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Prepared in cooperation with the
BUREAU OF LAND MANAGEMENT

Hydrologic Characteristics of the Agua Fria National Monument, Central Arizona, Determined from the Reconnaissance Study

Scientific Investigations Report 2004—5163

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By John B. Fleming

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U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
acre	0.004047	square kilometer
square foot (ft^2)	929.0	square centimeter
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$F=(1.8°C)+32$$

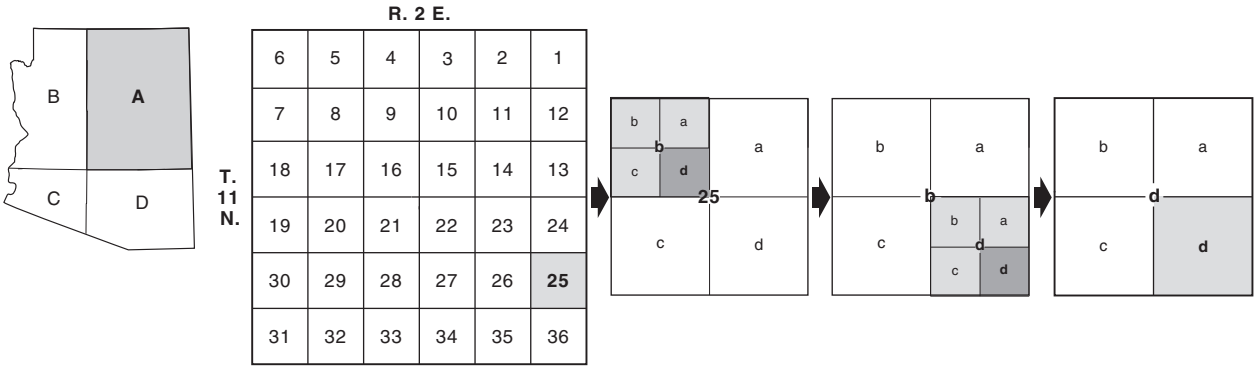
Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929; horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27). Altitude, as used in this report, refers to distance above or below NGVD 29.

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the solute mass (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

WELL-NUMBERING AND NAMING SYSTEM

WELL (A-11-02)25bdd



Quadrant A, Township 11 North, Range 2 East, section 25, 160-acre tract b, 40-acre tract d, 10-acre tract d

The well numbers used by the U.S. Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River Meridian and Base Line, which divide the State into four quadrants that are designated by capital letters A, B, C, and D in a counterclockwise direction, beginning in the northeast quarter. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes. In the example shown, well number (A-11-02)25bdd designates the well as being in the SE1/4, SE1/4, NW1/4, section 25, Township 11 North, and Range 2 East.

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Hydrologic Characteristics of the Agua Fria National Monument, Central Arizona, Determined from the Reconnaissance Study

By John B. Fleming

Abstract

Hydrologic conditions in the newly created Agua Fria National Monument were characterized on the basis of existing hydrologic and geologic information, and streamflow data collected in May 2002. The study results are intended to support the Bureau of Land Management's future water-resource management responsibilities, including quantification of a Federal reserved water right within the monument. This report presents the study results, identifies data deficiencies, and describes specific approaches for consideration in future studies.

Within the Agua Fria National Monument, the Agua Fria River flows generally from north to south, traversing almost the entire 23-mile length of the monument. Streamflow has been measured continuously at a site near the northern boundary of the monument since 1940. Streamflow statistics for this site, and streamflow measurements from other sites along the Agua Fria River, indicate that the river is perennial in the northern part of the monument but generally is intermittent in downstream reaches. The principal controls on streamflow along the river within the monument appear to be geology, the occurrence and distribution of alluvium, inflow at the northern boundary and from tributary canyons, precipitation, and evapotranspiration. At present, (2004) there is no consistent surface-water quality monitoring program being implemented for the monument.

Ground-water recharge within the monument likely results from surface-water losses and direct infiltration of precipitation. Wells are most numerous in the Cordes Junction and Black Canyon City areas. Only eight wells are within the monument. Ground-water quality data for wells in the monument area consist of specific-conductance values and fluoride concentrations. During the study, ground-water quality data were available for only one well within the monument. No ground-water monitoring program is currently in place for the monument or surrounding areas.

Introduction

The Agua Fria National Monument is a recently (2000) designated preserve in central Arizona (**fig. 1**) that is managed by the Bureau of Land Management (BLM). Information was needed to provide a basis for development of resource-management strategies. In 2002 the U.S. Geological Survey (USGS), in cooperation with the BLM, began a hydrologic characterization of the monument. This reconnaissance study compiled information that can be used by the BLM to support future water-resource management responsibilities within the monument, including quantification of a Federal Reserve water right.

Purpose and Scope

The purpose of this report is to present existing hydrologic and geologic information, supplemented with new streamflow data, and describe the surface-water and ground-water conditions in the monument on the basis of this information. The report describes the ground-water flow system and its interaction with streams within the monument and in adjacent areas, and in general terms, the surface-water flow regime. The study results will enable the BLM to design and implement detailed hydrologic and hydrogeologic data-collection programs.

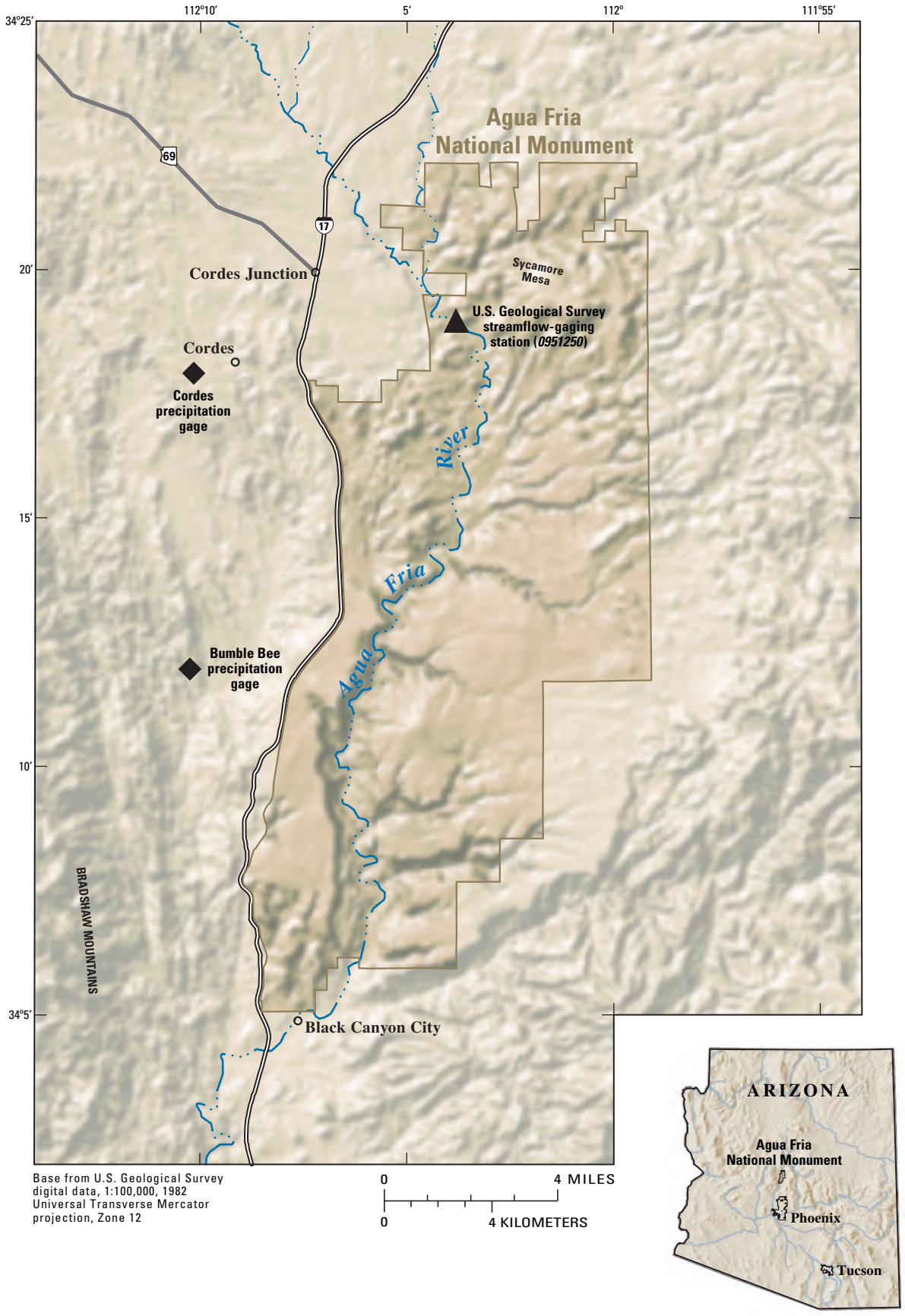

Figure 1. Locations of the study area, Agua Fria National Monument, the U.S. Geological Survey streamflow-gaging station, and precipitation gages, central Arizona.

Description of the Study Area

The Agua Fria National Monument lies within the Transition Zone between the Basin and Range and Colorado Plateau Physiographic Provinces (Fenneman, 1931) about 40 mi north of Phoenix, Arizona (**fig. 1**). It encompasses about 71,000 acres within the Agua Fria watershed and includes 23 mi of perennial and intermittent reaches of the Agua Fria River that support highly valued riparian areas. The study area was extended beyond the monument boundaries to include information on hydrologic and geologic factors in areas adjacent to the monument that, in part, control hydrologic conditions within the monument.

Within the monument, the Agua Fria River generally flows from north to south, traversing almost the entire length of the monument (fig. 1). The geology within the monument is closely reflected in the terrain. Precambrian granitic rocks and schist in the Bradshaw Mountains bordering the western margin of the monument are exposed as rugged, deep canyons with steep slopes. To the east, surficial units are mostly Tertiary and Quaternary basaltic rocks underlain by Precambrian granitic rocks and schist (Wilson, 1988). These areas are typified by broad, gently sloping mesas separated by deeply incised, steep side canyons. In the southern half of the monument, the river has carved a deep canyon through the basaltic rocks and into the Precambrian granitic rocks and schist that, in some places, exceeds 1,000 ft. Land-surface altitude within the monument ranges from about 2,050 ft along the Agua Fria River near Black Canyon City to about 4,600 ft in the northern hills near Sycamore Mesa.

The semiarid climate in the monument is characterized by hot and relatively dry summers and mild winters. Average seasonal high temperatures measured in Cordes, Arizona, northwest of the monument, range from 35°C in the summer to 13.9°C in the winter (Western Regional Climate Center, Desert Research Institute, 2004). Precipitation predominantly occurs during two periods. Summer monsoonal rains, which generally occur from July through September, are characterized by often intense, isolated thunderstorms. Winter precipitation from December through March is predominantly rain, but includes snow. Average annual precipitation within the monument probably is less than 20 inches. Precipitation amounts vary greatly with altitude; higher altitudes generally receive greater amounts (Sellers and Hill, 1974).

The varied geology and climate within the monument provide favorable habitat for a wide variety of desert plants including several species of grasses, mesquite, palo verde, yucca, and cacti, such as prickly pear and saguaro (**fig. 2**). Vegetated areas along the Agua Fria River contain mixed grasses, shrubs, and trees.

Previous Investigations

Although no detailed geologic mapping specific to the monument has been conducted, Anderson and Blacet (1972) provide detailed geology for most of the northern half of the monument. A less detailed map of Yavapai County was published by the Arizona Bureau of Mines (1958). Additional geologic data (Richard and others, 2000) are also available. Littin (1981) provided the first generalized description of the hydrogeologic conditions in the Agua Fria watershed. He described the major hydrogeologic units; produced maps showing locations of wells and springs, water-level conditions, and generalized direction of ground-water flow; and presented water-quality data. Wilson (1988) reported on the water resources in the northern part of the Agua Fria watershed and provided an updated description of the hydrogeologic conditions in the area that would eventually become the northern half of the monument. Partly in response to public concern over increased development in the watershed, Barnett and others (2003) provided a reassessment of the hydrogeologic conditions in the upper Agua Fria watershed with an emphasis on planning for sustainability of water resources.

Acknowledgments

Paul Summers and Jim Fogg (BLM, Denver, Colorado), and Lin Fehlman and Chris Horyza (BLM, Phoenix Field Office, Arizona) provided geographic information system (GIS) covers, maps, and water-quality and streamflow data, as well as thoughtful and valuable editorial comments on drafts of the manuscript. Kelly Ashton, Robert Fritzinger, and Fletcher Brinkerhoff, USGS, Tucson, Arizona, assisted with data collection.

Approach

Information was compiled from the Arizona Geological Survey, the USGS National Water Information System (NWIS), the BLM Phoenix Field Office archives, and databases maintained by the Arizona Departments of Environmental Quality and Water Resources, the Western Regional Climate Center in Reno, Nevada, and the Arizona Game and Fish Department. Information included bibliographic data, hydrologic data, spatial data sets, paper maps, published reports, and other relevant documents.

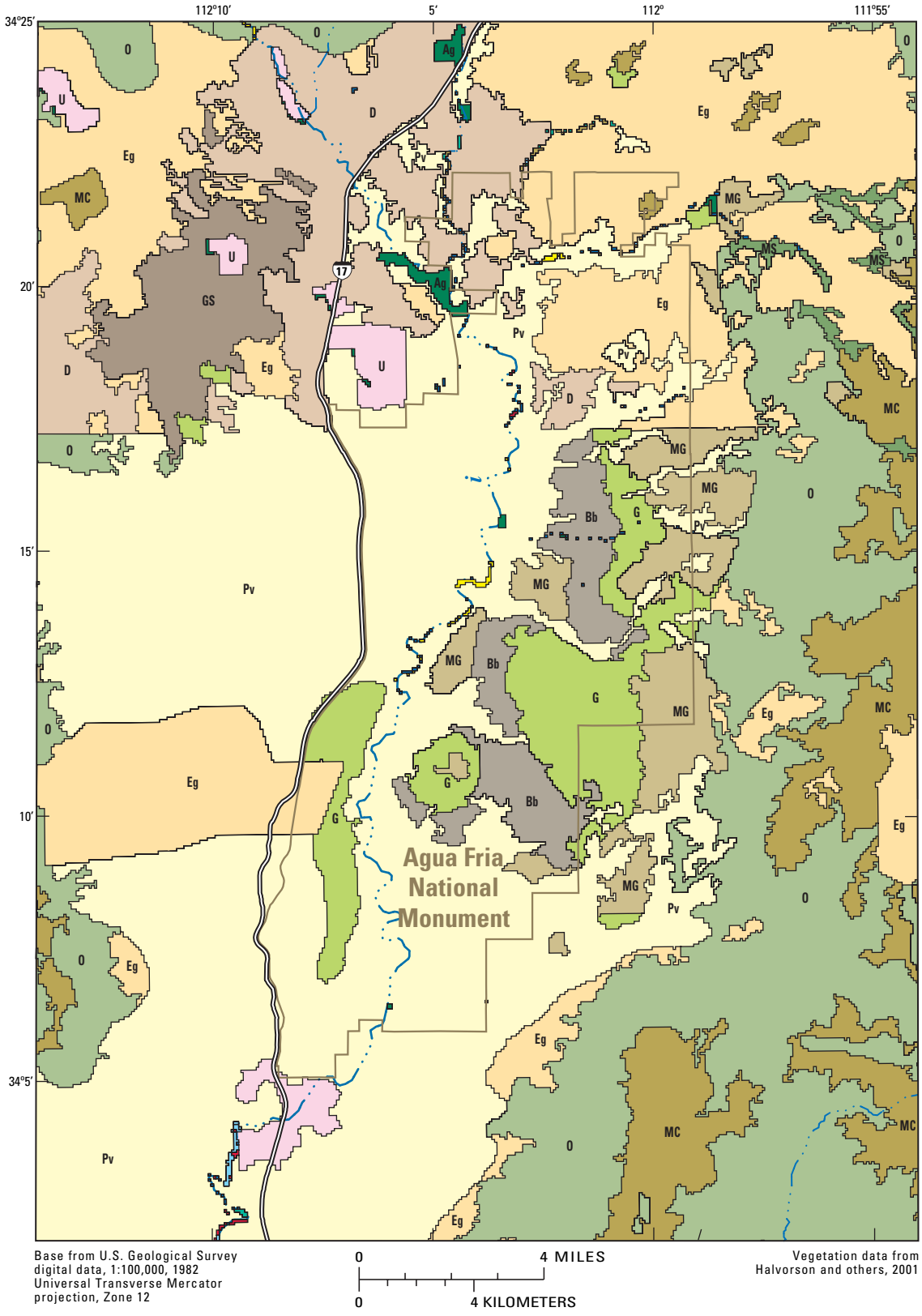

Figure 2. Vegetation types in the Agua Fria National Monument study area, central Arizona.

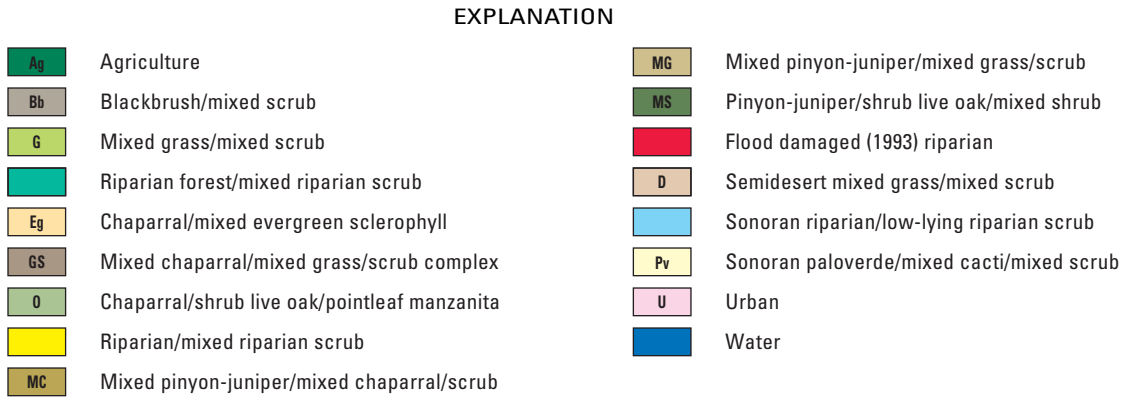

Figure 2. Continued.

A reconnaissance field trip was conducted in March 2002 to develop a preliminary understanding of the physical setting. In May 2002, a seepage study was conducted during which streamflow, specific conductance, and temperature were measured at 14 sites along the Agua Fria River within the monument. Existing data were combined with these newly collected data to aid in the preliminary characterization of the surface-water and ground-water hydrology of the study area.

Ground Water

The main water-bearing unit within the monument is the stream-channel alluvium, which is bounded by outcrops of igneous and metamorphic rocks. Although no thickness data exist for the alluvial aquifer along the river channel within the monument, the distance between bedrock outcrops bisected by the channel and evidence of high-volume scouring flows indicate that, in some areas, the cross-sectional area of the alluvium is probably less than a few hundred square feet. This is especially true where the river has incised the bedrock to form a deep canyon. Recharge to the alluvial aquifer probably is from infiltration of surface water and precipitation. Decreases in streamflow along the river in the monument indicate that surface water is being lost to the alluvial aquifer.

A secondary aquifer could comprise the igneous and metamorphic rock units that transmit water as a result of secondary porosity related to fracturing. The main source of recharge for these units likely is local precipitation that infiltrates directly into permeable zones associated with fracturing and indirectly though overlying alluvium. Ground water within these zones likely discharges at several springs in and near the monument.

Hydrogeologic Units

According to Richard and others (2000), geologic units in the study area vary in age from about 1.8 billion years for Proterozoic metamorphic rocks to modern for alluvial and eolian deposits (**fig. 3**). Along much of its length within the monument, the Agua Fria River has incised the Tertiary basaltic rocks, Tertiary sedimentary units, and Proterozoic granitic rocks that make up the river canyon. These rocks likely are the principal sources of alluvium within the canyon. On the basis of a review of drillers' logs, the alluvium ranges in size from silt to boulder, and in some areas, the alluvial thickness exceeds 150 ft. The areal extent and thickness of alluvium likely are the principal controls on the availability of usable ground water. The reported depths to water from the same drillers' logs range from an unknown height above land surface to 328 ft below land surface.

Available geologic maps show no faults or other major structural features within the monument. Richard and others (2000) reported largely northwest-trending faults east and west of the monument, and northeast-trending faults northwest and southeast of the monument. The nearest of these faults, which offset only the Proterozoic rocks, are about 3 mi east of the eastern monument boundary (fig. 3).

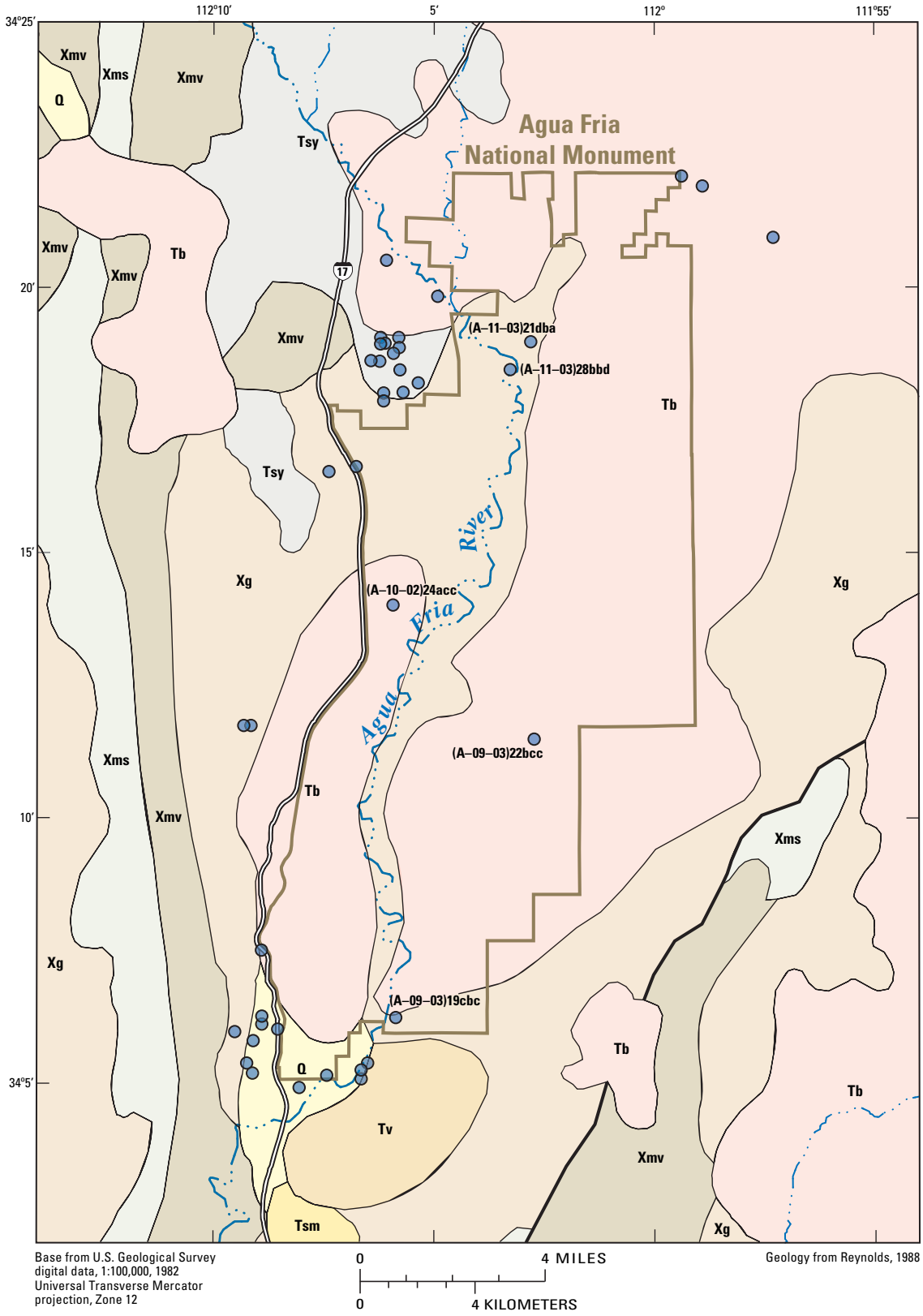

Figure 3. Geology and locations of wells for which a driller's log is available, Agua Fria National Monument study area, central Arizona.

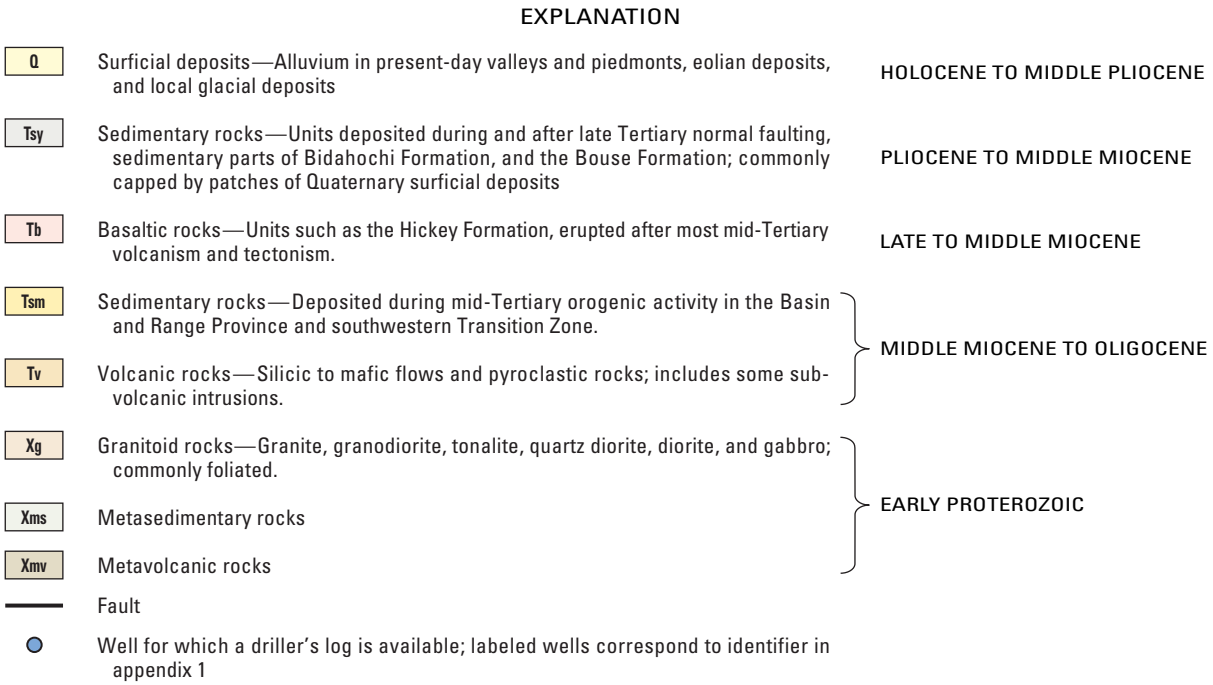

Figure 3. Continued.

On the basis of the distribution of low-permeability crystalline igneous and metamorphic basement rocks that separate ground-water flow systems, Wilson (1988) divided much of the Agua Fria watershed into three ground-water subareas: Lonesome Valley, Mayer, and Black Hills. Wilson (1988) provides generalized descriptions for the hydrogeologic rock units that make up the major aquifer in each of these subareas. The Black Hills subarea, which occupies most of the southeastern half of the watershed, includes the monument and adjacent areas. Within the monument, the hydrogeologic units are the Quaternary alluvium, Tertiary basaltic rocks, and the early Proterozoic granitic rocks.

The basaltic rocks into which tributary drainages are incised are higher in altitude than the alluvium, overlie granitic rocks, and crop out in the eastern half of the monument. Because the thickness of the basaltic rocks is unknown, the amount of water that could be moving through these rocks cannot easily be estimated. Basaltic rocks west of the river that underlie the southern half of the monument's western boundary have a limited extent due to erosional isolation and likely contribute little water to the alluvium.

Wells

Data obtained from the Arizona Department of Water Resources (ADWR) and USGS databases for wells in the study area include drillers' logs and information about well use, well location, water levels, and water quality. Of the 88 wells for which data were obtained, only 8 are within the monument. Many of the 88 wells are in the Cordes Junction and Black Canyon City areas and are private, domestic, or agricultural wells that are not routinely monitored for water levels or water quality.

Drillers' logs were obtained from the ADWR database for 39 wells in or near the monument (**fig. 3**). Of these 39 wells, 5 are within the monument. Most of the 39 wells are in the towns of Cordes and Black Canyon City as there is little ground-water development in rural areas. Drillers' logs generally are consistent with the mapped geology. In areas mapped as Quaternary surficial deposits, which include alluvium, drillers' logs showed that these deposits vary in thickness from 0 ft to as much as 150 ft and are typically underlain by metamorphic rocks including granite and schist (fig. 3). In areas mapped as Tertiary basaltic rocks, drillers' logs showed thicknesses in excess of 500 ft in some areas. A summary of the five drillers' logs for wells within the monument is given in appendix 1 of this report.

Springs

Data obtained from the USGS Ground-Water Site Inventory (GWSI) database indicated four springs in the study area. Of these, only one (Badger Spring) is reported as being within the monument (**fig. 4** and **table 1**). Data obtained from the BLM database indicated 24 springs in the study area (fig. 4 and table 1). There is disagreement, however, between the two databases with respect to the location of Badger Spring.

There are more springs in the northern part of the monument than in the southern part. In relation to the scale of the mapped geology in the area, many of the springs appear to issue from dissected areas within the Tertiary basaltic rocks and the early Proterozoic granitic rocks and metasedimentary units. Littin (1981) reported that most springs issuing from basaltic rocks are seasonal, whereas most springs issuing from granitic rocks and metasedimentary units are perennial; however, the means by which this conclusion was drawn are not clear.

Water Levels

Littin (1981) constructed a map of ground-water altitude and generalized direction of ground-water flow in the Agua Fria area. That work, however, had little or no detailed information for the area that is now the monument. As a follow-up to the work of Littin (1981), León and Ferré (2003) constructed a ground-water altitude map for the upper Agua Fria watershed using water levels measured between January 1962 and April 2002 at 363 wells (**fig. 5**). Although data are sparse for areas within the monument and east of the monument, the map shows that ground-water flow is generally from north to south and follows the longitudinal axis of the river channel. Water-level altitudes range from about 3,900 ft near the northern boundary of the monument to about 2,000 ft near the southern boundary.

Ground-Water Quality

Water-quality data supplied by the BLM included measured discharge and field-measured water properties—specific conductance, dissolved solids, pH, dissolved oxygen, turbidity, and temperature—for 19 springs (**table 2**). No clear correlation was evident between measured values and spring location. No water-quality data were available for springs inventoried in the USGS GWSI database.

Water-quality data were available for 22 of the 88 wells identified in the Agua Fria National Monument study area. These data consisted of specific-conductance values and fluoride concentrations. For these 22 wells, specific-conductance values ranged from 490 to 3,380 µS/cm, and fluoride concentrations ranged from 0.3 to 14.0 mg/L.

Water-quality data were available for one well within the monument. A list of these data is provided in **appendix 2** of this report.

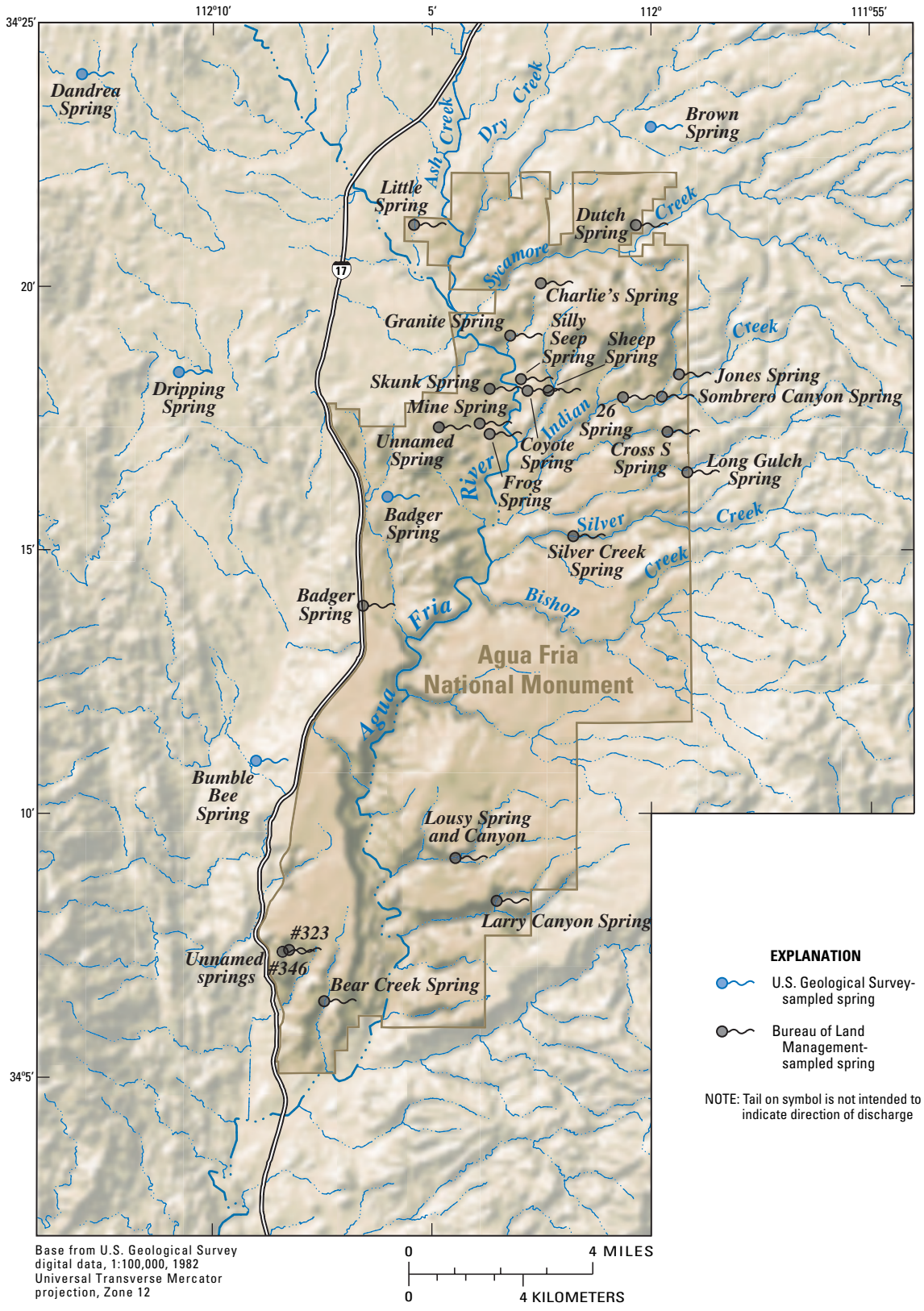

Figure 4. Locations of springs in the Agua Fria National Monument area, central Arizona.

Table 1. Springs in the Agua Fria National Monument study area, central Arizona

[Data from Bureau of Land Management and U.S. Geological Survey databases]

Name	Latitude/longitude	Name	Latitude/longitude
From Bureau of Land Management database			
Little Spring	34°21'08.3"/112°05'24.2"	Silver Creek Spring	34°15'15.1"/112°01'46.2"
Dutch Spring	34°21'08.4"/112°00'19.9"	Jones Spring	34°18'19.2"/111°59'21.5"
Charlie's Spring	34°20'02.3"/112°02'30.0"	Sombrero Canyon Spring	34°17'53.6"/111°59'45.3"
Granite Spring	34°19'03.2"/112°03'12.6"	Cross S Spring	34°17'13.9"/111°59'37.2"
26 Spring	34°17'53.3"/112°00'38.9"	Long Gulch Spring	34°16'27.7"/111°59'09.8"
Sheep Spring	34°18'00.7"/112°02'20.0"	Badger Spring	34°13'56.3"/112°06'33.7"
Coyote Spring	34°18'00.3"/112°02'48.3"	Lousy Spring and Canyon	34°09'09.8"/112°04'27.2"
Silly Seep	34°18'13.5"/112°02'57.8"	Larry Canyon Spring	34°08'21.1"/112°03'31.2"
Skunk Spring	34°18'02.7"/112°03'40.8"	Dripping Spring	34°18'37.0"/112°11'19.0"
Unnamed Spring	34°17'18.8"/112°04'50.9"	Unnamed Spring #323	34°07'25.4"/112°08'14.3"
Mine Spring	34°17'23.4"/112°03'54.3"	Unnamed Spring #346	34°07'23.2"/112°08'23.2"
Frog Spring	34°17'11.5"/112°03'40.9"	Bear Creek Spring	34°06'27.3"/112°07'26.9"
From U.S. Geological Survey database			
Brown Spring	34°23'00"/112°00'50"	Unnamed Spring	34°23'25"/112°13'45"
Bumble Bee Spring	34°11'35"/112°09'25"	Badger Spring	34°16'05"/112°06'40"

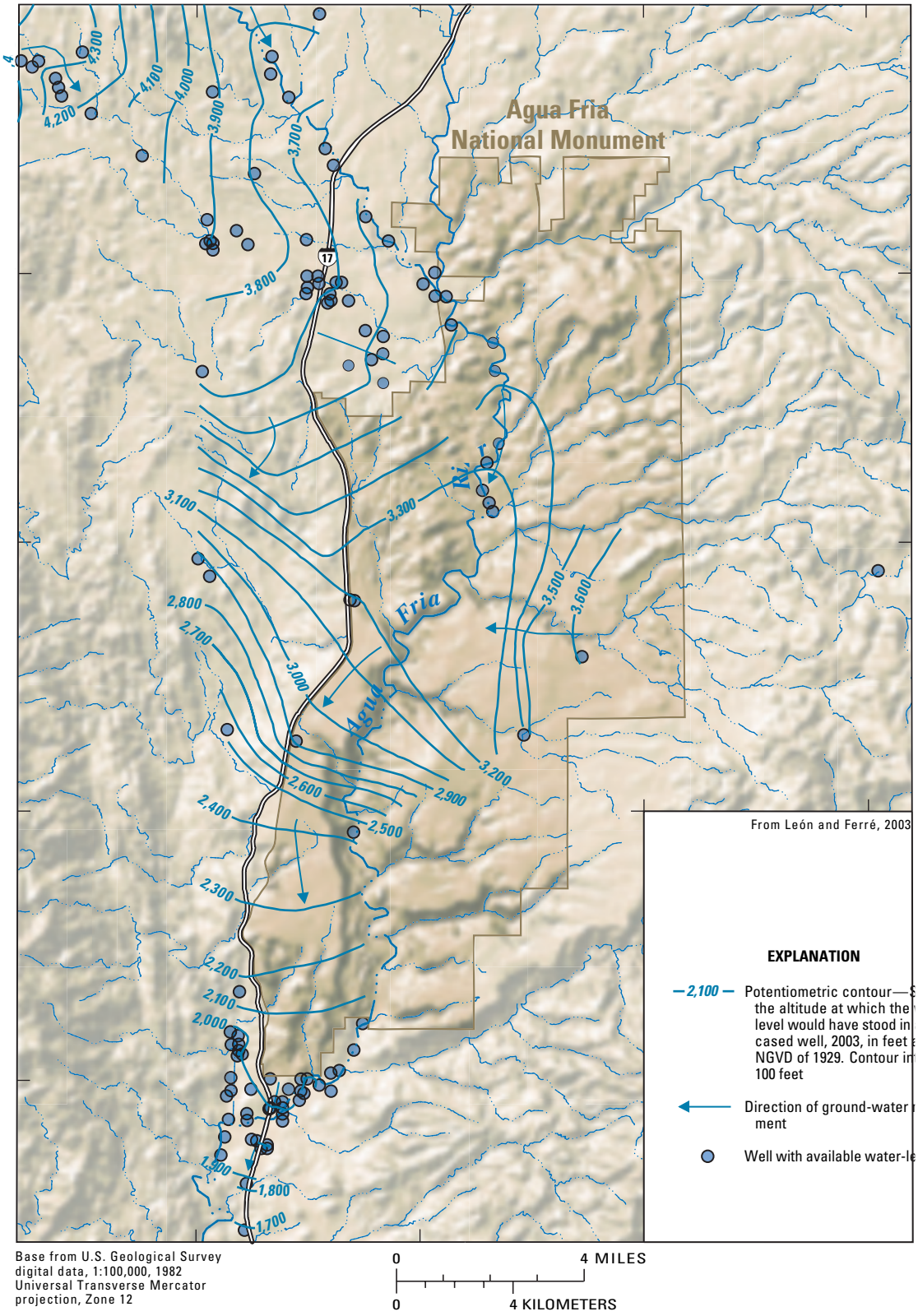

Figure 5. Potentiometric surface, 2003, Agua Fria National Monument area, central Arizona.

Table 2. Field-measured water properties and discharge data from the Bureau of Land Management for springs in the Agua Fria National Monument study area, central Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; GPM, gallons per minute; ---, not reported]

Name	Sampling date(s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (GPM)
Little Spring	09/---/1985	---	---	---	---	---	---	---	1
Charlie's Spring	09/28/1993	470	7.5	19	---	---	---	---	3
Granite Spring	09/29/1993	920	7.5	18	---	---	---	---	.375
26 Spring	09/13/1993	540	7.9	27	---	---	---	---	.375
Sheep Spring	09/---/1993	---	---	---	---	---	---	---	3.1
Coyote Spring	09/16/1993	740	7.7	19	---	---	---	---	6
Silly Seep	09/16/1993	470	7.8	18	---	---	---	---	Seep
Skunk Spring	09/16/1993	710	7.7	25	---	---	---	---	.375
Unnamed Spring	---	---	---	---	---	---	---	---	Seep
Mine Spring	09/02/1993	1,000	7.4	20	---	---	---	---	.13
Frog Spring	09/02/1993	1,280	7.3	28	---	---	---	---	.4
Silver Creek Spring	08/---/1993	540	7.6	23	---	---	---	---	1.8
Jones Spring	09/13/1993	170	8.7	29	---	---	---	---	Pool
Sombrero Canyon Spring	09/09/1993	550	7.2	21	---	---	---	---	4.5
Badger Spring	04/09/1998	1,270	7.8	15	---	---	---		1.8
Lousy Spring	09/24/1992–10/24/1995	[1]557	[1]8.0	22	[1]0.88	[1]7.1	[1]89.9	[1]368	[1].24
Larry Canyon Spring	---	---	---	---	---	---	---	---	5.87
Dripping Spring	09/3/1992–05/21/1998	[1]452	[1]7.8	19	[1]1.3	[1]5.8	[1]70.7	[1]301	[1].01
Bear Creek Spring	---	---	---	---	---	---	---	---	1

[1]Denotes average of measured values.

Surface Water

Stream Descriptions and Monitoring

Brown and others (1981) classified as perennial several reaches of the Agua Fria River and identified perennial reaches in tributaries of the Agua Fria River within and near the monument boundaries (Ash Creek, Little Ash Creek, Big Bug Creek, Little Sycamore Creek, Sycamore Creek, Indian Creek, and Silver Creek; **fig. 6** and **table 3**). It is not known how the perennial reaches were delineated. More recent data by the Arizona Game and Fish Department (Valencia and others, 1993; Wahl and others, 1997) provided reclassification of several reaches of the Agua Fria River and its tributaries. GIS covers for these reclassified areas were not available during this study.

Within the monument, the Agua Fria River flows generally north to south, traversing almost the entire 23-mile length of the monument. The river is perennial in the northern part of the monument. Further downstream, however, streamflow is intermittent. Several tributary streams join the river within the monument; most of these drain the eastern part of the monument (fig. 6).

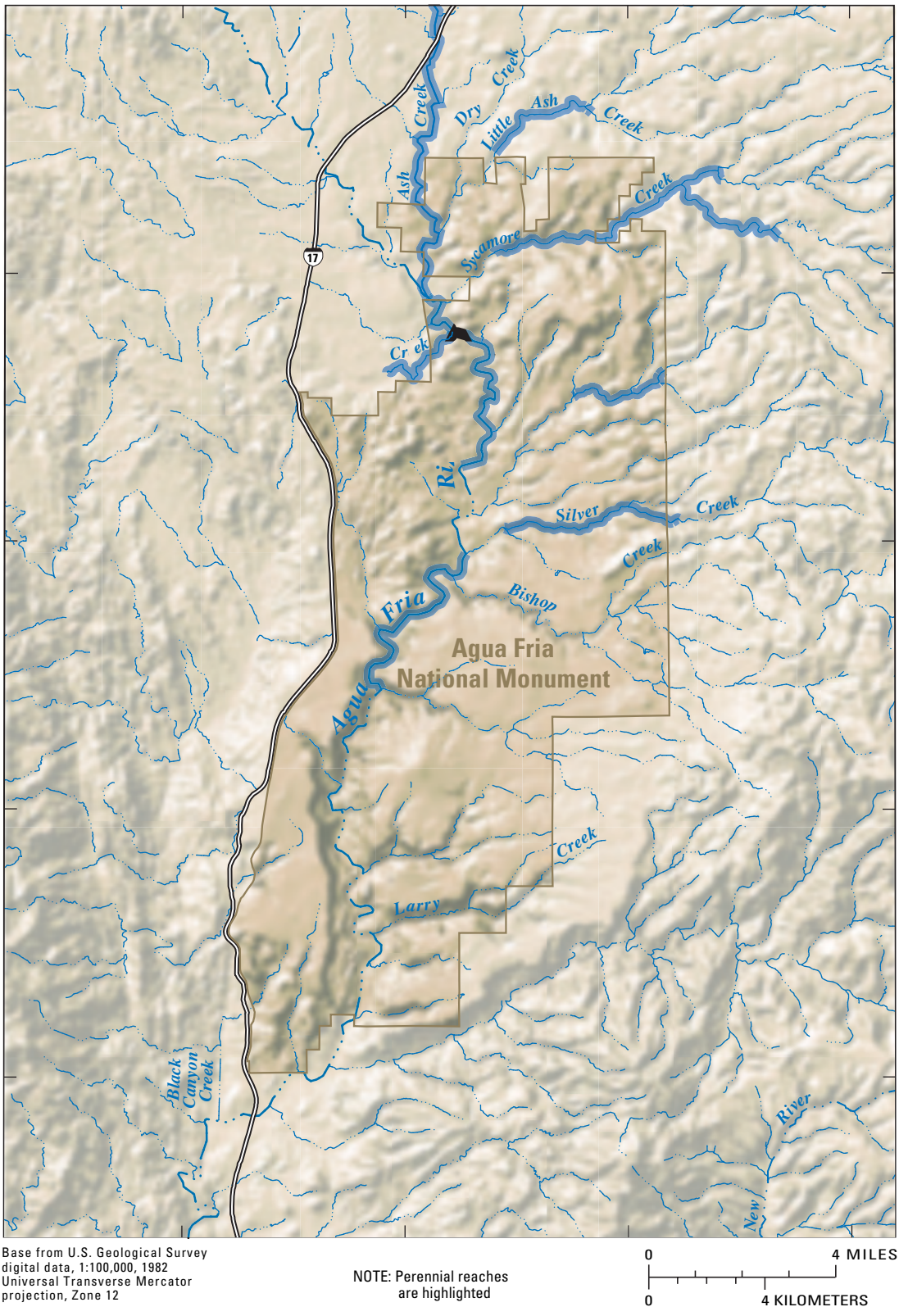

Figure 6. Agua Fria River and major tributaries in the Agua Fria National Monument study area, central Arizona.

Table 3. Lengths of perennial reaches of the Agua Fria River and tributaries of the Agua Fria River, Agua Fria National Monument study area, central Arizona

[Modified from Brown and others, 1981]

Name	Length (miles)
Agua Fria River	6.2
Ash Creek	8.1
Little Ash Creek	2.9
Little Sycamore Creek	1.1
Sycamore Creek	7.9
Big Bug Creek	2.4
Indian Creek	2.4
Silver Creek	4.2

Streamflow in the Agua Fria River near the monument is monitored by the USGS at two streamflow-gaging stations (**fig. 6** and table 4). One station is within the monument near the northern boundary and the other is about 8.3 mi downstream from the southern boundary (not shown on figures). The upstream station (Agua Fria River near Mayer, Arizona, 09512500) is at the Sycamore damsite about 0.18 mi downstream from the mouth of Big Bug Creek and has been in operation since 1940.

Table 4. U.S. Geological Survey streamflow-gaging stations on the Agua Fria River in the Agua Fria National Monument study area, central Arizona

Station name	Station number	Drainage area (square miles)	Period of record
Agua Fria River near Mayer, Arizona	09512500	585	1940–2004
Agua Fria River near Rock Springs, Arizona	09512800	1,111	1970–2004

Streamflow measured at Agua Fria near Mayer represents drainage from an area of 585 mi^2 that includes flow from tributaries Ash, Little Ash, Dry, Sycamore, and Big Bug Creeks. The downstream station (Agua Fria River near Rock Springs, Arizona, 09512800) is 2.5 mi southwest of Rock Springs, Arizona, and has been in operation since January 1970. Streamflow measured at this site represents base flow and runoff from a drainage area of 1,111 mi^2 that includes outflow from tributaries Indian Creek, Silver Creek, Bishop Creek, Antelope Creek, Badger Spring Wash, Lousy Canyon, Larry Creek, and Black Canyon Creek. Data for these two stations are available online at **http://waterdata.usgs.gov/ az/nwis/**.

Additional surface-water data were obtained from USGS NWIS database records, from BLM surface-water monitoring records, and from data collected by USGS staff during a seepage study conducted in May 2002.

The USGS NWIS database contained records for six sites on the Agua Fria River within and near the monument boundaries for which either water-quality or streamflow data were available (**fig. 7** and **table 5**). The two sites outside the monument are Agua Fria River above Arcosanti and Agua Fria River above Sycamore Creek. The four sites within the monument are Agua Fria River below Sycamore Creek; Agua Fria River near Mayer, Arizona; Agua Fria River near Bloody Basin Road; and Agua Fria River below Bloody Basin Road at Horseshoe Ranch.

Streamflow and field properties were measured at main-stem and tributary sites by BLM staff between June 1992 and November 1998 (fig. 7 and **table 6**). Measurements were made at 16 sites within and near the boundaries of the monument including 3 sites along the Agua Fria River and 13 sites along tributaries within and near the monument. Field properties included specific conductance, dissolved solids, pH, dissolved oxygen, and turbidity.

In May 2002, a seepage study was conducted to measure streamflow, specific conductance, and temperature along the Agua Fria River at 14 sites within and near the monument (fig. 7 and **table 7**). During this study, almost the entire length of the river within the monument was traversed. Measurements were made using standard USGS procedures (Rantz and others, 1982; Wilde and Radtke, 1998).

Streamflow Characteristics

Streamflow in the Agua Fria River within the monument varies by season. Snowmelt runoff and rainfall contribute to high streamflows during the winter and early spring, respectively. Streamflow is also high in late summer as a result of runoff from monsoonal storms. Streamflow is low in May, June, October, and November (**figs. 8, 9, 10**, and **11**) when precipitation typically is significantly less than at other times of the year.

Winter rains (those during November–March) have a significant effect on streamflow (figs. 8 and 10). Although the mean monthly rainfall is higher during the summer monsoon season, diminished evapotranspiration demands and elevated antecedent soil-moisture conditions during the winter provide greater opportunity for runoff. Additionally, winter storms tend to cover large areas.

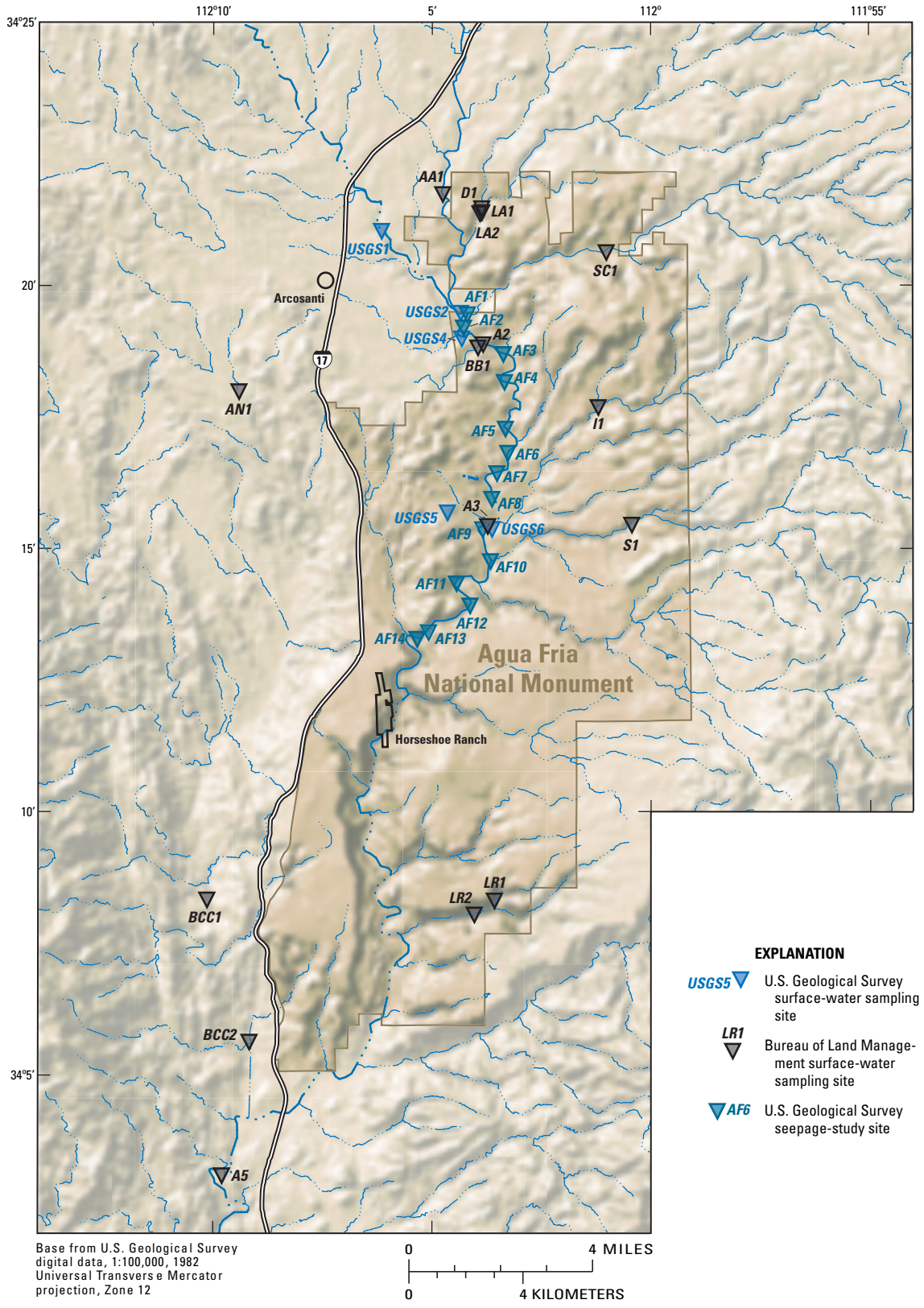

Figure 7. Surface-water sites in the Agua Fria National Monument study area, central Arizona, at which data were collected by the U.S. Geological Survey or the Bureau of Land Management, 1980–2002.

Table 5. Surface-water sites on the Agua Fria River in the Agua Fria National Monument study area, central Arizona, for which records were available in the U.S. Geological Survey National Water Information System, 2003

Site name	Site identifier	Latitude/longitude	Number of records	Date of record(s)
Agua Fria River above Arcosanti	USGS1	34°21'05"/112°06'08"	1	11/23/1980
Agua Fria River above Sycamore Creek	USGS2	34°19'29"/112°04'10"	2	11/24/1980, 06/04/1981
Agua Fria River below Sycamore Creek	USGS3	34°19'25"/112°04'17"	2	11/24/1980, 06/04/1981
Agua Fria River near Mayer, Arizona	USGS4 (09512500)	34°18'55"/112°03'48"	2	11/25/1980, 05/22/1996
Agua Fria River near Bloody Basin Road	USGS5	34°15'43"/112°04'39"	1	05/21/1996
Agua Fria River below Bloody Basin Road at Horseshoe Ranch	USGS6	34°15'28"/112°03'46"	1	12/12/1980

Table 6. Surface-water sites in the Agua Fria National Monument study area, central Arizona, at which streamflow and field properties were measured by Bureau of Land Management staff, June 1992 to November 1998

Location	Site identifier	Latitude/longitude	Number of records	Period of records
Dry Creek	D1	34°21'29"/112°03'52"	13	10/06/1992 to 11/04/1998
Ash Creek	AA1	34°21'47"/112°04'47"	21	09/05/1992 to 10/03/1995
Little Ash Creek	LA1	34°21'26"/112°03'50"	12	10/05/1992 to 10/03/1995
Little Ash Creek	LA2	34°21'26"/112°03'55"	13	10/05/1992 to 11/04/1998
Sycamore Creek	SC1	34°20'41"/112°01'00"	8	08/19/1992 to 10/25/1995
Agua Fria River	A2	34°18'59"/112°03'59"	27	09/25/1992 to 10/04/1995
Big Bug Creek	BB1	34°18'52"/112°03'57"	27	06/25/1992 to 11/04/1998
Antelope Creek	AN1	34°18'00"/112°09'27"	8	09/30/1994 to 04/14/1998
Indian Creek	I1	34°17'43"/112°01'11"	9	09/14/1992 to 10/27/1994
Agua Fria River	A3	34°15'28"/112°03'44"	20	06/25/1992 to 10/09/1998
Silver Creek	S1	34°15'29"/112°00'52"	12	10/05/1992 to 11/13/1998
Larry Creek Tributary	LR1	34°08'21"/112°03'31"	9	12/17/1992 to 06/22/1995
Larry Creek	LR2	34°08'05"/112°04'01"	1	12/17/1992
Agua Fria River	A5	34°03'09"/112°09'47"	49	03/01/1992 to 10/08/1998
Black Canyon Creek	BCC1	34°08'23"/112°10'10"	29	03/19/1993 to 10/20/1998
Black Canyon Creek	BCC2	34°05'41"/112°09'10"	17	03/13/1992 to 02/03/1993

Table 7. Surface-water sites on the Agua Fria River in the Agua Fria National Monument, central Arizona, at which streamflow, specific conductance, and temperature were measured during the seepage study in May 2002

Site name	Latitude/longitude	Date
AF1	34°19'30"/112°04'20"	05/20/2002
AF2	34°19'02"/112°04'18"	05/20/2002
AF3	34°18'42"/112°03'22"	05/20/2002
AF4	34°18'10"/112°03'19"	05/21/2002
AF5	34°17'17"/112°03'20"	05/21/2002
AF6	34°16'50"/112°03'15"	05/20/2002
AF7	34°16'28"/112°03'30"	05/20/2002
AF8	34°15'58"/112°03'36"	05/20/2002
AF9	34°15'28"/112°03'41"	05/20/2002
AF10	34°14'48"/112°03'41"	05/21/2002
AF11	34°14'24"/112°04'27"	05/21/2002
AF12	34°13'58"/112°04'06"	05/22/2002
AF13	34°13'28"/112°05'05"	05/22/2002
AF14	34°13'18"/112°05'20"	05/22/2002

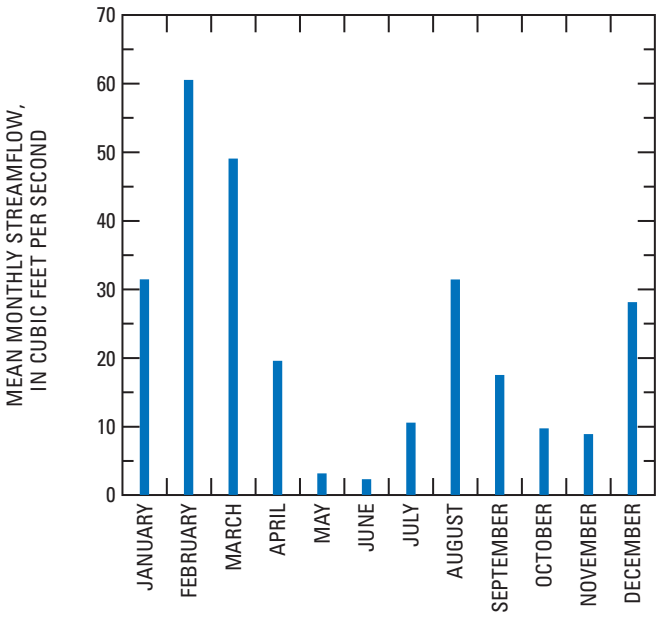

Figure 8. Mean monthly streamflow at Agua Fria River near Mayer, Arizona, 1940–2002.

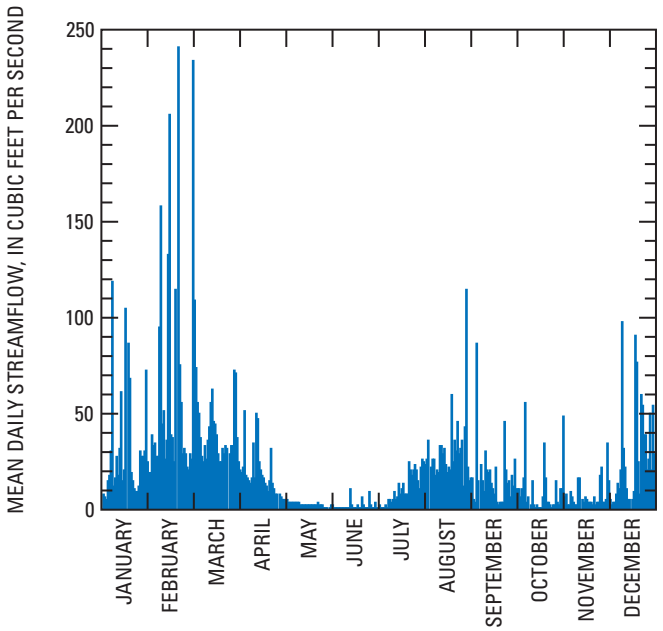

Figure 9. Mean daily streamflow at Agua Fria River near Mayer, Arizona, 1940–2002.

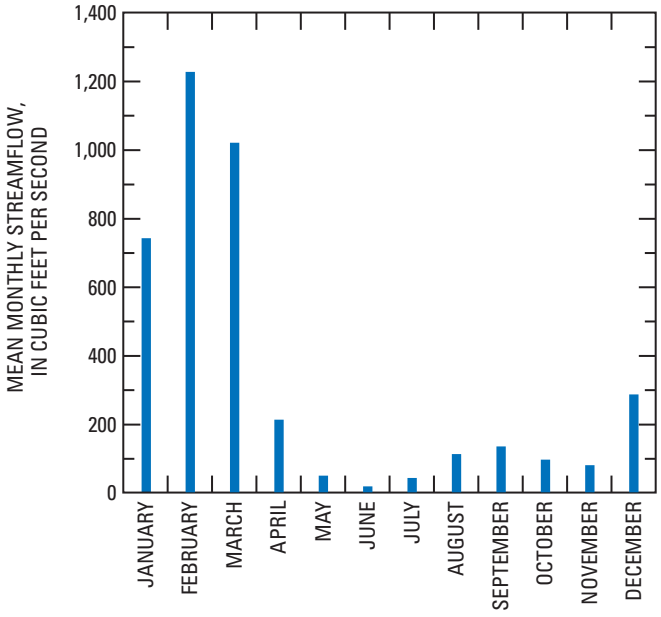

Figure 10. Mean monthly streamflow at Agua Fria River near Rock Springs, Arizona, 1970–2002.

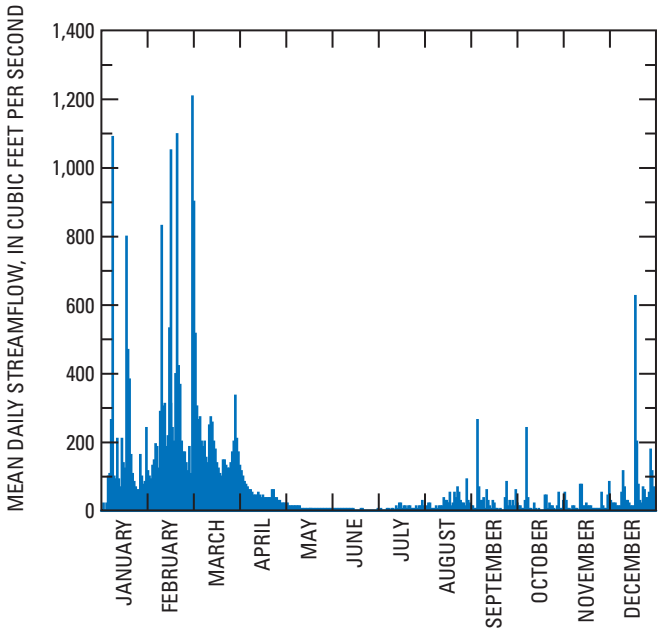

Figure 11. Mean daily streamflow at Agua Fria River near Rock Springs, Arizona, 1970–2002.

Monsoonal storms during the summer tend to develop rapidly and can be intense, but generally are localized and short lived. Consequently, runoff from these storms can be significant and cause rapid increases in streamflow. This is particularly true in areas where the alluvium is thin and depth to bedrock is shallow. There are several reaches of the Agua Fria River where the river canyon is narrow and deeply incised and the alluvium is thin or absent.

Records were obtained for four precipitation gages near the monument (table 8 and **figs. 1** and **12**). Records for two of these gages, Cordes and Crown King, were obtained from the Western Regional Climate Center Desert Research Institute (2004).

Table 8. Precipitation gages in the Agua Fria National Monument study area, central Arizona

[Altitude data from Barnett and others, 2003]

Station name (number)	Altitude (feet)	Period of record	Mean annual precipitation (inches)
Cordes (022109)	3,770	1948–2003	15.03
Crown King (022329)	[1, 2]5,920-6,000	1914–1995	28.47
Bumble Bee	2,500	1954–1979	15.79
Dugas 2SE	[1, 2]4,000-4,040	1920–1972	17.23

[1]Station location changed during period of record; beginning and ending altitudes given.

[2]Station location outside of study area.

Records for the other two gages, Bumble Bee and Dugas 2SE, were obtained from the University of Arizona Institute of Atmospheric Physics (2004). Although none of these gages are within the monument, data from the Cordes, Bumble Bee, and Dugas 2SE gages likely are representative of precipitation within the monument owing to their locations and altitudes. Precipitation measured at the Crown King gage likely is greater than what would be measured within the monument because the gage is at a higher altitude than the monument.

Daily, monthly, and annual streamflow data, and streamflow statistics for Agua Fria River near Mayer and Agua Fria River near Rock Springs have been summarized in the annual Water Data Report for Arizona (such as Smith and others, 1997). Pope and others (1998) computed statistical summaries of streamflow at USGS stations in Arizona, including the two Agua Fria River stations. Data presented in this section are derived primarily from Pope and others (1998).

The highest measured streamflow at Agua Fria River near Mayer between 1940 and 2002 was 33,100 ft^3/s on February 19, 1980 (**fig. 13**). This flow has a recurrence interval of between 50 and 100 years. The maximum annual mean flow was 143 ft^3/s (1993) and the minimum was 1.35 ft^3/s (1962; **fig. 14**).

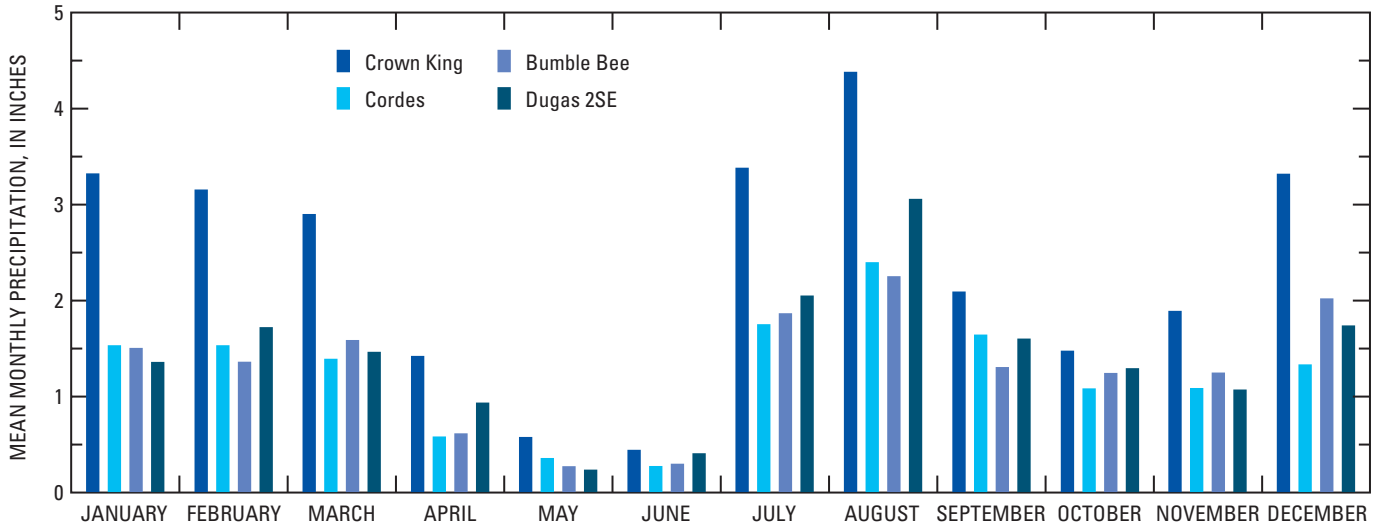

Figure 12. Mean monthly precipitation at gages near the Agua Fria National Monument area, central Arizona.

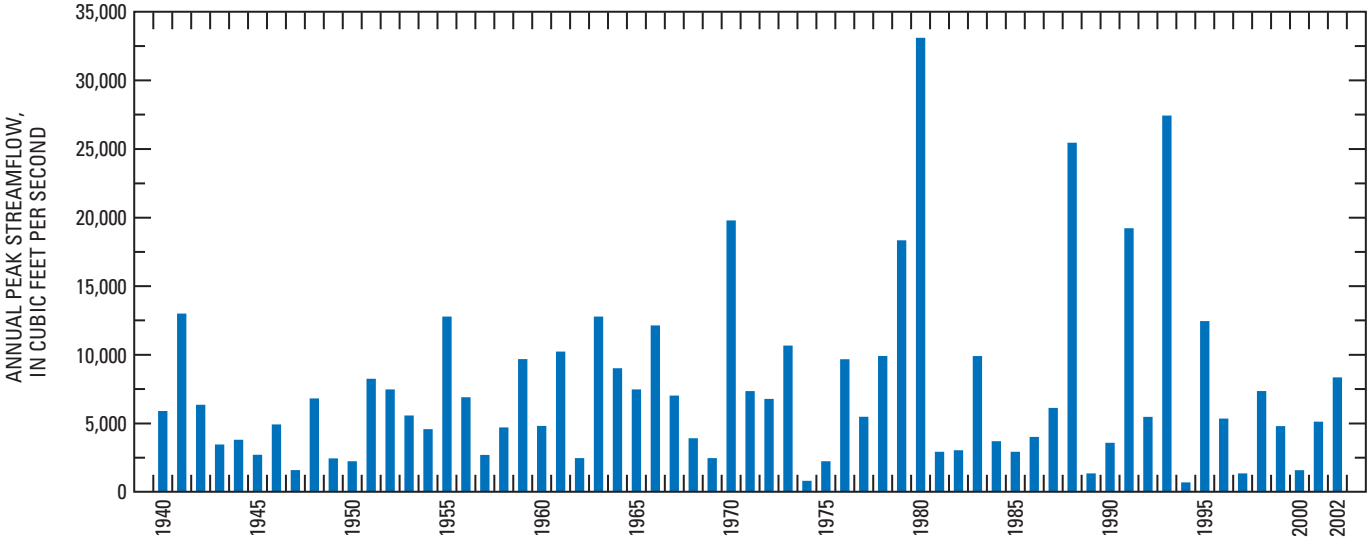

Figure 13. Annual peak streamflow at Agua Fria River near Mayer, Arizona, 1940–2002.

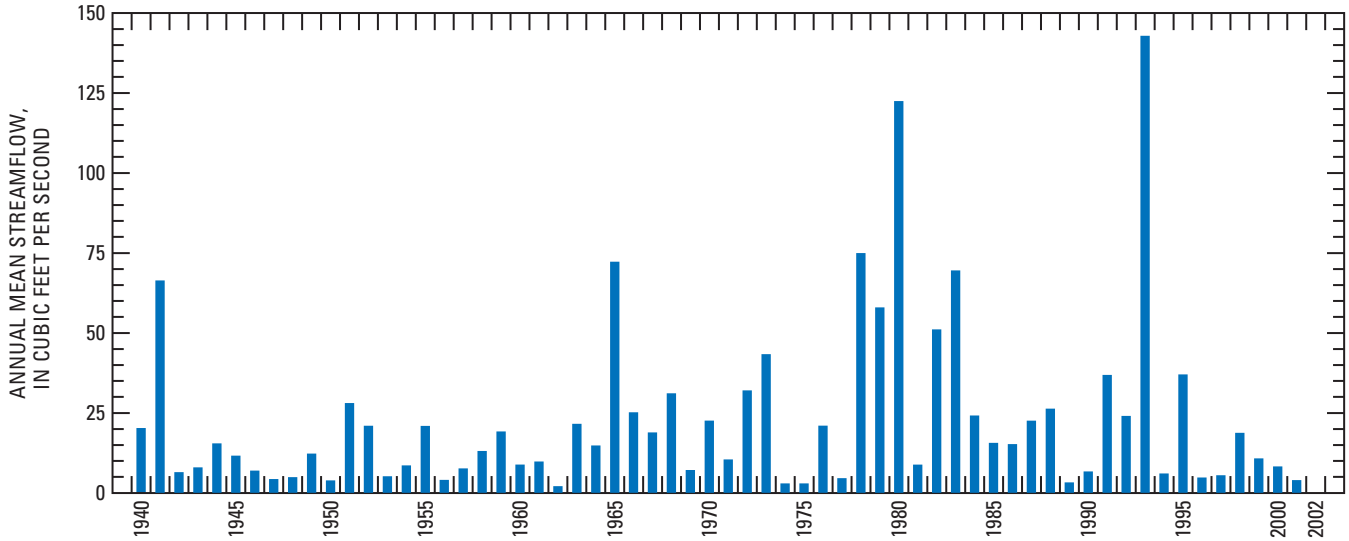

Figure 14. Annual mean streamflow at Agua Fria River near Mayer, Arizona, 1940–2001.

Between 1970 and 2002, the highest streamflow recorded at Agua Fria River near Rock Springs was 59,500 ft^3/s on February 19, 1980 (**fig. 15**). A peak flow of 85,000 ft^3/s was measured in 1920 before systematic recording began. These peak flows have recurrence intervals of between 10 and 25 years. The maximum annual mean flow at this site was 498 ft^3/s (1993), and the minimum was 2.11 ft^3/s (1975; **fig. 16**). Because streamflow measured at the Rock Springs station is derived from a larger drainage area, high flows measured at Agua Fria River near Rock Springs are higher than those measured at Agua Fria River near Mayer and are likely higher than those within the monument.

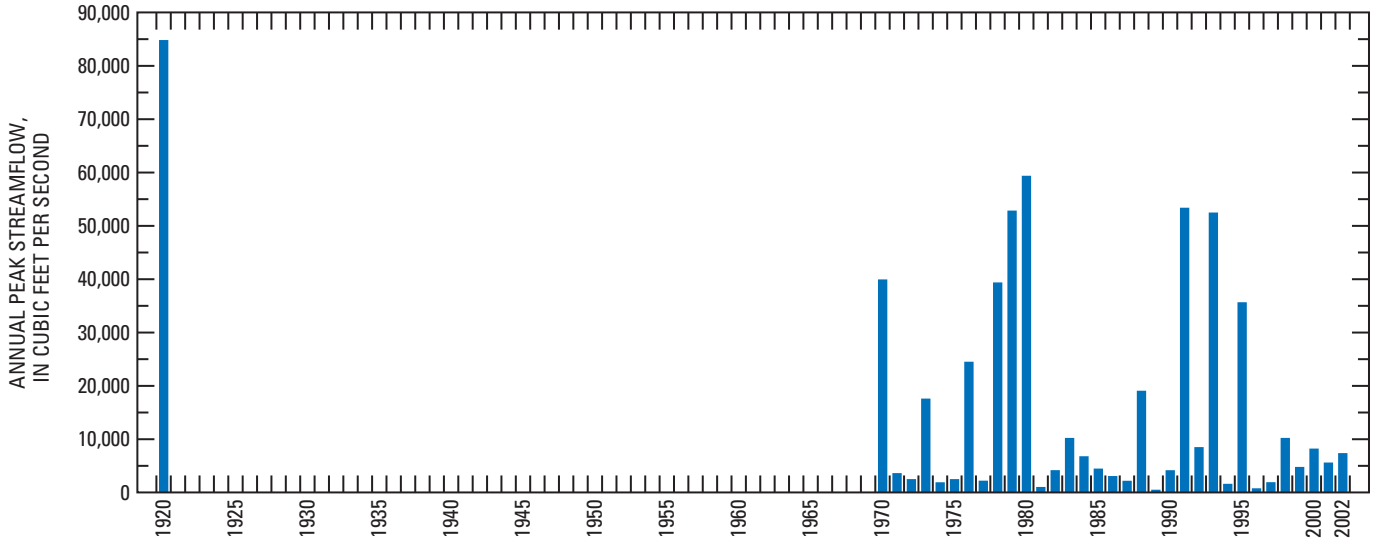

Figure 15. Annual peak streamflow at Agua Fria River near Rock Springs, Arizona, 1920–2002.

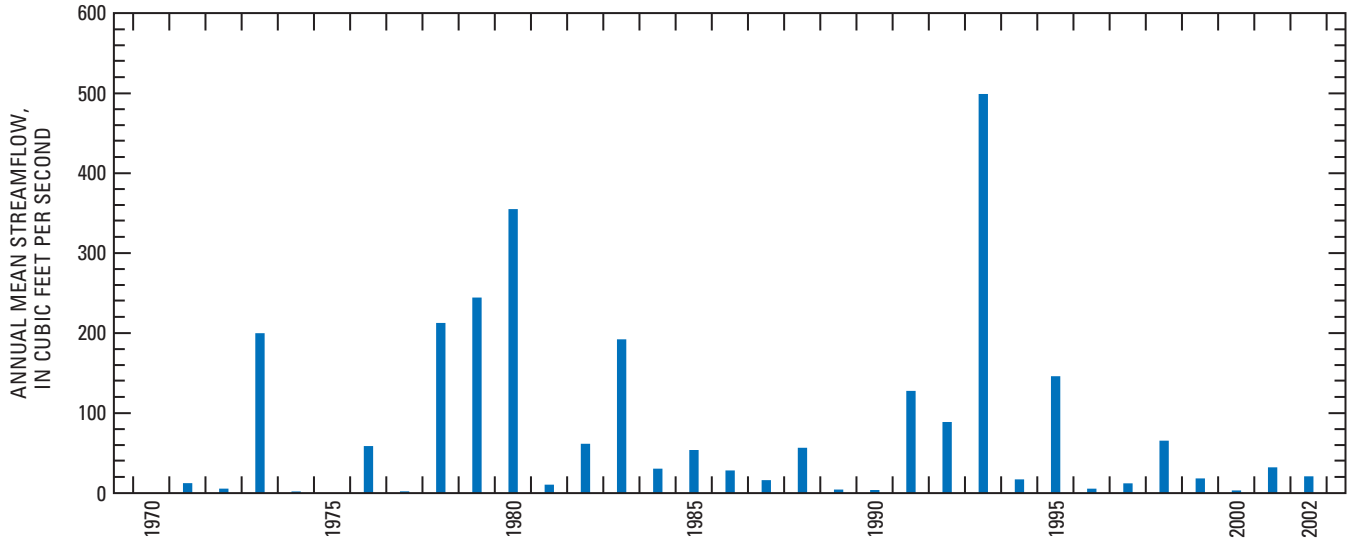

Figure 16. Annual mean streamflow at Agua Fria River near Rock Springs, Arizona, 1971–2001.

The maximum and minimum mean monthly streamflows at Agua Fria River near Mayer occur in February (60.4 ft^3/s) and June (2.57 ft^3/s), respectively (**fig. 8**). The maximum and minimum mean daily flows occur on February 20 (242 ft^3/s) and July 4 (1.03 ft^3/s), respectively (**fig. 9**). Daily mean flow-duration data for this site indicate that for 50 percent of the time, flow equaled or exceeded 2.2 ft^3/s (table 9). Prior to 1978, low and negligible flows at this streamflow-gaging station were affected by diversions to a canal. This canal has been inoperative since 1977, and water is no longer being diverted.

Table 9. Duration of mean daily flow, Agua Fria River near Mayer, Arizona, 1941–96

[Data from Pope and others, 1998. Streamflow, in cubic feet per second, which was equaled or exceeded for indicated percentage of time]

Streamflow	Percentage of time
408	1
73	5
21	10
11	15
7.4	20
4.5	30
3.1	40
2.2	50
1.5	60
.92	70
.56	80
.32	90
.15	95
.10	98
.09	99
.00	99.5
.00	99.9

The maximum and minimum mean monthly streamflows at Agua Fria River near Rock Springs occur in February (309 ft^3/s) and June (4.34 ft^3/s), respectively (**fig. 10**). The maximum and minimum mean daily flows occur on March 1 (1,211 ft^3/s) and July 6 (1.61 ft^3/s), respectively (**fig. 11**). Daily mean flow-duration data for this site indicate that for 50 percent of the time, flow equaled or exceeded 3.5 ft^3/s (table 10).

Table 10. Duration of daily mean flow, Agua Fria River near Rock Springs, Arizona, 1971–73 and 1976–96

[Data from Pope and others, 1998. Streamflow, in cubic feet per second, which was equaled or exceeded for indicated percentage of time]

Streamflow	Percent of time
1,168	1
309	5
127	10
61	15
34	20
13	30
6.3	40
3.5	50
2.3	60
1.5	70
0.80	80
0.32	90
0.08	95
0.00	98
0.00	99
0.00	99.5
0.00	99.9

For Agua Fria River near Mayer and Agua Fria River near Rock Springs, there is a 50-percent chance that the highest average streamflow in a continuous 30-day interval during a 2-year period will be greater than or equal to 84 ft^3/s and 219 ft^3/s, respectively (**tables 11** and **12**). There is a 50-percent chance that the lowest average flow in a continuous 30-day interval during a 2-year period at these sites will be less than or equal to 0.42 ft^3/s and 0.97 ft^3/s, respectively (**tables 13** and **14**).

Streamflow data were available for four of the six surface-water sites in the USGS NWIS: Agua Fria River above Arcosanti, Agua Fria River below Sycamore Creek, Agua Fria River below Bloody Basin Road at Horseshoe Ranch, and Agua Fria River near Mayer, (**fig. 7** and **table 15**). Data for these sites indicate that flow increases along the reach of the river that extends from Arcosanti to below Sycamore Creek.

Streamflow was measured by BLM staff between June 1992 and November 1998 at 16 main-stem and tributary sites within and near the monument (fig. 7). Hydrographs and a listing of the streamflow measurements are given in **appendix 3**.

Table 11. Magnitude and probability of high flow, Agua Fria River near Mayer, Arizona, 1941–96

[Data from Pope and others, 1998]

Period (consecutive days)	Streamflow, in cubic feet per second, for indicated recurrence interval, in years (non-exceedance probability, in percent)					
	2 years (50 percent)	5 years (20 percent)	10 years (10 percent)	25 years (4 percent)	50 years (2 percent)	100 years (1 percent)
1	817	2,220	3,830	6,970	10,300	14,800
3	399	1,090	1,880	3,460	5,170	7,490
7	219	603	1,040	1,880	2,770	3,940
15	130	353	603	1,080	1,580	2,250
30	84	224	375	652	932	1,290
60	53	144	243	425	611	847
90	38	103	174	306	443	619

Table 12. Magnitude and probability of high flow, Agua Fria River near Rock Springs, Arizona, 1971–73 and 1976–96

[Data from Pope and others, 1998]

Period (consecutive days)	Streamflow, in cubic feet per second, for indicated recurrence interval, in years (non-exceedance probability, in percent)					
	2 years (50 percent)	5 years (20 percent)	10 years (10 percent)	25 years (4 percent)	50 years (2 percent)	100 years (1 percent)
1	1,860	8,200	18,100	42,900	75,400	126,000
3	957	4,390	9,760	22,900	39,900	65,600
7	594	2,610	5,590	12,400	20,800	32,800
15	347	1,540	3,300	7,410	12,400	19,700
30	219	943	2,000	4,450	7,410	11,700
60	145	623	1,330	2,980	5,020	8,020
90	108	456	959	2,110	3,510	5,530

Table 13. Magnitude and probability of low flow, Agua Fria River near Mayer, Arizona, 1941–96

[Data from Pope and others, 1998]

Period (consecutive days)	Streamflow, in cubic feet per second, for indicated recurrence interval, in years (non-exceedance probability, in percent)					
	2 years (50 percent)	5 years (20 percent)	10 years (10 percent)	20 years (5 percent)	50 years (2 percent)	100 years (1 percent)
1	0.24	0.10	0.06	0.00	0.00	0.00
3	.25	.10	.06	.00	.00	.00
7	.27	.11	.06	.00	.00	.00
15	.32	.12	.07	.00	.00	.00
30	.42	.17	.10	.00	.00	.00
60	.65	.22	.12	.07	.04	.02
90	1.00	.34	.18	.10	.05	.03
120	2.00	.74	.39	.22	.10	.06
183	4.50	.17	.92	.53	.27	.17

Table 14. Magnitude and probability of low flow, Agua Fria River near Rock Springs, Arizona, 1971–73 and 1976–96

[Data from Pope and others, 1998]

Period (consecutive days)	Streamflow, in cubic feet per second, for indicated recurrence interval, in years (non-exceedance probability, in percent)					
	2 years (50 percent)	5 years (20 percent)	10 years (10 percent)	20 years (5 percent)	50 years (2 percent)	100 years (1 percent)
1	0.60	0.00	0.00	0.00	0.00	0.00
3	.63	.00	.00	.00	.00	.00
7	.68	.00	.00	.00	.00	.00
15	.74	.00	.00	.00	.00	.00
30	.97	.00	.00	.00	.00	.00
60	1.30	.14	.00	.00	.00	.00
90	1.70	.40	.13	.02	.00	.00
120	3.00	.87	.37	.17	.06	.03
183	5.10	1.8	.95	.55	.29	.19

Table 15. Streamflow data from sites on the Agua Fria River in the Agua Fria National Monument study area, central Arizona, that were retrieved from the U.S. Geological Survey National Water Information System, 2002

Site name	Site identifier	Streamflow (cubic feet per second)	Date
Agua Fria River above Arcosanti	USGS1	1.2	11/23/1980
Agua Fria River below Sycamore Creek	USGS3	3.8, 1.2	11/24/1980, 06/04/1981
Agua Fria River near Mayer, Arizona	USGS4 (09512500)	4.9	11/25/1980
Agua Fria River below Bloody Basin Road at Horseshoe Ranch	USGS6	6.5	12/12/1980

Streamflow measured during a seepage study in May 2002 was spatially variable but generally decreased from site AF2 to site AF14 (table 16 and **figs. 7** and **17**). During the seepage study, the river did not flow beyond AF14. It is assumed that the flow data represent base flow (ground-water discharge) because measurements were made following an unusually dry winter and spring.

Surface-Water Quality

Surface-water quality data for sites within and near the monument (tables 17–19) were obtained from USGS NWIS records, BLM records, and from measurements made during a seepage study in May 2002. USGS NWIS records contain stream-property and chemical-constituent data. Stream-property data derived from BLM monitoring consist of specific-conductance, dissolved-solids, pH, dissolved-oxygen, and turbidity values. Data from the seepage study in May 2002 include specific conductance and temperature.

Table 16. Streamflow of Agua Fria River at the seepage study sites, Agua Fria National Monument, central Arizona, May 2002

Site name	Latitude/longitude (cubic feet per second)	Streamflow
AF1	34°19'30"/112°04'20"	0.39
AF2	34°19'02"/112°04'18"	1.00
AF3	34°18'42"/112°03'22"	0.72
AF4	34°18'10"/112°03'19"	0.45
AF5	34°17'17"/112°03'20"	0.37
AF6	34°16'50"/112°03'15"	0.22
AF7	34°16'28"/112°03'30"	0.06
AF8	34°15'58"/112°03'36"	0.09
AF9	34°15'28"/112°03'41"	0.01
AF10	34°14'48"/112°03'41"	0.14
AF11	34°14'24"/112°04'27"	0.31
AF12	34°13'58"/112°04'06"	0.27
AF13	34°13'28"/112°05'05"	0.04
AF14	34°13'18"/112°05'20"	0.03

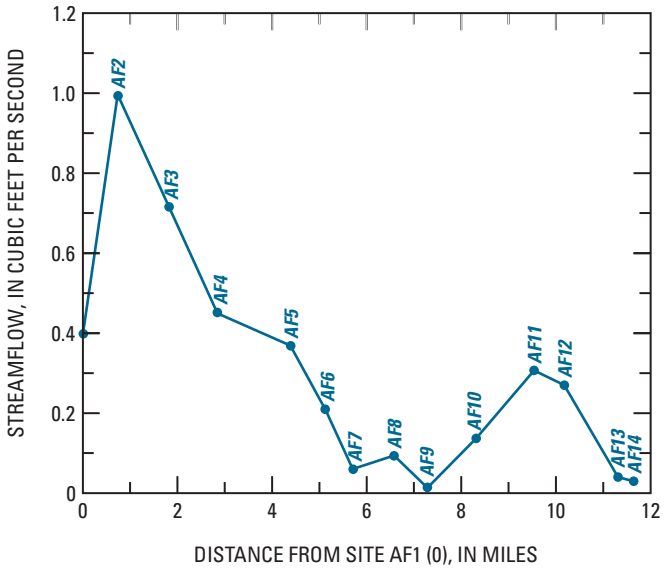

Figure 17. Streamflow of the Agua Fria River at the seepage study sites, Agua Fria National Monument, central Arizona, May 2002.

Table 17. Specific-conductance, pH, and selected cation concentration data for sites on the Agua Fria River in the Agua Fria National Monument study area, central Arizona, that were retrieved from the U.S. Geological Survey National Water Information System, 2002

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; ---, not reported]

Site name	Specific conductance (µS/cm at 25°C)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
Agua Fria River above Arcosanti	1,210	8.5	120	43	69	1.6
Agua Fria River above Sycamore Creek	974, 1,080	8.2, 8.1	---	---	---	---
Agua Fria River below Sycamore Creek	858, 994	8.2, 8.1	---	---	---	---
Agua Fria River near Mayer, Arizona	885	8.6	78	35	47	2.3
Agua Fria River near Bloody Basin Road	---	---	---	---	---	---
Agua Fria River below Bloody Basin Road at Horseshoe Ranch	---	8.8	76	36	51	2.1

Table 18. Average stream-property values at sites in the Agua Fria National Monument study area, central Arizona, measured by Bureau of Land Management staff, June 1992 to November 1998

[µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ---, not reported]

Location	Site identifier	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)
Dry Creek	D1	548	8.3	1.7	7.8	90.5	362
Ash Creek	AA1	661	8.1	3.1	7.6	92.1	438
Little Ash Creek	LA1	480	8.3	1.4	8.6	93.3	318
Little Ash Creek	LA2	510	8.3	1.2	8.2	90.4	338
Sycamore Creek	SC1	478	8.4	2.1	8.4	95.2	318
Agua Fria River	A2	799	8.3	34.1	8.3	95.5	536
Big Bug Creek	BB1	733	8.3	2.1	8.9	99.9	490
Antelope Creek	AN1	793	8.2	1.3	7.6	86.0	522
Indian Creek	I1	670	7.9	1.2	8.6	97.0	446
Agua Fria River	A3	722	8.1	22.6	7.3	88.0	481
Silver Creek	S1	613	8.3	1.0	8.4	96.4	405
Larry Creek Tributary	LR1	596	8.1	.74	7.3	86.2	395
Larry Creek	LR2	775	8.6	.45	10.6	102.0	530
Agua Fria River	A5	623	8.2	24.2	7.7	91.5	411
Black Canyon Creek	BCC1	776	8.4	1.8	8.3	97.5	528
Black Canyon Creek	BCC2	283	8.3	---	10.0	102.0	181

Table 19. Specific-conductance and temperature data for the seepage study sites along the Agua Fria River, Agua Fria National Monument, central Arizona, May 2002

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; ---, not reported]

Site name	Latitude/longitude	Specific conductance (µS/cm at 25°C)	Temperature (°C)
AF1	34°19'30"/112°04'20"	895	23.7
AF2	34°19'02"/112°04'18"	816	26.0
AF3	34°18'42"/112°03'22"	---	26.0
AF4	34°18'10"/112°03'19"	892	17.0
AF5	34°17'17"/112°03'20"	891	20.0
AF6	34°16'50"/112°03'15"	959	24.6
AF7	34°16'28"/112°03'30"	1,037	26.4
AF8	34°15'58"/112°03'36"	945	24.7
AF9	34°15'28"/112°03'41"	944	22.0
AF10	34°14'48"/112°03'41"	1,005	28.0
AF11	34°14'24"/112°04'27"	958	24.0
AF12	34°13'58"/112°04'06"	943	18.7
AF13	34°13'28"/112°05'05"	905	20.0
AF14	34°13'18"/112°05'20"	908	22.5

The Arizona Department of Environmental Quality (ADEQ) assigns specific designated uses to reaches of major streams in Arizona (State of Arizona, 1996). Within the monument, designated uses for the Agua Fria River are domestic water use, full body contact, aquatic and wildlife (warm water fishery), fish consumption, agricultural irrigation, and agricultural livestock watering. Several tributaries, including Little Ash Creek, Sycamore Creek, Big Bug Creek, Antelope Creek, and Black Canyon Creek, have similar designations. Water-quality standards for each stream property (for example: pH, turbidity, and dissolved-oxygen concentration) and certain chemical constituents vary by designated use.

Water-quality data for the six sites that were identified from USGS NWIS queries included values for specific conductance, pH, and selected cation concentrations (calcium, magnesium, sodium, and potassium; **table 17**). The reported pH values are within the State of Arizona water-quality standards for the designated uses. Specific-conductance values decrease in the downstream direction.

Average values of stream properties for tributary and main-stem BLM monitoring sites did not exceed the State of Arizona water-quality standards for aquatic and wildlife (warm water fishery) use (**table 18**). In a few instances, however, discrete values exceeded these standards. Dissolved-oxygen concentrations did not meet the standard (minimum 6.0 mg/L and percent saturation less than 90 percent) one or more times at LA2 (Little Ash Creek), A3 (Agua Fria River), and BCC1 (Black Canyon Creek). The pH exceeded the maximum allowable value (9.0) on two occasions at A5 on the Agua Fria River (**appendix 3**). Average specific-conductance values for the Agua Fria River decreased in the downstream direction. No other consistent trends, however, were noted in the other analyses.

Specific-conductance values obtained during the seepage study in May 2002 (**table 19**) are consistent with those from the USGS NWIS and the BLM monitoring data sets. No consistent trend is noted with respect to sampling location.

Ground-Water/Surface-Water Interaction

The duration and magnitude of streamflow within the monument are influenced by streamflow at the northern boundary of the monument, tributary inflows within the monument, hydraulic connection with the subsurface water-bearing zones, precipitation, and vegetation. On the basis of field observations, inflows to the river from tributaries are ephemeral, and the frequency and magnitude of these flows likely reflect the seasonal distribution of precipitation. The degree of bedrock fracturing and the occurrence and distribution of alluvium within the river canyon influence the efficacy of hydraulic connection with subsurface water-bearing zones. Tributary streamflow to the river and recharge to the subsurface occur as concentrated runoff and direct infiltration of precipitation. The amount of recharge represents some fraction of annual precipitation.

Inflows to the monument include streamflow and ground-water inflow at the northern boundary, ephemeral streamflow from tributary canyons in response to precipitation, and ground-water underflow from alluvium in tributary canyons. Outflows from the monument include streamflow and ground-water underflow at the southern boundary, ground-water pumpage, and evapotranspiration from riparian vegetation. Anning and Duet (1994) reported that annual ground-water withdrawals in the Agua Fria Basin for 1987-90 ranged from 3,000 to 9,000 acre-ft.

Field observations of the Agua Fria River canyon in the monument indicate that the river is most likely to be perennial where bedrock is at shallow depths below the river or constricts the canyon, because streamflow losses to infiltration in these areas are small. This tendency is moderated by the presence of riparian vegetation, which could reduce streamflow when evaportanspiration rates are high. The extent to which surface-water diversions or ground-water pumping influences streamflow is unknown.

Alluvial deposits within the river channel vary in composition and are discontinuous. In areas where streamflow tends to diminish or cease altogether, sediments generally are highly permeable, well sorted, angular to subangular, medium- to coarse-grained sand. The sediments appear to have derived from the surrounding outcrops, but much of the material could have been transported from sources upstream.

On the basis of observed flow during and following one of the driest years on record, only the most upstream portion of the river within the monument (closest to the northern boundary) appears to be perennial, and downstream reaches appear to be intermittent. Flow duration in downstream reaches is likely controlled by precipitation within the drainage area and by the lithology of surface and subsurface rocks in the drainage area, the geometry of the river channel, and the thickness of alluvial sediments underlying and adjacent to the channel. During a site visit in May 2002, streamflow

was continuous from a point upstream from the northern boundary of the monument to below the USGS streamflow-gaging station near Mayer, Arizona. Downstream from this point, however, streamflow became intermittent as a function of downstream position and was altogether absent about 0.6 mi upstream from the well that supplies water for a rest area on Interstate 17.

Considerations for Further Study

Currently (2004) available data provide a general overview of hydrologic conditions within the monument. The likely influence of surface-water/ground-water interactions on variations in surface-water conditions along the Agua Fria River within the monument suggest the need for additional study to better describe the hydrogeology of the area. No active studies that involve hydrologic data collection within the monument were identified. Development of programs for collection of geologic, surface-water, ground-water, and water-quality data would benefit the BLM efforts to manage the water resources in the monument.

The USGS streamflow-gaging station Agua Fria River near Mayer, Arizona, near the northern boundary of the monument has been in continuous operation since 1940 and provides measurements of surface-water inflow to the monument. A station near the southern boundary would provide measurements of surface-water outflow from the monument.

Additional measurements of streamflow that include periods of maximum and minimum evapotranspiration could be made over a period of several years to aid in quantification of water losses due to evaportanspiration. These measurements could also be used to help identify possible geologic controls that affect streamflow and identify losses to other sinks such as ground-water pumping.

A synoptic well and spring inventory could be used to gain a better understanding of the current ground-water conditions in the monument area. Data obtained from such an effort could include not only an inventory of wells and springs, but also water levels, water-quality information, and spring discharge. These data could provide useful baseline information for establishing a Federal Reserve water right for the monument.

Installation and monitoring of piezometers would provide information about vertical and horizontal head gradients adjacent to and beneath the Agua Fria River. This information would further aid in identifying areas of streamflow gains and losses. Monitoring changes in ground-water levels could also provide information on consumptive transpiration demands along selected reaches of the river. Additional water-quality samples could be collected from the piezometers in these transects.

Surface geophysical surveys could be used to determine the geometry of the alluvial aquifer to better characterize the important geologic controls affecting surface-water/ground-water interactions. Possible geophysical survey methods include seismic refraction, direct-current electrical resistivity, or electromagnetic induction. Results from these surveys could also be used to estimate the amount of ground-water flow through the study area.

Summary

Existing hydrologic and surface-water data collected during May 2002 for the reconnaissance study were used to characterize the hydrology of the Agua Fria National Monument. This information will be used by the BLM to help support future water-resource management responsibilities, including quantification of a Federal Reserve water right within the monument, and to guide potential future data-collection programs.

Currently (2004), few hydrologic and hydrogeologic data are available for the monument. The USGS streamflow-gaging station near Mayer, Arizona, has been in continuous operation since 1940 and provides measurements of surface-water inflow to the monument. Water-quality data are also available for this site. Measurements of streamflow and specific conductance were made along the Agua Fria River within the monument in May 2002. The data indicate that upstream reaches of the river near the northern boundary of the monument are perennial, and that streamflow generally decreases in the downstream direction as water infiltrates the streambed.

With the exception of a few measurements of dissolved oxygen and pH, the surface-water quality data collected by the BLM and USGS indicate that values did not exceed State of Arizona standards. Few data are available, however, for wells and springs in the monument. Well-drillers' logs were generally in good agreement with the mapped geology.

Additional data collection and analysis would increase the understanding of hydrologic processes within the monument. This could include the construction and operation of a streamflow-gaging station near the southern boundary of the monument, a synoptic well and spring inventory, additional surface-water data collection, installation and monitoring of piezometers, and surface geophysical surveys.

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Appendix 1

Summary of drillers' logs for wells within the Agua Fria National Monument, central Arizona

[Source: Arizona Department of Water Resources]

Well number	Depth from (feet)	Depth to (feet)	Description of formation material
(A-11-03)21dba	0	10	Sands
	10	125	Hard rock and granite
	125	135	Granite
	135	210	Hard rock and granite
(A-11-03)28bbd	0	60	Sand and river rock
	60	210	Granite and cascading sand
(A-10-02)24acc	0	2	Topsoil
	2	39	Cemented conglomerate
	39	160	Red granite
(A-09-03)a	0	8	Surface silt and boulders
	8	206	Basalt and cinders
	206	316	Layers of altered basalt mixed with granite layers
	316	355	Basalt, fractured with calcite and ash
	355	395	Basalt, fractured (water at 385–390)
	395	416	Hard black basalt
(A-09-03)19cbc	0	165	Overburden-volcanic rock, sand, and gravel
	165	470	Volcanic rock, granite and black Malapai

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Appendix 2

Ground-water quality data for wells in the Agua Fria National Monument study area, central Arizona

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; ---, not reported]

Well number	Well altitude (feet)	Sampling date	Depth to water (feet)	Water level altitude (feet)	Zone 12		Specific conductance (µS/cm)	Fluoride (mg/L)
					UTM Easting	UTM Northing		
(A-11-02)25bdd	3,700	05/18/1977	123	3,577	399052	3795675	490	0.6
(A-09-02)26ddd	2,050	05/03/1978	9	2,041	396983	3772026	510	.5
(A-11-02)14dac	3,760	05/24/1977	55	3,705	397445	3799155	510	.5
(A-09-02)35bcb1	2,040	04/28/1978	32	2,008	395542	3771483	545	.5
(A-09-02)35baa	2,030	05/04/1978	14	2,016	396173	3771832	620	.5
(A-11-02)14ccd1	3,760	05/25/1977	17	3,743	396431	3798781	620	.6
(A-09-02)34dda	2,020	05/04/1978	37	1,983	395322	3770649	705	.6
(A-09-02)34daa1	2,020	05/04/1978	15	2,005	395322	3771066	730	.4
(A-09H02)36cda1	2,440	05/19/1978	27	2,413	397870	3780290	740	.3
(A-09-02)34dac1	2,010	04/28/1978	13	1,997	395059	3770847	750	.5
(A-11-03)18ada	3,555	05/23/1977	22	3,533	400854	3799462	785	.4
(A-09-02)35bdb	2,020	05/04/1978	19	2,001	395968	3771431	790	.5
(A-09-02)34dad	2,020	05/02/1978	15	2,005	395344	3770847	860	.5
(A-08-02)03dbd2	2,030	04/20/1978	22	2,008	394778	3769469	870	.5
(A-09-02)25bdc	2,110	05/04/1978	17	2,094	397799	3772819	900	.5
(A-09-02)34ccd2	1,980	04/21/1978	17	1,963	394093	3770429	950	.5
(A-09-02)24dcd2	2,080	05/03/1978	25	2,055	398111	3773720	990	.5
(A-08-02)10cba	1,950	04/20/1978	70	1,880	394049	3768255	1,040	.5
(A-11-02)12bda	3,620	05/23/1977	25	3,595	398492	3801400	1,300	1.3
(A-09-02)28aab1	2,000	04/28/1978	29	1,971	393560	3773482	2,120	11.5
(A-09-02)27cba	2,030	05/02/1978	0	2,030	393983	3772713	2,950	14.0
(A-09-02)34aba	2,060	04/28/1978	0	2,060	394905	3771857	3,380	3.7

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Appendix 3

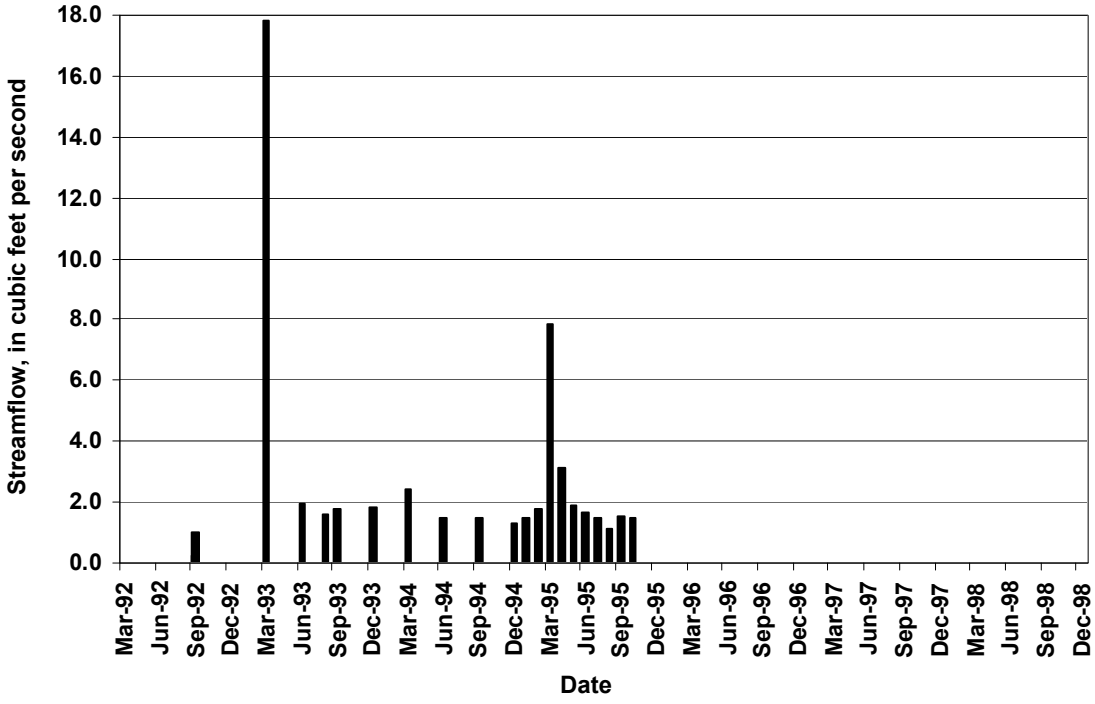
Bureau of Land Management field-measured water properties and streamflow data from sites in the Agua Fria National Monument study area, central Arizona

Site AA1, Ash Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
09/05/92	1615	638	8.1	22.0/27.0	---	6.9	90	440	0.25
09/25/92	1215	628	7.6	28.0/23.0	---	5.9	78	430	1.00
03/18/93	0900	590	8.5	10.5/11.5	3.10	10.0	104	390	17.80
06/04/93	1215	670	8.1	24.5/22.5	1.07	7.4	97	440	1.96
08/05/93	1230	650	7.9	29.0/22.3	0.56	6.9	90	430	1.58
09/16/93	1000	720	8.2	23.0/19.0	3.70	6.7	83	480	1.75
12/07/93	1445	670	8.3	18.0/15.0	1.11	7.2	81	440	1.83
03/09/94	1110	640	8.2	16.0/14.5	0.51	8.3	94	420	2.42
06/07/94	1105	730	8.2	28.0/21.5	0.69	7.6	98	480	1.45
09/13/94	1235	750	7.8	26.5/24.0	3.17	6.3	86	500	1.50
12/20/94	1400	580	8.6	19.0/15.0	2.50	8.2	94	380	1.30
01/13/95	1105	660	8.3	15.5/15.0	2.05	8.5	97	440	1.49
02/08/95	1240	670	8.2	17.5/17.0	1.26	7.8	92	440	1.76
03/02/95	1220	620	8.2	15.0/16.0	16.70	---	---	410	7.87
04/03/95	1050	650	8.3	20.0/17.5	2.01	8.4	100	430	3.10
05/03/95	1330	670	8.2	25.0/25.0	1.51	---	---	440	1.88
06/01/95	0820	650	8.3	21.0/17.0	1.02	8.2	98	430	1.66
07/12/95	0945	660	7.9	27.0/22.5	0.97	---	---	440	1.50
08/08/95	0915	670	7.9	28.0/22.5	1.33	---	---	440	1.13
09/08/95	0925	680	8.1	26.0/22.5	13.9	---	---	450	1.51
10/03/95	0945	680	8.2	20.0/19.0	2.06	---	---	450	1.46

Site AA1, Ash Creek, Arizona—Continued

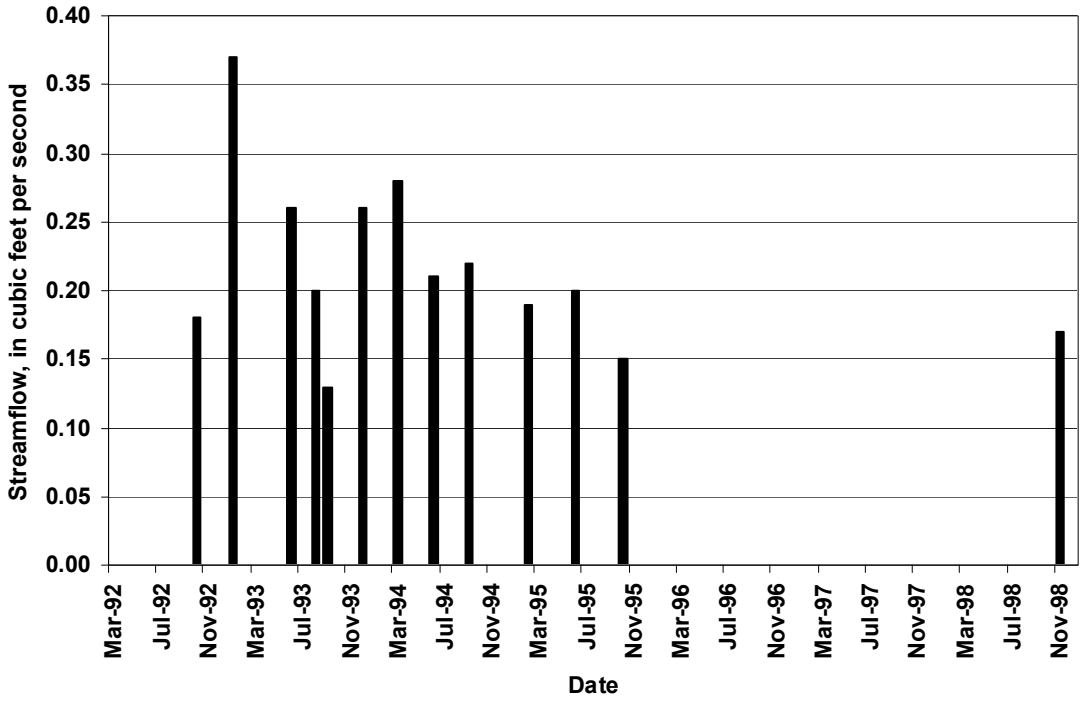


Site D1, Dry Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
10/05/92	1415	494	8.4	27.0/21.0	---	[1]9.2?	---	340	0.18
01/25/93	1000	620	8.3	9.5/8.0	2.47	8.2	79	410	0.37
06/04/93	1045	550	8.6	24.0/19.5	2.23	8.1	100	360	0.26
08/05/93	1630	570	8.2	27.0/24.0	0.95	5.7	77	380	0.2
09/22/93	1030	550	8.5	26.0/18.5	1.14	7.5	92	360	0.13
12/07/93	1220	510	8.5	16.5/12.5	0.52	9.3	99	340	0.26
03/09/94	0935	520	8.4	12.0/11.0	0.62	9.5	99	340	0.28
06/07/94	0925	560	8.4	26.0/17.5	2.18	7.9	94	370	0.21
09/13/94	0950	620	8.2	23.5/20.0	1.07	7.5	95	410	0.22
02/09/95	1150	530	8.4	17.0/14.0	4.67	7.5	83	350	0.19
06/07/95	1000	530	8.1	21.0/18.5	0.76	7.2	87	350	0.20
10/03/95	1305	530	8.2	25.5/24.0	2.51	---	---	350	0.15
11/04/98	1210	540	8.2	18.0/15.0	---	---	---	350	0.17

[1]Value was marked with a "?" by the Bureau of Land Management.

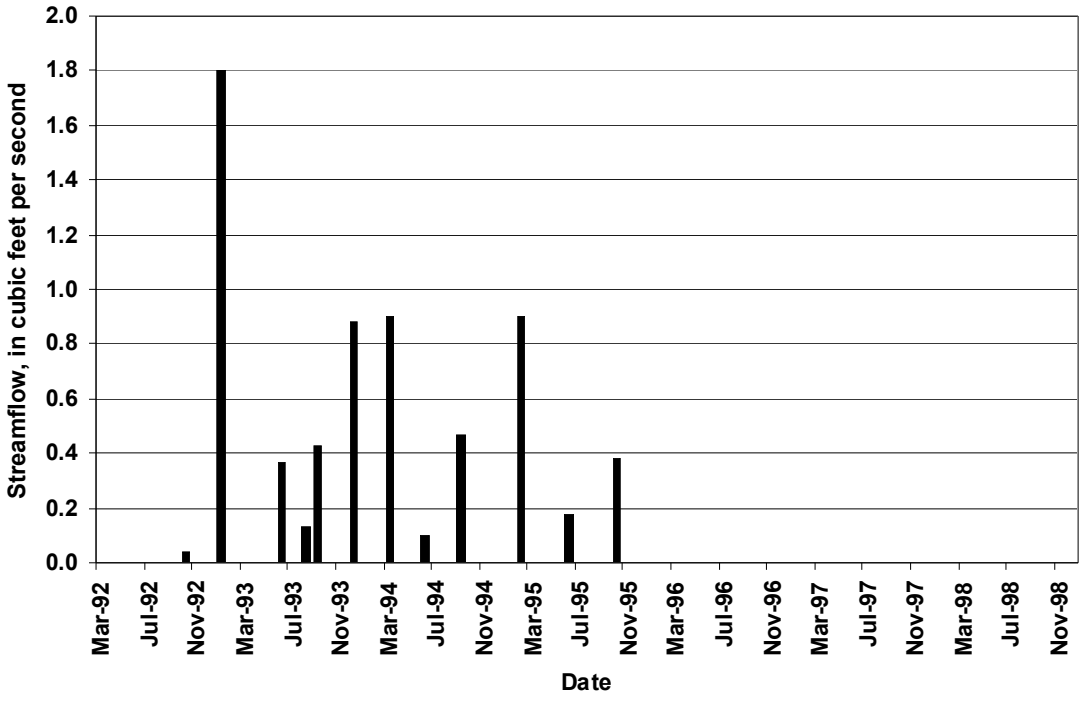


Site LA 1, Little Ash Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
10/05/92	1330	488	8.4	26.0/21.0	---	[1]9.4?	---	330	0.04
01/25/93	1130	400	8.4	10.0/4.5	0.51	9.5	83	260	1.80
06/04/93	0900	550	8.4	21.5/19.0	1.11	8.3	98	360	0.37
08/05/93	1445	540	8.4	29.0/29.5	0.59	7.0	104	360	0.13
09/22/93	0930	510	8.4	25.0/17.5	1.97	7.6	91	340	0.43
12/07/93	0950	440	8.4	3.0/1.5	0.49	12.4	101	290	0.88
03/09/94	0755	420	8.4	2.5/5.5	0.90	9.0	82	280	0.90
06/07/94	0745	500	8.2	19.0/18.0	1.16	8.2	99	330	0.10
09/13/94	0840	570	8.1	23.0/19.5	3.19	7.2	90	380	0.47
02/09/95	1125	430	8.4	16.5/8.5	1.60	9.4	92	280	0.90
06/07/95	0935	470	8.3	21.0/21.5	1.08	7.2	93	310	0.18
10/03/95	1155	450	8.1	24.0/22.0	2.68	---	---	300	0.38

[1]Value was marked with a "?" by the Bureau of Land Management.

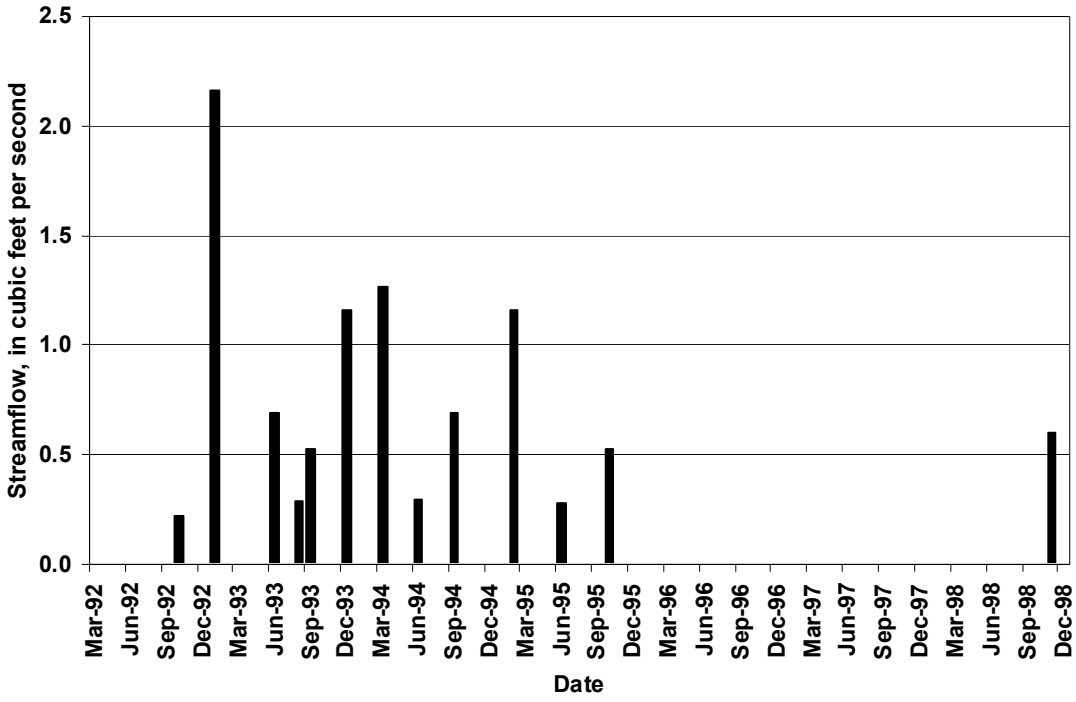


Site LA2, Little Ash Creek, Arizona

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; e, estimated; ---, not reported]

Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
10/05/92	1345	490	8.4	27.0/20.0	---	[1]9.2?	---	340	e.22
01/25/93	1200	420	8.4	12.0/7.0	0.62	8.0	75	280	2.16
06/04/93	1000	550	8.3	28.0/19.0	1.28	8.1	99	360	0.69
08/05/93	1530	580	8.0	27.0/24.0	0.54	4.3	58	380	0.29
09/22/93	1145	520	8.5	31.0/22.0	1.65	7.1	93	340	0.53
12/07/93	1110	470	8.6	16.0/6.5	0.52	10.9	101	310	1.16
03/09/94	0840	460	8.4	7.0/7.5	0.73	10.4	100	300	1.27
06/07/94	0830	590	8.1	25.5/17.0	0.72	7.5	88	390	0.30
09/13/94	0905	610	8.0	25.0/21.0	1.81	7.3	94	400	0.69
02/09/95	1030	450	8.4	15.5/8.5	1.73	10.3	100	300	1.16
06/07/95	0945	510	8.2	21.0/20.0	0.89	7.7	96	340	0.28
10/03/95	1225	480	8.1	25.0/23.0	2.12	---	---	320	0.53
11/04/98	1045	500	8.3	17.0/12.0	---	---	---	330	0.60

[1]Value was marked with a "?" by the Bureau of Land Management.

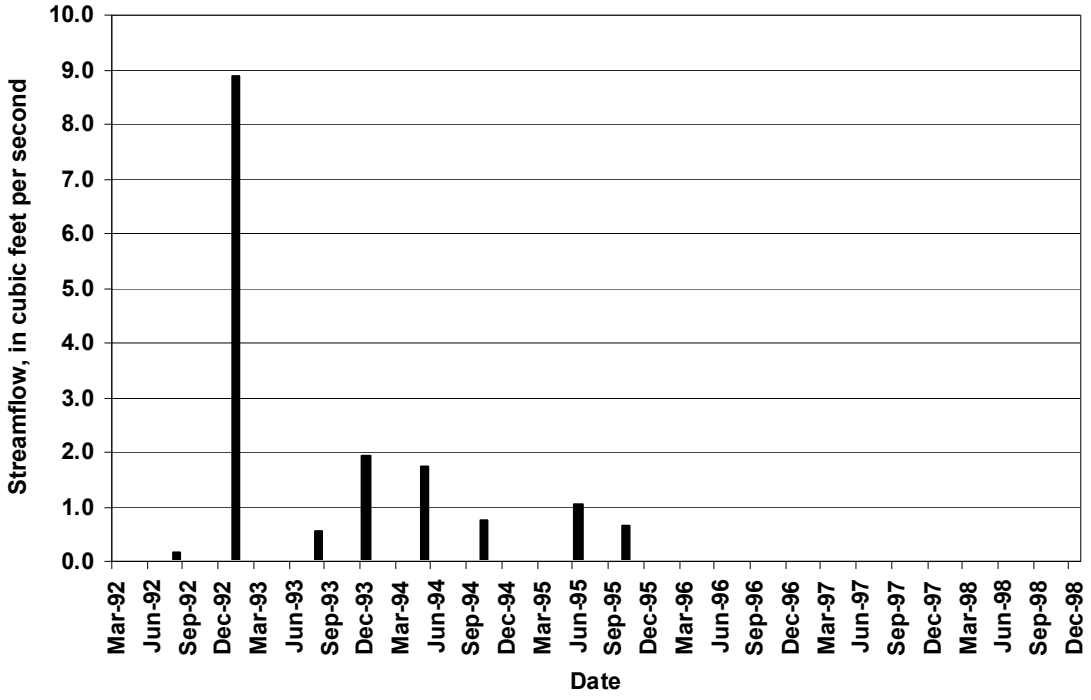


Site SC1, Sycamore Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
08/19/92	1230	472	8.2	33.0/29.5	---	[1]7.7?	---	320	0.17
01/28/93	1030	310	8.3	13.5/8.0	0.85	8.6	83	210	8.90
08/12/93	0930	530	8.4	30.5/25.5	5.70	7.5	104	350	0.57
12/09/93	0940	470	8.7	8.5/5.0	0.65	11.4	103	310	1.95
05/10/94	0840	510	8.3	15.0/13.0	2.44	8.4	92	340	1.73
10/26/94	1320	530	8.3	30.0/20.0	2.18	7.3	92	350	0.75
06/05/95	1015	460	8.6	28.0/24.0	0.81	7.0	97	300	1.06
10/25/95	0950	540	8.4	18.0/14.0	---	---	---	360	0.67

[1]Value was marked with a "?" by the Bureau of Land Management.

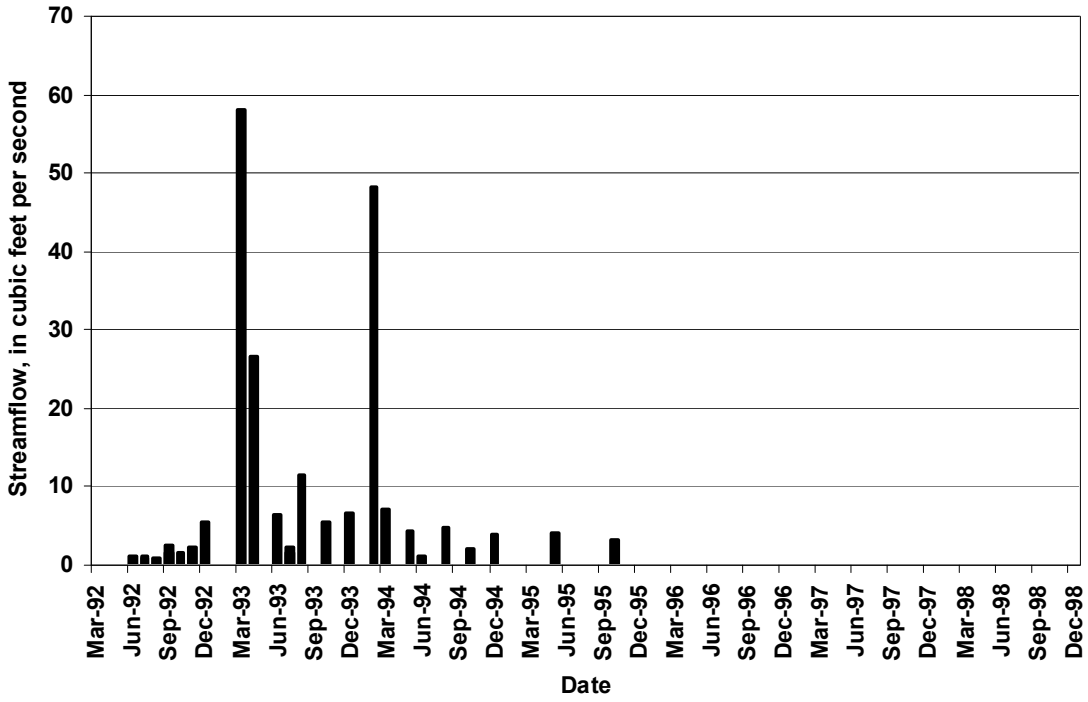


Site A2, Agua Fria River, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; e, estimated; ---, not reported; >, greater than]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
06/25/92	1030	870	8.1	32.0/26.0	---	---	---	595	1.23
07/13/92	0900	880	8.2	25.0/23.5	---	---	---	600	0.91
07/31/92	0900	960	8.2	26.0/24.5	---	---	---	660	1.1
08/19/92	0940	1,015	8.2	29.0/27.0	---	---	---	694	1.02
09/04/92	0815	785	8.2	26.0/20.0	---	7.7	96	539	2.63
09/25/92	0900	922	8.3	25.0/22.0	---	8.4	106	631	1.68
10/20/92	0815	970	8.3	18.5/15.5	---	9.1	103	670	1.50
11/06/92	0930	890	8.4	14.0/12.5	---	9.9	105	610	2.37
12/07/92	1100	670	8.5	12.0/11.0	---	---	---	460	5.58
03/04/93	0930	530	8.4	11.0/9.0	406.00	9	89	350	e150
03/18/93	1200	740	8.2	19.5/18.0	77.40	8.2	99	490	58.14
04/19/93	1015	750	8.1	19.5/17.5	20.30	7.1	79	500	26.61
06/01/93	0830	800	8.4	22.0/19.5	1.48	8.3	90	530	6.36
07/02/93	1215	840	8.4	31.0/29.0	1.83	6.7	99	550	2.22
07/29/93	1430	840	8.6	34.0/28.0	1.88	---	---	550	1.68
08/31/93	0845	700	8.4	23.5/22.0	24.00	8.4	109	460	11.4
10/22/93	0800	830	8.5	11.0/13.0	2.79	9.4	101	550	5.58
12/06/93	1245	710	8.5	17.5/15.0	4.34	8.7	98	470	6.73
02/10/94	1020	360	8.4	9.5/10.0	33.00	9.1	92	240	48.29
03/25/94	0800	720	8.3	8.0/9.0	1.02	10.1	100	480	7.14
05/09/94	1105	720	8.2	19.0/19.0	3.13	7.3	89	480	4.35
06/15/94	0910	880	8.5	26.0/22.5	3.23	7.2	95	580	1.06
08/09/94	0740	690	8.5	24.5/21.0	> 1,000	6.7	86	460	4.92
10/25/94	0810	1,140	8.4	14.0/13.0	2.02	8.0	89	750	1.99
12/21/94	1010	760	8.3	17.5/9.5	1.55	9.0	90	500	3.86
05/23/95	1145	740	8.4	23.0/24.0	1.5	7.1	95	490	4.09
10/04/95	0930	860	8.3	20.0/19.5	1.52	---	---	570	3.31

Site A2, Agua Fria River, Arizona—Continued

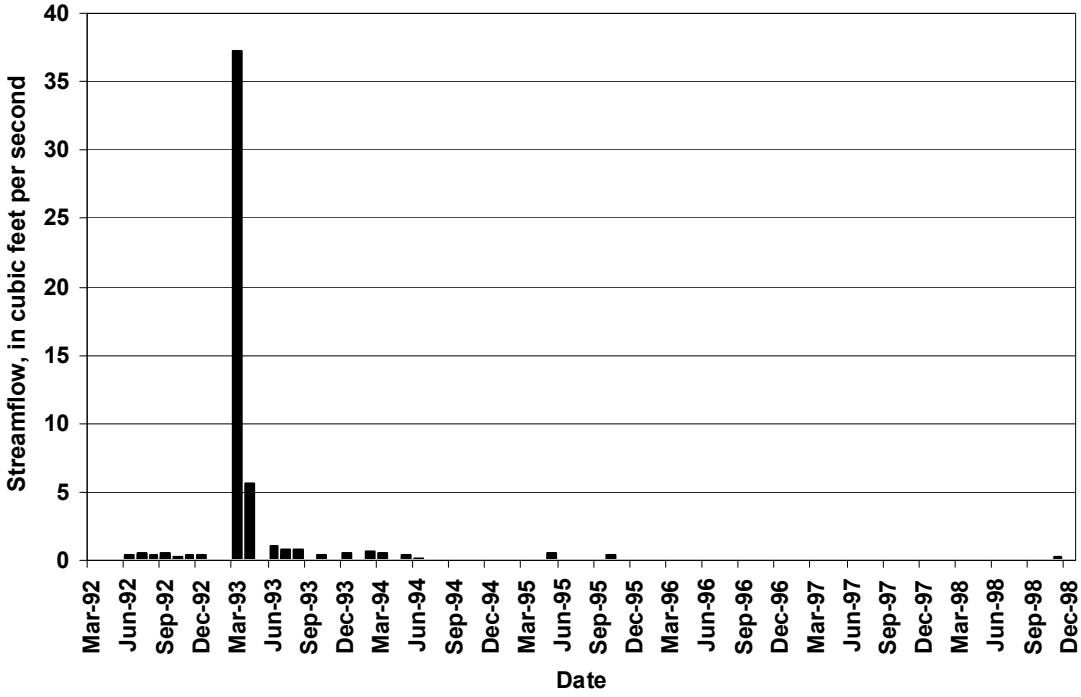


Site BB1, Big Bug Creek, Arizona

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
06/25/92	1115	560	7.9	33.0/26.0	---	---	---	390	0.45
07/13/92	0930	630	8.3	25.0/23.0	---	---	---	430	0.56
07/31/92	0945	650	8.3	24.0/25.0	---	---	---	450	0.44
08/19/92	1015	625	8.3	29.0/26.0	---	7.5	105	430	0.36
09/04/92	0900	690	8.4	26.0/18.0	---	8.9	106	460	0.56
09/25/92	0945	650	8.3	25.0/20.0	---	8.8	107	440	0.30
10/20/92	0900	690	8.5	17.5/12.0	---	9.7	102	470	0.29
11/06/92	1015	690	8.4	15.0/8.5	---	10.5	102	480	0.38
12/07/92	1200	650	8.5	12.0/8.0	---	11	106	450	0.36
03/04/93	0830	500	8.4	11.0/9.0	14.60	9.7	96	330	37.20
04/19/93	1115	770	8.3	19.5/17.5	0.79	7.8	93	510	5.65
06/01/93	0930	820	8.5	24.0/18.5	0.70	9.1	110	540	1.08
07/02/93	0957	800	8.2	23.0/23.0	2.76	8.8	104	530	0.77
07/29/93	1300	770	8.7	29.0/20.5	1.44	---	---	510	0.38
08/31/93	1015	890	8.0	24.0/22.5	1.54	8.4	110	590	0.74
10/22/93	0900	880	8.6	12.0/11.0	0.85	10.0	103	580	0.44
12/06/93	1415	800	8.4	17.5/10.5	0.77	9.5	97	530	0.58
02/10/94	1145	740	8.4	12.0/10.0	1.10	9.0	91	490	0.61
03/25/94	0910	810	8.3	11.5/9.0	1.11	9.2	91	530	0.51
05/09/94	1145	790	8.1	18.0/18.5	0.67	8.1	98	520	0.35
06/15/94	0955	890	8.4	28.0/23.0	0.88	7.6	100	590	0.07
08/09/94	0815	---	---	---	---	---	---	---	0.00
10/28/94	0840	---	---	---	---	---	---	---	0.00
12/21/94	1105	900	8.3	18.0/8.0	1.64	9.1	87	590	0.015
05/23/95	1250	670	8.4	23.0/25.5	1.52	6.5	90	440	0.59
10/04/95	1040	760	8.3	24.0/17.0	1.25	---	---	500	0.38
11/04/98	1430	700	8.4	20.0/20.0	---	---	---	460	0.3

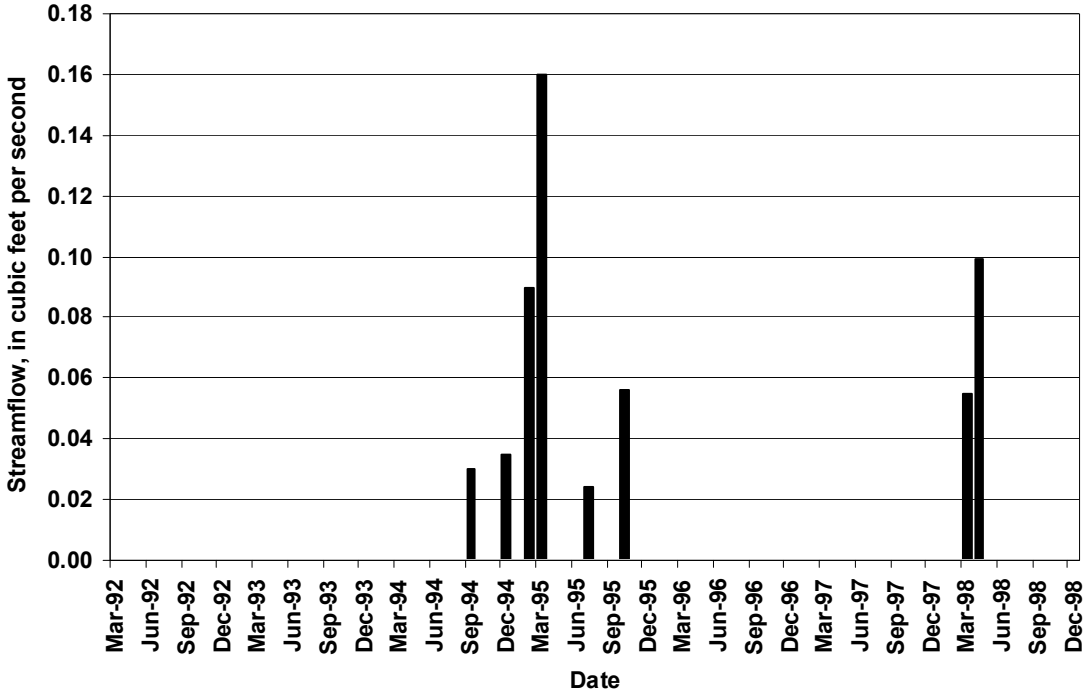
Site BB1, Big Bug Creek, Arizona—Continued



Site AN1, Antelope Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

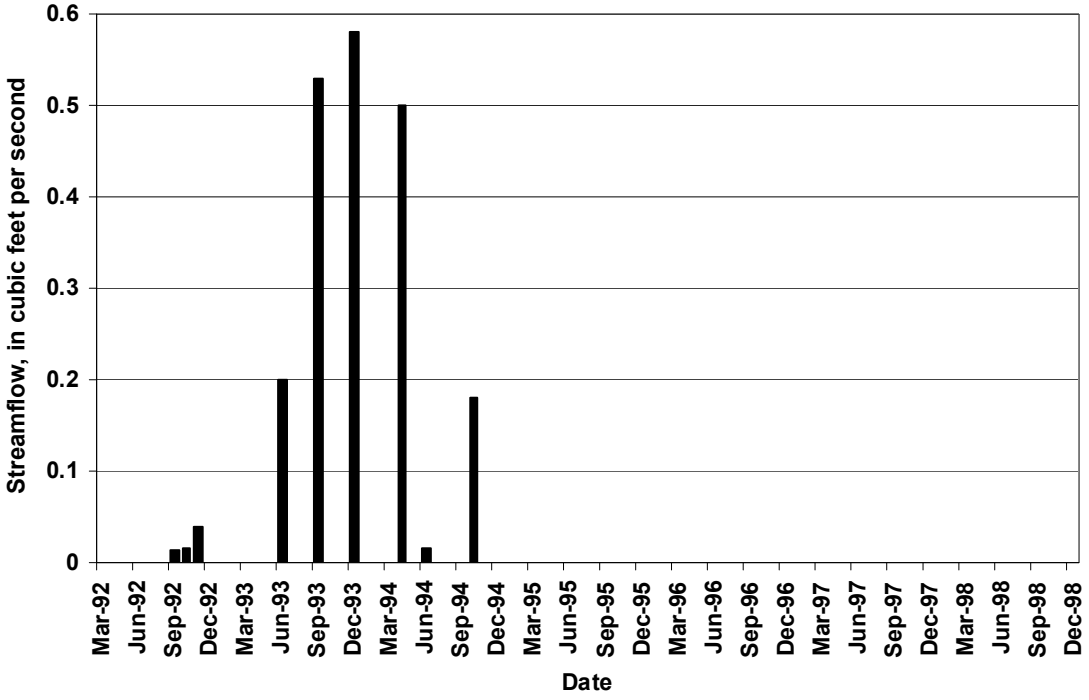
Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
09/30/94	0825	900	8.2	23.5/19.0	0.66	6.7	83	600	0.03
12/21/94	1215	760	8.3	19.0/12.0	0.89	8.5	89	500	0.035
02/08/95	1445	770	8.3	18.0/15.5	1.15	---	---	510	0.09
03/15/95	0840	810	8.3	17.0/14.0	2.19	---	---	530	0.16
07/13/95	0925	800	8.0	24.0/24.0	1.85	---	---	530	0.024
10/20/95	1035	780	8.3	25.5/18.0	1.50	---	---	510	0.056
03/23/98	1420	760	8.3	27.0/23.0	---	---	---	500	0.055
04/14/98	1450	770	8.3	16.0/18.0	1.03	---	---	500	0.099



Site I1, Indian Creek, Arizona

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

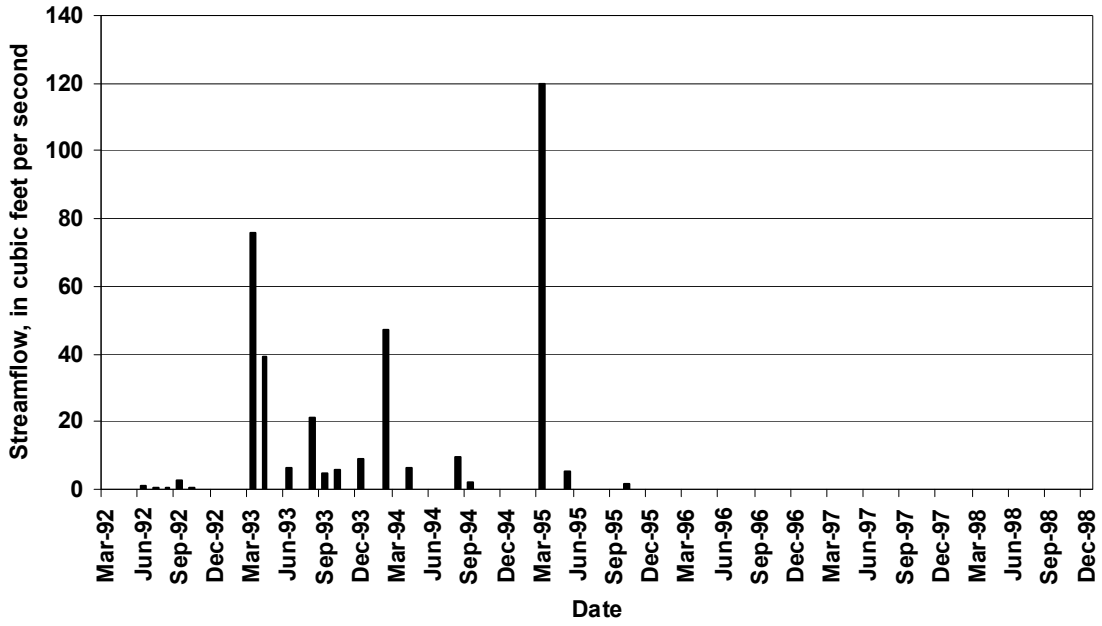
Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
09/14/92	1345	670	7.3	37.0/25.0	---	---	---	460	0.014
10/05/92	1030	742	7.7	25.0/22.0	---	---	---	510	0.015
11/18/92	0915	640	8.2	10.5/10.0	---	8.5	86	420	0.04
06/15/93	0845	640	8.5	27.0/22.0	1.27	7.8	102	420	0.20
09/02/93	0815	620	8.3	23.0/21.5	1.48	8.5	109	410	0.53
12/21/93	1000	530	8.4	6.0/5.0	0.53	11.4	102	350	0.58
04/05/94	0840	580	8.5	11.5/12.0	0.51	9.3	98	380	0.50
06/29/94	0835	850	8.3	33.0/24.0	1.94	6.5	88	560	0.016
10/27/94	0955	760	8.3	20.0/15.5	1.18	8.2	94	500	0.18



Site A3, Agua Fria River, Arizona

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported; >, greater than]

Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
06/25/92	1400	620	7.9	35.0/25.0	---	---	---	430	0.81
07/13/92	1130	720	7.9	29.0/25.0	---	---	---	490	0.43
08/19/92	0830	760	7.9	28.0/22.0	---	---	---	520	0.66
09/13/92	1030	670	8.2	28.0/23.0	---	5.5	70	450	2.42
10/20/92	1015	780	7.8	24.5/22.5	---	5.8	73	530	0.51
03/18/93	1400	720	8.3	20.5/19.5	58.30	7.4	90	480	75.81
04/19/93	1330	790	8.1	23.0/23.0	20.20	7.2	94	520	39.05
06/01/93	1200	820	8.3	27.0/25.5	1.82	6.7	92	540	6.53
08/04/93	1000	680	8.4	30.0/24.3	---	---	---	450	21.11
09/16/93	1330	890	8.4	28.0/26.5	9.76	6.4	90	590	5.03
10/22/93	1050	840	8.5	20.0/19.0	2.50	7.2	87	550	5.92
12/08/93	1200	730	8.5	13.5/11.0	2.59	9.7	99	480	8.93
02/11/94	1005	500	8.4	7.5/7.0	30.50	10.5	97	330	47.10
04/25/94	0940	680	8.4	12.0/15.5	4.51	8.4	95	450	6.16
08/09/94	0955	600	7.8	30.0/26.0	> 1,000	4.9	67	400	9.57
09/14/94	1225	970	8.1	27.5/28.5	15.8	6.3	90	640	1.93
03/14/95	1405	480	8.2	24.0/20.0	122	7.9	97	320	120
05/24/95	0930	720	8.3	21.5/20.5	0.84	7.6	94	480	5.28
10/16/95	1455	790	8.1	28.0/22.5	2.07	---	---	520	1.40
10/09/98	1530	690	8.6	23.0/23.0	---	---	---	450	0.06

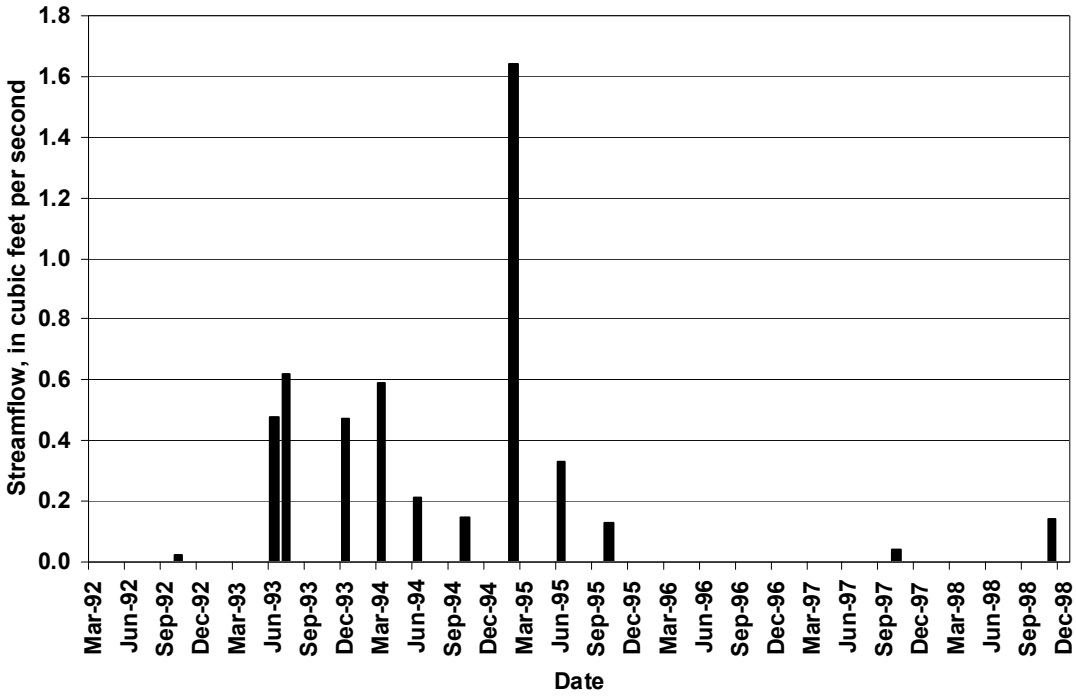


Site S1, Silver Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
10/05/92	0830	630	8.4	24.0/16.0	---	[1]9.3?	---	430	0.024
06/01/93	1330	550	8.5	30.5/27.0	0.69	7.2	103	360	0.48
07/13/93	0830	630	8.2	25.0/22.5	0.76	8.1	105	420	0.62
12/08/93	0940	550	8.6	6.0/5.0	0.30	11.6	103	360	0.47
03/10/94	0820	540	8.40	6.0/6.5	0.36	8.8	69	360	0.59
06/05/94	0915	630	8.40	28.5/19.0	0.62	8.0	98	420	0.21
10/27/94	1415	660	8.30	25.0/19.0	1.74	7.6	96	440	0.15
02/20/95	1130	460	8.30	20.0/18.0	0.62	8.3	98	300	1.64
06/01/95	1050	590	8.40	30.5/23.5	0.80	7.3	99	390	0.33
10/16/95	1255	610	8.30	28.5/21.0	0.84	---	---	400	0.13
10/04/97	1050	820	8.00	26.0/26.0	3.33	---	---	540	0.04
11/13/98	1050	690	8.30	18.0/10.5	---	---	---	450	0.14

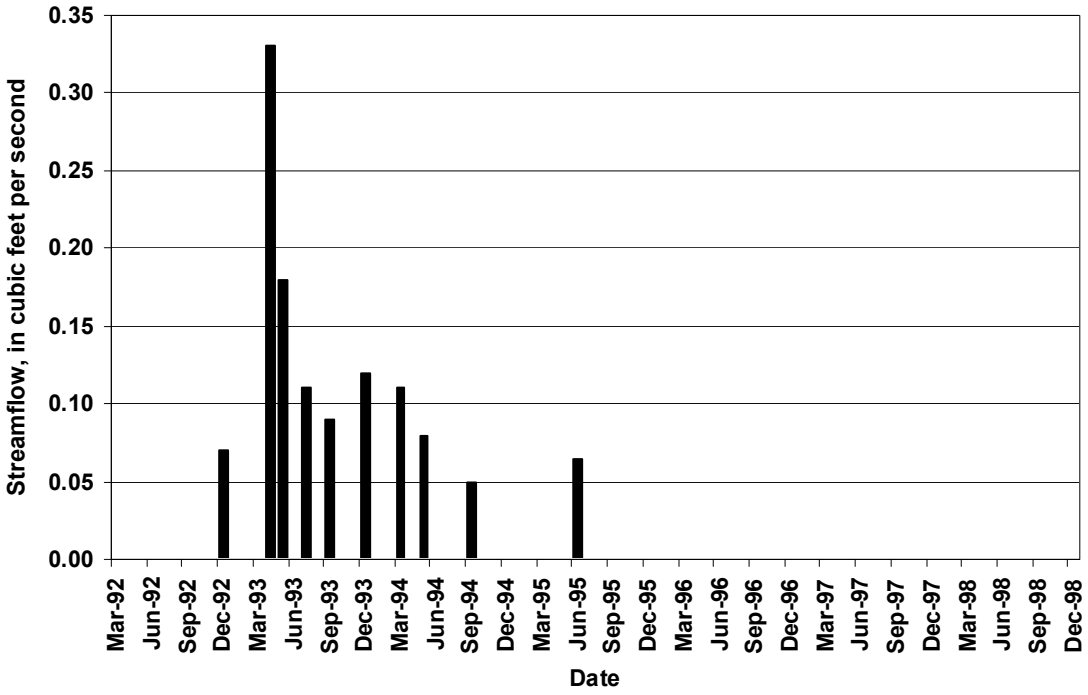
[1]Value was marked with a "?" by the Bureau of Land Management.



Site LR1, Larry Creek Tributary, Arizona

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

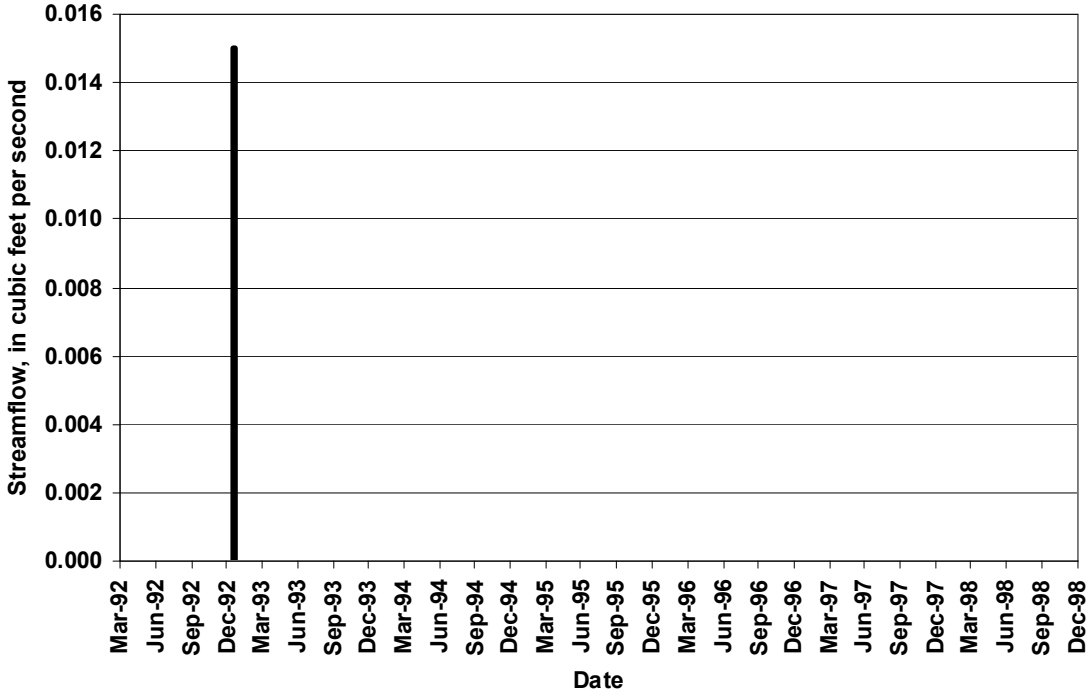
Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
12/17/92	1400	625	8.1	8.0/15.0	0.20	5.9	65	425	0.07
04/17/93	1000	610	8.1	15.0/17.0	0.85	7.8	90	400	0.33
05/21/93	0930	610	8.3	21.5/20.0	1.16	7.6	93	400	0.18
07/08/93	0845	620	8.0	26.0/22.0	1.04	6.8	87	410	0.11
09/24/93	0830	620	8.3	20.5/20.0	1.90	7.9	97	410	0.09
12/20/93	1145	500	8.1	10.5/13.0	0.19	8.9	94	330	0.12
03/11/94	0830	540	8.2	12.0/15.0	0.46	7.3	80	360	0.11
05/25/94	0830	590	8.1	18.5/18.5	0.55	6.4	76	390	0.08
09/14/94	0835	650	8.0	18.0/20.0	0.47	7.3	89	430	0.05
06/22/95	0835	590	8.0	21.0/20.0	0.62	7.4	91	390	0.06



Site LR2, Larry Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
12/17/92	1200	775	8.6	9.0/9.5	0.45	10.6	102	530	0.015

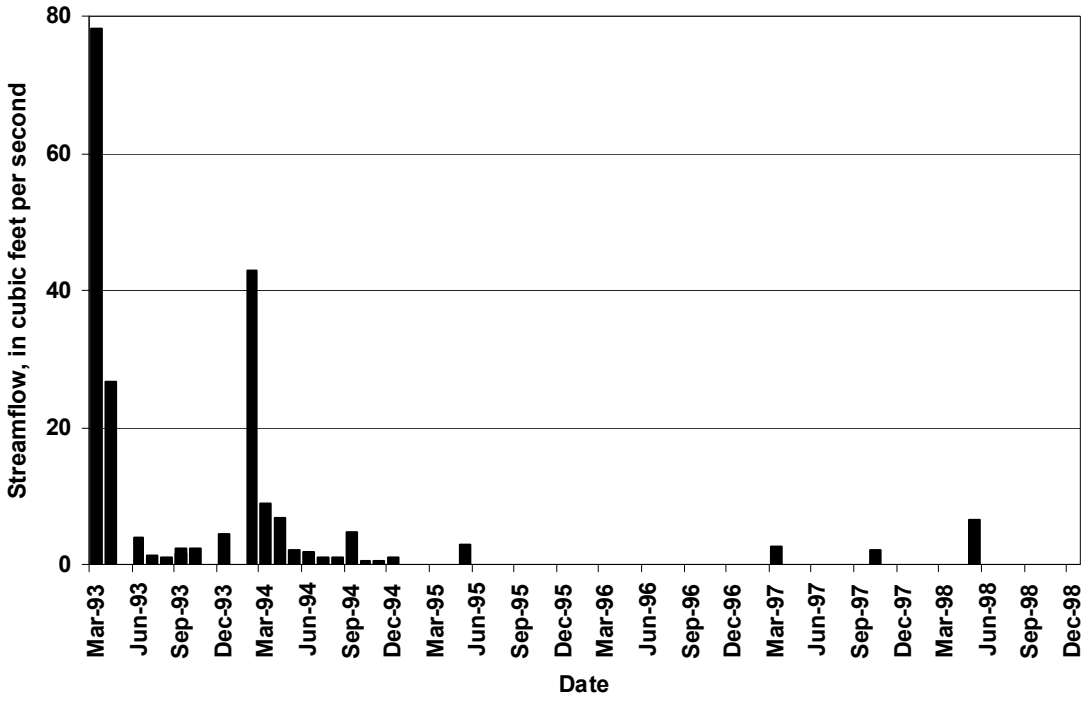


Site BCC1, Black Canyon Creek, Arizona

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; ---, not reported]

Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
03/19/93	1200	670	8.4	22.0/15.5	0.94	9.1	99	440	78.18
04/20/93	1130	770	8.3	25.0/19.0	0.49	8.5	99	510	26.58
06/02/93	0835	850	8.1	25.5/20.5	0.76	8.2	99	560	4.03
07/01/93	1415	760	8.6	33.0/31.0	0.98	7.2	104	500	1.33
08/04/93	1300	730	8.9	31.0/30.2	0.65	7.0	112	480	1.17
09/01/93	1300	810	8.5	33.5/32.0	3.67	7.2	106	530	2.40
09/28/93	0930	800	8.5	28.0/19.5	1.11	8.8	104	530	1.58
10/23/93	1200	860	8.6	23.0/18.5	0.93	8.7	100	570	2.37
12/05/93	1430	780	8.8	21.0/13.5	1.71	9.7	101	510	4.38
02/11/94	1155	400	8.4	13.0/9.5	14.00	9.9	94	260	42.92
03/08/94	1115	710	8.5	16.0/13.0	0.94	9.3	96	470	8.88
04/01/94	1445	720	8.7	27.0/23.0	0.69	8.0	100	480	6.80
05/06/94	1145	970	8.1	27.5/22.0	1.03	7.6	95	640	2.04
06/03/94	0735	1,020	8.3	25.0/19.0	0.97	7.9	93	670	1.70
07/01/94	0740	1,190	8.2	29.5/25.0	1.16	7.2	93	790	0.99
08/04/94	0735	1,230	8.3	25.0/24.0	2.65	---	---	810	1.12
09/11/94	0720	1,100	8.2	22.5/22.5	4.88	5.2	65	730	4.73
10/02/94	1010	1,170	8.3	27.0/19.0	1.36	8.5	100	770	0.53
11/10/94	1635	1,020	8.3	22.0/16.5	1.09	8.5	95	670	0.61
12/14/94	1230	1,010	8.4	15.0/10.5	0.62	9.7	95	670	0.96
05/24/95	1140	610	8.6	23.0/21.5	1.56	8.1	100	400	3.00
07/26/95	0850	---	---	---	---	---	---	---	0.00
03/24/97	1400	410	8.4	26.0/20.0	0.97	---	---	270	2.58
10/15/97	1130	19	7.9	27.5/---	---	---	---	490	0.03
10/30/97	1120	420	8.3	19.0/8.0	---	---	---	270	2.12
05/07/98	1050	360	8.6	19.0/8.0	0.43	---	---	230	6.61
06/12/98	1140	560	8.1	28.5/25.0	1.47	---	---	360	0.00
10/20/98	0920	540	8.7	20.0/14.5	---	---	---	350	0.00

Site BCC1, Black Canyon Creek, Arizona—Continued

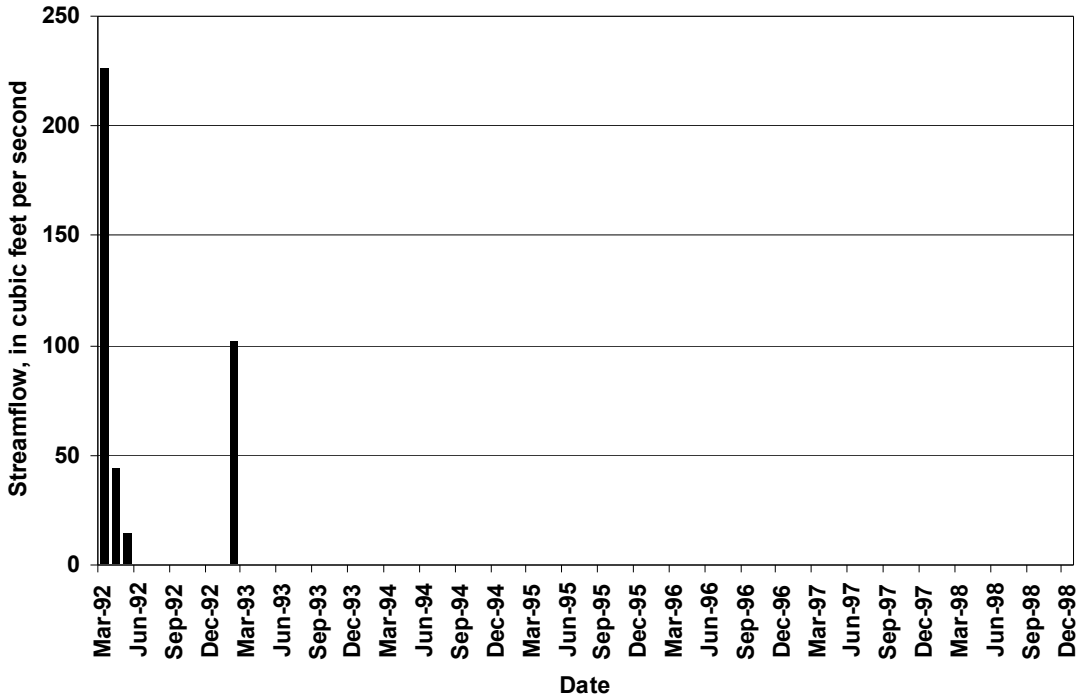


Site BCC2, Black Canyon Creek, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; e, estimated; ---, not reported; sl, slightly; v, very]

Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity[1] (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
03/13/92	1030	150	8.1	18.0/12.0	cloudy	9.4	104	100	226.00
03/25/92	0845	260	8.4	13.1/12.7	clear	---	---	170	52.50
03/31/92	1230	180	8.3	13.0/15.0	clear	---	---	120	131.70
04/10/92	0915	230	8.2	19.0/16.5	clear	---	---	150	44.10
04/23/92	1340	360	8.4	31.0/25.5	clear	---	---	240	8.40
05/07/92	1105	350	8.3	28.5/23.0	sl cloudy	---	---	230	14.40
05/21/92	1000	---	---	---	---	---	---	---	0.00
06/05/92	0730	500	---	23.0/21.0	clear	---	---	270	0.05
06/25/92	0915	---	---	---	---	---	---	---	0.00
07/30/92	1600	---	---	---	---	---	---	---	0.00
08/19/92	0815	---	---	---	---	---	---	---	0.00
09/25/92	0900	---	---	---	---	---	---	---	0.00
10/20/92	1100	---	---	---	---	---	---	---	0.00
11/07/92	1700	---	---	---	---	---	---	---	0.00
12/08/92	1230	295	8.5	11.0/9.5	v cloudy	---	---	200	e80
01/07/93	1715	110	8.4	13.5/11.5	896	---	---	73	e1,000
02/03/93	1100	390	8.2	15.0/13.0	4.5	10.6	100	260	102.00

[1]Some entries are descriptive rather than NTU values.



Site A5, Agua Fria River, Arizona

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; ppm, parts per million; ft^3/s, cubic feet per second; e, estimated; ---, not reported; sl, slightly]

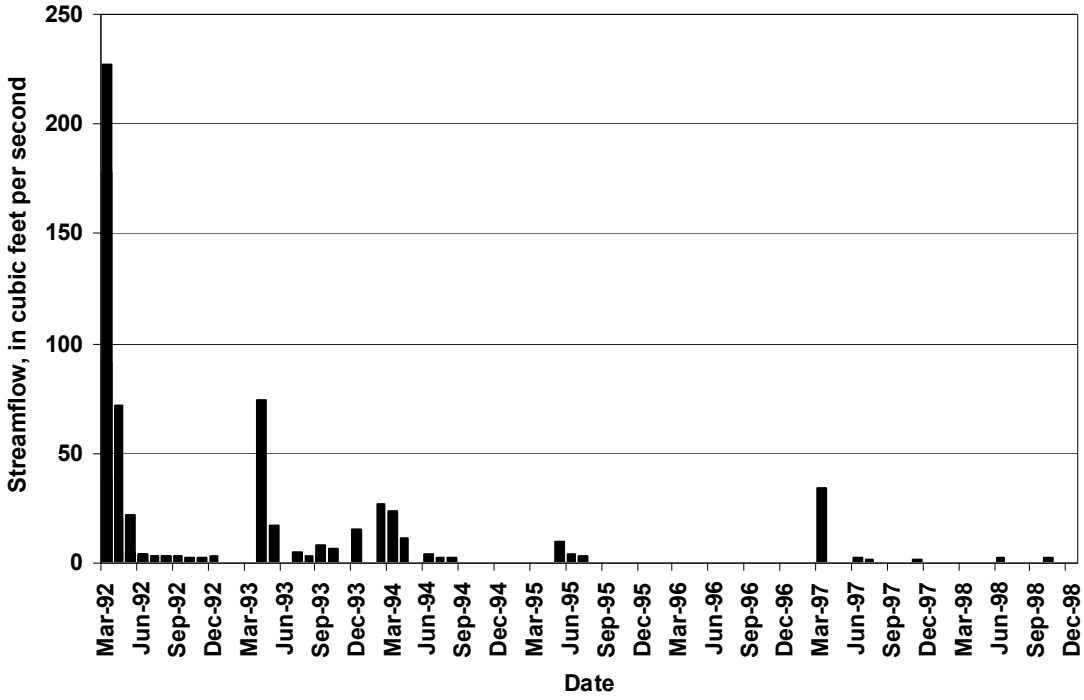
Date	Time	Specific conductance (µS/cm)	pH	Air/water temperature (°C)	Turbidity[1] (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
03/01/92	1130	440	8.6	19.5/17.0	---	---	---	290	38.40
03/05/92	1745	320	8.7	15.0/14.2	cloudy	---	---	210	178.50
03/13/92	1500	240	8.9	24.0/17.5	cloudy	---	---	160	e 400
03/25/92	1010	370	9.1	18.0/14.5	clear	---	---	240	91.40
03/31/92	1430	280	9.2	16.0/18.0	---	---	---	180	226.80
04/10/92	1100	360	9.2	24.0/19.0	clear	---	---	240	72.10
04/23/92	1515	420	8.5	32.0/25.7	clear	---	---	280	20.20
05/08/92	1245	400	8.1	26.0/23.0	sl cloudy	---	---	260	22.40
05/21/92	1120	570	8.4	20.0/20.5	clear	---	---	380	4.90
05/29/92	1130	570	8.3	29.5/25.0	clear	---	---	380	4.60
06/05/92	845	600	8.0	25.0/21.0	clear	---	---	320	4.10
06/15/92	1900	600	7.9	29.0/21.0	clear	---	---	320	2.60
06/25/92	800	640	7.8	26.0/22.0	clear	---	---	440	4.20
07/13/92	645	685	7.9	19.0/20.5	clear	---	---	465	3.20
07/31/92	700	670	7.9	24.0/22.0	sl cloudy	5.9	73	460	3.30
08/02/92	800	645	8.1	26.0/24.0	clear	6.0	77	440	2.90
08/19/92	715	660	7.9	29.0/24.0	sl cloudy	7.4	95	450	2.90
09/05/92	1230	580	8.1	29.0/27.5	clear			400	3.40
09/26/92	1030	630	8.0	33.0/23.5	clear	7.4	94	430	3.10
10/20/92	1130	660	8.1	26.5/21.5	clear	9.1	111	450	2.80
11/07/92	1730	660	8.0	16.5/19.5	clear	7.0	82	450	2.60
12/26/92	1100	600	8.2	16.0/14.5	1.00	8.5	89	400	3.2
01/06/93	1430	380	8.2	12.0/12.0	9.00	---	---	250	e 150
03/05/93	1000	530	8.5	18.0/11.0	61.50	9.5	93	350	e 350
04/20/93	930	730	8.3	21.5/16.0	1.69	8.1	88	480	74.21
05/29/93	---	760	8.4	27.0/23.5	0.92	6.7	85	500	17.11
07/11/93	1118	720	8.4	31.0/25.5	1.03	---	---	480	4.75
08/04/93	1500	730	8.4	31.0/28.5	0.92	---	---	480	3.25
09/01/93	1630	750	8.2	33.0/30.5	36.40	5.8	83	500	8.44
09/28/93	1130	790	8.5	31.0/27.5	1.69	6.2	85	520	3.37
10/22/93	1545	760	8.5	23.0/22.0	1.13	8.1	100	500	6.47
12/04/93	1045	720	8.6	13.0/12.5	0.94	10.0	101	480	15.16
02/04/94	1030	690	8.3	14.5/10.5	1.03	9.7	94	460	27.18
03/08/94	1530	710	8.5	18.5/18.0	1.03	8.6	98	470	23.69
04/15/94	1500	730	8.3	31.5/27.0	1.18	6.8	92	480	11.63
06/03/94	925	880	8.3	31.5/23.0	1.71	7.9	99	580	4.23
07/10/94	740	990	8.1	30.0/21.0	1.50	8.1	85	650	2.65

See footnote at end of table.

Site A5, Agua Fria River, Arizona—Continued

Date	Time	Specific conductance (μS/cm)	pH	Air/water temperature (°C)	Turbidity[1] (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Dissolved solids (ppm)	Discharge (ft^3/s)
08/09/94	1155	910	8.2	34.0/30.5	2.30	---	---	600	2.59
09/13/94	1510	780	8.0	33.0/28.5	401.00	6.9	96	510	e 20.5
03/14/95	1405	310	8.2	27.0/19.0	40.1	8.5	99	200	e 480
05/15/95	900	670	8.6	24.0/20.0	1.96	7.8	93	440	9.7
06/27/95	925	720	8.1	29.0/22.0	1.02	---	---	480	4.02
07/26/95	1020	720	8.1	34.0/24.0	1.10	---	---	480	2.86
03/12/97	1415	410	8.4	30.0/22.0	5.32	---	---	270	34.06
06/05/97	900	760	8.1	28.0/21.0	29.10	---	---	500	2.40
07/03/97	910	730	7.6	30.5/22.0	---	---	---	480	1.66
11/18/97	1505	770	8.2	21.0/19.0	---	---	---	510	1.44
06/09/98	1130	660	8.5	27.0/22.5	0.43	---	---	430	2.41
10/08/98	1025	640	8.3	26.0/20.0	---	---	---	420	2.37

[1]Some entries are descriptive rather than NTU values.



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