake Sanitary District (w); Lac du Flambeau Indian Reservation (w); Madison Metropolitan Sewage District (w); Madison Water Utility (w); Menominee Indian Tribe of Wisconsin (w); Middleton, City of (w); Schleswig, Town of, Sanitary District No. 1 (w); Southeastern Wisconsin Regional Planning Commission (w); University of Wisconsin—Extension, Geological and Natural History Survey (n, w); University of Wisconsin, Milwaukee (w); Wisconsin Department of—Natural Resources (g, n, w), Transportation—Bridge Section (w), Division of Highways (w)

Wyoming:
Cheyenne Board of Public Utilities (w); University of Wyoming—Water Resources Research Institute and Institute for Policy Research (e); Water Development Commission (w); Wyoming Department of—Agriculture (w), Economic Planning and Development (w), Environmental Quality (w), Highways (w); Wyoming State Engineer (n, w)

Cooperators and Other Financial Contributors

Federal Cooperators

Appalachian Regional Commission (e)

Central Intelligence Agency (g)

Council on Environmental Quality (e)

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

Department of the Air Force:
Air Force Academy (w); Bolling Air Force Base (g); Hanscom Air Force Base (g); Headquarters, AFTAC/AC (g); Holloman Air Force Base (w); Homestead Air Force Base (w); Los Angeles (w); Myrtle Beach (w); Vandenberg Air Force Base (w); Wurtsmith Air Force Base (w)

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

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

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

Department of Energy:
Albuquerque Operations Office (g, w); Argonne National Laboratory (c); Batelle National Laboratory (c); National Aeronautics and Space Administration (e, g, w, n); National Science Foundation (e, g, w, n); Nuclear Regulatory Commission (g, w); Tennessee Valley Authority (n, w); United States Arms Control and Disarmament Agency (g); Veterans Administration (g, w); Water Resources Council (n, w); Bonneville Power Administration (w); Chicago Operations Office (w); Energy Programs Division (e); Idaho Operations Office (w); Laramie Energy Tech Center (w); Lawrence Livermore Laboratory (g, w); Los Alamos Science Laboratory (w); Morgantown Energy Technology Center (w); Nevada Operations Office (g, w); Oak Ridge Operations Office (w); Office of Energy Research (g); Procurement Operations Office (g); Richland Operations Office (g, w); San Francisco Operations (g, w); Sandia National Laboratories (g); Western Area Powth Administration (g)

Department of Health, and Human Services (w)

Department of Housing and Urban Development (w)

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

Department of the Navy:
Kings Bay (w); Naval Facilities Engineer Command Contracts, Trident (w); Naval Explosive Ordnance Disposal Test Center (g); Naval Oceanographic Office (g, n); Naval Weapons Center, China Lake (g, w); Office of Naval Research (g); U.S. Marines Corps, Camp Pendleton (w); U.S. Coast Guard (w)

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

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

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

Environmental Protection Agency: (n)
Corvallis Environmental Research Laboratory (w); Environmental Monitoring Systems Laboratory (g); Office of Environmental Engineering and Technology (g); Office of Monitoring and Technical Support (w)

Federal Emergency Management Agency (e, g, w)

Federal Energy Regulating Commission Licensees (w)

General Services Administration (w)

Great Lakes Basin Commission (e)

Missouri River Basin Commission (e, w)

Other Cooperators and Contributors

Government of Guam (w)

Government of Peru (g)

Government of Saudi Arabia (w, g)

Organization of American States (e)

People's Republic of China (e, g)

Puerto Rico:
Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of Agriculture (w); Puerto Rico Department of Health (w); Puerto Rico Department of Natural Resources (w, g); Puerto Rico Department of Transportation and Public Works (w); Puerto Rico Electric Power Authority (w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Land Authority (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Planning Board (w); Puerto Rico Sugar Corporation (w)

Trust Territory of the Pacific Islands (w)

United Nations:
United Nation Development Program (w)

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

Budgetary and Statistical Data

TABLE 1.—*Geological Survey budget for fiscal years 1977 to 1982, by activity and sources of funds*[1]

[In thousands of dollars]

Budget activity	1977	1978	1979	1980	1981	1982
Total	**$433,403**	**$698,272**	**$764,718**	**$782,136**	**$769,757**	**$661,842**
Direct program	319,460	576,393	634,886	639,143	623,057	509,983
Reimbursable program	113,943	121,879	129,832	142,993	146,700	151,859
States, counties and municipalities	39,621	40,784	44,124	46,849	48,700	50,418
Miscellaneous non-Federal sources	10,229	12,825	15,789	16,817	19,605	24,376
Other Federal agencies	64,093	68,270	69,919	79,327	78,395	77,065
Alaska Pipeline Related Investigations	**317**	**272**	------	------	------	------
Direct program	317	272	------	------	------	------
Reimbursable program	------	------	------	------	------	------
Other Federal agencies	------	------	------	------	------	------
National Mapping, Geography, and Surveys	**57,073**	**69,520**	**74,566**	**82,683**	**89,177**	**88,133**
Direct program	50,311	61,356	65,584	72,759	77,449	77,687
Reimbursable program	6,762	8,164	8,982	9,924	11,727	10,446
States, counties, and municipalities	3,268	3,320	3,371	3,083	2,985	3,000
Miscellaneous non-Federal sources	601	499	597	610	1,095	1,100
Other Federal agencies	2,893	4,345	5,014	6,231	7,648	6,346
Geologic and Mineral Resource Surveys and Mapping	**130,269**	**163,193**	**178,556**	**193,652**	**208,287**	**212,355**
Direct program	100,007	123,830	134,846	146,963	162,756	163,731
Reimbursable program	30,262	39,363	43,710	46,689	45,531	48,624
States, counties, and municipalities	1,403	956	584	640	758	480
Miscellaneous non-Federal sources	6,439	8,510	10,914	11,258	13,192	16,844
Other Federal agencies	22,420	29,897	32,212	34,791	31,761	31,300
Water Resources Investigations	**131,509**	**146,014**	**168,598**	**184,871**	**194,016**	**190,096**
Direct program	68,555	[2]78,487	96,847	108,664	115,458	108,637
Reimbursable program	62,954	67,527	71,751	76,207	78,558	81,459
States, counties, and municipalities	34,761	36,457	40,156	43,126	45,138	46,938
Miscellaneous non-Federal sources	1,331	1,429	1,673	1,778	2,088	2,679
Other Federal agencies	26,862	29,641	29,922	31,303	31,332	31,842
Conservation of Lands and Minerals	**67,427**	**77,409**	**85,484**	**106,395**	**127,001**	**130,468**
Direct program	67,239	77,299	85,362	105,928	125,739	129,868
Reimbursable program	188	110	122	467	1,262	600
Miscellaneous non-Federal sources	16	9	------	12	29	210
Other Federal agencies	172	101	122	455	1,233	390
Office of Earth Science Applications	**23,476**	**23,226**	**23,965**	**23,734**	**23,205**	**20,853**
Direct program	17,698	18,132	19,959	18,935	18,849	14,359
Reimbursable program	5,778	5,094	4,006	4,799	4,356	6,494
States, counties, and municipalities	189	51	13	------	------	------
Miscellaneous non-Federal sources	1,741	2,153	2,333	2,808	3,139	3,482
Other Federal agencies	3,848	2,890	1,600	1,991	1,217	3,012
National Petroleum Reserve in Alaska	**9,154**	**202,704**	**216,886**	**169,845**	**107,001**	**2,196**
Direct program	2,079	202,598	216,886	169,845	107,001	2,196
Allocation transfer	7,063	106	------	------	------	------
Reimbursable program (Federal)	12	------	------	------	------	------
General Administration	**3,760**	**3,650**	**3,661**	**3,776**	**3,896**	**3,407**
Direct program	3,760	3,650	3,661	3,776	3,896	3,407
Facilities	**9,494**	**10,769**	**11,741**	**12,273**	**11,909**	**10,098**
Direct program	9,494	10,769	11,741	12,273	11,909	10,098
Miscellaneous services to other accounts	**924**	**1,515**	**1,261**	**4,907**	**5,266**	**4,236**
Reimbursable program	924	1,515	1,261	4,907	5,266	4,236
Miscellaneous non-Federal sources	102	225	272	351	62	61
Other Federal agencies	822	1,290	989	4,556	5,204	4,175

[1] Includes 1982 appropriation for Minerals Management Service.

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

TABLE 2.—*Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1977 to 1982, by agency*

[In thousands of dollars]

Agency	1977	1978	1979	1980	1981	1982
Total	**$57,017**	**$68,164**	**$69,919**	**$79,326**	**$78,395**	**$76,675**
Department of Agriculture	2,130	2,727	2,619	3,878	3,567	2,675
Department of Commerce	334	183	141	276	------	------
National Oceanic and Atmospheric Administration	1,947	1,708	1,464	2,388	823	1,781
Ozarks Regional Commission	------	------	------	76	------	------
Department of Defense	12,308	15,655	16,760	17,447	18,490	21,459
Department of Energy	8,573	14,980	15,338	14,406	10,885	10,529
Bonneville Power Administration	(141)	(138)	(48)	(61)	(81)	(75)
Department of Housing and Urban Development	6,003	3,789	1,967	302	188	------
Department of the Interior	12,186	16,528	17,746	22,926	22,553	20,328
Bureau of Indian Affairs	915	2,385	4,345	9,295	3,999	5,001
Bureau of Land Management	9,011	10,791	9,712	7,807	13,800	10,551
Bureau of Mines	200	108	240	297	299	275
Bureau of Reclamation	1,199	1,871	1,975	2,257	2,231	1,800
National Park Service	542	791	771	818	1,121	1,015
Office of the Secretary	------	------	82	203	154	100
Office of Surface Mining	------	135	21	1,563	469	1,176
U.S. Fish and Wildlife Service	178	447	600	686	480	410
Department of State	1,075	1,010	1,455	2,449	2,272	3,445
Department of Transportation	313	193	149	291	273	500
Environmental Protection Agency	2,137	3,074	2,873	2,645	1,259	675
National Aeronautics and Space Administration	2,648	2,763	4,033	2,793	5,065	3,885
National Science Foundation	2,712	848	896	1,211	2,001	1,958
Nuclear Regulatory Commission	1,758	1,318	1,583	1,325	1,781	1,544
Tennessee Valley Authority	297	216	261	243	317	290
Miscellaneous Federal agencies	1,774	1,882	1,645	2,105	3,717	3,431
Miscellaneous services to other accounts	822	1,290	989	4,556	5,204	4,175

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.

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849