U.S. Department of the Interior
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Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003–04

Open-File Report 2005–1080

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

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By Margot Truini, J.P. Macy, and T.J. Porter

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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:

$$F=(1.8°C)+32$$

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

ABBREVIATED WATER-QUALITY UNITS

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

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2003–04

By Margot Truini, J.P. Macy, and T.J. Porter

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 2003, total ground-water withdrawals were 7,240 acre-feet, industrial withdrawals were 4,450 acre-feet, and municipal withdrawals were 2,790 acre-feet. From 2002 to 2003, total withdrawals decreased by 10 percent, industrial withdrawals decreased by 4 percent, and municipal withdrawals decreased by 20 percent. Flowmeter testing was completed for 24 municipal wells in 2004. The median difference between pumping rates for the permanent meter and a test meter for all the sites tested was -2.9 percent. Values ranged from -10.9 percent at Forest Lake NTUA 1 to +7.8 percent at Rough Rock NTUA 2. From 2003 to 2004, water levels declined in 6 of 12 wells in the unconfined part of the aquifer, and the median change was -0.1 foot. Water levels declined in 7 of 11 wells in the confined part of the aquifer, and the median change was -2.7 feet.

From the prestress period (prior to 1965) to 2003, the median water-level change for 26 wells was -23.2 feet. Median water-level changes were -6.1 feet for 14 wells in the unconfined parts of the aquifer and -72.1 feet for 12 wells in the confined part.

Discharges were measured once in 2003 and once in 2004 at four springs. Discharge stayed the same at Pasture Canyon Spring, increased 9 percent at Moenkopi Spring, decreased 26 percent at an unnamed spring near Dennehotso, and decreased 50 percent at Burro Spring. For the past 12 years, 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 2003 at Moenkopi Wash, 1996 to 2003 at Laguna Creek, 1993 to 2003 at Dinnebito Wash, and 1994 to 2003 at Polacca Wash. 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 2004, water samples were collected from 12 wells and 4 springs and analyzed for selected chemical constituents. Dissolved-solids concentrations ranged from 100 to 649 milligrams per liter. Water samples from 11 of the wells and from all the springs had less than 500 milligrams per liter of dissolved solids. There are no appreciable time trends in the chemistry of water samples from 7 wells and 2 springs; increasing trends in dissolved-solids and chloride concentrations were evident from the more than 10 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. per year (U.S. Department of Agriculture, 1999).

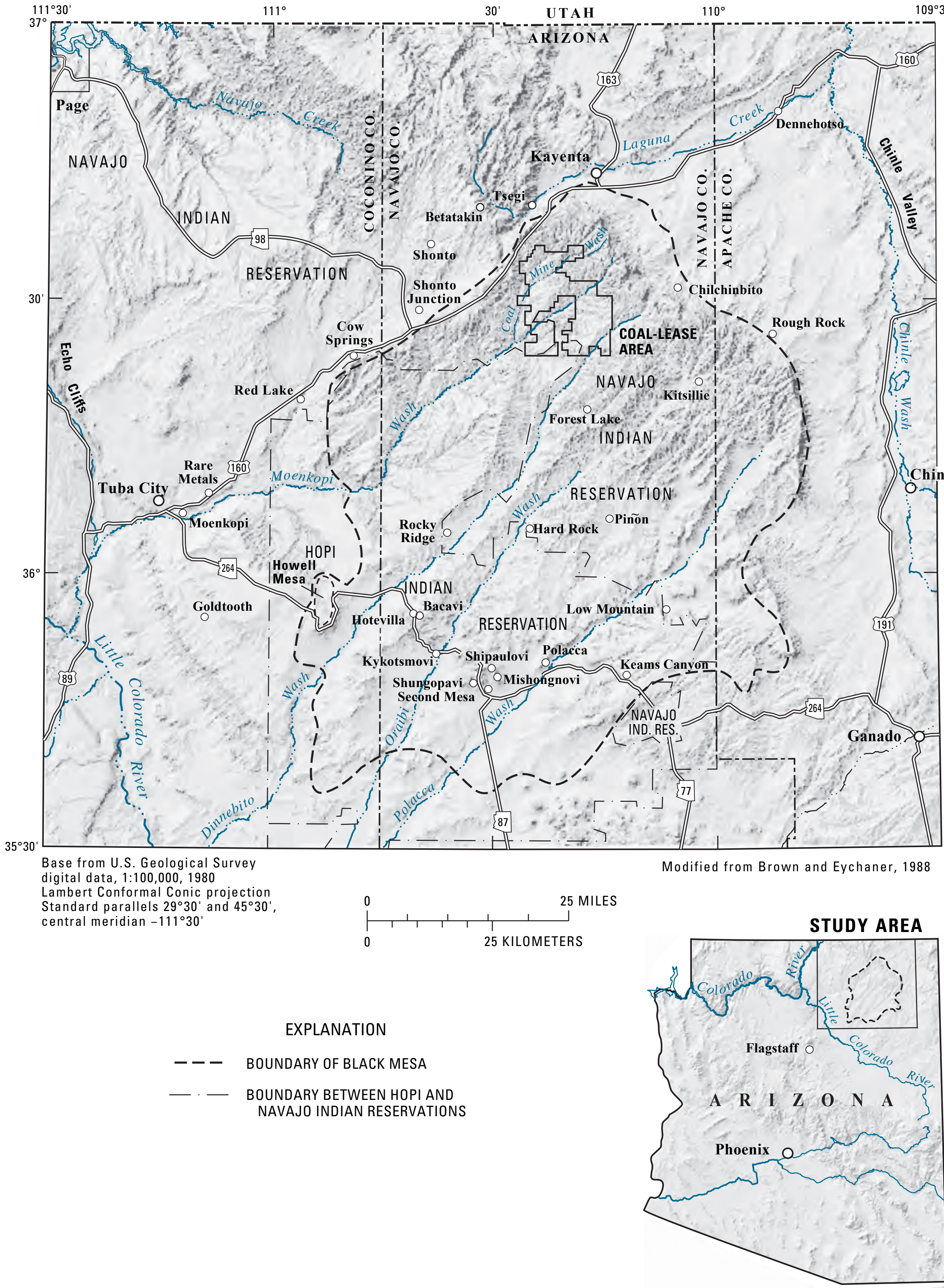


Figure 1. Location of study area.

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[1] of the Wingate Sandstone—that are hydraulically connected and function as a single aquifer (fig. 2). 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 33 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 4,450 acre-ft of water was pumped in 2003 by PWCC. Withdrawals for municipal use from the N aquifer increased from an estimated 250 acre-ft in 1968 to 3,360 acre-ft in 2002, and decreased in 2003 to 2,530 acre-ft. 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, Chinle Agency, and 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 2003 to September 2004. 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. Flowmeter testing included comparing the pumpage measured by permanent meters at 31 wells to that measured by a calibrated mechanical flowmeter.

[1]The name Lukachukai Member was formerly abandoned by Dubiel (1989) and is used herein for report continuity in the monitoring program as it relates to that part of the Wingate Sandstone included in the N aquifer.

Previous Investigations

Twenty-one 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; and Truini and Thomas, 2004). 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), and Fisk and others (2004). 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.

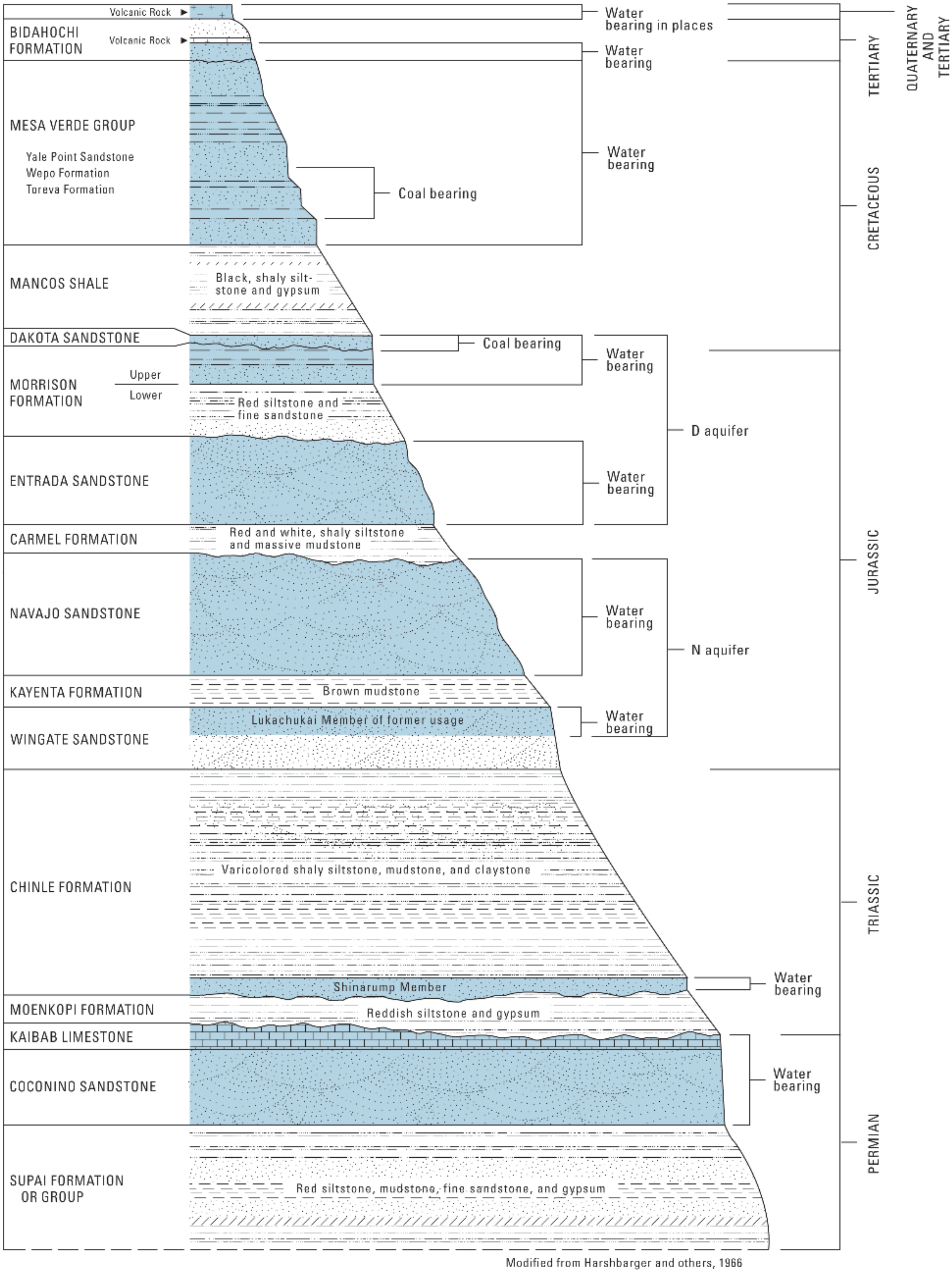


Figure 2. Rock formations and hydrogeologic units of the Black Mesa area, Arizona (not to scale).

Table 1. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–2003

[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 part of the aquifer]

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

[1]Metered pumpage from the confined part 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, 1986–2000.

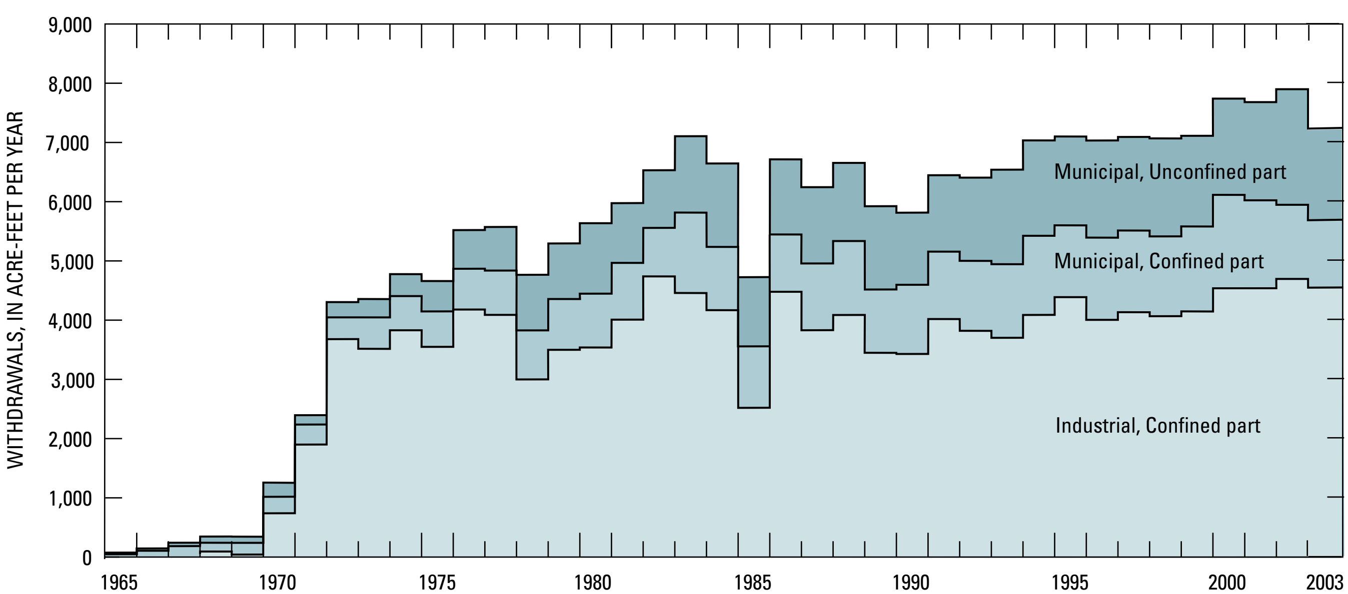


Figure 3. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–2003.

Hydrologic Data

In 2003–04, the Black Mesa monitoring program included metering and estimating ground-water withdrawals, measuring depth to ground water, measuring discharge in streams and springs, collecting and analyzing water samples from wells and springs, and periodic testing of flowmeters for accuracy. Ground-water withdrawals from 36 well systems, water levels at 6 observation wells, and surface-water discharge at 4 sites were monitored continuously during this period. Continuous recorders at three of the six observation wells were 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**). Annual measurements were made of discharge at 4 springs and ground-water levels at 26 wells. Spring discharges and ground-water levels were measured between March and May 2004. Ground-water samples were collected from 12 wells and 4 springs in March–May 2004 and analyzed for chemical constituents. Identification information for the 51 wells used for water-level measurements and water-quality sampling is shown in table 2.

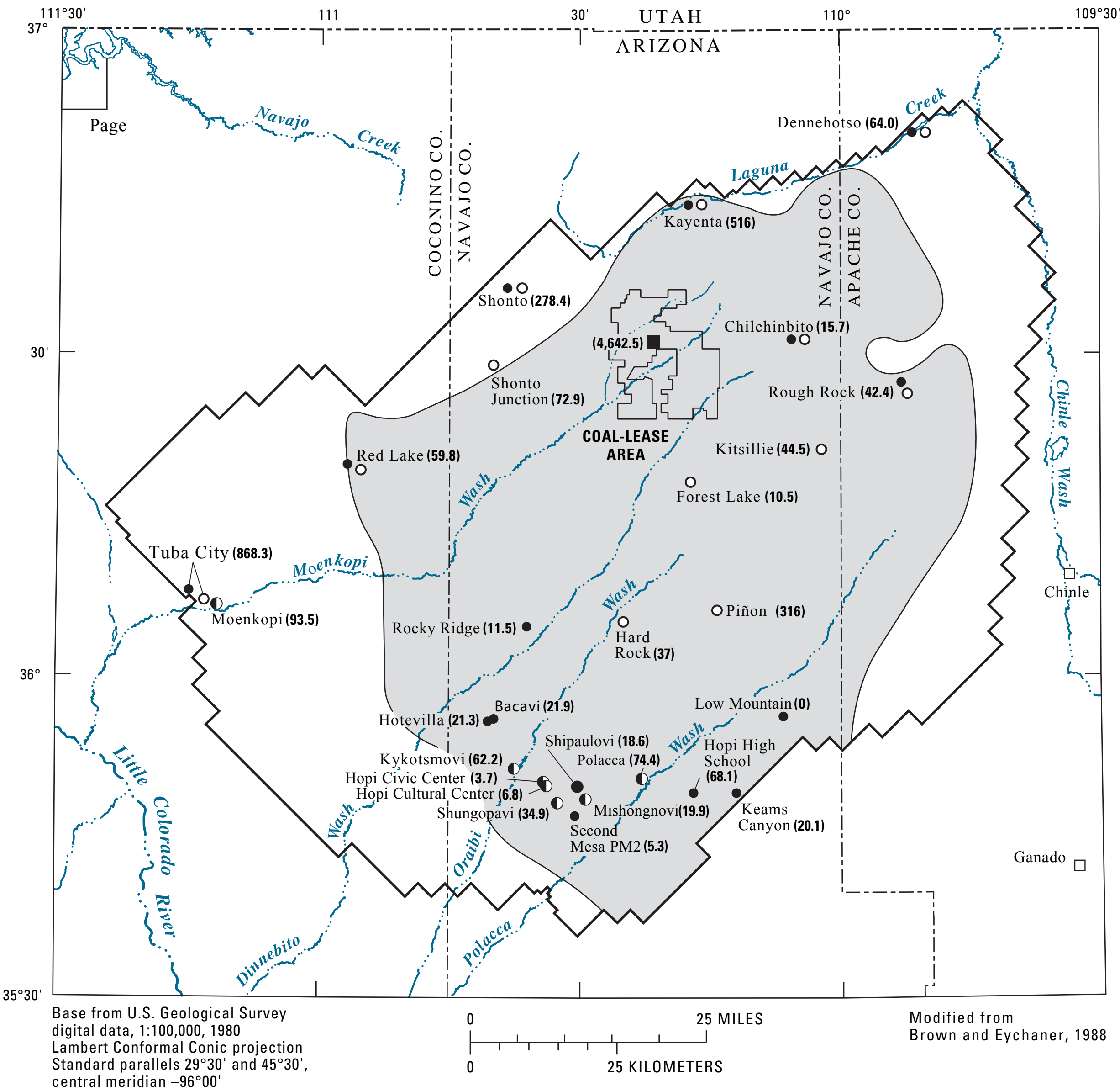
Withdrawals from the N Aquifer

Withdrawals from the N aquifer are separated into three categories: (1) industrial withdrawals from the confined part of the aquifer, (2) municipal withdrawals from the confined part of the aquifer, and (3) municipal withdrawals from the unconfined parts of the aquifer (**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).

Table 2. Identification numbers and names of study wells, 2003–04, Black Mesa area, Arizona

[Dashes indicate no data]

U.S. Geological Survey identification number	Common name or location	Bureau of Indian Affairs site number
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	Kitsillie NTUA 2	---
360418110352701	Rocky Ridge PM 2	--
362149109463301	Rough Rock	10R-111
363130110254501	Peabody 8	--
362406110563201	White Mesa Arch	1K-214
362418109514601	Rough Rock PM5	---
362456110503001	Cow Springs	1K-225
362647110243501	Peabody 4	---
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
361933110565001	Red Lake PM 1	--
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



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)

WELL-SYSTEM OWNER

- ● Bureau of Indian Affairs
- ○ Navajo Tribal Utility Authority
- ◐ Hopi Tribe
- ■ Peabody Western Coal Company

Piñon **(316)** WITHDRAWALS FROM THE N AQUIFER—Piñon, is the well-system name; **316**, is the total withdrawal in acre-feet for 2003. The total is cumulative at locations served by multiple wells

Figure 4. Locations of well systems monitored for withdrawals from the N aquifer, Black Mesa area, Arizona, 2003.

Table 3. Withdrawals from the N aquifer by well system, Black Mesa area, Arizona, 2003

[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	3.9	
Dennehotso	BIA	USGS/BIA		22.6
Hopi High School	BIA	USGS/BIA	68.1	
Hotevilla	BIA	USGS/BIA	21.3	
Kayenta	BIA	USGS/BIA	45.4	
Keams Canyon	BIA	USGS/BIA	20.1	
Low Mountain	BIA	USGS/BIA	[1]0	
Piñon	BIA	USGS/BIA	[1]0	
Red Lake	BIA	USGS/BIA		8.4
Rocky Ridge	BIA	USGS/BIA	11.5	
Rough Rock	BIA	USGS/BIA	34.3	
Second Mesa	BIA	USGS/BIA	5.3	
Shonto	BIA	USGS/BIA		160.6
Tuba City	BIA	USGS/BIA		96.5
Chilchinbito	NTUA	USGS/NTUA	11.8	
Dennehotso	NTUA	USGS/NTUA		41.4
Forest Lake	NTUA	USGS/NTUA	10.2	
Hard Rock	NTUA	USGS/NTUA	37.0	
Kayenta	NTUA	USGS/NTUA	470.5	
Kitsillie	NTUA	USGS/NTUA	44.5	
Piñon	NTUA	USGS/NTUA	316	
Red Lake	NTUA	USGS/NTUA		51.4
Rough Rock	NTUA	USGS/NTUA	8.1	
Shonto	NTUA	USGS/NTUA		117.7
Shonto Junction	NTUA	USGS/NTUA		72.9
Tuba City	NTUA	USGS/NTUA		771.8
Mine Well Field	Peabody	Peabody	[2]4,448.9	
Bacavi	Hopi	USGS/Hopi	21.9	
Hopi Civic Center	Hopi	USGS/Hopi	3.7	
Hopi Cultural Center	Hopi	USGS/Hopi	6.8	
Kykotsmovi	Hopi	USGS/Hopi	62.2	
Mishongnovi	Hopi	USGS/Hopi	19.9	
Moenkopi	Hopi	USGS/Hopi		93.5
Polacca	Hopi	USGS/Hopi	[3]74.4	
Shipaulovi	Hopi	USGS/Hopi	18.6	
Shungopovi	Hopi	USGS/Hopi	34.9	

[1]Well taken out of service.

[2]Industrial pumpage.

[3]Estimated. Well PM4 not metered. Annual pumpage from PM4 was estimated as 40 acre-feet 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.

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.

In 2003, the total ground-water withdrawal from the N aquifer was about 7,240 acre-ft (**table 1**), which is about a 10-percent decrease from the total withdrawal in 2002. Withdrawals for municipal use from the confined part of the aquifer totaled 1,350 acre-ft, which is about a 10-percent decrease from 2002. Withdrawals for municipal use from the unconfined parts of the aquifer totaled 1,440 acre-ft, which is about a 23-percent decrease from 2002. Withdrawals for industrial use totaled 4,450 acre-ft, which is a 4-percent decrease from 2002.

Withdrawals from the N aquifer have been increasing since the 1970s (table 1 and fig. 3). Total withdrawals increased by about 12 percent per year from the mid-1960s to 2003—from the mid-1960s to 1979, the increase was 28 percent per year. Municipal withdrawals increased by about 20 percent per year in the 1970s, by about 4 percent per year in the 1980s, by about 2 percent per year in the 1990s, and decreased by about 2 percent per year from 2000 to 2003.

In the 1970s, industrial withdrawals were about 70 percent of the total withdrawals each year. With the increase in municipal withdrawals during the last 30 years, industrial withdrawals, as a percentage of total withdrawals, have declined to an average of about 60 percent per year in the 1990s through 2003.

In an effort to improve and ensure the accuracy of ground-water withdrawal data, a quality-assurance program was begun in 1985 for withdrawal data from industrial and municipal wells completed in the N aquifer. Nearly all industrial and municipal wells in the study area are equipped with totalizing flowmeters to measure ground-water withdrawals. The flowmeters on the municipal wells are tested about every 5 years by measuring pumpage with a calibrated mechanical flowmeter and comparing the measured pumpage to the metered pumpage. For the purpose of this study, the allowable difference between the discharge measured by the permanent totalizing flowmeter and the test meter is 10 percent.

Flowmeter testing was done on approximately one-third of the wells (31 wells were visited and 24 wells were tested) during June 2004 (**table 4**). Most of the remaining municipal wells were tested in 2003 (Truini and Thomas, 2004). The median percent difference between pumping rates for the permanent meter and the test meter for all the sites tested was -2.9 percent. Values ranged from -10.9 percent at Forest Lake NTUA 1 to +7.8 percent at Rough Rock NTUA 2 (table 4). Only the value for Forest Lake NTUA 1 exceeded the 10-percent allowable difference.

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, the south towards the Hopi Reservation, and the east towards Rough Rock and Dennehotso (Eychaner, 1983).

Ground-water levels are measured each year and compared with levels from previous years to determine changes over time. Only water levels from municipal and stock wells that are not considered recently pumped, influenced by nearby pumping, or blocked or obstructed are used for comparison. During May and June 2004, water levels in 26 of the 34 wells that are used for observation met these criteria (**table 5**). Six of the 26 wells are continuous-recording observation wells, and water levels were measured manually in these wells six times between May 2003 and June 2004. Water levels in 23 of the 26 wells in 2004 were compared with water levels in 2003. Water levels in the remaining 3 wells could not be compared because of obstructions in the well, effects of pumping, or other conditions that prevented an accurate water level to be measured in 2003 and (or) 2004. Kitsillie NTUA 2 was added to the observation-well network this year because Forest Lake NTUA 1 has been obstructed for the last few years, leaving a gap in water-level data for the northern part of Black Mesa.

The wells used for water-level measurements are distributed throughout the study area (fig. 5). Although all the wells are completed in the N aquifer, characteristics of the wells vary considerably. Construction dates range from 1934 to 1999, depths range from 107 ft near Dennehotso to 3,535 ft near PWCC, and depths to the top of the N aquifer range from 0 to 2,617 ft (**table 6**).

From 2003 to 2004, water levels declined in 13 of the 23 wells for which comparisons could be made (table 5). The median water-level change in the 23 wells was -0.2 ft (**table 7**). From 2003 to 2004, water levels declined in 6 of the 12 wells in the unconfined parts of the aquifer. The median water-level change was -0.1 ft. Water-level changes ranged from -30.8 ft at 9Y-95 in Rough Rock to +6.2 ft at Tuba City NTUA 1. In the confined area, water levels declined in 7 of 11 wells from 2003 to 2004. The median water-level change was -2.7 ft. Water-level changes ranged from -14.6 ft at Keams Canyon PM 2 to +4.0 ft at Kykotsmovi PM 1 (tables 5 and 7).

Annual median water-level changes for the water-level network wells from 1983 to 2004 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 -1.8 ft, and there was no appreciable trend in the annual water-level changes from 1983 to 2004. For wells in unconfined areas, the annual median water-level change was +0.2 ft, and there is no appreciable trend from 1983 to 2004.

Table 4. Flowmeter-test results for selected municipal wells that are completed in the N aquifer, Black Mesa area, Arizona, 2004

		Pumping rate (gallons per minute)				
Well name	**Date tested or visited**	**Permanent meter**	**Test meter[1]**	**Percent difference[2]**	**Name and number of permanent meter**	
		Navajo Tribal Utility Authority (NTUA)				
Chilchinbito NTUA1	06–08–04	51	51	-0.2	Sensus	62569678
Chilchinbito NTUA 2	06–08–04	59	62	-6.4	Rockwell	1236134
Dennehotso NTUA 1	06–08–04	69	74	-7.8	Rockwell	33447300
Dennehotso NTUA 2	06–08–04	98	101	-4.1	Rockwell	1306471
Forest Lake NTUA 1	06–09–04	41	46	-10.9	Hersey	6049985
Hard Rock NTUA 1	06–10–04	([3])	([3])	([3])	([3])	([3])
Hard Rock NTUA 2	06–14–04	110	110	-1.2	Sensus	1469178
Kayenta NTUA 1	06–08–04	([3])	([3])	([3])	([3])	([3])
Kayenta NTUA 2	06–08–04	([3])	([3])	([3])	([3])	([3])
Kayenta NTUA 3	06–08–04	140	133	4.0	Sensus	1385421
Kayenta NTUA 4	06–08–04	252	253	-1.7	Sensus	24673169
Kayenta NTUA 5	06–08–04	([3])	([3])	([3])	([3])	([3])
Kayenta NTUA 6	06–08–04	140	153	-9.2	Sensus	1412051
Kayenta NTUA 7	06–08–04	([3])	([3])	([3])	([3])	([3])
Kitsillie NTUA 1	06–10–04	29	30	-2.8	Sensus	53189191
Kitsillie NTUA 2	06–10–04	72	74	-3.8	Sensus	1451526
Piñon NTUA 1	06–09–04	100	101	-1.9	Sensus	1442466
Piñon NTUA 2	06–09–04	122	133	-9.1	Sensus	1432493
Piñon NTUA 3	06–09–04	163	165	-2.4	Sensus	1604511
Red Lake NTUA 1	06–14–04	71	73	-2.9	Sensus	1550832
Rough Rock NTUA 1	06–10–04	40	43	-7.0	Rockwell	1320677
Rough Rock NTUA 2	06–10–04	95	87	7.8	Sensus	1329324
Shonto Junction NTUA 1	06–09–04	110	110	-1.8	Sensus	60406257
Shonto Junction NTUA 2	06–09–04	98	95	2.0	Brooks	9504HC090486
Shonto NTUA 1	06–09–04	54	57	-5.6	Rockwell	28945149
Tuba City NTUA 1	06–02–04	([4])	([4])	([4])	([4])	([4])
Tuba City NTUA 2	06–02–04	183	173	4.9	Sparling	129709
Tuba City NTUA 3	06–02–04	159	161	-2.6	Sensus	46571
Tuba City NTUA 4	06–02–04	177	188	-7.0	Sparling	126447
Tuba City NTUA 5	06–02–04	199	204	-3.6	Sparling	126189
Tuba City NTUA 6	06–02–04	([5])	([5])	([5])	([5])	([5])

[1]Invensys 125-W portable large meter tester (maximum flow rate of 300 gallons per minute).

[2]Percent difference = ((([average rate at the permanent meter]/[average rate at the test meter])*[accuracy coefficient])-100)/100. A positive difference indicates that the permanent meter is registering more pumpage than the test flowmeter, whereas a negative difference indicates that it is registering less.

[3]Well not in operation during quality-assurance visit.

[4]Well not tested because test meter could not be connected.

[5]Well not tested because pumpage exceeded the maximum flow rate of the test meter.

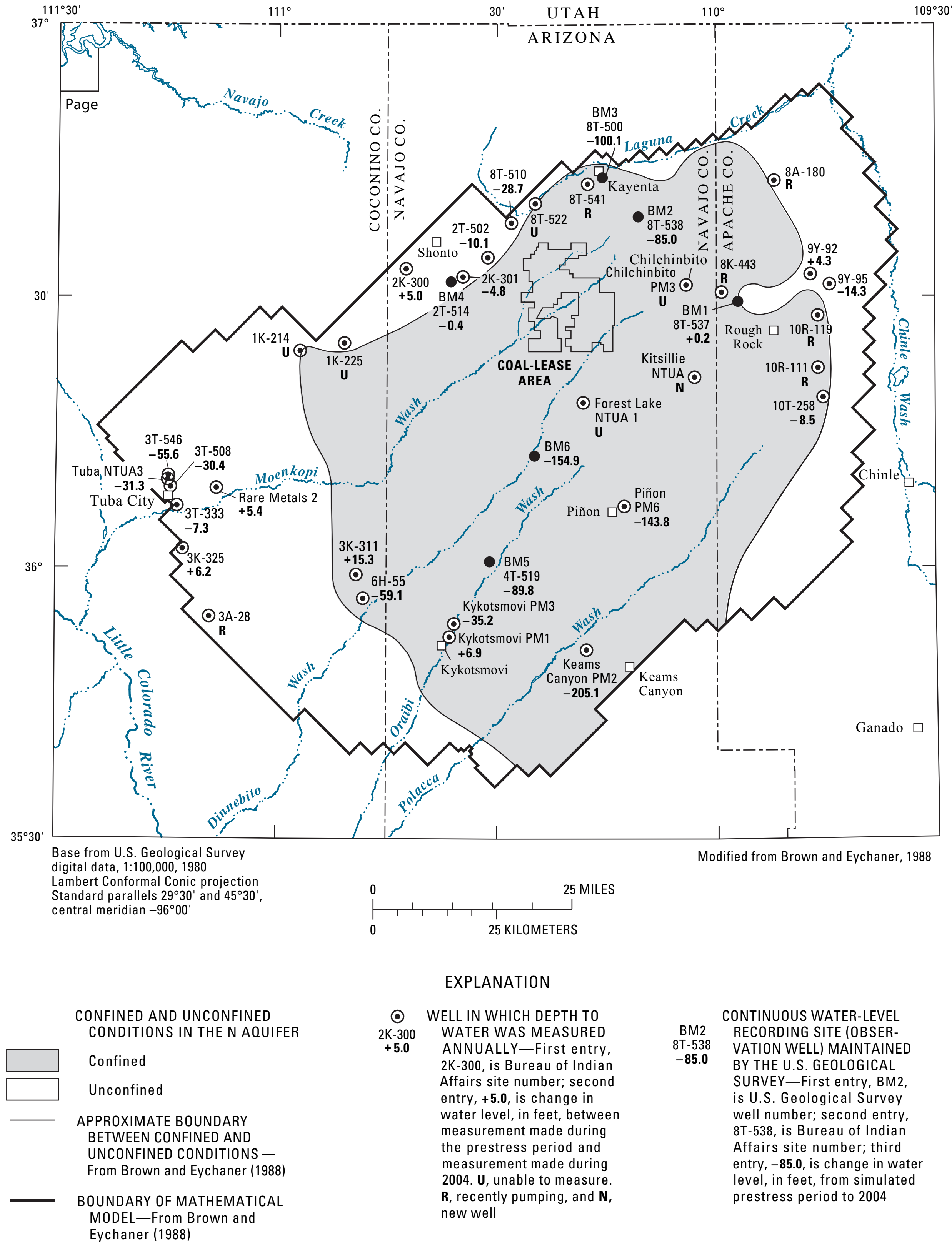


Figure 5. Water-level changes in N aquifer wells from the prestress period to 2004, Black Mesa area, Arizona.

Table 5. Water-level changes in wells completed in the N aquifer, Black Mesa area, Arizona, prestress period to 2004.

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

Common name or location	Bureau of Indian Affairs site number	Change in water level from preceding year (feet)		Water level (feet below land surface), 2004[1]	Prestress period water level[2]		Change in water level from prestress period to 2004 (feet)
		2003	2004		Feet below land surface	Date	
Unconfined areas							
BM observation well 1[3]	8T-537	+0.2	+0.3	373.8	374	([3])	+0.2
BM observation well 4[3]	2T-514	+1.8	+0.0	216.4	[4]216	([3])	-0.4
Goldtooth	3A-28	-5.5	([5])	([6])	230.0	10–29–53	([5])
Long House Valley	8T-510	([5])	([5])	128.1	99.4	08–22–67	-28.7
Northeast Rough Rock	8A-180	+0.0	-0.2	([6])	46.9	11–13–53	([5])
Rough Rock	9Y-95	+1.9	-30.8	133.8	119.5	08–03–49	-14.3
Do.	9Y-92	-3.4	+4.8	164.5	168.8	12–13–52	+4.3
Shonto	2K-300	+0.0	+0.0	171.5	176.5	06–13–50	+5.0
Shonto Southeast	2K-301	([5])	([5])	288.7	283.9	12–10–52	-4.8
	2T-502	([5])	([5])	415.9	405.8	08–22–67	-10.1
Tuba City	3T-333	+0.6	-1.6	30.3	23.0	12–02–55	-7.3
Do.	3K-325	-0.6	+0.4	201.8	208	06–30–55	+6.2
Tuba City Rare Metals 2	---	+0.0	-0.1	51.6	57	09–24–55	+5.4
Tuba City NTUA 1	3T-508	+5.6	+6.2	59.4	29	02–12–69	-30.4
Tuba City NTUA 3	---	-0.4	-4.2	65.5	34.2	11–08–71	-31.3
Tuba City NTUA 4	3T-546	-1.4	-24.3	89.3	33.7	08–06–71	-55.6
Confined area							
BM observation well 2[3]	8T-538	-2.0	-1.5	210.0	125	([3])	-85.0
BM observation well 3[3]	8T-500	+1.6	-4.7	155.1	55.0	04–29–63	-100.1
BM observation well 5[3]	4T-519	-1.1	-3.0	413.8	324	([3])	-89.8
BM observation well 6[3]	---	-1.8	-5.2	851.9	[4]697	([3])	-154.9
Howell Mesa	3K-311	-2.8	+2.6	447.7	463.0	11–03–53	+15.3
Howell Mesa	6H-55	-2.0	+1.2	271.1	212	07–08–54	-59.1
Kayenta West	8T-541	([5])	([5])	([6])	230	03–17–76	([5])
Keams Canyon PM2	---	+1.0	-14.6	497.6	292.5	06–10–70	-205.1
Kitsillie NTUA 2	---	([5])	([5])	1,315.6	1,297.9	01–14–99	-17.7
Kykotsmovi PM1	---	+9.0	+4.0	213.1	220	05–20–67	+6.9
Kykotsmovi PM3	---	-0.8	-2.7	245.2	210	08–28–68	-35.2
Marsh Pass	8T-522	([5])	([5])	([4])	125.5	02–07–72	([5])
Piñon PM6	---	-2.8	-3.9	887.4	743.6	05–28–70	-143.8
Rough Rock	10R-119	+1.8	([5])	([6])	256.6	12–02–53	([5])
Do.	10T-258	+10.6	+1.3	309.5	301.0	04–14–60	-8.5
Do.	10R-111	-2.5	([5])	([6])	170	08–04–54	([5])
Sweetwater Mesa	8K-443	([5])	([5])	([6])	529.4	09–26–67	([5])
White Mesa Arch	1K-214	([5])	([5])	([6])	188	06–04–53	([5])

[1]Water level measured during May to June 2004.

[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]Water level not measured because of obstruction in well, no access to well, or not visited.

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

[6]Well recently pumped.

Table 6. Well-construction characteristics, depth to top of N aquifer, and type of data collected for wells in the monitoring program, Black Mesa area, Arizona, 2003–04

Bureau of Indian Affairs 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[1])	Type of data collected
8T-537 (BM observation well 1)	02–01–72	5,864	850	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	12–08–44	5,635	361	310–335	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

See footnotes at end of table.

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, 2003–04—Continued

Bureau of Indian Affairs 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[1])	Type of data collected
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
Keams Canyon PM2	[3]05–00–70	5,809	1,106	906–1,106	900	Water level, withdrawals
Keams Canyon PM3	[3]01–00–76	5,806	1,090	931–1,090	930	Water chemistry
Kitsillie NTUA 2	11–09–93	6,780	2,620	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	5,717	1,160	950–1,160	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 4	[3]05–00–68	6,229	3,535	2,029–3,458	2,280	Water chemistry, withdrawals
Peabody 8	07-01-80	6,675	3,418	2,460-3,180	2,617	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	1,420	1,180–1,420	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	0	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.

Table 7. Median changes in water levels, 2003–04 and prestress period to 2004, Black Mesa area, Arizona

Years	Aquifer conditions	Number of wells	Median change in water level (feet)
2003-04	All	23	-0.2
	Unconfined	12	-0.1
	Confined	11	-2.7
Prestress-2004	All	26	-23.2
	Unconfined	14	-6.1
	Confined	12	-72.1

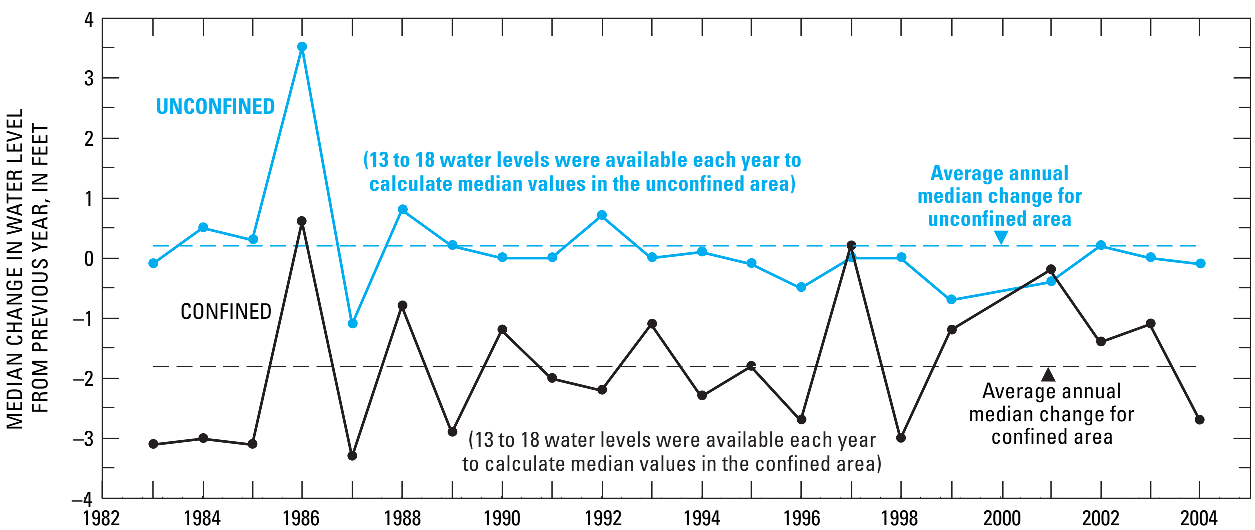


Figure 6. Annual median water-level changes for observation wells completed in the N aquifer, Black Mesa area, Arizona, 1983–2004.

From the prestress period (prior to 1965) to 2004, the median water-level change in 26 wells was -23.2 ft (table 7). Water levels in 14 unconfined wells had a median change of -6.1 ft. Water-level changes ranged from -55.6 ft at Tuba City NTUA 4 to +6.2 ft at 3K–325, which also is in Tuba City. Water levels in 12 confined wells had a median change of -72.1 ft. Water-level changes ranged from -205.1 ft at Keams Canyon PM2 to +15.3 ft at 3K-311 (fig. 5 and tables 5 and 7).

The areal distribution of water-level changes from the prestress period to 2004 is shown in figure 5. Hydrographs of water levels in the annual observation-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 to 56 ft (fig. 5). Water levels have declined in most of the confined area; however, the magnitudes of declines are variable. Larger declines have occurred near the municipal pumping centers (wells Piñon PM6, Keams Canyon PM2, BM3) or near PWCC wells (BM6). Smaller declines have occurred away from the pumping centers (well 10T-258; fig. 5).

Hydrographs for the Black Mesa observation wells show continuous water-level changes since about 1963 (fig. 8). Water levels in the two wells in the unconfined areas (BM1 and BM4) have had small seasonal or year-to-year variation and have had small long-term changes since 1972. Water levels in wells in the confined area, except BM3, also have had little seasonal variation; however, the water levels have consistently declined in all these wells since the early to mid-1960s (fig. 8).

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 2004 at the four springs (table 8). Measurements have been made from the same location at each of the spring sites. 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 2004, measured discharges were 0.2 gal/min from Burro Spring, 12.2 gal/min from Moenkopi School Spring, 12.6 gal/min from the unnamed spring near Dennehotso, and 30.6 gal/min from Pasture Canyon Spring. From 2003 to 2004, discharge decreased by 50 percent at Burro Spring, increased by 9 percent for Moenkopi School Spring, decreased by 26 percent for the unnamed spring near Dennehotso, and stayed about the same for Pasture Canyon Spring. For the consistent periods of record at all four springs, the discharges have fluctuated but long-term trends are not apparent (fig. 10).

Surface-Water Discharge

Surface-water discharge in the study area includes ground-water discharge to streams and direct or shallow subsurface 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 is a result of the temporal variation in snow accumulation, air temperatures, and rate of snowmelt. Although most rainfall runoff is in the summer, rainfall can result in surface-water runoff 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 2003, continuous discharge data were collected at four streamflow-gaging stations (tables 9–12). Data collection at these stations began in July 1976 (Moenkopi Wash), July 1996 (Laguna Creek), June 1993 (Dinnebito Wash), and April 1994 (Polacca Wash; fig. 9 and table 13). In August of 2004, a continuous-recording gage was installed at Pasture Canyon Spring downstream from the discharge-measuring point for the spring. The annual average discharges at the four gaging stations vary considerably during their periods of record (fig. 11*B*), and no long-term trends are apparent.

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*C*). 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 entire 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.

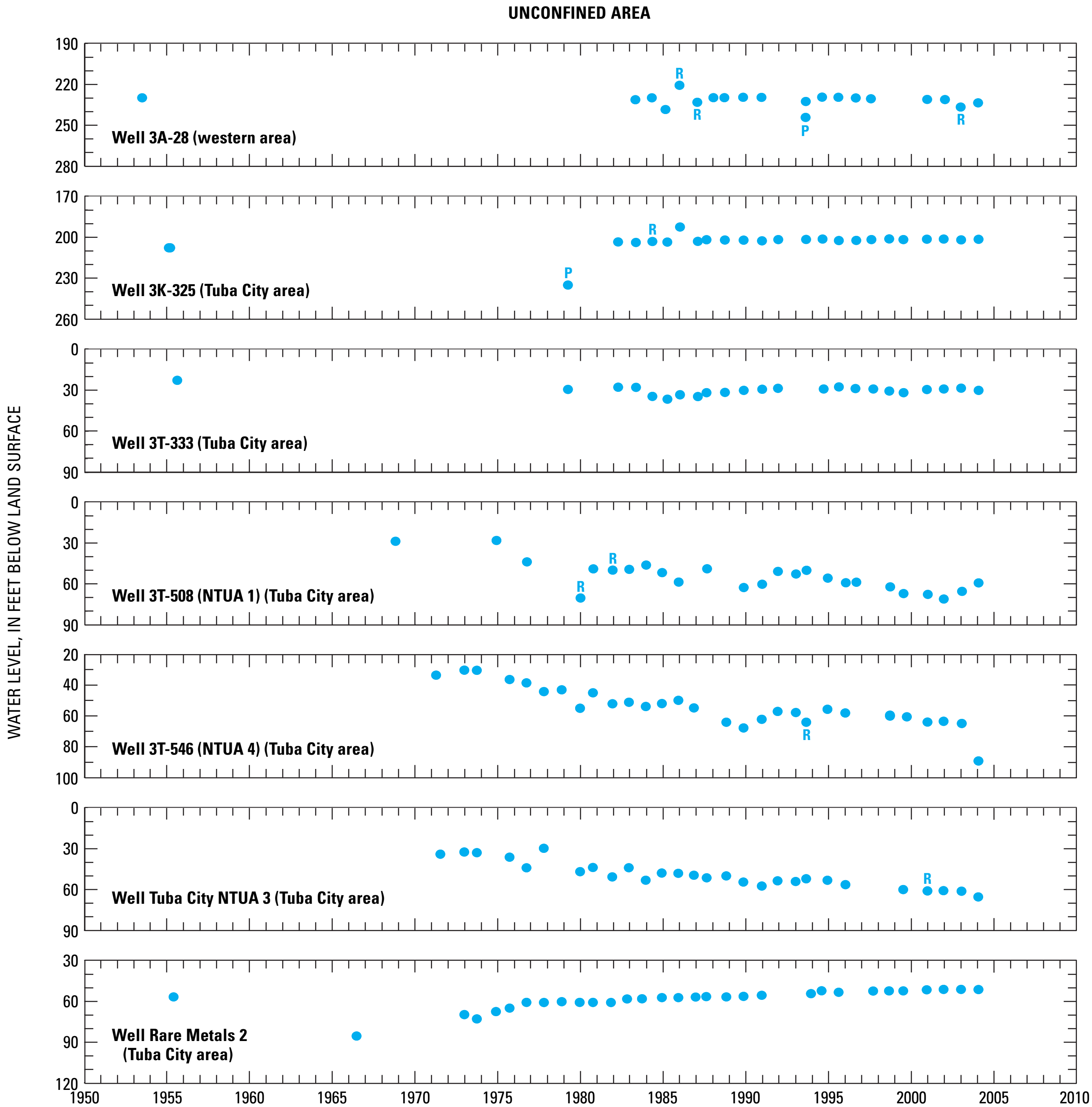
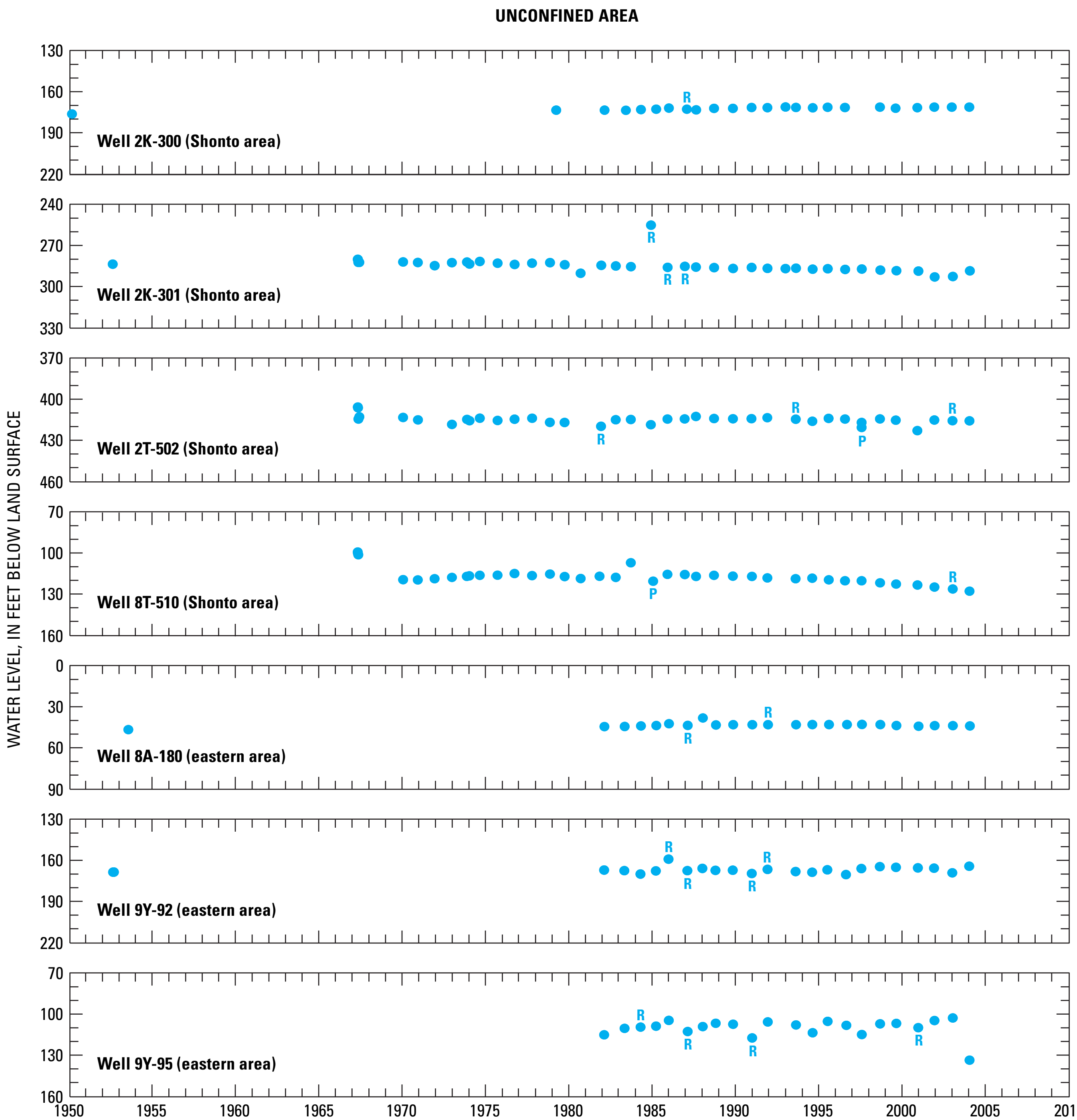


Figure 7. Observed water levels (1950–2004) in annual observation-well network, Black Mesa area, Arizona. P, pumping, R, recently pumping.



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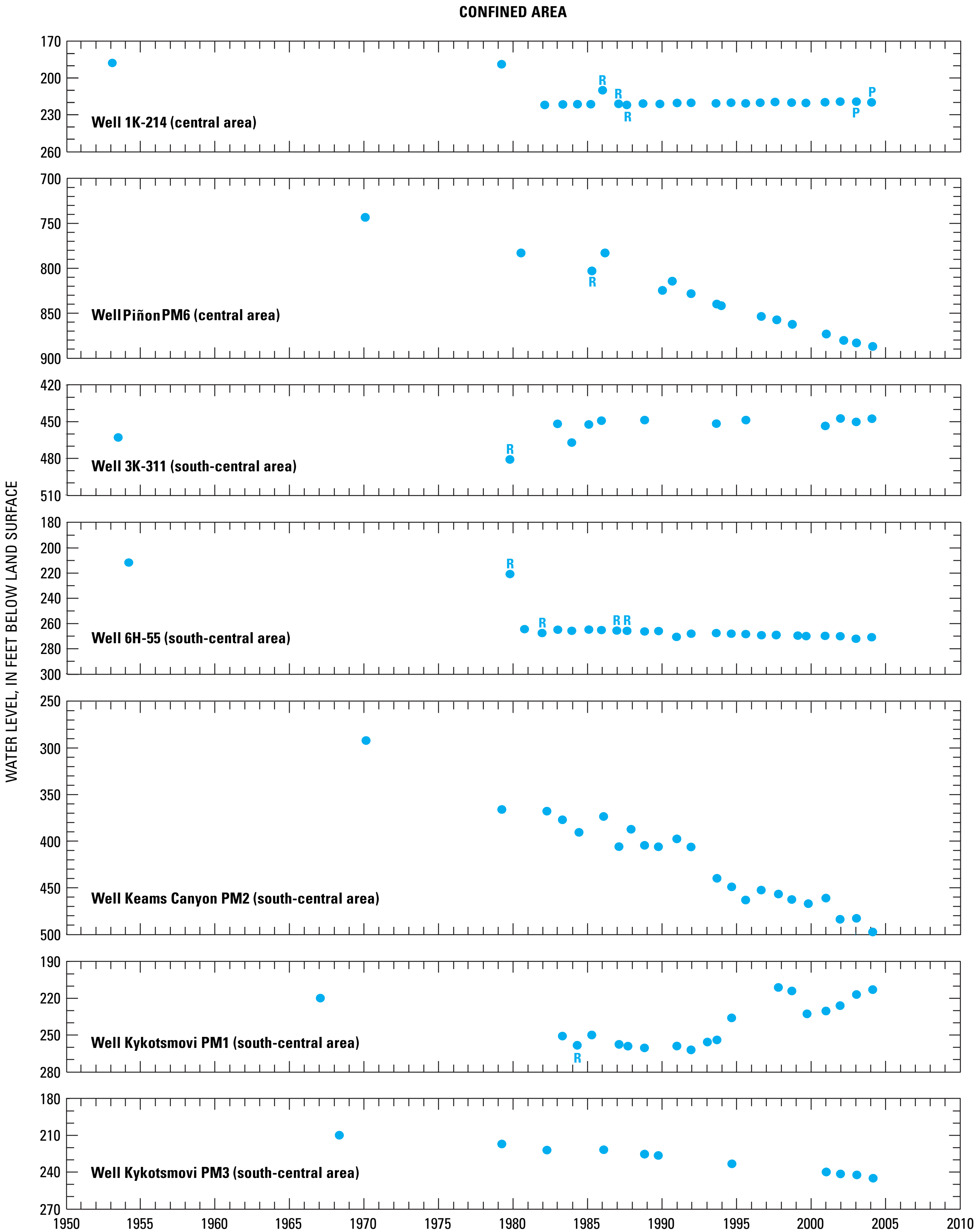

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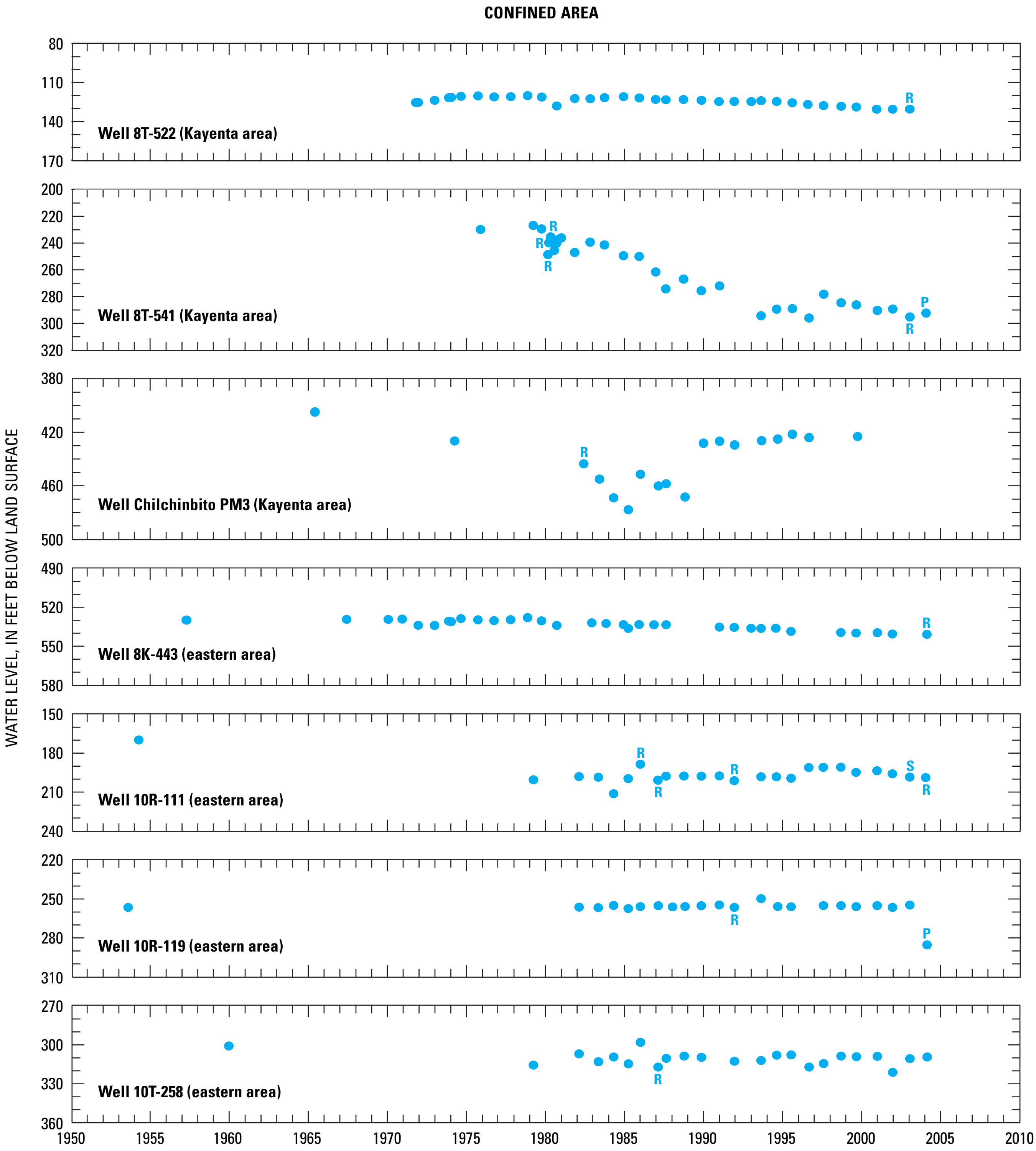

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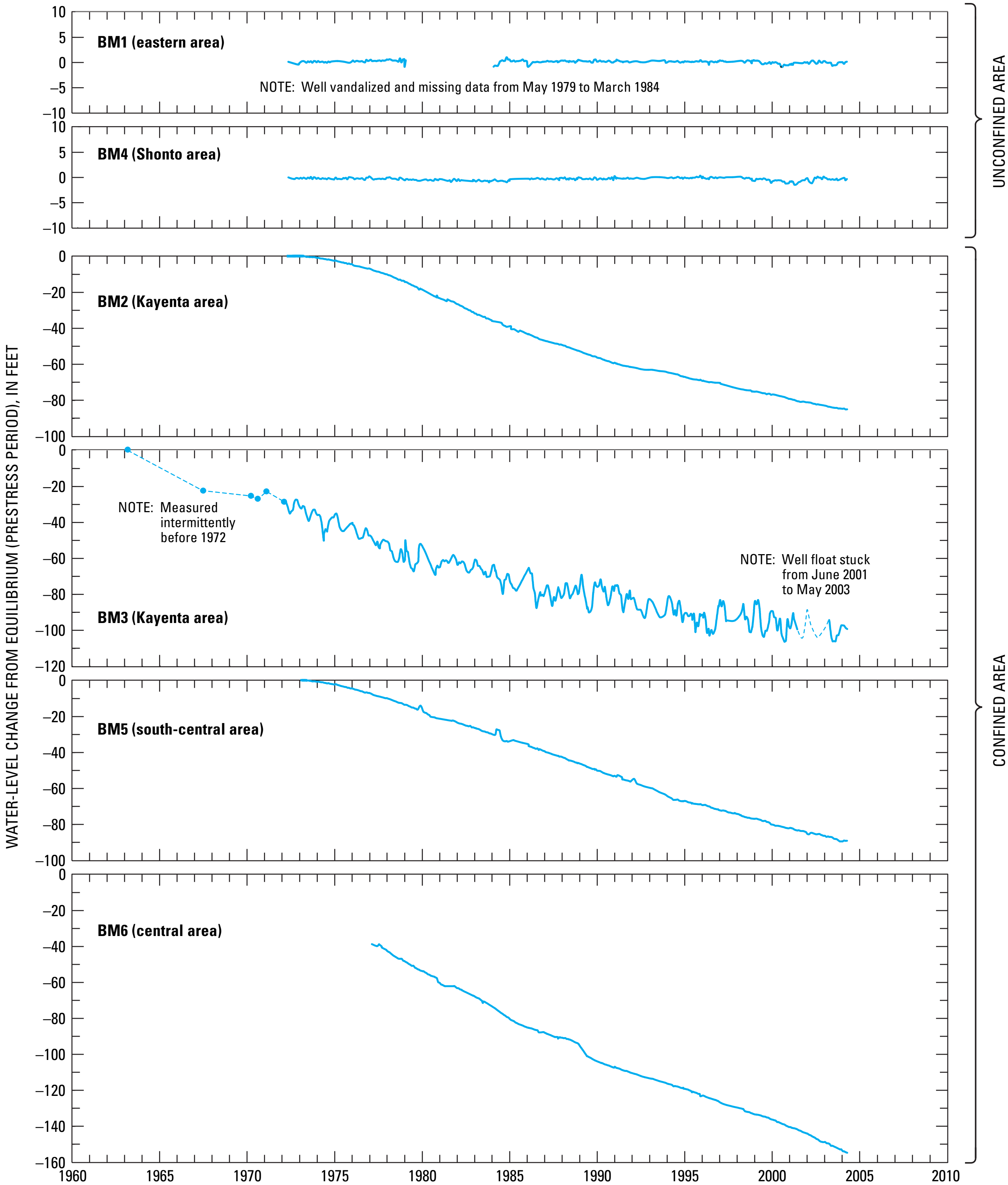

Figure 8. Observed water-level changes in continuous-record observation wells, BM1–BM6, Black Mesa area, Arizona.

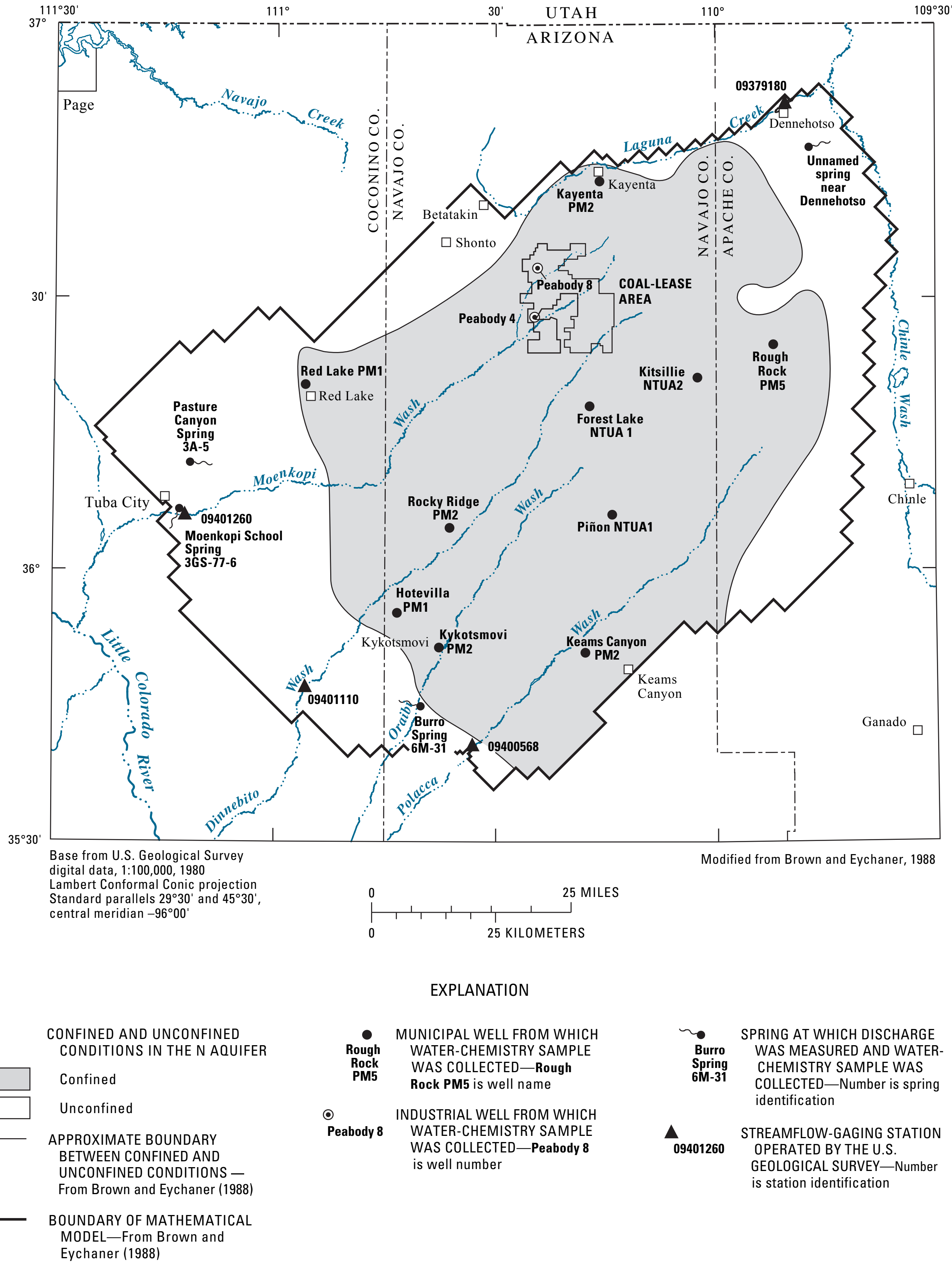

Figure 9. Surface-water and water-chemistry data-collection sites, Black Mesa area, Arizona, 2003–04.

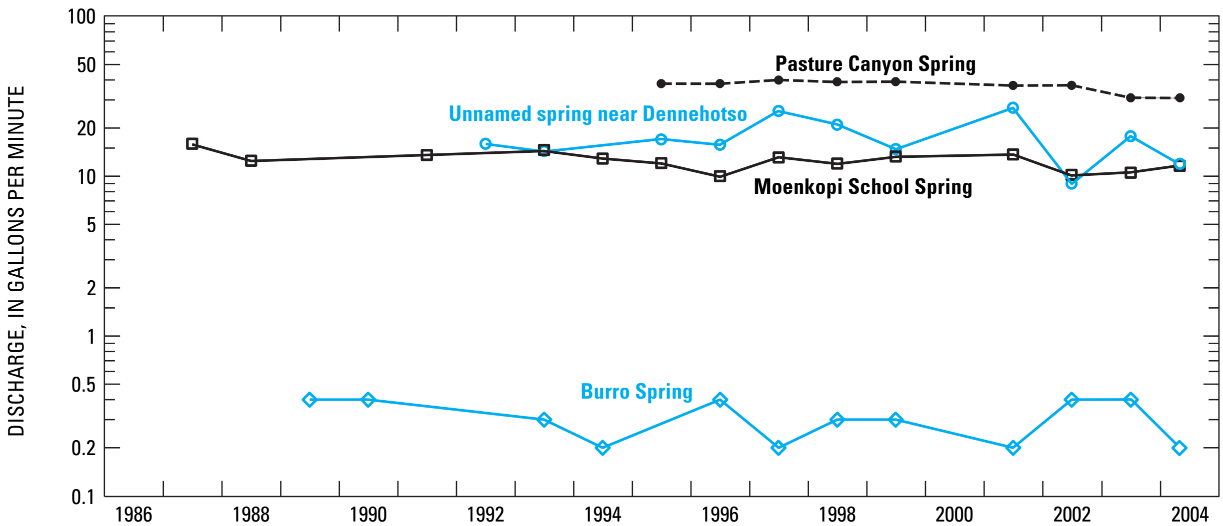

Figure 10. Discharge from selected springs, Black Mesa area, Arizona, 1987–2004. Data from earlier measurements at Moenkopi School Spring, the unnamed spring near Dennehotso, and Pasture Canyon Spring are not shown because different measuring locations were used.

Table 8. Discharge measurements of selected springs, Black Mesa area, Arizona, 1952–2004

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

Bureau of Indian Affairs site number	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]12.5
		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]12.0
		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
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
		12–31–97	25.6
		12–14–98	21.0
		12–15–99	14.8
		03–14–01	26.8
		07–15–02	9.0
		05–01–03	17.1
		04-01-04	12.6
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
		06–19–02	[7]37.0
		05–01–03	[7]30.9
		04-26-04	[7]30.6
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

[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 2003

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	9.9	4.3	3.8	2.2	2.0	0.38	0.00	0.00	0.94	0.58	3.0	81
2	9.6	4.3	3.6	2.0	2.0	.34	.00	12	.78	39	4.0	.95
3	9.2	4.6	3.5	2.0	1.7	.15	.00	e.05	.61	1,360	4.5	.96
4	9.0	4.4	3.5	2.2	1.7	.00	.00	.00	8.0	543	3.7	.94
5	8.4	4.1	3.5	2.3	1.8	.00	.00	.00	18	72	3.3	13
6	8.0	4.5	3.4	2.4	1.8	.00	.00	.00	12	e8.9	2.7	1.0
7	7.2	6.9	3.3	2.4	1.7	.00	.00	.00	62	e7.8	4.2	.99
8	8.8	5.3	3.4	2.4	1.4	.00	.00	.00	29	e6.5	3.7	1.0
9	6.0	5.7	3.3	2.4	1.4	.00	.00	.00	412	e6.0	3.8	1.2
10	5.3	6.5	3.3	2.5	1.4	.00	.00	.00	e1,800	e5.3	5.2	1.0
11	5.0	4.2	3.4	2.5	1.6	.00	.00	.00	48	e4.2	e5.4	1.1
12	4.5	4.1	3.4	2.5	1.5	.00	.00	.00	13	e3.5	e5.6	1.6
13	4.0	4.8	3.4	2.1	1.4	.00	.00	.00	5.4	e2.5	202	1.1
14	4.0	4.6	3.4	2.2	1.3	.00	.00	.00	3.3	e1.8	139	1.1
15	3.7	4.0	3.5	2.6	1.4	.00	.00	.00	2.2	e1.5	18	.94
16	3.7	3.7	4.3	2.8	1.4	.00	.00	.00	1.9	e1.8	5.5	.91
17	3.5	3.6	15	2.6	1.3	.00	.00	.00	1.1	e2.3	3.6	1.0
18	3.6	3.8	5.2	2.7	1.1	.00	.00	.00	1.1	e2.3	3.4	1.2
19	3.7	3.8	3.3	3.5	1.0	.00	.00	5.1	.87	e1.6	3.0	1.3
20	3.6	3.6	3.0	2.9	.95	.00	.00	445	.92	e1.6	3.0	1.8
21	3.3	3.7	3.0	2.0	1.0	.00	.00	18	.85	e1.3	3.0	1.5
22	3.3	3.6	2.7	1.9	.95	.00	.00	7.6	.75	e1.4	2.8	1.5
23	2.8	3.5	2.6	2.3	.94	.00	.22	37	.80	e1.4	2.7	1.5
24	2.9	3.6	2.5	2.4	.88	.00	.00	23	.79	e1.4	2.9	1.3
25	3.4	3.5	2.6	2.1	.75	.00	.00	22	.72	e1.2	3.5	1.2
26	3.8	3.6	2.5	1.7	.64	.00	.00	27	.62	e1.2	3.3	1.2
27	3.7	4.2	2.4	1.7	.63	.00	.00	12	.54	e1.6	2.7	1.2
28	4.0	4.1	2.3	1.9	.63	.00	2.6	14	.45	e1.6	3.2	1.6
29	4.0	---	2.1	1.9	.60	.00	.20	39	.55	e1.8	3.5	1.2
30	4.1	---	2.2	2.0	.54	.00	.00	6.4	.50	e2.0	4.1	1.8
31	4.3	---	2.3	---	.45	---	.00	1.3	---	e2.4	---	1.6
TOTAL	160.3	120.6	109.7	69.1	37.86	.87	3.02	669.45	2,427.69	2,089.48	458.3	129.69
MEAN	5.17	4.31	3.54	2.30	1.22	.03	.10	21.6	80.9	67.4	15.3	4.18
MAX	9.9	6.9	15	3.5	2.0	.38	2.6	445	1,800	1,360	202	81
MIN	2.8	3.5	2.1	1.7	.45	.00	.00	.00	.45	.58	2.7	.91
MED	4.0	4.1	3.3	2.3	1.3	.00	.00	.00	1.00	2.0	3.5	1.2
AC-FT	318	239	218	137	75	1.7	6.0	1,330	4,820	4140	909	257
CFSM	.00	.00	.00	.00	.00	.00	.00	.01	.05	.04	.01	.00

CAL YR 2003 TOTAL 6,276.06 MEAN 17.2 MAX 1,800 MIN 0.00 MED 2.1 AC-FT 12,450 CFSM 0.01

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

Table 10. Discharge data, Laguna Creek at Dennehotso, Arizona (09379180), calendar year 2003

[e, estimated. Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.00	e0.80	1.0	0.00	0.00	0.00	0.00	e5.0	0.37	0.00	0.00	0.14
2	.00	e.50	1.3	.00	.00	.00	.00	e30	.08	.00	.00	.17
3	e.20	e.10	1.2	.00	.00	.00	.00	e32	.06	e405	.00	.21
4	e.20	e.04	1.2	.00	.00	.00	.00	e20	.02	e92	.00	1.5
5	e.15	.01	1.0	.00	.00	.00	.00	3.9	30	e25	.00	1.7
6	e1.5	.00	.64	.00	.00	.00	.00	e.20	33	e10	.00	1.5
7	e2.0	.00	.60	.00	.00	.00	.00	e.00	e45	e2.3	.00	1.8
8	e1.0	.00	1.3	.00	.00	.00	.00	.00	e.10	.51	.00	2.8
9	e3.0	.00	.58	.00	.00	.00	.00	.45	e70	.05	.00	1.0
10	e4.0	.00	.33	.00	.00	.00	.00	.67	518	.00	.00	.43
11	e10	.00	.13	.00	.00	.00	.00	.47	e10	.00	.00	.16
12	e8.0	.00	.00	.00	.00	.00	.00	.16	.73	.00	.19	.04
13	e5.0	.00	.00	.00	.00	.00	.00	.00	.05	.00	155	.17
14	e1.3	e1.3	.00	.00	.00	.00	.00	.00	.00	.00	25	.22
15	e5.6	e5.6	.00	.00	.00	.00	.00	.00	.00	.00	7.9	.25
16	e3.7	e3.7	.00	.00	.00	.00	.00	.12	.00	.00	3.2	.01
17	e1.7	e1.8	.41	.00	.00	.00	.00	.91	.00	.00	1.8	.00
18	e.63	e.63	e14	.00	.00	.00	.00	e.05	.00	.00	1.3	.00
19	e.14	e.14	14	.00	.00	.00	.00	.00	.00	.00	1.1	.00
20	e.50	e1.0	e14	.00	.00	.00	.00	.00	.00	.00	1.0	.00
21	e1.0	e.50	e5.0	.00	.00	.00	.00	.00	.00	.00	.80	.00
22	e.50	.55	e3.0	.00	.00	.00	.00	.00	.00	.00	.84	.00
23	e.50	.19	.94	.00	.00	.00	.00	.15	.00	.00	.23	.03
24	e.40	.00	e1.1	.00	.00	.00	.00	.00	.00	.00	.07	.01
25	e.30	.33	e1.2	.00	.00	.00	.00	.00	.00	.00	.05	2.5
26	e.80	.38	e3.8	.00	.00	.00	.00	e3.0	.00	.00	.00	e3.1
27	e.50	.47	e1.8	.00	.00	.00	.00	1.7	.00	.00	.00	e2.0
28	e.80	.60	.05	.00	.00	.00	.00	.43	.00	.00	.00	.74
29	e1.0	---	.00	.00	.00	.00	e32	.08	.00	.00	.00	e.90
30	e1.1	---	e1.0	.00	.00	.00	e8.0	.02	.00	.00	.18	.56
31	e1.0	---	e.05	---	.00	---	e15	e.00	---	.00	---	.74
TOTAL	56.52	18.64	69.63	.00	.00	.00	55.00	99.31	707.41	534.86	198.66	22.68
MEAN	1.82	.67	2.25	.00	.00	.00	1.77	3.20	23.6	17.3	6.62	.73
MAX	10	5.6	14	.00	.00	.00	32	32	518	405	155	3.1
MIN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MED	1.0	.26	1.0	.00	.00	.00	.00	.12	.00	.00	.03	.22
AC-FT	112	37	138	.00	.00	.00	109	197	1,400	1,060	394	45
CFSM	.00	.00	.01	.00	.00	.00	.00	.01	.06	.04	.02	.00

CAL YR 2003 TOTAL 1,762.71 MEAN 4.83 MAX 518 MIN 0.00 MED 0.00 AC-FT 3,500 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 2003

[Dashes indicate no data. e, estimated]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.22	0.31	0.31	0.22	0.21	0.12	0.07	7.0	0.22	0.15	0.19	0.29
2	.29	.25	.40	.27	.21	.12	.07	26	.10	.49	.21	.32
3	.34	.25	.31	.22	.17	.10	.07	11	41	375	.21	.31
4	.29	.24	.30	.23	.19	.10	.07	1.5	6.7	136	.21	.31
5	.33	.25	.29	.22	.21	.11	.07	.25	6.5	24	.22	.29
6	.63	.23	.27	.25	.22	.10	.06	.15	13	3.7	.23	.37
7	.51	.27	.29	.26	.20	.10	.06	.13	74	.31	.24	.35
8	.40	.30	.29	.26	.19	.10	.06	.11	36	.26	.24	.38
9	.42	.29	.29	.27	.18	.10	.06	.10	5.4	.25	.25	.29
10	.36	.30	.29	.26	.20	.09	.07	.09	100	.25	.25	.31
11	.34	.28	.30	.27	.21	.09	.07	.09	15	.24	.25	.35
12	.28	.35	.30	.26	.22	.09	.07	.09	5.2	.22	.48	.36
13	.28	.87	.28	.23	.23	.10	.06	.09	.70	.21	112	.33
14	.28	.46	.28	.23	.23	.09	.07	.08	.20	.20	35	.34
15	.28	.39	.30	.25	.22	.09	.06	.10	.18	.21	3.9	.28
16	.25	.32	.53	.27	.22	.09	.06	.18	.16	.21	.40	.24
17	.25	.30	.46	.24	.21	.09	.06	.13	.13	.21	.28	.28
18	.28	.33	.32	.25	.18	.09	.06	.10	.13	.22	.27	.30
19	.27	.30	.29	.37	.18	.09	.06	4.2	.14	.23	.27	.32
20	.29	.30	.29	.32	.18	.07	.06	196	.14	.22	.28	.37
21	.29	.28	.27	.25	.18	.07	.06	7.7	.13	.23	.27	.39
22	.28	.26	.27	.22	.18	.08	.06	1.1	.14	.23	.23	.35
23	.27	.24	.27	.24	.18	.07	62	10	.14	.23	.19	.35
24	.29	.29	.26	.25	.17	.06	2.5	.73	.17	.21	.26	.37
25	.29	.30	.30	.23	.16	.07	1.7	.25	.16	.18	.30	.40
26	.28	.33	.27	.21	.15	.08	7.8	19	.14	.18	.26	1.7
27	.29	.34	.24	.20	.15	.08	14	12	.14	.20	.23	.23
28	.29	.37	.22	.19	.14	.08	25	5.7	.14	.22	.23	.27
29	.29	---	.23	.18	.14	.08	27	1.5	.14	.22	.25	.29
30	.29	---	.25	.18	.13	.07	24	7.7	.13	.18	.27	e.35
31	.30	---	.25	---	.12	---	14	1.4	---	.17	---	.32
TOTAL	9.75	9.00	9.22	7.30	5.76	2.67	179.41	314.47	306.33	544.83	157.87	11.41
MEAN	.31	.32	.30	.24	.19	.09	5.79	1.1	1.2	17.6	5.26	.37
MAX	.63	.87	.53	.37	.23	.12	62	196	100	375	112	1.7
MIN	.22	.23	.22	.18	.12	.06	.06	.08	.10	.15	.19	.23
MED	.29	.30	.29	.24	.18	.09	.07	.73	.17	.22	.25	.32
AC-FT	19	18	18	14	11	5.3	356	624	608	1,080	313	23
CFSM	.00	.00	.00	.00	.00	.00	.01	.02	.02	.04	.01	.00

CAL YR 2003 TOTAL 1,558.02 MEAN 4.27 MAX 375 MIN 0.06 MED 0.25 AC-FT 3,090 CFSM 0.01

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

Table 12. Discharge data, Polacca Wash near Second Mesa, Arizona (09400568), calendar year 2003

[Dashes indicate no data]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.10	0.11	0.18	0.22	0.09	0.02	0.00	2.3	0.09	0.02	0.05	0.07
2	.07	.10	.19	.20	.09	.02	.00	139	1.2	.06	.05	.07
3	.07	.08	.19	.17	.07	.01	.00	34	17	99	.05	.09
4	.09	.08	.18	.20	.05	.01	.00	2.2	.62	148	.04	.09
5	.10	.08	.16	.19	.08	.00	.00	.33	45	54	.05	.09
6	.14	.07	.16	.18	.11	.00	.00	.06	32	3.0	.05	.10
7	.11	.09	.16	.17	.09	.00	.00	.03	101	.28	.05	.10
8	.11	.08	.16	.17	.07	.00	.00	.03	55	.04	.05	.13
9	.11	.09	.16	.18	.06	.00	.00	60	16	.03	.05	.09
10	.11	.08	.17	.18	.06	.00	.00	4.7	6.5	.03	.05	.10
11	.11	.08	.19	.16	.09	.00	.00	1.5	2.2	.03	.05	.11
12	.09	.13	.20	.17	.09	.00	.00	.10	.44	2.3	.10	.11
13	.09	.32	.20	.16	.08	.00	.00	.02	.04	.24	.11	.10
14	.09	.18	.19	.15	.09	.00	.00	.02	.02	.06	9.2	.11
15	.09	.13	.21	.16	.11	.00	.00	20	.03	.05	2.4	.09
16	.09	.11	.33	.15	.09	.00	.00	3.5	.02	.05	.39	.07
17	.08	.11	.35	.15	.08	.00	.00	15	.02	.03	.25	.08
18	.08	.12	.30	.14	.04	.00	.00	5.3	.02	.03	.20	.10
19	.08	.11	.30	.22	.04	.00	.00	1.1	.02	.03	.14	.11
20	.09	.11	.30	.18	.05	.00	.00	.10	.02	.03	.12	.13
21	.10	.10	.29	.16	.06	.00	.00	2.9	.02	.03	.10	.15
22	.09	.09	.24	.15	.04	.00	.00	29	.02	.03	.10	.12
23	.10	.09	.24	.14	.05	.00	.00	93	.02	.03	.10	.12
24	.11	.12	.25	.16	.04	.00	17	320	.03	.03	.09	.14
25	.11	.14	.28	.14	.04	.00	1.3	242	.03	.03	.08	.15
26	.10	.18	.25	.11	.04	.00	.02	17	.02	.03	.07	.21
27	.10	.18	.22	.10	.03	.00	.00	7.7	.02	.03	.06	.12
28	.11	.22	.20	.09	.03	.00	36	2.4	.02	.03	.06	.08
29	.10	---	.20	.09	.03	.00	143	.27	.02	.04	.08	.09
30	.10	---	.21	.07	.03	.00	17	1.3	.02	.04	.08	.17
31	.11	---	.22	---	.02	---	4.9	.41	---	.04	---	.14
TOTAL	3.03	3.38	6.88	4.71	1.94	.06	219.22	1,005.27	277.46	307.67	14.27	3.43
MEAN	.10	.12	.22	.16	.06	.00	7.07	32.4	9.25	9.92	.48	.11
MAX	.14	.32	.35	.22	.11	.02	143	320	101	148	9.2	.21
MIN	.07	.07	.16	.07	.02	.00	.00	.02	.02	.02	.04	.07
MED	.10	.11	.20	.16	.06	.00	.00	2.4	.03	.03	.08	.10
AC-FT	6.0	6.7	14	9.3	3.8	.1	435	1,990	550	610	28	6.8
CFSM	.00	.00	.00	.00	.00	.00	.01	.04	.01	.01	.00	.00

CAL YR 2003 TOTAL 1,847.32 MEAN 5.06 MAX 320 MIN 0.00 MED 0.09 AC-FT 3,660 CFSM 0.01

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

Table 13. Date that data collection began and drainage areas for streamflow-gaging stations, Black Mesa area, Arizona

Station name	Station number	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

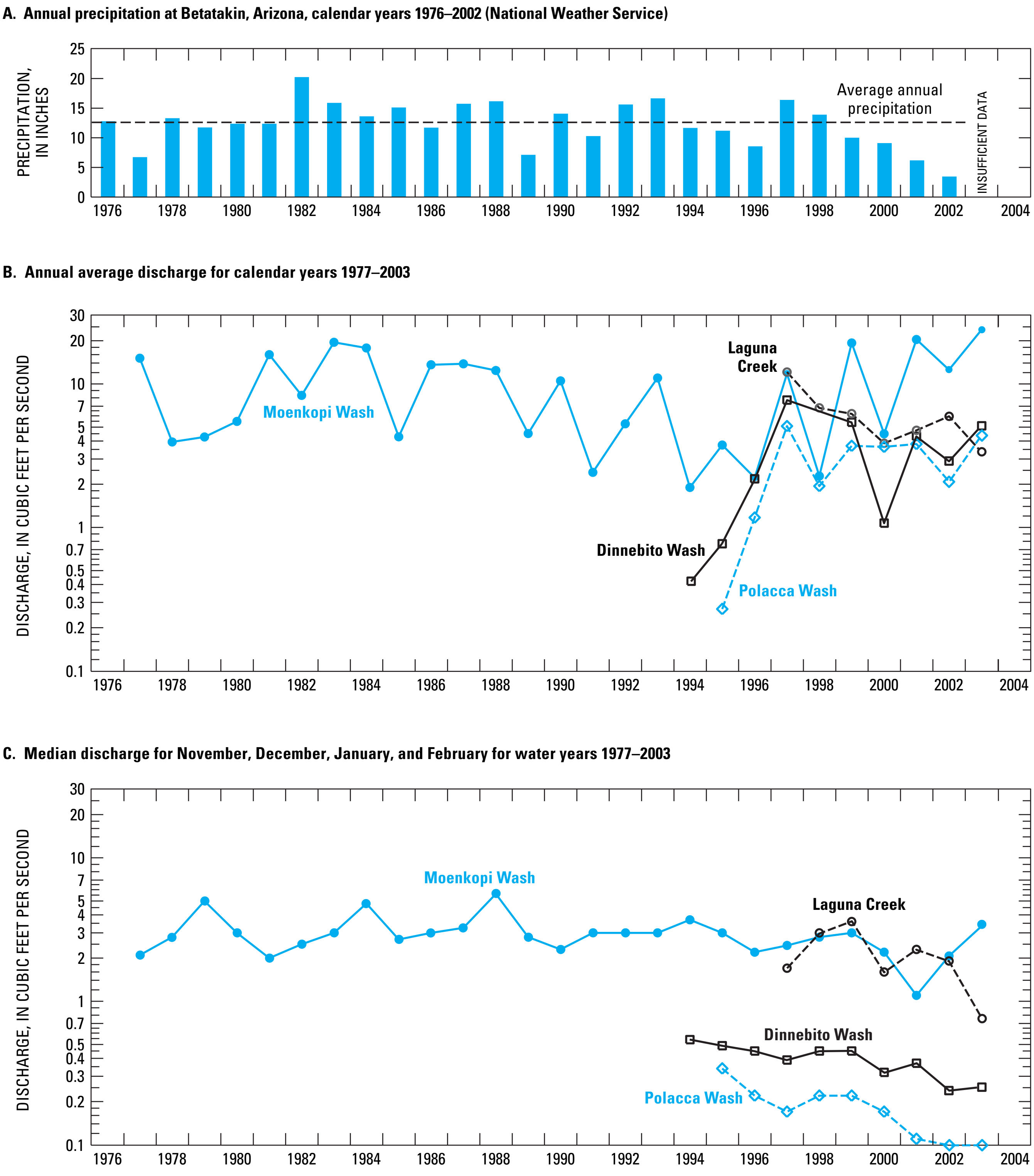

Figure 11. Annual precipitation at Betatakin, Arizona, and streamflow characteristics at Moenkopi Wash (09401260), Laguna Creek (09379180), Dinnebito Wash (09401110), and Polacca Wash (09400568), Black Mesa area, Arizona. ***A***, Annual precipitation at Betatakin, Arizona, calendar years 1976–2002 (National Weather Service); ***B***, Annual discharge for calendar years 1977–2003; ***C***, Median discharge for November, December, January, and February for water years 1977–2003.

Also, evapotranspiration from streams is at a minimum during the winter. During the summer, much of the flow in streams evaporates or is transpired by plants. 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 include 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 2003 water year; thus, daily mean flows for November and December 2002 (Truini and Thomas, 2004) were combined with daily mean flows for January and February 2003. These median winter flows were 3.45 ft^3/s for Moenkopi Wash, 0.75 ft^3/s for Laguna Creek, 0.25 ft^3/s for Dinnebito Wash, and 0.10 ft^3/s for Polacca Wash (fig. 11*C*). Since 1995, the median flows for Moenkopi Wash, Dinnebito Wash, and Polacca Wash have generally decreased; however, in 2003 flows for Moenkopi Wash and Dinnebito Wash increased, and flow for Polacca Wash remained constant (fig. 11*C*). Median flows for Laguna Creek are only available since 1997, and there is no consistent trend in these flows. Annual precipitation at Betatakin, about 15 miles west of Kayenta, has been less than average for 6 of the 9 years since 1995 (fig. 11*A*). Precipitation data for 2003 are incomplete.

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 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. 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 2004, water samples were collected from 12 wells completed in the N aquifer (**fig. 9**). Sample analyses indicated primarily sodium bicarbonate water except for samples from Kayenta PM2 and Red Lake PM1, which are on the western edge of the confined part of the aquifer.

Rough Rock PM5 yielded an appreciably higher dissolved-solids concentration (649 mg/L) than did the other 11 sites (**fig. 12** and **table 14**). Concentrations of dissolved solids in samples from the other 11 wells ranged from 100 at Red Lake PM1 to 429 mg/L at Keams Canyon PM 2 (fig. 12 and table 14). There is no apparent areal trend in dissolved solids concentrations.

There are no appreciable long-term trends in the chemistry of water samples from 7 wells having more than 10 years of data (**table 15** and **fig. 13**). In the 7 wells, there are small year-to-year variations in concentrations of dissolved solids, chloride, and sulfate; however, increasing or decreasing trends are not apparent. The chemistry of water samples from the Forest Lake NTUA 1 well has varied considerably between 1982 and 2004 (table 15 and fig. 13). This variation may be from inconsistent purging volumes of this deep well (2,674 ft) that has multiple screens throughout an interval of about 800 ft.

Constituents analyzed from the 12 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 12 wells sampled in 2004 were less than MCLs and SMCLs (table 14). The pH, however, exceeded the SMCL maximum pH of 8.5 units in samples from 9 of the 12 wells. The dissolved-solids SMCL of 500 mg/L was exceeded in the sample from Rough Rock PM5 (649 mg/L). Samples from two wells, Keams Canyon PM3 (41 μg/L) and Rough Rock PM5 (48 μg/L), had arsenic concentrations that exceeded the MCL of 10 μg/L (**http://www.epa.gov/safewater/mcl.html#mcls**).

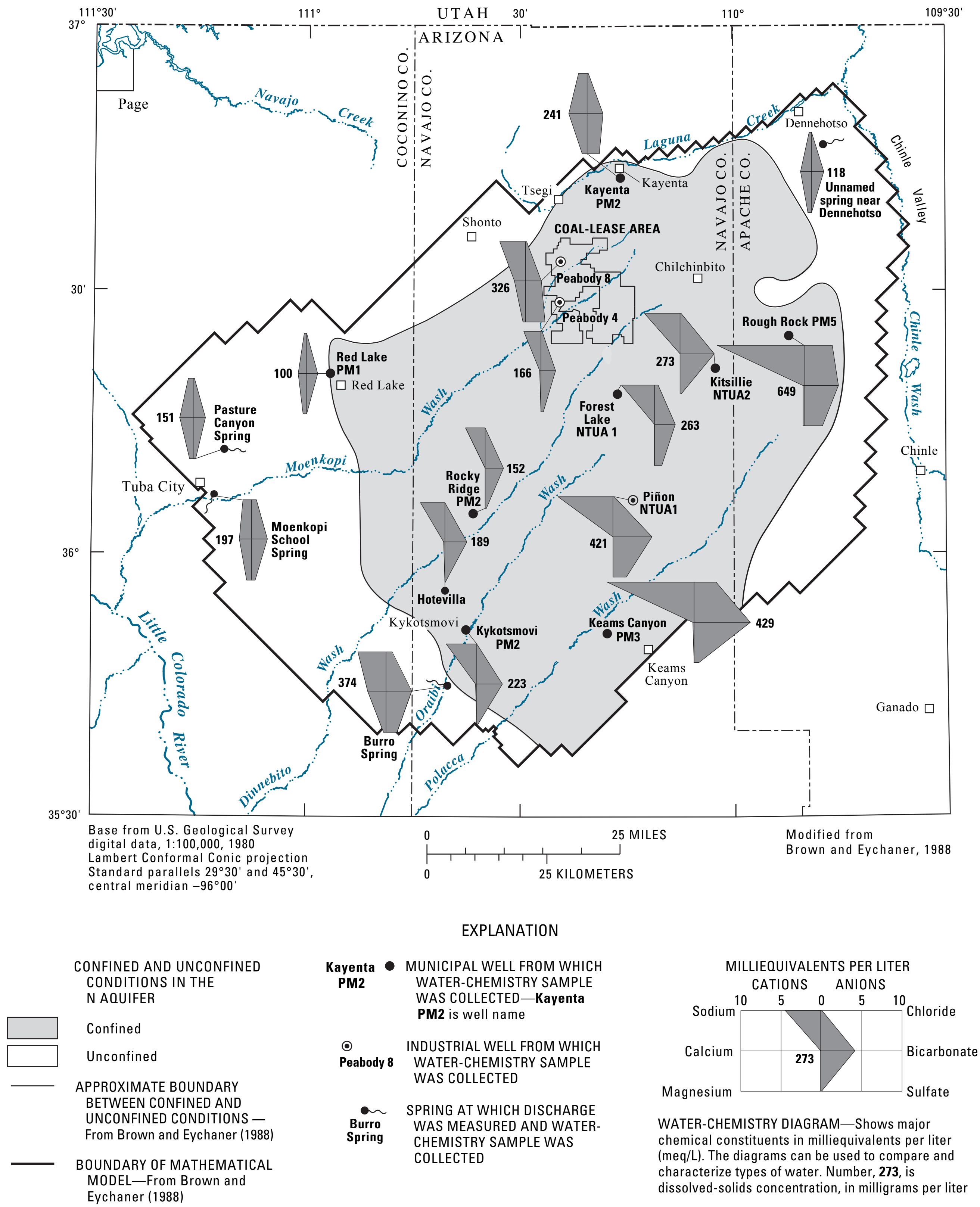

Figure 12. Water chemistry and distribution of dissolved solids in the N aquifer, Black Mesa area, Arizona, 2004.

Table 14. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 2004

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

Common well name	U.S. Geological Survey identification number	Date of sample	Temperature, field (°C)	Specific conductance, field (µS/cm)	pH, field (units)
Forest Lake NTUA1	361737110180301	04–07–04	28.4	222	9.3
Hotevilla PM 1	355518110400301	04–05–04	24.3	258	9.6
Kayenta PM 2	364344110151201	03–30–04	16	303	8.0
Keams Canyon PM 2	355023110182701	04–05–04	19.5	945	9.1
Kitsillie NTUA 2	362043110030501	05–11–04	28.7	367	9.7
Kykotsmovi PM 2	355215110375001	04–06–04	22	261	9.8
Peabody 4	362647110243501	03–31–04	31.5	118	9.1
Peabody 8	363130110254501	03–31–04	29.3	402	8.1
Piñon NTUA 1	360527110122501	04–08–04	25.9	691	9.9
Rough Rock PM5	362418109514601	03–30–04	21.5	653	8.8
Red Lake PM 1	361933110565001	03–29–04	17.1	131	8.3
Rocky Ridge PM 2	360418110352701	04–07–04	26.5	170	9.4

Common well name	Alkalinity, field, dissolved (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Forest Lake NTUA1	130	0.59	<.02	0.84	0.08
Hotevilla PM 1	143	1.1	[1].02	.68	.02
Kayenta PM 2	105	.99	<.02	45	7.0
Keams Canyon PM 2	354	<.06	<.02	.84	.16
Kitsillie NTUA 2	211	1.4	[1].01	.53	.01
Kykotsmovi PM 2	168	1.2	.03	.52	.02
Peabody 4	92	1.03	<.02	4.6	.03
Peabody 8	102	1.7	<.02	26	3.9
Piñon NTUA1	248	1.3	[1].02	1.2	.19
Rough Rock PM 5	226	1.3	[1].01	2.2	.3
Red Lake PM 1	72.4	1.35	<.2	19	5.61
Rocky Ridge PM 2	116	1.31	.02	.43	.012

See footnote at end of table.

Table 14. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 2004—Continued

Common well name	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)
Forest Lake NTUA1	96	0.62	16	40.5	0.4
Hotevilla PM 1	70.1	.47	1.4	5.4	<.2
Kayenta PM2	25	1.4	4.0	72	<.2
Keams Canyon PM 2	246	.82	96.7	32	1.4
Kitsillie NTUA 2	100	.57	4.0	4.6	.2
Kykotsmovi PM 2	86	.44	3.5	8.3	.2
Peabody 4	48	.85	4.5	12.2	.2
Peabody 8	73	3.1	4.9	116	<.2
Piñon NTUA 1	158	.56	7.0	76	.3
Rough Rock PM 5	245	1.6	128	109	1.7
Red Lake PM 1	134	2.21	1.84	2.1	<.2
Rocky Ridge PM 2	24	.39	1.45	5.8	<.2

Common well name	Silica, dissolved (mg/L as SiO_2)	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	21	2.3	116	72	263
Hotevilla PM 1	23	2.6	23	<6	189
Kayenta PM 2	16	1.5	22	25	241
Keams Canyon PM 2	13	41	636	<6	429
Kitsillie NTUA 2	25	3.6	50	<6	273
Kykotsmovi PM 2	24	4.0	29	<6	223
Peabody 4	22	3.1	27	<6	166
Peabody 8	20	1.9	46	[1]4	326
Piñon NTUA1	26	3.7	81	9	421
Rough Rock PM 5	12	48	408	17	649
Red Lake PM 1	11	.5	23	<6	100
Rocky Ridge PM 2	20	2.3	19	<6	152

[1]Estimated value.

Table 15. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 1974–2004

[μS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams 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
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
		Hotevilla PM1		
1990	290	192	1.6	5.0
1991	[1]304	208	0.7	5.4
1993	305	180	1.2	5.5
1994	[1]307	166	1.4	4.8
1995	282	196	1.4	3.7
1996	328	186	1.3	5.3
1997	[1]307	185	1.5	5.2
2001	267	170	1.4	5.2
2002	287	182	1.3	4.8
2003	303	189	1.5	5.1
2004	258	189	1.4	5.4
		Peabody 4		
1974	200	140	3.8	13
1975	220	144	3.4	13
1976	240	138	2.9	19
1979	220	--	3.9	19
1980	230	139	4.3	13
1986	205	--	4.2	12
1987	194	135	[3]5.0	13
1992	224	125	4.3	12
1993	214	124	[3]3.0	12
1996	214	140	3.8	12
1997	[1]203	139	3.5	12
1999	216	142	4.0	13
2001	181	138	4.0	13
2002	214	133	3.9	13
2003	221	144	3.5	13
2004	[4]198	166	4.5	12

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)
		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	1,030	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	34
1996	1,030	596	96	34
1997	1,070	590	96	33
1998	908	558	78	29
1999	1,040	595	97	35
2004	945	429	97	32
		Kitsillie NTUA 2		
1997	[1]524	269	3.6	4.3
1998	379	270	3.8	4.1
1999	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
		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
		Rocky Ridge PM 2		
1986	247	164	2.4	6.4
1998	215	140	1.4	<.10
1999	241	154	1.4	5.3
2004	170	152	1.4	5.8

See footnotes at end of table.

Table 15. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the N aquifer, Black Mesa area, Arizona, 1974–2004—Continued

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)
		Peabody 8		
1986	453	--	4.9	110
1988	812	516	7.2	250
1990	456	287	4.3	110
1991	452	280	6.1	110
2003	460	316	4.5	118
2004	402	326	4.9	116
		Piñon NTUA 1		
1998	460	304	4.6	4.7
2001	473	304	4.9	5.5
2002	512	--	5.0	5.5
2003	716	421	6.7	83
2004	691	421	7.0	76
		Rough Rock PM5		
1983	1,090	(2)	130	110
1984	[1]1,100	613	130	99
1986	1,010	633	140	120
1988	1,120	624	130	[3]110
1991	[1]1,210	574	130	110
1993	1,040	614	130	110
1994	[1]1,070	626	130	110
1995	1,110	648	140	110
1996	1,100	634	130	110
1997	[1]1,060	628	130	110
1998	894	637	130	110
1999	1,050	630	130	110
2001	980	628	120	110
2002	1,120	636	130	110
2003	1,080	642	127	110
2004	653	649	128	109
		Red Lake PM 1		
1992	164	87	2.6	1.9
1993	156	84	1.6	2.1
1995	157	92	1.6	2.0
1997	[1]156	96	3.2	1.7
1999	153	91	1.6	2.1
2001	132	102	1.8	2.2
2004	131	100	1.8	2.1
		Kayenta PM2		
1982	360	(2)	4.5	58
1983	375	(2)	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

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

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

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

[4]Estimated lab value listed owing to questionable field measurement.

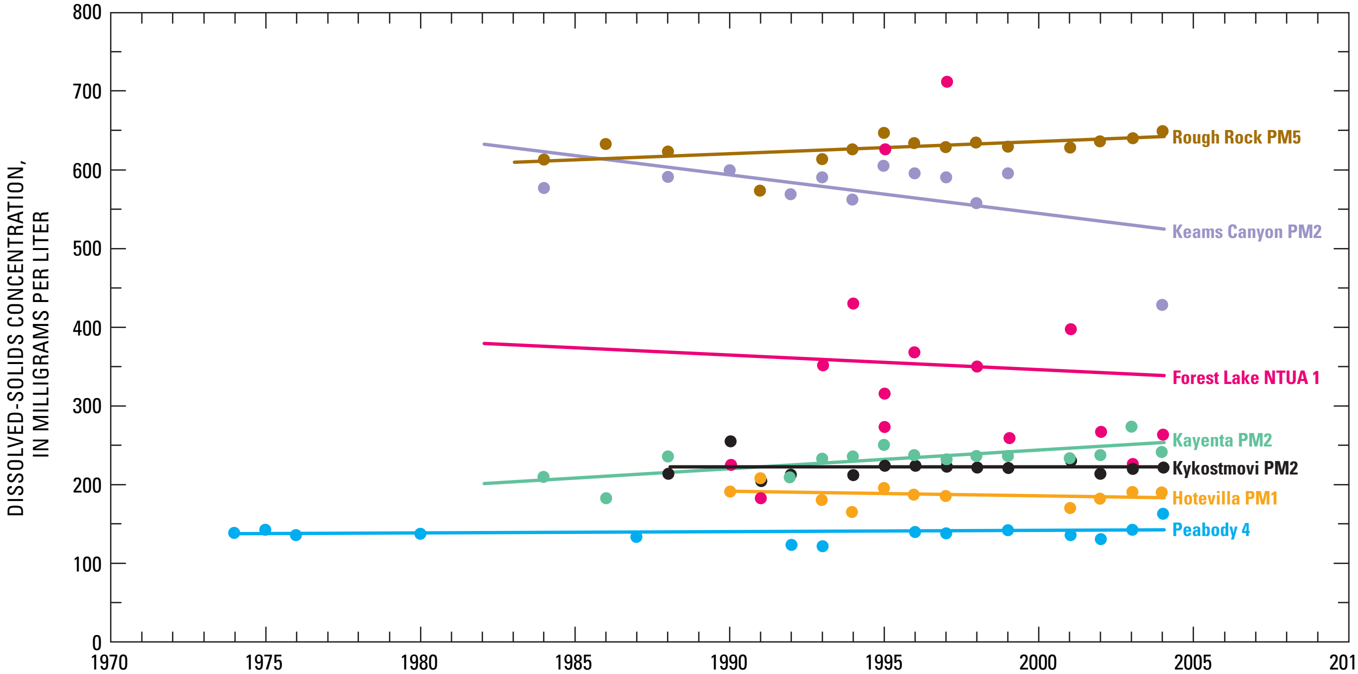

Figure 13. Dissolved-solids concentrations with linear trend lines for water from selected wells, Black Mesa area, Arizona, 1974–2004.

Water Chemistry from Springs that Discharge from the N Aquifer

In 2004, 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 parts 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.

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 117 to 196 mg/L (table 16). The sample from Burro Spring had a dissolved-solids concentration of 337 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 17 and fig. 14). There may be an increasing trend in concentrations of dissolved solids and chloride at Burro Spring and Moenkopi School Spring (figs. 14 and 15; table 17).

Table 16. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 2004

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

Spring name	Bureau of Indian Affairs site number	U.S. Geological Survey identification number	Date of sample	Temperature (°C)	Specific conductance, field (µS/cm)	pH, field (units)
Burro Spring	6M-31	354156110413701	04–06–04	21.5	558	8.3
Unnamed spring near Dennehotso	8A-224	364656109425400	04–01–04	12.7	170	8.2
Moenkopi School Spring	3GS-77-6	360632111131101	05–01–03	16.9	349	7.6
Pasture Canyon Spring	3A-5	361021111115901	04–26–04	16.6	248	7.9

Spring name	Alkalinity, field, dissolved (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
Burro Spring	188	0.15	<0.2	130	---	47
Unnamed spring near Dennehotso	78	1.5	.03	82	---	26
Moenkopi School Spring	102	2.4	<.02	110	---	32
Pasture Canyon Spring	72	4.6	e.02	99	---	32

Spring name	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)
Burro Spring	4.7	3.3	0.51	25	64	0.4
Unnamed spring near Dennehotso	4.2	4.8	1.2	2.7	5.0	<.2
Moenkopi School Spring	6.9	26	1.5	19	21	.2
Pasture Canyon Spring	4.3	13	1.5	5.5	16	<.2

Spring name	Silica, dissolved (mg/L as SiO_2)	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	14	0.8	78	<6	337
Unnamed spring near Dennehotso	12	3.1	16	<6	117
Moenkopi School Spring	14	2.5	37	<6	196
Pasture Canyon Spring	10	1.5	35	22	150

Table 17. Specific conductance and concentrations of selected chemical constituents in water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 1948–2004

[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
		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
		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

See footnotes at end of table.

Table 17. Specific conductance and concentrations of selected chemical constituents in water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 1948–2004—Continued

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)
		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

[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.

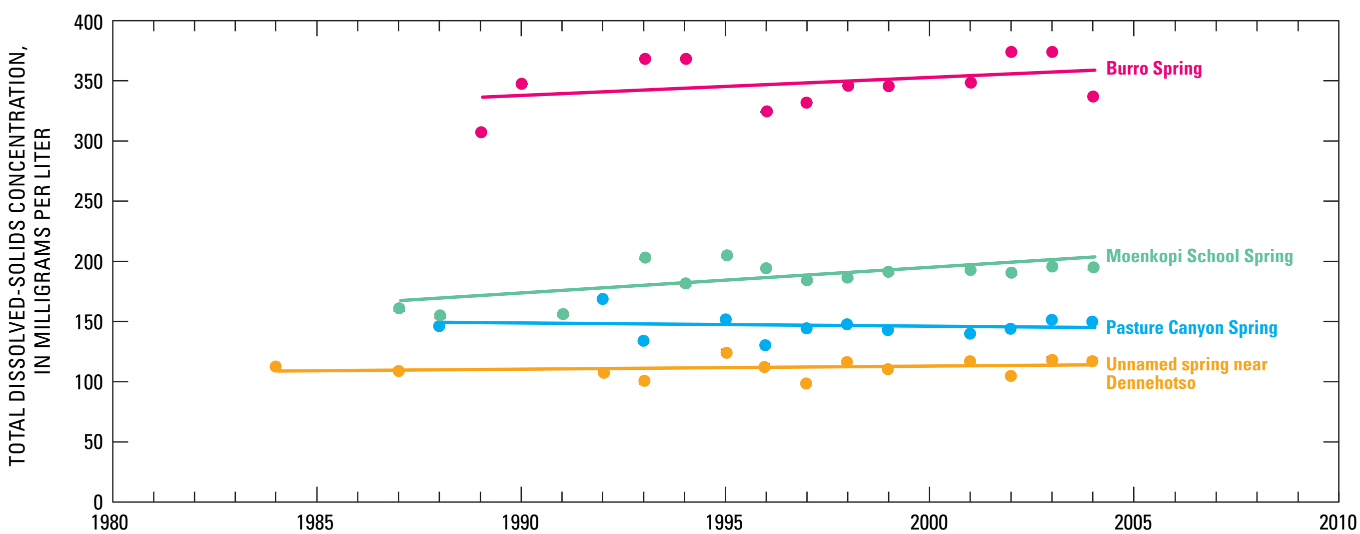

Figure 14. Dissolved-solids concentrations with linear trend lines for water from selected springs, Black Mesa area, Arizona, 1984–2004.

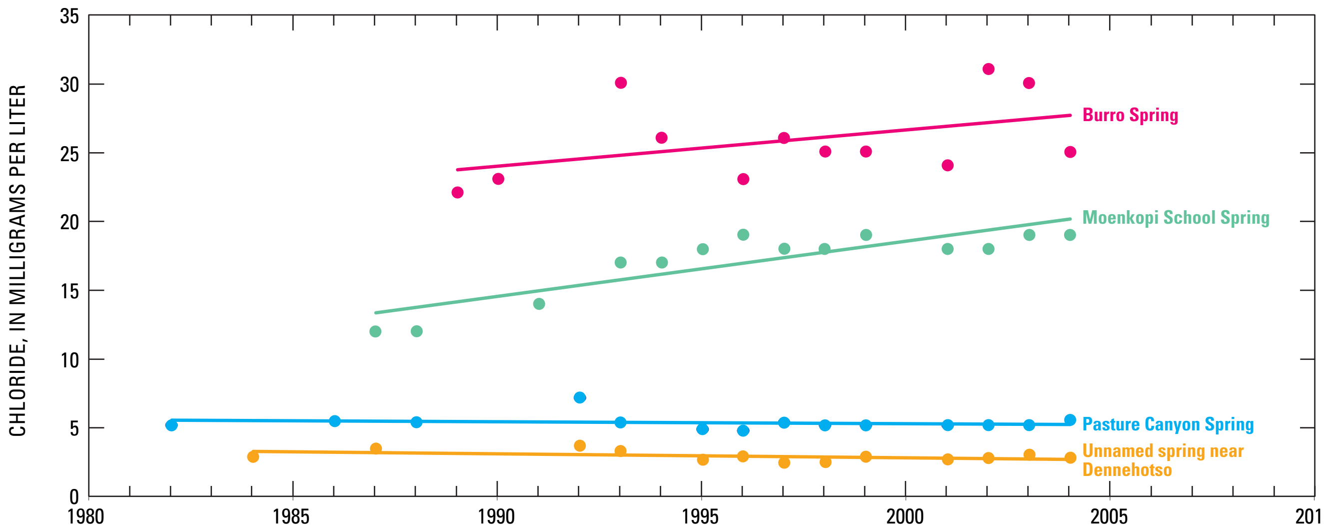

Figure 15. Chloride concentrations with linear trend lines for water from selected springs, Black Mesa area, Arizona, 1982–2004.

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 2003 to September 2004. The monitoring data for 2003–04 are compared with data for 2002–03 and with historical data from the 1950s to the present.

In 2003, total ground-water withdrawals were 7,240 acre-ft, industrial withdrawals were 4,450 acre-ft, and municipal withdrawals were 2,790 acre-ft. From 2002 to 2003, total withdrawals decreased by 10 percent, municipal withdrawals decreased by 20 percent, and industrial withdrawals decreased by 4 percent. Flowmeter testing was completed for 24 municipal wells in June 2004. The median difference between pumping rates for the permanent meter and a test meter for all the sites tested was -2.9 percent. Differences ranged from -10.9 percent at Forest Lake NTUA 1 to +7.8 percent at Rough Rock NTUA 2.

From 2003 to 2004, ground-water levels declined in 13 of 23 wells. The median water-level change for the 23 wells was -0.2 ft. In unconfined areas, water levels declined in 6 of 12 wells, and the median change was -0.1 ft. In the confined area, water levels declined in 7 of 11 wells, and the median change was -2.7 ft.

For wells in the confined area, 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 2004. For wells in unconfined areas, the annual median water-level change was +0.2 ft, and there is no appreciable trend from 1983 to 2004.

From the prestress period (prior to 1965) to 2004, the median water-level change in 26 wells was -23.2 ft. Water levels in the 14 wells in the unconfined parts of the aquifer had a median change of -6.1 ft, and the changes ranged from -55.6 ft to +6.2 ft. Water levels in the 12 wells in the confined part of the aquifer had a median change of -72.1 ft, and the changes ranged from -205.1 ft to +15.3 ft.

Discharges were measured annually at four springs in 2003 and 2004. Between 2003 and 2004, spring flow decreased 50 percent at Burro Spring, decreased 26 percent at the unnamed spring near Dennehotso, increased 9 percent at Moenkopi School Spring, and stayed the same 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 consistent trend in the median winter flow in Laguna Creek.

In 2004, water samples were collected from 12 wells and analyzed for selected chemical constituents. Dissolved-solids concentrations ranged from 100 to 649 mg/L, and samples from 11 of the wells had dissolved-solids concentrations less than 500 mg/L. There are no appreciable 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 (500 mg/L), and samples from 9 of the 12 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 117 to 196 mg/L, and the dissolved-solids concentration in the water sample from Burro Spring was 337 mg/L. From the mid-1980s to 2004, 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. There may be an increasing trend in concentrations of dissolved solids and chloride at Burro Spring and Moenkopi School Spring.

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