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Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2004–05

Open-File Report 2006–1058

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

Cover: Photograph of the northern cliffs of Black Mesa on Indian Route 59 near Rough Rock on the Navajo Indian Reservation, Arizona. (Photograph taken by Margot Truini, U.S. Geological Survey, Flagstaff, Arizona, 2006.)

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By Margot Truini and J.P. Macy

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U.S. Department of the Interior
P. Lynn Scarlett, Acting Secretary

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

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

$$°F=(1.8\times°C)+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Elevation, as used in this report, refers to distance above the vertical datum.

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Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2004–05

By Margot Truini and J.P. Macy

Abstract

The N aquifer is the major source of water in the 5,400-square-mile area of Black Mesa in northeastern Arizona. Availability of water is an important issue in this area because of continued industrial and municipal use, a growing population, and precipitation of about 6 to 14 inches per year.

The monitoring program in the Black Mesa area has been operating since 1971 and is designed to determine the long-term effects of ground-water withdrawals from the N aquifer for industrial and municipal uses. The monitoring program includes measurements of (1) ground-water pumping, (2) ground-water levels, (3) spring discharge, (4) surface-water discharge, (5) ground-water chemistry, and (6) periodic testing of ground-water withdrawal meters.

In 2004, total ground-water withdrawals were 7,210 acre-feet, industrial withdrawals were 4,370 acre-feet, and municipal withdrawals were 2,840 acre-feet. From 2003 to 2004, total withdrawals decreased by less than 1 percent, industrial withdrawals decreased by 2 percent, and municipal withdrawals increased by 2 percent.

From 2004 to 2005, annually measured water levels declined in 6 of 13 wells in the unconfined areas of the aquifer, and the median change was -0.1 foot. Water levels declined in 8 of 12 wells in the confined area of the aquifer, and the median change was -1.2 feet. From the prestress period (prior to 1965) to 2005, the median water-level change for 33 wells was -9.0 feet. Median water-level changes were -0.6 foot for 16 wells in the unconfined areas and -32.0 feet for 17 wells in the confined area.

Discharges were measured once in 2004 and once in 2005 at four springs. Discharge increased by 8 percent at Pasture Canyon Spring, decreased by 5 percent at Moenkopi School Spring, increased by 71 percent at an unnamed spring near Dennehotso, and stayed the same at Burro Spring. For the period of record at each spring, discharges from the four springs have fluctuated; however, an increasing or decreasing trend is not apparent.

Continuous records of surface-water discharge have been collected from 1976 to 2004 at Moenkopi Wash, 1996 to 2004 at Laguna Creek, 1993 to 2004 at Dinnebito Wash, 1994 to 2004 at Polacca Wash, and August 2004 to December 2004 at Pasture Canyon Spring. Median flows for November, December, January, and February of each water year were used as an index of ground-water discharge to those streams. Since 1995, the median winter flows have decreased for Moenkopi Wash, Dinnebito Wash, and Polacca Wash. Since the first continuous record of surface-water discharge in 1997, there is no consistent trend in the median winter flow for Laguna Creek.

In 2005, water samples were collected from 11 wells and 4 springs and analyzed for selected chemical constituents. Dissolved-solids concentrations ranged from 122 to 639 milligrams per liter. Water samples from 9 of the wells and from all the springs had less than 500 milligrams per liter of dissolved solids. There are some long-term trends in the chemistry of water samples from 7 wells having more than 10 years of data and from 2 springs. Rough Rock PM5, Keams Canyon PM2, Second Mesa PM2, and Kayenta PM2 show an increasing trend in dissolved solids; Forest Lake NTUA1 and PWCC 2 show a decreasing trend in dissolved solids; and Kykostmovi PM2 shows a steady trend. Increasing trends in dissolved-solids and chloride concentrations were evident from the more than 11 years of data for 2 springs.

Introduction

The Black Mesa study area includes about 5,400 mi^2 in northeastern Arizona (fig. 1) and has a diverse topography that includes flat plains, mesas, and incised drainages. Black Mesa is about 2,000 mi^2, is bounded by 2,000-foot cliffs on the north and northeast sides, and slopes gradually down in elevation to the south and southwest. Availability of water is an important issue in the study area because of continued ground-water withdrawals, a growing population, and precipitation that averages about 6 to 14 in./yr (U.S. Department of Agriculture, 1999). The N aquifer is the major source of water for industrial and municipal uses in the Black Mesa area. It consists of three formations—the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Member of the Wingate Sandstone—that are hydraulically connected and function as a single aquifer (fig. 2).

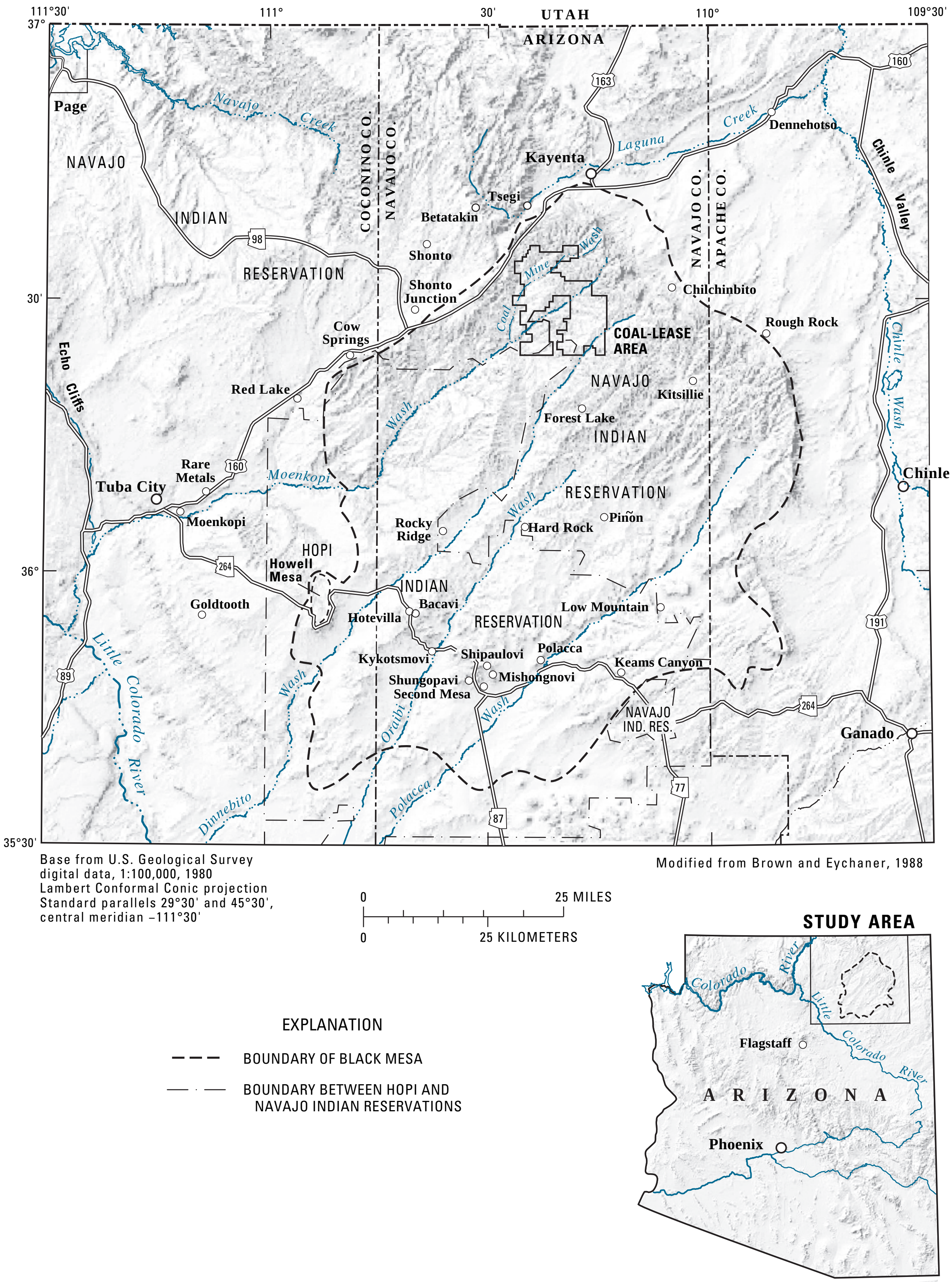


Figure 1. Location of study area.

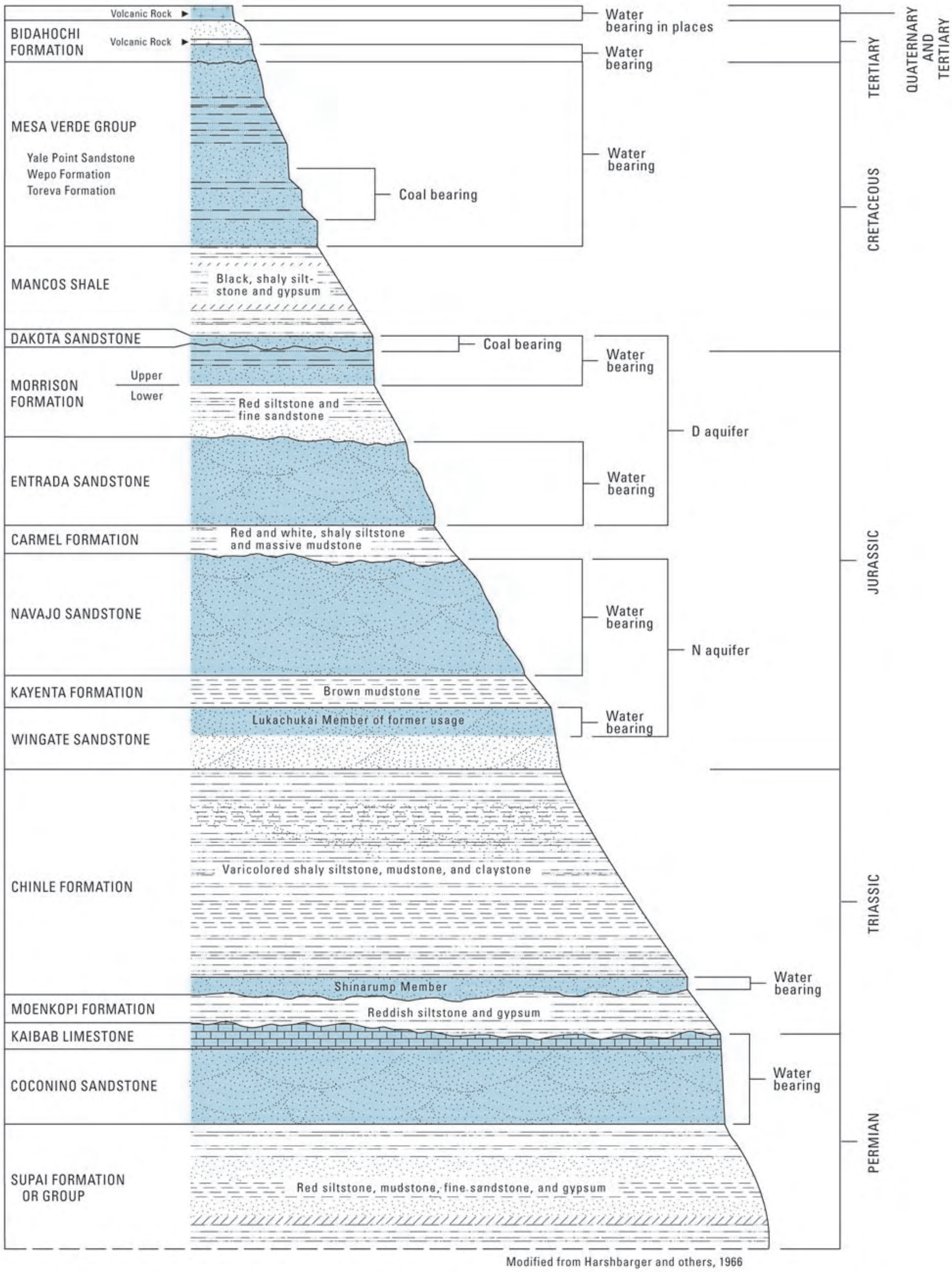


Figure 2. Rock formations and hydrogeologic units of the Black Mesa area, Arizona (not to scale).

Within the Black Mesa study area, Peabody Western Coal Company (PWCC) is the principal industrial water user, and the Navajo Nation and Hopi Tribe are the principal domestic and municipal water users. Withdrawals from the N aquifer in the Black Mesa area have been increasing during the last 34 years (table 1 and fig. 3). PWCC began operating a strip mine in the northern part of the mesa in 1968. The quantity of water pumped by PWCC increased from about 100 acre-ft in 1968 to a maximum of 4,740 acre-ft in 1982. About 4,370 acre-ft of water was pumped in 2004 by PWCC. Withdrawals for municipal use from the N aquifer increased from an estimated 250 acre-ft in 1968 to 2,840 acre-ft in 2004. The period before appreciable ground-water withdrawals began for mining or municipal purposes (about 1965) is referred to in this report as the prestress period.

The Navajo Nation and the Hopi Tribe have been concerned about the long-term effects of withdrawals from the N aquifer on available water supplies, on stream and spring discharge, and on ground-water chemistry. In 1971, these concerns led to the establishment of a monitoring program of the water resources in the Black Mesa area by the U.S. Geological Survey (USGS) in cooperation with the Arizona Department of Water Resources (ADWR). In 1983, the Bureau of Indian Affairs (BIA) joined the cooperative effort. Since 1983, the Navajo Tribal Utility Authority (NTUA); PWCC; the Hopi Tribe; and the Western Navajo Agency, the Chinle Agency, and the Hopi Agency of the BIA have assisted in the collection of hydrologic data.

Table 1. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–2004.

[Values are rounded to nearest 10 acre-feet. Data for 1965–79 from Eychaner (1983). Total withdrawals in Littin and Monroe (1996) were for the confined area of the aquifer]

Year	Industrial[1]	Municipal[2,3]		Total withdrawals
		Confined	Unconfined	
1965	0	50	20	70
1966	0	110	30	140
1967	0	120	50	170
1968	100	150	100	350
1969	40	200	100	340
1970	740	280	150	1,170
1971	1,900	340	150	2,390
1972	3,680	370	250	4,300
1973	3,520	530	300	4,350
1974	3,830	580	360	4,770
1975	3,500	600	510	4,610
1976	4,180	690	640	5,510
1977	4,090	750	730	5,570
1978	3,000	830	930	4,760
1979	3,500	860	930	5,290
1980	3,540	910	880	5,330
1981	4,010	960	1,000	5,970
1982	4,740	870	960	6,570
1983	4,460	1,360	1,280	7,100
1984	4,170	1,070	1,400	6,640
1985	2,520	1,040	1,160	4,720
1986	4,480	970	1,260	6,710
1987	3,830	1,130	1,280	6,240
1988	4,090	1,250	1,310	6,650
1989	3,450	1,070	1,400	5,920
1990	3,430	1,170	1,210	5,810
1991	4,020	1,140	1,300	6,460
1992	3,820	1,180	1,410	6,410
1993	3,700	1,250	1,570	6,520
1994	4,080	1,210	1,600	6,890
1995	4,340	1,220	1,510	7,070
1996	4,010	1,380	1,650	7,040
1997	4,130	1,380	1,580	7,090
1998	4,030	1,440	1,590	7,060
1999	4,210	1,420	1,480	7,110
2000	4,490	1,610	1,640	7,740
2001	4,530	1,490	1,660	7,680
2002	4,640	1,500	1,860	8,000
2003	4,450	1,350	1,440	7,240
2004	4,370	1,240	1,600	7,210

[1]Metered pumpage from the confined area of the aquifer by Peabody Western Coal Company.

[2]Does not include withdrawals from the wells equipped with windmills.

[3]Includes estimated pumpage, 1965–73, and metered pumpage, 1974–79, at Tuba City; metered pumpage at Kayenta and estimated pumpage at Chilchinbito, Rough Rock, Piñon, Keams Canyon, and Kykotsmovi before 1980; metered and estimated pumpage furnished by the Navajo Tribal Utility Authority and the Bureau of Indian Affairs and collected by the U.S. Geological Survey, 1980–85; and metered pumpage furnished by the Navajo Tribal Utility Authority, the Bureau of Indian Affairs, various Hopi Village Administrations, and the U.S. Geological Survey, 1986–2004.

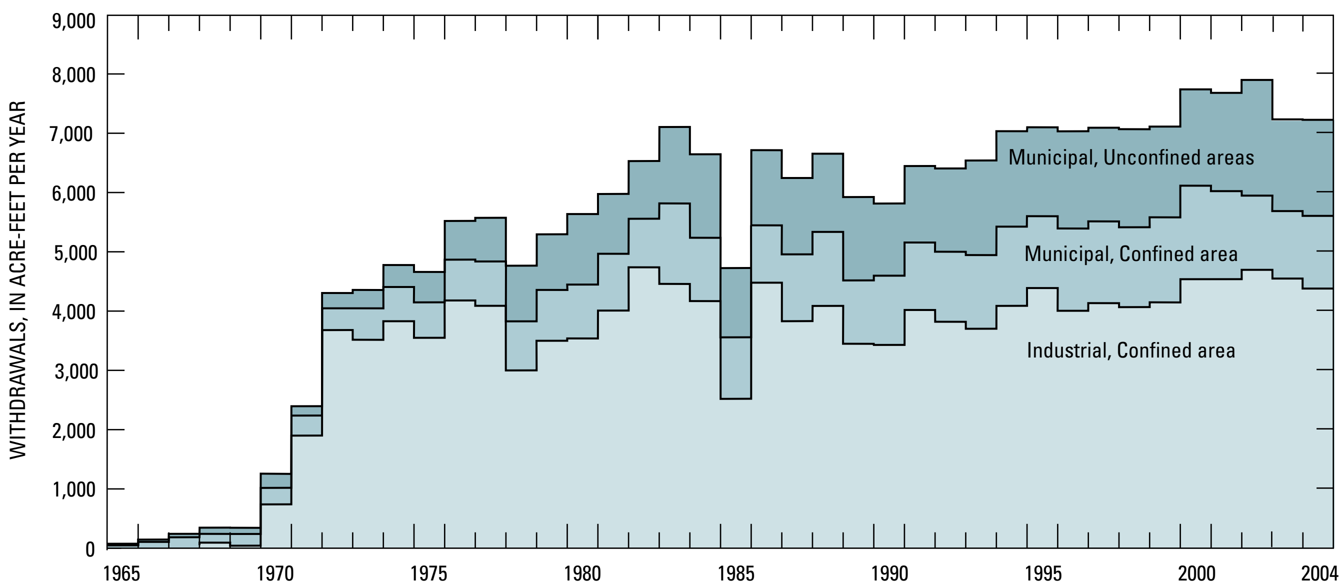


Figure 3. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–2004.

Purpose and Scope

This report presents results of ground-water, surface-water, and water-chemistry monitoring in the Black Mesa area from January 2004 to September 2005. The monitoring is designed to determine the effects of industrial and municipal pumpage from the N aquifer on ground-water levels, stream and spring discharge, and ground-water chemistry. Continuous and periodic data are collected for ground water and surface water. Ground-water data include pumpage, water levels, spring discharges, and water chemistry. Surface-water data include discharges at four continuous-record streamflow-gaging stations.

Previous Investigations

Twenty-two progress reports on the monitoring program for the Black Mesa area have been prepared by the USGS (U.S. Geological Survey, 1978; G.W. Hill, Hydrologist, written commun., 1982, 1983; Hill, 1985; Hill and Whetten, 1986; Hill and Sottilare, 1987; Hart and Sottilare, 1988, 1989; Sottilare, 1992; Littin, 1992, 1993; Littin and Monroe, 1995a, 1995b, 1996, 1997; Littin and others, 1999; Truini and others, 2000; Thomas and Truini, 2000; Thomas, 2002a, 2002b; Truini and Thomas, 2004; and Truini and others, 2005). Most of the data from the monitoring program are contained in these reports. Stream-discharge and periodic water-quality data from Moenkopi Wash collected before the 1982 water year were published by the USGS (1963–64a, b; 1965–74a, b; and 1976–83). Stream-discharge data from water years 1983 to 2003 for Moenkopi Wash and other streams in the Black Mesa area were published in White and Garrett (1984, 1986, 1987, and 1988), Wilson and Garrett (1988, 1989), Boner and others (1989, 1990, 1991, 1992), Smith and others (1993, 1994, 1995, 1996, 1997), Tadayon and others (1998, 1999, 2000, 2001), McCormack and others (2002, 2003), Fisk and others (2004, 2005). Before the monitoring program, a large data-collection effort in the 1950s resulted in a compilation of well and spring data for the Navajo and Hopi Indian Reservations (Davis and others, 1963).

Many interpretive studies have been done in the Black Mesa area. Cooley and others (1969) made the first comprehensive evaluation of the regional hydrogeology of the Black Mesa area. Eychaner (1983) developed a two-dimensional numerical model of ground-water flow in the N aquifer. Brown and Eychaner (1988) recalibrated the model using a finer grid and revised estimates of selected aquifer characteristics. GeoTrans (1987) also developed a two-dimensional model of the N aquifer in the 1980s. In the late 1990s, HSIGeoTrans and Waterstone Environmental Hydrology and Engineering (1999) developed a detailed three-dimensional numerical model of the D and N aquifers.

Kister and Hatchett (1963) made the first comprehensive evaluation of the chemistry of water from wells and springs in the Black Mesa area. HSIGeoTrans (1993) evaluated the major-ion and isotopic chemistry of the D and N aquifers. Lopes and Hoffmann (1997) analyzed ground-water ages, recharge, and hydraulic conductivity of the N aquifer using geochemical techniques. Zhu and others (1998) estimated ground-water recharge using isotopic data and flow estimates from the model developed by GeoTrans (1987). Zhu (2000) estimated recharge again using the same isotopic data, but added numerical flow and transport modeling to the method. Truini and Longsworth (2003) described the hydrogeology of the D aquifer and movement and ages of ground water using geochemical and isotopic analyses.

Hydrologic Data

In 2004–05, the Black Mesa monitoring program included metering and estimating ground-water withdrawals, measuring depth to ground water, measuring discharge in streams and springs, and collecting and analyzing water samples from wells and springs. Annual ground-water withdrawals are gathered from 28 well systems within the NTUA, BIA, and Hopi municipal systems and the PWCC industrial well field. Annual measurements of discharge were made at 4 springs, and annual measurements of ground-water levels were made at 33 wells. Spring discharges and ground-water levels were measured between January and May 2005. Ground-water samples were collected from 11 wells and 4 springs in March–May 2005 and analyzed for chemical constituents. Continuous recorders at the 6 observation wells have been upgraded for telemetry, and the water-level data from these wells are available on the World Wide Web (http://waterdata.usgs.gov/az/nwis/rt). Identification information for the 50 wells used for water-level measurements and water-quality sampling is shown in table 2.

Withdrawals from the N Aquifer

Withdrawals from the N aquifer are separated into three categories: (1) industrial withdrawals from the confined area, (2) municipal withdrawals from the confined area, and (3) municipal withdrawals from the unconfined areas (table 1 and fig. 3). The industrial category includes eight wells in the well field of PWCC in northern Black Mesa (fig. 4). The BIA, NTUA, and Hopi Tribe operate about 70 municipal wells that are combined into 28 well systems (fig. 4). Withdrawals from the N aquifer were compiled primarily on the basis of metered data (tables 1 and 3).

Withdrawals from wells equipped with windmills are not measured in this monitoring program. About 270 windmills in the Black Mesa area withdraw water from the D and N aquifers, and estimated total withdrawals by the windmills are about 65 acre-ft/yr (HSIGeoTrans, Inc. and Waterstone Environmental Hydrology and Engineering, Inc., 1999). This amount is less than 1 percent of the total annual withdrawal from the N aquifer.

Table 2. Identification numbers and names of study wells, 2004–05, Black Mesa area, Arizona.

[Dashes indicate no data]

U.S. Geological Survey identification No.	Common name or location	Bureau of Indian Affairs site No.
354749110300101	Second Mesa PM2	---
355023110182701	Keams Canyon PM2	---
355034110183001	Keams Canyon PM3	---
355215110375001	Kykotsmovi PM2	---
355230110365801	Kykotsmovi PM1	---
355236110364501	Kykotsmovi PM3	---
355428111084601	Goldtooth	3A-28
355518110400301	Hotevilla PM1	---
355638110060401	Low Mountain PM2	---
355648110475501	Howell Mesa	6H-55
355924110485001	Howell Mesa	3K-311
360055110304001	BM observation well 5	4T-519
360217111122601	Tuba City	3K-325
360418110352701	Rocky Ridge PM2	---
360527110122501	Piñon NTUA 1	---
360614110130801	Piñon PM6	---
360734111144801	Tuba City	3T-333
360904111140201	Tuba City NTUA 1	3T-508
360918111080701	Tuba City Rare Metals 2	---
360924111142201	Tuba City NTUA 3	---
360953111142401	Tuba City NTUA 4	3T-546
361225110240701	BM observation well 6	---
361737110180301	Forest Lake NTUA 1	4T-523
361832109462701	Rough Rock	10T-258
362043110030501	Kits'illi NTUA 2	---
362149109463301	Rough Rock	10R-111
363005110250901	Peabody 2	---
362406110563201	White Mesa Arch	1K-214
362418109514601	Rough Rock PM5	---
362456110503001	Cow Springs	1K-225
363007110221201	Peabody 6	---
362823109463101	Rough Rock	10R-119
362936109564101	BM observation well 1	8T-537
363013109584901	Sweetwater Mesa	8K-443
363103109445201	Rough Rock	9Y-95
363137110044702	Chilchinbito PM3	---
363143110355001	BM observation well 4	2T-514
363213110342001	Shonto Southeast	2K-301
363232109465601	Rough Rock	9Y-92
363309110420501	Shonto	2K-300
363423110305501	Shonto Southeast	2T-502
363558110392501	Shonto PM2	---
363727110274501	Long House Valley	8T-510
363850110100801	BM observation well 2	8T-538
364226110171701	Kayenta West	8T-541
364248109514601	Northeast Rough Rock	8A-180
364338110154601	BM observation well 3	8T-500
364344110151201	Kayenta PM2	8A-295
364034110240001	Marsh Pass	8T-522
365045109504001	Dennehotso PM2	---

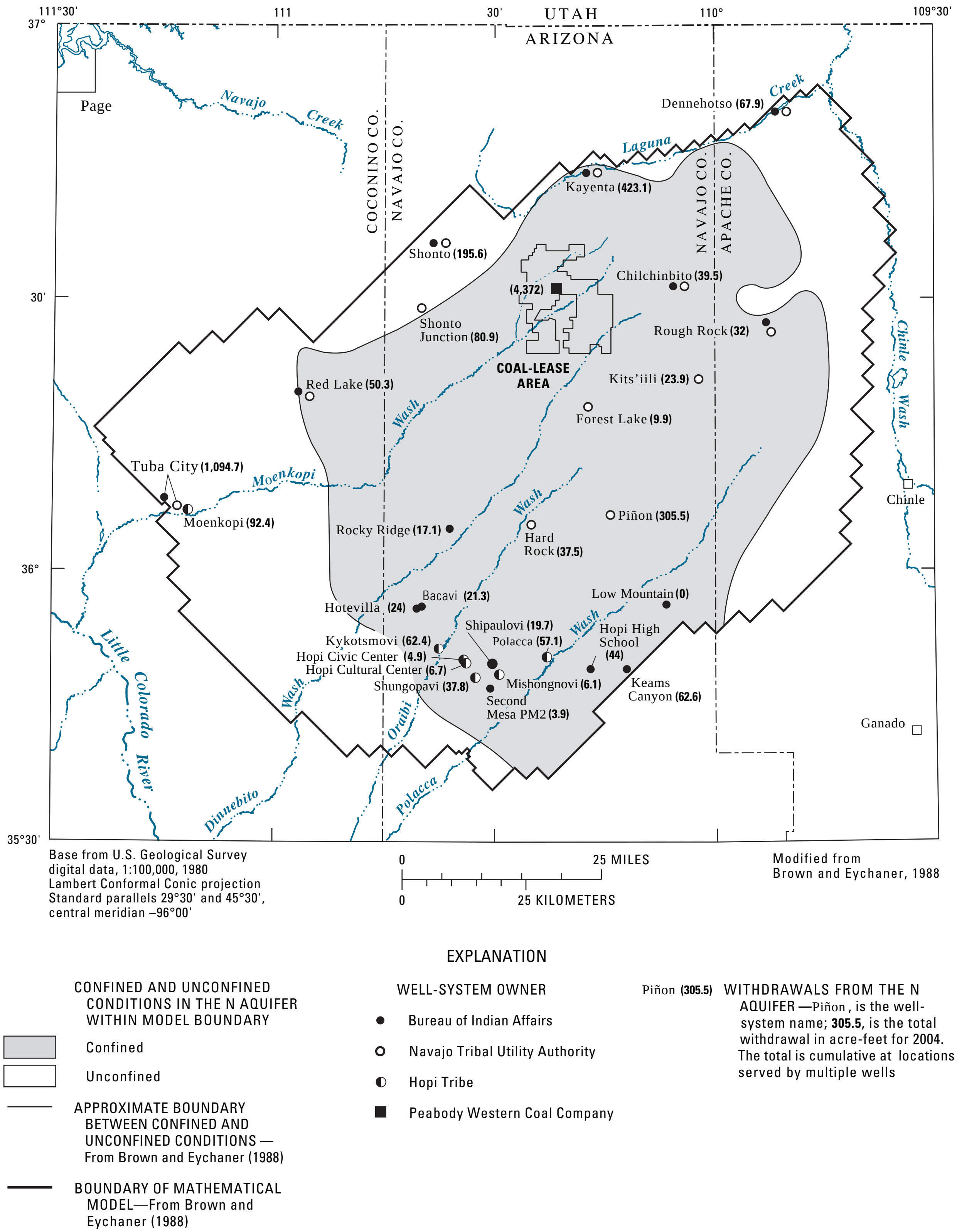


Figure 4. Locations of well systems monitored for withdrawals from the N aquifer, Black Mesa area, Arizona, 2004.

Table 3. Withdrawals from the N aquifer by well system, Black Mesa area, Arizona, 2004.

[Withdrawals, in acre-feet, are from flowmeter measurements. BIA, Bureau of Indian Affairs; NTUA, Navajo Tribal Utility Authority; USGS, U.S. Geological Survey; Peabody, Peabody Western Coal Company; Hopi, Hopi Village Administrations]

Well system (one or more wells)	Owner	Source of data	Withdrawals	
			Confined aquifer	Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	2.3	
Dennehotso	BIA	USGS/BIA		22.0
Hopi High School	BIA	USGS/BIA	44.0	
Hotevilla	BIA	USGS/BIA	24.0	
Kayenta	BIA	USGS/BIA	47.0	
Keams Canyon	BIA	USGS/BIA	62.6	
Low Mountain	BIA	USGS/BIA	[1]0	
Piñon	BIA	USGS/BIA	[1]0	
Red Lake	BIA	USGS/BIA		7.0
Rocky Ridge	BIA	USGS/BIA	17.1	
Rough Rock	BIA	USGS/BIA	24.6	
Second Mesa	BIA	USGS/BIA	3.9	
Shonto	BIA	USGS/BIA		179.6
Tuba City	BIA	USGS/BIA		133.8
Chilchinbito	NTUA	USGS/NTUA	37.2	
Dennehotso	NTUA	USGS/NTUA		45.9
Forest Lake	NTUA	USGS/NTUA	9.9	
Hard Rock	NTUA	USGS/NTUA	37.5	
Kayenta	NTUA	USGS/NTUA	376.1	
Kits'iili	NTUA	USGS/NTUA	23.9	
Piñon	NTUA	USGS/NTUA	305.5	
Red Lake	NTUA	USGS/NTUA		43.3
Rough Rock	NTUA	USGS/NTUA	7.4	
Shonto	NTUA	USGS/NTUA		16.0
Shonto Junction	NTUA	USGS/NTUA		80.9
Tuba City	NTUA	USGS/NTUA		960.9
Mine Well Field	Peabody	Peabody	[2]4,372	
Bacavi	Hopi	USGS/Hopi	21.3	
Hopi Civic Center	Hopi	USGS/Hopi	4.9	
Hopi Cultural Center	Hopi	USGS/Hopi	6.7	
Kykotsmovi	Hopi	USGS/Hopi	62.4	
Mishongnovi	Hopi	USGS/Hopi	6.1	
Moenkopi	Hopi	USGS/Hopi		92.4
Polacca	Hopi	USGS/Hopi	[3]57.1	
Shipaulovi	Hopi	USGS/Hopi	19.7	
Shungopovi	Hopi	USGS/Hopi	37.8	

[1]Well taken out of service.

[2]Industrial pumpage.

[3]Estimated. Well PM4 not metered. Annual pumpage from PM4 was estimated as 40 acre-ft on the basis of previous metered data and a per capita consumption of 40 gallons per day. Pumping from the remaining wells (PM5 and PM6) may include some water from the D aquifer.

In 2004, the total ground-water withdrawal from the N aquifer was about 7,210 acre-ft (table 1), which is less than a 1-percent decrease from the total withdrawal in 2003. Withdrawals for municipal use from the confined area totaled 1,240 acre-ft, which is about an 8-percent decrease from 2003. Withdrawals for municipal use from the unconfined areas totaled 1,600 acre-ft, which is about an 11-percent increase from 2003. Withdrawals for industrial use totaled 4,370 acre-ft, which is a 2-percent decrease from 2003, and withdrawals for municipal use totaled 2,840 acre-ft, which is a 2-percent increase from 2003.

Withdrawals from the N aquifer have been increasing since the 1970s; however, the percentages of withdrawals for industrial and municipal uses have varied during this time (tables 1 and 4, fig. 3). For 1965–2004, industrial withdrawals were 63 percent of the total withdrawals and municipal withdrawals were 37 percent. From 1965 to 1972, total withdrawals increased from 70 to 8,760 acre-ft, industrial withdrawals were 74 percent of total withdrawals, and municipal withdrawals were 28 percent of total withdrawals. From 1973 to 1984, total withdrawals were 66,470 acre-ft, industrial withdrawals were 70 percent of total withdrawals, and municipal withdrawals were 30 percent of total withdrawals. In 1985, total withdrawals were 4,720 acre-ft, industrial withdrawals were 53 percent of total withdrawals, and municipal withdrawals were 47 percent of total withdrawals. From 1986 to 2003, total withdrawals were 123,640 acre-ft, industrial withdrawals were 60 percent of total withdrawals, and municipal withdrawals were 40 percent of total withdrawals. In 2004, total withdrawals were 7,210 acre-ft, industrial withdrawals were 61 percent of total withdrawals, and municipal withdrawals were 39 percent of total withdrawals.

Table 4. Withdrawals from the N aquifer by water-use category for 1965-2004 and for other periods, Black Mesa, Arizona.

Period	Total withdrawals (acre-feet)	Industrial withdrawals (acre-feet)	Municipal withdrawals (acre-feet)	Percent industrial	Percent municipal
1965–2004	210,970	133,620	77,350	63	37
1965–1972	8,930	6,460	2,470	74	28
1973–1984	66,470	46,540	19,930	70	30
1985	4,720	2,520	2,200	53	47
1986–2003	123,640	73,730	49,910	60	40
2004	7,210	4,370	2,840	61	39

Ground-Water Levels in the N Aquifer

Ground water in the N aquifer is under confined conditions in the central part of the study area and under unconfined or water-table conditions around the periphery (fig. 5). The ground water generally moves radially from the recharge areas near Shonto to the southwest towards Tuba City, to the south towards the Hopi Reservation, and to the east towards Rough Rock and Dennehotso (Eychaner, 1983).

Ground-water levels are measured once a year and compared with levels from previous years to determine changes over time. Only water levels from municipal and stock wells that were not considered recently pumped, influenced by nearby pumping, or blocked or obstructed were used for comparison. During February to April 2005, water levels in 33 of the 34 wells that are used for annual measurements met these criteria (table 5). Six of the 33 wells are the continuous-recording observation wells, and water levels were measured manually in these wells 4 times between June 2004 and June 2005. Twenty-five of the 33 water levels measured in 2005 were compared with water levels for the same wells measured in 2004. Water levels in the remaining 8 wells could not be compared because of obstructions, effects of pumping, or other conditions that prevented an accurate water level to be measured in 2004 and (or) 2005.

The wells used for water-level measurements are distributed throughout the study area (fig. 5). All but one of the wells are completed in the N aquifer; however, the characteristics of the wells vary considerably. Well 6H-55 was previously thought to be completed in the N aquifer but is actually completed in the D aquifer. Construction dates range from 1934 to 1993, depths range from 107 ft near Dennehotso, Arizona, to 3,636 ft near PWCC, and depths to the top of the N aquifer range from 0 near Tuba City, Arizona, to 2,205 ft near Forest Lake, Arizona (table 6).

From 2004 to 2005, water levels declined in 14 of the 25 wells for which comparisons could be made (table 5). The median water-level change in the 25 wells was -0.4 ft (table 7). From 2004 to 2005, water levels declined in 6 of the 13 wells in the unconfined areas of the N aquifer. The median water-level change was -0.1 ft. Water-level changes in the unconfined areas ranged from -2.8 ft at Tuba City NTUA 1 to 29.3 ft at 9Y-95 in Rough Rock. In the confined area, water levels declined in 8 of 12 wells from 2004 to 2005. The median water-level change was -1.2 ft. Water-level changes in the confined area ranged from -4.9 ft at Kits'iili NTUA 2 to 11.8 ft at Keams Canyon PM2 (tables 5 and 7).

Annual median water-level changes for the water-level network wells from 1983 to 2005 are shown in figure 6. Annual median changes before 1983 are not shown because there were insufficient water-level data to compute median values. For wells in the confined area, the annual median water-level change was -1.7 ft, and there is no appreciable trend in the annual median water-level changes from 1983 to 2005. For wells in unconfined areas, the annual median water-level change was 0.2 ft, and there is no appreciable trend in the annual median water-level changes from 1983 to 2005.

From the prestress period (prior to 1965) to 2005, the median water-level change in 33 wells was -9.0 ft (table 7). Water levels in 16 wells in the unconfined areas had a median change of -0.6 ft. Water-level changes in the unconfined areas ranged from -33.2 ft at Tuba City NTUA 1 to +15.0 ft at 9Y-95 in Rough Rock (table 5). Water levels in 17 wells in the confined area had a median change of -32.0 ft (table 7). Water-level changes in the confined area ranged from -193.3 ft at Keams Canyon PM2 to 14.0 ft at 3K-311 (fig. 5 and table 5).

The areal distribution of water-level changes from the prestress period to 2005 is shown in figure 5. Hydrographs of water levels in the annual well network show the time trends of changes since the 1950s, 1960s, or 1970s (fig. 7). In most of the unconfined areas, water levels have changed only slightly. In the Tuba City area, however, water levels in three wells have declined about 30 ft (fig. 5). Water levels have declined in most of the confined area; however, the magnitudes of declines are varied. Larger declines are near the municipal pumping centers (wells Piñon PM6, Keams Canyon PM2) or near the industrial pumping centers (BM6). Smaller declines occur away from the pumping centers (wells 10T-258, 8K-443, 10R-111, BM4; fig. 5).

Hydrographs for the Black Mesa continuous-record observation wells show continuous water-level since the early 1970s (fig. 8). Water levels in the two wells in the unconfined areas (BM1 and BM4) have had small seasonal or year-to-year variation since 1972. Water levels in wells BM2, BM3, BM5, and BM6 in the confined area have consistently declined since the early to mid-1960s (fig. 8).

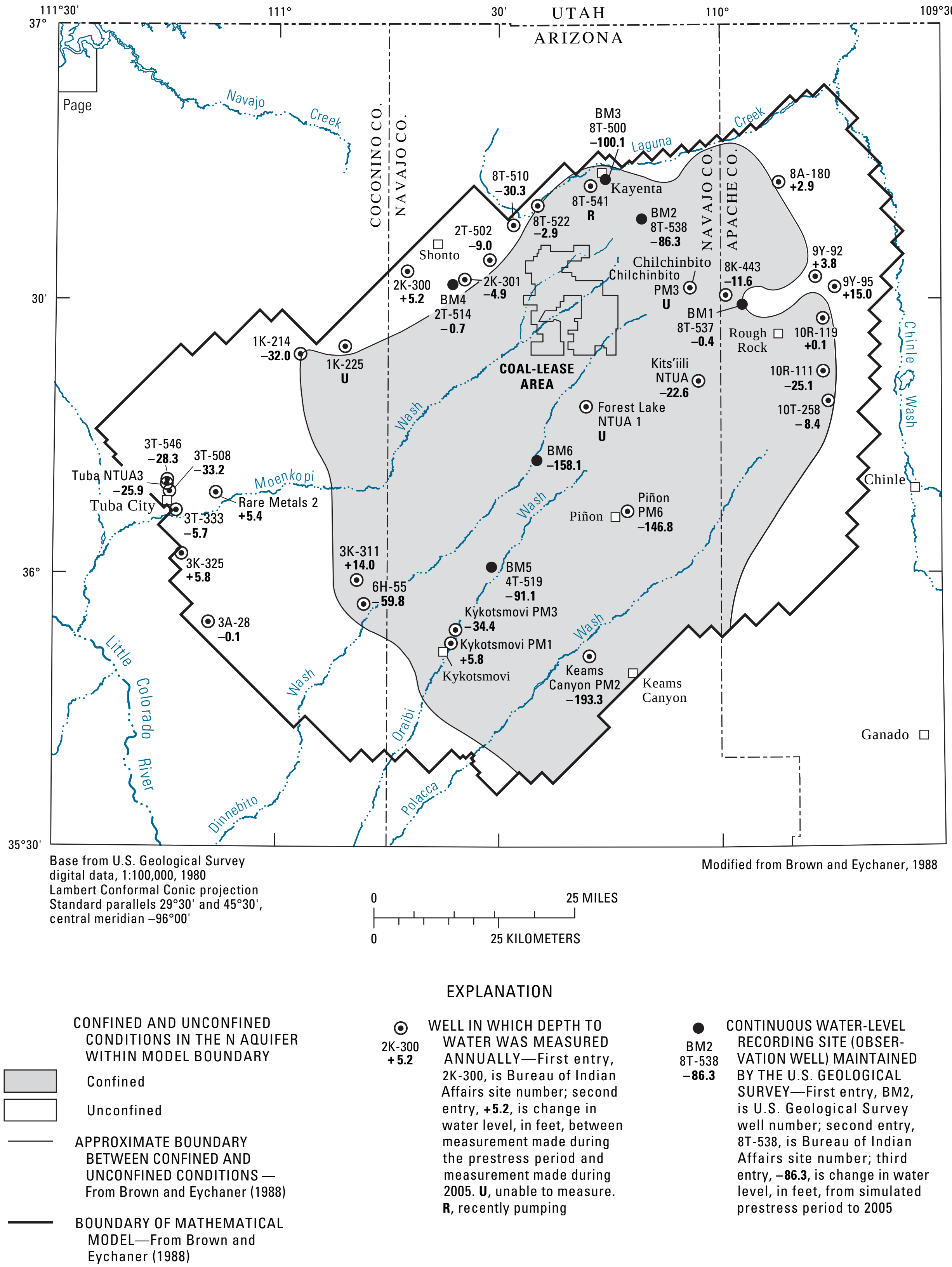


Figure 5. Water-level changes in N aquifer wells from the prestress period to 2005, Black Mesa area, Arizona.

Table 5. Water-level changes in wells completed in the N aquifer, Black Mesa area, Arizona, prestress period to 2005.

[Dashes indicate no data. R, reported from driller's log]

Common name or location	Bureau of Indian Affairs site No.	Change in water level from preceding year (feet)		Water level (feet below land surface), 2005[1]	Prestress period water level[2]		Change in water level from prestress period to 2005 (feet)
		2004	2005		Feet below land surface	Date	
Unconfined areas							
BM observation well 1[3]	8T-537	+0.3	-0.6	374.4	374.0	([3])	-0.4
BM observation well 4[3]	2T-514	+0.0	-0.3	216.7	[4]216.0	([3])	-0.7
Goldtooth	3A-28	([4])	([4])	230.1	230.0	10–29–53	-0.1
Long House Valley	8T-510	([4])	([4])	129.7	99.4	08–22–67	-30.3
Northeast Rough Rock	8A-180	([4])	([4])	44.0	46.9	11–13–53	+2.9
Rough Rock	9Y-95	-30.8	+29.3	104.5	119.5	08–03–49	+15.0
Rough Rock	9Y-92	+4.8	-0.5	165.0	168.8	12–13–52	+3.8
Shonto	2K-300	+0.0	+0.2	171.3	176.5	06–13–50	+5.2
Shonto Southeast	2K-301	([4])	-0.1	288.8	283.9	12–10–52	-4.9
Shonto Southeast	2T-502	([4])	+1.1	414.8	405.8	08–22–67	-9.0
Tuba City	3T-333	-1.6	+1.6	28.7	23.0	12–02–55	-5.7
Tuba City	3K-325	+0.4	-0.4	202.2	208.0	06–30–55	+5.8
Tuba City Rare Metals 2	---	-0.1	0.0	51.6	57.0	09–24–55	+5.4
Tuba City NTUA 1	3T-508	+6.2	-2.8	62.2	29.0	02–12–69	-33.2
Tuba City NTUA 3	---	-4.2	+5.4	60.1	34.2	11–08–71	-25.9
Tuba City NTUA 4	3T-546	-24.3	+27.3	62.0	33.7	08–06–71	-28.3
Confined area							
BM observation well 2[3]	8T-538	-1.5	-1.3	211.3	125.0	([3])	-86.3
BM observation well 3[3]	8T-500	-4.7	0	155.1	55.0	04–29–63	-100.1
BM observation well 5[3]	4T-519	-3.0	-1.3	415.1	324.0	([3])	-91.1
BM observation well 6[3]	---	-5.2	-3.2	855.1	[4]697.0	([3])	-158.1
Howell Mesa	3K-311	+2.6	-1.3	449	463.0	11–03–53	+14.0
Howell Mesa	6H-555	+1.2	-0.7	271.8	212.0	07–08–54	-59.8
Kayenta West	8T-541	([4])	([4])	([6])	230.0	03–17–76	([6])
Keams Canyon PM2	---	-14.6	11.8	485.8	292.5	06–10–70	-193.3
Kits'iili NTUA 2	---	([4])	-4.9	1,320.5	1,297.9	01–14–99	-22.6
Kykotsmovi PM1	---	+4.0	-1.1	214.2	220.0	05–20–67	+5.8
Kykotsmovi PM3	---	-2.7	+0.8	244.4	210.0	08–28–68	-34.4
Marsh Pass	8T-522	([4])	([4])	128.4	125.5	02–07–72	-2.9
Piñon PM6	---	-3.9	-3.0	890.4	743.6	05–28–70	-146.8
Rough Rock	10R-119	([4])	([4])	256.5	256.6	12–02–53	+0.1
Rough Rock	10T-258	+1.3	+0.1	309.4	301.0	04–14–60	-8.4
Rough Rock	10R-111	([4])	([4])	195.1	170.0	08–04–54	-25.1
Sweetwater Mesa	8K-443	([4])	([4])	541.0	529.4	09–26–67	-11.6
White Mesa Arch	1K-214	([4])	([4])	220.0	188.0	06–04–53	-32.0

[1]Water level measured during February to April 2005.

[2]Prestress refers to the period of record before appreciable ground-water withdrawals for mining or municipal purposes—about 1965. For wells that had no water-level measurement before 1965, the earliest water-level measurement is shown.

[3]Continuous recorder. Except for well BM3, prestress water levels were estimated from a ground-water model (Brown and Eychaner, 1988).

[4]Can not be determined because at least one of the water-level measurements is not available.

[5]D aquifer well.

[6]Well recently pumped.

Table 6. Well-construction characteristics, depth to top of N aquifer, and type of data collected for wells in monitoring program, Black Mesa area, Arizona, 2004–05.

Bureau of Indian Affairs site No., and (or) common name	Date well was completed	Land-surface elevation (feet)	Well depth (feet below land surface)	Screened/open interval(s) (feet below land surface)	Depth to top of N aquifer (feet below land surface[1])	Type of data collected
8T-537 (BM observation well 1)	02–01–72	5,864	851	300–360; 400–420; 500–520; 600–620; 730–780	290	Water level
8T-538 (BM observation well 2)	01–29–72	5,656	1,338	470–1,338	452	Water level
8T-500 (BM observation well 3)	07–29–59	5,724	868	712–868	155	Water level
2T-514 (BM observation well 4)	02–15–72	6,320	400	250–400	160	Water level
4T-519 (BM observation well 5)	02–25–72	5,869	1,683	1,521–1,683	1,520	Water level
BM observation well 6	01–31–77	6,332	2,507	1,954–2,506	1,950	Water level
1K-214	05–26–50	5,771	356	168–356	250	Water level
1K-225	07–04–54	5,722	251	19–251	[2]10	Water level
2K-300	[3]06–00–50	6,264	300	260–300	0	Water level
2K-301	06–12–50	6,435	500	318–328; 378–500	[2]30	Water level
2T-502	08–10–59	6,670	523	12–523	[2]5	Water level
3A-28	04–19–35	5,381	358	([4])	60	Water level
3K-311	[3]11–00–34	5,855	745	380–395; 605–745	615	Water level
3K-325	06–01–55	5,250	450	75-450	[2]30	Water level
3T-333	12–02–55	4,940	229	63–229	[2]4	Water level
3T-508 (Tuba City NTUA 1)	08–25–59	5,119	475	([4])	0	Water level, withdrawals
3T-546 (Tuba City NTUA 4)	[3]08–00–71	5,206	612	256–556	0	Water level, withdrawals
4T-523 (Forest Lake NTUA 1)	10–01–80	6,654	2,674	1,870–1,910; 2,070–2,210; 2,250–2,674	([5])	Water level, water chemistry, withdrawals
6H-55[6]	12–08–44	5,635	361	310–335	[6]310	Water level
8A-180	01–20–39	5,200	107	60–107	[2]40	Water level
8A-295 (Kayenta PM2)	[3]00–00–36	5,623	840	268–280; 691–788	95	Water chemistry, withdrawals
8K-443	08–15–57	6,024	720	619–720	590	Water level
8T-510	02–11–63	6,262	314	130–314	[2]125	Water level
8T-522	[3]07–00–63	6,040	933	180–933	480	Water level
8T-541	03–17–76	5,885	890	740–890	700	Water level
9Y-92	01–02–39	5,615	300	154–300	[2]50	Water level
9Y-95	11–05–37	5,633	300	145–300	[2]68	Water level
10R-111	04–11–35	5,757	360	267–360	210	Water level
10R-119	01–09–35	5,775	360	([4])	310	Water level
10T-258	04–12–60	5,903	670	465–670	460	Water level
Chilchinbito PM3	09–25–65	5,950	1,600	1,140–1,570	1,136	Withdrawals
Hotevilla PM1	[3]06–00–57	6,357	1,757	1,500–1,750	1,450	Water chemistry, withdrawals

Table 6. Well-construction characteristics, depth to top of N aquifer, and type of data collected for wells in monitoring program, Black Mesa area, Arizona, 2004–05.—Continued

Bureau of Indian Affairs site No., and (or) common name	Date well was completed	Land-surface elevation (feet)	Well depth (feet below land surface)	Screened/open interval(s) (feet below land surface)	Depth to top of N aquifer (feet below land surface[1])	Type of data collected
Keams Canyon PM2	[3]05–00–70	5,809	1,106	906–1,106	900	Water level, withdrawals, water chemistry
Keams Canyon PM3	[3]01–00–76	5,806	1,090	931–1,090	930	Water chemistry
Kits'iili NTUA 2	10–30–93	6,780	2,549	2,217–2,223; 2,240–2,256; 2,314–2,324; 2,344–2,394; 2,472–2,527	2,205	Water chemistry, withdrawals
Kykotsmovi PM1	02–20–67	5,657	995	655–675; 890–990	880	Water level, withdrawals
Kykotsmovi PM2	10–14–77	5,760	1,155	950–1,155	890	Water chemistry, withdrawals
Kykotsmovi PM3	08–07–68	5,618	1,220	850–1,220	840	Water level, withdrawals
Low Mountain PM2	[3]04–00–72	6,123	1,343	1,181–1,262	1,153	Water level
Peabody 2	[3]06–00–67	6,530	3,636	1,816–3,603	728	Water chemistry, withdrawals
Peabody 6	06–00–65	6,645	3,559	2,047–3,494	894	Water chemistry, withdrawals
Piñon NTUA 1	02–25–80	6,336	2,350	1,860–2,350	1,850	Water chemistry, withdrawals
Piñon PM6	[3]02–00–70	6,397	2,248	1,895–2,243	1,870	Water level, withdrawals
Rocky Ridge PM2	06–26–63	5,985	1,780	1,480–1,780	1,442	Water level
Rough Rock PM5	06–27–64	6,299	1,425	1,175–1,425	1,156	Water chemistry, withdrawals
Second Mesa PM2	[3]10–00–68	5,777	1,090	740–1,090	720	Water chemistry, withdrawals
Shonto PM2	05–05–61	6,465	554	485–510; 514-539	0	Water chemistry
Dennehotso PM2	06–05–64	5,005	675	475-675	8	Water chemistry
Tuba City NTUA 3	[3]10–00–71	5,176	442	142–442	34	Water level, withdrawals
Tuba City Rare Metals 2	[3]09–00–55	5,108	705	100–705	255	Water level

[1]Depth to top of N aquifer from Eychaner (1983) and Brown and Eychaner (1988).

[2]All material between land surface and top of the N aquifer is unconsolidated—soil, alluvium, or dune sand.

[3]00, indicates month or day is unknown.

[4]Screened and (or) open intervals are unknown.

[5]Depth to top of N aquifer was not estimated.

[6]Developed into the D aquifer.

Table 7. Median changes in water levels, 2004–05 and prestress period to 2005, Black Mesa area, Arizona.

Years	Aquifer conditions	Number of wells	Median change in water level (feet)
2004–05	All	25	-0.4
	Unconfined	13	-.1
	Confined	12	-1.2
Prestress–2005	All	33	-9.0
	Unconfined	16	-.6
	Confined	17	-32.0

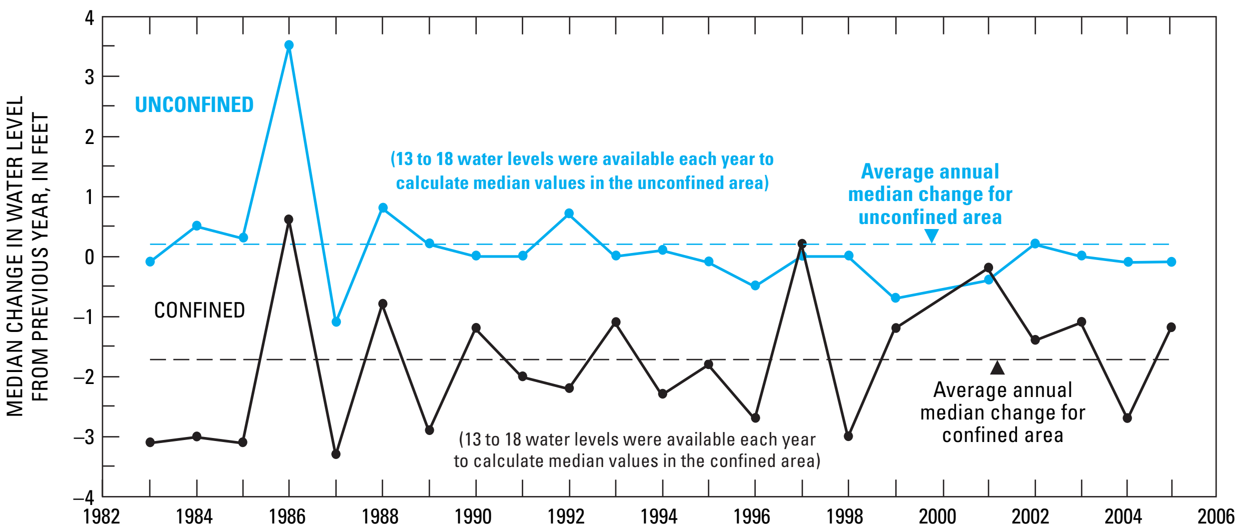


Figure 6. Annual median water-level changes for observation wells completed in the N aquifer, Black Mesa area, Arizona, 1983–2005.

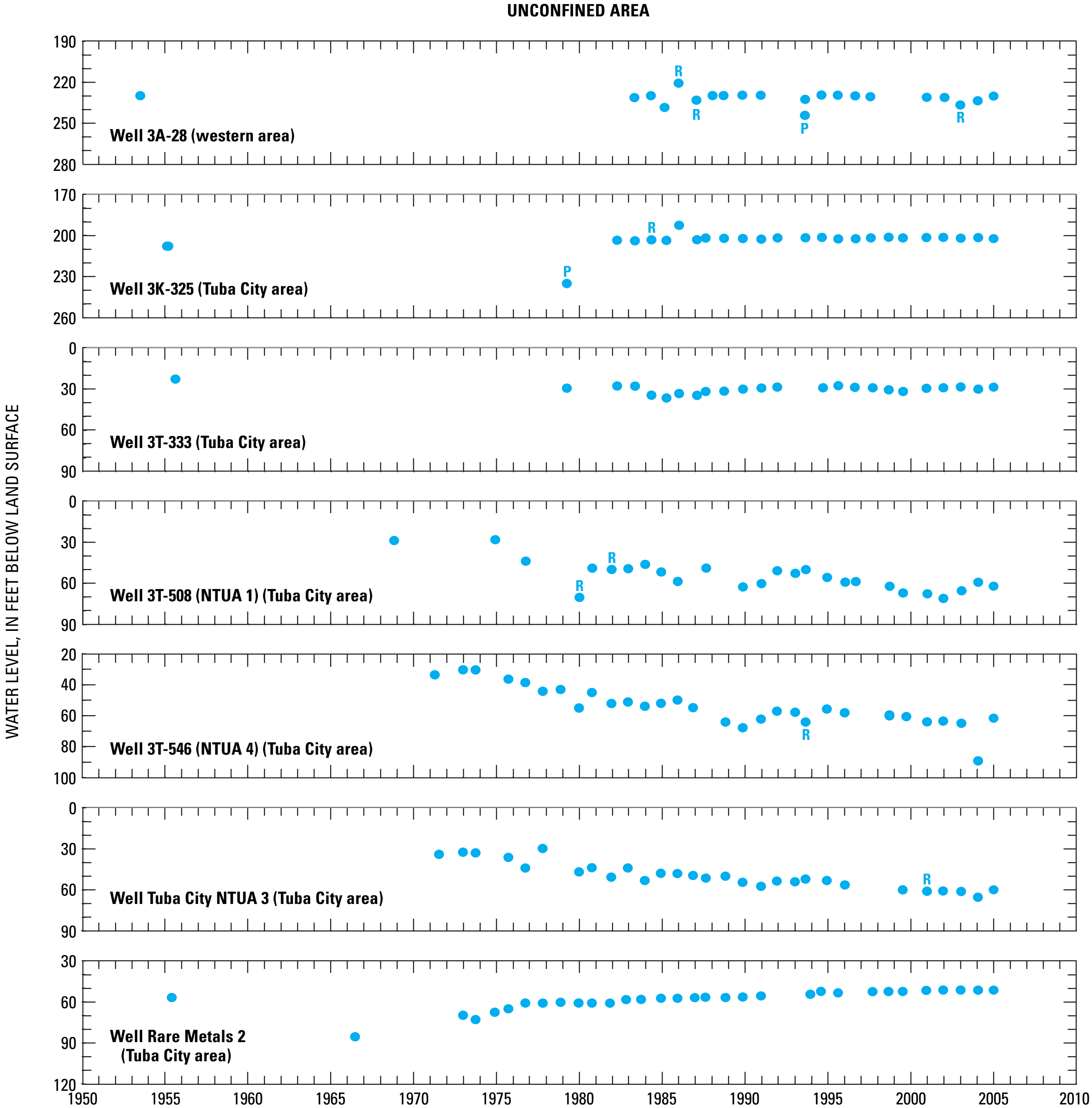


Figure 7. Observed water levels (1950–2005) in annual observation well network, Black Mesa area, Arizona. P, pumping; R, recently pumping.

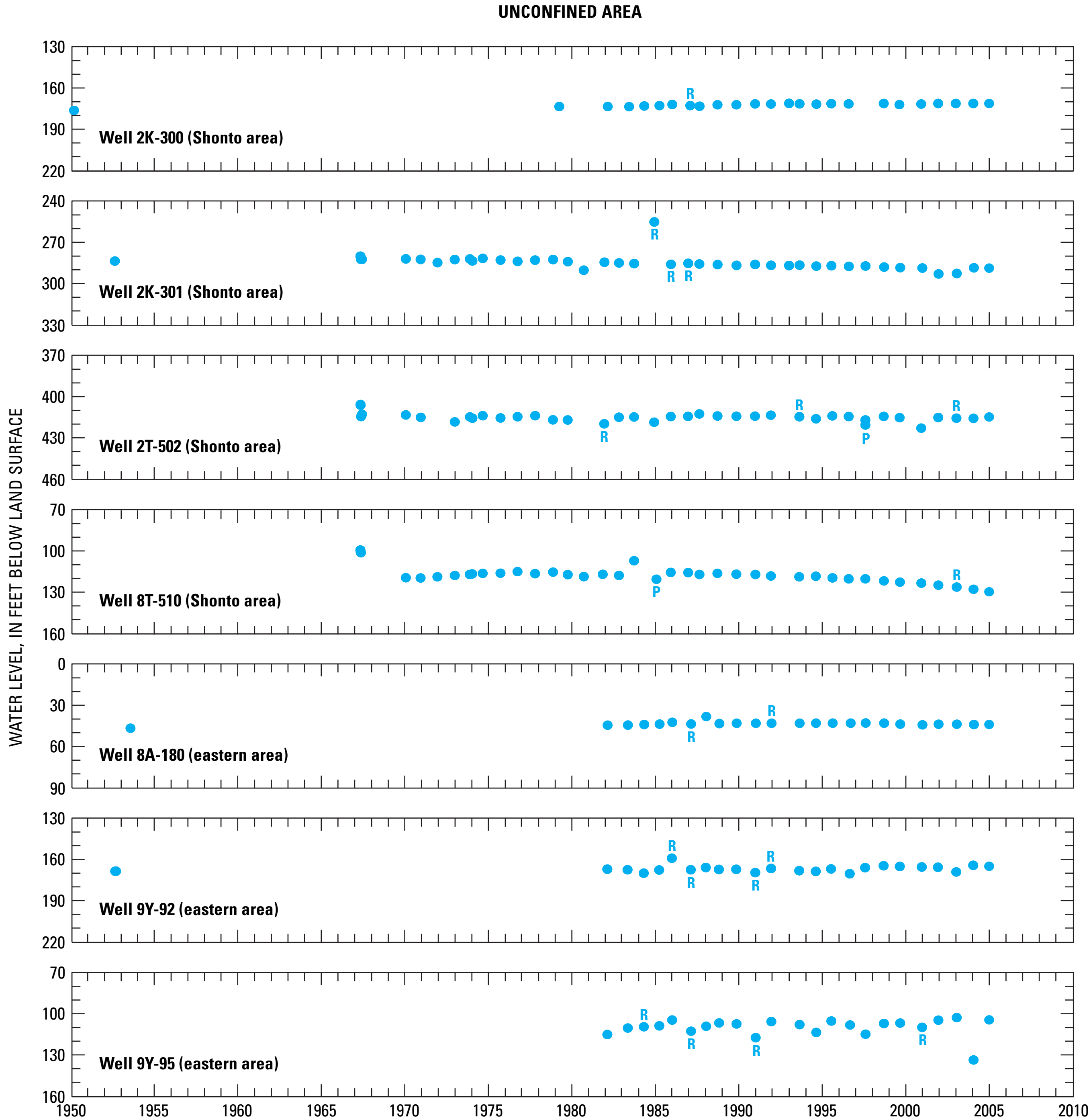


Figure 7. Continued.

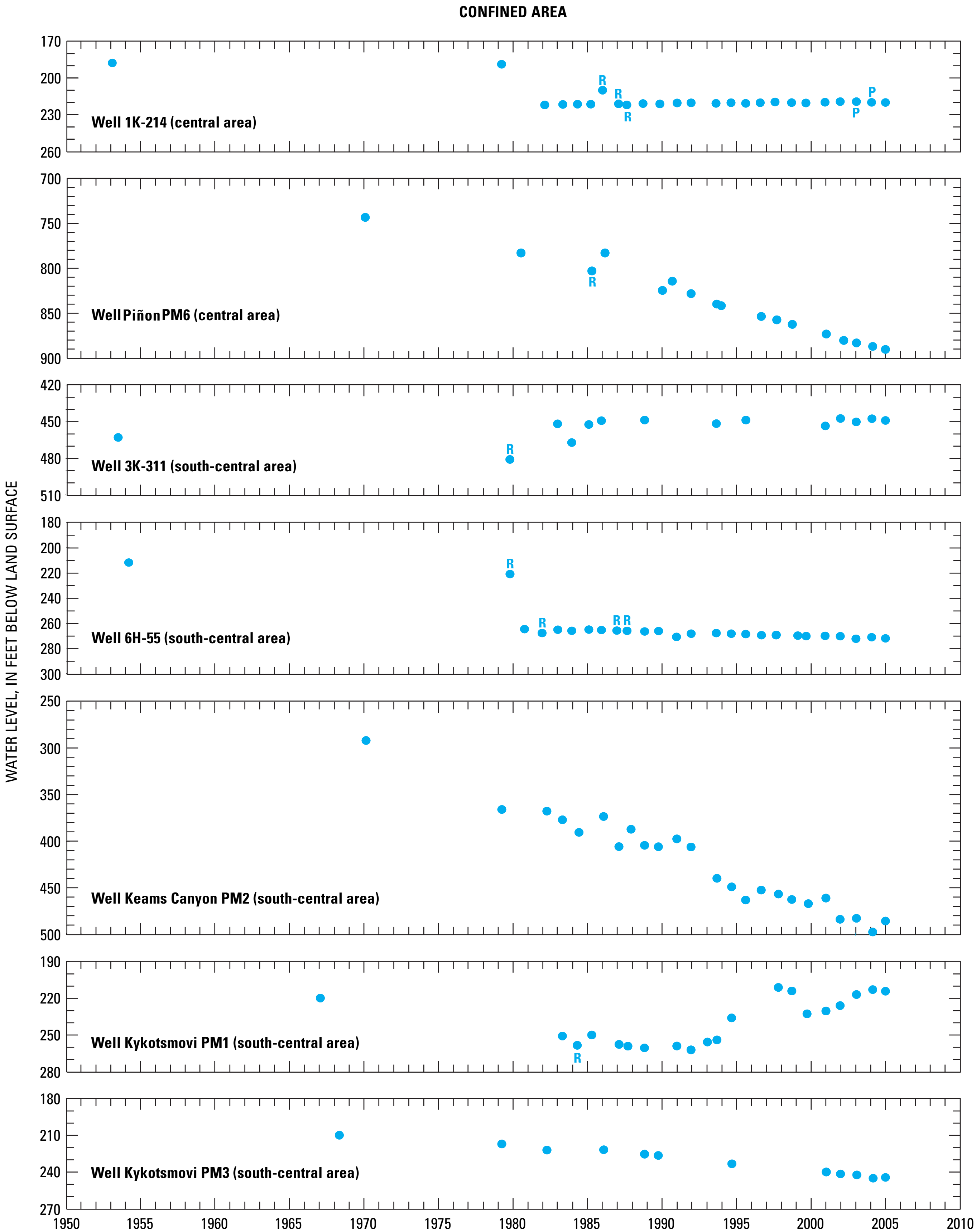


Figure 7. Continued.

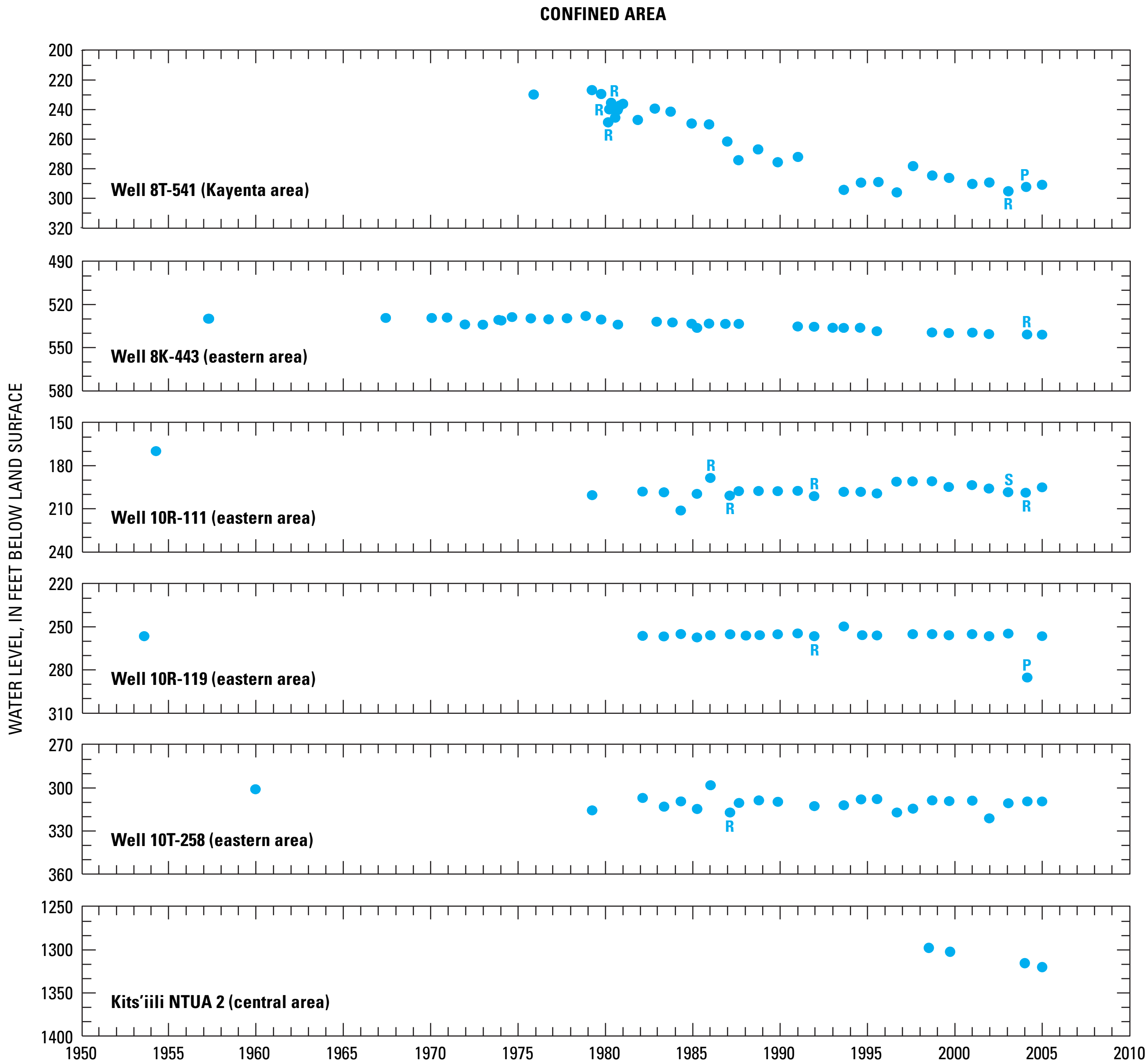


Figure 7. Continued.

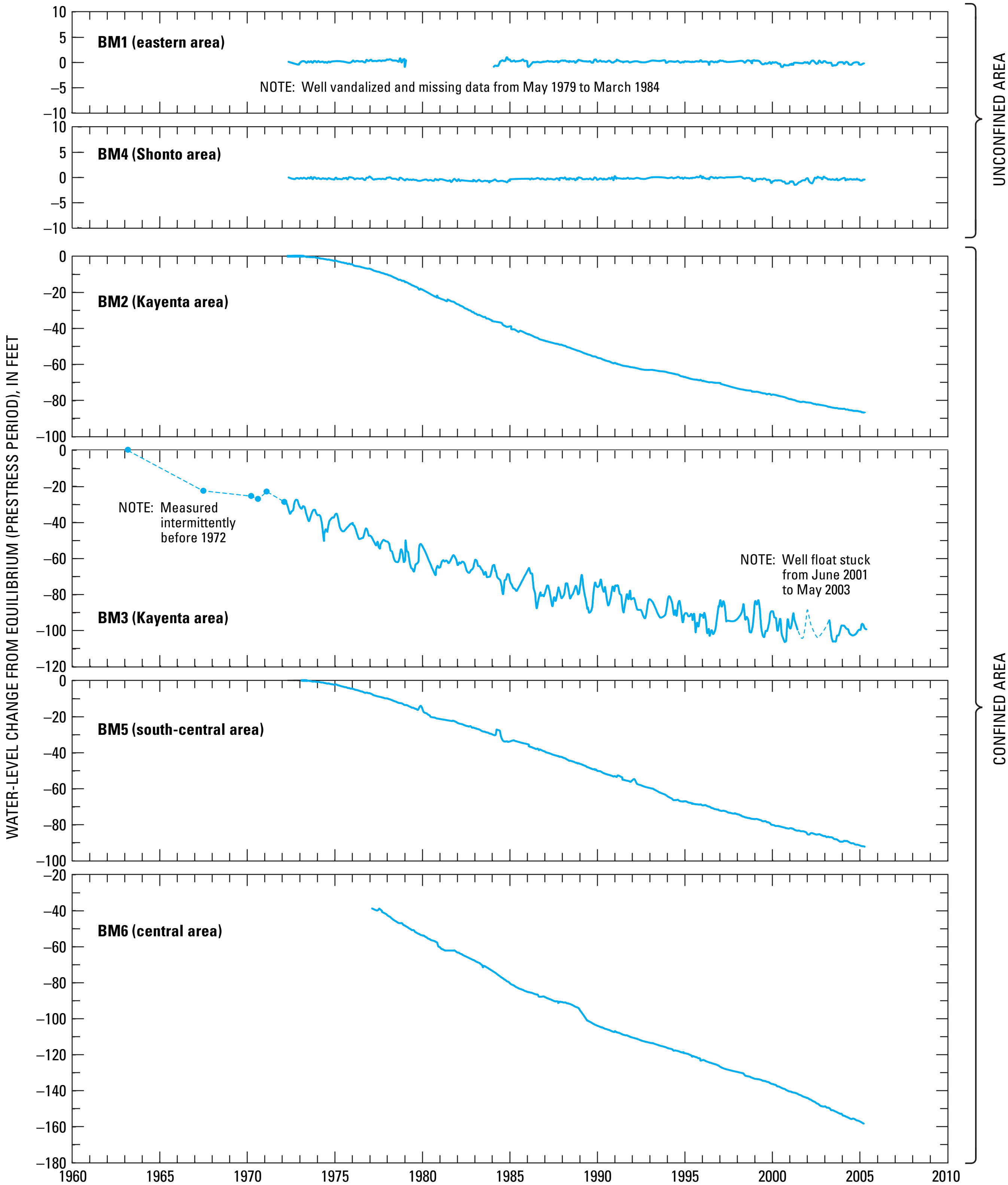
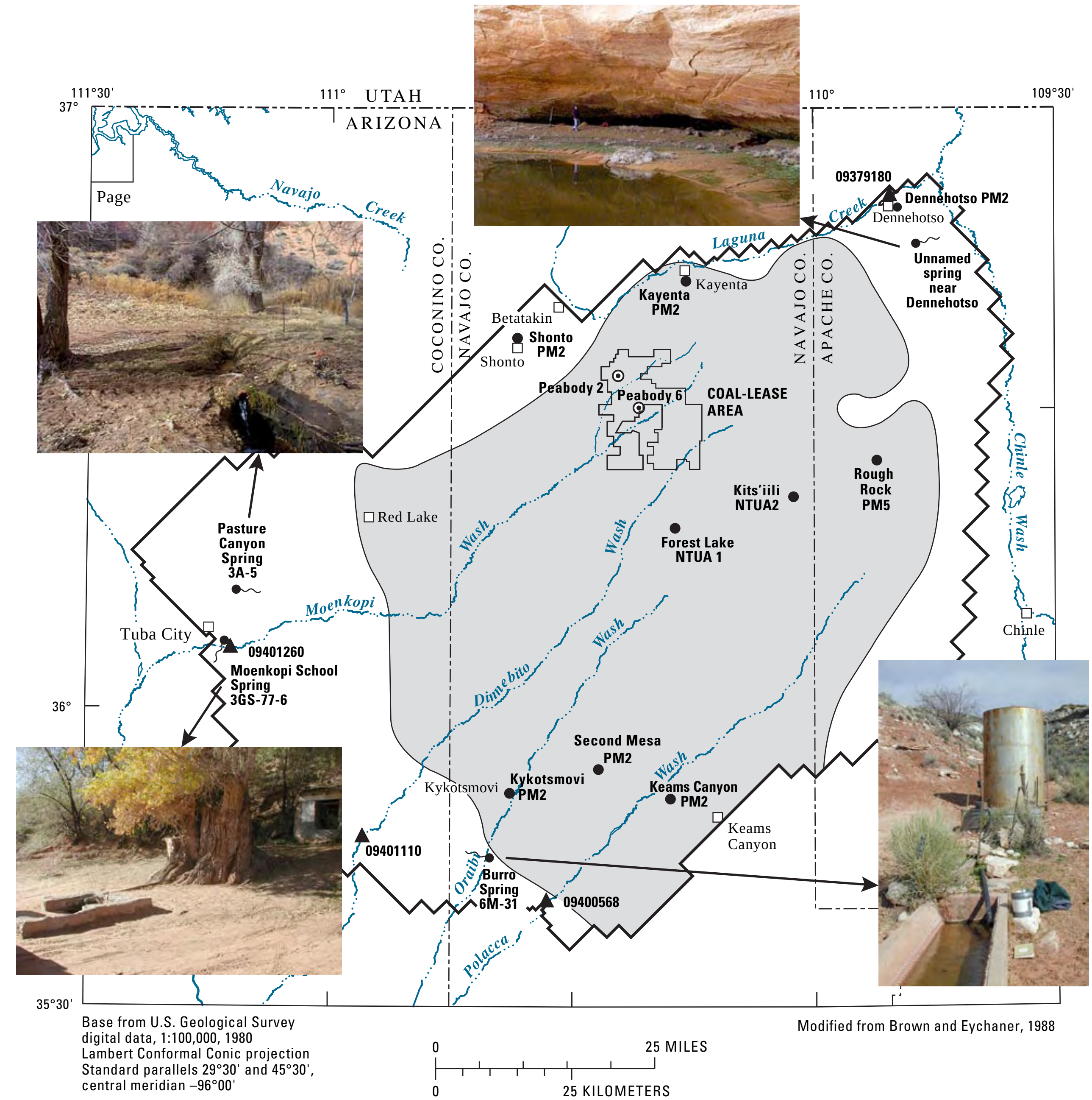


Figure 8. Observed water-level changes in continuous-record observation wells, BM1–BM6, 1963–2005, Black Mesa area, Arizona.



EXPLANATION

CONFINED AND UNCONFINED CONDITIONS IN THE N AQUIFER WITHIN MODEL BOUNDARY

- Confined
- Unconfined

APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS — From Brown and Eychaner (1988)

BOUNDARY OF MATHEMATICAL MODEL—From Brown and Eychaner (1988)

Rough Rock PM5 — MUNICIPAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—**Rough Rock PM5** is well name

Peabody 6 — INDUSTIAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—**Peabody 6** is a well number

Burro Spring 6M-31 — SPRING AT WHICH DISCHARGE WAS MEASURED AND WATER-CHEMISTRY SAMPLE WAS COLLECTED—Number is spring identification

09401260 — STREAMFLOW-GAGING STATION OPERATED BY THE U.S. GEOLOGICAL SURVEY—Number is station identification

Figure 9. Surface-water and water-chemistry data-collection sites, Black Mesa area, Arizona, 2004–05. Photograph of Pasture Canyon Spring has been digitally altered.

Spring Discharge from the N Aquifer

Ground water in the N aquifer discharges from many springs around the margins of Black Mesa, and four of these springs are monitored for discharge. Three springs are in the western or southwestern part of the Black Mesa area, and one is in the northeastern part (fig. 9). Discharges from Moenkopi School Spring, the unnamed spring near Dennehotso, Pasture Canyon Spring, and Burro Spring are measured annually and compared to discharges from previous years to determine changes over time (fig. 10). Discharge was measured in March–April 2005 at the four springs (table 8). Measurements at Burro Spring, Moenkopi School Spring, and Pasture Canyon Spring are made volumetrically, and measurements at the unnamed spring near Dennehotso are made with a flume. The measurements may not reflect the total discharge at each site because some ground water may rise to the land surface downgradient from the measuring point.

In 2005, measured discharges were 0.2 gal/min from Burro Spring, 11.5 gal/min from Moenkopi School Spring, 21.5 gal/min from the unnamed spring near Dennehotso, and 33.3 gal/min from Pasture Canyon Spring (table 8). From 2004 to 2005, discharge stayed the same at Burro Spring, decreased by 5 percent at Moenkopi School Spring, increased by 71 percent at the unnamed spring near Dennehotso, and increased by 8 percent at Pasture Canyon Spring. For the periods of record at all four springs, the discharges have fluctuated but no increasing or decreasing trends are apparent (fig. 10).

Surface-Water Discharge

Surface-water discharge in the study area is a measurement of ground-water discharge to streams and direct runoff of rainfall or snowmelt. Ground water discharges to some channel reaches at a fairly constant rate throughout the year; however, the amount of discharge that results in surface flow is affected by seasonal fluctuations in water uptake by plants and in evapotranspiration (Thomas, 2002a). In contrast, the amount of rainfall or snowmelt runoff varies widely throughout the year. In the winter and spring, the amount and timing of snowmelt runoff are a result of the temporal variation in snow accumulation, air temperatures, and rate of snowmelt. Although most rainfall runoff is in the summer, runoff can occur throughout the year. The amount and timing of rainfall runoff depend on the intensity and duration of thunderstorms in the summer and cyclonic storms in the fall, winter, and spring.

Continuous surface-water discharge data have been collected at selected streams each year since the monitoring program began in 1971 to provide information about ground-water discharge and runoff from rainfall and snowmelt. In this study, the total discharge in streams is roughly separated into ground-water discharge and runoff so that the temporal trends in ground-water discharge can be monitored.

In 2004, discharge data were collected at five continuous-recording streamflow-gaging stations (tables 9–13). Data collection at these stations began in July 1976 (Moenkopi Wash, 09401260), July 1996 (Laguna Creek, 09379180), June 1993 (Dinnebito Wash, 09401110), April 1994 (Polacca Wash, 09400568), and August 2004 (Pasture Canyon Spring, 09401256; fig. 9 and table 14).

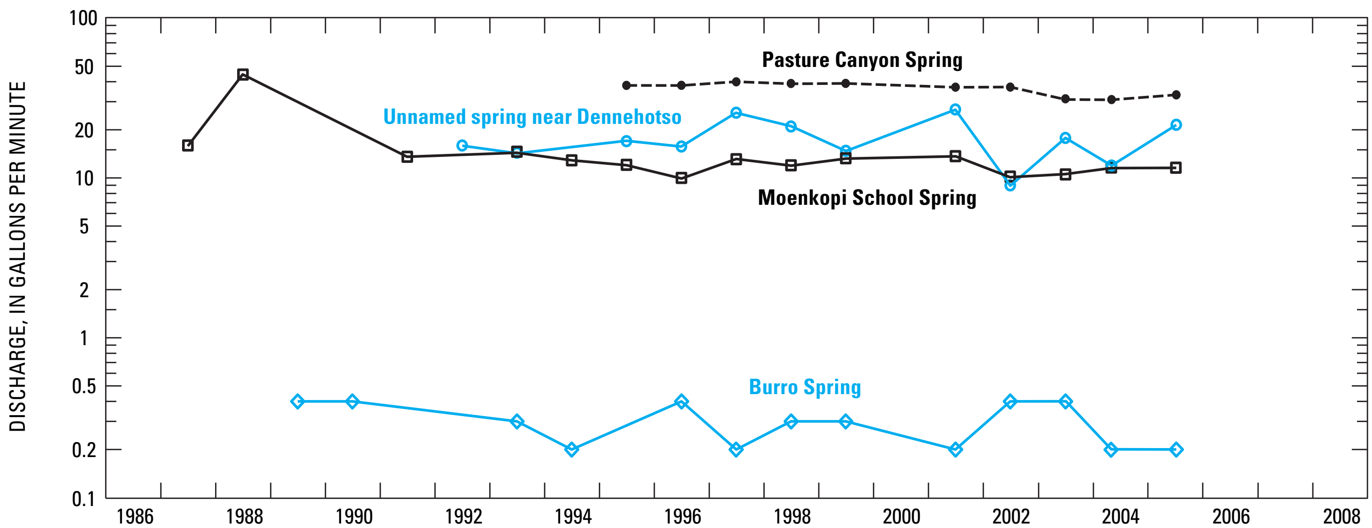


Figure 10. Discharge from selected springs, Black Mesa area, Arizona, 1987–2005.
Data from earlier measurements at Moenkopi School Spring, unnamed spring near Dennehotso, and Pasture Canyon Spring are not shown because different measuring locations were used.

Table 8. Discharge measurements of selected springs, Black Mesa area, Arizona, 1952–2005.

[All the measured discharges do not represent the total discharge from the springs]

Bureau of Indian Affairs site No.	Rock formation(s)	Date of measurement	Discharge (gallons per minute)
Moenkopi School Spring[1]			
3GS-77-6	Navajo Sandstone[2]	05–16–52	40
		04–22–87	[3]16
		11–29–88	[3]43.6
		02–21–91	[3]13.5
		04–07–93	[3]14.6
		12–07–94	[3]12.9
		12–04–95	[3]12.1
		12–16-96	[3]10
		12–17–97	[3]13.1
		12–08–98	[3]12
		12–13–99	[3]13.3
		03–12–01	[3]13.7
		06–19–02	[3]10.2
		05–01–03	[3]11.2
		03–29–04	[3]12.2
		04–04–05	[3]11.5
Unnamed spring near Dennehotso[4]			
8A-224	Navajo Sandstone	10–06–54	[5]1
		06–27–84	[5]2
		11–17–87	[5]5
		03–26–92	16
		10–22–93	14.4
		12–05–95	17
		12–19–96	15.7
		12–30–97	25.6
		12–14–98	21
		12–15–99	14.8
		03–14–01	26.8
		04–03–02	9
		05–01–03	17.1
		04–01–04	12.6
		04–06–05	21.5
Pasture Canyon Spring[1]			
3A-5	Navajo Sandstone, alluvium	11–18–88	[6]211
		03–24–92	[6]233
		10–12–93	[6]211
		12–04–95	[7]38
		12–16–96	[7]38
		12–17–97	[7]40
		12–10–98	[7]39
		12–21–99	[7]39.0
		06–12–01	[7]37.0
		04–04–02	[7]37.0
		05–01–03	[7]30.9
		04–26–04	[7]30.6
		04–27–05	[7]33.3
Burro Spring[1]			
6M-31	Navajo Sandstone	12–15–89	0.4
		12–13–90	.4
		03–18–93	.3
		12–08–94	.2
		12–17–96	.4
		12–30–97	.2
		12–08–98	.3
		12–07–99	.3
		04–02–01	.2
		04–04–02	.4
		04–30–03	.4
		04–06–04	[8].2
		03–28–05	.2

[1]Volumetric discharge measurement.

[2]Tongue in the Kayenta Formation.

[3]Discharge measured at water-quality sampling site and at a different point than the measurement in 1952.

[4]Flume discharge measurement.

[5]Discharge measured at a different point than later measurements.

[6]Discharge measured in an irrigation ditch about 0.25 mile below water-quality sampling point.

[7]Discharge measured at water-quality sampling point about 20 feet below upper spring on west side of canyon.

[8]Discharge is approximate because the container used for the volumetric measurement was not calibrated.

Table 9. Discharge data, Moenkopi Wash at Moenkopi, Arizona (09401260), calendar year 2004.

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	1.7	2.9	e2.9	2.3	1.7	0.00	0.00	0.00	0.00	19	1.5	e2.5
2	1.7	3.7	e2.7	2.6	1.4	.00	.00	.00	.00	e6.4	1.3	e3.1
3	1.3	3.2	e2.5	4.3	1.4	.00	.00	.00	.00	e3.3	1.3	e3.3
4	1.4	3.2	e2.5	3.9	1.3	.00	.00	.00	.00	e2.4	1.4	e3.8
5	1.3	3.1	e2.5	23	1.3	.00	.00	.00	16	1.6	1.6	e5.1
6	1.2	2.6	e2.4	9.0	1.2	.00	.00	.00	3.1	1.3	1.5	e4.7
7	1.3	2.9	e2.3	3.0	1.2	.00	.00	.00	.88	e1.9	1.8	e3.9
8	1.5	3.1	e2.1	2.7	1.1	.00	.00	.00	.13	e1.8	2.4	3.7
9	1.8	3.3	e2.1	2.6	.92	.00	.00	.00	.00	e1.3	5.4	3.2
10	2.4	3.2	e2.0	2.0	.78	.00	.00	.00	.00	e1.1	2.9	3.0
11	2.8	3.4	e2.0	2.1	.63	.00	.00	.00	.00	e.96	2.3	2.9
12	4.4	3.1	e1.9	1.8	.58	.00	.00	.00	18	e1.1	2.2	3.0
13	3.7	2.7	e2.0	1.5	.64	.00	.00	.00	14	1.6	3.0	3.0
14	3.5	3.3	e2.1	1.7	.67	.00	.00	.00	1.9	1.3	2.6	3.0
15	3.0	4.7	e2.1	1.6	.70	.00	5.2	.00	.87	1.3	2.0	2.9
16	2.3	3.3	e1.9	1.6	.59	.00	19	493	.68	1.3	1.9	2.9
17	2.0	2.9	e1.7	1.4	.59	.00	126	323	.62	1.3	1.9	e2.8
18	2.1	2.7	1.4	1.3	.54	.00	6.7	37	.69	1.3	1.4	e3.0
19	2.0	2.6	1.3	1.3	.38	.00	.34	6.1	720	1.3	1.3	e3.1
20	2.6	2.6	1.1	1.3	.28	.00	.02	4.4	389	1.3	2.6	e3.2
21	2.2	2.5	.95	1.6	.30	.00	.00	3.7	21	1.4	3.6	e3.5
22	2.7	2.5	1.00	1.8	.28	.00	.00	.93	6.4	1.9	23	e3.3
23	1.9	2.5	1.1	1.9	.21	.00	.00	.69	3.4	1.5	28	e1.9
24	1.9	2.3	2.4	1.9	.35	.00	.00	.28	2.3	1.4	7.0	e6.5
25	2.5	7.3	3.0	1.8	.38	.00	6.8	.07	1.8	1.3	3.6	4.4
26	1.9	8.9	5.4	1.7	.35	.00	7.2	.00	1.4	1.4	3.2	6.3
27	2.2	5.7	4.7	1.5	.37	.00	13	.00	1.3	1.3	3.1	11
28	2.9	3.0	3.5	1.4	.25	.00	.74	.00	4.9	2.6	3.0	6.8
29	2.6	3.0	3.2	1.5	.00	.00	.00	.00	340	6.9	e2.9	23
30	2.5	---	2.9	1.8	.00	.00	.00	.00	360	3.3	e2.5	41
31	2.9	---	2.7	---	.00	---	.00	.00	---	2.1	---	14
TOTAL	70.2	100.2	72.35	87.9	20.39	.00	185.00	869.17	1,908.37	77.96	122.2	187.8
MEAN	2.26	3.46	2.33	2.93	.66	.00	5.97	28.0	63.6	2.51	4.07	6.06
MAX	4.4	8.9	5.4	23	1.7	.00	126	493	720	19	28	41
MIN	1.2	2.3	.95	1.3	.00	.00	.00	.00	.00	.96	1.3	1.9
MED	2.2	3.1	2.1	1.8	.59	.00	.00	.00	1.6	1.4	2.5	3.3
AC-FT	139	199	144	174	40	.00	367	1,720	3,790	155	242	373
CFSM	.00	.00	.00	.00	.00	.00	.00	.02	.04	.00	.00	.00
CAL YR 2004; TOTAL 3,701.54; MEAN 1.1; MAX 720; MIN .00; MED 1.8; AC-FT 7,340; CFSM .01												

[1]Month in which data are provisional, subject to revision.

Table 10. Discharge data, Laguna Creek at Dennehotso, Arizona (09379180), calendar year 2004.

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.51	e1.5	5.3	0.00	0.00	0.00	0.00	0.00	0.00	5.8	0.38	0.02
2	1.3	e1.4	e3.5	.00	.00	.00	.00	.00	.00	2.0	.12	.01
3	1.7	.29	e2.5	.00	.00	.00	.00	.00	.00	.44	.02	.00
4	e1.2	.70	e2.8	3.5	.00	.00	.00	.00	.00	.06	.00	.00
5	e.90	e1.1	e3.5	e2.2	.00	.00	.00	.00	.00	.00	.00	.00
6	.27	.80	e3.3	e3.1	.00	.00	.00	.00	.00	.00	.00	.00
7	.03	.46	e1.6	5.9	.00	.00	.00	e35	.00	.00	.14	.00
8	.67	1.1	e1.8	34	.00	.00	.00	e8.0	.00	.00	.36	.00
9	.01	.66	e1.4	e8.7	.00	.00	.00	e.50	.00	.00	.57	.00
10	.02	1.1	e.25	e3.9	.00	.00	.00	.00	.00	.00	1.3	.00
11	.78	1.6	e.67	e1.6	.00	.00	.00	.00	.00	.00	.59	12
12	.80	1.2	e.80	e.96	.00	.00	.00	.00	.25	.00	.22	10
13	.32	e1.0	e.67	e.71	.00	.00	.00	.00	2.3	.00	12	8.7
14	.33	1.0	e1.4	e.53	.00	.00	.00	.00	.02	1.3	5.6	11
15	.09	.41	e.71	e.25	.00	.00	.00	.00	.00	.38	2.8	5.5
16	.80	1.4	e.60	.00	.00	.00	.00	.00	.00	.04	2.5	4.2
17	2.2	1.9	.57	.00	.00	.00	.56	12	.00	.00	.93	4.2
18	.52	3.7	.45	.00	.00	.00	.14	28	.00	.00	1.2	1.3
19	1.1	5.6	.00	.00	.00	.00	.00	2.2	.00	.00	1.0	.27
20	3.3	6.6	.00	.00	.00	.00	.00	.63	106	.00	1.1	.36
21	2.2	6.5	.00	.00	.00	.00	.00	.88	25	.00	2.9	.13
22	1.3	7.6	.00	.00	.00	.00	.00	.87	5.2	.00	28	.00
23	2.2	8.3	.00	.00	.00	.00	.00	.13	2.5	.00	16	.00
24	1.6	9.4	.00	.00	.00	.00	.00	.00	.77	.62	6.2	.00
25	.73	13	.00	13	.00	.00	.00	.00	.11	.35	4.3	.00
26	1.0	e11	.00	2.0	.00	.00	6.7	.00	.00	.29	5.0	.00
27	e1.9	e7.5	.00	.77	.00	.00	14	.00	.00	.27	4.0	.00
28	e1.9	e5.0	.00	.01	.00	.00	e4.0	.00	.00	.36	4.1	.25
29	e1.3	8.6	.00	.00	.00	.00	.19	.00	72	11	.64	3.6
30	1.5	---	.00	.00	.00	.00	.00	.00	54	3.6	.07	43
31	.80	---	.00	---	.00	---	.00	.00	---	1.1	---	7.9
TOTAL	33.28	110.42	31.82	81.13	.00	.00	25.59	88.21	268.15	27.61	102.04	112.44
MEAN	1.07	3.81	1.03	2.70	.00	.00	.83	2.85	8.94	.89	3.40	3.63
MAX	3.3	13	5.3	34	.00	.00	14	35	106	11	28	43
MIN	.01	.29	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MED	.90	1.5	.57	.13	.00	.00	.00	.00	.00	.00	1.1	.02
AC-FT	66	219	63	161	.00	.00	51	175	532	55	202	223
CFSM	.00	.01	.00	.01	.00	.00	.00	.01	.02	.00	.01	.01
CAL YR 2004; TOTAL 880.69; MEAN 2.41; MAX 106; MIN 0.00; MED 0.00; AC-FT 1,750; CFSM 0.01												

[1]Month in which data are provisional, subject to revision.

Table 11. Discharge data, Dinnebito Wash near Sand Springs, Arizona (09401110), calendar year 2004.

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.36	0.35	0.36	0.32	0.24	0.13	11	0.08	0.15	e39	0.35	0.42
2	.38	.39	.37	.41	.23	.13	0.72	.20	.14	e3.0	.36	.37
3	.36	.43	.37	.39	.22	.12	.13	.12	.13	e.50	.40	.38
4	.26	.50	.36	.32	.21	.11	.11	6.4	.23	e.40	.40	.34
5	.26	.39	.33	.42	.19	.11	.11	14	77	e.40	.40	.54
6	.27	.41	.32	.33	.18	.11	.10	2.0	9.1	e.40	.41	.55
7	.32	.44	.34	.40	.18	.10	.10	.17	1.1	e.40	.49	.50
8	.33	.41	.35	.33	.19	.09	.10	.12	.09	e.40	.77	.54
9	.34	.41	.35	.32	.19	.09	.10	.10	.09	e.40	.46	.51
10	.38	.39	.37	.28	.16	.09	.10	.10	.09	e.40	.44	.49
11	.37	.36	.37	.27	.13	.10	.10	.10	.08	e.40	.44	.49
12	.35	.31	.49	.27	.15	.11	.10	.09	.09	e.40	.44	.49
13	.34	.32	.38	.27	.16	.10	.11	.10	.09	e.40	.38	.52
14	.36	.41	.34	.25	.17	.10	.48	.19	.09	.38	.30	.51
15	.44	.35	.36	.24	.17	.10	19	103	.09	.41	.30	.50
16	.39	.35	.35	.24	.15	.10	.17	76	.09	.40	.31	.47
17	.38	.36	.36	.22	.14	.10	13	78	.09	.38	.31	.45
18	.35	.35	.36	.23	.14	.10	25	19	.09	.37	.66	.45
19	.37	.34	.36	.25	.14	.09	69	3.8	e601	.38	1.0	.44
20	.47	.33	.36	.25	.13	.09	e13	6.9	e783	.37	.55	.46
21	.45	.40	.35	.24	.13	.09	e.31	74	7.6	.38	3.7	.48
22	.37	.34	.37	.23	.14	.09	e.21	23	.71	.50	16	.40
23	.38	.39	.44	.26	.14	.09	e.12	4.9	.54	.40	1.1	.34
24	.39	.34	.49	.26	.15	.09	59	.51	.54	.40	.48	.32
25	.35	.34	.35	.24	.15	.09	69	.22	.53	.39	.45	.37
26	.30	.33	.32	.24	.14	.09	45	.19	.53	.38	.44	.39
27	.35	.40	.33	.23	.14	.09	34	.17	.52	.38	.41	.43
28	.43	.37	.32	.22	.14	.14	17	.17	.53	.89	.31	.53
29	.39	.33	.35	.23	.13	.14	5.0	.16	20	.51	.28	23
30	.37	---	.36	.25	.13	18	.18	.16	e575	.42	.52	e294
31	.45	---	.36	---	.13	---	.08	.15	---	.42	---	19
TOTAL	11.31	10.84	11.29	8.41	4.99	20.98	382.43	414.10	2,079.33	54.26	32.86	348.68
MEAN	.36	.37	.36	.28	.16	.70	12.3	13.4	69.3	1.75	1.10	11.2
MAX	.47	.50	.49	.42	.24	18	69	103	783	39	16	294
MIN	.26	.31	.32	.22	.13	.09	.08	.08	.08	.37	.28	.32
MED	.37	.36	.36	.25	.15	.10	.21	.19	.38	.40	.44	.48
AC-FT	22	22	22	17	9.9	42	759	821	4,120	108	65	692
CFSM	.00	.00	.00	.00	.00	.00	.03	.03	.15	.00	.00	.02

CAL YR 2004; TOTAL 3,379.48; MEAN 9.23; MAX 783; MIN 0.08; MED 0.35; AC-FT 6,700; CFSM 0.02

[1]Month in which data are provisional, subject to revision.

Table 12. Discharge data, Polacca Wash near Second Mesa, Arizona (09400568), calendar year 2004.

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.17	0.18	0.16	0.11	0.11	0.03	0.00	e0.05	0.01	56	0.09	0.16
2	.18	.17	.17	.15	.10	.03	.00	.00	.02	3.8	.10	.15
3	.16	.24	.17	.22	.09	.03	.00	e.03	.02	.31	.10	.15
4	.11	.33	.16	.21	.08	.03	.00	e.03	.02	.06	.11	.09
5	.09	.21	.15	.36	.07	.02	.00	e.05	.02	.03	.12	.23
6	.10	.18	.14	.23	.06	.02	.00	e.02	.02	.03	.13	.30
7	.16	.19	.14	.22	.06	.02	.00	e.00	.02	.04	.17	.25
8	.16	.17	.14	.19	.06	.02	.00	e.00	.01	.05	.31	.24
9	.16	.17	.14	.17	.05	.01	.00	.00	.01	.05	.15	.18
10	.15	.17	.14	.16	.05	.00	.00	.00	.01	.10	.15	.17
11	.14	.16	.14	.15	.04	.01	.00	.00	.01	.08	.14	.17
12	.14	.15	.14	.14	.03	.02	.00	.00	.01	.07	.15	.17
13	.14	.14	.14	.14	.04	.02	.00	.00	.01	.06	.14	.18
14	.14	.16	.13	.13	.05	.03	.00	.00	.00	.06	.14	.18
15	.21	.16	.13	.11	.05	.02	.00	.00	.01	.07	.15	.18
16	.17	.16	.13	.11	.05	.02	.00	3.8	.01	.07	.16	.17
17	.15	.16	.13	.12	.04	.02	21	2.3	.01	.07	.15	.16
18	.14	.17	.13	.10	.04	.02	11	6.8	.04	.07	.16	.16
19	.14	.16	.13	.12	.03	.01	.49	.28	2.2	.08	.15	.16
20	.19	.16	.13	.12	.04	.00	5.7	.00	254	.08	.19	.17
21	.22	.24	.12	.11	.03	.00	.14	.00	115	.09	.68	.17
22	.17	.39	.13	.10	.03	.00	.02	.00	9.5	.08	.39	.15
23	.16	.24	.55	.14	.04	.00	.02	.00	1.1	.08	.20	.11
24	.17	.19	.28	.15	.04	.00	.00	.45	.18	.08	.17	.10
25	.18	.17	.14	.13	.04	.00	.00	.02	.06	.09	.17	.14
26	.14	.17	.13	.11	.03	.00	.34	.01	.04	.08	.17	.17
27	.16	.18	.12	.12	.03	.00	2.2	.02	.03	.09	.17	.19
28	.19	.19	.12	.12	.04	.00	4.6	.01	.03	.33	.16	.22
29	.17	.16	.12	.10	.03	.00	e.50	.01	14	.15	.14	.77
30	.17	---	.11	.11	.03	.00	e.05	.01	225	.11	.12	39
31	.19	---	.11	---	.03	---	e.05	.01	---	.10	---	2.9
TOTAL	4.92	5.52	4.77	4.45	1.51	.38	46.11	13.90	621.40	62.46	5.33	47.54
MEAN	.16	.19	.15	.15	.05	.01	1.49	.45	20.7	2.01	.18	1.53
MAX	.22	.39	.55	.36	.11	.03	21	6.8	254	56	.68	39
MIN	.09	.14	.11	.10	.03	.00	.00	.00	.00	.03	.09	.09
MED	.16	.17	.14	.13	.04	.01	.00	.01	.02	.08	.15	.17
AC-FT	9.8	11	9.5	8.8	3.0	.8	91	28	1,230	124	11	94
CFSM	.00	.00	.00	.00	.00	.00	.00	.00	.02	.00	.00	.00
CAL YR 2004; TOTAL 818.29; MEAN 2.24; MAX 254; MIN 0.00; MED 0.12; AC-FT 1,620; CFSM 0.00												

[1]Month in which data are provisional, subject to revision.

Table 13. Discharge data, Pasture Canyon Spring near Tuba City, Arizona (09401265), August through December, calendar year 2004.

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	---	---	---	---	---	---	---	---	0.26	0.32	0.38	0.41
2	---	---	---	---	---	---	---	---	.25	.32	.38	.40
3	---	---	---	---	---	---	---	---	.26	.32	.38	.40
4	---	---	---	---	---	---	---	---	.28	.32	.37	.39
5	---	---	---	---	---	---	---	---	.27	.32	.36	.39
6	---	---	---	---	---	---	---	---	.28	.32	.36	.41
7	---	---	---	---	---	---	---	---	.28	.32	.36	.41
8	---	---	---	---	---	---	---	---	.27	.33	.39	.41
9	---	---	---	---	---	---	---	---	.28	.34	.41	.40
10	---	---	---	---	---	---	---	0.25	.28	.34	.41	.38
11	---	---	---	---	---	---	---	.25	.28	.34	.40	.38
12	---	---	---	---	---	---	---	.26	.28	.34	.39	.38
13	---	---	---	---	---	---	---	.26	.28	.34	.38	.38
14	---	---	---	---	---	---	---	.26	.28	.34	.38	.38
15	---	---	---	---	---	---	---	.26	.28	.34	.38	.38
16	---	---	---	---	---	---	---	.29	.28	.34	.38	.38
17	---	---	---	---	---	---	---	.27	.28	.34	.38	.38
18	---	---	---	---	---	---	---	.26	.30	.34	.38	.38
19	---	---	---	---	---	---	---	.26	.34	.34	.38	.38
20	---	---	---	---	---	---	---	.27	.31	.34	.39	.38
21	---	---	---	---	---	---	---	.26	.31	.36	.46	.38
22	---	---	---	---	---	---	---	.26	.30	.38	.44	.38
23	---	---	---	---	---	---	---	.26	.30	.38	.42	.38
24	---	---	---	---	---	---	---	.26	.30	.37	.41	.38
25	---	---	---	---	---	---	---	.26	.30	.36	.41	.38
26	---	---	---	---	---	---	---	.25	.30	.36	.41	.38
27	---	---	---	---	---	---	---	.25	.30	.36	.41	.38
28	---	---	---	---	---	---	---	.26	.31	.40	.41	.38
29	---	---	---	---	---	---	---	.26	.36	.38	.41	e.60
30	---	---	---	---	---	---	---	.26	.33	.38	.41	e.50
31	---	---	---	---	---	---	---	.26	---	.38	---	e.40
TOTAL	---	---	---	---	---	---	---	---	8.73	10.76	11.83	12.34
MEAN	---	---	---	---	---	---	---	---	.29	.35	.39	.40
MAX	---	---	---	---	---	---	---	---	.36	.40	.46	.60
MIN	---	---	---	---	---	---	---	---	.25	.32	.36	.38
MED	---	---	---	---	---	---	---	---	.28	.34	.39	.38
AC-FT	---	---	---	---	---	---	---	---	17	21	23	24

[1]Month in which data are provisional, subject to revision.

Table 14. Date that data collection began and drainage areas for streamflow-gaging stations, Black Mesa area, Arizona.

[Dashes indicate not determined]

Station name	Station No.	Date data collection began	Drainage area (square miles)
Moenkopi Wash at Moenkopi	09401260	July 1976	1,629
Laguna Creek at Dennehotso	09379180	July 1996	414
Dinnebito Wash near Sand Springs	09401110	June 1993	473
Polacca Wash near Second Mesa	09400568	April 1994	905
Pasture Canyon Spring	09401265	August 2004	---

Discharge data from August through December 2004 for Pasture Canyon Spring is published in this report; however, they are not sufficient to enable evaluation of possible trends or provide comparisons to data for previous years. The annual average discharges at the other four gaging stations vary considerably during the stations' periods of record (fig. 11*A*), and no long-term trends are apparent except for Moenkopi Wash. Discharge of Moenkopi Wash shows a decreasing trend from 1983 to 1993 and an increasing trend from 1995 to 2003.

The ground-water discharge component of total flow at the four streamflow-gaging stations was estimated by computing the median flow for four winter months—November, December, January, and February (fig. 11*B*). The 120 consecutive daily mean flows for those four months were used to compute the median flow. Ground-water discharge is assumed to be constant throughout the year, and the median winter flow is assumed to represent this constant annual ground-water discharge. Most flow during the winter is ground-water discharge; rainfall and snowmelt runoff are minimal. Most of the precipitation in the winter falls as snow, and the cold temperatures prevent appreciable snowmelt. Also, evapotranspiration is at a minimum during the winter. The median flow for November, December, January, and February, rather than the average flow, is used to estimate ground-water discharge because the median is less affected by occasional winter runoff.

The median flow for November, December, January, and February is an index of ground-water discharge rather than an absolute estimate of discharge. A more rigorous and accurate estimate would involve detailed evaluations of streamflow hydrographs, flows into and out of bank storage, gain and loss of streamflow as it moves down the stream channel, and interaction of ground water in the N aquifer with ground water in the shallow alluvial aquifers in the stream valleys. The median winter flow, however, is useful as a consistent index for evaluating possible time trends in ground-water discharge.

Median winter flows were calculated for the 2004 water year; thus, daily mean flows for November and December 2003 (Truini and others, 2005) were combined with daily mean flows for January and February 2004. These median winter flows were 2.65 ft^3/s for Moenkopi Wash, 0.56 ft^3/s for Laguna Creek, 0.34 ft^3/s for Dinnebito Wash, and 0.13 ft^3/s for Polacca Wash (fig. 11*B*). In 2004, flows for Moenkopi Wash and Laguna Creek both decreased, and flows for Polacca and Dinnebito Washes both increased (fig. 11*B*). Since 1995, the median flows for Moenkopi Wash, Dinnebito Wash, and Polacca Wash have generally decreased. Median flow values for Laguna Creek are available only since 1997 but no increasing or decreasing trend is apparent. Annual precipitation at Betatakin, about 15 mi west of Kayenta (fig. 1), has been less than average for 6 of the 9 years since 1995 (fig. 11*C*). Precipitation data for 2003 are incomplete. Precipitation was above average for calendar year 2004 (19.8 in.; fig. 11*C*).

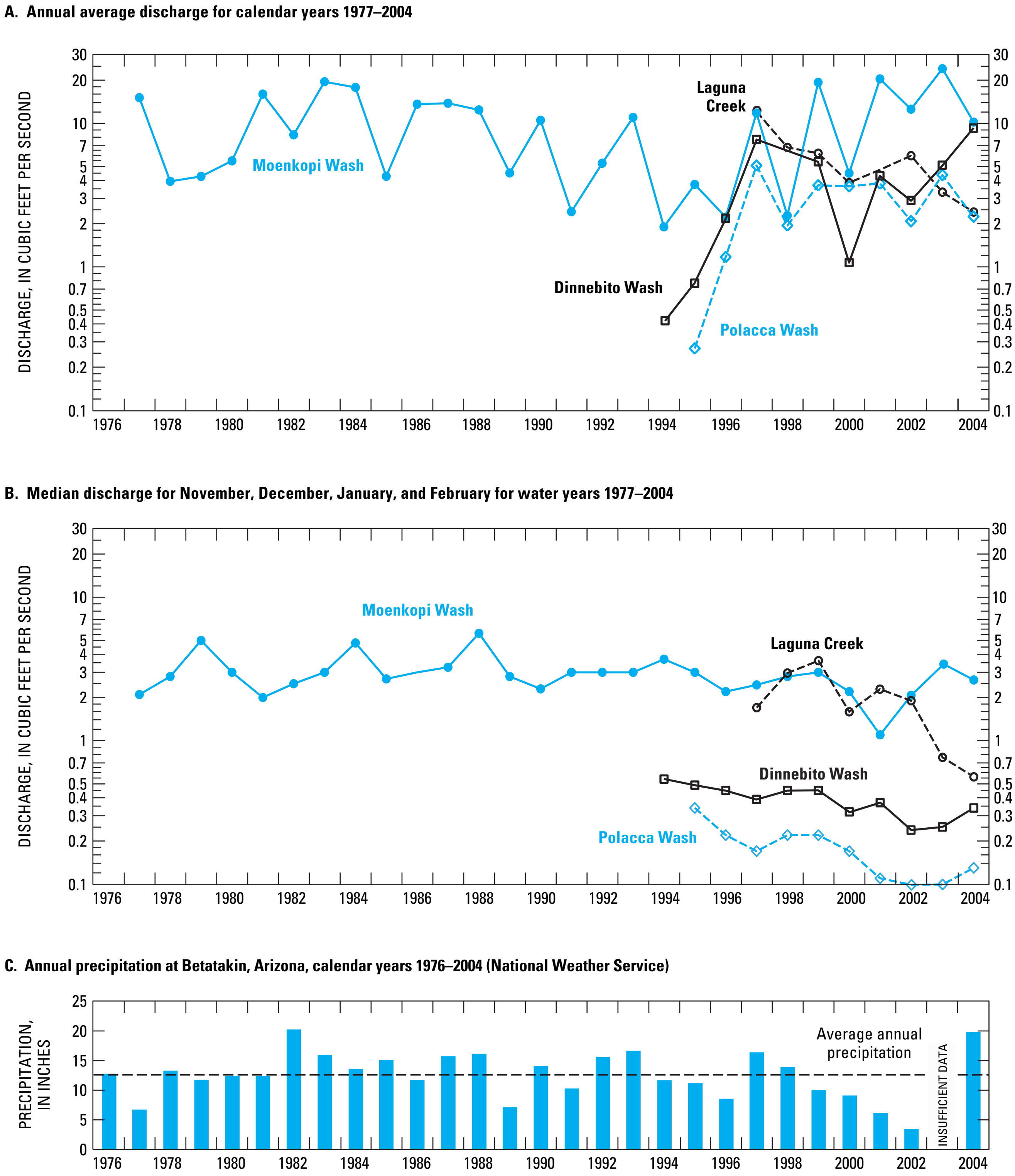


Figure 11. Annual precipitation at Betatakin, Arizona, and streamflow characteristics at Moenkopi Wash (09401260), Laguna Creek (09379180), Dinnebito Wash (09401110), and Polacca Wash (09400568), Black Mesa area, Arizona. A, Annual average discharge for calendar years 1977–2004; B, Median discharge for November, December, January, and February for water years 1977–2004; C, Annual precipitation at Betatakin, Arizona, calendar years 1976–2004 (National Weather Service).

Water Chemistry

Water samples are collected from selected wells and springs each year of the Black Mesa monitoring program. Field measurements are made and water samples are analyzed for major ions, nutrients, iron, boron, and arsenic. Samples typically are collected from 12 wells and 4 springs in each year of the program—from the same 8 wells every year and from the other 4 wells on a rotational basis. In 2005, samples could not be collected at Pĩnon PM1 because of well maintenance and repairs. Since 1989, samples have been collected from the same 4 springs. Long-term data for specific conductance, total dissolved solids, chloride, and sulfate for the wells and springs sampled each year are shown in the report published for that year. Historical data for other constituents for all the wells and springs are available from the USGS water-quality database (http://waterdata.usgs.gov/az/nwis/qw) or can be found in the past monitoring reports that are cited in the "Previous Investigations" section of this report.

Water Chemistry from Wells Completed in the N Aquifer

The primary types of water in the N aquifer are calcium bicarbonate and sodium bicarbonate. Calcium bicarbonate water generally is in the recharge areas of the northern and northwestern parts of the Black Mesa area, and sodium bicarbonate water is in the area that is downgradient to the south and east (Lopes and Hoffmann, 1997). In 2005, water samples were collected from 11 wells completed in the N aquifer (figs. 9 and 12). Sample analyses indicated primarily sodium bicarbonate water except for samples from Kayenta PM2 which is in the western part of the confined area of the N aquifer and Shonto PM2, which is in the western part of the unconfined recharge area of the N aquifer (fig. 12 and table 15).

Rough Rock PM5 and Keams Canyon PM2 yielded appreciably higher dissolved-solids concentrations (639 mg/L and 601 mg/L, respectively) than did the other 9 wells (fig. 12 and table 15). Concentrations of dissolved solids in samples from the other 9 wells ranged from 122 mg/L at Peabody 6 to 361 mg/L at Second Mesa PM2 (fig. 12 and table 15).

There are some long-term trends in the chemistry of water samples from the 7 wells having more than 10 years of data (table 16 and fig. 13). Rough Rock PM5, Keams Canyon PM2, Second Mesa PM2, and Kayenta PM2 show an increasing trend in dissolved solids; Forest Lake NTUA 1 and Peabody 2 show a decreasing trend in dissolved solids, and Kykostmovi PM2 shows a steady trend (fig. 13). The chemistry of water samples from Forest Lake NTUA 1 has varied considerably between 1982 and 2005 (table 16 and fig. 13).

Constituents analyzed from the 11 well samples were compared to U.S. Environmental Protection Agency (USEPA) Primary and Secondary Drinking-Water Regulations (U.S. Environmental Protection Agency, 2002). Maximum Contaminant Levels (MCLs), which are the primary regulations, are legally enforceable standards that apply to public water systems. MCLs protect drinking-water quality by limiting the levels of specific contaminants that can adversely affect public health. Secondary Maximum Contaminant Levels (SMCLs) provide guidelines for the control of contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The USEPA recommends compliance with SMCLs for public water systems; however, compliance is not required.

The concentrations of most of the analyzed constituents from the 11 wells sampled in 2005 were less than MCLs and SMCLs (table 15). The pH, however, exceeded the SMCL maximum pH of 8.5 units in samples from 9 of the 11 wells. The dissolved-solids SMCL of 500 mg/L was exceeded in the sample from Rough Rock PM5 (639 mg/L) and Keams Canyon PM2 (601 mg/L). Samples from three wells, Keams Canyon PM2 (42.7 µg/L), Rough Rock PM5 (50.8 µg/L), and Second Mesa PM2 (16.3 µg/L) had arsenic concentrations that exceeded the MCL of 10 µg/L (0.01 mg/L; table 15; U.S. Environmental Protection Agency, 2002).

Water Chemistry from Springs that Discharge from the N Aquifer

In 2005, water samples were collected from four springs in the study area. Burro Spring is in the southern part of the study area, the unnamed spring near Dennehotso is in the northeastern part, and Moenkopi School Spring and Pasture Canyon Spring are in the western part (fig. 9). All the springs discharge water from unconfined areas of the N aquifer. At Burro Spring, samples are collected from a metal pipe that discharges from a holding tank. At Moenkopi School Spring, samples are collected from a horizontal metal pipe that is developed into the hillside. At the unnamed spring near Dennehotso, samples are collected from a cavity dug into the sand where the water discharges from the bedrock. At Pasture Canyon Spring, samples are collected from a pipe at the end of a channel and approximately 50 feet away from the spring.

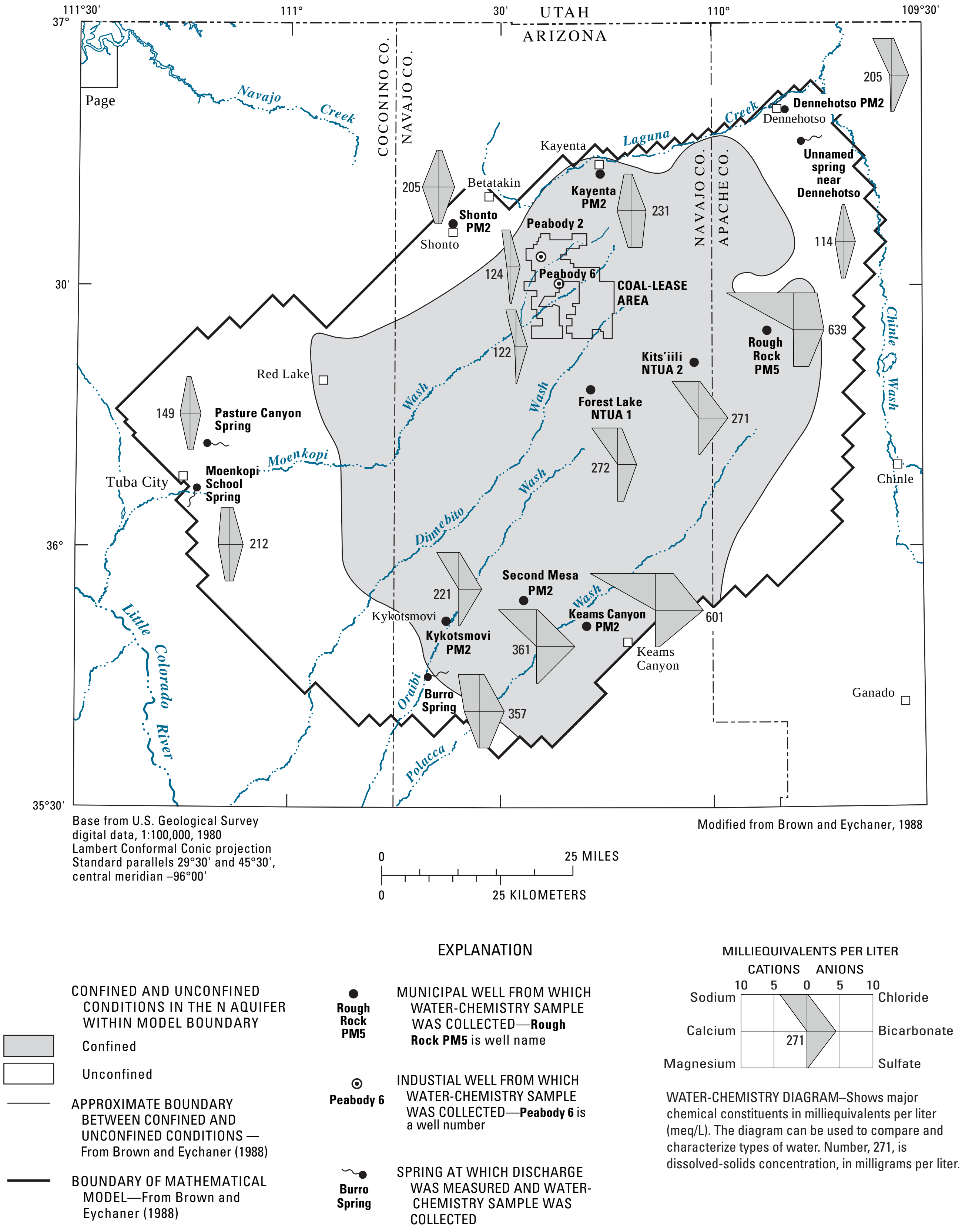


Figure 12. Water chemistry and distribution of dissolved solids in the N aquifer, Black Mesa area, Arizona, 2005.

Table 15. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 2005.

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligram per liter; µg/L, microgram per liter; <, less than]

Common well name	U.S. Geological Survey identification No.	Date of samples	Temperature field (°C)	Specific conductance field (µS/cm)	pH field (units)	Alkalinity, field, dissolved (mg/L as $CaCO_3$)	Nitrogen NO_2 + NO_3 dissolved (mg/L as N)	Ortho-Phosphate dissolved (mg/L as P)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)
Kits'iili NTUA 2	362043110030501	03–29–05	27.1	424	9.2	216	1.39	<0.02	0.53	0.013
Forest Lake NTUA 1	361737110180301	03–29–05	28.5	402	8.9	139	.58	<.02	.77	.082
Second Mesa PM2	354749110300101	03–30–05	19.3	615	9.3	296	<.06	[1].01	.48	.033
Keams Canyon PM2	355023110182701	03–30–05	19.6	828	8.8	367	<.06	<.02	.86	.172
Kykotsmovi PM2	355215110375001	03–31–05	22.3	316	9.8	173	1.19	.03	.48	.015
Rough Rock PM5	362418109514601	04–05–05	20.9	1,053	8.9	233	1.05	<.02	2.04	.275
Kayenta PM2	364344110151201	04–05–05	16.1	374	8.0	111	1.01	<.02	44.3	6.45
Dennehotso PM2	365045109504001	04–06–05	15.9	339	8.9	132	1.49	<.02	6.97	1.75
Shonto PM2	363558110392501	04–07–05	14.6	346	7.6	121	4.36	<.02	49.6	6.82
Peabody 6	363007110221201	05–12–05	32.5	174	9.2	88	.67	<.02	3.8	.03
Peabody 2	363005110250901	05–12–05	30.9	134	8.6	76	.97	<.02	8.7	.14

Common well name	Potassium dissolved (mg/L as K)	Sodium dissolved (mg/L as Na)	Chloride dissolved (mg/L as Cl)	Flouride dissolved (mg/L as F)	Silica dissolved (mg/L as SiO_2)	Sulfate dissolved (mg/L as SO_4)	Arsenic dissolved (µg/L as As)	Boron dissolved (µg/L as B)	Iron dissolved (µg/L as Fe)	Dissolved solids residue at 180°C (mg/L)
Kits'iili NTUA 2	0.59	94.8	3.67	0.2	25.5	3.7	3.8	51	[1]4	271
Forest Lake NTUA 1	.65	90	17.9	.5	20.4	43.8	3	136	<6	272
Second Mesa PM2	.5	132	6.83	.4	20	13.4	16.3	102	<6	361
Keams Canyon PM2	.88	227	97.4	1.4	12.3	33.6	42.7	631	<6	601
Kykotsmovi PM2	.47	76.7	3.08	.2	23.6	6.9	5.1	35	58	221
Rough Rock PM5	1.41	234	128	1.7	12.2	113	50.8	404	<6	639
Kayenta PM2	1.23	24.4	3.69	.2	15.6	76.3	1.6	23	12	231
Dennehotso PM2	.82	66.5	10.5	.2	11.6	14.4	6.9	40	<6	205
Shonto PM2	1.77	7.26	17.2	.1	14.2	19.9	1	16	[1]4	205
Peabody 6	.69	35.8	1.5	.1	21.2	5.7	3.8	19	<6	122
Peabody 2	.77	27.6	2.1	.1	21.8	8.2	2.8	19	<6	124

[1]Estimated value.

Table 16. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 1974–2005.

[µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligram per liter; <, less than. Dashes indicate no data]

Year	Specific conductance, field (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
		Forest Lake NTUA 1		
1982	470	---	11	67
1986	---	660	35	300
1990	375	226	8.2	38
1991	[1]350	183	10	24
1993	693	352	35	88
1994	[1]734	430	56	100
1995	470	274	13	60
1995	1,030	626	86	160
1995	488	316	16	71
1996	684	368	44	79
1997	[1]1,140	714	78	250
1998	489	350	37	71
1999	380	259	16	49
2001	584	398	50	84
2002	452	268	22	50
2003	385	228	10	40
2004	222	263	16	40
2005	402	272	18	44
		Second Mesa PM2		
1968	670	---	14	35
1990	590	364	6.5	16
1991	[1]595	292	10	15
1993	630	350	7.5	15
1994	[1]605	342	7.6	15
1995	610	357	7.2	14
1997	[1]646	356	7.1	14
2001	597	352	7.1	15
2002	608	357	7.5	14
2003	601	359	6.3	14
2005	615	361	6.8	13
		Peabody 2		
1967	221	---	5.0	21
1971	211	---	2.8	18
1974	210	144	2.8	17
1975	230	163	5.0	20
1976	260	133	3.6	16
1979	220	---	3.4	24
1980	225	145	11	20
1986	172	---	2.6	8.1
1987	149	113	5.0	9.1
1993	163	124	1.7	8.9
1998	93	119	2.2	7.9
1999	167	115	2.3	8.1
2005	134	124	2.1	8.2
		Keams Canyon PM2		
1982	1,010	---	94	35
1983	1,120	---	120	42
1984	1,060	578	96	36
1988	1,040	591	97	34
1990	1,020	600	94	34
1992	1,010	570	93	36
1993	1,040	590	92	36
1994	975	562	86	32
1995	1,010	606	99	32
1996	1,020	596	96	34
1997	1,070	590	96	33
1998	908	558	78	29
1999	1,040	595	97	35
2004	945	[2]603	97	32
2005	828	601	97	34
		Kits'iili NTUA 2		
1997	[1]524	269	3.6	4.3
1998	379	270	3.8	4.1
2000	454	274	4.0	4.1
2001	409	276	5.0	4.5
2002	439	264	4.5	4.4
2003	445	275	4.2	4.4
2004	367	273	4.0	4.6
2005	424	271	3.7	3.7
		Kykotsmovi PM2		
1988	368	212	3.2	8.6
1990	355	255	3.2	9.0
1991	[1]374	203	4.4	7.9
1992	363	212	3.3	8.4
1994	[1]365	212	3.6	8.5
1995	368	224	3.1	6.2
1996	365	224	3.3	8.5
1997	[1]379	222	3.0	8.0
1998	348	223	3.3	7.3
1999	317	221	3.5	7.9
2001	339	230	3.5	8.2
2002	350	215	3.4	7.9
2003	364	219	3.5	7.8
2004	261	223	3.5	8.3
2005	316	221	3.1	6.9

Table 16. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 1974–2005.—Continued

[µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligram per liter; <, less than. Dashes indicate no data]

Year	Specific conductance, field (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Dennehotso PM2				
1964	350	---	12	31
1992	226	131	9.8	19
1993	298	164	8.2	16
1997	[1]305	190	11	14
1999	314	196	14	15
2005	339	205	10.5	14
Peabody 6				
1968	201	---	3.0	13
1974	500	333	11.0	40
1977	240	---	3.2	13
1979	260	---	3.2	19
1980	260	160	3.5	15
1986	182	---	2.3	9.6
1988	173	127	2.4	9.1
1993	181	126	1.9	6.6
1996	177	122	1.5	6
2005	174	122	1.5	5.7
Rough Rock PM5				
1964	1,120	([3])	100	110
1970	610	([3])	13	50
1983	1,090	([3])	130	110
1984	[1]1,100	613	130	99
1986	1,010	633	140	120
1988	1,120	624	130	[4]110
1991	[1]1,210	574	130	110
1993	1,040	614	130	110
1994	[1]1,180	626	130	110
1995	1,110	648	140	110
1996	1,100	634	130	110
1997	[1]1,060	628	130	112
1998	894	637	133	112
1999	1,050	630	129	110
2001	980	628	125	110
2002	1,120	636	129	109
2003	1,080	642	127	110
2004	653	649	128	109
2005	1,053	639	128	113

Year	Specific conductance, field (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Shonto PM2				
1961	290	---	10	16
1973	280	---	7.1	20
1986	302	---	10	14
1988	285	171	13	14
1992	321	186	22	19
1993	324	197	17	16
1996	323	188	15	17
2002	355	215	22	22
2003	357	239	20	22
2005	346	205	17	20
Kayenta PM2				
1982	360	([3])	4.5	58
1983	375	([3])	5.9	60
1984	[1]370	209	4.2	51
1986	300	181	8.2	30
1988	358	235	3.8	74
1992	383	210	5.6	78
1993	374	232	3.7	78
1994	[1]371	236	4.2	77
1995	371	250	4.2	72
1996	370	238	3.8	76
1997	379	230	3.9	77
1998	349	236	3.7	71
1999	364	236	4.0	72
2001	331	234	5.0	73
2002	363	237	5.1	67
2003	378	273	5.9	88
2004	303	241	4.0	72
2005	374	231	3.7	76

[1]Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports showed values determined by laboratory analysis.

[2]Value changed from Black Mesa monitoring report for 2003–2004.

[3]Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports showed values determined by the sum of constituents.

[4]Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports applied a different rounding definition.

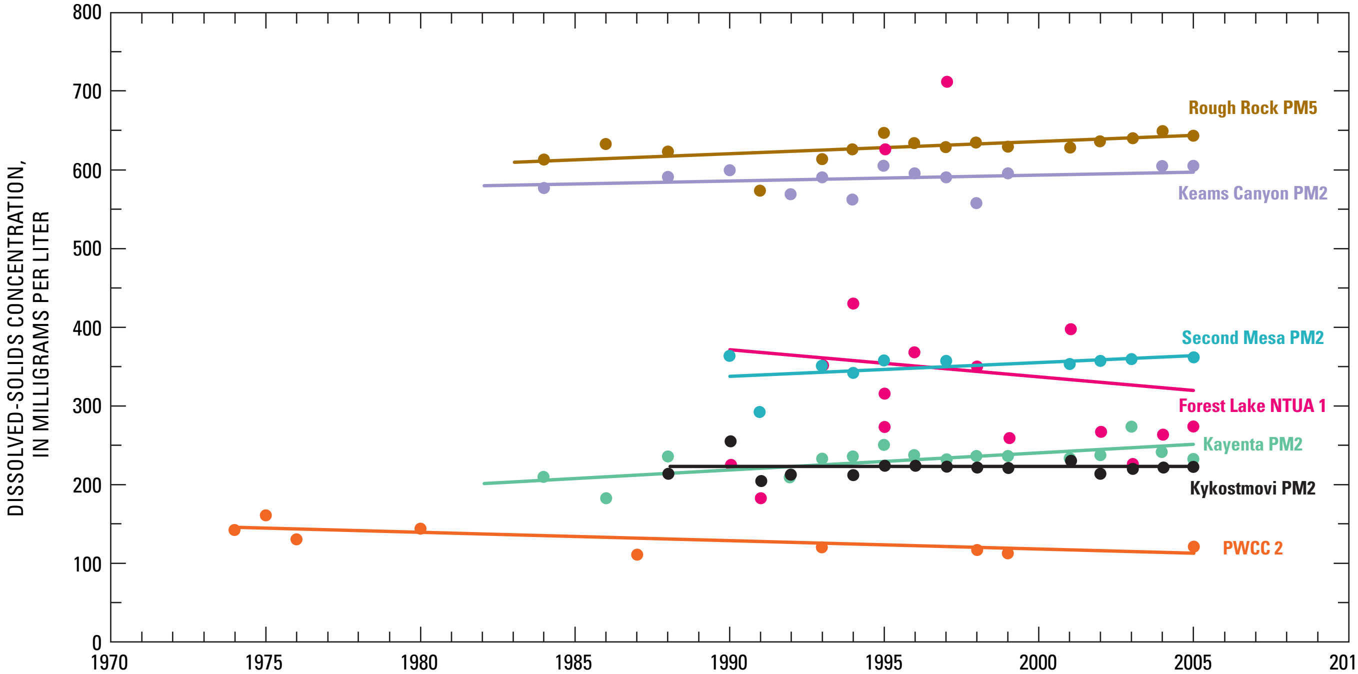


Figure 13. Dissolved-solids concentrations with linear trend lines for water from selected wells, Black Mesa area, Arizona, 1980–2005.

Two water types were identified from the samples from the four springs. The unnamed spring near Dennehotso and Pasture Canyon Spring yielded a calcium bicarbonate type water, and Burro Spring and Moenkopi School Spring yielded a calcium sodium bicarbonate type water (fig. 12). Samples from the unnamed spring near Dennehotso, Moenkopi School Spring, and Pasture Canyon Spring had low dissolved-solids concentrations that ranged from 114 to 212 mg/L (table 17). The sample from Burro Spring had a dissolved-solids concentration of 357 mg/L. Concentrations of all the analyzed constituents in samples from the four springs were less than current USEPA MCLs and SMCLs (U.S. Environmental Protection Agency, 2002).

No long-term trends, since the mid-1980s, are apparent in concentrations of dissolved solids, chloride, and sulfate in water samples from the unnamed spring near Dennehotso and Pasture Canyon Spring (table 18 and fig. 14*A–C*). Increasing trends in concentrations of dissolved solids and chloride are evident in data from Burro Spring and Moenkopi School Spring, and an increasing trend in sulfate is evident in data from Moenkopi School Spring (table 18 and figs. 14*A–C*).

Table 17. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 2005.

[°C, degree Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligram per liter; µg/L, microgram per liter; <, less than. Dashes indicate no data]

Spring name	Bureau of Indian Affairs site No.	U.S. Geological Survey identification No.	Date of sample	Temperature, field (°C)	Specific conductance, field (µS/cm)	pH, field (units)
Burro Spring	6M-31	354156110413701	03–28–05	---	558	7.4
Moenkopi School Spring	3GS-77-6	360632111131101	04–04–05	17.3	349	7.4
Unnamed spring near Dennehotso	8A-224	364656109425400	04–06–05	8.4	194	7.7
Pasture Canyon Spring	3A-5	361021111115901	04–27–05	16.1	250	7.6

Spring name	Alkalinity, field, dissolved (mg/L as $CaCO_3$)	Nitrogen $NO_2 + NO_3$, dissolved (mg/L as N)	Ortho-phosphate, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Burro Spring	190	0.21	<0.02	47.9	3.22
Moenkopi School Spring	107	2.54	<.02	33.2	6.96
Unnamed spring near Dennehotso	87	1.88	.02	26.9	4.05
Pasture Canyon Spring	80	4.49	[1].02	30.5	4.43

Spring name	Potassium, dissolved (mg/L as K)	Sodium, dissolved (mg/L as Na)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
Burro Spring	0.51	75.4	25.8	0.5	13.5
Moenkopi School Spring	1.47	27.5	23.3	.2	13.4
Unnamed spring near Dennehotso	1.15	5.97	2.65	.2	12.1
Pasture Canyon Spring	1.46	12	5.07	.2	10.0

Spring name	Sulfate, dissolved (mg/L as SO_4)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids, residue at 180°C (mg/L)
Burro Spring	68.9	1.5	88	<6	357
Moenkopi School Spring	29.6	2.8	39	<6	212
Unnamed spring near Dennehotso	8.7	3.0	18	<6	114
Pasture Canyon Spring	16.3	2.0	33	<6	149

[1]Estimated value.

Table 18. Specific conductance and concentrations of selected chemical constituents in water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 1948–2005.

[µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; °C, degrees Celsius. Dashes indicate no data]

Year	Specific conductance, field (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Burro Spring				
1989	485	308	22	59
1990	[1]545	347	23	65
1993	595	368	30	85
1994	[1]597	368	26	80
1996	525	324	23	62
1997	[1]511	332	26	75
1998	504	346	25	70
1999	545	346	25	69
2001	480	348	24	68
2002	591	374	31	77
2003	612	374	30	81
2004	558	337	25	64
2005	558	357	25	69
Unnamed spring near Dennehotso				
1984	195	112	2.8	7.1
1987	178	[2]109	3.4	7.5
1992	178	108	3.6	7.3
1993	184	100	3.2	8.0
1995	184	124	2.6	5.7
1996	189	112	2.8	8.2
1997	[1]170	98	2.4	6.1
1998	179	116	2.4	5.4
1999	184	110	2.8	6.3
2001	176	116	2.6	6.0
2002	183	104	2.7	7.4
2003	180	118	2.9	7.2
2004	170	117	2.7	5.0
2005	194	114	2.6	8.7

Year	Specific conductance, field (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Moenkopi School Spring				
1952	222	---	6	---
1987	270	161	12	19
1988	270	155	12	19
1991	297	157	14	20
1993	313	204	17	27
1994	305	182	17	23
1995	314	206	18	22
1996	332	196	19	26
1997	[1]305	185	18	24
1998	296	188	18	24
1999	305	192	19	26
2001	313	194	18	26
2002	316	191	18	23
2003	344	197	19	23
2004	349	196	19	21
2005	349	212	23	30
Pasture Canyon Spring				
1948	[1]227	([2])	5	13
1982	240	---	5.1	18
1986	257	---	5.4	19
1988	232	146	5.3	18
1992	235	168	7.1	17
1993	242	134	5.3	17
1995	235	152	4.8	14
1996	238	130	4.7	15
1997	232	143	5.3	17
1998	232	147	5.1	16
1999	235	142	5.1	14
2001	236	140	5.1	17
2002	243	143	5.1	16
2003	236	151	5.1	16
2004	248	150	5.5	16
2005	250	149	5.1	16

[1]Value is different in Black Mesa monitoring reports before 2000. Earlier reports showed values determined by laboratory analysis.

[2]Value is different in Black Mesa monitoring reports before 2000. Earlier reports showed values determined by the sum of constituents.

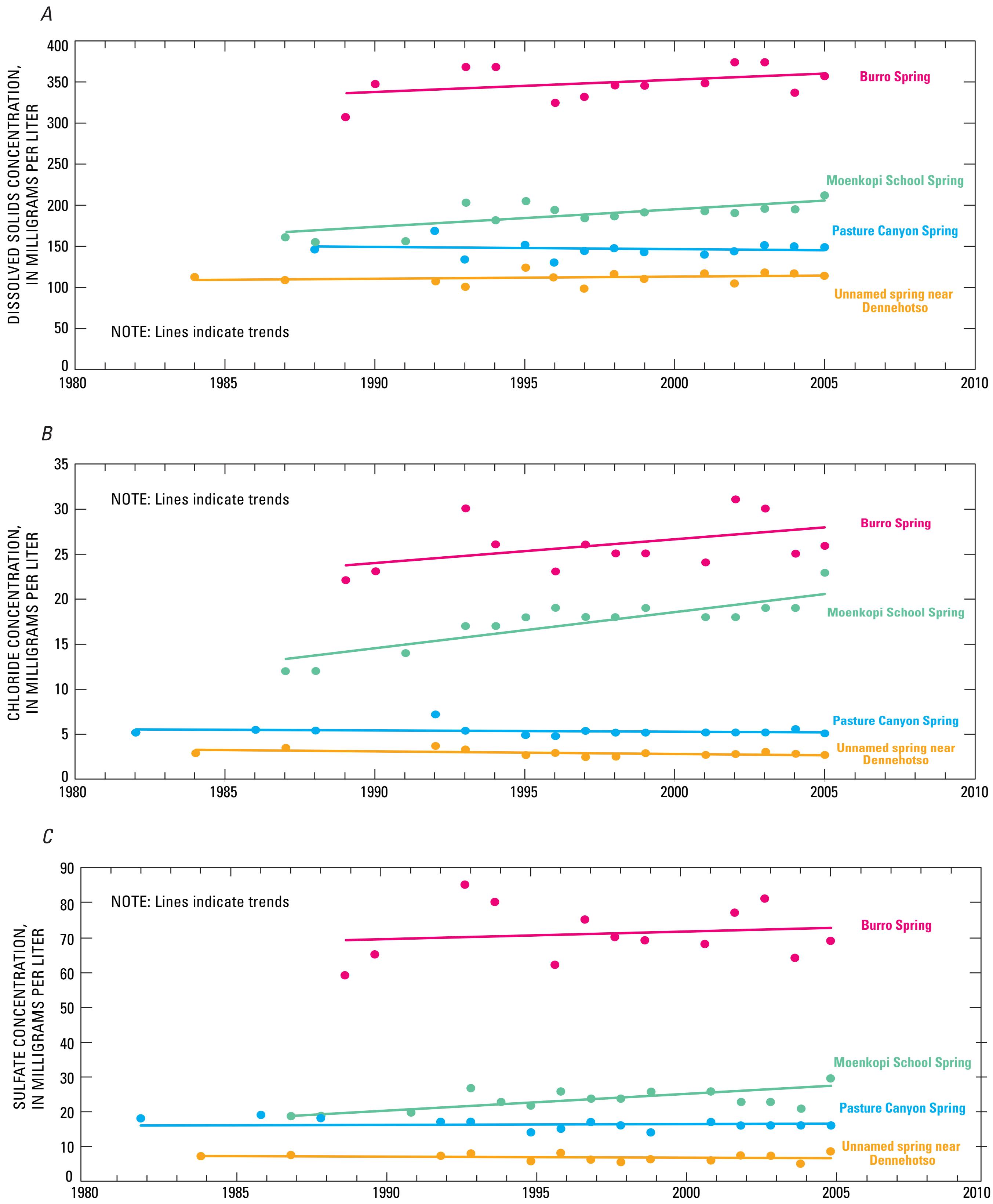


Figure 14. Concentrations of dissolved solids, chloride, and sulfate for water from selected springs, Black Mesa area, Arizona, 1984–2005. A, Dissolved solids; B, Chloride; C, Sulfate.

Summary

The N aquifer is the major source of water for industrial and municipal users in the Black Mesa area of northeastern Arizona. Availability of water is an important issue in the Black Mesa area because of continued industrial and municipal use, a growing population, and precipitation of about 6 to 14 in. per year.

This report presents results of ground-water, surface-water, and water-chemistry monitoring in the Black Mesa area from January 2004 to September 2005. The monitoring data for 2004–05 are compared with data for 2003–04 and with historical data from the 1950s to the present.

In 2004, total ground-water withdrawals were 7,210 acre-ft, industrial withdrawals were 4,370 acre-ft, and municipal withdrawals were 2,840 acre-ft. From 2003 to 2004, total withdrawals decreased by less than 1 percent, industrial withdrawals decreased by 2 percent, and municipal withdrawals increased by 2 percent.

From 2004 to 2005, annually measured ground-water levels declined in 14 of 25 wells. The median water-level change for the 25 wells was -0.4 ft. In unconfined areas, water levels declined in 6 of 13 annual wells, and the median change was -0.1 ft. In the confined area, water levels declined in 8 of 12 wells, and the median change was -1.2 ft. For wells in the confined area, the median water-level change was -1.7 ft, and there is no appreciable trend in the water-level changes from 1983 to 2005. For wells in unconfined areas, the median water-level change was 0.2 ft, and there is no appreciable trend from 1983 to 2005.

From the prestress period (prior to 1965) to 2005, the median water-level change in 33 wells was -9.0 ft. Water levels in the 16 wells in the unconfined areas of the aquifer had a median change of -0.6 ft, and the changes ranged from -33.2 ft to 15.0 ft. Water levels in the 17 wells in the confined area of the aquifer had a median change of -32.0 ft, and the changes ranged from -193.3 ft to 14.0 ft.

Discharges were measured annually at four springs in 2004 and 2005. Between 2004 and 2005, spring flow stayed the same at Burro Spring, increased by 71 percent at the unnamed spring near Dennehotso, decreased by 5 percent at Moenkopi School Spring, and increased by 8 percent at Pasture Canyon Spring. For about the past 12 years, discharges in the four springs have fluctuated; however, increasing or decreasing trends are not apparent.

Annual average discharges at four streamflow-gaging stations—Moenkopi Wash, Laguna Creek, Dinnebito Wash, and Polacca Wash—vary considerably during the periods of record. No trends are apparent in streamflow at the four gaging stations. Median flows for November, December, January, and February of each water year are used as an index of ground-water discharge to those streams. Since 1995, the median winter flows have decreased in Moenkopi Wash, Dinnebito Wash, and Polacca Wash. Since 1997, there is no increasing or decreasing trend apparent in the median winter flow in Laguna Creek.

In 2005, water samples were collected from 11 wells and analyzed for selected chemical constituents. Dissolved-solids concentrations ranged from 122 to 639 mg/L, and samples from 9 of the wells had dissolved-solids concentrations less than the SMCL (500 mg/L). There are some long-term trends in the chemistry of water samples from 7 wells with more than 10 years of data.

Samples from Rough Rock PM5 exceeded the SMCL for dissolved solids, samples from Keams Canyon PM2, Rough Rock PM5, and Second Mesa PM2 exceeded the MCL for arsenic (10 μg/L), and samples from 9 of the 11 wells exceeded the SMCL maximum for pH (8.5).

Dissolved-solids concentrations in water samples from the unnamed spring near Dennehotso, Pasture Canyon Spring, and Moenkopi School Spring ranged from 114 to 212 mg/L, and the dissolved-solids concentration in the water sample from Burro Spring was 357 mg/L. From the mid-1980s to 2005, long-term trends are not apparent in the concentrations of dissolved solids, chloride, and sulfate in water samples from the unnamed spring near Dennehotso and Pasture Canyon Spring. Increasing trends in concentrations of dissolved solids and chloride are evident in data from Burro Spring and Moenkopi School Spring, and an increasing trend in sulfate is evident in data from Moenkopi School Spring.

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