Prepared in cooperation with the BUREAU OF INDIAN AFFAIRS and the ARIZONA DEPARTMENT OF WATER RESOURCES

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2005–06

Open-File Report 2007–1041

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By Margot Truini and J.P. Macy

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Conversion Factors and Datums

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

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

$$°F=(1.8\times°C)+32$$

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).

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

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).

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2005–06

By Margot Truini and J.P. Macy

Abstract

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

The water monitoring program in the Black Mesa area began in 1971 and is designed to provide information about the long-term effects of ground-water withdrawals from the N aquifer for industrial and municipal uses. This report presents results of data collected for the monitoring program in the Black Mesa area from January 2005 to September 2006. 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 2005, ground-water withdrawals in the Black Mesa area totaled 7,330 acre-feet, including ground-water withdrawals for industrial (4,480 acre-feet) and municipal (2,850 acre-feet) uses. From 2004 to 2005, total withdrawals increased by less than 2 percent, industrial withdrawals increased by approximately 3 percent, and total municipal withdrawals increased by 0.35 percent.

From 2005 to 2006, annually measured water levels in the Black Mesa area declined in 10 of 13 wells in the unconfined areas of the N aquifer, and the median change was -0.5 foot. Measurements indicated that water levels declined in 12 of 15 wells in the confined area of the aquifer, and the median change was -1.4 feet. From the prestress period (prior to 1965) to 2006, the median water-level change for 29 wells was -8.5 feet. Median water-level changes were -0.2 foot for 13 wells in the unconfined areas and -46.6 feet for 16 wells in the confined area.

Ground-water discharges were measured once in 2005 and once in 2006 at Moenkopi School Spring and Burro Spring. Discharge decreased by 3.5 percent at Moenkopi School Spring and by 15 percent at Burro Spring. During the period of record at each spring, discharges fluctuated; a decreasing trend was apparent.

Continuous records of surface-water discharge in the Black Mesa area have been collected from streamflow gages at the following sites: Moenkopi Wash (1976 to 2005), Dinnebito Wash (1993 to 2005), Polacca Wash (1994 to 2005), Pasture Canyon Spring (August 2004 to December 2005), and Laguna Creek (1996 to 2005). Median flows during November, December, January, and February of each water year were used as an index of the amount of ground-water discharge to the above named sites. For the period of record at each streamflow-gaging station, the median winter flows have decreased for Moenkopi Wash, Dinnebito Wash, and Polacca Wash. There is not a long enough period of record for Pasture Canyon Spring and Laguna Creek was discontinued at the end of December 2005.

In 2006, water samples were collected from 6 wells and 2 springs in the Black Mesa area and analyzed for selected chemical constituents. Dissolved-solids concentrations ranged from 111 to 588 milligrams per liter. Water samples from 5 of the wells and both of the springs had less than 500 milligrams per liter of dissolved solids. Trends in the chemistry of water samples from the 6 wells show the Piñon NTUA 1 and Peabody 9 wells increasing in dissolved solids, Forest Lake NTUA 1 and Peabody 2 wells decreasing in dissolved solids, and Kykotsmovi PM2 and Keams Canyon PM2 wells show a steady trend. Increasing trends in dissolved-solids, chloride, and sulfate concentrations were evident from the more than 11 years of data for the 2 springs.

Introduction

The Black Mesa study area in northeastern Arizona 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 covers about 2,000 mi^2; it has 2,000-foot-high cliffs on its northern and northeastern sides, but slopes gradually down 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 an average precipitation rate of 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, and it consists of three hydraulically connected formations—the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Member of the Wingate Sandstone—that function as a single aquifer (fig. 2).

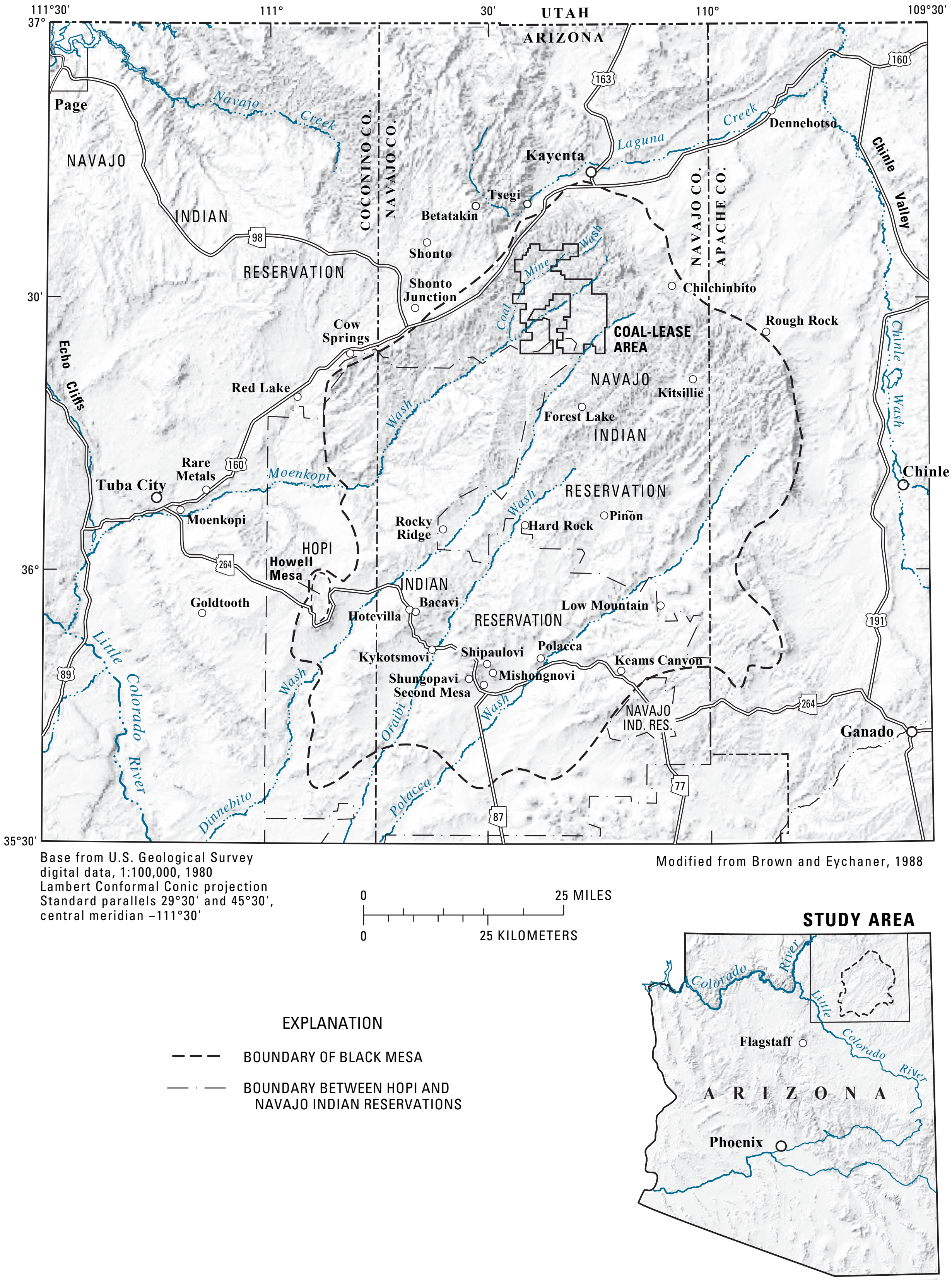


Figure 1. Location of study area, Black Mesa area, Arizona.

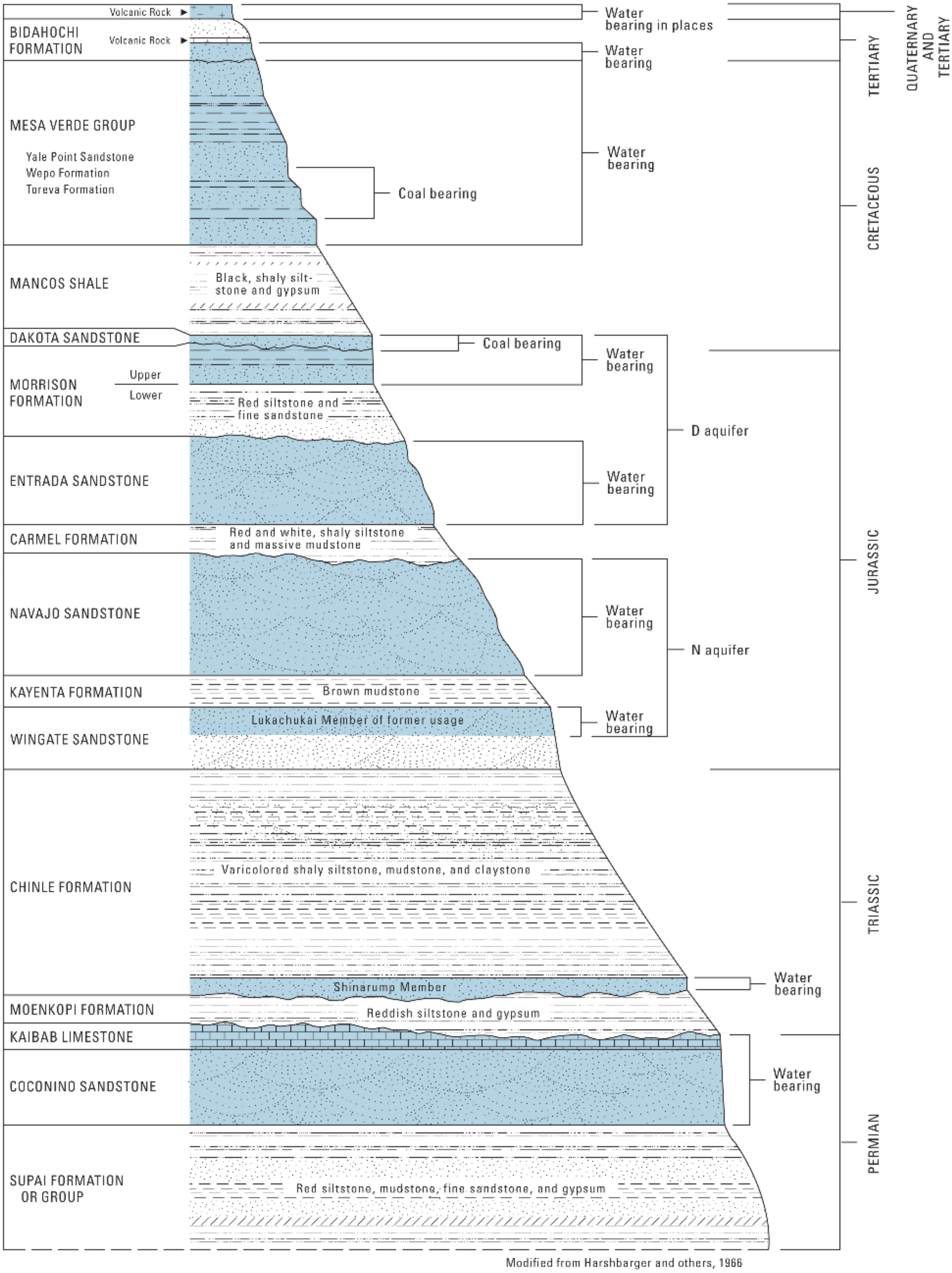


Figure 2. Rock formations and hydrogeologic units of the Black Mesa area, Arizona (not to scale). The N aquifer is approximately 1,000 feet thick.

The N aquifer is confined under most of Black Mesa with the overlying stratigraphy (fig. 2) preventing recharge to this part of the aquifer. The N aquifer is unconfined in areas around Black Mesa and most recharge occurs where the Navajo Sandstone is exposed in the area near Shonto, Arizona (fig. 1).

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 municipal water users. Withdrawals from the N aquifer in the Black Mesa area have been increasing during the last 40 years (table 1 and fig. 3). PWCC began operating a strip mine in the northern part of the study area 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. In 2005, about 4,480 acre-ft of water was pumped by PWCC. Withdrawals from the N aquifer for municipal use increased from an estimated 250 acre-ft in 1968 to 2,850 acre-ft in 2005. 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. This is the last year that PWCC will be the principal water user because of the shutdown of the 273-mi-long slurry line from the mining area on Black Mesa to Laughlin, Nevada. PWCC plans on pumping between 500 and 1,000 acre-ft per year, primarily for dust control.

The members of 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 water supply concerns led to the establishment of a monitoring program for 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.

Purpose and Scope

This report presents results of ground-water, surface-water, and water-chemistry monitoring in the Black Mesa area from January 2005 to September 2006. Results from the monitoring program are 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 ground-water and surface-water data are collected. Ground-water data include pumpage, water levels, spring discharge rates, and water chemistry. Surface-water data include discharge rates at five continuous-record streamflow-gaging stations.

Previous Investigations

Twenty-three progress reports on the Black Mesa area monitoring program 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; Truini and others, 2005; and Truini and Macy, 2006). Most of the data from the Black Mesa area monitoring program are contained in these reports. Stream-discharge and periodic water-quality data collected from Moenkopi Wash 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, 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, 2006). 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 Eychaner’s model by using a finer grid and revised estimates of selected aquifer characteristics. GeoTrans (1987) also developed a two-dimensional numerical 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 by using geochemical techniques. Zhu and others (1998) estimated ground-water recharge in the Black Mesa area by using isotopic data and flow estimates from the N aquifer model developed by GeoTrans (1987). Zhu (2000) estimated recharge by using the same isotopic data from the GeoTrans model, but added numerical flow and transport modeling to the method. Truini and Longsworth (2003) described the hydrogeology of the D aquifer and the movement and ages of ground water in the Black Mesa area by using data from geochemical and isotopic analyses. Truini and Macy (2006) address leakage through the confining unit between the D aquifer to the N aquifer in a characterization of the Carmel Formation.

Table 1. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–2005.

[Values are rounded to nearest 10 acre-feet. Industrial values indicate metered pumpage from the Peabody Western Coal Company. Municipal values include 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, the Bureau of Indian Affairs, various Hopi Village Administrations, and the U.S. Geological Survey, 1986–2004. Municipal values do no include withdrawals from wells equipped with windmills. Data for 1965–79 from Eychaner (1983). Total withdrawals in Littin and Monroe (1996) were for the confined area of the aquifer]

Year	Industrial	Municipal		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
2005	4,480	1,280	1,570	7,330

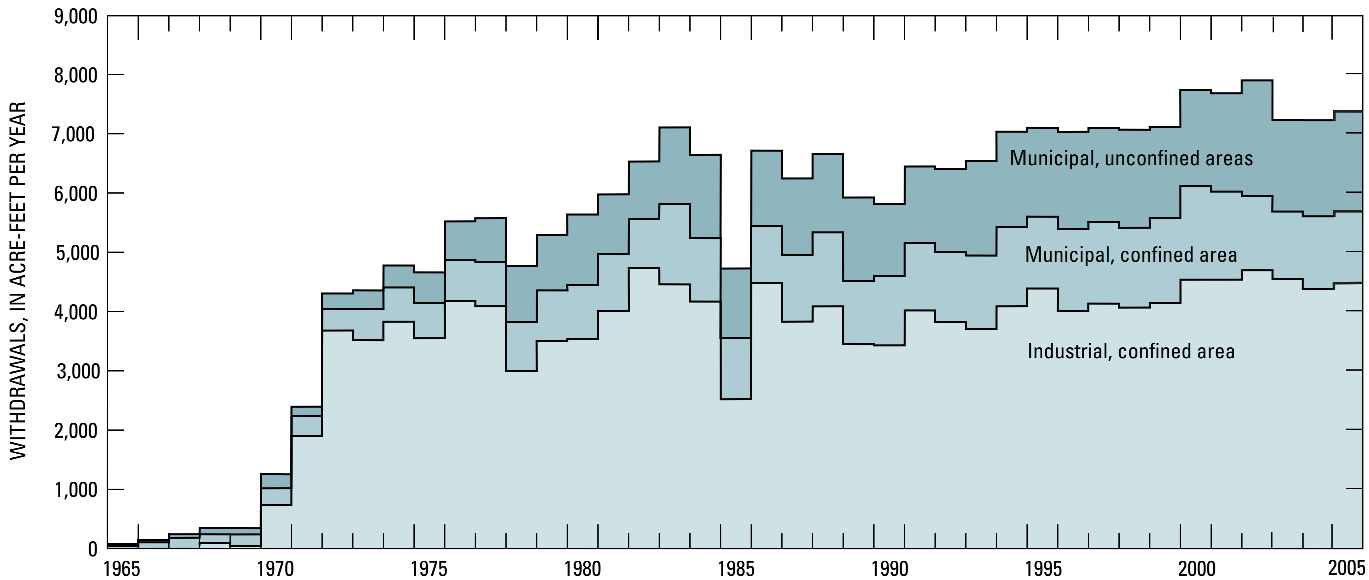


Figure 3. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–2005.

Hydrologic Data

In 2005–06, the Black Mesa area 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 withdrawal data are collected from 28 well systems within the NTUA, BIA, and Hopi municipal systems and the PWCC industrial well field (fig. 4). Annual discharge measurements were made at 2 springs, and annual ground-water level measurements were made at 29 wells. Six of the 29 annual wells are continuous- recording observation wells that have been upgraded for telemetry. The water-level data from these wells are available on the World Wide Web (http://waterdata.usgs.gov/az/nwis/rt). Spring discharges and ground-water levels were measured from January to April 2006. Ground-water samples were collected from 6 wells and 2 springs in March 2006 and analyzed for chemical constituents. Identification information for the 34 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 PWCC well field in the northern Black Mesa area (fig. 4). The BIA, NTUA, and Hopi Tribe operate about 70 municipal wells that are combined into 28 well systems (fig. 4). Information about withdrawals from the N aquifer was 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 the estimated total withdrawal by the windmills is about 65 acre-ft/yr (HSIGeoTrans, Inc. and Waterstone Environmental Hydrology and Engineering, Inc., 1999). The total withdrawal by the windmills is less than 1 percent of the total annual withdrawal from the N aquifer.

In 2005, the total ground-water withdrawal from the N aquifer was about 7,330 acre-ft (table 1), which is less than a 2-percent increase from the total withdrawal in 2004 (table 1). Withdrawals for municipal use from the confined area totaled 1,280 acre-ft, an increase of about 3 percent from 2004. Withdrawals for municipal use from the unconfined areas totaled 1,570 acre-ft, a decrease of about a 2 percent from 2004. Withdrawals for industrial use totaled 4,480 acre-ft, a 3-percent increase from 2004, and withdrawals for municipal use totaled 2,850 acre-ft, a 0.35-percent increase from 2004.

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 1965–2005 withdrawals totaled 218,300 acre-ft, industrial withdrawals were 63 percent of the total withdrawals and municipal withdrawals were 37 percent of total withdrawals. From 1965 to 1972, total withdrawals increased from 70 to 4,300 acre-ft, industrial withdrawals were 72 percent of total withdrawals, and municipal withdrawals were 28 percent of total withdrawals.

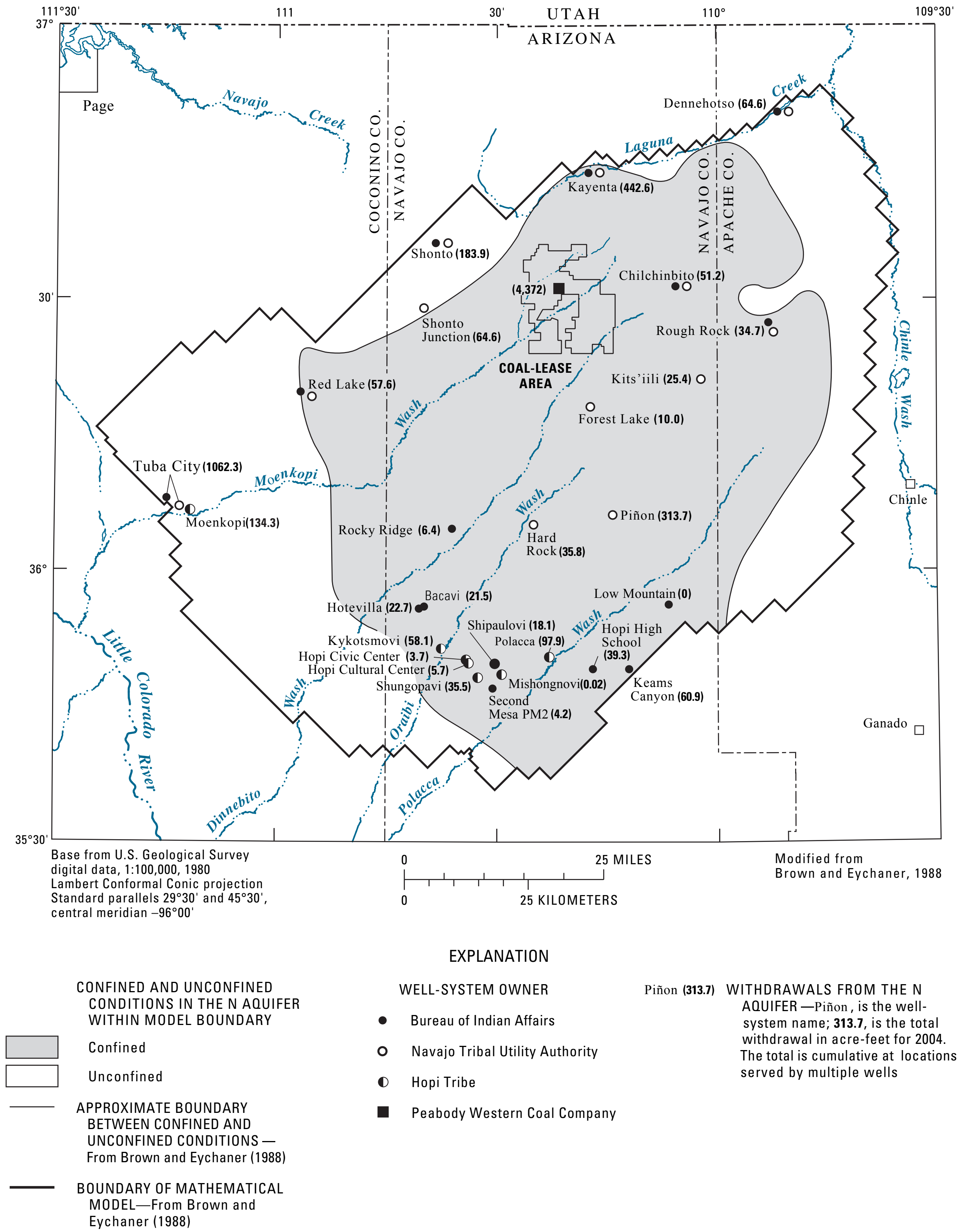


Figure 4. Locations of well systems monitored for withdrawals from the N aquifer, Black Mesa area, Arizona, 2005.

Table 2. Identification numbers and names of study wells, 2005–06, Black Mesa area, Arizona.

[USGS, U.S. Geological Survey; BIA, Bureau of Indian Affairs; dashes indicate no data]

USGS identification number	Common name or location	BIA site number
355023110182701	Keams Canyon PM2	---
355215110375001	Kykotsmovi PM2	---
355230110365801	Kykotsmovi PM1	---
355428111084601	Goldtooth	3A-28
355648110475501	Howell Mesa	6H-55
355924110485001	Howell Mesa	3K-311
360055110304001	BM observation well 5	4T-519
360217111122601	Tuba City	3K-325
360527110122501	Piñon NTUA 1	---
360614110130801	Piñon PM6	---
360734111144801	Tuba City	3T-333
360918111080701	Tuba City Rare Metals 2	---
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
362333110250001	Peabody 9	---
362936109564101	BM observation well 1	8T-537
363013109584901	Sweetwater Mesa	8K-443
363103109445201	Rough Rock	9Y-95
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
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
364034110240001	Marsh Pass	8T-522

Table 3. Withdrawals from the N aquifer by well system, Black Mesa area, Arizona, 2005.

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

Well system	Owner	Source of data	Withdrawals	
			Confined aquifer	Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	2.1	
Dennehotso	BIA	USGS/BIA		20.2
Hopi High School	BIA	USGS/BIA	39.3	
Hotevilla	BIA	USGS/BIA	22.7	
Kayenta	BIA	USGS/BIA	40.7	
Keams Canyon	BIA	USGS/BIA	60.9	
Low Mountain	BIA	USGS/BIA	0	
Piñon	BIA	USGS/BIA	0	
Red Lake	BIA	USGS/BIA		6.3
Rocky Ridge	BIA	USGS/BIA	6.4	
Rough Rock	BIA	USGS/BIA	34.7	
Second Mesa	BIA	USGS/BIA	4.2	
Shonto	BIA	USGS/BIA		166.7
Tuba City	BIA	USGS/BIA		103.5
Chilchinbito	NTUA	USGS/NTUA	49.2	
Dennehotso	NTUA	USGS/NTUA		44.4
Forest Lake	NTUA	USGS/NTUA	10	
Hard Rock	NTUA	USGS/NTUA	35.8	
Kayenta	NTUA	USGS/NTUA	401.9	
Kits'iili	NTUA	USGS/NTUA	25.4	
Piñon	NTUA	USGS/NTUA	313.7	
Red Lake	NTUA	USGS/NTUA		6.3
Rough Rock	NTUA	USGS/NTUA	0	
Shonto	NTUA	USGS/NTUA		17.2
Shonto Junction	NTUA	USGS/NTUA		64.6
Tuba City	NTUA	USGS/NTUA		958.9
Mine Well Field	Peabody	Peabody	4,483	
Bacavi	Hopi	USGS/Hopi	21.5	
Hopi Civic Center	Hopi	USGS/Hopi	3.7	
Hopi Cultural Center	Hopi	USGS/Hopi	5.7	
Kykotsmovi	Hopi	USGS/Hopi	58.1	
Mishongnovi	Hopi	USGS/Hopi	.02	
Moenkopi	Hopi	USGS/Hopi		134.3
Polacca	Hopi	USGS/Hopi	87.9	
Shipaulovi	Hopi	USGS/Hopi	18.1	
Shungopovi	Hopi	USGS/Hopi	35.5	

Table 4. Percent values and pumpage in acre-feet per year for total withdrawal and discreet periods of time based on trends during 1965 to 2005, Black Mesa area, Arizona.

Period	Total withdrawals (acre-feet)	Industrial withdrawals (acre-feet)	Municipal withdrawals (acre-feet)	Percent industrial	Percent municipal
1965–2005	218,300	138,100	80,200	63	37
1965–1972	8,930	6,460	2,470	72	28
1973–1984	66,470	46,540	19,930	70	30
1985	4,720	2,520	2,200	53	47
1986–2004	130,850	78,100	52,750	60	40
2005	7,330	4,480	2,850	61	39

From 1973 to 1984, withdrawals totaled 66,470 acre-ft, industrial withdrawals were 70 percent of total withdrawals, and municipal withdrawals were 30 percent of total withdrawals. In 1985, withdrawals totaled 4,720 acre-ft, industrial withdrawals were 53 percent of total withdrawals, and municipal withdrawals were 47 percent of total withdrawals. From 1986 to 2004, withdrawals totaled 130,850 acre-ft, industrial withdrawals were 60 percent of total withdrawals, and municipal withdrawals were 40 percent of total withdrawals. In 2005, total withdrawals were 7,330 acre-ft, industrial withdrawals were 61 percent of total withdrawals, and municipal withdrawals were 39 percent of total withdrawals.

Ground-Water Levels in the N Aquifer

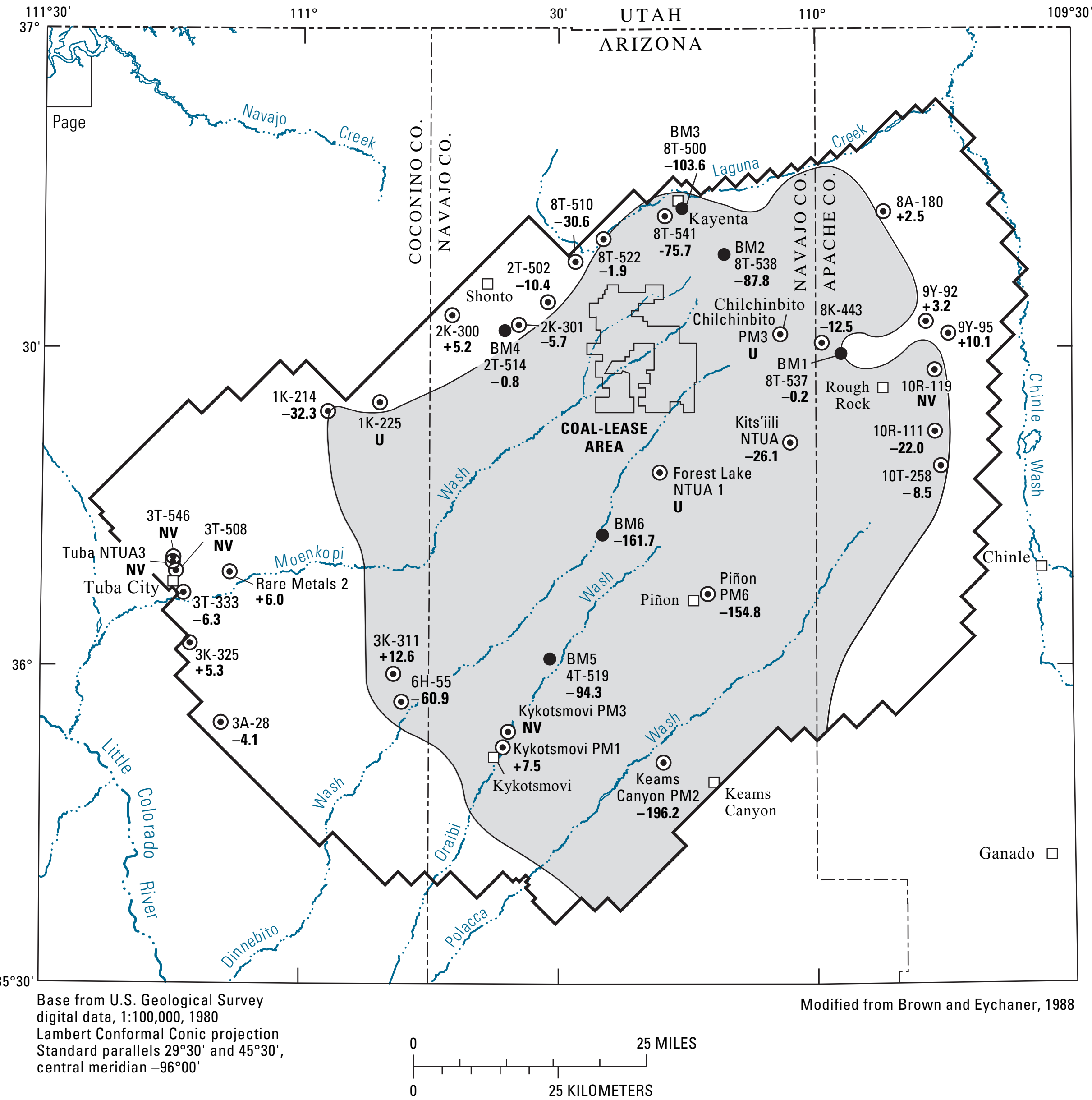
Ground water in the N aquifer is under confined conditions in the central part of the study area and under unconfined or water-table conditions around the periphery (fig. 5). The ground water generally moves radially from the recharge areas near Shonto, Ariz., toward Tuba City, Ariz., to the southwest,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

Ground-water levels are measured once a year and compared to 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 December 2005 to March 2006, water levels in 28 of the 29 wells in the Black Mesa area monitoring program that are used for annual measurements met these criteria (table 5). Six of the 28 wells are continuous-recording observation wells, and water levels were measured manually in these wells 3 times between March 2005 and April 2006. Twenty-eight of the 29 water levels measured in 2006 were compared to 2005 water level measurements for the same wells. Water level measurements in the one remaining well could not be compared because of effects of pumping that prevented measurement of an accurate water level in 2005.

Water-level measurements are collected from wells 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. Well 6H-55 was thought to be completed in the N aquifer but is completed in the D aquifer. Construction dates for annual wells in the Black Mesa study area range from 1934 to 1993, depths range from 107 ft near Dennehotso, Ariz., to 3,636 ft near PWCC, and depths to the top of the N aquifer range from 0 near Tuba City, Ariz., to 2,205 ft near Kits'iili, Ariz., (table 6).

From 2005 to 2006, water levels declined in 22 of the 28 wells for which comparisons could be made (table 5). The median water-level change in the 28 wells was -0.7 ft (table 7). From 2005 to 2006, water levels declined in 10 of the 13 wells in the unconfined parts of the aquifer. The median water-level change was -0.5 ft. Water-level changes in the unconfined part of the aquifer ranged from -4.9 ft at 9Y-95 in Rough Rock to 0.6 ft at Tuba City Rare Metals (table 5). In the confined area of the N aquifer, water levels declined in 12 of 15 wells from 2005 to 2006. The median water-level change was -1.4 ft (table 7). Water-level changes in the confined part of the aquifer ranged from -8.0 ft at Piñon PM6 to 3.1 ft at 10R-111 in Rough Rock (table 5).

Annual median water-level changes for the water-level network wells from 1983 to 2006 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 of the N aquifer, the annual median water-level change was -1.8 ft, and there is no appreciable trend in the annual water-level changes from 1983 to 2006. For wells in unconfined areas, the annual median water-level change was 0.1 ft, and there is no appreciable trend from 1983 to 2006.



EXPLANATION

CONFINED AND UNCONFINED CONDITIONS IN THE N AQUIFER

Confined

Unconfined

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

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

2K-300 **+5.2** WELL IN WHICH DEPTH TO WATER WAS MEASURED ANNUALLY—First entry, 2K-300, is Bureau of Indian Affairs site number; second entry, **+5.2**, is change in water level, in feet, between measurement made during the prestress period and measurement made during 2006. **U**, unable to measure. **R**, recently pumping. NV, site not visited

BM2 8T-538 **–87.8** CONTINUOUS WATER-LEVEL RECORDING SITE (OBSERVATION WELL) MAINTAINED BY THE U.S. GEOLOGICAL SURVEY—First entry, BM2, is U.S. Geological Survey well number; second entry, 8T-538, is Bureau of Indian Affairs site number; third entry, **–87.8**, is change in water level, in feet, from simulated prestress period to 2006

Figure 5. Water-level changes in N aquifer wells from the prestress period to 2006, Black Mesa area, Arizona.

Table 5. Water-level changes in wells completed in the N aquifer, Black Mesa area, Arizona, prestress period to 2006.

[BIA, Bureau of Indian Affairs. Water level measured December 2005 to March 2006. 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. Dashes indicate no data; R, reported from driller's log]

Common name or location	BIA site number	Change in water level from preceding year (feet) 2005	Change in water level from preceding year (feet) 2006	Water level (feet below land surface), 2006	Prestress period water level: Feet below land surface	Prestress period water level: Date	Change in water level from prestress period to 2006 (feet)
Unconfined areas							
BM observation well 1[1]	8T-537	-0.6	+0.2	374.2	374.0	([1])	-0.2
BM observation well 4[1]	2T-514	-.3	-.1	216.8	4,216.0	([1])	-0.8
Goldtooth	3A-28	([2])	-4.0	234.1	230.0	10-29-1953	-4.1
Long House Valley	8T-510	-1.6	-.3	130.0	99.4	08-22-1967	-30.6
Northeast Rough Rock	8A-180	([2])	-.4	44.4	46.9	11-13-1953	+2.5
Rough Rock	9Y-95	+29.3	-4.9	109.4	119.5	08-03-1949	+10.1
Rough Rock	9Y-92	-.5	-.6	165.6	168.8	12-13-1952	+3.2
Shonto	2K-300	+0.2	+.0	171.3	176.5	06-13-1950	+5.2
Shonto Southeast	2K-301	-0.1	-.8	289.6	283.9	12-10-1952	-5.7
Shonto Southeast	2T-502	+1.1	-1.4	416.2	405.8	08-22-1967	-10.4
Tuba City	3T-333	+1.6	-.6	29.3	23.0	12-02-1955	-6.3
Tuba City	3K-325	-.4	-.5	202.7	208.0	06-30-1955	+5.3
Tuba City Rare Metals 2	---	.0	+.6	51.0	57.0	09-24-1955	+6.0
Tuba City NTUA 1	3T-508	-2.8	([3])	([3])	29.0	02-12-1969	([3])
Tuba City NTUA 3	---	+5.4	([3])	([3])	34.2	11-08-1971	([3])
Tuba City NTUA 4	3T-546	+27.3	([3])	([3])	33.7	08-06-1971	([3])
Confined area							
BM observation well 2[1]	8T-538	-1.3	-1.5	212.8	125.0	([1])	-87.8
BM observation well 3[1]	8T-500	+.0	-3.5	158.6	55.0	04-29-1963	-103.6
BM observation well 5[1]	4T-519	-1.3	-3.2	418.3	324.0	([1])	-94.3
BM observation well 6[1]	---	-3.2	-3.6	858.7	4,697.0	([1])	-161.7
Howell Mesa	3K-311	-1.3	-1.4	450.4	463.0	[1]1-03-1953	+12.6
Howell Mesa	6H-55	-.7	-1.1	272.9	212.0	07-08-1954	-60.9
Kayenta West	8T-541	([2])	([2])	305.7	230.0	03-17-1976	-75.7
Keams Canyon PM2	---	+11.8	-2.9	488.7	292.5	06-10-1970	-196.2
Kitsillie NTUA 2	---	-4.9	-3.5	1,324.0	1,297.9	01-14-1999	-26.1
Kykotsmovi PM1	---	-1.1	+1.7	212.5	220.0	05-20-1967	+7.5
Kykotsmovi PM3	---	+0.8	([3])	([3])	210.0	08-28-1968	([3])
Marsh Pass	8T-522	([2])	+1.0	127.4	125.5	02-07-1972	-1.9
Piñon PM6	---	-3.0	-8.0	898.4	743.6	05-28-1970	-154.8
Rough Rock	10R-119	([2])	([3])	([3])	256.6	12-02-1953	([3])
Rough Rock	10T-258	+0.1	-0.1	309.5	301.0	04-14-1960	-8.5
Rough Rock	10R-111	([2])	+3.1	192.0	170.0	08-04-1954	-22.0
Sweetwater Mesa	8K-443	([2])	-0.9	541.9	529.4	09-26-1967	-12.5
White Mesa Arch	1K-214	([2])	-0.3	220.3	188.0	06-04-1953	-32.3

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

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

[3]Site not visited during 2005-06.

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, 2005–06.

[BIA, Bureau of Indian Affairs. Depth to top of N aquifer from Eychaner (1983) and Brown and Eychaner (1988)]

BIA site number 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)	Type of data collected
8T-537 (BM observation well 1)	02-01-1972	5,864	851	300–360; 400–420; 500-520; 600-620; 730-780	290	Water level
8T-538 (BM observation well 2)	01-29-1972	5,656	1,338	470–1,338	452	Water level
8T-500 (BM observation well 3)	07-29-1959	5,724	868	712–868	155	Water level
2T-514 (BM observation well 4)	02-15-1972	6,320	400	250–400	160	Water level
4T-519 (BM observation well 5)	02-25-1972	5,869	1,683	1,521–1,683	1,520	Water level
BM observation well 6	01-31-1977	6,332	2,507	1,954–2,506	1,950	Water level
1K-214	05-26-1950	5,771	356	168–356	250	Water level
2K-300	[1]06-00-1950	6,264	300	260–300	0	Water level
2K-301	06-12-1950	6,435	500	318–328; 378–500	[2]30	Water level
2T-502	08-10-1959	6,670	523	12–523	[2]5	Water level
3A-28	04-19-1935	5,381	358	([3])	60	Water level
3K-311	[1]11-00-1934	5,855	745	380–395; 605–745	615	Water level
3K-325	06-01-1955	5,250	450	75-450	[2]30	Water level
3T-333	12-02-1955	4,940	229	63–229	[2]40	Water level
4T-523 (Forest Lake NTUA 1)	10-01-1980	6,654	2,674	1,870–1,910; 2,070–2,210; 2,250–2,674	([4])	Water level, water chemistry, withdrawals
6H-556	12-08-1944	5,635	361	310–335	[5]310	Water level
8A-180	01-20-1939	5,200	107	60–107	[2]4	Water level
8K-443	08-15-1957	6,024	720	619–720	590	Water level
8T-510	02-11-1963	6,262	314	130–314	[2]125	Water level
8T-522	[1]07-00-1963	6,040	933	180–933	480	Water level
8T-541	03-17-1976	5,885	890	740–890	700	Water level
9Y-92	01-02-1939	5,615	300	154–300	[2]50	Water level
9Y-95	11-05-1937	5,633	300	145–300	[2]68	Water level
10R-111	04-11-1935	5,757	360	267–360	210	Water level
10T-258	04-12-1960	5,903	670	465–670	460	Water level
Keams Canyon PM2	[1]05-00-1970	5,809	1,106	906–1,106	900	Water level, withdrawals, water chemistry
Kits'iili NTUA 2	10-30-1993	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	02-20-1967	5,657	995	655–675; 890–990	880	Water level, withdrawals
Kykotsmovi PM2	10-14-1977	5,760	1,155	950–1,155	890	Water chemistry, withdrawals
Peabody 2	[1]06-00-1967	6,530	3,636	1,816–3,603	4000	Water chemistry, withdrawals
Peabody 9	07-01-1983	6,385	3,510	2,886-4,049	3991	Water chemistry, withdrawals
Piñon NTUA 1	02-25-1980	6,336	2,350	1,860–2,350	1,850	Water chemistry, withdrawals
Piñon PM6	[1]02-00-1970	6,397	2,248	1,895–2,243	1,870	Water level, witdrawals
Tuba City Rare Metals 2	[1]09-00-1955	5,108	705	100–705	255	Water level

[1]00 indicates day is unknown.

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

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

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

[5]Developed into the D aquifer.

Table 7. Median changes in water levels, 2005–06 and prestress period to 2006, Black Mesa area, Arizona.

Aquifer conditions	Number of wells	Median change in water level (feet)
	2005–06	
All	28	-0.7
Unconfined	13	-.5
Confined	15	-1.4
	Prestress–2006	
All	29	-8.5
Unconfined	13	-.2
Confined	16	-46.6

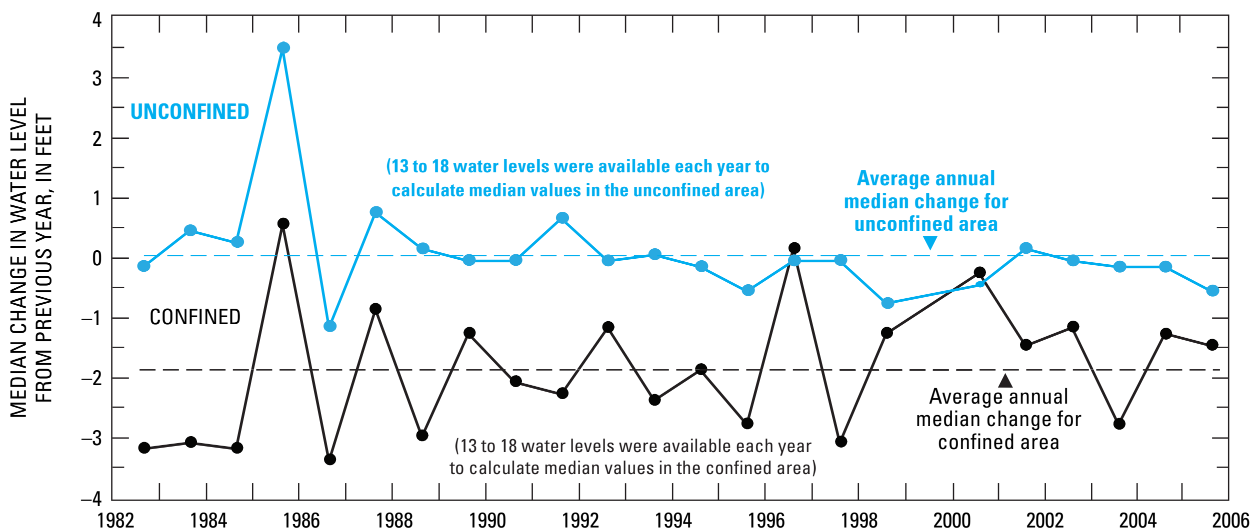


Figure 6. Annual median water-level changes for observation wells completed in the N aquifer, Black Mesa area, Arizona, 1983–2006.

From the prestress period (prior to 1965) to 2006, the median water-level change in 29 wells was -8.5 ft (table 7). In unconfined areas of the aquifer, water levels in 13 wells had a median change of -0.2 ft. Water-level changes in the unconfined part of the aquifer ranged from -30.6 ft at 8T-510 near Long House Valley to +10.1 ft at 9Y-95 in Rough Rock (table 5). Water levels in 16 wells in the confined part of the N aquifer had a median change of -46.6 ft (table 7). Water-level changes in the confined part of the aquifer ranged from -196.2 ft at Keams Canyon PM2 to 12.6 ft at 3K-311 at Howell Mesa (fig. 5 and table 5).

The areal distribution of water-level changes from the prestress period to 2006 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 area, water levels have changed only slightly. Near Long House Valley, however, the water level in well 8T-510 has declined about 30 ft (fig. 5). Water levels have declined in most of the confined area; however, the magnitudes of declines are varied. Larger water-level declines are near the municipal pumping centers (wells Piñon PM6, Keams Canyon PM2) or near the annual wells for PWCC (BM6). Smaller water-level declines occur away from the pumping centers (wells 10T-258, 8K-443, 10R-111, 8T-522; fig. 5).

Hydrographs for the six continuous-record observation wells show continuous water levels 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 declined consistently (fig. 8).

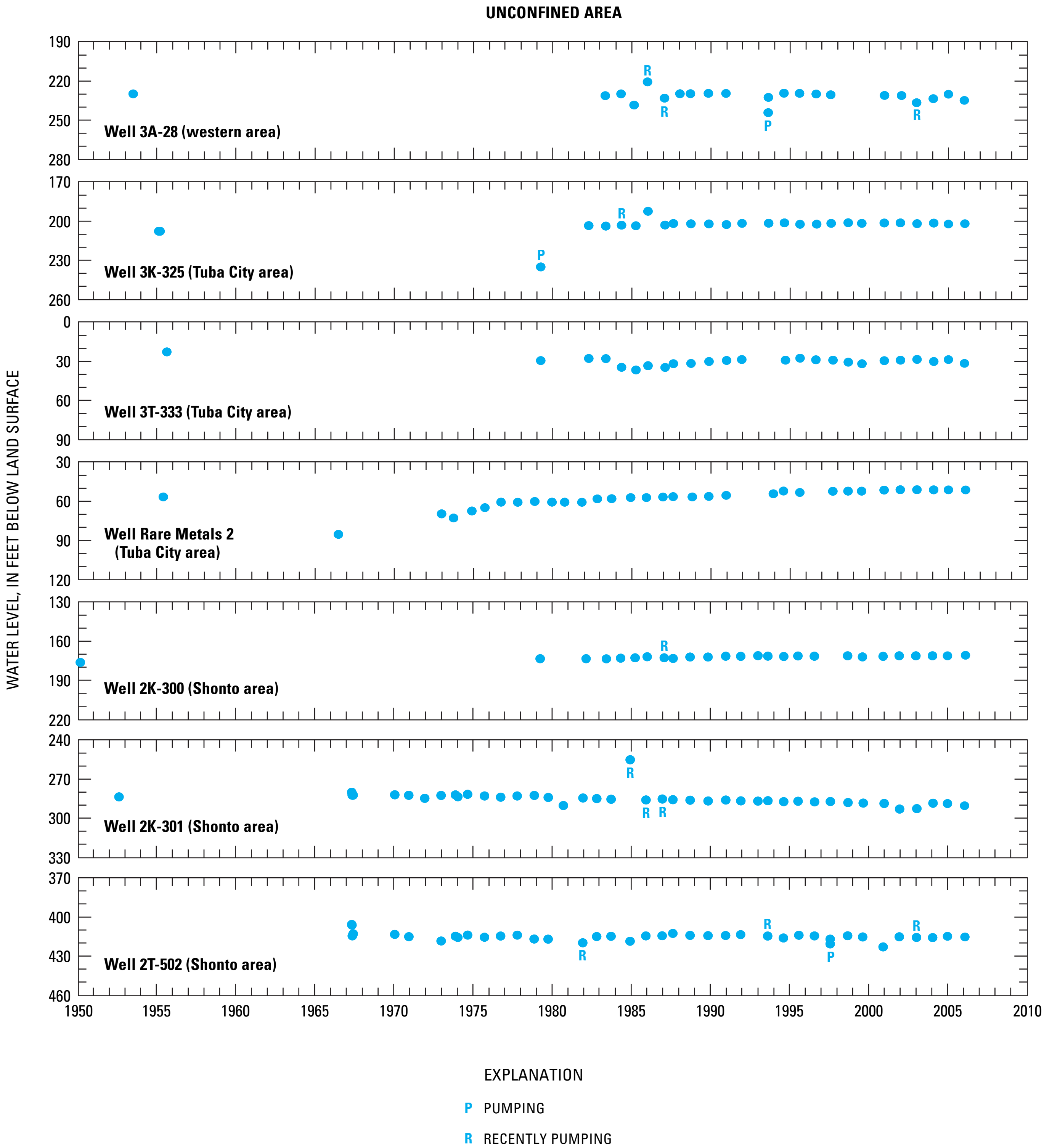


Figure 7. Observed water levels (1950–2006) in annual observation well network, Black Mesa area, Arizona.

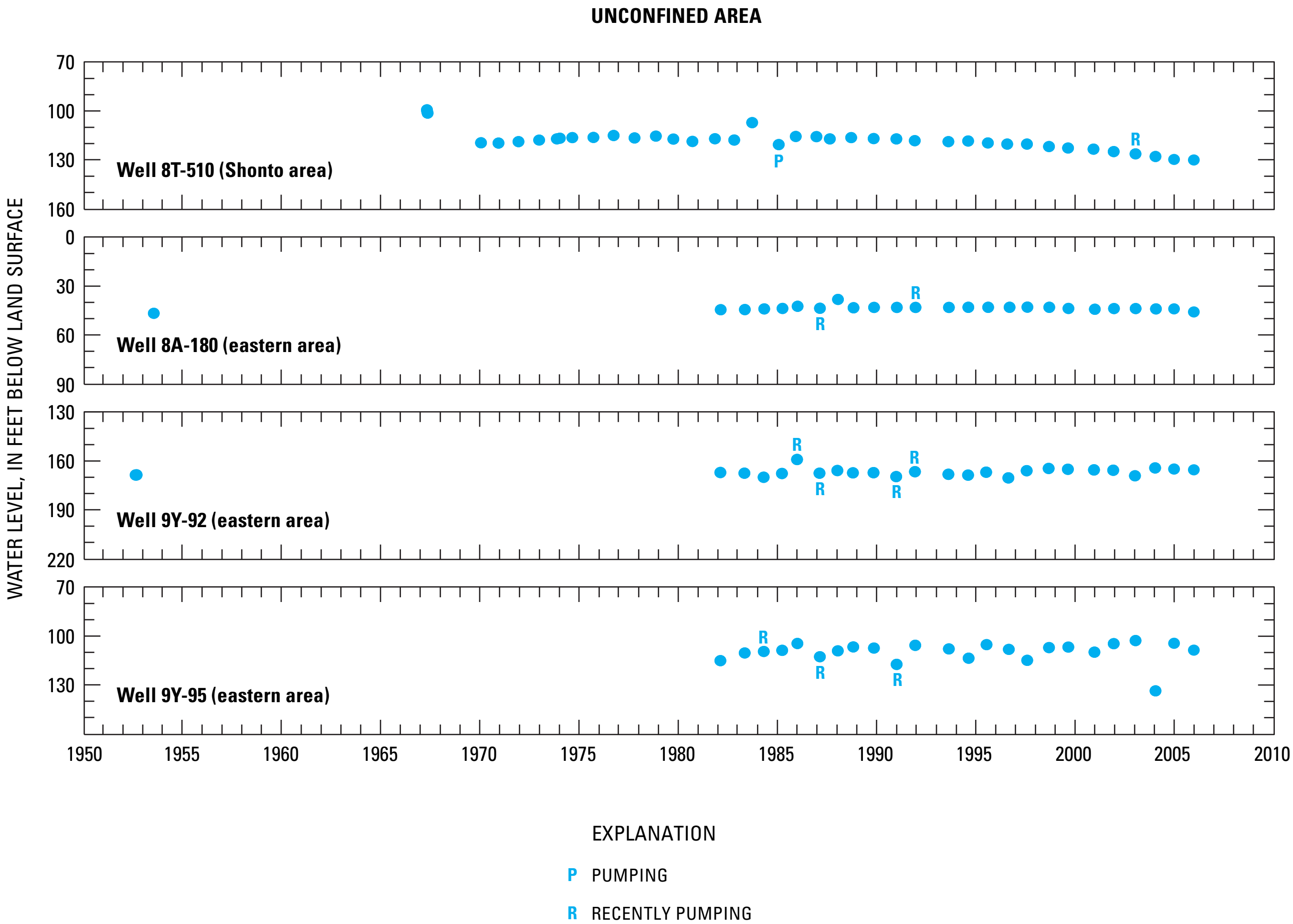
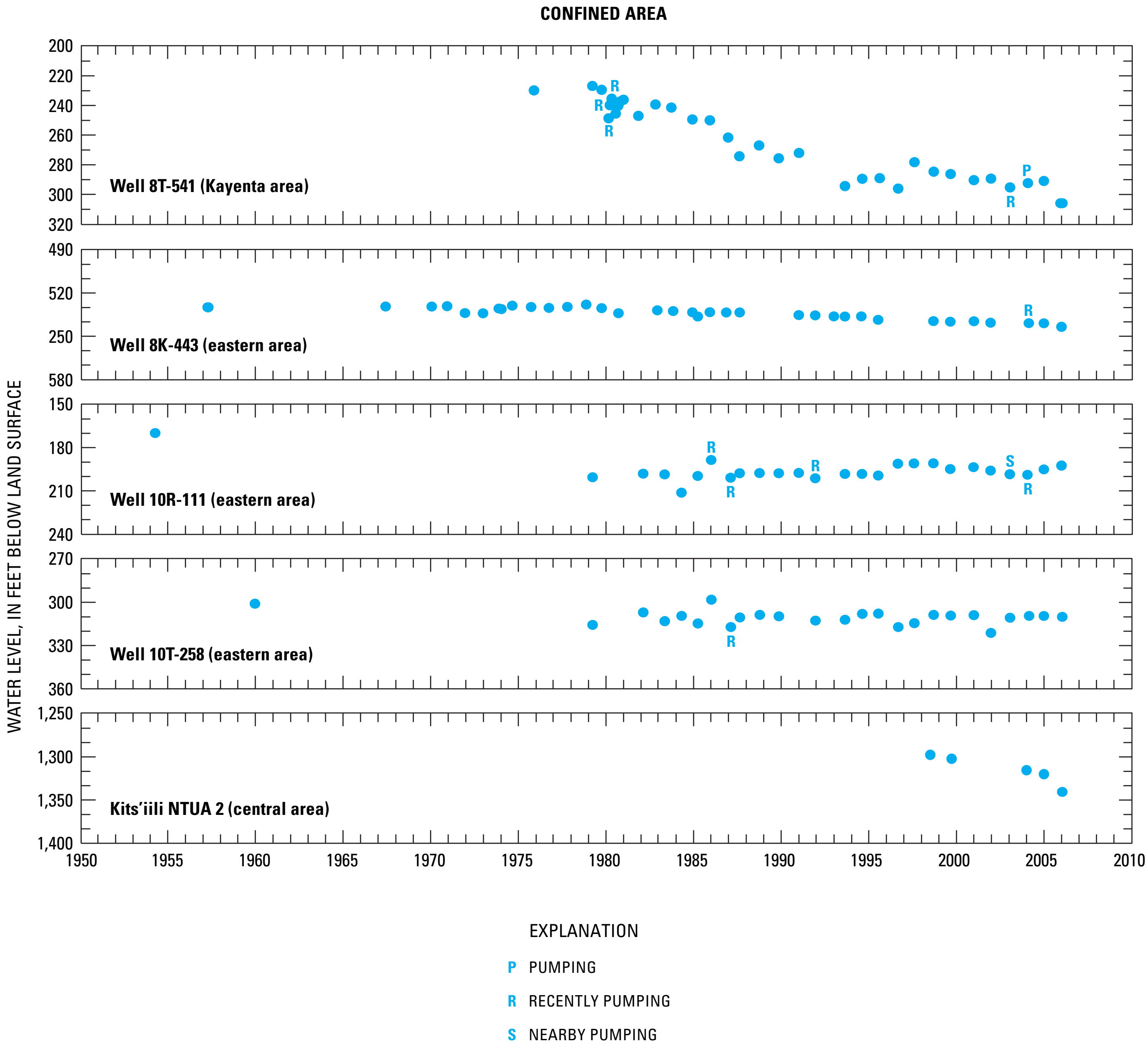


Figure 7. Continued.

Figure 7. Continued.



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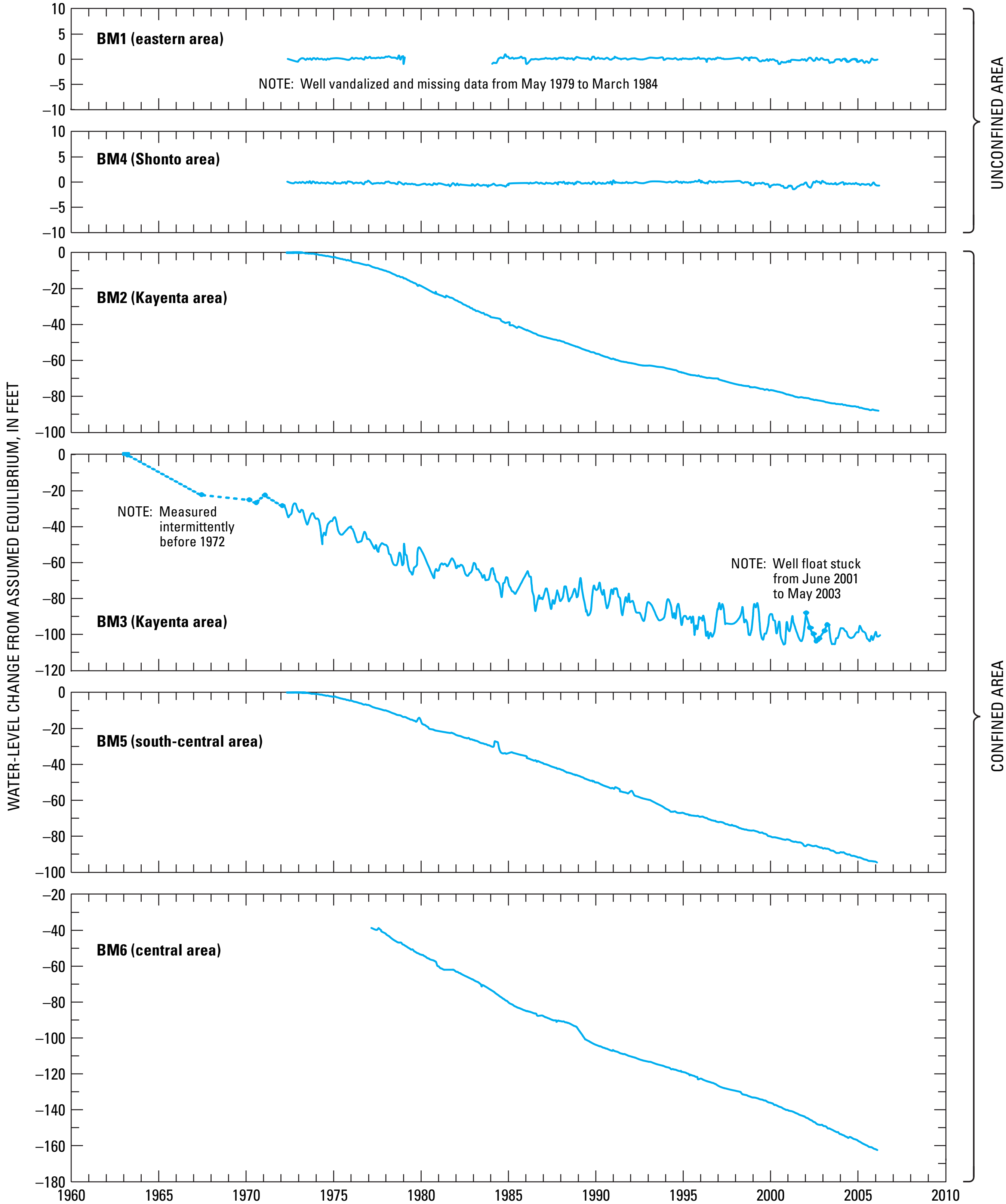

Figure 8. Observed water-level changes in continuous-record observation wells, BM1–BM6, 1963–2006, Black Mesa, Arizona.

Spring Discharge from the N Aquifer

Ground water in the N aquifer discharges from many springs around the margins of Black Mesa. In 2006 two of four of springs that have been measured annually were monitored for discharge. The two springs are in the western and southwestern part of the Black Mesa area (fig. 9). Discharges from Moenkopi School Spring and Burro Spring have been measured annually and compared to discharge data from previous years to determine changes over time (fig. 10). Discharge was measured in April 2006 at Moenkopi School Spring and Burro Spring (table 8). Measurements at Moenkopi School Spring, and Burro Spring are made volumetrically. 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 2006, measured discharges were 11.1 gal/min from Moenkopi School Spring and 0.17 gal/min from Burro Spring, (table 8). From 2005 to 2006, discharge decreased by 3.5 percent at Moenkopi School Spring and by 15 percent at Burro Spring. For the periods of record at both springs, the discharge measurements have fluctuated and indicated a decreasing trend (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 ground-water discharge that results in surface flow is affected by seasonal fluctuations in water uptake by plants and by 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 rainfall can occur throughout the year, most rainfall runoff occurs during the summer months. The amount and timing of rainfall runoff depend on the intensity and duration of thunderstorms during the summer and cyclonic storms during 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 separated into ground-water discharge and runoff so that the temporal trends in ground-water discharge can be monitored.

In 2005, 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), June 1993 (Dinnebito Wash, 09401110), April 1994 (Polacca Wash, 09400568), August 2004 (Pasture Canyon Spring, 09401265), and July 1996 (Laguna Creek, 09379180; fig. 11 and table 14). The annual average discharges at the five gaging stations vary during the periods of record (fig. 11A), and no trends are apparent for Moenkopi Wash, Polacca Wash, Dinnebito Wash, or Laguna Creek. No trends can be determined for Pasture Canyon Wash because there is not a long enough period of record. In 2005, annual average flows for Moenkopi Wash, Polacca Wash, and Dinnebito Wash decreased, and annual average flow for Laguna Creek increased (fig. 11).

The ground-water discharge component of total flow at the five streamflow-gaging stations was estimated by computing the median flow for four winter months—November, December, January, and February (fig. 12). The 120 consecutive daily mean flows for those four months were used to compute the median flow. Ground-water discharge was assumed to be constant throughout the year, and the median winter flow was assumed to represent the constant annual ground-water discharge. Most flow that occurs 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. Evapotranspiration is at a minimum during the winter. Rather than the average flow, the median flow for November, December, January, and February 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 2005 water year; thus, daily mean flows for November and December 2005 were combined with daily mean flows for January and February 2006. These median winter flows were 2.4 ft^3/s for Moenkopi Wash, 0.41 ft^3/s for Dinnebito Wash, and 0.13 ft^3/s for Polacca Wash (fig. 12 A-D). The Laguna Creek surface-water gage was discontinued in January of 2006, and there is not enough data to compute the median daily winter flows for this site. For the period of record at each streamflow-gaging station, the median winter flows have generally decreased (fig. 12 A-D). Trend lines in figure 12 were generated by using the least-squares method.

Annual precipitation at Betatakin, about 15 mi west of Kayenta (fig. 1), has been less than average from 1995 through 2004 (fig. 11B). Precipitation data for 2003 were incomplete and unavailable. Precipitation was above average for calendar year 2005 (19.8 in.; fig. 11B).

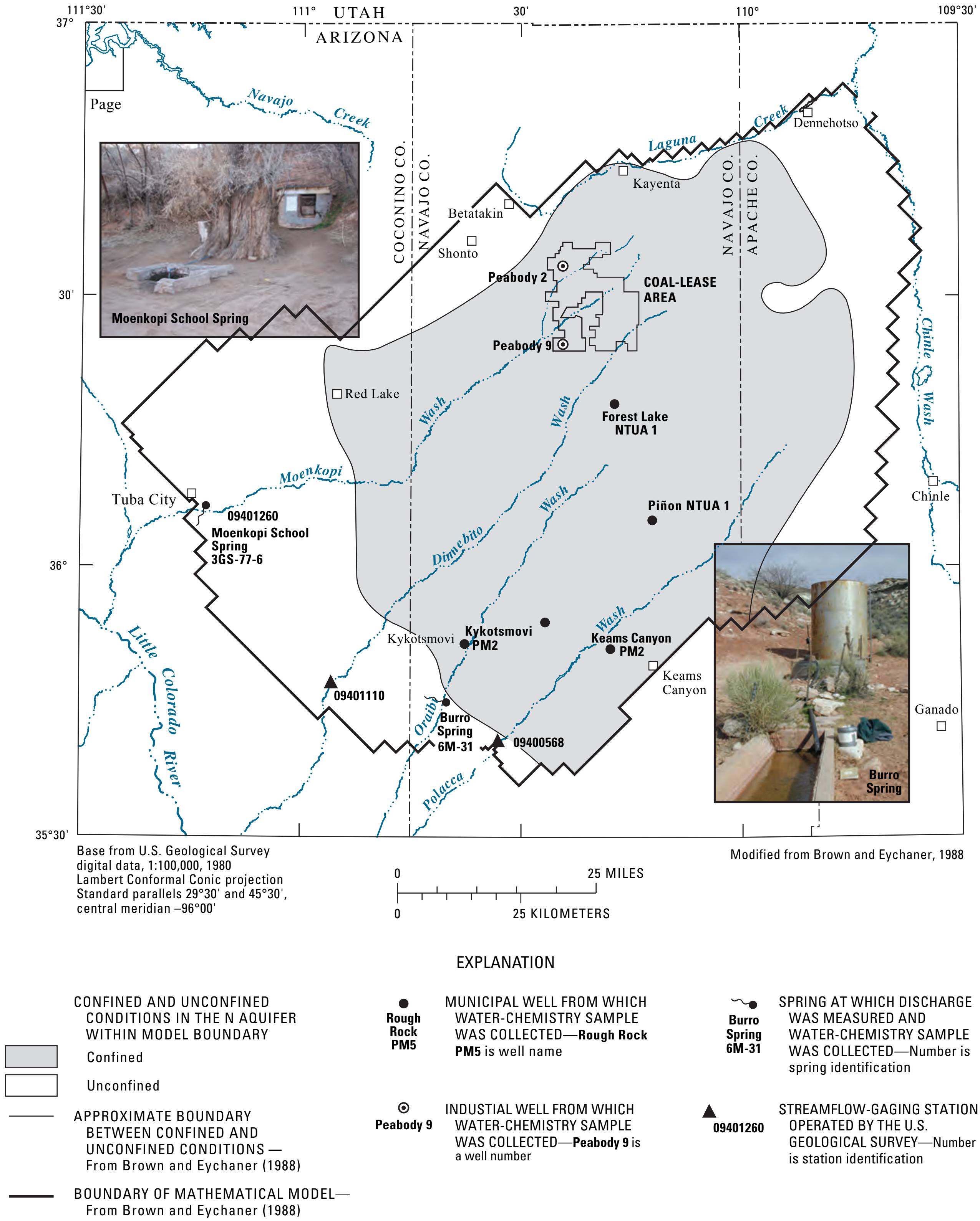

Figure 9. Surface-water and water-chemistry data-collection sites, Black Mesa area, Arizona, 2005–06.

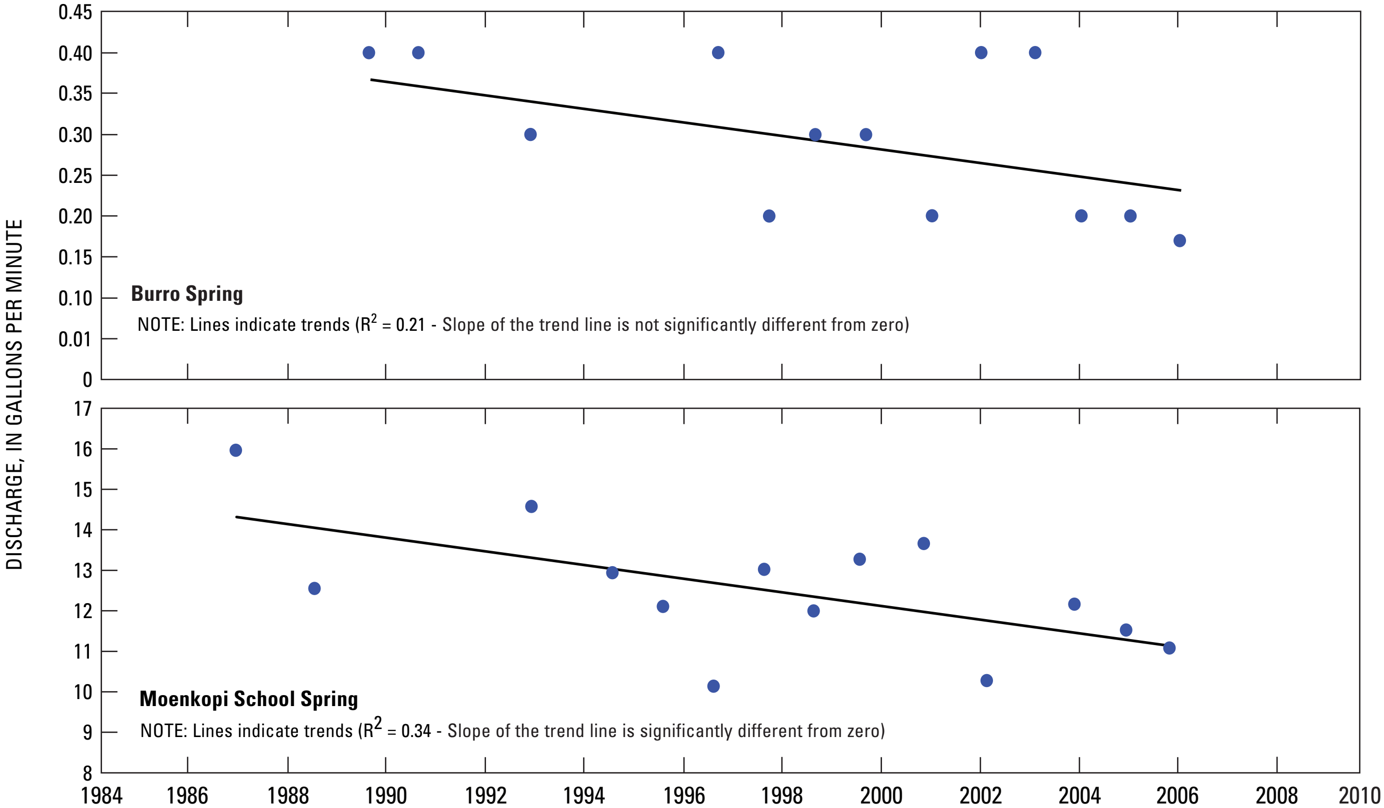

Figure 10. Discharge from selected springs, Black Mesa area, Arizona, 1987–2006. Data from earlier measurements at Moenkopi School Spring, are not shown because different measuring locations were used.

Table 8. Discharge measurements of selected springs, Black Mesa area, Arizona, 1952–2006.

[BIA, Bureau of Indian Affairs. All the measured discharges do not represent the total discharge from the springs]

BIA site number	Rock formation(s)	Date of measurement	Discharge (gallons per minute)
		Moenkopi School Spring[1]	
3GS-77-6	Navajo Sandstone[2]	05-16-1952	40
		04-22-1987	[3]16
		11-29-1988	[3]43.6
		02-21-1991	[3]13.5
		04-07-1993	[3]14.6
		12-07-1994	[3]12.9
		12-04-1995	[3]10
		12-16-1996	[3]13.1
		12-17-1997	[3]12
		12-08-1998	[3]13.3
		12-13-1999	[3]13.7
		03-12-2001	[3]10.2
		06-19-2002	[3]11.2
		05-01-2003	[3]11.2
		03-29-2004	[3]12.2
		04-04-2005	[3]11.5
		03-13-2006	11.1
		Burro Spring[1]	
6M-31	Navajo Sandstone	12-15-1989	.4
		12-13-1990	.4
		03-18-1993	.3
		12-08-1994	.2
		12-17-1996	.4
		12-30-1997	.2
		12-08-1998	.3
		12-07-1999	.3
		04-02-2001	.2
		04-04-2002	.4
		04-30-2003	.4
		04-06-2004	[4].2
		03-28-2005	.2
		03-28-2006	.17

[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]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 2005 (October, November, and December discharge data is provisional and subject to change).

[e, estimated. Dashes indicate no data. Acre-ft, acre-feet]

Day	January	February	March	April	May	June	July	August	September	October	November	December
1	10	2.3	3.1	1.7	2.4	0.00	0.00	0.46	0.00	0.00	0.89	e1.8
2	5.7	2.2	3.0	1.9	2.8	0.00	0.00	0.45	0.00	0.00	0.77	e1.9
3	11	2.2	3.1	2.1	4.2	0.00	0.00	6.8	9.2	0.00	0.82	1.8
4	87	2.4	3.1	2.2	3.2	0.00	0.00	21	19	0.00	0.84	e1.6
5	41	2.7	2.9	2.5	2.4	0.00	0.00	98	8.4	0.00	0.84	1.4
6	8.1	2.9	3.0	2.3	2.4	0.00	0.00	208	3.4	0.00	0.91	1.3
7	4.7	3.0	3.0	2.5	2.8	0.00	0.00	50	0.13	0.00	0.96	e1.2
8	3.7	3.3	3.0	2.5	3.0	0.00	0.00	21	0.00	0.00	1.1	e1.3
9	2.8	3.3	2.9	2.8	2.7	0.00	0.00	112	0.00	0.00	1.1	e1.3
10	2.5	3.9	2.8	4.2	2.2	0.00	0.00	456	0.00	0.00	1.1	e1.2
11	3.3	4.1	2.6	3.5	2.3	0.00	0.00	63	0.00	0.00	1.2	e1.2
12	e4.6	8.9	2.6	2.6	2.5	0.10	0.00	77	0.00	0.00	1.2	e1.2
13	e5.3	26	2.6	2.1	2.5	0.17	0.00	40	0.00	0.00	1.4	e1.3
14	e3.5	14	2.6	2.0	2.9	0.01	0.00	28	0.00	0.00	1.4	e1.1
15	e3.0	4.9	2.5	2.0	3.2	0.00	0.00	20	0.00	0.00	1.3	e1.1
16	e2.5	3.6	2.4	2.0	3.4	0.00	0.00	59	0.00	0.00	1.4	e1.0
17	e2.5	4.5	2.5	1.9	1.5	0.00	0.00	e40	0.00	0.00	1.5	e1.0
18	e2.4	6.3	2.4	1.9	0.97	0.00	0.00	e40	0.00	197	1.5	e2.0
19	2.4	5.2	2.6	1.9	0.92	0.00	0.00	51	0.00	514	1.6	e2.0
20	2.7	5.0	2.8	1.9	0.88	0.00	0.00	35	0.00	12	1.6	e2.0
21	2.9	4.0	2.9	1.9	0.70	0.00	0.00	17	0.00	4.0	1.6	e2.0
22	2.8	4.1	2.5	2.0	0.55	0.00	0.00	7.7	0.00	3.2	e1.7	e2.5
23	2.6	4.0	2.4	2.2	0.13	0.00	0.00	2.2	0.00	2.9	e1.7	e2.5
24	2.5	3.8	2.4	25	0.48	0.00	0.00	0.65	0.00	2.2	1.8	e2.5
25	2.5	5.5	2.1	21	0.16	0.00	0.47	0.00	0.00	1.7	1.9	e2.5
26	2.6	5.1	2.0	7.5	0.19	0.00	220	0.00	0.00	1.5	1.8	e2.0
27	3.1	4.3	1.9	3.6	0.19	0.00	38	0.00	0.00	1.4	e1.6	e2.0
28	3.0	3.3	2.0	3.0	0.20	0.00	2.6	0.00	0.00	1.5	e1.3	e2.0
29	2.1	---	2.3	3.6	0.15	0.00	1.2	0.00	0.00	1.7	1.5	e2.0
30	2.5	---	2.2	2.9	0.02	0.00	0.45	0.00	0.00	1.2	e1.7	e2.0
31	2.4	---	1.9	---	0.00	---	0.45	0.00	---	1.3	---	e2.0
Total	237.7	144.8	80.1	119.2	51.94	0.28	263.17	1454.26	40.13	745.60	40.03	52.7
Mean	7.67	5.17	2.58	3.97	1.68	0.01	8.49	46.9	1.34	24.1	1.33	1.70
Max	87	26	3.1	25	4.2	0.17	220	456	19	514	1.9	2.5
Min	2.1	2.2	1.9	1.7	0.00	0.00	0.00	0.00	0.00	0.00	0.77	1.0
Med	2.9	4.0	2.6	2.3	2.2	0.00	0.00	21	0.00	0.00	1.4	1.8
Acre-ft	471	287	159	236	103	0.6	522	2,880	80	1,480	79	105
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.01	0.00	0.00

Calendar year 2005 Total 3,229.91 Mean 8.85 Max 514 Min 0.00 Med 1.9 Acre-ft 6, 410 CFSM 0.01

Table 10. Discharge data, Dinnebito Wash near Sand Springs, Arizona (09401110), calendar year 2005.

[e, estimated. Dashes indicate no data]

Day	January	February	March	April	May	June	July	August		October	November	December
1	6.2	0.56	0.45	0.34	0.29	0.20	0.14	0.11	0.17	0.17	0.30	0.31
2	1.7	0.43	0.44	0.34	0.28	0.18	0.13	0.11	0.17	0.17	0.31	0.32
3	3.8	0.41	0.58	0.33	0.27	0.19	0.12	15	0.18	0.16	0.30	0.31
4	28	0.42	0.45	0.31	0.27	0.20	0.13	46	7.5	0.16	0.30	0.28
5	17	e0.40	0.47	0.31	0.25	0.19	0.12	26	1.3	0.19	0.31	0.26
6	3.5	e0.40	0.45	0.32	0.25	0.18	0.12	181	0.26	0.23	0.31	0.26
7	0.85	e0.50	0.43	0.31	0.27	0.16	0.12	35	0.20	0.19	0.32	0.27
8	0.74	e0.40	0.40	0.28	0.26	0.15	0.12	17	0.20	0.18	0.32	0.26
9	0.60	0.41	0.40	0.44	0.66	0.21	0.12	44	0.19	0.20	0.33	0.27
10	0.62	0.44	0.39	0.50	0.28	0.26	0.12	126	0.16	0.19	0.34	0.27
11	142	0.74	0.39	0.34	0.29	0.29	0.11	27	0.15	0.20	0.37	0.27
12	74	1.4	0.37	0.34	0.22	0.30	0.11	39	0.15	0.21	0.35	0.29
13	17	30	0.36	0.33	0.22	0.19	0.11	12	0.16	0.22	0.34	0.31
14	2.6	13	0.45	0.33	0.42	0.18	0.11	2.4	0.16	0.22	0.35	0.29
15	0.84	4.0	0.37	0.33	0.29	0.18	0.11	0.37	0.16	0.22	0.33	0.26
16	0.55	1.3	0.38	0.32	0.26	0.15	0.11	25	0.15	0.24	0.33	0.24
17	0.50	0.53	0.39	0.31	0.26	0.15	0.11	13	0.16	0.24	0.35	0.25
18	e0.50	0.63	0.38	0.29	0.26	0.14	0.10	7.7	0.16	59	0.35	0.29
19	e0.50	1.3	0.42	0.27	0.27	0.14	0.10	1.9	0.16	13	0.35	0.33
20	0.50	0.53	0.42	0.28	0.26	0.15	0.10	0.31	0.17	8.4	0.34	0.34
21	0.50	0.48	0.40	0.27	0.25	0.15	0.10	0.26	0.18	3.3	0.30	0.33
22	0.47	0.50	0.39	0.29	0.24	0.16	0.10	0.24	0.17	0.57	0.30	0.34
23	0.46	0.47	0.37	0.30	0.23	0.17	0.11	0.24	0.16	0.36	0.31	e0.34
24	0.69	0.59	0.40	2.2	0.22	0.18	0.11	0.23	0.15	0.32	0.31	e0.40
25	0.51	0.52	0.46	0.41	0.22	0.15	0.12	0.23	0.16	0.31	0.30	0.49
26	0.59	0.39	0.36	0.35	0.22	0.13	0.12	0.22	0.16	0.31	0.31	0.47
27	0.57	0.50	0.37	0.34	0.23	0.12	0.11	0.21	0.17	0.31	0.28	0.46
28	0.46	0.44	0.37	0.33	0.25	0.12	0.09	0.20	0.17	0.33	0.27	0.44
29	0.48	---	0.35	0.45	0.24	0.13	0.12	0.20	0.17	0.35	0.30	0.46
30	0.57	---	0.45	0.30	0.20	0.14	0.11	0.19	0.17	0.31	0.31	0.43
31	0.52	---	0.32	---	0.20	---	0.10	0.17	---	0.30	---	0.44
Total	307.82	61.69	12.63	11.86	8.33	5.24	3.50	621.29	13.57	90.56	9.59	10.28
Mean	9.93	2.20	0.41	0.40	0.27	0.17	0.11	20.0	0.45	2.92	0.32	0.33
Max	142	30	0.58	2.2	0.66	0.30	0.14	181	7.5	59	0.37	0.49
Min	0.46	0.39	0.32	0.27	0.20	0.12	0.09	0.11	0.15	0.16	0.27	0.24
Med	0.60	0.50	0.40	0.33	0.26	0.17	0.11	1.9	0.17	0.24	0.31	0.31
Acre-ft	611	122	25	24	17	10	6.9	1230	27	180	19	20
CFSM	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.00

Calendar year 2005 Total 1156.36 Mean 3.17 Max 181 Min 0.09 Med 0.31 Acre-ft 2290 CFSM 0.01

Table 11. Discharge data, Polacca Wash near Second Mesa, Arizona (09401265), calendar year 2005.

[e, estimated. Dashes indicate no data]

Day	January	February	March	April	May	June	July	August	September	October	November	December
1	1.0	0.20	0.18	0.13	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.10
2	0.44	0.18	0.16	0.14	0.13	0.03	0.00	0.00	0.00	0.00	0.02	0.09
3	1.5	0.17	0.30	0.13	0.12	0.02	0.00	0.03	0.00	0.00	0.03	0.08
4	18	0.17	0.19	0.12	0.12	0.02	0.00	0.00	0.00	0.00	0.03	0.04
5	17	0.18	0.21	0.12	0.11	0.04	0.00	0.00	0.00	0.00	0.04	0.01
6	4.7	0.17	0.21	0.12	0.11	0.03	0.00	0.00	0.00	0.00	0.05	0.00
7	1.2	0.26	0.19	0.13	0.10	0.01	0.00	0.00	0.00	0.00	0.06	0.00
8	0.80	0.22	0.16	0.13	0.11	0.01	0.00	0.00	0.00	0.00	0.06	0.00
9	0.55	0.17	0.15	0.17	0.11	0.01	0.00	0.00	0.00	0.00	0.06	0.00
10	0.42	0.18	0.15	0.18	0.10	0.03	0.00	13	0.00	0.00	0.07	0.00
11	31	0.36	0.15	0.16	0.10	0.06	0.00	24	0.00	0.00	0.07	0.03
12	41	15	0.15	0.16	0.10	0.10	0.00	16	0.00	0.00	0.06	0.04
13	15	43	0.14	0.15	0.10	0.06	0.00	6.4	0.00	0.00	0.07	0.10
14	3.5	14	0.41	0.14	0.11	0.03	0.00	1.5	0.00	0.00	0.07	0.11
15	0.93	2.4	0.23	0.14	0.10	0.02	0.00	0.72	0.00	0.00	0.07	0.04
16	0.42	0.70	0.18	0.14	0.10	0.01	0.00	0.59	0.00	0.00	0.06	0.00
17	0.22	0.39	0.17	0.13	0.08	0.01	0.00	3.5	0.00	0.00	0.07	0.00
18	0.17	0.57	0.17	0.12	0.08	0.01	0.00	2.2	0.00	0.01	0.07	0.03
19	0.17	1.0	0.16	0.13	0.08	0.01	0.00	0.85	0.00	0.01	0.07	0.09
20	0.17	1.8	0.17	0.11	0.08	0.01	0.00	0.42	0.00	0.01	0.07	0.10
21	0.18	0.81	0.14	0.12	0.07	0.01	0.00	0.08	0.00	0.01	0.07	0.12
22	0.17	0.26	0.14	0.12	0.06	0.02	0.00	0.03	0.00	0.01	0.07	0.12
23	0.16	0.22	0.15	0.14	0.05	0.03	0.00	0.01	0.00	0.01	0.07	0.15
24	0.21	0.20	0.13	0.60	0.05	0.02	0.00	0.00	0.00	0.01	0.07	0.12
25	0.18	0.19	0.24	0.21	0.04	0.02	0.00	0.00	0.00	0.01	0.07	0.10
26	0.22	0.19	0.16	0.16	0.05	0.01	0.00	0.00	0.00	0.00	0.07	0.12
27	0.28	0.18	0.15	0.14	0.06	0.00	0.00	0.00	0.00	0.00	0.06	0.09
28	0.20	0.17	0.16	0.14	0.07	0.01	0.00	0.00	0.00	0.01	0.01	0.09
29	0.22	---	0.14	0.15	0.09	0.00	0.00	0.00	0.00	0.01	0.04	0.09
30	0.38	---	0.13	0.13	0.06	0.01	0.00	0.00	0.00	0.01	0.09	0.08
31	0.22	---	0.12	---	0.03	---	0.00	0.00	---	0.01	---	0.11
Total	140.61	83.34	5.49	4.66	2.70	0.69	0.00	69.33	0.00	0.12	1.73	2.05
Mean	4.54	2.98	0.18	0.16	0.09	0.02	0.00	2.24	0.00	0.00	0.06	0.07
Max	41	43	0.41	0.60	0.13	0.10	0.00	24	0.00	0.01	0.09	0.15
Min	0.16	0.17	0.12	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Med	0.42	0.22	0.16	0.14	0.10	0.02	0.00	0.00	0.00	0.00	0.07	0.09
Acre-ft	279	165	11	9.2	5.4	1.4	0.00	138	0.00	0.2	3.4	4.1
CFSM	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Calendar year 2005 Total 310.72 Mean 0.85 Max 43 Min 0.00 Med 0.07 Acre-ft 616 CFSM 0.00

Table 12. Discharge data, Pasture Canyon near Tuba City, Arizona (09401265), calendar year 2005.

[e, estimated. Dashes indicate no data]

Day	January	Febraury	March	April	May	June	July	August	September	October	November	December
1	1.47	1.49	1.47	1.39	1.44	1.40	1.50	1.46	1.44	1.43	1.39	1.44
2	1.47	1.48	1.47	1.39	1.44	1.41	1.49	1.45	1.44	1.43	1.39	1.44
3	1.46	1.48	1.48	1.39	1.44	1.41	1.50	1.45	1.43	1.43	1.39	1.44
4	1.46	1.48	1.47	1.39	1.44	1.41	1.50	1.48	1.44	1.43	1.39	1.45
5	1.45	1.48	1.47	1.39	1.42	1.41	1.50	1.48	1.45	1.43	1.39	1.46
6	1.45	1.48	1.47	1.40	1.43	1.41	1.49	1.45	1.44	1.43	1.39	1.45
7	1.45	1.48	1.47	1.40	1.43	1.41	1.49	1.45	1.44	1.43	1.42	1.45
8	1.44	1.48	1.47	1.41	1.43	1.41	1.49	1.43	1.44	1.42	1.44	1.45
9	1.44	1.48	1.47	1.42	1.43	1.41	1.49	1.43	1.44	1.42	1.44	1.45
10	1.44	1.48	1.46	1.25	1.43	1.41	1.49	1.43	1.44	1.42	1.44	1.45
11	1.44	1.53	1.46	1.18	1.43	1.42	1.47	1.43	1.44	1.41	1.72	1.45
12	1.44	1.55	1.46	1.44	1.43	1.42	1.42	1.43	1.44	1.41	1.86	1.45
13	1.43	1.52	1.46	1.44	1.43	1.40	1.41	1.43	1.44	1.41	1.86	1.45
14	1.43	1.51	1.45	1.44	1.43	1.41	1.41	1.43	1.43	1.41	1.64	1.45
15	1.43	1.51	1.44	1.44	1.43	1.41	1.41	1.44	1.42	1.41	1.45	1.45
16	1.43	1.52	1.43	1.44	1.43	1.41	1.41	1.45	1.42	1.40	1.45	1.45
17	1.43	1.51	1.42	1.44	1.43	1.41	1.41	1.44	1.42	1.40	1.45	1.45
18	1.43	1.51	1.42	1.44	1.43	1.41	1.41	1.43	1.42	1.40	1.45	1.45
19	1.45	1.51	1.41	1.44	1.42	1.41	1.42	1.44	1.42	1.40	1.45	1.45
20	1.49	1.51	1.41	1.43	1.42	1.41	1.42	1.44	1.42	1.40	1.45	1.45
21	1.49	1.50	1.41	1.43	1.42	1.41	1.42	1.43	1.42	1.40	1.45	1.45
22	1.49	1.50	1.41	1.43	1.42	1.41	1.42	1.43	1.42	1.40	1.45	1.44
23	1.48	1.50	1.40	1.43	1.41	1.41	1.42	1.43	1.42	1.40	1.45	1.44
24	1.48	1.49	1.40	1.49	1.41	1.43	1.42	1.43	1.42	1.40	1.45	1.44
25	1.48	1.47	1.40	1.47	1.41	1.48	1.43	1.43	1.42	1.40	1.45	1.44
26	1.49	1.47	1.40	1.47	1.42	1.49	1.45	1.43	1.42	1.40	1.45	1.44
27	1.51	1.47	1.40	1.45	1.41	1.49	1.44	1.43	1.42	1.40	1.45	1.44
28	1.49	1.47	1.40	1.44	1.42	1.47	1.44	1.44	1.42	1.40	1.45	1.44
29	1.48	---	1.40	1.44	1.42	1.49	1.44	1.44	1.42	1.40	1.44	1.44
30	1.50	---	1.40	1.44	1.42	1.49	1.44	1.43	1.42	1.39	1.44	1.43
31	1.49	---	1.39	---	1.41	---	1.45	1.43	---	1.39	---	1.43
Total	45.31	41.86	44.47	42.45	44.18	42.77	44.90	44.62	42.87	43.70	44.34	44.81
Mean	1.46	1.50	1.43	1.42	1.43	1.43	1.45	1.44	1.43	1.41	1.48	1.45
Max	1.51	1.55	1.48	1.49	1.44	1.49	1.50	1.48	1.45	1.43	1.86	1.46
Min	1.43	1.47	1.39	1.18	1.41	1.40	1.41	1.43	1.42	1.39	1.39	1.43

Calendar year 2005 Total 526.28 Mean 1.44 Max 1.86 Min 1.18

Table 13. Discharge data, Laguna Creek at Dennehotso, Arizona (09379180), calendar year 2005.

[e, estimated. Dashes indicate no data]

Day	January	February	March	April	May	June	July	August	September	October	November	December
1	4.1	4.0	e7.8	e4.4	3.0	0.00	0.00	2.6	0.00	0.00	2.4	e4.0
2	e3.4	2.3	6.0	0.63	0.81	0.00	0.00	48	0.00	0.00	2.3	e3.0
3	e3.0	2.3	e5.3	0.50	12	0.00	0.00	44	0.00	0.00	2.4	e3.0
4	e3.1	2.4	e5.4	e0.00	8.9	0.00	0.00	22	24	0.00	2.0	e4.0
5	e2.8	2.5	5.8	e0.00	5.9	0.00	0.00	8.4	17	0.00	1.4	e3.0
6	e2.9	5.5	e7.1	0.00	1.7	0.00	0.00	6.0	6.1	0.00	0.94	e3.0
7	e2.5	9.8	e7.4	0.00	0.48	0.00	0.00	55	3.7	0.00	1.1	e1.0
8	e2.1	9.5	4.1	0.00	0.18	0.00	0.00	25	1.9	0.00	1.6	e2.0
9	1.5	13	3.8	0.00	0.13	0.00	0.00	5.7	7.7	0.00	1.8	e1.0
10	e2.6	12	2.5	0.00	0.24	0.00	0.00	e130	68	0.00	2.0	1.8
11	e4.0	5.1	1.8	0.00	0.08	0.00	0.00	e299	27	0.00	2.4	e2.0
12	e6.6	80	e2.7	0.17	0.00	0.00	0.00	e259	6.3	0.00	2.2	e1.0
13	e6.0	63	e2.3	0.01	0.00	0.00	0.00	34	0.86	0.00	2.3	e0.01
14	e4.1	16	1.9	0.00	0.00	0.00	0.00	7.6	0.05	0.00	2.6	0.00
15	1.5	4.8	e0.89	0.00	0.00	0.00	0.00	1.6	0.00	0.00	2.4	0.00
16	8.9	3.0	e0.89	0.00	0.00	0.00	0.00	0.37	0.00	0.00	1.8	0.00
17	7.8	5.7	0.34	0.00	0.00	0.00	0.00	1.7	0.00	0.31	2.3	0.00
18	6.1	5.2	0.59	0.00	0.00	0.00	0.00	2.5	0.00	2.7	1.8	0.00
19	6.4	4.7	e0.81	0.00	0.00	0.00	0.00	0.13	0.00	232	2.3	0.00
20	3.3	14	0.21	0.00	0.00	0.00	0.00	3.1	0.00	26	4.6	0.00
21	4.3	9.7	0.16	0.00	0.00	0.00	0.00	0.94	0.00	9.8	3.7	0.00
22	4.7	5.5	6.0	0.00	0.00	0.00	0.00	0.02	0.00	6.0	4.7	0.00
23	3.5	e0.72	0.77	0.00	0.00	0.00	0.00	0.00	0.00	4.4	6.4	6.9
24	2.8	e3.1	0.37	0.00	0.00	0.00	0.00	0.00	0.02	3.7	7.0	8.1
25	3.0	e9.8	0.29	16	0.00	0.00	27	0.00	0.00	3.3	6.6	10
26	4.3	e15	0.82	12	0.00	0.00	111	0.00	0.00	2.9	6.8	14
27	11	12	e3.3	4.1	0.00	0.00	42	0.00	0.00	3.0	e5.0	11
28	e15	e9.0	e6.9	0.89	0.00	0.00	11	0.00	0.00	4.0	e5.0	11
29	e15	---	e3.9	1.8	0.00	0.00	3.5	0.00	0.00	2.9	e5.0	11
30	e8.4	---	e10	3.1	0.00	0.00	2.1	0.00	0.00	2.4	e5.0	8.1
31	4.9	---	e6.3	---	0.00	---	1.1	0.00	---	2.2	---	8.6
Total	159.6	329.62	106.44	43.60	33.42	0.00	197.70	956.66	162.63	305.61	97.84	117.51
Mean	5.15	11.8	3.43	1.45	1.08	0.00	6.38	30.9	5.42	9.86	3.26	3.79
Max	15	80	10	16	12	0.00	111	299	68	232	7.0	14
Min	1.5	0.72	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00
Med	4.1	5.6	2.7	0.00	0.00	0.00	0.00	2.5	0.00	0.00	2.4	2.0
Acre-ft	317	654	211	86	66	0.00	392	1,900	323	606	194	233
CFSM	0.01	0.03	0.01	0.00	0.00	0.00	0.02	0.07	0.01	0.02	0.01	0.01

Calendar year 2005 Total 2510.63 Mean 6.88 Max 299 Min 0.00 Med 1.1 Acre-ft 4980 CFSM 0.02

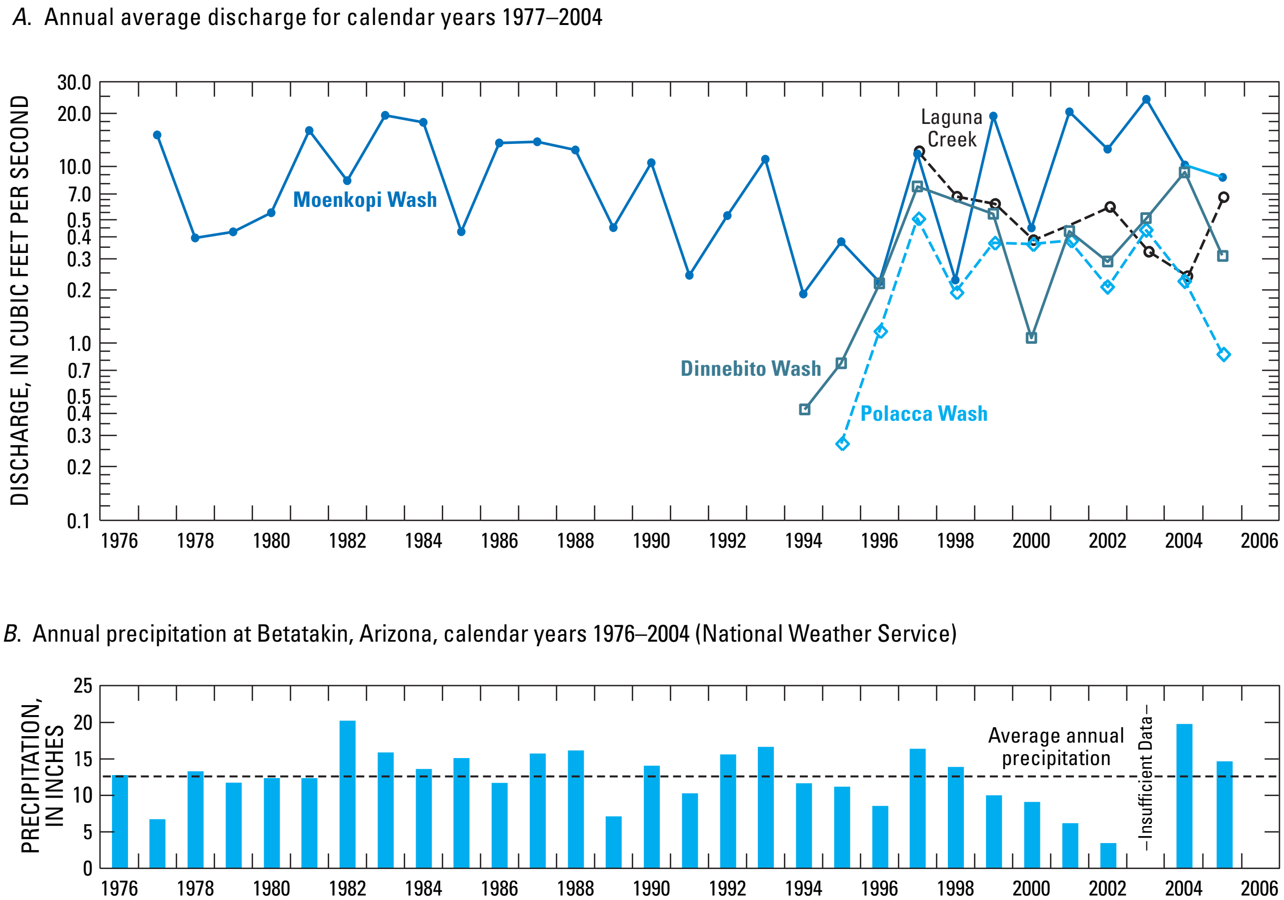

Figure 11. Annual precipitation at Betatakin, Arizona, and streamflow characteristics at Moenkopi Wash (09401260), Laguna Creek (09379180), Dinnebito Wash (09401110), and Polacca Wash (09400568), Black Mesa area, Arizona. *A*, Annual average discharge for calendar years 1977–2005; *B*, Annual precipitation at Betatakin, Arizona, calendar years 1976–2005 (National Weather Service).

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 number	Date data collection began	Drainage area (square miles)
Moenkopi Wash at Moenkopi	9401260	07-1976	1,629
Laguna Creek at Dennehotso	9379180	07-1996	414
Dinnebito Wash near Sand Springs	9401110	06-1993	473
Polacca Wash near Second Mesa	9400568	04-1994	905
Pasture Canyon Spring	9401265	08-2004	---

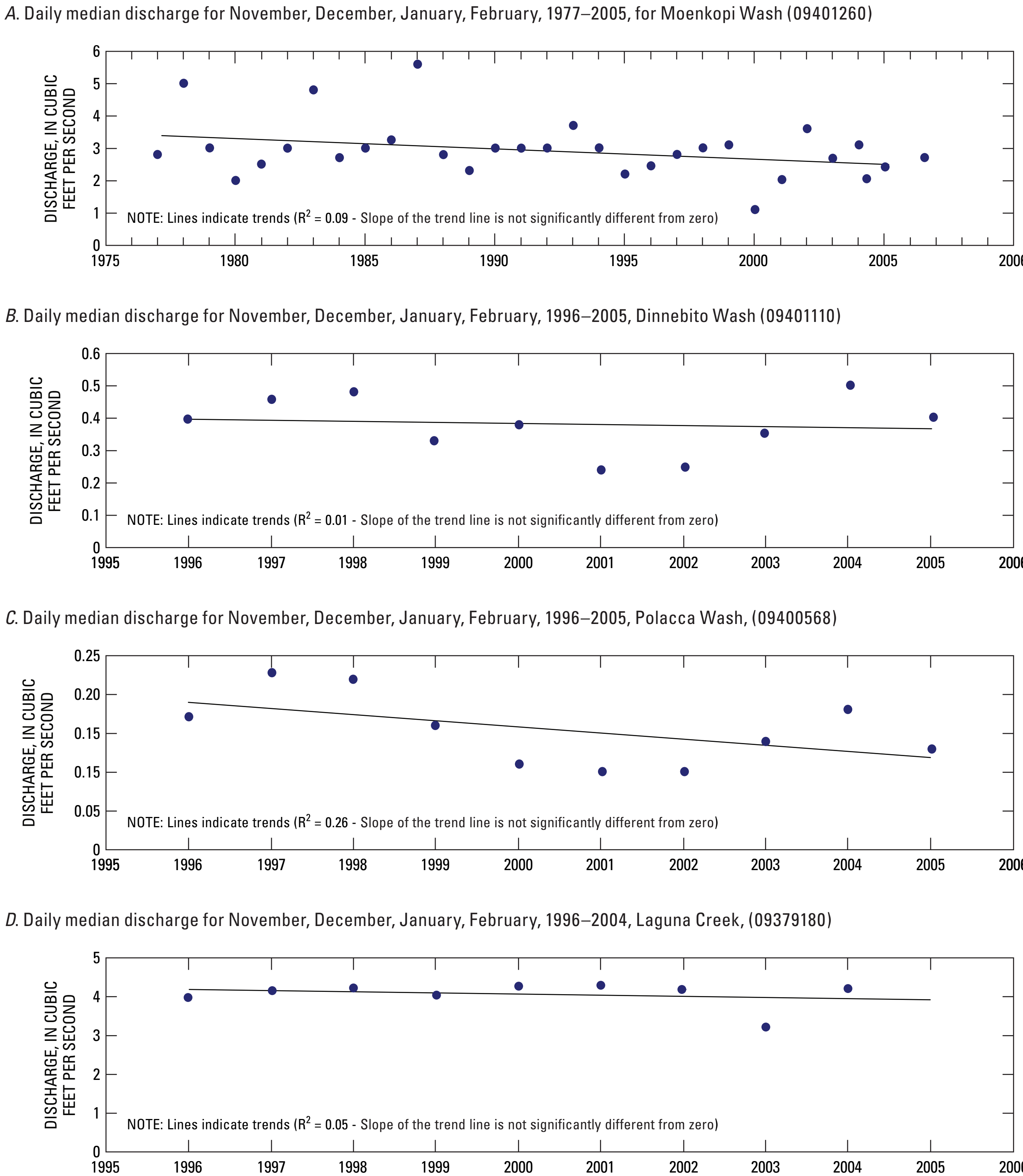

Figure 12. Median discharge for November, December, January, and February for water years 1977–2005 for Moenkopi Wash (09401260), Dinnebito Wash (09401110), Polacca Wash (09400568), and Laguna Creek (09379180), Black Mesa area, Arizona. Note: The Laguan Creek surface-water gage was discontinued in January 2006, and there is not enough data to compute the median winter discharge for 2005–06 calendar years.

Water Chemistry

Water samples for water-chemistry analyses 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. Water-chemistry samples are collected from 12 wells and 4 springs during each year of the program—from the same 8 wells every year and from the other 4 wells on a rotational basis. In 2006 the sampling sites were reduced and samples were collected at 6 of the wells sites that have long-term historical data. Since 1989, samples have been collected from the same 4 springs, however, in 2006, samples were collected from 2 springs (Moenkopi School Spring and Burro Spring). 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 in the Black Mesa study area are available from the USGS water-quality database (http://waterdata.usgs.gov/az/nwis/qw), or can be found in the past monitoring reports cited in the "Previous Investigations" section of this report.

Water-Chemistry Data for Wells Completed in the N Aquifer

The primary types of water in the N aquifer in the Black Mesa study area 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 study area, and sodium bicarbonate water is in the area that is downgradient to the south and east (Lopes and Hoffmann, 1997). In 2006, water samples were collected from 6 wells completed in the N aquifer (figs. 9 and 13).

Keams Canyon PM2 yielded higher dissolved-solids concentrations (588 mg/L) than did the other 5 wells (fig. 13 and table 15). Concentrations of dissolved solids in samples from the other 5 wells ranged from 111 mg/L at Peabody 9 to 399 mg/L at Piñon NTUA 1 (fig. 13 and table 15).

There are some trends in the chemistry of water samples from the 6 wells (table 16 and fig. 14). Samples from Piñon NTUA 1 and Peabody 9 show increasing trends in dissolved solids concentrations; Forest Lake NTUA 1 and Peabody 2 show decreasing trends in dissolved solids concentrations; and both Kykostmovi PM2 and Keams Canyon PM2 show a steady trend in dissolved solids concentrations (fig. 14). The chemistry of water samples from Forest Lake NTUA 1 has varied between 1982 and 1999 and stabilized from 1999 to 2006 (table 16 and fig. 14).

Constituents analyzed from the 6 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.

In 2006, the concentrations of most of the analyzed constituents in samples from the 6 wells were less than the MCLs and SMCLs. The pH level, however, exceeded the SMCL of 8.5 units in samples from 5 of the 6 wells. The dissolved-solids SMCL of 500 mg/L was exceeded in the sample from Keams Canyon PM2 (588 mg/L). Samples from one well, Keams Canyon PM2 (40.3 μg/L), had an arsenic concentration that exceeded the MCL of 10 μg/L (0.01 mg/L; table 15; U.S. Environmental Protection Agency, 2002; table 15).

Water-Chemistry Data for Springs that Discharge from the N Aquifer

In 2006, water samples were collected from Moenkopi School Spring in the southwestern part of the Black Mesa study area and Burro Spring in the southern part of the study area (fig. 9). Both of the springs discharge water from unconfined areas of the N aquifer. At Moenkopi School Spring, samples were collected from a horizontal metal pipe that is developed into the hillside. At Burro Spring, samples were collected from a metal pipe that discharges from a holding tank.

Both Burro Spring and Moenkopi School Spring yielded a calcium sodium bicarbonate-type water (fig. 13). The sample from the Moenkopi School Spring had a dissolved solids concentrations of 232 mg/L, and the sample from Burro Spring had a dissolved-solids concentration of 359 mg/L (table 17). Concentrations of all the analyzed constituents in samples from the two springs were less than current USEPA MCLs and SMCLs (U.S. Environmental Protection Agency, 2002).

Increasing trends in concentrations of dissolved solids and chloride are evident in data from Moenkopi School Spring and Burro Spring, and an increasing trend in sulfate concentrations is evident in data from Moenkopi School Spring (table 18 and figs. 15A–C). Trend lines in figure 15 were generated by applying the statistical least squares method in Microsoft Excel.

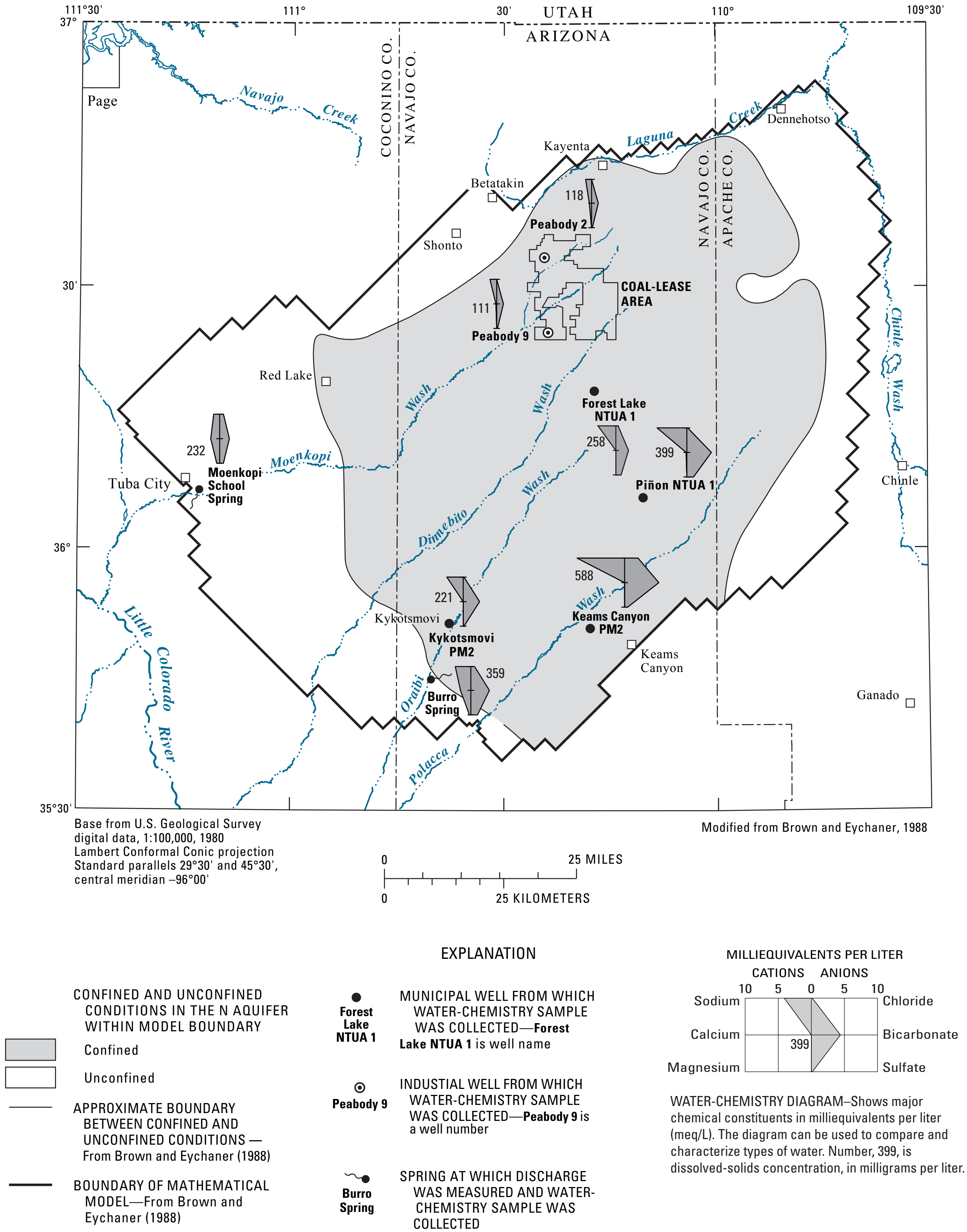

Figure 13. Water chemistry and distribution of dissolved solids in the N aquifer, Black Mesa area, Arizona, 2006.

Table 15. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 2006

[USGS, U.S. Geological Survey;°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter]

Common well name	USGS identification number	Date of samples	Temperature field (°C)	Specific conductance field (µS/cm at 25§C)	pH field	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)
Forest Lake NTUA 1	361737110180301	03-14-06	28.1	445	9.5	128.6	0.579	<.02
Pinon NTUA 1	360527110122501	03-14-06	26.4	709	9.9	250	1.29	<.02
Keams Canyon PM2	355023110182701	03-13-06	19.3	1067	9.0	347.2	<.06	<.02
Kykotsmovi PM2	355215110375001	03-13-06	22.2	367	9.6	168.4	1.17	0.03
Peabody 9	362333110250001	03-07-06	31.4	158	8.7	68.3	0.757	<.02
Peabody 2	363005110250901	03-07-06	30.9	167	8.4	67.5	0.953	<.02

Common well name	USGS identification number	Date of samples	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Potassium dissolved (mg/L as K)	Sodium dissolved (mg/L as Na)	Chloride dissolved (mg/L as Cl)	Flouride dissolved (mg/L as F)
Forest Lake NTUA 1	361737110180301	03-14-06	0.79	0.081	0.69	84.6	13.9	0.43
Pinon NTUA 1	360527110122501	03-14-06	1.06	0.154	0.54	138	6.56	0.33
Keams Canyon PM2	355023110182701	03-13-06	0.8	0.153	0.72	221	98.9	1.42
Kykotsmovi PM2	355215110375001	03-13-06	0.48	0.013	0.42	75.1	3.25	0.17
Peabody 9	362333110250001	03-07-06	3.55	0.035	0.56	30.8	2.59	0.18
Peabody 2	363005110250901	03-07-06	8.14	0.127	0.67	26.5	2.16	0.12

Common well name	USGS identification number	Date of samples	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)
Forest Lake NTUA 1	361737110180301	03-14-06	20.7	48.6	2.9	109	24	258
Pinon NTUA 1	360527110122501	03-14-06	23.7	66.9	4.2	76.7	16	399
Keams Canyon PM2	355023110182701	03-13-06	10.7	34	40.3	606	<6	588
Kykotsmovi PM2	355215110375001	03-13-06	22.3	7.7	5	28	<6	221
Peabody 9	362333110250001	03-07-06	19.6	4.43	2.9	20.5	<6	111
Peabody 2	363005110250901	03-07-06	21.9	8.23	2.8	16.1	<6	118

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, 1974–2006.

[μS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligram per liter; dashes indicate no data]

Year	Specific conductance, field (μS/cm at 25°C)	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
2006	445	258	14	49
Peabody 2				
1967	221	---	5	21
1971	211	---	2.8	18
1974	210	144	2.8	17
1975	230	163	5	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	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
2006	167	118	2.2	8.2
Peabody 9				
1986	181	---	3.1	4.9
1987	148	102	2.8	4.1
1990	158	106	1.6	3
1991	155	83	2.7	3.1
1993	157	94	1.6	2.9
1994	---	---	1.7	---
1995	154	122	1.6	1.6
1998	109	109	1.7	2.5
2001	88	112	1.8	2.7
2002	152	96	1.7	2.5
2006	158	111	2.6	4.4

Year	Specific conductance, field (μS/cm at 25°C)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
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	2603	97	32
2005	828	601	97	34
2006	1067	588	99	34
Piñon NTUA 1				
1998	460	304	4.6	4.7
2001	473	304	4.9	5.5
2002	512	---	5	5.5
2003	716	421	6.7	83
2004	691	421	7	76
2006	709	399	6.6	67
Kykotsmovi PM2				
1988	368	212	3.2	8.6
1990	355	255	3.2	9
1991	1374	203	4.4	7.9
1992	363	212	3.3	8.4
1994	1365	212	3.6	8.5
1995	368	224	3.1	6.2
1996	365	224	3.3	8.5
1997	1379	222	3	8
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
2004	653	649	128	109
2005	1,053	639	128	113
2006	367	221	3.25	7.7

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

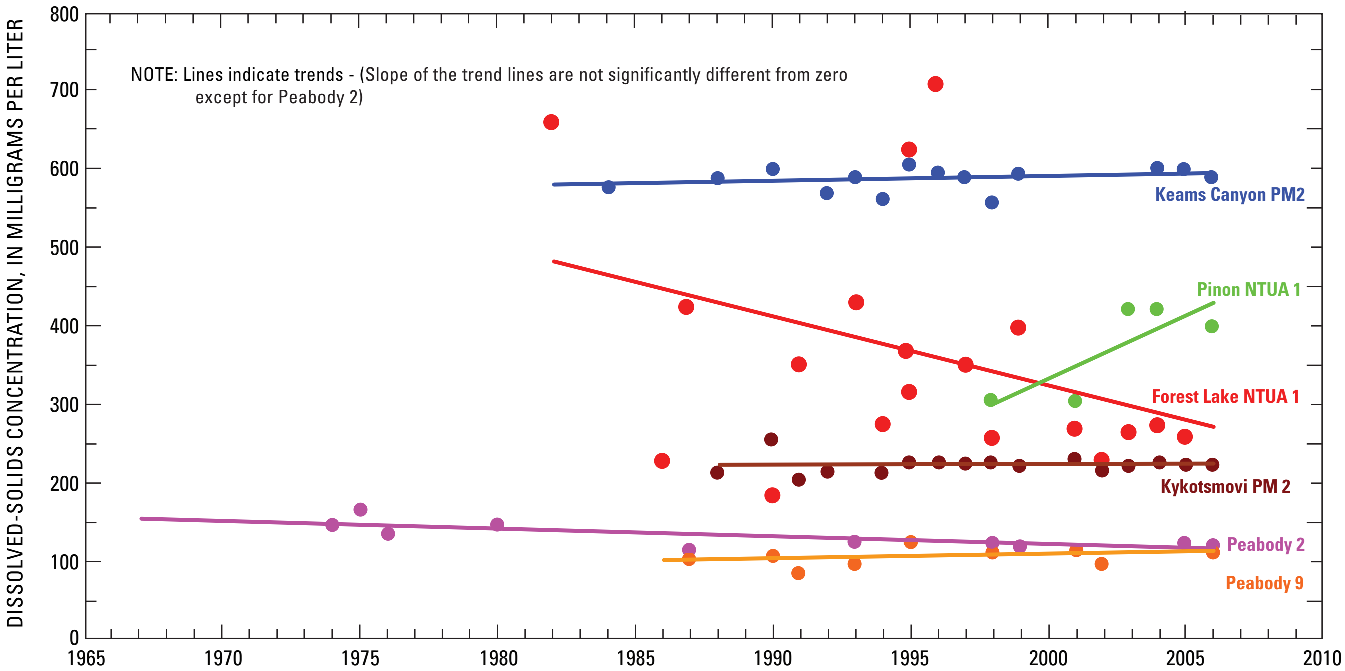

Figure 14. Dissolved-solids concentrations with linear trend lines for water from selected wells, Black Mesa area, Arizona, 1980–2006.

Table 17. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 2006.

[USGS, U.S. Geological Survey; BIA, Bureau of Indian Affairs; °C, degree Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; dashes indicate no data; e, estimated]

USGS identification number	BIA site number	Common spring name	Date of samples	Temperature field (°C)	Specific conductance field (µS/cm)	pH field	Alkalinity, field, dissolved (mg/L as $CaCO_3$)	Nitrogen $NO_2 + NO_3$ dissolved (mg/L as N)
360632111131101	3GS-77-6	Moenkopi School Spring	03-13-06	17.6	387	7.5	103.6	2.79
354156110413701	6M-31	Burro Spring	03-28-06	13.2	576	8.1	187.9	0.135

USGS identification number	BIA site number	Common spring name	Date of samples	Ortho-phosphate dissolved (mg/L as P)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Potassium dissolved (mg/L as K)	Sodium dissolved (mg/L as Na)
360632111131101	3GS-77-6	Moenkopi School Spring	03-13-06	<.02	35.8	7.21	1.5	26.4
354156110413701	6M-31	Burro Spring	03-28-06	<.02	43.7	2.95	0.36	74

USGS identification number	BIA site number	Common spring name	Date of samples	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)
360632111131101	3GS-77-6	Moenkopi School Spring	03-13-06	27.3	0.2	13.4	34.2	2.4
354156110413701	6M-31	Burro Spring	03-28-06	25	0.5	14.3	68.2	1.0

USGS identification number	BIA site number	Common spring name	Date of samples	Boron dissolved (µg/L as B)	Iron dissolved (µg/L as Fe)	Dissolved solids residue at 180°C (mg/L)
360632111131101	3GS-77-6	Moenkopi School Spring	03-13-06	38.4	<6	232
354156110413701	6M-31	Burro Spring	03-28-06	75.3	<6	359

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, 1948–2006.

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

Year	Specific conductance, field (µS/cm at 25°C)	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
2006	576	359	25	68.2
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
2006	387	232	27	34

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

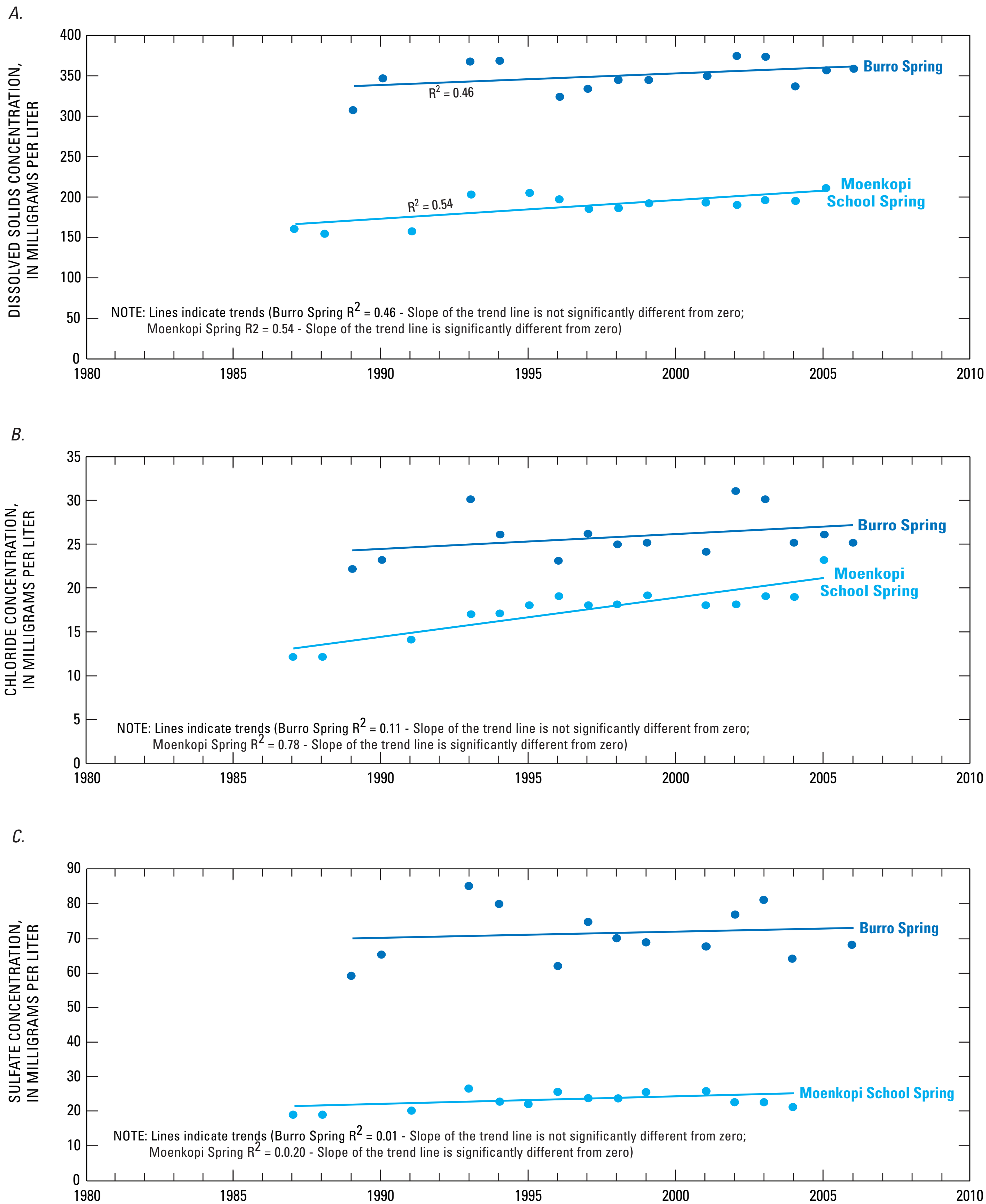

Figure 15. Concentrations of dissolved solids, chloride, and sulfate for water from selected springs, Black Mesa area, Arizona, 1984–2006. *A*, Dissolved solids; *B*, Chloride; *C*, Sulfate.

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 2005 to September 2006. The monitoring data for 2005–06 are compared with data for 2004–05 and with historical data from the 1950s to September 2006.

In 2005, total ground-water withdrawals were 7,330 acre-ft, industrial withdrawals were 4,480 acre-ft, and total municipal withdrawals were 2,850 acre-ft. From 2004 to 2005, total withdrawals increased by 2 percent, industrial withdrawals increased by 3 percent, and municipal withdrawals increased by 0.35 percent.

From 2005 to 2006, annually measured ground-water levels declined in 22 of 28 wells. The median water-level change for the 28 wells was -0.7 ft. In unconfined areas of the N aquifer, water levels declined in 10 of 13 annual wells, and the median change was -0.5 ft. In the confined area of the N aquifer, water levels declined in 12 of 15 wells, and the median change was -1.4 ft. For wells in the confined area of the N aquifer, the median water-level change was -1.8 ft, and there is no appreciable trend in the water-level changes from 1983 to 2006. For wells in unconfined areas, the median water-level change was 0.1 ft, and there is no appreciable trend from 1983 to 2006.

From the prestress period (prior to 1965) to 2006, the median water-level change in 29 wells was -8.5 ft. Water levels in the 13 wells in the unconfined areas of the N aquifer had a median change of -0.2 ft, and the changes ranged from -30.6 ft to 10.1 ft. Water levels in the 16 wells in the confined area of the N aquifer had a median change of -46.6 ft, and the changes ranged from -196.2 ft to 12.6 ft.

Discharges were measured annually at two springs in 2005 and 2006. Between 2005 and 2006, spring flow decreased by 15 percent at Burro Spring and decreased by 3.5 percent at Moenkopi School Spring. For about the past 12 years, discharges at the two springs have fluctuated and indicate a decreasing trend.

Annual average discharges at five streamflow-gaging stations—Moenkopi Wash, Dinnebito Wash, Pasture Canyon Spring, Polacca Wash, and Laguna Creek—vary during the periods of record. No trends are apparent in streamflow at the five streamflow-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. The Laguna Creek gaging station was discontinued in January, 2006 and there was not enough data to compute the median winter flow.

In 2006, water samples were collected from 6 wells and analyzed for selected chemical constituents. Dissolved-solids concentrations ranged from 111 to 588 mg/L, and samples from 5 of the wells had dissolved-solids concentrations less than the SMCL (500 mg/L). There are some trends in the chemistry of water samples from the 6 wells.

Water samples from Keams Canyon PM2 exceeded the SMCL for dissolved solids concentrations and the MCL for arsenic (10 μg/L), and samples from 5 wells exceeded the SMCL for pH (8.5).

Dissolved-solids concentrations in water samples from Moenkopi School Spring and Burro Spring range from 232 to 359 mg/L, respectively. From the mid-1980s to 2006, long-term trends indicating increasing trends in concentrations of dissolved solids, chloride, and sulfate are apparent.

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