U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

# Activities of the Water Resources Division in Arizona, 1996–97

*Compiled by* STEVE A. LONGSWORTH, ELLEN K. VAN DE VANTER, *and* SIDNEY H. ALWIN

**Open-File Report 98–185**

Tucson, Arizona
1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director



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For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
520 North Park Avenue, Suite 221
Tucson, AZ 85719–5035

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Denver Federal Center
Denver, CO 80225–0046

# MESSAGE FROM THE DISTRICT CHIEF

The collection of hydrologic data and the investigation of the quantity, quality, and use of surface- and ground-water resources are major components of the mission of the Water Resources Division (WRD), U.S. Geological Survey (USGS). To accomplish this mission, the Arizona District is organized into a District office in Tucson and field offices in Tempe, Flagstaff, and Yuma, Arizona. These offices are geographically located in the State to provide access and response to hydrologic events and to maintain liaison with cooperating State and Federal agencies. The Arizona District technical staff is organized into two major sections: (1) the Hydrologic Data Section, which maintains the systematic hydrologic-data programs for the State, and (2) the Hydrologic Investigations and Research Section, which investigates and assesses the quantity, quality, and use of the State's water resources.

The Hydrologic Data Section maintains a network of hydrologic data-collection sites and compiles hydrologic data collected from these sites for public distribution. These hydrologic data include records of (1) stage and discharge of principal rivers and tributaries; (2) chemistry and suspended-sediment concentration of selected rivers; (3) water levels and quality of the water in the principal aquifers; and (4) surface- and ground-water use. Data from this network are compiled and entered into the District data base and published annually in the report series "Water Resources Data—Arizona." To provide a single point of retrieval for the public, data from this network also are compiled on the USGS World Wide Web server, located in Reston, Virginia (**water.usgs.gov**). The Hydrologic Data Section has made substantial progress in developing a real-time hydrologic data base. Surface-water data from selected sites are transmitted to the Arizona District's central hydrologic data base at regular intervals using satellite telemetry. This information is accessible to scientists or water managers to assess current hydrologic conditions. Real-time stream-discharge data for 121 streamflow-gaging stations are available at the Arizona District home page on the World Wide Web at **http://wwwdaztcn.wr.usgs.gov**.

The updated version of the National Water-Information System (NWIS) was installed in all WRD offices in 1997. This version is a Unix-based system that runs on the Data General platform. This release includes improvements for the National Water-Quality Assessment (NAWQA) study, programs to retrieve real-time data for display on the World Wide Web, and programs to facilitate management of real-time data. As this report was being compiled, the Arizona NWIS staff was working on another NWIS release scheduled for December 1997 that would include performance and technical improvements.

The investigation and assessment of the surface- and ground-water resources of Arizona is accomplished through a series of projects conducted by the Hydrologic Investigations and Research Section. Each project is managed by a designated project chief who is responsible for managing the investigative aspects of the project, maintaining a project budget, and providing public access to the findings of the project. Program emphasis for the Arizona District in 1998–99 is to provide timely, objective hydrologic information to Federal, tribal, State, and local agencies regarding water-supply availability, water quality, water-source identification, and water-resource management. Programs are expected to grow in the Lower Colorado River region where a method of accounting for ground-water withdrawal from wells is being implemented by the Bureau of Reclamation. Native Americans in the State are working to understand and protect the water resources on their lands. The District is working cooperatively with many of the tribes in Arizona to assist them in their efforts to manage their water resources.

The characterization of ground-water and surface-water quality in the Central Arizona Basins study area is a major focus for the NAWQA program in Arizona. Surface-water quality, aquatic ecological communities, and bioaccumulation of contaminants in bed sediment and tissue are being assessed at 11 major surface-water sites in the Santa Cruz, San Pedro, Salt, Gila, and Verde River Basins. Continuous water-quality measurements from several sites will be used to determine the quantity of nutrients and salts that enter and leave the 34,700 square-mile study area. Three of the surface-water sites are effluent-dependent streams where data will be used to evaluate the differences in water quality and ecology between these "manmade streams" and natural streams in an arid environment. Plans for fiscal year 1998 include the completion of 2 years of surface-water quality sampling at the 11 sites and the third and final ecological assessment at the multiple-year, multiple-reach sites on the San Pedro River and West Clear Creek.

Ground-water quality sampling in the Central Arizona Basins study area will provide a broad assessment of water-quality conditions for the most important present and future ground-water resources (subunit survey) and to determine the effects of particular land uses on recently recharged ground water (land-use survey). Subunit surveys were completed in the west Salt River Valley, which includes Phoenix, and in the Sierra Vista area of the San Pedro Basin in 1997. Assessing the effects of agriculture on shallow ground-water quality was the focus of a land-use survey in the west Salt River Valley. Most of the approximately 30 wells sampled for each subunit and land-use survey are existing domestic wells; however, 9 shallow monitoring wells were installed by NAWQA staff in the west Salt River Valley in fiscal year 1997 in order to more thoroughly assess land-use effects on shallow ground water. Plans for fiscal year 1998 include a subunit survey for the Tucson Basin with additional wells sampled in the Tucson metropolitan area.

The San Pedro and Verde River basins are rapidly growing in population and are particularly water-scarce regions of the State. Significant controversy exists between water users as to whether ground-water withdrawals are diminishing the flow of water in the adjacent rivers. Modeling and geochemical techniques have been used in ground-water studies of the San Pedro River Basin and are planned for use in a study of the Verde River Basin. Population growth and industrial expansion along the international border with Mexico are increasing the demands on the limited water supply. Additional development of water resources could potentially affect the quality of ground and surface waters. Studies of transboundary aquifers and the movement of contaminated ground water are needed to improve the understanding of the effects of this rapid development. In some alluvial basins of Arizona, intensive pumping of ground water for irrigation and municipal use continues to cause the land surface to subside. The greatest measured land subsidence in the State has occurred near Luke Air Force Base west of Phoenix. Land subsidence has gained renewed attention as a geohydrologic hazard and more study of the processes and potential means of mitigation are expected.

The effects of releases of water from Glen Canyon Dam on sediment-related resources along the Colorado River in the Grand Canyon have been the focus of the Glen Canyon Environmental Studies of the Bureau of Reclamation since 1982. As a part of that program and now under the auspices of the Grand Canyon Monitoring and Research Center, District staff have been monitoring flow, sediment transport, and sand storage in the river and major tributaries and are working with staff of the USGS National Research Program (NRP) to develop a suite of models for prediction of the response of flow and sand deposits to dam releases. In 1996, a controlled flood in the river created by releases that exceeded the powerplant range enabled the

collection of data to verify model predictions and permit revisions to the models to increase the accuracy of predictions for future releases designed for sandbar building. The Record of Decision on an Environmental Impact Statement on operations of Glen Canyon Dam was signed by the Secretary of the Interior in November 1996. That signing set in motion a process of adaptive management that recognizes the need to consider the downstream environmental effects in the operation of the dam and to incorporate in that management current scientific knowledge about the status of the riparian system and the effects of releases on it. The ongoing monitoring and research activities of the District staff and their NRP colleagues is a critical part of that knowledge and predictive capability.

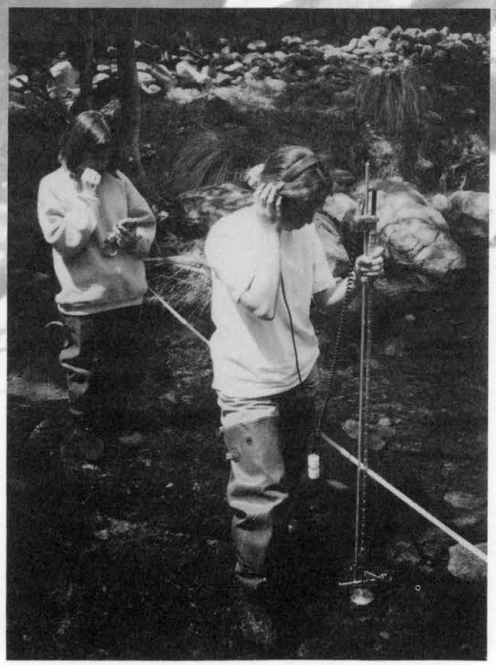
Because much of southern Arizona's population depends on ground water for municipal supplies, the hydrologic budgets of source-water areas are a topic of significant interest and concern to planners, resource managers, and environmental groups. The Arizona District has been at the forefront of the application of microgravity measurements to determine ground-water storage changes. Work is ongoing in the San Pedro and Tucson Basins to monitor storage changes that result from recharge of episodic flows in specific ephemeral streams. The upper San Pedro Basin also is the site of a microgravity network designed to measure basinwide storage changes. Conventional gravity measurements have been used in the Plateau Uplands physiographic province of northern Arizona to augment USGS understanding of the framework of the geohydrologic system in an area where the potentiometric surface is on the order of 1,200 ft below land surface.

Utilizing the energy and interests of the Arizona District staff, the Arizona District will continue to assist cooperating agencies and the public by providing accurate and timely hydrologic information. I look forward to continuing partnerships that will provide the basis for the management and beneficial use of Arizona's water resources.

Nick B. Melcher
District Chief
U.S. Geological Survey
Tucson, Arizona

# OUTREACH INITIATIVE

As part of the USGS outreach initiative, the Arizona District staff participates in community programs that serve to increase public understanding of the Earth Sciences. This participation includes an emphasis on information transfer using general-audience reports and presentations at symposiums and conferences, information release using videotapes and the Internet, and participation in local education and community functions. In response to the increasing public awareness and concern for water issues, it is imperative that the scientific findings and knowledge of the USGS be the basis for the development of public policy. Commitment to the District outreach program will help to facilitate this goal for Arizona.



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## FIGURES

FIGURES—CONTINUED Page



## CONVERSION FACTORS

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| acre | 4,047 | square meter |
| square mile ($mi^2$) | 2.590 | square kilometer |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| gallon per minute (gal/min) | 0.06308 | liter per second |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second |

**Fiscal Year and Water Year:** Both comprise the 12-month period from October 1 through September 30 and are designated by the year in which that period ends (for example, fiscal year 1997 began October 1, 1996, and ended September 30, 1997).

# INTRODUCTION

The U.S. Geological Survey (USGS) has been collecting water-resources data in Arizona since 1889. Since 1921, the USGS has maintained a District office in Arizona and has worked in cooperation with local, State, and Federal agencies to provide hydrologic information for the use and management of the State's water resources. This report describes the data-collection activities and water-resources investigations in Arizona for fiscal years 1996 and 1997 (October 1, 1995, to September 30, 1997). The water-resources data and the results of the interpretive investigations and research are published or released by the USGS or by cooperating agencies. Reports published in fiscal years 1995, 1996, and 1997 are included in the section entitled, "Publications from the Arizona District, fiscal years 1995–97," at the back of this report.

# ORIGIN OF THE U.S. GEOLOGICAL SURVEY

The USGS was established by an act of Congress on March 3, 1879, to provide a permanent Federal agency to conduct the systematic and scientific "classification of the public lands, and examination of the geological structure, mineral resources, and products of national domain." An integral part of that original mission includes publishing and disseminating the earth-science information needed to understand, to plan the use of, and to manage the Nation's energy, land, mineral, and water resources.

Since 1879, the research and fact-finding role of the USGS has grown and been modified to meet the changing needs of the Nation it serves. As part of that evolution, the USGS has become the Federal Government's largest earth-science research agency, the Nation's largest civilian map-making agency, the primary source of data on the Nation's surface-water and ground-water resources, and the employer of the largest number of professional earth scientists. Information provided by the USGS is used to (1) minimize loss of life and property from natural disasters; (2) manage water, biological, energy, and mineral resources; (3) enhance and protect the quality of life; and (4) contribute to wise economic and physical development.

# BASIC MISSION AND PROGRAM OF THE WATER RESOURCES DIVISION

The mission of the Water Resources Division, which supports the overall mission of the U.S. Department of the Interior and the Geological Survey, is to provide the hydrologic information and understanding needed for the best use and management of the Nation's water resources for the benefit of the people of the United States.

The mission of the Division is accomplished through programs supported by the USGS independent of, or in cooperation with, other Federal and non-Federal agencies. These programs include:

- Data collection on a systematic basis for the continuing determination and evaluation of the quantity, quality, and use of the Nation's water resources.

- Analytical and interpretive water-resources appraisals to describe the occurrence, availability, and the physical, chemical, and biological characteristics of surface water and ground water.

- Basic problem-oriented research in hydrology to improve the scientific basis for investigations and measurement techniques and to predict quantitatively the response of hydrologic systems to stress.

- Dissemination of water data and results of investigations and research through reports, maps, computerized information services, and other forms of public releases.

- Coordination of the activities of Federal agencies in the acquisition of water data for streams, lakes, reservoirs, estuaries, and ground water.

- Scientific and technical assistance in hydrology to other Federal, State, and local agencies; to licensees of the Federal Power Commission; and to international agencies on behalf of the Department of State.

# ARIZONA DISTRICT

## History and Organization

The USGS has been involved in water-resource activities in Arizona since 1889 when personnel began measuring streamflow in the Gila River Basin. Ground-water studies began with an assessment of water resources in the Sulphur Springs Valley in 1910. Cooperative agreements were established with the State government in 1912 and the first permanent field office was established in Phoenix in 1915. The USGS established a separate District in Arizona in 1921 with headquarters in Tucson.

The Arizona District is under the direction of the District Chief, Nick Melcher. Hydrologic investigations and data-collection activities are conducted from offices in Tucson, Tempe, Flagstaff, and Yuma. At the end of fiscal year 1997, the Arizona District employed a total of 98 employees (88 full time and 10 other than full time)—16 in Flagstaff, 21 in Tempe, 54 in Tucson, and 7 in Yuma. The location of Water Resources Division offices and the organization of the Arizona District are shown on figure 1. Inquiries regarding projects described in this report may be directed to one of the offices listed in figure 1.

Arizona District Office
(520) North Park Avenue, Suite 221
Tucson, Arizona 85719
(520) 670–6671

Office for Northern Arizona Program
2255 North Gemini Drive
Flagstaff, Arizona 86001
(520) 556–7136

Office for Central Arizona Program
1545 West University Drive
Tempe, Arizona 85281
(602) 379–3086

Yuma Field Office
1940 South Third Avenue
Yuma, Arizona 85364
(520) 782–6024

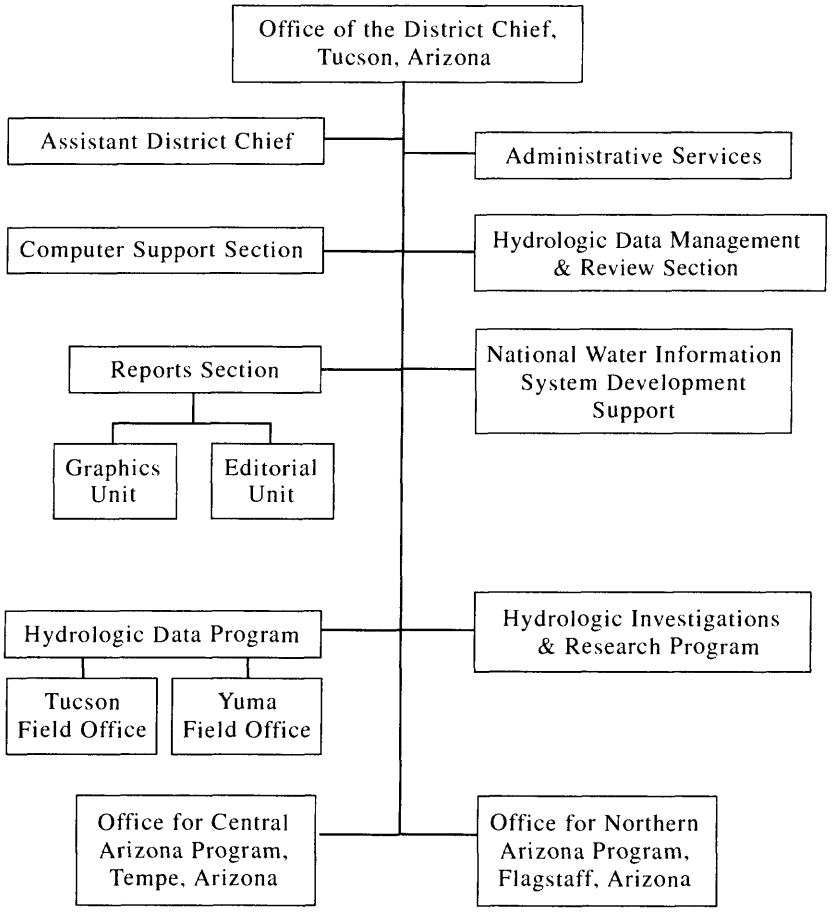




**Figure 1.** Location of Water Resources Division offices in Arizona and organization of the Arizona District, 1997.

## Funding and Cooperating Agencies

The hydrologic investigations and data-collection efforts in the Arizona District are supported by services and joint funding provided by State and local agencies on a 50-50 basis with Federal monies (cooperative program); by funds transferred from other Federal agencies (OFA program), such as the U.S. Army Corps of Engineers; and by funds appropriated directly to the USGS (Federal program). In fiscal year 1997, the financial support for these programs in Arizona was about $8.4 million, which was distributed as shown in figure 2. Agencies that supported water-resources investigations through cooperative agreements in fiscal years 1996–97 are listed below:

### Local and State Agencies

Arizona Department of Environmental Quality
Arizona Department of Water Resources
Arizona Game and Fish Department
Arizona Municipal Water Users' Association
Central Arizona Water Conservation District
City of Flagstaff
City of Nogales
City of Safford
City of Scottsdale
City of Tucson
City of Williams
Cochise County Department of Highways and Flood Control
Flood Control District of Maricopa County
Fort McDowell Indian Community
Gila Valley Irrigation District
Gila Valley Water Commission
The Havasupai Tribe
The Hopi Tribe
The Hualapai Tribe
Kaibab-Paiute Indian Tribe
The Navajo Nation
Metropolitan Domestic Water Improvement District
Metropolitan Water District of Southern California
Pima County Board of Supervisors (Pima County Department of Transportation and Flood Control District)
Salt River Valley Water Users' Association
San Carlos Irrigation and Drainage District
Show Low Irrigation Company
Tohono O'odham Nation
Town of Oro Valley
University of Arizona
The Yavapai Tribe

### Federal Agencies

Federal Energy Resource Commission (Arizona Public Service and Phelps Dodge Corporation)
International Boundary and Water Commission
U.S. Department of Agriculture
    Forest Service
U.S. Department of the Interior
    Bureau of Indian Affairs
    Bureau of Land Management
    Bureau of Reclamation
    U.S. Fish and Wildlife Service
    National Park Service
    Office of the Secretary
U.S. Department of Defense
    U.S. Air Force
    U.S. Army
        U.S. Army Corps of Engineers
U.S. Environmental Protection Agency

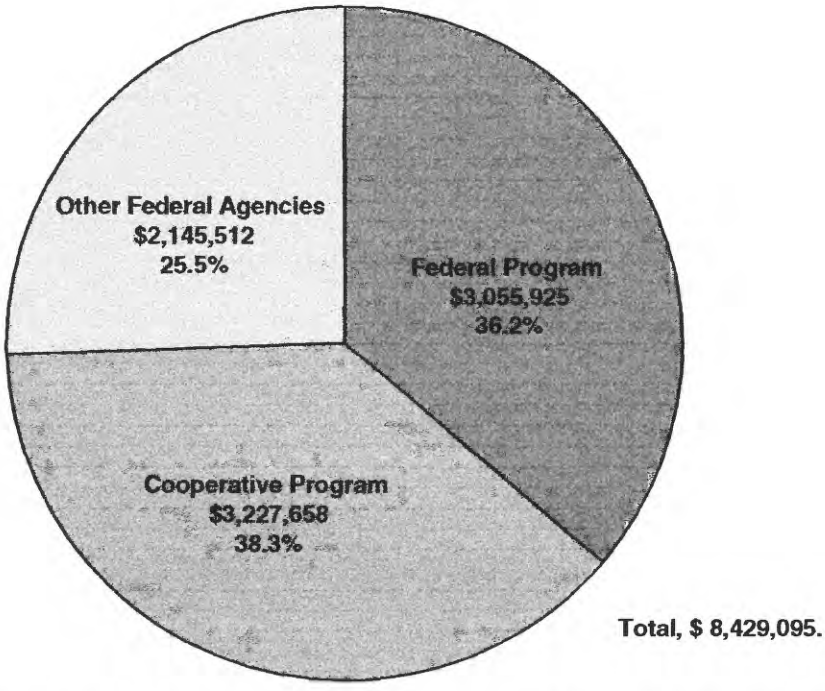


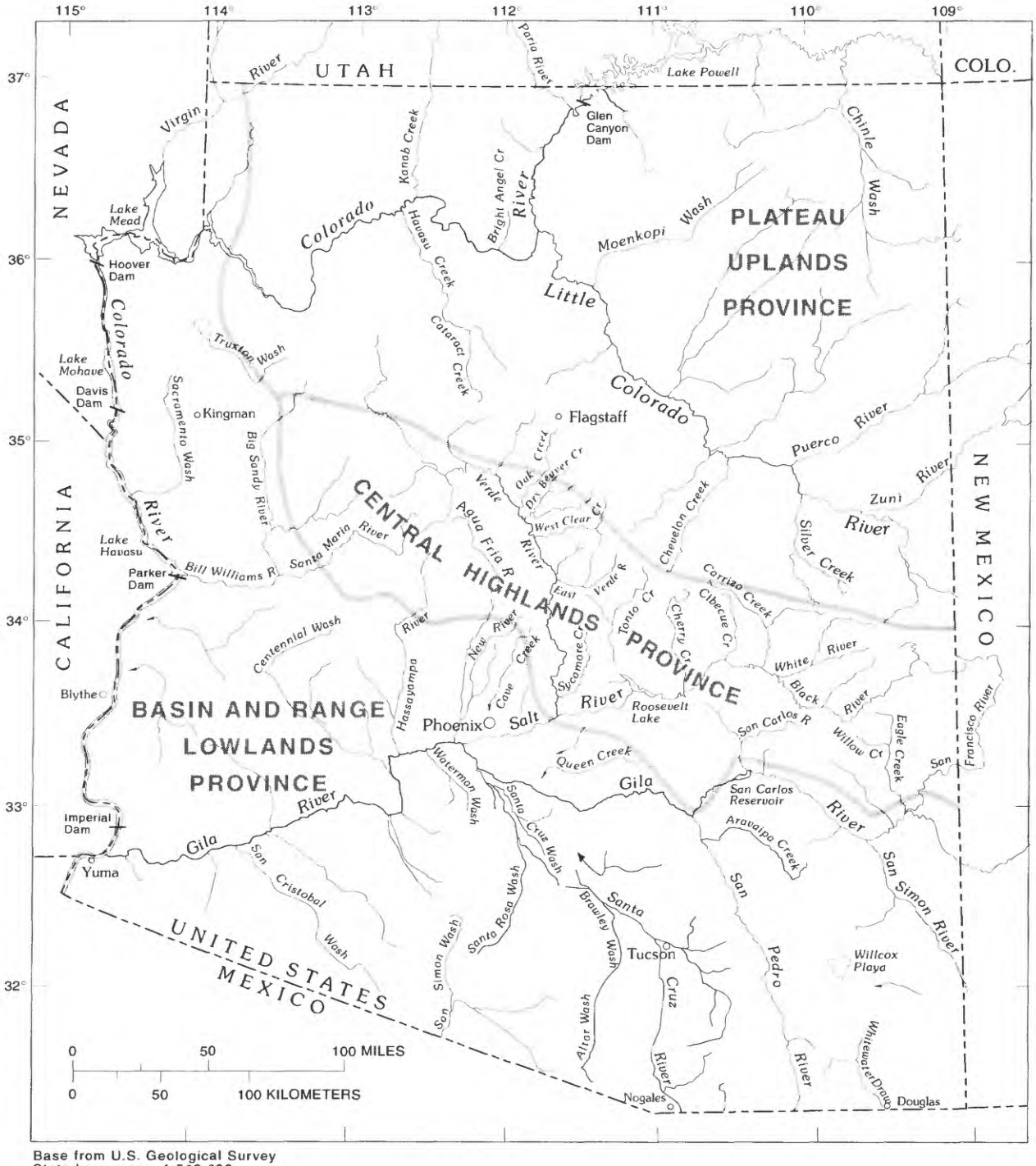

**Figure 2.** Distribution of funding of the U.S. Geological Survey in Arizona, fiscal year 1997.

# WATER CONDITIONS IN ARIZONA

The two major physiographic provinces of the southwestern United States—the Colorado Plateau province and the Basin and Range province—are separated across much of the State by the mountainous region to the south of the Mogollon Rim. The separated physiographic provinces form three distinct water provinces—the Plateau Uplands in the northern part of the State, the Central Highlands, and the Basin and Range Lowlands in the southern and southwestern parts of the State (fig. 3). The Plateau Uplands water province has many arid rock benches separated by slopes and valleys. Annual precipitation ranges from 10 to 25 in. The Central Highlands water province is bounded on the north by the Mogollon Rim escarpment and consists of rugged mountains. Annual precipitation ranges from about 15 to 30 in. The Basin and Range Lowlands water province is characterized by arid base-level plains separated by steep high mountains. Annual precipitation ranges from 4 to 12 in. in the basins of this province.

## Surface Water

The Colorado River enters Arizona from the north and flows westward and southward to the southwest corner of the State. Nearly all streams in Arizona are tributary to the Colorado, although the quantity of tributary inflow is small because of the intensive use and storage within the State. Major tributaries to the Colorado River that drain large parts of Arizona are the Little Colorado, Bill Williams, and Gila Rivers. A few small streams drain to Mexico. Streamflow data are collected at a network of streamflow-gaging stations (figs. 4, 5, and 6).

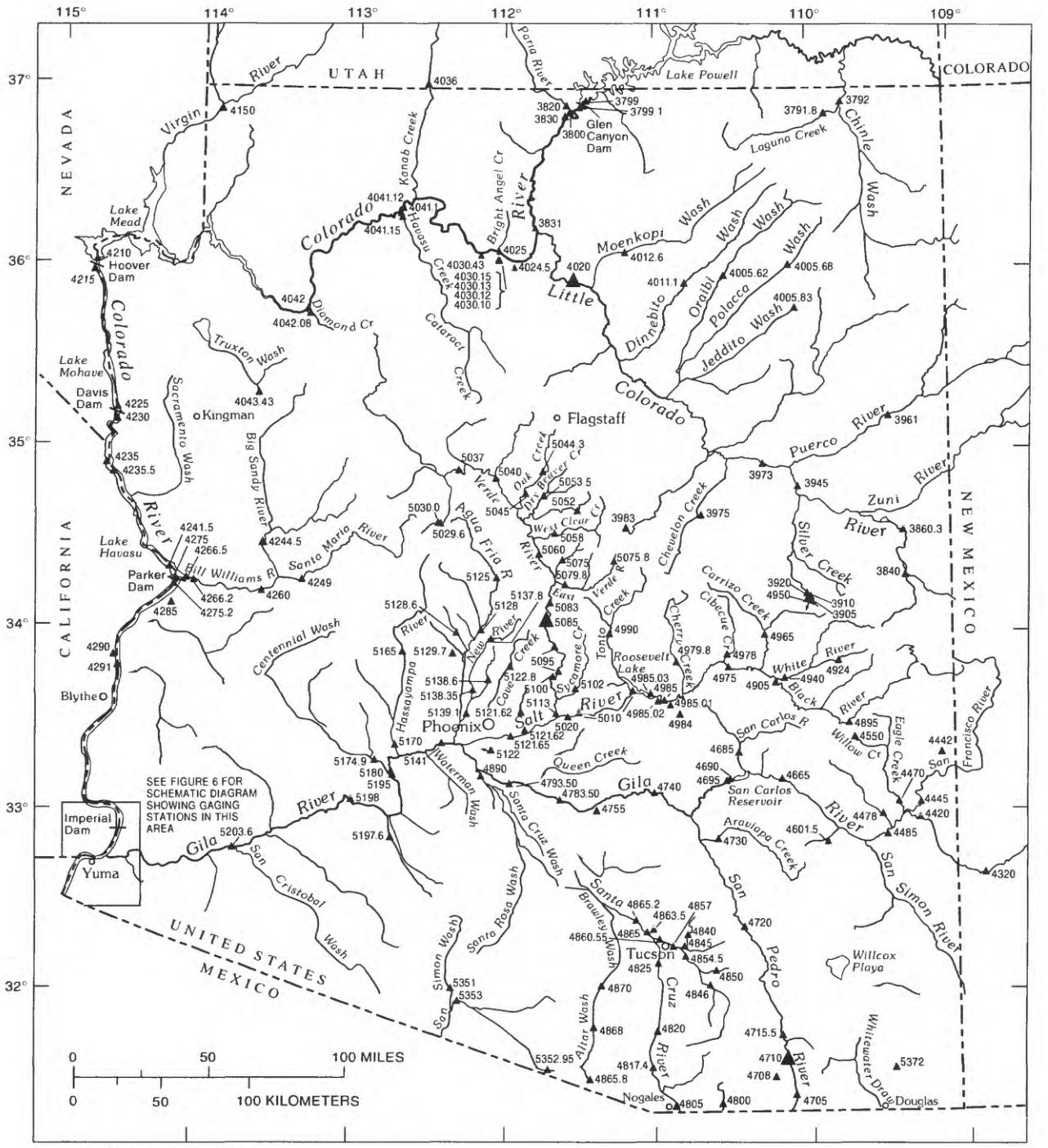



Base from U.S. Geological Survey
State base maps, 1:500,000.
Arizona, 1974; Nevada, 1965;
New Mexico, 1965; and Utah, 1959

EXPLANATION

BOUNDARY OF WATER PROVINCE

**Figure 3.** Water provinces of Arizona.



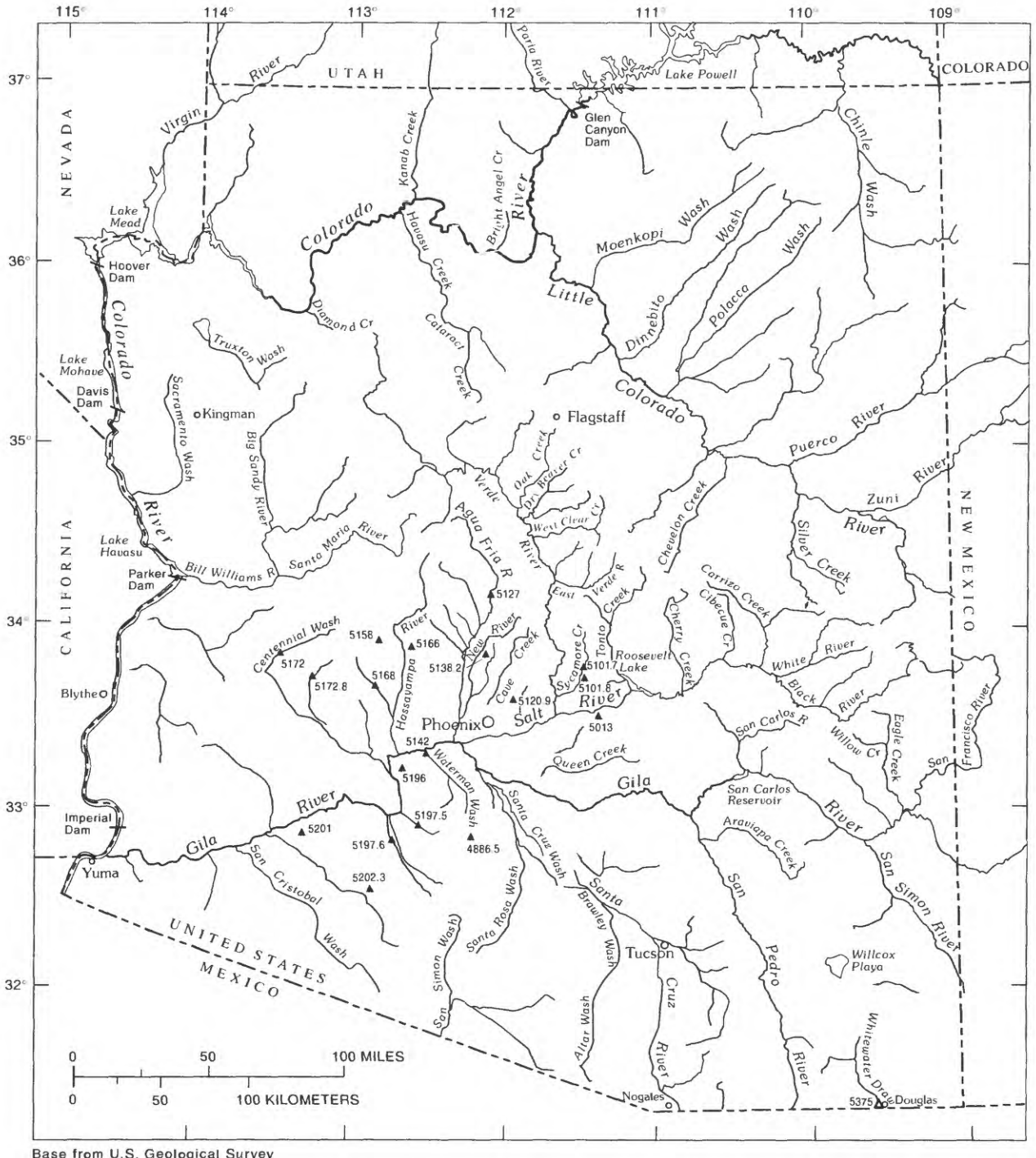

Base from U.S. Geological Survey
State base maps, 1:500,000,
Arizona, 1974; Nevada, 1965;
New Mexico, 1965; and Utah, 1959

## EXPLANATION

▲4665 STREAMFLOW-GAGING STATION—Abbreviated number is station identifier. The complete station number is 09466500

▲4020 STREAMFLOW-GAGING STATION FOR WHICH RUNOFF IS SHOWN IN FIGURE 7—Abbreviated number is station identifier. The complete station number is 09402000

**Figure 4.** Streamflow-gaging stations, October 1997.




Base from U.S. Geological Survey
State base maps, 1:500,000,
Arizona, 1974; Nevada, 1965;
New Mexico, 1965; and Utah, 1959

EXPLANATION

▲5172 PARTIAL-RECORD STREAMFLOW-GAGING STATION EQUIPPED WITH CREST-STAGE GAGE ONLY—Abbreviated number is station identifier. The complete station number is 09517200

▲5375 PARTIAL-RECORD STREAMFLOW-GAGING STATION EQUIPPED WITH CREST-STAGE GAGE ONLY AND FLOOD-HYDROGRAPH RECORDER—Abbreviated number is station identifier. The complete station number is 09537500

**Figure 5.** Partial-record streamflow-gaging stations, October 1997.

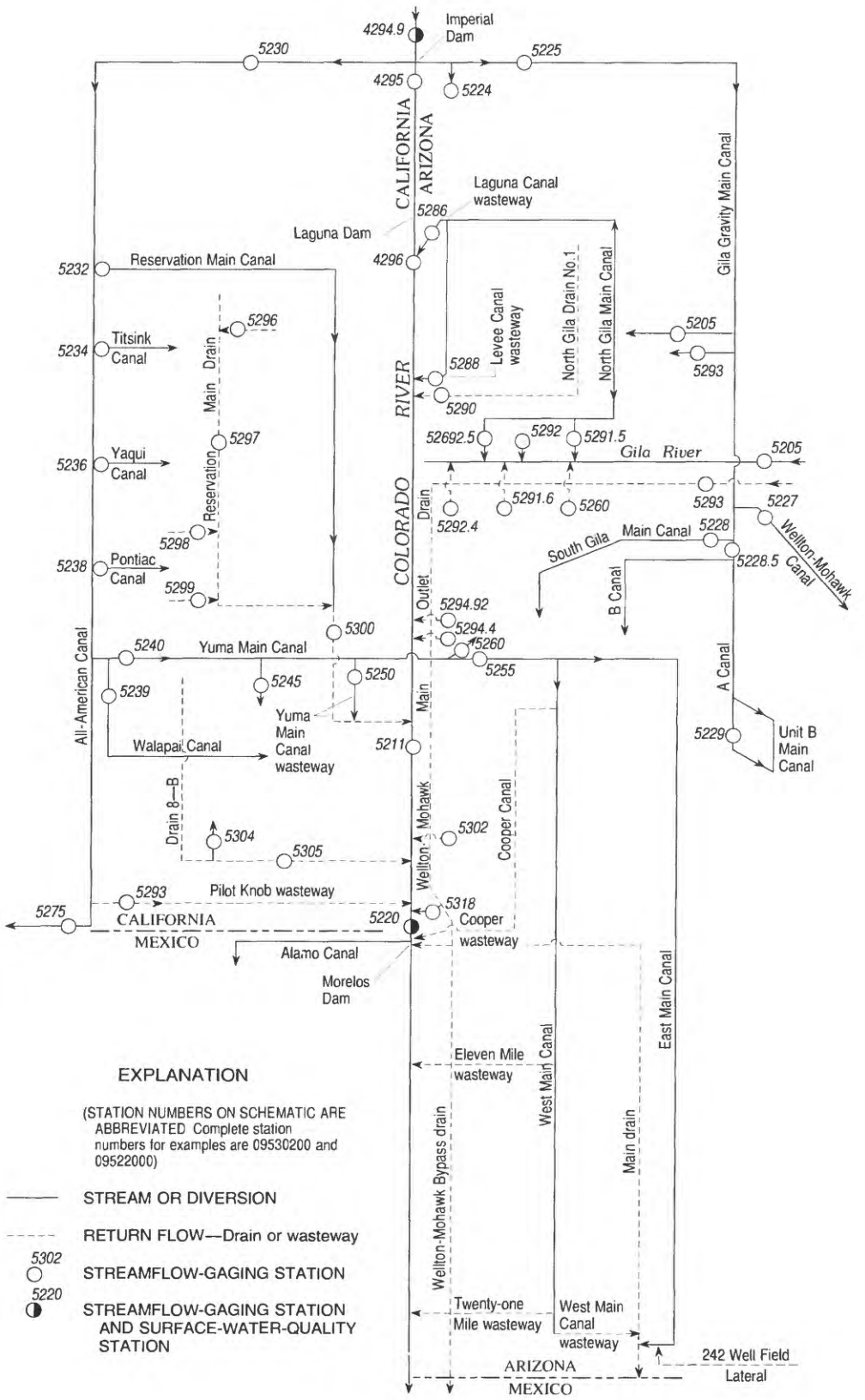



**Figure 6.** Streamflow-gaging stations and surface-water-quality stations on streams, diversions, and return flows between Imperial Dam and the southerly international boundary.

Runoff patterns in Arizona vary greatly. In desert areas of the Plateau Uplands water province and the Basin and Range Lowlands water province, average annual runoff is less than 0.1 in. In the mountainous parts of these provinces and in most of the Central Highlands water province, annual runoff is as much as 5 in. Runoff from perennial streams in the Central Highlands is collected in storage reservoirs that provide water for use in the Basin and Range Lowlands. Some precipitation infiltrates and recharges the ground-water reservoirs. From October 1, 1995, to June 30, 1997, Arizona experienced one of the driest periods on record. Streamflow during this period averaged 50 percent of normal for the Gila, Salt, and Verde Rivers. In water year 1996, measured runoff was the lowest on record for some streamflow-gaging stations on the Santa Cruz, San Pedro, White, East Fork White, and Black Rivers, and on Oak and West Clear Creeks. The quantity of monthly runoff for water year 1997 is compared with median monthly runoff for water years 1951–80 for three representative streamflow-gaging stations (fig. 7).

Except for the Colorado River, few streams in the Plateau Uplands water province are perennial. In the Central Highlands water province, the principal stream is the Gila River, which has its headwaters in New Mexico. The Salt, Verde, and Aqua Fria Rivers originate in the Central Highlands and are important tributaries to the Gila River. In the deserts of the Basin and Range Lowlands water province, few streams are perennial. Major agricultural areas and the homes of seven of every eight Arizonans are in this province; the economy depends on ground water and water from surface-storage reservoirs.

## Ground Water

The Basin and Range Lowlands province is the most highly developed of the three water provinces. In 1995, about 2.9 million acre-ft of ground water was withdrawn in the province, which was more than 91 percent of the total ground-water withdrawal in the State. In general, most water levels declined significantly during the 1950's through the 1970's when ground-water withdrawal was the greatest. From the mid-1970's to the late 1980's, however, ground-water withdrawal decreased and the rate of water-level declines was reduced, and in some areas, water levels began to rise. The Central Highlands province is the transition zone between the other two provinces and is the smallest. In 1995, an all-time maximum of 160,000 acre-ft of water was withdrawn in this province. In the Plateau Uplands province, ground water is used mainly by scattered farms and homes, industrial and utility sites, and a few population centers. Annual ground-water withdrawals in this province generally are increasing and the total withdrawal for 1995 reached an all-time maximum of 130,000 acre-ft.

## Quality of Water

Many rivers in Arizona provide water suitable for most uses although human activities have adversely affected the quality of surface water in parts of the State. In 1996, surface-water quality data were collected at 16 sites (fig. 8). Hydrologic modifications in the form of dams, reservoirs, diversion canals, vegetation removal, sand and gravel mining, and irrigation return flows have had a significant negative effect on native fish and wildlife in Arizona and directly impair water quality. Livestock grazing, mining activities, intense recreational use, and urbanization also had a negative effect on stream quality.

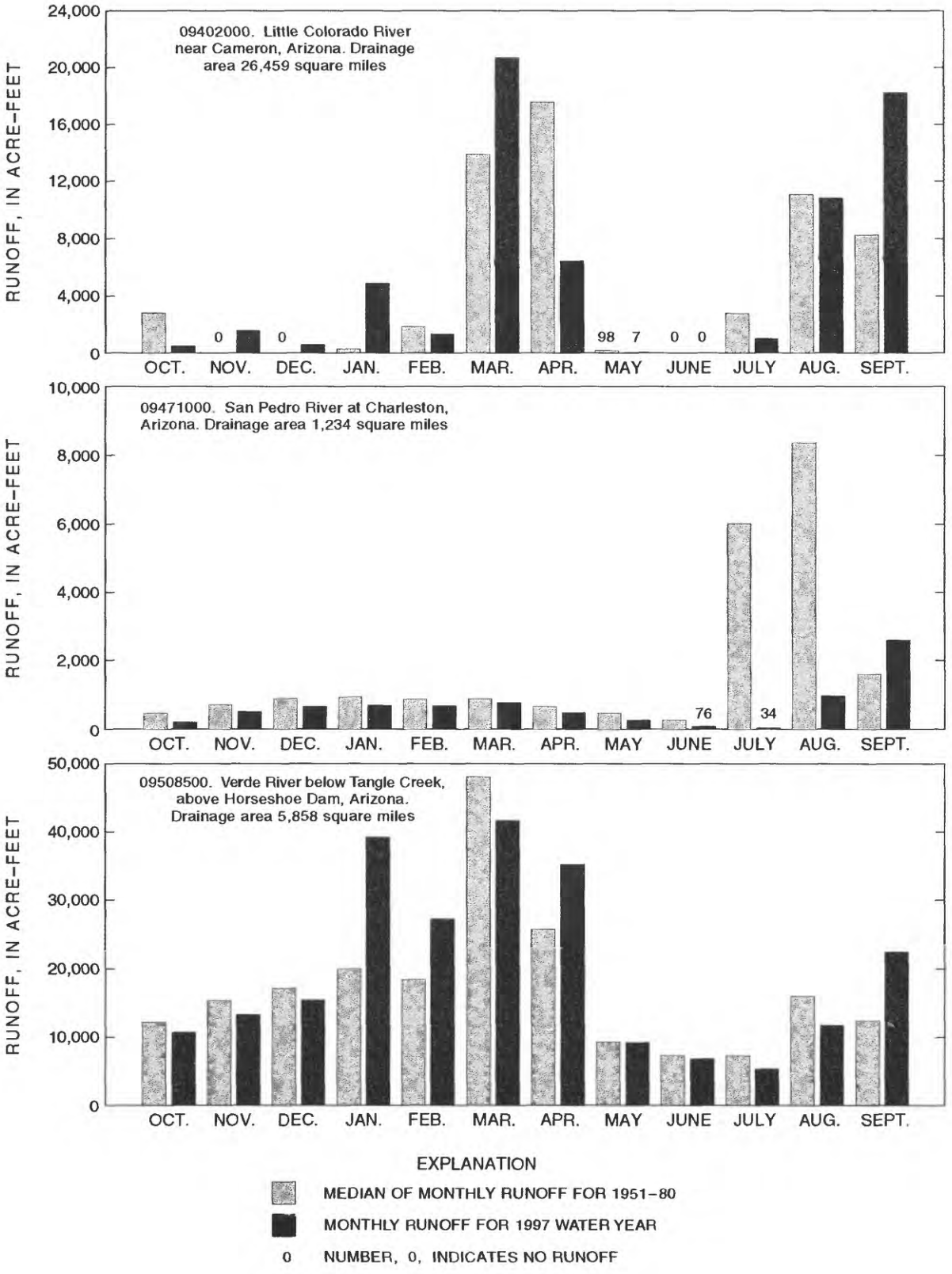
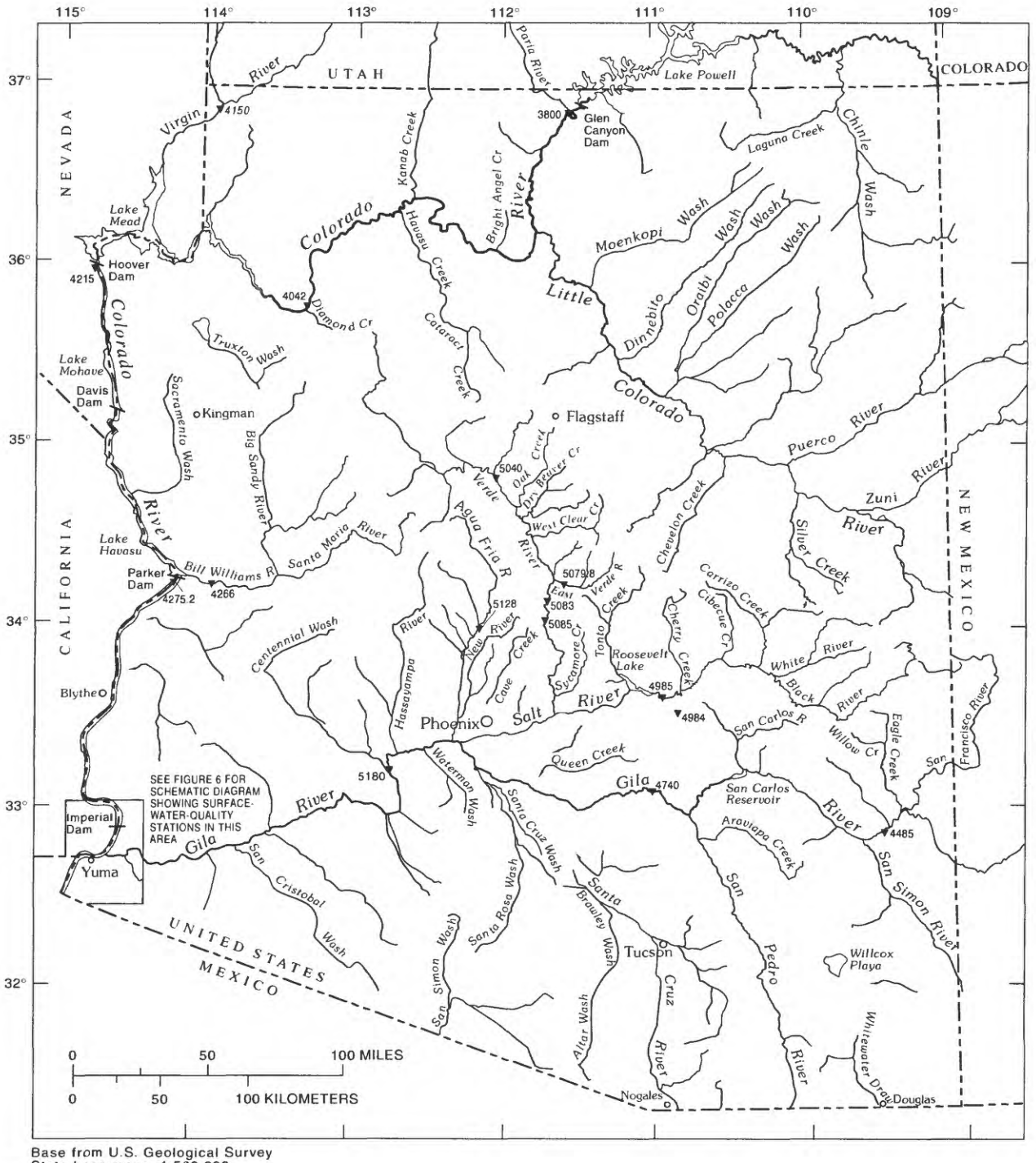



**Figure 7.** Runoff during 1997 water year compared with median runoff for period 1951-80 for three representative gaging stations.




Base from U.S. Geological Survey
State base maps, 1:500,000,
Arizona, 1974; Nevada, 1965;
New Mexico, 1965; and Utah, 1959

EXPLANATION

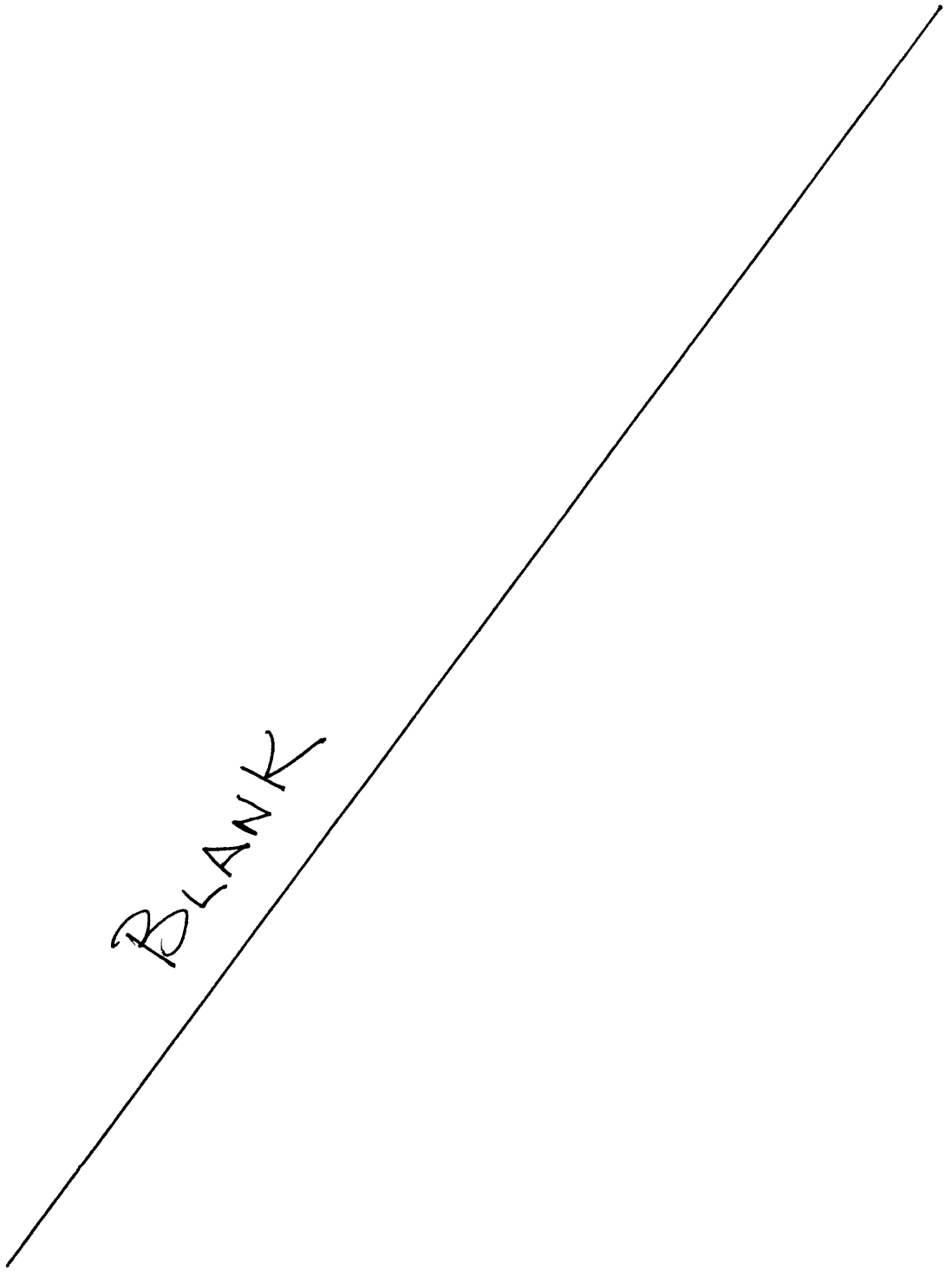
▼4984 SURFACE-WATER-QUALITY STATION—Abbreviated number is station identifier. The complete station number is 09498400

**Figure 8.** Surface-water-quality stations, October 1997.

Quality of the ground water is a major concern because ground water is the principal source for public supply. Most of the ground water is of suitable quality for human consumption and most other uses although ground-water-quality problems exist locally at several locations throughout the State. Ground-water-quality problems attributed to anthropogenic and naturally occurring contamination can be found throughout Arizona. In some areas, changes in ground-water quality are caused by (1) recirculation of salts in irrigation water and infiltration of chemicals used in agriculture, (2) leachates from septic tanks, mining and livestock operations, (3) disposal of toxic wastes, (4) leaking underground storage tanks, and (5) leachates from landfills.

## Water Use

Water-use patterns in Arizona are dominated primarily by agriculture and secondarily by rapidly growing urban population centers in Maricopa and Pima Counties. Almost all field and orchard crops are irrigated because the climate is semiarid and precipitation is too little and erratic to be useful for growing crops. Land irrigated by surface water is concentrated in the valleys and basins near the Colorado, Gila, Salt, and Verde (Yavapai County) Rivers. Land irrigated by ground water is mainly in the alluvial basins in the southern and the western parts of the State. In the Basin and Range Lowlands province, about 81 percent of the total amount of ground water withdrawn in 1995 was for irrigation, 12 percent was for public supply, and 4 percent was for industrial use. In 1995, about 50 percent of withdrawals in the Central Highlands province was for public water supply, and mining and irrigation withdrawals represented 28 and 15 percent, respectively. In 1995, withdrawals in the Plateau Uplands province for public supply, industrial use, and irrigation were 25, 40, and 27 percent, respectively, of the total withdrawal for this province. Additional withdrawals in the State were used for commercial, domestic, and stock uses.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# PROJECTS FUNDED IN FISCAL YEARS 1997 AND 1998

## Surface-Water Stations *(AZ001)*

**Location:** Statewide (see figures 4, 5, and 6)

**Project Chief:** Christopher F. Smith

**Period of Project:** Continuous since 1912

**Cooperating Agencies:** Arizona Department of Environmental Quality, Arizona Department of Water Resources, Arizona Public Service Co., Bureau of Land Management, Bureau of Reclamation, Central Arizona Water Conservation District, City of Tucson, Cochise County Department of Highways and Flood Control, Federal Energy Resource Commission, Flood Control District of Maricopa County, Forest Service, Gila Valley Irrigation District, International Boundary and Water Commission, Metropolitan Water District of Southern California, National Park Service, Pima County Department of Transportation and Flood Control District, Salt River Valley Water Users' Association, Show Low Irrigation Company, U.S. Army, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service

**Problem:** Surface-water runoff is highly variable, both areally and seasonally, throughout the State. Information is needed for purposes of hydrologic surveillance, planning, design, hazard warning, and management. Monitoring of runoff is essential to water-related fields such as water supply, hydroelectric power, flood control, flood warning, irrigation, bridge and culvert design, wildlife management, pollution abatement, flood-plain management, and water-resources development. An appropriate data base is necessary to provide this information.

**Objectives:** Data are collected for (1) assessment of surface-water resources; (2) operation of reservoirs for power, flood control, and irrigation; (3) flow forecasting and flood warning; (4) monitoring of flow for instream-use requirements; (5) water-quality estimations; (6) waste disposal and pollution control; (7) compact and legal requirements; and (8) definition of statistical streamflow characteristics needed for research, planning, and design of dams, bridges, culverts, canals, flood-management projects, and ground-water-recharge facilities.

**Approach:** Standard USGS methods are used to measure and record stages and discharges of streams and stages and contents of lakes and reservoirs. Frequency of data collection is determined by the principal purpose of each site.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Monitoring continued at continual-record streamflow-gaging stations, partial-record peak-flow stations, lakes and reservoirs, and supplemental streamflow stations. In fiscal year 1996, data from 192 continual-record streamflow-gaging stations, 18 partial-record peak-flow stations, 9 lakes and reservoirs, and 1 supplemental streamflow station were collected and compiled for publication. In fiscal year 1997, data from 194 continual-record streamflow-gaging stations, 19 partial-record peak-flow stations, 9 lakes and reservoirs, and 2 supplemental streamflow stations were collected and compiled for publication. Retrieval programs for real-time and historical data were placed on the Arizona District Internet home page. Data records were checked for accuracy and

completeness and the data were stored in the District computer data base. Annual data reports for the 1995 and 1996 water years were published.

**Plans for Fiscal Year 1998:** Statewide surface-water data collection, computation, and compilation will continue. Field surveys and computations for indirect measurements of flow will be made as needed. The annual data report for 1997 will be compiled and published, and data will be stored in the District computer data base.

**Publications, Fiscal Years 1995–97:**

Pope, G.L., 1996, Surface-water quality-assurance plan for the Arizona District of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 96–332, 25 p.

Smith, C.F., Anning, D.W., Duet, N.R. Fisk, G.G., McCormack, H.F., Pope, G.L., Rigas, P.D., and Wallace, B.L., 1995, Water Resources Data, Arizona, water year 1994: U.S. Geological Survey Water-Data Report AZ–94–1, 320 p.

Smith, C.F., Duet, N.R. Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., Rigas, P.D., and Tadayon, Saeid, 1996, Water Resources Data, Arizona, water year 1995: U.S. Geological Survey Water-Data Report AZ–95–1, 306 p.

## Hydro 21 *(AZ00146)*

**Location:** International

**Project Chief:** Nick Melcher

**Cooperating Agencies:** Federal Program

**Problem:** Many of the methods for standard hydrologic-field measurements were developed over 50 years ago and remain unchanged. The methods for computing discharge require periodic direct measurements of river width, depth, and velocity, and the equipment needed for these measurements are a major part of the costs associated with hydrologic-data collection. The costs and limitations associated with these methods are severely affecting the ability of the USGS to provide critical hydrologic information needed for resource management, future planning, economic growth, and natural-hazard mitigation.

**Objective:** The principal objective is to identify and incorporate new technologies in the USGS hydrologic-data network to ensure the vitality of these programs.

**Approach:** New technologies will be identified and incorporated using a multistep approach:

1. Create a USGS technology network.
2. Identify potential technologies.
3. Systematically assess new technologies.
4. Develop and build prototypes of new instruments.
5. Implement new instruments.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** A workplan was completed and approved during fiscal year 1997. Members of the Hydro 21 Committee attended several symposia during the year and visited a number of research laboratories. Opportunities were identified in remote sensing, electo-optics, lasers, and acoustics. An internal call for new technologies from USGS staff was released. The potential for ion-specific sensors is being evaluated. Several research laboratories agreed to submit proposals for new technologies to the Hydro 21 Committee.

**Plans for Fiscal Year 1998:** The search for relevant new technologies will continue. Identified technologies will be assessed to learn more about capabilities and limitations. Briefing statements for potential technologies will be developed. A technology solicitation will be submitted to the Small Business Administration.

## Ground-Water Stations *(AZ002)*

**Location:** Statewide

**Project Chief:** Norbert R. Duet, Jr.

**Period of Project:** Continuous since 1939

**Cooperating Agency:** Arizona Department of Water Resources

**Problem:** Long-term water-level records are needed to evaluate the effects of climatic variations on the recharge to and discharge from the ground-water systems, provide a data base from which the effects of development can be measured, assist in the prediction of future supplies, and provide data for management of the resource.

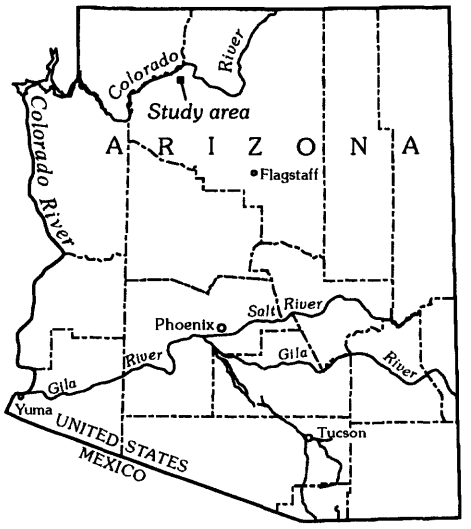
**Objectives:** (1) Ground-water-level data will be collected and a long-term data base will be provided that can be used to monitor the general response of the hydrologic system to natural and manmade stresses. (2) A data base will be provided against which the short-term records acquired in areal studies can be analyzed. The analysis must provide an assessment of the ground-water resource, allow prediction of future conditions, and provide the data base necessary for management of the resource.

**Approach:** In 1990, the ADWR expanded their role in the operation of the observation-well network. Each year, the ADWR conducts investigations in several ground-water areas. The studies include well inventories, water-level measurements, and water-quality samples. The results of the studies are published in the State's Hydrologic Map Series Reports (HMS), which typically show depth to water, change in water levels, altitude of the water levels, and quality of water. The USGS publishes water-quality data from wells sampled by the ADWR in the annual data reports for Arizona.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Since 1991, the ADWR has maintained the leading role in collection of ground-water data. The ADWR presently has a monitoring network of approximately 1,200 ground-water data-collection sites. The ADWR maintains the responsibility for ground-water basin studies and published three map reports (HMS) during 1996–97. Water-quality data from 202 wells were published in the USGS 1995 data report for Arizona and water-quality data from 201 wells were published in the USGS 1996 data report.

**Plans for Fiscal Year 1998:** The ADWR will continue maintaining the network, and the USGS will continue with minimal data collection, review, and entry into the Ground-Water Site Inventory (GWSI) data base.

**Ground-Water Site Feasibility for the Havasupai Indian Reservation *(AZ00202)***




**Location:** Northern Arizona, Hualapai Hilltop

**Project Chief:** Robert J. Hart

**Period of project:** October 1, 1996, to September 30, 1997

**Cooperating Agency:** Havasupai Indian Tribe

**Problem:** Because of present water-supply conditions, the Havasupai Indians are currently limited to living in Havasu Canyon, a remote tributary canyon to the Grand Canyon in northern Arizona. The only modes of transportation to the village of Supai is by Supai pony, by foot, or by helicopter. The tribe's only option for expansion and growth is to move out of the canyon onto their lands on the rim country. Access to water supplies on the rim is difficult, and because surface-water resources are not adequate, the tribe must rely on ground water. Drilling and development costs are high, however, because depths to ground water exceed 2,500 ft. Gaining an understanding of the regional geohydrology of the rim country is important in assessing the water-supply conditions on the reservation.

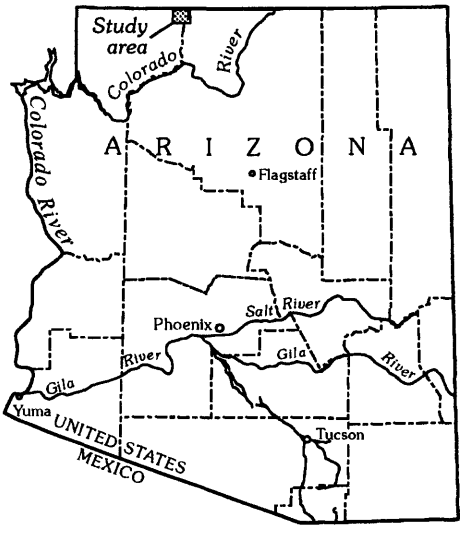
**Objective:** The objective of the study is to provide the Havasupai Tribe with information on the regional ground-water flow system that can be used in the management of their ground-water resources.

**Approach:** Review available literature and data on the hydrology and geology near the Havasupai Indian Reservation and summarize the available information. Field reconnaissance of the reservation will be made to determine geohydrologic characteristics and geologic structure. Information on ground-water wells in the area will be compiled from the USGS data base. This well information will be used to characterize the primary aquifer from which ground water is withdrawn.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** An exploratory well exceeding 3,000 ft in depth was drilled into the Redwall Limestone to provide information on the regional ground-water system in the vicinity of Hualapai Hilltop. Water levels in the well rose several hundred feet in the well casing. Valuable data on aquifer characteristics and borehole properties were obtained from the exploratory well. Because the exploratory well has the potential for producing water, the Indian Health Service currently is planning the infrastructure for a water-distribution system using the well. Information on the ground-water flow system was provided to the tribe.

**Plans for Fiscal Year 1998:** There are no plans for further evaluation of reservation ground-water resources. Discussions and technical expertise will be provided as requested.

**Ground-Water Site Feasibility for the Kaibab-Paiute Indian Reservation *(AZ00212)***




**Location:** Northern Arizona, Arizona Strip

**Project Chief:** Robert J. Hart

**Period of Project:** October 1, 1996, to September 30, 1997

**Cooperating Agency:** Kaibab Band of Paiute Indians

**Problem:** The small Kaibab-Paiute Indian Reservation consists of about 120,000 acres (188 $mi^2$) and is on the Arizona Strip of northern Arizona. The residents of the reservation rely on various sources for their water supply. Sixmile Village and the community of Steamboat Springs, on the east side of the reservation, currently receive their water supply from the Town of Fredonia through a contractual agreement. The tribe wants to develop a water supply within their reservation boundary to eliminate their reliance on the Town of Fredonia and also to begin development of service facilities near the junction of Highway 389 and Sixmile Road.

**Objective:** The objective of the study is to provide the Kaibab-Paiute Indian Tribe with information on the ground-water flow system on the reservation, particularly in the eastern part.

**Approach:** Review available literature and data on the hydrology and geology near the Kaibab-Paiute Indian Reservation and summarize available information. Field reconnaissance of the reservation will be made to determine the geohydrologic and topographic characteristics. Surface-water and spring sites will be field checked, and flow and field-chemistry measurements will be made to help determine the sources of the water. Available information on ground-water wells in the area will be compiled from the USGS data base. This well information will be used to determine the primary aquifer from which ground water is being withdrawn.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Field reconnaissance and review of available literature and data were completed. Depths to ground water were estimated using historical data, spring characteristics, and drillers' logs from existing wells on the Arizona Strip. Information was compiled and provided to the tribe.

**Plans for Fiscal Year 1998:** Additional resource evaluations have not been planned for fiscal year 1998.

## Quality of Water Stations *(AZ003)*

**Location:** Statewide (see figure 8)

**Project Chief:** Christopher F. Smith

**Period of Project:** Continuous since 1969

**Cooperating Agencies:** Arizona Department of Environmental Quality, Bureau of Indian Affairs, Bureau of Reclamation, and U.S. Army Corps of Engineers

**Problem:** Water-resource planning and water-quality assessment require a nationwide data base of standardized information. For intelligent planning and realistic assessment of the water resource, the chemical, biological, and physical quality of the surface water of Arizona must be defined and monitored.

**Objectives:** Provide nationally consistent water-quality data needed by government agencies and other groups involved in natural or regional water-quality planning and management. This includes data necessary for Federal management of interstate waters.

**Approach:** A network of surface-water/water-quality stations is operated to provide average chemical concentrations, loads, and time trends as required by planning and management agencies.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** The sampling and analytical program was continued throughout the year. Data from this program are entered into the District data base. Data from 20 streamflow-gaging stations were published in the 1995 data report for Arizona and data from 16 streamflow-gaging stations were published in the 1996 data report.

**Plans for Fiscal Year 1998:** Water-quality data will be collected at 16 surface-water sites.

## Sediment Stations *(AZ004)*

**Location:** Statewide

**Project Chief:** Gregory G. Fisk

**Period of Project:** Continuous since 1925

**Cooperating Agencies:** Bureau of Reclamation, Flood Control District of Maricopa County, and U.S. Army Corps of Engineers

**Problem:** Water-resources planning and water-quality assessment require a nationwide data base of standardized information. Erosion, transport, and deposition of sediment can have major effects on streams, lakes, and reservoirs; knowledge of sediment transport is essential for appropriate planning and assessment. To obtain the necessary information, bed material and suspended-sediment transport must be monitored on a regular basis on a wide variety of streams throughout the country.

**Objective:** Provide data on bed material and suspended-sediment transport in streams in the arid Southwest in a computer data base for use in broad Federal and State planning and action programs and for Federal management of interstate waters.

**Approach:** Bed-material and suspended-sediment samples are collected at regular intervals at a network of stations in Arizona, and the data are entered into the national data base. Bed-material samples are collected from one to four times per year. Suspended-sediment samples are collected from 6 to 12 times per year during regular site visits or on a storm basis by automatic sampler.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Suspended-sediment and bed-material samples were collected during regular site visits at streamflow-gaging station 09474000, Gila River at Kelvin. Suspended-sediment samples were collected during regular site visits and by automatic samplers at streamflow-gaging stations: 09382000, Paria River at Lees Ferry; 09397300, Little Colorado River near Joseph City; and 09402000, Little Colorado River near Cameron. For water years 1989–94, daily suspended-sediment loads and concentrations were computed for streamflow-gaging stations 09397300, Little Colorado River near Joseph City, for days when the instantaneous discharge was greater than 500 $ft^3/s$; and 09401000, Little Colorado River at Grand Falls, for days when the instantaneous daily discharge was greater than 200 $ft^3/s$. For water years 1990–96, daily suspended-sediment loads, sand loads, and sand concentrations were computed for streamflow-gaging stations 09382000, Paria River at Lees Ferry, when the daily discharge exceeded 30 $ft^3/s$, and 09402000, Little Colorado River near Cameron, when the daily discharge exceeded 20 $ft^3/s$. Sample collection was discontinued at streamflow-gaging station 09473100, San Pedro River below Aravaipa Creek near Mammoth, at the end of the 1995 water year.

**Plans for Fiscal Year 1998:** Collection of data will continue at the sites listed above. Discrete suspended-sediment and bed-material data collected during water year 1997 for the Gila River will be published in the 1997 annual data report. Daily suspended-sediment loads and concentrations

will be computed for streamflow-gaging stations 09397300, Little Colorado River near Joseph City, for the 1995 and 1996 water years; and 09402000, Little Colorado River near Cameron, and 09382000, Paria River at Lees Ferry, for the 1997 water year.

## Water Use *(AZ007)*

**Location:** Statewide

**Project Chief:** Saeid Tadayon

**Period of Project:** Continuous since June 1979

**Cooperating Agency:** Arizona Department of Water Resources

**Problem:** Water-use data presently are collected by several local, State, and Federal agencies. Water use refers to the quantity of water withdrawn and used for agricultural, industrial, power-generation, municipal, or domestic purposes and returned to the ground-water or surface-water system. A comprehensive water-use data base was needed to provide (1) data for planners or governmental agencies that need generalized information relating water use to irrigated acreage, ore production, municipal use, and other uses; (2) data with areal and temporal detail that can be used to model and evaluate management alternatives; and (3) easy accessibility.

**Objectives:** Information on water-use rates and consumptive use by area for specific time periods will be provided so that decisions can be made realistically regarding changes in delivery systems and associated economic studies. A data base of ground-water withdrawals will be provided that (1) can be used to evaluate management alternatives through modeling techniques, (2) is easily accessible by authorized agencies and which, at the same time, will honor and protect the privacy of individual water users, and (3) will be expandable to accommodate new development and will permit the removal of out-of-date or abandoned points of withdrawal.

**Approach:** The Arizona District water-use program in fiscal year 1998 will continue collecting data on ground-water withdrawals outside the State of Arizona Active Management Areas and Irrigation Non-Expansion Areas. Data will be compiled for municipal, industrial, and irrigation withdrawals using the ground-water basin boundaries defined by the Arizona Department of Water Resources (ADWR). The USGS and ADWR will cooperate on the development of a new method for estimating nonmetered ground-water withdrawals for irrigation. The two agencies will use this new method in the analysis of data for 1996.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** As part of the 1995 estimate of the use of water in Arizona, the Arizona District compiled and entered the water-use data into the Aggregate Water-Use Data System. Most of the ground-water withdrawals for 1991–95 also were estimated using the ADWR ground-water basin boundaries.

**Plans for Fiscal Year 1998:** The overall goal for Arizona's fiscal year 1998 water-use program is to continue collecting and compiling total basin withdrawals by ADWR ground-water basins for municipal, industrial, and irrigation use. The data for 1991–95 will be published.

## Special Site Studies for Other Federal Agencies *(AZ023)*

**Location:** Statewide

**Project Chief:** Nick Melcher

**Period of Project:** Continuous since 1971

**Cooperating Agencies:** Other Federal agencies

**Problem:** Other Federal agencies occasionally require the assistance of the USGS for special small-scale studies to assist them in their work.

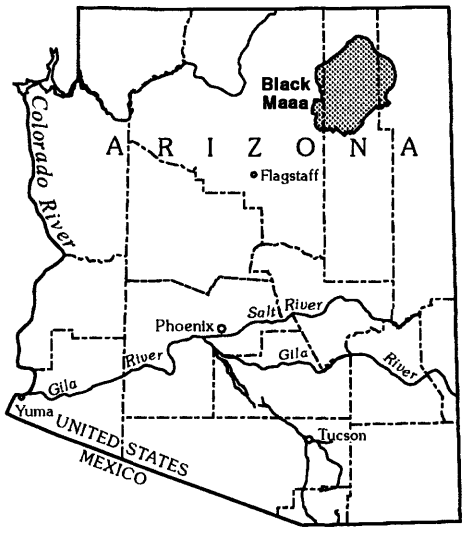
**Objectives:** Special site studies are used to provide technical assistance to other Federal agencies for small-scale assignments of a consulting nature.

**Approach:** Technical assistance is provided as requested.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Consulting services and technical assistance were provided as requested by other Federal agencies.

**Plans for Fiscal Year 1998:** Work for other Federal agencies will continue as requested.

**Monitoring Hydrologic Effects of Ground-Water Withdrawals and Strip Mining at Black Mesa**
***(AZ028 and AZ080)***




**Location:** Northeastern Arizona

**Project Chief:** Gregory R. Littin

**Period of Project:** Continuous since 1971

**Cooperating Agencies:** Arizona Department of Water Resources and Bureau of Indian Affairs

**Problem:** Strip mining of coal on Black Mesa has caused concern about the effects of ground-water withdrawals on the potentiometric surface of the N aquifer (Navajo Sandstone).

**Objectives:** The magnitude of water-level changes in the N aquifer near Black Mesa and water-level changes caused by pumping by Peabody Coal Company and by nearby communities for public supply will be determined.

**Approach:** Observation wells and Peabody Coal Company wells will be used to monitor water-level changes in the N aquifer. Flowmeters will measure pumpage from all public-supply wells and Peabody wells to determine the total quantity of water withdrawn from the system.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Continued data collection of water levels and water chemistry from selected wells; discharge and water chemistry of selected springs; annual pumpage from coal-mine well fields and Indian communities; and continuous discharge data on one stream. In 1995, water levels declined in about 60 percent of those wells penetrating the confined part of the N aquifer and in about 55 percent of those wells penetrating the unconfined parts. Water chemistry was consistent with that of samples collected from the same wells in previous years. Ground-water pumpage decreased slightly from 1995 to 1996. A presentation was made at the Arizona Hydrological Society meeting in September 1996.

**Plans for Fiscal Year 1998:** Data collection and data evaluation will continue. Discharge will be measured along Laguna Creek, Moenkopi Wash, Dinnebito Wash, and Polacca Wash. A progress report for the 1997 calendar year will be prepared.

**Publications, Fiscal Years 1995–97:**

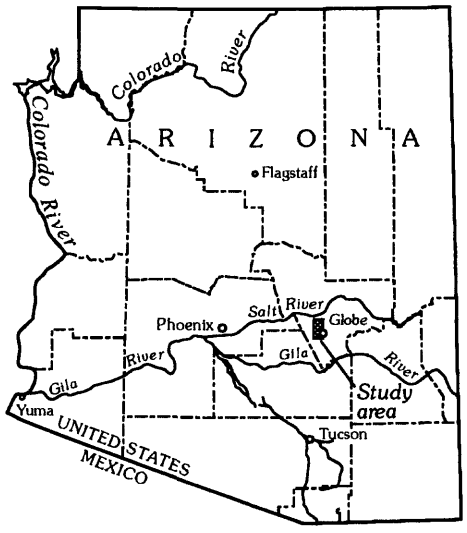
Littin, G.R., and Monroe, S.A.,1995a, Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1992–93: U.S. Geological Survey Water-Resources Investigations Report 95–4156, 37 p.

_____1995b, Results of ground-water, surface-water, and water-chemistry monitoring, Black Mesa area, northeastern Arizona—1994: U.S. Geological Survey Water-Resources Investigations Report 95–4238, 25 p.

_____1996a, Monitoring ground-water withdrawals from the N aquifer in the Black Mesa area, northeastern Arizona, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 155–157.

_____1996b, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1995: U.S. Geological Survey Open-File Report 96–616, 22 p.

**Contaminant-Transport Interactions in Ground Water and Surface Water in Pinal Creek Basin near Globe, Arizona**
***(AZ082)***




**Location:** East-central Arizona

**Project Chief:** James G. Brown

**Period of Project:** Continuous since April 1984

**Supporting USGS program:** U.S. Geological Survey Toxic Substances Hydrology Program

**Problem:** Ground water in the Pinal Creek Basin is contaminated with acidic-waste solutions from copper-mining and extraction activities. Trace metals have been mobilized in large concentrations in the alluvial aquifer, and emergence of trace metals with ground-water discharge to Pinal Creek may eventually threaten water quality at Lake Roosevelt, a major water supply for the city of Phoenix. Research at Pinal Creek has significantly advanced understanding of the role of mineral-water reactions in controlling transport of trace metals in contaminated ground water; however, important questions remain unresolved and are the focus of ongoing and planned studies in the Pinal Creek Basin.

**Objectives:** Research in the Pinal Creek Basin has the overall objective of increasing scientific understanding of the controls on contaminant transport of metals in ground water and streamflow. This effort includes developing new methods and models to investigate contaminant transport and publishing outstanding findings. Research has been and continues to be a cooperative effort among personnel of the Arizona District, the National Research Program (NRP) in Reston and Menlo Park, the University of Arizona, and Arizona State University. The methods and models developed at Pinal Creek should be applicable to some of the thousands of sites nationwide that have been affected by acidic contamination from abandoned and active mines.

**Approach:** The reactions that controlled the observed chemical changes in the plume are being identified through sampling of ground water, unsaturated-zone gases, and aquifer materials; and geochemical transport modeling. Chlorofluorocarbon-age dates will be used to help calibrate a three-dimensional ground-water flow model of the basin currently under development. Interactions between contaminated ground water and surface water are being characterized through the use of stream-tracer experiments, detailed sampling, and computer modeling of stream/shallow ground-water transport interactions.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** A USGS Water-Supply Paper was published in 1996. The report summarizes nearly a decade of research at Pinal Creek. An article on the analysis and modeling of plume evolution was approved and submitted to the *Journal of Hydrology* for publication in a special volume on simulation of reactive transport in natural systems. A USGS Fact Sheet that includes an overview of contamination at the site, a

summary of recent findings, and a discussion of ongoing activities and research goals was published in 1997. Information from the Fact Sheet is available on the Internet at the project home page. Four new wells were drilled in February 1997 near the front of the acidic plume. Core material was collected for use in laboratory and field experiments. District personnel assisted with water-quality and tracer sampling and sediment coring during a surface-water field experiment in May 1997 led by NRP and University of Arizona researchers. Slug tests were done at selected monitor wells in September 1997. A network of 10 rainfall collectors was installed in the Pinal Creek basin for isotope analysis.

**Plans for Fiscal Year 1998:** The development of a three-dimensional ground-water finite-difference model of the basin will continue. Working with NRP researchers, core material from the drilling in 1997 will be placed in selected wells for 6 to 18 months to examine mineralogic changes that result from contact with contaminated ground water. An article on the comparison of two reactive-transport models and reactive-transport simulation of a column experiment will be submitted for approval and to the journal *Groundwater*. Reaction kinetics will be incorporated into one-dimensional reactive-transport models of the study area. Sampling of rainfall for isotope analysis by NRP researchers will continue through the spring of 1998.

**Publications, Fiscal Years 1995–97:**


Brown, J.G., Bassett, R.L., Glynn, P.D., and Parkhurst, D.L., 1995, Reactive transport of metal contaminants in ground water in Pinal Creek Basin, Arizona, *in* Geddis, A.M., ed., Water Use in Arizona—Cooperation or conflict: Arizona Hydrological Society Proceedings of the Eighth Annual Symposium, September 14–16, 1995, p. 104–105.

Brown, J.G., Brew, Robert, and Harvey, J.W., 1997, Research on acidic metal contaminants in Pinal Creek Basin near Globe, Arizona: U.S. Geological Survey Fact Sheet FS–005–97, 4 p.

Brown, J.G., and Favor, Barbara, eds., 1996, Hydrology and geochemistry of aquifer and stream contamination related to acidic water in Pinal Creek Basin near Globe, Arizona: U.S. Geological Survey Water-Supply Paper 2466, 103 p.

Brown, J.G., and Harvey, J.W., 1996, Hydrologic and geochemical factors affecting metal contaminant transport in Pinal Creek Basin near Globe, Arizona, *in* Morganwalp, D.W., and Aronson, D.A., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Colorado Springs, Colorado, September 20–24, 1993: U.S. Geological Survey Water-Resources Investigations Report 94-4015, v. 2, p. 1035–1042.

Harvey, J.W., and Fuller, C.C., 1994, Hydrologic controls on manganese transport in a contaminated stream-aquifer system, Pinal Creek Basin, Arizona [abs.]: American Geophysical Union 1994 Fall Meeting, Supplement to EOS, November 1, 1994, p. 259.

_____1995, Role of stream-subsurface water exchange in enhancing manganese precipitation in a contaminated drainage basin: American Geophysical Union, Programs and Abstracts of Fifteenth Annual Hydrology Days, Report 95.2, April 3–7, 1995, Fort Collins, Colorado.

_____1996, Association of selected metals with colloidal and suspended particulate material in shallow ground water and surface water at Pinal Creek, Arizona, *in* Morganwalp, D.W., and Aronson, D.A., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Colorado Springs, Colorado, September 20–24,

1993: U.S. Geological Survey Water-Resources Investigations Report 94–4015, v. 2, p. 1073–1079.

Harvey, J.W., Fuller, C.C., and Wagner, B.J., 1996, Interactions between shallow ground water and surface water that affect metal transport in Pinal Creek, Arizona, *in* Morganwalp, D.W., and Aronson, D.A., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Colorado Springs, Colorado, September 20–24, 1993: U.S. Geological Survey Water-Resources Investigations Report 94-4015, v. 2, p. 1065–1072.

Hulsapple, Scott, Conklin, Martha, and Harvey, Judson, 1995, A field study of volatile solute transport in a stream contaminated with heavy metals: American Geophysical Union 1995 Fall Meeting, December 11–15, 1995, San Francisco, California, published as a supplement to EOS, November 7, 1995, p. F226.

Konieczki, A.D., and Angeroth, C.E., 1997, Hydrologic data from the study of acidic contamination in the Miami Wash-Pinal Creek area, Arizona, water years 1994–96: U.S. Geological Survey Open-File Report 97–247, 94 p.

Wagner, B.J., and Harvey, J.W., 1997, Experimental design for estimating parameters of rate-limited mass transfer—Analysis of stream tracer studies: American Geophysical Union, Water Resources Research, v. 33, no. 7, p. 1731–1741.

## National Water Information System (NWIS) Program—Development and Support *(AZ114)*

**Location:** National

**Project Chief:** Colleen A. Babcock

**Period of Project:** Continuous since January 1989

**Supporting USGS program:** Headquarters

**Problem:** Hydrologic data for the WRD are currently stored in several data bases. These data bases have been designed and developed over the past 25 to 30 years. The current data bases are either hierarchical or sequential in design. In recent years as water issues are being evaluated with a more multidiscipline approach, accessing several different archaic data systems hampers the effective use of the hydrologic data. Newer technology provides for better integration of data through the use of a relational data model. The new National Water Information System (NWIS) must be designed, developed, and implemented and the existing NWIS maintained.

**Objectives:** The Arizona NWIS Team provides data-management support to the Division. The Team will develop new software (programs), maintain existing software, and provide user assistance and training related to analysis, storage, and retrieval of hydrologic data.

**Approach:** This project will provide funds for the project chiefs in District, State, and Field offices to provide the following software design and maintenance activities: (1) Assure computer software compatibility with new revisions of the UNIX operating system, test all software functions under new revisions of the UNIX operating system, and make necessary modifications to software and report operating-system problems to the distributed-information systems (DIS) staff; (2) identify and repair reported malfunctions in the computer software and prioritize items needing attention on the basis of importance, identify solutions to problems using various software-debugging techniques, make modifications to software code, and test revised software; (3) prepare revisions of the computer software as a part of NWIS releases; (4) provide user support and training for computer-processing techniques in a distributed-computer environment; (5) coordinate activities with other NWIS data managers; and (6) evaluate new hardware and software technology to determine features for the hydrologic data bases.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Converted the PRIME-based NWIS to a UNIX-based system. The conversion uses Ingres, a relational data-base management system. Divisionwide implementation of NWIS on UNIX-based platforms was completed in September 1997.

**Plans for Fiscal Year 1998:** Performance and technical improvements will be developed, tested, and documented for release in the winter of 1997. The Data Base Administrator (DBA) guide will be completed, and a DBA course will be developed. The NWIS team is planning two releases each year to meet the identified requirements for the NWIS data-base system.

**Lake Powell Water Quality *(AZ118)***


**Location**: Northern Arizona and southern Utah

**Project Chief:** Robert J. Hart

**Period of Project:** June 1990 to September 30, 1999

**Cooperating Agency:** Bureau of Reclamation

**Problem:** The location of the penstocks of Glen Canyon Dam in the water column of the dam pool controls the quality of water being released to the downstream environment of the Colorado River. Because of their location, the penstocks generally take in cold water from the hypolimnion (deep layer), which is released downstream. Native fish and other aquatic life may not be able to thrive in this cold water.

**Objectives:** The objective is to document water quality on a monthly basis and to define oscillation characteristics in the forebay of Glen Canyon Dam.

**Approach:** Water-column measurements will be made using an oceanographic sonde instrument that consists of probes for measuring dissolved-oxygen concentration, pH, specific conductance, and water temperature. Three vertical sections in the forebay will be measured to determine variability in physical and chemical structure. In addition, thermistors will be placed at 1-meter (3.28 ft) intervals, 10 m (32.8 ft) above and 10 m below the penstock intakes. Water temperature will be recorded continuously over a period of several days and on a seasonal basis.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** A USGS Water-Resources Investigations Report was published in fiscal year 1996 that describes the results of studies during 1990–91.

**Plans for Fiscal Year 1998:** Depth-profile measurements in the dam pool of Lake Powell will resume in fiscal year 1998. Water temperature, specific conductance, pH, and dissolved-oxygen concentration will be measured in the water column. Thermistors will be placed in the penstock zone on a seasonal basis. Detailed measurements of temperature will be collected to document the oscillation of the water column that results from dam operations or natural physical processes.

**Publications, Fiscal Years 1995–97:**

Hart, R.J., and Sherman, K.M., 1996, Physical and chemical characteristics of Lake Powell at the forebay and outflows of Glen Canyon Dam, northeastern Arizona, 1990–91: U.S. Geological Survey Water-Resources Investigations Report 96–4016, 78 p.


Deploying a multiparameter water-quality sonde unit through the water column of Lake Powell. The sonde unit measures water temperature, specific conductance, pH, dissolved-oxygen concentration, and depth; and is capable of recording every 0.5 seconds.

**Grand Canyon Sediment Transport *(AZ121)***


**Location:** Northern Arizona

**Project Chief:** Julia B. Graf

**Period of Project:** Continuous since June 1990

**Cooperating Agency:** Bureau of Reclamation

**Problem:** State and Federal agencies charged with management of the Colorado River in Glen and Grand Canyons must be able to assess the effects on sand deposits of alternative flow releases to get maximum benefit from the control of flow with minimum adverse effects to the riparian environment. The characteristics of hydraulic controls and flow in the river downstream from the dam that control sand transport and deposition must be understood physically and modeled mathematically before the effects of dam operation on the sand deposits can be assessed.

**Objective:** Models capable of accurate predictions of stage, discharge, sand transport, and bed evolution will be developed to provide tools for evaluation of the effects of various dam-operation scenarios on the riparian-zone sand deposits in Grand Canyon. The development of physically based numerical models requires the collection and analysis of a limited but carefully designed set of accurate field data to define the channel characteristics that determine sand-storage characteristics and to provide an accurate data base for checking model results.

**Approach:** A program of data collection was designed and begun in 1991 that included mapping of detailed bed geometry and bed-material characteristics in selected reaches, monitoring of sand storage at a network of monumented cross sections, measurement of reach-averaged water velocity at four different rates of dam releases, and measurement of stage about every 5 mi along the channel. In addition, measurements of detailed flow-velocity and suspended-sediment fields at streamflow-gaging stations were designed to enable development of theoretical rating curves for the sand fraction to improve the estimate of sand transport. Data collected at three sandbars were planned to relate fluctuating river stage to water levels in sandbars and bar slumping. Field measurements of channel geometry and bed materials as well as flow and sediment transport during runoff made in the two largest tributaries—the Little Colorado and Paria Rivers—will be used in developing models of sand transport that will improve estimates of sand inputs from these important sources.

Field data are being used to develop physically based models of flow and sediment transport. Both one-dimensional and multidimensional models of flow, sand transport, and bed evolution are being developed. One-dimensional models are intended to route water and sand through long reaches; whereas, multidimensional models are being used in short reaches where patterns of flow and sand deposition and erosion in reaches of the scale of individual pools are required.

The studies are being carried out in collaboration with the NRP, and include the work of J. Dungan Smith, Stephen M. Wiele, Eleanor R. Griffin, and others in that program as well as that of Arizona District personnel.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Data from streamflow-gaging stations and a network of more than 40 stage-gaging stations aided in the development of an accurate one-dimensional discharge-routing model. The model was used to compute hydrographs at 38 sites along the river. The model also is in use by Arizona District personnel to aid in streamflow gaging and to compute discharge at ungaged locations.

Bathymetric surveys were combined with topographic data above the water line to develop topographic maps of the river channel downstream from the Paria and Little Colorado Rivers and to prepare grids that represent the channel geometry for use in multidimensional models. Multidimensional models of flow, sand transport, and bed evolution were used to estimate sand deposition in the channel of the Colorado River that resulted from a flood on the Little Colorado River in January 1993. Data from monumented cross sections show that model results agree with measured changes to within about 5 percent.

Sand-storage monitoring shows that sand brought to the river by tributaries and deposited in the channel is transported downstream even under the relatively low daily peak discharges allowed under the restricted dam operating rules in effect since 1991. Sand initially deposited in eddies along the channel margins is eroded more slowly than sand in the channel. High runoff in the upper Colorado River Basin has caused dam releases to be higher and steadier than average since June of 1995. Tributary inflows downstream from the dam were below average during the same period until August 1997.

Releases of 45,000 $ft^3/s$ from Glen Canyon Dam in March 1996 created a controlled flood that provided an opportunity for collection of data for testing model predictions at discharge rates larger than normal powerplant releases. Because of the combined effect of higher preceding dam releases and low tributary inflows, sand storage in the channel downstream from the Paria River was less immediately before the controlled flood than when first measured in 1992. The flood releases scoured sand from the channel bed, however, and redeposited it in higher elevation sandbars as predicted. Load-cell sensors were installed in one sand bar before the flood and documented the short-term changes in sand storage and bar evolution during the rising stage and floodflow. River stage monitored at 29 locations during the controlled flood provided data on amplitude and shape of the free surface wave for extension of the previously developed one-dimensional discharge-routing model to releases larger than the powerplant range. The stage-gage network was discontinued following the flood experiment. Reach-average velocity measured by tracing rhodamine wt dye through a 225-mile reach was 1.8 m/s (6 ft/s).

A series of floods on the Paria River, the primary source of sand to the reach of river upstream from the Little Colorado River, prompted additional measurements of sand storage at the monumented cross sections and sampling of bed material and suspended sand at the streamflow-gaging station at the downstream end of that reach in August and September of 1997.

**Plans for Fiscal Year 1998:** A new study plan focusing on the 100-mile reach downstream from the dam will be implemented. The plan includes monitoring at a reduced number of monumented

cross sections but extends the network upstream from Lees Ferry into Glen Canyon. The plan includes measurement of sand storage and sampling of bed material at cross sections twice during the year and additional measurements if flows from the dam are greater than powerplant releases. Sampling of bed material and suspended sediment at streamflow-gaging stations at Lees Ferry (river mile 0), above the Little Colorado River (river mile 61), and near Grand Canyon (river mile 87) will be done to track the movement of sand carried to the river by flows in the Paria River. Expanded measurement of water temperature, specific conductance, pH, and turbidity at those streamflow-gaging stations also is planned.

A short period of dam releases near the powerplant maximum releases (31,000 $ft^3/s$) was used in November 1997 to test the ability of powerplant releases to move sand to eddies and to sandbars above the normal operation stage. Data collected on sand-storage changes since the 1996 experimental flood and data on bed-material evolution and suspended-sediment transport will be evaluated to provide information on the rate and mechanism of downstream movement of sand brought to the river by floods on the Paria River. An increased emphasis on sampling floods on the Paria River also will be implemented to improve estimates of sand delivered by the Paria River.

**Publications, Fiscal Years 1995–97:**


Anderson, M.T., Graf, J.B., and Marzolf, G.R., 1996, Controlled flooding of the Colorado River in Grand Canyon—The rationale and data collection planned: U.S. Geological Survey Fact Sheet FS–089–96, 1 sheet.

Carpenter, M.C., 1995, Deformation of a sandbar in response to changes in effective stress along the Colorado River in the Grand Canyon, Arizona, *in* Diversity in Engineering Geology and Groundwater Resources: Association of Engineering Geologists 38th Annual Meeting and the Groundwater Resources Association of California 4th Annual Meeting, Programs and Abstracts, p. 40.

_____1996a, Monitoring erosion and deposition during the spring 1996 controlled-flood experiment on the Colorado River in the Grand Canyon using an array of load-cell scour sensors, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 29–31.

_____1996b, Monitoring erosion and deposition using an array of load-cell scour sensors during the spring 1996 controlled flood experiment on the Colorado River in the Grand Canyon, Arizona: American Geophysical Union 1996 Fall Meeting, Supplement to EOS, Transactions, v. 77, no. 46, November 12, 1996, abstract no. H42A–1, poster presentation, p. F271.

Carpenter, M.C., Carruth, R.L., Fink, J.B., Boling, J.K., and Cluer, B.L., 1995, Hydrogeology and deformation of sandbars in response to fluctuations in flow of the Colorado River in the Grand Canyon, Arizona: U.S. Geological Survey Water-Resources Investigations Report 95–4010, 16 p.

Carpenter, M.C., Crosswhite, J.A., and Carruth, R.L., 1995, Water-level fluctuations, water temperatures, and tilts in sandbars -6.5R, 43.1L, and 172.3L, Grand Canyon, Arizona, 1990–93: U.S. Geological Survey Open-File Report 94–485, 17 p.

Carpenter, M.C., Crosswhite, J.A., and Marie, J.R., 1995, A load-cell scour sensor to measure erosion and deposition in the regulated Colorado River in the Grand Canyon, Arizona: American Geophysical Union 1995 Fall Meeting, December 11–15, 1995, San Francisco, California, published as a supplement to EOS, November 7, 1995, p. F271.

Gauger, R.W., 1997, River-stage data, Colorado River, Glen Canyon Dam to upper Lake Mead, Arizona, 1990–94: U.S. Geological Survey Open-File Report 96–626, 20 p.

Graf, J.B., 1995, Measured and predicted velocity and longitudinal dispersion at steady and unsteady flow, Colorado River, Glen Canyon Dam to Lake Mead: American Water Resources Association Bulletin, April 1995, v. 31, no. 2, p. 265–281.

_____1996, Velocity and longitudinal dispersion of the Colorado River in Grand Canyon during the controlled flood of March 1996: American Geophysical Union 1996 Fall Meeting, Supplement to EOS, Transactions, v. 77, no. 46, November 12, 1996, abstract no. H42A–3, poster presentation, p. F271.

Graf, J.B., Jansen, S.M.D., Fisk, G.G., and Marlow, J.E., 1995, Topography and bathymetry of the Colorado River, Grand Canyon National Park, Little Colorado River confluence to Tanner Rapids: U.S. Geological Survey Open-File Report 95–726, 7 sheets.

Graf, J.B., Jansen, S.M.D., Smith, J.D., and Wiele, S.M., 1995, Development of channel-geometry information for flow and sediment-transport models, *in* Wright, P.J., Wegner, D.L., and Protiva, Frank, A Pilot for Long-Term Monitoring of Resources on the Colorado River in the Grand Canyon using Geographic Information System: Bureau of Reclamation Report R–95–14, p. 29–36.

Graf, J.B, Marlow, J.E., Fisk, G.G., and Jansen, S.M.D., 1995, Sand-storage changes in the Colorado River downstream from the Paria and Little Colorado Rivers, June 1992 to February 1994: U.S. Geological Survey Open-File Report 95–446, 61 p.

Graf, J.B., Marlow, J.E., Rigas, P.D., and Jansen, S.M.D., 1997, Sand-storage changes in the Colorado River downstream from the Paria and Little Colorado Rivers, April 1994 to August 1995: U.S. Geological Survey Open-File Report 97–206, 41 p.

Griffin, E.R., and Wiele, S.M., 1996, Calculated hydrographs for unsteady research flows at selected sites along the Colorado River downstream from Glen Canyon Dam, Arizona, 1990 and 1991: U.S. Geological Survey Water-Resources Investigations Report 95–4266, 30 p.

Jansen, S.M.D., Graf, J.B., Marlow, J.E., and Fisk, G.G., 1995, Monitoring channel sand storage in the Colorado River in Grand Canyon: U.S. Geological Survey Colorado River Studies Fact Sheet FS–120–95, 1 sheet.

Konieczki, A.D., Graf, J.B., and Carpenter, M.C., 1997, Streamflow and sediment data collected to determine the effects of a controlled flood in March and April 1996 on the Colorado River between Lees Ferry and Diamond Creek, Arizona: U.S. Geological Survey Open-File Report 97–224, 55 p.

O'Day, C.M., and Graf, J.B., 1996, Effects of the 1996 controlled flood on channel-sand storage in the Colorado River, Grand Canyon, Arizona: American Geophysical Union 1996 Fall Meeting, Supplement to EOS, Transactions, v. 77, no. 46, November 12, 1996, abstract no. H42A–2, poster presentation, p. F271.

Rote, J.J., Flynn, M.E., and Bills, D.J., 1997, Hydrologic data, Colorado River and major tributaries, Glen Canyon Dam to Diamond Creek, Arizona, water years 1990–95: U.S. Geological Survey Open-File Report 97–250, 474 p.

Wiele, S.M., 1997, Modeling sand movement and storage in the Colorado River through the Grand Canyon: U.S. Geological Survey Fact Sheet FS–227–96, 1 sheet.

Wiele, S.M., and Graf, J.B., 1995, Monitoring of sand storage with combined field measurements and bed-evolution modeling, Colorado River below Glen Canyon Dam: American Geophysical Union 1995 Fall Meeting, December 11–15, 1995, San Francisco, California, published as a supplement to EOS, November 7, 1995, p. F995.

Wiele, S.M., Graf, J.B., and Smith, J.D., 1996, Sand deposition in the Colorado River in the Grand Canyon from flooding of the Little Colorado River: American Geophysical Union, Water Resources Research, v. 32, no. 12, p. 3579–3596.

Wiele, S.M., and Griffin, E.R., 1997, Modifications to a one-dimensional model of unsteady flow in the Grand Canyon, Arizona: U.S. Geological Survey Water-Resources Investigations Report 97–4046, 17 p.

Wiele, S.M, and Smith, J.D., 1996, A reach-averaged model of diurnal discharge wave propagation down the Colorado River through the Grand Canyon: American Geophysical Union, Water Resources Research, v. 32, no. 5, p. 1375–1386.

Velocity measurements were made and water samples were collected before, during, and after the controlled flood of March 1996 in the Grand Canyon (left). Below, the amount of sand in the flooded channel was monitored by mapping the bottom with a sonic sounder.

**Water-Quality Characterization of Urban Runoff, Maricopa County, Arizona *(AZ127)***


**Location:** Maricopa County, Arizona

**Project Chief:** Kenneth D. Fossum

**Period of Project:** October 1, 1993, to September 30, 1999

**Cooperating Agency:** Flood Control District of Maricopa County

**Problem:** Section 402(p) of the Water Quality Act of 1987 requires municipalities with a population of 100,000 or greater to obtain National Pollution Discharge Elimination System (NPDES) permits to control the quality of stormwater discharged into streams. To comply with conditions of the permit, the chemistry and toxicity of urban stormwater and streams that receive urban runoff must be monitored for the permit term. Chemistry and toxicity data for urban stormwater and streams receiving urban runoff in the Phoenix metropolitan area are needed by the Environmental Branch of the Flood Control District of Maricopa County for their NPDES program. Data on stormwater chemistry and toxicity are needed to implement management strategies that are intended to reduce pollutant loads and stormwater toxicity and to determine if the quality of streams that receive urban runoff is degraded.

**Objectives:** The study will identify factors that contribute to the variability in stormwater chemistry and toxicity at basins in which land use is classified as heavy industrial, light industrial, residential, or commercial; characterize the chemistry and toxicity of Salt River streamflow at various discharge rates; and determine if urban runoff from Indian Bend Wash is affecting the quality of streamflow in the Salt River. Data will be provided to allow for the implementation of best management practices to clean up stormwater discharges.

**Approach:** Stormwater and streamflow samples will be collected at four urban drainage basins and at four existing streamflow-gaging stations on the Salt River and Indian Bend Wash. Flow-weighted composite samples of urban stormwater will be collected at the four drainage basins using automatic samplers. Streamflow samples from the Salt River and Indian Bend Wash will be collected manually using the equal-width-increment method. Samples will be analyzed to measure concentrations of constituents discharged from the drainage basins. Toxicity analyses using photoluminescent bacteria will measure adverse effects of stormwater on aquatic organisms. Toxicity analyses of whole water and filtered samples will determine if constituents in the dissolved and (or) solid phases cause a toxic response. Statistical methods will be used to evaluate factors that contribute to the variability in the chemistry and toxicity of stormwater and streamflow.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** The planned data report, which contains data collected from water years 1992 to 1995 was published. Sample collection is on schedule at all sites and sample equipment is operating well. Errors in prediction for the new regression equations have been significantly reduced.

**Plans for Fiscal Year 1998:** Data-collection activities at urban and streamflow-gaging stations will continue, and streamflow and water-quality data bases will be maintained. Planning documents for technical reports will be prepared, and report writing will continue. A Fact Sheet comparing data from USGS NPDES study units will be published.

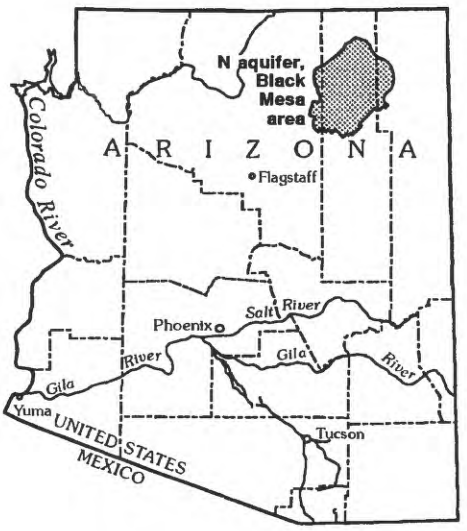
**Publications, Fiscal Years 1995–97:**

Fossum, K.D., 1995, Methods for adjusting regional-regression equations in Maricopa County, Arizona, *in* Loethen, M.L., ed., Water Management in Urban Areas: American Water Resources Association Symposium Proceedings, Houston, Texas, November 5–10, 1995, p. 11–18.

Fossum, K.D., and Davis, R.G., 1996, Physical, chemical, biological, and toxicity data from the study of urban stormwater and ephemeral streams, Maricopa County, Arizona, water years 1992–95: U.S. Geological Survey Water-Resources Investigations Report 96–394, 71 p.

Lopes, T.J., Fossum, K.D., Phillips, J.V., and Monical, J.E., 1995, Statistical summary of selected physical, chemical, and microbial characteristics, and estimates of constituent loads in urban stormwater, Maricopa County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 94–4240, 62 p.

**Chemical Characteristics of Water in the N Aquifer in the Black Mesa Area, Arizona *(AZ134)***




**Location:** Northeastern Arizona

**Project Chief:** John P. Hoffmann

**Period of Project:** May 1992 to September 30, 1998

**Cooperating Agency:** Arizona Department of Water Resources

**Problem:** A description of the water chemistry in the N aquifer (Navajo Sandstone, Kayenta Formation, and Wingate Sandstone) and the geochemical processes that control it is needed for the Black Mesa area in the Navajo and Hopi Indian Reservations, Arizona. This aquifer is the most heavily pumped in the reservations for both municipal and industrial purposes and is the only aquifer capable of supplying potable water in sufficient quantities for communities and institutions in much of the Black Mesa area. Concern exists that increasing withdrawals from the N aquifer for municipal use, combined with the continued withdrawal of water to slurry coal, will cause excessive water-level declines or infiltration of poor-quality water from the overlying D aquifer.

**Objectives:** The objectives of this study are to describe the water chemistry of the D and N aquifers, develop a geochemical model of the aquifers, and improve the conceptual model of the flow system on the basis of water chemistry and ground-water ages. This study will provide data or results useful to multiple parties in potentially contentious conflicts over water resources.

**Approach:** Available hydrologic, geologic, and water-chemistry data for the N and D aquifers will be compiled, evaluated, and entered into a relational data base. Standard graphical and geochemical procedures will be used. Samples will be collected from wells and springs from both aquifers and analyzed for selected inorganic ions, nutrients, $^{14}C$, deuterium, and ratios of $^{18}O$ to $^{16}O$ and $^{34}S$ to $^{32}S$. Samples also will be analyzed for $^{13}C$ and tritium in support of the $^{14}C$ determination. Rock samples from the N aquifer will be collected for mineralogical and isotope analyses. Geochemical models will be used to define the principal reactions along the flow paths and estimate ground-water ages. By defining these reactions, a conceptual model of the ground-water flow system will be improved.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Samples were collected for chemical and isotope analyses from wells selected for their areal distribution and well construction that indicated the samples came entirely from the N aquifer or the D aquifer. A Water-Resources Investigations Report that describes the results to date was published in 1997.

**Plans for Fiscal Year 1998:** Additional water samples will be collected from wells and springs from both aquifers and analyzed for selected common ions, nutrients, $^{14}C$, deuterium, and ratios of $^{18}O$ to $^{16}O$ and $^{34}S$ to $^{32}S$. Samples also will be analyzed for $^{13}C$ and tritium in support of the $^{14}C$ determination. An interpretive report will be published.

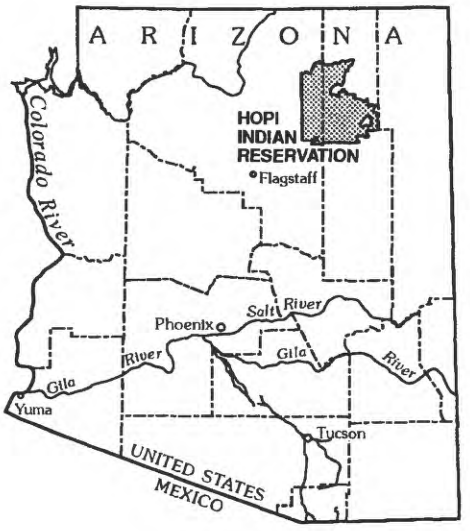
**Publications, Fiscal Years 1995–97:**


Hoffmann, J.P., and Lopes, T.J., 1996a, Geochemical interpretations of the hydrogeology of the N and D aquifers, Black Mesa, Arizona, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 183–186.

_____1996b, Geochemical evidence of leakage between the D and N aquifers and estimates of recharge to and hydraulic conductivity of the N aquifer, Black Mesa area, Arizona: American Geophysical Union 1996 Fall Meeting, Supplement to EOS, Transactions, v. 77, no. 46, November 12, 1996, abstract no. H21C–7, poster presentation, p. F223.

Lopes, T.J., and Hoffmann, J.P., 1997, Geochemical analyses of ground-water ages, recharge rates, and hydraulic conductivity of the N aquifer, Black Mesa area, Arizona: U.S. Geological Survey Water-Resources Investigations Report 96–4190, 42 p.

**Water-Resources Evaluation of the Hopi Indian Reservation *(AZ141)***




**Location:** Northeastern Arizona

**Project Chief:** Robert J. Hart (Gregory R. Littin)

**Period of Project:** Continuous since October 1, 1992

**Cooperating Agency:** Hopi Tribe

**Problem:** The Hopi Tribe has developed a long-range plan for land use on the Hopi Indian Reservation and for economic development. The tribe needs to evaluate the ground-water and surface-water resources within the reservation to implement their long-range plan.

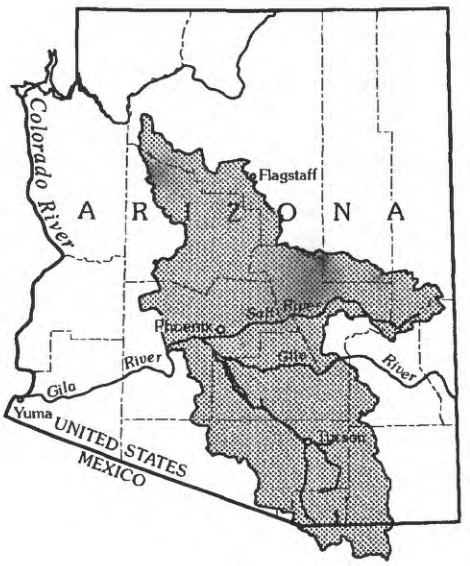
**Objectives:** Information will be provided to the Hopi Tribe that will allow the evaluation of local and regional water resources of the Hopi Reservation, and the capability to gather, analyze, and interpret water-resources data in support of tribal management-information needs.

**Approach:** *Phase I* includes collection and review of all existing hydrogeologic data; establishment of ground-water, surface-water, and water-quality monitoring networks; and training of Hopi technicians in the operation and maintenance of field equipment and in data-collection techniques. *Phase II* includes the evaluation of water resources using data collected during *Phase I* and as a result of ongoing data-collection activities. *Phase III* will include the evaluation of long-term effects of water use on the quality and availability of water on the reservation.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Surface-water data are being collected at two streamflow-gaging stations. Hopi technicians are being trained in water-quality sampling, ground-water level monitoring, gaging of streamflow, and station operation and maintenance. Basic data were provided to the Hopi Tribe. Lithologic logs of wells in the Kykotsmovi, Polacca, and Keams Canyon areas were analyzed. Well cuttings were analyzed. The north Oraibi stock tank is being prepared for runoff- and sediment-yield monitoring.

**Plans for Fiscal Year 1998:** Training of Hopi technicians in water-resources data collection will continue. Operation of streamflow-gaging stations will continue.

**Central Arizona Basins National Water-Quality Assessment Program *(AZ142)***




**Location:** Central and southern Arizona, northern Mexico

**Project Chief:** Gail E. Cordy

**Period of Project:** Continuous since October 1, 1993

**Supporting USGS program:** National Water-Quality Assessment Program

**Problem:** In order to make decisions about water-quality issues for the Nation, consistent information representing multiple areal scales over a long period of time are needed. This information is not currently available, and as a result, Congress initiated funding for the development of the National Water-Quality Assessment Program (NAWQA).

**Objectives:** The study will provide a consistent description of current water-quality conditions in the study area; define long-term trends in water quality; and identify, describe, and explain, if possible, the major natural and human factors that affect observed water-quality conditions and trends.

**Approach:** Available water-quality information will be compiled; surface and ground water will be sampled and analyzed for a wide array of physical, chemical, and biological properties; and interpretations will be published in reports.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Ground-water sampling in the agricultural land-use area of the west Salt River Valley (WSRV) (32 wells) and the desert scrub area of WSRV (5 wells) was completed in 1996. Drilling and sampling of 9 shallow wells in the WSRV agricultural area was completed in summer 1997 in order to characterize the quality of recently recharged water. An additional 24 existing wells were sampled throughout the WSRV. Data from the WSRV 1997 sampling were checked, reviewed, and will be published in the 1997 annual data report for Arizona. Data collected in the 1996 water year were published in the 1996 annual data report. A study to determine current ground-water quality in the Sierra Vista area was completed in cooperation with the Arizona Department of Environmental Quality (ADEQ). Nineteen wells were sampled by the NAWQA staff, and 7 split samples were collected with the ADEQ. A Fact Sheet describing the USGS-ADEQ cooperative sampling in the Sierra Vista area was published in 1997.

Monthly surface-water sampling at the nine basic fixed sites (BFS) and two intensive fixed sites (IFS) began in early fiscal year 1996 and continued through fiscal year 1997. The frequency of surface-water sampling was increased in 1997 from monthly to 2 to 3 times per month during times of pesticide and fertilizer application at the two IFS (Buckeye Canal heading and the

Hassayampa River at Arlington). Analyses of pesticides were included in samples taken at both IFS in fiscal year 1997. Probes to measure continuous temperature and specific conductance were installed at seven BFS and the two IFS. A synoptic study (multiple site, multiple reach) of the effluent-dependent reach of the Salt and Gila Rivers downstream from the 91st Avenue Wastewater Treatment Plant in Phoenix was completed.

Ecological assessments were completed at most of the surface-water BFS. Bed-sediment and fish-tissue samples were collected at most of the BFS and at six additional sites. Multiple-reach/ multiple-year sampling, part of the ecological assessment program, was completed on West Clear Creek and the San Pedro River in 1996 and 1997. In addition, the ecological assessment part of a synoptic study and collection of three water-quality samples were completed on the San Pedro River in 1997 to determine baseline conditions.

**Plans for Fiscal Year 1998:** Approximately 30 wells in the upper Santa Cruz Basin will be sampled as part of a basinwide survey. Additional wells in the Tucson area will be sampled to characterize urban ground-water quality. Data will be checked and published in the 1998 annual data report. By February 1998, monthly and intensive sampling of surface-water quality will end at all sites except for high-flow (flood) sampling when possible. Temperature/conductance probes will be removed from most sites. The final water-quality sample for the ecological synoptic study on the San Pedro River will be collected. Ecological assessments at sites on West Clear Creek and the San Pedro River will complete the multiple-reach/multiple-year sampling requirements. Major efforts in 1998 will be on publication of data and completion of interpretive reports.

**Publications, Fiscal Years 1995–97:**


Coes, Alissa, Gellenbeck, Dorinda, and Towne, Doug, 1997, Collection and analysis of ground-water samples in the Sierra Vista Basin, Arizona, 1996: U.S. Geological Survey Fact Sheet FS–107–97, 1 sheet.

Cordy, Gail, 1996a, NAWQA and AZ water quality, *in* Arizona Water Resources, March–April 1996: Tucson, University of Arizona, p. 9 and 12.

_____1996b, Water-quality assessment in Arizona—Sampling design for NAWQA, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 87–89.

Wirt, Laurie, Anning, D.W., and Westerhoff, Paul, 1996, Diurnal, monthly, and spatial changes in water quality of effluent-dominated streamflow in the Salt and Gila Rivers west of Phoenix, Arizona, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 91–92.

Wirt, Laurie, and Gebler, J.B., 1996, Aquatic biology and water quality of effluent-dominated reaches of the Santa Cruz River, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 201–202.

Electrofishing is used by NAWQA staff to collect fish for ecological assessment. After weighing, measuring, and observation, fish are returned to the stream unharmed.

A composite water-quality sample across a section of West Clear Creek is collected for the NAWQA program.

**U.S. Air Force Plant 44, Tucson, Arizona**
***(AZ144)***


**Location:** Pima County, Arizona

**Project Chief:** David D. Graham

**Period of Project:** October 1, 1995, to September 30, 1998

**Cooperating Agency:** Aeronautical Systems Center of the U.S. Air Force

**Problem:** The presence of organic contaminants in ground water from parts of the sole-source regional aquifer underlying the City of Tucson in Pima County, southeastern Arizona, has been an issue of public concern since confirmed in 1981. The principal contaminant of concern at the site is trichloroethylene (commonly referred to as TCE), a volatile organic compound that was widely used as an industrial solvent at several locations within the boundary of the site, among them Air Force Plant 44 (AFP 44). A report published by the USGS in 1987 summarized the results of preliminary characterization investigations in the area around the Tucson International Airport. Characterization studies subsequent to those done in the early 1980's have provided much additional information about the extent of environmental contamination at the Tucson International Airport Area Superfund Site. The large amount and technical nature of the information released to the public have made it difficult for the public to develop an understanding of technical issues relevant to cleanup activities and the progress being made to resolve them.

**Objectives:** The history of ground-water contamination at the Tucson International Airport Area Superfund Site, cleanup activities, and associated geohydrologic and technical issues are to be summarized in a USGS report. Technical assistance will be provided to the Aeronautical Systems Center (ASC) of the U.S. Air Force for their oversight responsibilities for cleanup activities being conducted by contractors at AFP 44.

**Approach:** A GIS data base was created for TCE concentration data from monitoring wells located at AFP 44 and other areas within the boundaries of the Tucson International Airport Area Superfund Site. The GIS data base was used to delineate the extent of contaminated ground water at the site. Information about site characterization and cleanup activities contained in technical documents produced by private contractors and government agencies were reviewed and summarized and used in conjunction with other information about the hydrogeology and processes of contaminant behavior at the site to produce a retrospective summary report.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Although the size of the area where ground water has been contaminated with TCE has decreased slightly in some areas and concentrations have declined in the discharge of many wells, complete and permanent aquifer restoration may be more difficult and time consuming than originally anticipated. The

heterogeneity of sediments in the Tucson regional aquifer and overlying unsaturated zone hinders cleanup efforts. Studies by the University of Arizona at AFP 44 have demonstrated tailing of TCE concentrations while extraction wells are pumping and rebound of concentrations when pumping ceases. The studies also indicate that high permeable gravel layers serve as major zones of preferential flow, which are characterized by rapid ground-water velocities and low TCE sorption. In contrast, lenses of clay and silt are characterized by low permeability, very slow ground-water velocities, and high TCE sorption. Immediately north of AFP 44, the occurrence of extremely high concentrations of TCE in ground water from a fine-grained layer in the uppermost part of the aquifer suggests the presence of TCE in a dense nonaqueous phase liquid (DNAPL) form. Large amounts of solvent are thought to have been disposed at this location. Even small amounts of undissolved TCE are sufficient to cause extensive contamination of ground water to regulatory levels. Cleanup by removal of air or water from this layer is likely to be limited by low permeability. A similar but much less contaminated mound of saturated sediments in the uppermost part of the aquifer is present near the northern boundary of AFP 44. A Water-Resources Investigations Report was approved for publication.

**Plans for Fiscal Year 1998:** The final report will be published. Technical assistance will be provided to the ASC as requested.

### *n* Verification *(AZ146)*


**Location:** Maricopa County, Arizona, and the surrounding area

**Project Chief:** Jeffrey V. Phillips (Christie O'Day)

**Period of Project:** March 1994 to September 30, 1998

**Cooperating Agency:** Flood Control District of Maricopa County

**Problem:** Flood profiles are computed using water-surface profile computer models that are based on open-channel hydraulic principles. All water-surface profile computer-model areas are based on three fundamental open-channel hydraulic equations—Manning's equation, the continuity equation, and the energy equation. Manning's equation requires an evaluation of channel characteristics and an estimate of the roughness coefficient ($n$). The ability to assess roughness coefficients has been called an art developed through experience. Because of the subjective nature of $n$-value selection, verifications of channel-roughness coefficients are needed. In addition, significant changes in Manning's roughness coefficient can result from flood-stage flows either removing or laying-over riparian vegetation. Since computed conveyances are directly related to $n$ values, major inaccuracies will cause considerable errors in related studies such as flood-plain delineation and bridge design.

**Objectives:** The objectives are to verify Manning's roughness coefficient on selected streams in Maricopa County and surrounding areas and develop a predictive method for determining the floodflow-related effects of changing riparian-vegetation conditions on channel conveyances.

**Approach:** Measurements of channel characteristics will be used to verify roughness coefficients for selected channel reaches in Maricopa County. In addition, riparian vegetation will be documented and studied at selected locations in central Arizona. A set of photographs will be taken at each site seasonally (each summer and winter) and after significant flows. Riparian vegetation affected by flows will be evaluated by computing stream power at cross sections and studying the resultant effect on the vegetation. A relation will be developed that can be used to predict the effect of flow on vegetation conditions.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** A relation among Manning's $n$, median size of the bed material ($d_{50}$), and hydraulic radius ($R$) has been developed for gravel-bed streams in central Arizona. This equation is significantly different from the similar equations derived from verified $n$ values for gravel-bed streams in other western States. The relation developed for central Arizona streams suggests much lower base values of Manning's $n$. Several possible explanations for this apparent shift in relations for the different regions of the

United States were published in a paper and presented at the Association of State Floodplain Managers Association Conference in May 1997.

Another relation has been developed that can be used to estimate the vegetation component of Manning's *n*. At Skunk Creek near Phoenix, where the channel vegetation was maintained, the vegetation component for the documented conditions was actually considered verified because the base *n* value was separately verified for a range of flow magnitudes and vegetation densities.These data were used to develop a simple relation between the area of flow blocked by vegetation and the corresponding magnitude of the vegetation component. This simple relation can be used at similar sites in the arid to semiarid southwestern United States for which the effect of vegetation on total roughness must be determined.

The original proposal was revised to include the publication of three papers that describe a re-evaluation of peak discharge for the flood of August 19, 1971, on Bronco Creek near Wikieup, Arizona. Recent findings indicate that a rare hydraulic phenomenon known as translatory waves may have been produced in this natural, high-gradient, sand channel. Translatory waves greatly complicate the evaluation of peak-discharge computations and may present severe complications in the design of hydraulic structures.

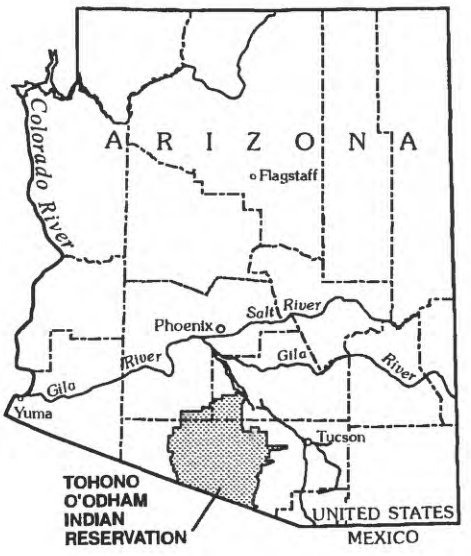
**Plans for Fiscal Year 1998:** Two interpretive reports will be submitted for approval and publication.

**Publications, Fiscal Years 1995–97:**

Hjalmarson, H.W., and Phillips, J.V., 1997, Potential effects of translatory waves on estimation of peak flows: American Society of Civil Engineers, Journal of Hydraulic Engineering, v. 123, no. 6, p. 571–575.

Phillips, J.V., and Hjalmarson, H.W., 1996, Implications of translatory-wave phenomena for engineering design, *in* Maxwell, W.H.C., Preul, H.C., and Stout, G.E., eds., Proceedings, RIVERTECH96: International Water Resources Association, First International Conference on New/Emerging Concepts for Rivers, Chicago, Illinois, September 22–26, 1996, p. 453–460.

**Preliminary Assessment of Hydrologic Conditions in the Southern Boundary Area of the Tohono O'odham Indian Reservation, Arizona *(AZ147)***




**Location:** Tohono O'odham Indian Reservation, Arizona

**Project Chief:** Michael C. Carpenter

**Period of Project:** October 1, 1993, to September 30, 1998

**Cooperating Agency:** Tohono O'odham Nation

**Problem:** Information on the quantity and quality of water resources in the southern boundary area of the Tohono O'odham Indian Reservation is needed for effective resource management.

**Objectives:** Identify data needs for an intensive study of surface-water and ground-water resources in the southern boundary area of the reservation. Install and maintain network of load-cell scour sensors for automated slope-area streamflow gaging of Vamori Wash at the international boundary.

**Approach:** Existing ground-water and surface-water data will be reviewed. Transducer packages for load-cell sensor will be assembled, calibrated, tested, installed, and monitored.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Load-cell pans have been built.

**Plans for Fiscal Year 1998:** Technical assistance will be provided to the Tohono O'odham Water-Resources Department for program development. Load-cell sensors will be completed. A proposal for an intensive surface-water and ground-water study of the southern boundary area will be completed.

**Well Inventory of the Lower Colorado River Flood Plain and Adjacent Areas in Arizona, California, Nevada, and Utah *(AZ148)***


**Location:** Lower Colorado River

**Project Chief:** Sandra J. Owen-Joyce

**Period of Project:** March 1994 until complete

**Cooperating Agency:** Bureau of Reclamation

**Problem:** Water in the lower Colorado River is apportioned among the States of California, Arizona, and Nevada by a U.S. Supreme Court Decree, 1964, Arizona v. California, in terms of consumptive use. The Decree is specific about the responsibility of the Secretary of the Interior to account for consumptive use of water from the mainstream. Accounting for the consumptive use of Colorado River water withdrawn from the river aquifer by wells requires that each well within the boundary of the river aquifer be located and inventoried in order to apply the accounting-surface method, which can be used to identify those wells that yield water that will be replaced by water from the river.

**Objectives:** Wells on the flood plain of the lower Colorado River will be inventoried and the inventory of wells on the adjacent alluvial slopes and tributary valleys will be completed.

**Approach:** (1) Wells will be visited in the field and owners interviewed to collect current available data required to fill out well-inventory forms and to obtain additional ownership information and drillers' logs. (2) Well positions will be determined or updated within 33 ft by using Global-Positioning System (GPS) satellite surveys. Well sites and measuring points will be photographed. (3) Water levels will be measured where required and access is possible. (4) USGS and Bureau of Reclamation (BOR) well-inventory forms will be coded for each well. (5) Appropriate data will be entered in a USGS data base.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** An inventory of 75 wells and 29 river pumps on the Chemehuevi Indian Reservation and adjacent areas near Lake Havasu in California was completed; data for 19 wells have been updated in the data base. Since early November 1994, 1,163 wells, 4 springs, and 146 river pumps have been inventoried on or near the Colorado River Indian Reservation in Parker Valley; data for 343 wells have been entered or updated in the data base. In Cibola Valley, Arizona, 117 wells and 5 river pumps were inventoried; 90 wells have been entered or updated in the data base. About 1,150 wells were inventoried in the Yuma area in 1994; data for 855 have been added or updated in the data base. In southeastern Imperial Valley, California, 23 wells have been inventoried. In fiscal year 1997, river pumps were added to the inventory. The USGS NWIS data base was adapted to include river pumps and will be used to store the inventory data for the wells and river pumps; data for 16 river

pumps have been entered. Data processing and entry into the USGS data base is an ongoing process in all areas.

Current and past water-level measurements in wells in and near Parker indicate that static water-level elevations have risen approximately 4 ft in response to cessation of pumping associated with irrigation of alfalfa east and south of the airport. Current water levels commonly are less than 10 ft above or below the accounting surface. Static water-level elevations in much of the river aquifer from Parker Dam to Palo Verde Dam probably will be less than 50 ft above the accounting surface except for the eastern part of Cactus Plain and La Posa Plain. Measured static water levels in three wells on La Posa Plain 2 to 3 mi east of the flood plain and east of Poston were about 8 (±10) ft above the accounting surface and about 45 ft below the elevation of static water levels beneath the north end of La Posa Plain. Accurate measurements of the difference between the elevation of static water levels in wells and the accounting surface will not be possible until the precise elevations of the measuring points have been determined.

About 20 well sites in the southeast end of Imperial Valley, California, were inventoried on July 17, 1996, to provide water-level data needed to evaluate possible solutions to drawing the river-aquifer boundary northwest of Pilot Knob near Yuma. These wells were previously measured during the 1960's to determine the amount of water-level rise. A number of the old observation wells have been destroyed. Water levels northeast of Pilot Knob and north of the All American Canal have risen about 6 to 8 ft since 1979 and 2.5 ft since 1989. Northwest of Pilot Knob, water levels have risen about 9 to 16 ft since the 1960's.

A series of maps that display GPS locations of sites visited in the field overlaid with well data from the USGS data base have been created using GIS at various scales. The wells are shown with a variety of colors and symbols to indicate use of water, use of site, or other variables in the data base. The maps include geology, hydrology, and river-aquifer boundaries from the accounting-surface project as well as public-land net, transportation, and 7.5-minute-quadrangle coverages in the States in the project area. These maps are used to track entry of new sites and updates of existing sites in the data base, to distinguish individual wells and check the designation of site names in subdivisions where sites are close together, to improve efficiency of field work, and to plan future inventories with the BOR. Plots at 1:24,000 and larger scales are useful in working on problem sites in the field.

An inventory of wells on the Colorado River Indian Reservation was completed except for the domestic wells. In March 1997, at the request of the BOR, the USGS made the Parker Strip area (Parker Dam to the northern boundary of the Colorado River Indian Reservation) top priority for data collection and processing to meet the needs of the ADWR and Brooke Water Company. To meet the time lines of the *AZ159* project, which began in July 1997, data collection and processing in the Dome area and southeastern Imperial Valley became the second priority to be started as soon as the Parker Strip area is completed. A personal-computer-based data base that handles images was completed and 881 photographs with associated data of 537 well sites have been entered.

**Plans for Fiscal Year 1998:** Entry of well data and river-pump data from the Parker Strip area into the District data base will be completed. Entry of well data and river-pump data from the Colorado River Indian Reservation into the data base will continue. The inventory of wells in

Parker Valley off the Colorado River Indian Reservation will be completed. The inventory of wells in the Dome area and southeastern Imperial Valley associated with the *AZ159* project will be completed. Inventory of wells in and east of Ehrenberg, Arizona, will continue. The inventory of wells in Cibola Valley will be completed. An inventory of wells in the Bill Williams flood-plain area and in the Lake Havasu area in Arizona will begin. Data processing and data entry into the USGS data base will continue for all areas.

**Publications, Fiscal Years 1995–97:**

Owen-Joyce, S.J., and Wilson, R.P., 1995, Accounting for consumptive use of lower Colorado River water in Arizona, California, Nevada, and Utah: U.S. Geological Survey Fact Sheet 94–074, 1 p.

Wilson, R.P., and Owen-Joyce, S.J., 1995, Identifying wells to be included in the accounting of consumptive use of water from the lower Colorado River, *in* Water Use in Arizona—Cooperation or conflict: Arizona Hydrological Society, Proceedings of the Eighth Annual Symposium, Tucson, Arizona, September 14–16, 1995, p. 26.

Measuring the water level in an observation well during well inventory.

**Hydrologic Investigations in the Upper San Pedro Basin, Cochise County, Arizona *(AZ150)***


**Location:** Sierra Vista subbasin of the upper San Pedro River Basin, southeastern Arizona

**Project Chief:** Donald R. Pool

**Period of Project:** October 1995 to September 30, 1998

**Cooperating Agencies:** Cochise County Department of Highways and Flood Control

**Problem:** Water in the upper San Pedro River Basin supports riparian vegetation, agricultural, military, domestic, municipal, and industrial needs. The basin includes the San Pedro Riparian National Conservation Area (SPRNCA), which is a narrow band of riparian vegetation along the river. Ground-water pumpage and general demands on the water supply threaten streamflow in the San Pedro River and the SPRNCA. Improved information on how the aquifer interacts with streamflow in the river and on the water budget in the basin are needed to properly evaluate the effects on streamflow.

**Objectives:** The study will provide an improved definition of stream-aquifer relations and water-budget components in the upper San Pedro Basin.

**Approach:** Several methods of investigation are being used including: geochemical studies, stream-aquifer monitoring, aquifer-storage monitoring, and geophysical investigations. Geochemical studies are focused on estimating the relative amounts of ground water from various sources that contribute to flow in the San Pedro River. Wells near Lewis Springs are being monitored, and water levels are being related to streamflow to improve knowledge of aquifer properties. Changes in the amount of ground water in storage are being monitored on a large scale in the Sierra Vista area and on a small scale along Garden Canyon near the Huachuca Mountains. The large-scale monitoring will provide long-term information on the ground-water storage-change component of the basin water budget. The small-scale monitoring will improve knowledge of rates and mechanisms of ground-water recharge near the mountains. Geophysical investigations using electrical and seismic methods will improve knowledge of aquifer geometry and lithology.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Data collected during the project have led to a significantly improved conceptual model of the ground-water flow system and stream-aquifer interactions. An aquifer storage-monitoring network was established in the Sierra Vista area, and baseline surveys were completed. Since June 1995, large losses in aquifer storage have occurred in the Garden Canyon area, which indicate a lack of mountain-front recharge for the period. Resistivity surveys and lithologic information from boreholes indicate

that an interval of silt and clay, as much as a few hundred feet in thickness, separates the ground-water flow system into shallow and deep components. Some of the shallow components discharge as springs west of the river. Changes in water-level gradients in the Lewis Springs area are consistent with the effects of ground-water withdrawals in the regional aquifer.

**Plans for Fiscal Year 1998:** Data-collection efforts will continue in the form of stream-aquifer monitoring and aquifer-storage monitoring. Planned reports include map reports with text describing the results of each aspect of the study.

## Water-Resources Remote-Sensing Data Base *(AZ151)*

**Location:** Various international areas

**Project Chief:** Wesley D. Meehan

**Period of Project:** Continuous since October 1994

**Funding Agency:** U.S. Army Corps of Engineers

**Problem:** In the past, U.S. military deployments have been in nonarid regions of the world where fresh surface-water supplies were readily available. Recently, U.S. military planners have recognized a need for water-support planning in the event of rapid deployment in unfamiliar parts of the world where adequate water resources are not easily accessible.

**Objectives:** The quantity, quality, and availability of surface-water, ground-water, and water-supply facility resources in arid regions of the world will be evaluated. Studies of the various areas will result in a better understanding of the water resources of the world and provide valuable information for defense and humanitarian needs. Products from the study will serve as input to an automated data base and overall hydrologic evaluation of assigned areas for future use in defense planning and operations.

**Approach:** Assignments of study areas are made by the U.S. Army Corps of Engineers (USACE), through the USGS WRD headquarters office. Analyses are completed on smaller work areas of about 5,000 $mi^2$ at a time. First, all available geohydrologic information is reviewed by WRD personnel with secret-level security clearances issued by the Department of Defense. Significant hydrologic and geologic data are incorporated into the water-resources data base. The information is then used to evaluate and estimate surface-water, ground-water, and water-supply facility resources. Unpublished interpretative reports are generated that summarize all aspects of water availability within a specified region. These reports usually are classified.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** A previous study area, in progress since April 1994, was completed ahead of schedule in December 1996. Starting in January 1997, the project was assigned a new study area covering approximately 130,000 $mi^2$, or 25 smaller work areas, in Eritrea, Djibouti, and northern Somalia. A training program was prepared for the USACE software, and training was given to USACE employees in Alexandria, Virginia.

**Plans for Fiscal Year 1998:** Analyses will be completed on schedule. At that time, three more study areas will be assigned with full-time funding for one analyst. The USACE intends these three study areas to be a "funding bridge" to carry the project through the end of fiscal year 1998. Additional software and operational training will be conducted for a private GIS agency in Tucson, Arizona, that is hired by the USACE. Funding for fiscal year 1999 is still uncertain, but USACE could request additional assistance.

**Investigation of the Causes of Sinks on the Farmlands of the San Xavier District, Tohono O'odham Nation, Pima County, Arizona *(AZ152)***


**Location:** Southeastern Arizona

**Project Chief:** John P. Hoffmann

**Period of Project:** June 1995 to September 30, 1997

**Cooperating Agency:** Bureau of Reclamation and San Xavier District, Tohono O'odham Nation

**Problem:** Land subsidence in the form of sinkhole-like depressions (sinks) has occurred within discrete areas on the farmlands of the San Xavier District of the Tohono O'odham Nation near Tucson, Arizona. These sinks make the farmlands dangerous and unsuitable for farming.

**Objectives:** The objective of this study is to investigate the occurrence of sinks on the District farmlands. Data from this study will be used to provide information on the causes of sinks so that mitigation measures can be identified and hazards can be reduced or eliminated.

**Approach:** Methods used in this study include: (1) detailed mapping of the distribution of the sinks, (2) hydrogeologic analysis of susceptibility of sediments to compaction, (3) resurveying existing bench marks to detect land subsidence, (4) inspection and laboratory analyses of near-surface materials, and (5) geophysical investigations to determine properties of near-surface sediments and to detect subsurface voids and cracks.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** More than 1,700 sinks were mapped from aerial photographs. Sediments were collected and analyzed from 13 trenches to depths of 19 ft. Electromagnetic surveys were made near sink and nonsink areas. Surveys were completed to determine if land subsidence has occurred. A USGS Open-File Report has been published, and two journal articles have been approved for publication.

**Plans for Fiscal Year 1998:** A proposal for a phase II part of the study has been written that is designed to provide a means of delineating areas of potential sink development and evaluating possible sink-mitigation measures. The journal articles are scheduled for publication in 1998.

**Publications, Fiscal Years 1995–97:**

Hoffmann, J.P., Pool, D.R., Konieczki, A.D., and Carpenter, M.C., 1997, Investigation of the causes of sinks in the San Xavier District, Tohono O'odham Nation, Pima County, Arizona: U.S. Geological Survey Open-File Report 97–19, 2 sheets.

Konieczki, A.D., Hoffmann, J.P., and Pool, D.R., 1996, Methods of investigation of the causes of sinkholes on the farmlands of the San Xavier District, Tohono O'odham Nation, Pima County, Arizona, *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 187–189.

Large coalescent sinkhole on the San Xavier farmlands.

**Assessment of Natural Recharge, Ground-Water Storage, and Aquifer-Storage Properties in the Lower Cañada Del Oro Basin, Pima County, Arizona *(AZ153)***


**Location:** Lower Cañada del Oro Basin, Pima County Arizona

**Project Chief:** Donald R. Pool

**Period of Project:** October 1, 1996, to September 30, 1998

**Cooperating Agencies:** Arizona Department of Water Resources and Metropolitan Domestic Water Improvement District

**Problem:** The project addresses three problems—poorly defined ground-water budgets, poorly defined aquifer-storage properties, and unknown distributions of natural recharge along the Cañada del Oro. Improved knowledge of the ground-water storage component of the water budget in the basin and aquifer-storage properties is needed for water-management decisions. A better understanding of the distribution of natural recharge along the Cañada del Oro would help in the siting of possible artificial-recharge facilities.

**Objectives:** Aquifer storage in the lower Cañada del Oro Basin and along detailed profiles near the Cañada del Oro will be monitored.

**Approach:** Aquifer storage is monitored on a quarterly basis using the temporal-gravity method at a network of 63 stations relative to 3 bedrock-reference stations. Thirteen of the stations are at wells where water levels are monitored. Relations between water levels and aquifer-storage changes will be developed and analyzed for aquifer-storage properties. A site selected for an aquifer test will be used for aquifer-storage monitoring and the results will be analyzed for aquifer-storage properties.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** The monitoring network was developed and four quarters of aquifer-storage monitoring have been completed.

**Plans for Fiscal Year 1998**: Quarterly surveys will continue and aquifer-storage monitoring will begin at a site selected for an aquifer test; the aquifer test is planned for May. A report will document the establishment of the aquifer-storage monitoring network and results of the first four quarterly surveys.

**Ground-Water Availability and Flow Characteristics of the Colorado Plateau, in the Vicinity of Flagstaff, Arizona *(AZ154)***


**Location:** Northern Arizona

**Project Chief:** Donald J. Bills

**Period of Project:** October 1, 1994, to September 30, 1998

**Cooperating Agency:** City of Flagstaff

**Problem:** The city of Flagstaff is growing rapidly, and a dependable water supply is needed to meet present and future requirements. Faulting, folding, and fracturing of regional-aquifer material with low permeability has enhanced the permeability and has increased well productivity in areas developed by the City of Flagstaff at Lake Mary and Woody Mountain. Whether these conditions prevail in other areas in and around Flagstaff with similar geology is unknown.

**Objectives:**. The study is designed to provide an improved understanding of the regional ground-water flow system in the Colorado Plateau near Flagstaff. Geologic controls on the distribution and movement of ground water, locations of recharge areas, current water levels, and directions of ground-water movement will be defined. A second objective is to determine which of the geophysical methods, or combination of methods, can be used to identify probable zones of high permeability related to geologic structure within the regional aquifer. Methods to be used and tested include ground-penetrating radar, seismic refraction and reflection, remote sensing, square-array resistivity, existing gravity surveys, and possibly new gravity surveys. These methods first will be tested in control areas to allow corroboration of specific known paths of ground-water flow near Flagstaff. The third objective is to use the successful exploratory methods to identify and determine the areal extent of major water-bearing zones.

**Approach:** This investigation is based on the assumption that regional ground-water flow near Flagstaff is strongly influenced by geologic structure. Although many hydrologic studies have described the flow of ground water in fractured rocks as a function of the number, orientation, length, and interconnection of fractures, few have attempted to do so for such a deep-seated ground-water flow system in consolidated sedimentary rocks. Data from existing wells, geophysical investigations, geochemical studies, and information from geologic investigations conducted by the Geologic Division (GD) of the USGS will be compiled and analyzed. The study will use a GIS to integrate results of investigations by GD of the surface and structural geology of the Flagstaff area with the geohydrologic information. The GIS then can be used to display the locations of wells, depth to water, well yield, and hydraulic characteristics within the study area

and overlay this information onto displays of other data sets such as structural geology and selected chemical characteristics of ground water in the study area.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** GD investigations of the surface geology and structure of the study area were completed in 1996. Data indicate that the geologic structure of the study area is more complex than previously indicated. The initial geophysical investigations by both the WRD and GD were completed in 1996. Several of the techniques used were shown to be useful for locating and defining structural features in the shallow and deep subsurface. A correlation of borehole data from wells drilled at some of these locations has verified the findings of the surface-geophysical analyses. Aquifer testing was completed in 1997 to determine the hydraulic properties of the regional aquifer at these sites. The water-chemistry investigations completed in 1997 show promise as an independent means of verifying the results of the geophysical investigations.

**Plans for Fiscal Year 1998:** Data collection will be completed, and a draft of the interpretive report will be prepared. The remaining data-collection activities include: sampling of selected wells and springs for chemical analyses, water-level measurements in selected wells, borehole logs in selected wells, and the determination of hydraulic properties from selected wells.

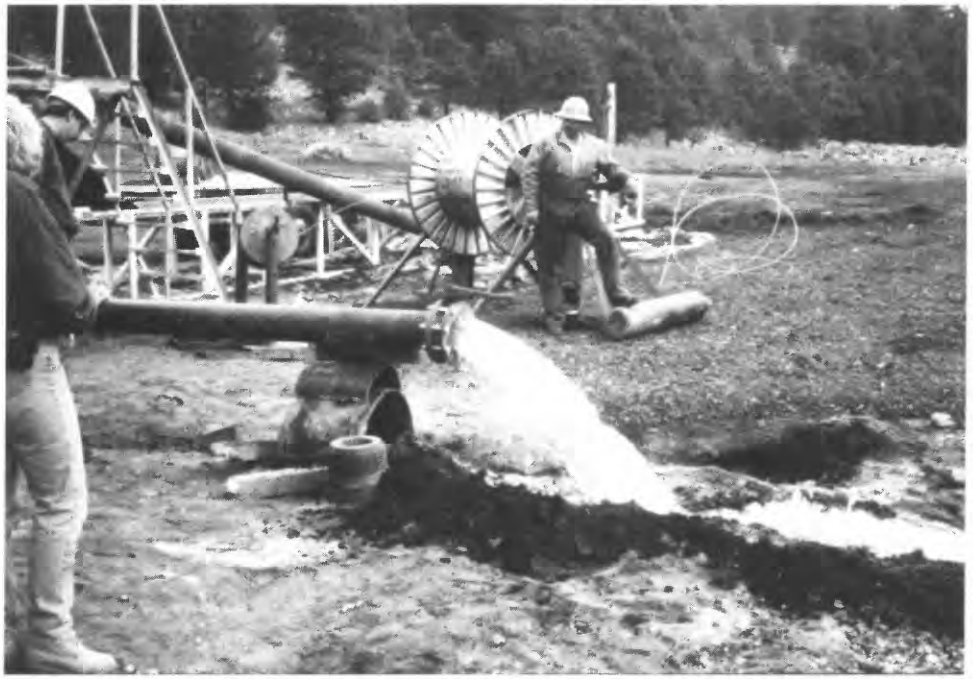
**Publications, Fiscal Years 1995–97:**


Bills, D.J., 1995, Ground-water availability and flow characteristics of the Colorado Plateau near Flagstaff, Arizona, *in* Annual Report and 16th Meeting of the Western States Seismic Policy Council, Extended Abstracts, Flagstaff, Arizona, September 18–20, 1995, p. 142–143.

Bills, D.J., Flynn, M.E., and Truini, Margot, 1996, Investigation of ground-water availability and flow characteristics of the Colorado Plateau near Flagstaff, Arizona [abs.], *in* Wanted—Water for Rural Arizona: Arizona Hydrological Society Proceedings of the Ninth Annual Symposium, Extended Abstracts, Prescott, Arizona, September 12–14, 1996, p. 111–113.

O'Day, C.M., and Leake, S.A., 1995, Ground-water availability in the Flagstaff area of the Colorado Plateau, Arizona, *in* Geddis, A.M., ed., Water Use in Arizona—Cooperation or conflict: Arizona Hydrological Society, Proceedings of the Eighth Annual Symposium, Tucson, Arizona, September 14–16, 1995, p. 2–3.

Pierce, H.A., and Hoffmann, J.P., 1996, Use of square-array direct-current resistivity method to detect fractures in consolidated sedimentary rocks in the Colorado Plateau near Flagstaff, Arizona: American Geophysical Union 1996 Fall Meeting, Supplement to EOS, Transactions, v. 77, no., 46, November 12, 1996, abstract no. H31A–1, p. F184.



Skunk Canyon well development and flow test (above). Right, geophysical investigations; collecting ground-penetrating radar data near Lake Mary Well 8.

**Availability and Quality of Surface-Water and Ground-Water Resources of the Yavapai-Prescott Indian Reservation, Arizona *(AZ155)***


**Location:** North-central Arizona

**Project Chief:** Gregory R. Littin

**Period of Project:** October 1, 1994, to September 30, 1998

**Cooperating Agencies:** Yavapai-Prescott Tribe and U.S. Environmental Protection Agency

**Problem:** Although the Yavapai-Prescott Tribe currently receives water-supply services from the City of Prescott pursuant to the Yavapai-Prescott Indian Water-Resources Settlement Act of 1994, continued growth and development will result in additional water-supply needs in the future.

**Objectives:** The study will (1) determine surface-water inflows and outflows along Granite Creek within the reservation boundary and the potential occurrence and concentration of suspected contaminants in water, sediments, and the alluvial aquifer of Granite Creek associated with past and current industrial activities within and near the reservation, (2) identify any contaminants and estimate the rate and direction of movement in the alluvial aquifer of Granite Creek, and (3) determine the potential for developing ground-water supplies on the reservation.

**Approach:** Streamflow and ground-water levels on the reservation will be measured and monitored; surface-water, ground-water, and sediment samples will be collected and analyzed for chemical constituents; historical ground-water data will be compiled and analyzed; the thickness and extent of alluvial material will be determined using surface- and borehole-geophysical techniques; and chemical and hydrogeologic data will be analyzed and correlated.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Water-chemistry data from surface-water and ground-water sources are being collected. Discharge data from two streamflow-gaging stations are being collected. Bimonthly water-level data are being collected from a network of 12 wells.

**Plans for Fiscal Year 1998:** Data-collection activities will be completed. A draft report on the evaluation of water resources on the Yavapai-Prescott Reservation will be prepared.

**Erosion and Sedimentation in the Navajo Partitioned Lands on Black Mesa, Northeastern Arizona**
***(AZ156)***


**Location:** Northeastern Arizona

**Project Chief:** John T.C. Parker

**Period of Project:** August 1994 to September 30, 1998

**Cooperating Agency:** Bureau of Indian Affairs

**Problem:** Extensive erosion in the drainage basins of Black Mesa on the lands of The Navajo Nation in northeastern Arizona has resulted in loss of productive grazing lands and infrastructure. Heavy sediment deposition has filled stock ponds and blocked culverts and stream channels. An understanding of mechanisms of erosion and deposition and rates of such processes is needed to assist in resources management and planning.

**Objectives:** Information from the investigation will be used to identify the mechanisms of erosion and deposition, estimate rates of erosion and deposition, and estimate sediment yields from drainage basins.

**Approach:** The study will include field observations to determine mechanisms of erosion and sedimentation; analysis of available streamflow, precipitation, and sediment data; delineation of areas of sediment production, erosion, and transport using aerial photographs, topographic maps and field observations; and dendrochronological analysis of growth rings on exposed tree roots for estimating hillslope-erosion rates and on sagebrush stems to determine ages of young surfaces and rates of aggradation in channels. Information will be used to classify the potential of a site for erosion, deposition, and transport on the basis of field characteristics.

**Progress and Significant Results, Fiscal Years 1996 and 1997**: Sediment transport is extremely discontinuous within the study area. Most common streamflows, on the basis of two seasons of observation, are small, less than 20 in. deep, and are heavily laden with sediment entrained from storage in upper tributaries. Preliminary efforts to use sagebrush to measure short-term rates of aggradation are promising. A classification system has been developed to aid in the prediction of future erosion or deposition.

**Plans for Fiscal Year 1998:** Additional sampling of sagebrush is planned to measure rates of aggradation throughout the study area. Drafts of reports will be completed.

Processes in incised channels of the Upper Dinnebito Wash drainage basin include the dissection of arroyo walls by the formation of vertical flutes caused by water that spills over the edge of the walls (above), and accumulation of sediment in channel bottoms from spalling, and disintegration of arroyo walls (right).

**Determination of Channel Adjustment Rates for Selected Stream Locations in Maricopa County, Arizona *(AZ157)***


**Location:** Maricopa County, Arizona

**Project Chief:** Joseph P. Capesius

**Period of Project:** October 1, 1996, to September 30, 1998

**Cooperating Agency:** Flood Control District of Maricopa County

**Problem:** Stream channels in arid regions, such as those in Maricopa County, have wide extremes in hydraulic, hydrologic, and sedimentologic conditions. The highly dynamic nature of these streams presents difficulties in the assumption of channel conditions during peak flood stage that are used as a basis for indirect measurements of discharge. The potential errors in discharge measurements and in analyses of channel characteristics limit the effectiveness of those involved with flood-safety issues, such as flood warning and flood-plain delineation.

**Objectives:** Rates of channel aggradation at stream locations in Maricopa County will be determined, applicability of the rating-curve method in assessing adjustment rates on the eight selected channels will be determined, and changes in cross-sectional area that may account for changes in channel capacity and consequent error in indirect estimates of flood peaks made after a flood will be documented.

**Approach:** The existing cross-section and rating data from current and discontinued USGS streamflow-gaging stations will be compiled to determine channel-adjustment rates. Cross-sectional data from indirect and direct discharge measurements will be examined. Channel changes from the 1993 flood (January through March) and through time at particular streamflow-gaging stations will be documented. The study will use four streamflow-gaging stations and four crest-stage gages.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Study sites have been identified and cross-section surveys have been completed at 10 sites. Graphs showing changes in cross section have been completed for five sites. Analyses of rating curves for five sites have been completed. A review of applicable literature is in progress.

**Plans for Fiscal Year 1998:** The present study will be expanded to include a systematic documentation of multiple cross sections at selected streamflow-gaging stations (both continuous and crest-stage gages) and photodocumentation of stream channel and overbank changes. A presentation of the study results will be made at a national scientific meeting. An interpretive report will be approved and published.

## Arizona Streamflow Statistics *(AZ158)*

**Location:** Statewide

**Project Chief:** Gregory L. Pope

**Period of Project:** October 1, 1996, to September 30, 1998

**Cooperating Agencies:** Arizona Department of Water Resources, Bureau of Reclamation, Flood Control District of Maricopa County, Pima County Department of Transportation and Flood Control District, and Salt River Project

**Problem:** Streamflow statistics and basin characteristics for Arizona have not been updated and published since 1989. This information is essential for development and management of surface-water resources and necessary to evaluate various land-use alternatives as well as hydrologic and hydraulic designs.

**Objectives:** Streamflow statistics will be generated and published for all streamflow-gaging stations on unregulated streams in Arizona that have at least 10 years of record. Basin and climatic characteristics will be computed for those stations for which characteristics have not been previously determined.

**Approach:** Objectives will be met by: (1) a compilation and review of all available streamflow data maintained in the USGS WATSTORE files; (2) the use of the computer program FLOWSTAT to generate and summarize daily and peak streamflow statistics on all unregulated streamflow-gaging stations within the study area; (3) a compilation and review of the most recent available climatic and basin data that have not been previously published; and (4) the publication of streamflow statistics, basin characteristics, and climatic characteristics for all unregulated streamflow-gaging stations.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Streamflow statistics have been generated for 141 continuous surface-water stations. Station manuscripts and annual peaks have been updated for 318 stations, flood-frequency statistics have been updated for 83 peak-flow partial-record stations. Text and tables for the final report have been completed for 129 stations. A draft text has been completed, and rating tables and files required to generate the various plots have been generated.

**Plans for Fiscal Year 1998:** Flood-frequency statistics will be completed. All graphic plots will be generated, and basin characteristics will be determined for the 129 stations mentioned above. The text will be finalized, and the report will be submitted for approval and publication.

**Determination of the Extent of the River Aquifer in the Lower Colorado River Valley near Yuma, Yuma County, Arizona, and Imperial County, California (*AZ159*)**


**Location:** Lower Colorado River valley below Laguna Dam in Arizona and California and southeastern Imperial Valley, California

**Project Chief:** Sandra J. Owen-Joyce

**Period of Project:** July 1997 through December 1999

**Cooperating Agency:** Bureau of Reclamation

**Problem:** The extent of the river aquifer must be determined as part of the method to identify wells downstream from Laguna Dam that yield water that will be replaced by water from the Colorado River. Particular areas of concern in delineating the boundary are in southeastern Imperial County, California, from the northerly international boundary with Mexico to the Chocolate Mountains, and in Yuma County, Arizona, between the Gila and Laguna Mountains.

**Objectives:** (1) The extent and thickness of the sediments and sedimentary rocks of the river aquifer between the northerly international boundary and the Chocolate Mountains and between the Gila and Laguna Mountains will be determined through the use of gravity studies.

(2) Maps and associated GIS coverages will be prepared that show the river-aquifer boundary, geology, and study-area boundary and will be used to match the maps created for the area upstream from Laguna Dam.

(3) A report will be prepared that documents the data collected, interpretation of those data, and the method proposed for the Yuma area. A USGS Fact Sheet on the Yuma method will be prepared.

**Approach:** (1) Gravity studies will be used to determine the extent of the river aquifer by estimating the lateral extent and thickness of low-density sediments and sedimentary rocks below river level that constitute the river aquifer and the subsurface position of bedrock. River-aquifer thickness can be approximated by using gravity methods because the river aquifer primarily includes permeable sediments that are much lower in density than the nearly impermeable bedrock. Gravity values will be collected at more than 300 stations and added to an existing data base for the area of the lower Colorado River.

(2) Wells outside the Colorado River flood plain will be visited in the field, water levels will be measured, and owners will be interviewed to collect current available data and drillers' logs as needed for processing gravity data and for input to delineate the river-aquifer boundary. This

well-inventory work will be done as part of the well-inventory project (*AZ148*) currently in progress in the Arizona District.

(3) Well data will be obtained from files of the USGS, Bureau of Reclamation, and State and county agencies; of particular interest are wells that penetrate bedrock, which will provide sites for ground-truth gravity data.

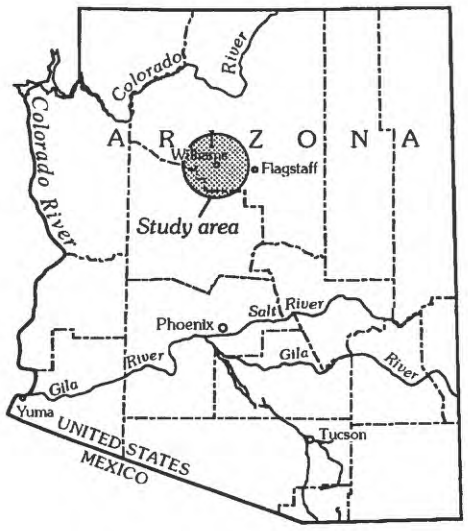
(4) The maps will be prepared by Richard Wilson, who prepared the maps for the area upstream from Laguna Dam, to maintain consistency in data interpretation and in application of the criteria used to delineate the river-aquifer boundary.

(5) A report and Fact Sheet will be compiled/prepared and will follow the format of the previous reports for the area upstream from Laguna Dam.

**Progress and Significant Results, Fiscal Year 1997:** A reconnaissance trip was made of the two areas to determine vehicle access and plan gravity-data collection. A digital copy of the Arizona gravity data base was obtained and the stations were plotted using GIS and combined with well-location plots. Work began on cleaning the gravity data base. Calibration of the gravity meters was delayed because one of the older meters was being repaired. Three Trimble 4000 surveying GPS units were borrowed from the BOR and upgraded GPS data-processing software was ordered from Trimble. Data-collection/well-inventory work in the Dome area and the area north and northwest of Pilot Knob in southeastern Imperial Valley began in September. Letters were sent requesting access to private property and to an Indian reservation to inventory wells and make gravity measurements. Mylar base-map materials were ordered.

**Plans for Fiscal Year 1998:** The gravity meter(s) will be calibrated at a known gravity-calibration line, a GPS/gravity field-assembly unit will be constructed to speed setup at stations, and field measurements will be completed. Gravity data will be modeled and interpreted. Illustrations showing the results of the modeling will be prepared. Complete Bouguer gravity-anomaly values will be added to the existing USGS data base. Data-collection/well-inventory work in the Dome area and the area north and northwest of Pilot Knob in southeastern Imperial Valley will be completed. Well data from files of the USGS, BOR, and State and county agencies will be compiled. Geology data needed to delineate the bedrock map layer will be compiled; field reconnaissance will be used to clarify geologic interpretation; and the boundary map layer for the study area, the bedrock map layer, and the river-aquifer boundary map layer will be prepared for the Yuma and Tinajas Altas Mountains 1:100,000-scale maps. The maps will be digitized to produce GIS coverages of the layers. Layers will be combined to produce the final plates, and reports will be completed.

**Ground-Water Flow System of the Colorado Plateau near Williams, Arizona *(AZ160)***




**Location:** Northern Arizona

**Project Chief:** Herbert A. Pierce

**Period of Project:** October 1, 1995, to September 30, 1999

**Cooperating Agency:** City of Williams

**Problem:** A better understanding of the regional ground-water flow system in and near the city of Williams, Arizona, is needed for an improved understanding and management of ground-water resources. Near-capacity use of surface water, population growth, and the drought of 1996 have motivated the city to look for additional water resources.

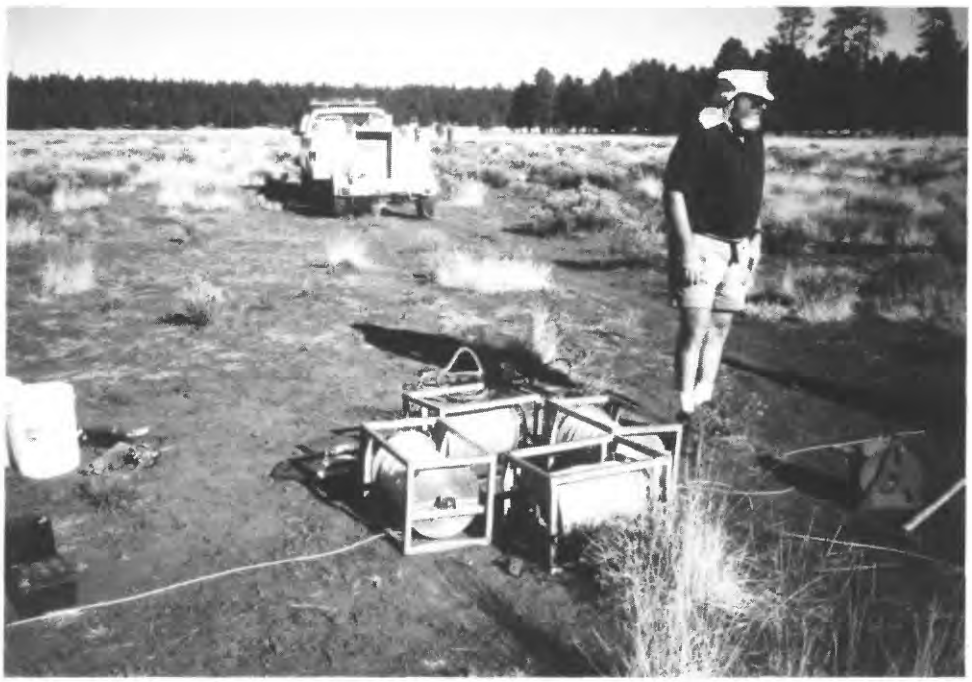
**Objective:** Develop an improved understanding of the regional ground-water system and determine its feasibility as a water supply for the future. In addition, a conceptual model of the Colorado Plateau geohydrologic system in the Williams area will be developed using new and existing information.

**Approach:** The objective will be accomplished by: (1) determining depths to the ground water in the regional aquifer and construction of a preliminary potentiometric map, (2) identifying fault and fracture zones and describing their subsurface orientations, and (3) examining spatial variations in ground-water chemistry data.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Thirty gravity soundings were collected and integrated into the National Geophysical Data Centers' existing data set to produce a high-resolution gravity map. This map was used to guide further investigations along known fractures near Williams. One square-array sounding was collected near Dogtown Reservoir to provide insight into the depth to ground water and changes in the image-fracture direction with depth. Five remotely sensed images of the Williams area were produced, and structure interpretation of the images has begun. This data will guide further exploration and geophysical work in the area.

**Plans for Fiscal Year 1998:** Development and calibration of the HEC-1 model for the Williams area will continue. Two streamflow-gaging stations equipped with DCP's and three crest-stage gages will be installed. The seven reservoirs will be surveyed, GIS coverages will be developed,

and interpretation of the remotely sensed images will continue. Geologic mapping will begin with emphasis on the structures that may affect the regional aquifer.



Square-array resistivity sounding data being collected near Poquette Homestead, Williams, Arizona.

**Hydrologic Investigation of Grande Wash, Fort McDowell Mohave-Apache Indian Community near Fountain Hills, Arizona *(AZ161)***


**Location:** South-Central Arizona

**Project Chief:** John P. Hoffmann

**Period of Project:** October 1, 1996, to September 30, 1998

**Cooperating Agency:** Fort McDowell Indian Community

**Problem:** The potential for ground-water contamination from discharge from a wastewater-treatment plant just west of the reservation; an abandoned landfill, which is within Grande Wash near the west edge of the reservation; and an active sanitary landfill, which is downstream from the abandoned landfill, is of greatest concern. The community also is concerned that the volume of streamflow will increase in the future, owing to the construction of impervious surfaces, such as paved streets, parking areas, and roofs within an adjacent development. The chemical character of the water flowing onto the lands of the reservation is of immediate concern. Increased runoff in Grande Wash will affect existing and planned land uses along the wash within the reservation. In addition, a small, nearly perennial surface flow has been observed at the west end of the wash during dry periods. While the origin of the water is unknown at this time, the source of the flow probably is not natural because adjacent washes are normally dry and contain runoff only after substantial amounts of rainfall.

**Objectives:** The objectives of this investigation are to furnish hydrologic data that contribute to the protection of life and property. Specifically, the investigation will: (1) determine if ground water near the landfills is contaminated and if the landfills are sources of that contamination; (2) determine the source, quantity, and quality of streamflow in Grande Wash at the west boundary of the Fort McDowell Reservation; (3) delineate a 100-year flood-plain elevation within Grande Wash; and (4) evaluate the effects of existing and planned land use upstream from the reservation on peak surface-water flows within the Grande Wash drainage.

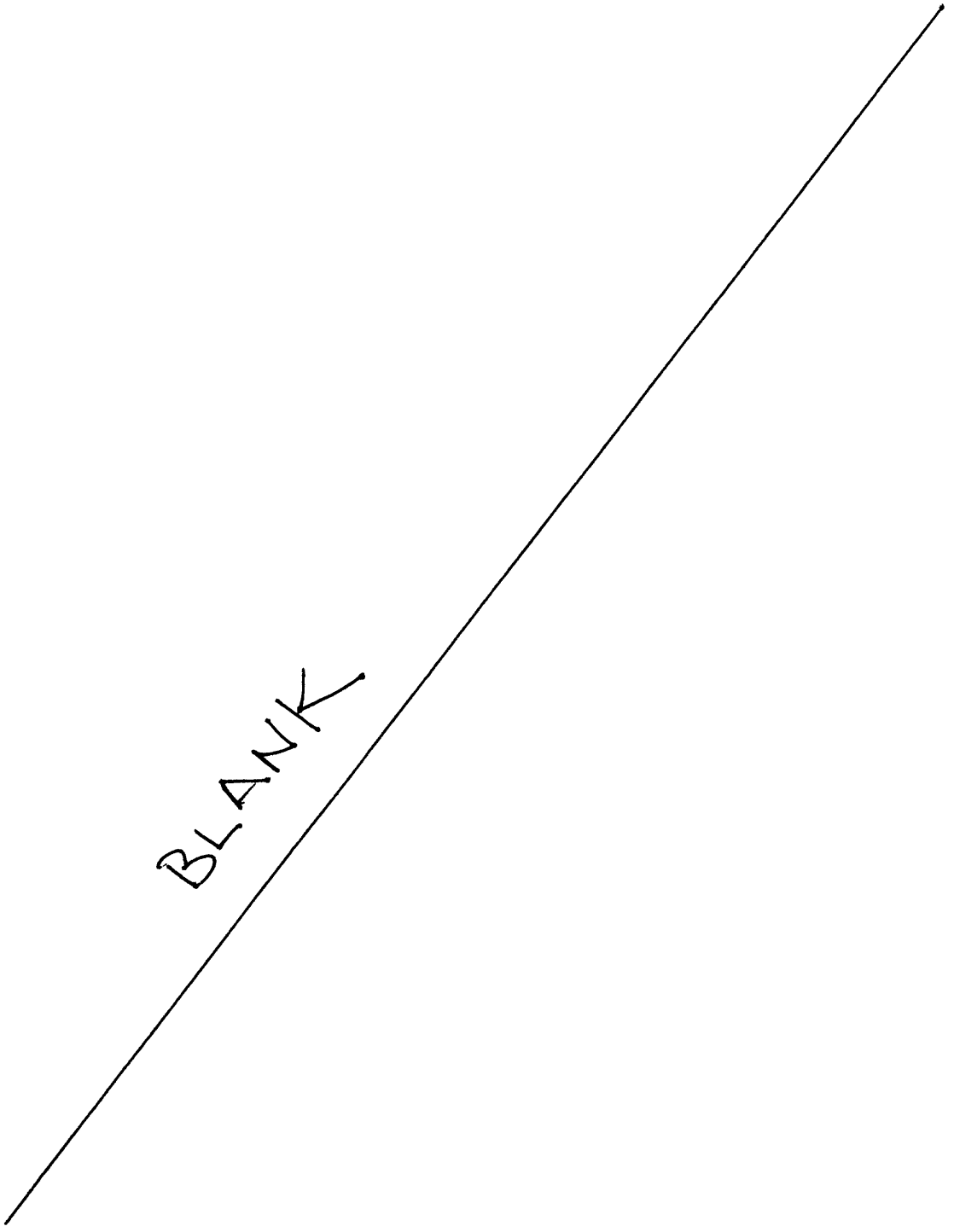
**Approach:** The approach will include the development of a step-backwater model of the Grande Wash drainage basin to determine the flood-plain elevation of the 100-year flood. Drilling, logging, instrumentation, and monitoring of several wells will be used to describe local geohydrologic conditions. Seismic-refraction and electromagnetic techniques will be used to determine the cross-sectional area of the stream-channel alluvium and will be correlated and verified with data from existing and new monitor wells. Water samples from the wash and from monitor wells will be analyzed to determine the presence or absence of contaminants. A conceptual model of the flow system will be developed.

**Progress and Significant Results, Fiscal Years 1996 and 1997:** Data needed for input to the step-backwater flood-plain model were collected, which included the construction of a hydrograph for the 100-year flood using HEC-1 and topographic cross sections at several locations along the wash. Seismic-refraction surveys were done along six lines normal to and crossing the wash. Depths of investigation for these surveys were a few hundred feet. Several shorter, more detailed refraction surveys were done for examination of shallow sediments and depth to the water table. Electromagnetic soundings and profiles were made throughout the wash. Locations for new monitor wells were selected using the seismic and electromagnetic results and the known locations of landfills. Fourteen monitor wells were drilled and completed to depths ranging from about 20 to 300 ft throughout Grande Wash to determine horizontal and vertical gradients of the ground water and to describe geologic conditions. The three deepest wells (greater than 300 ft) were logged with geophysical instruments. Water samples from three wells were collected and analyzed to determine the presence or absence of contaminants. The same wells were instrumented with continuous recorders to measure water-level fluctuations. Water levels at the 14 wells are monitored periodically to determine hydraulic gradients. Surface-water samples were collected twice immediately west of the reservation boundary. Both samples were collected shortly after storms and were analyzed to determine the presence or absence of contaminants.

**Plans for Fiscal Year 1998:** Water-level measurements will be made periodically at each of the 14 monitor wells. Water levels will be recorded at three wells using continuous recorders. Ground-water samples will be collected from three wells and analyzed for the same constituents as the first round of sampling. A surface-water sample will be collected if conditions permit, and a sediment sample will be collected from a sediment- and stormwater-retention basin in the lower part of Grande Wash and analyzed for potential contaminants.

Explosive charge being lowered into a borehole. Explosive charges were used as shotpoint energy on seismic lines across Grande Wash.

Using the electromagnetic induction tool, EM-34, in the main channel of Grande Wash to measure the electrical properties of subsurface materials.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