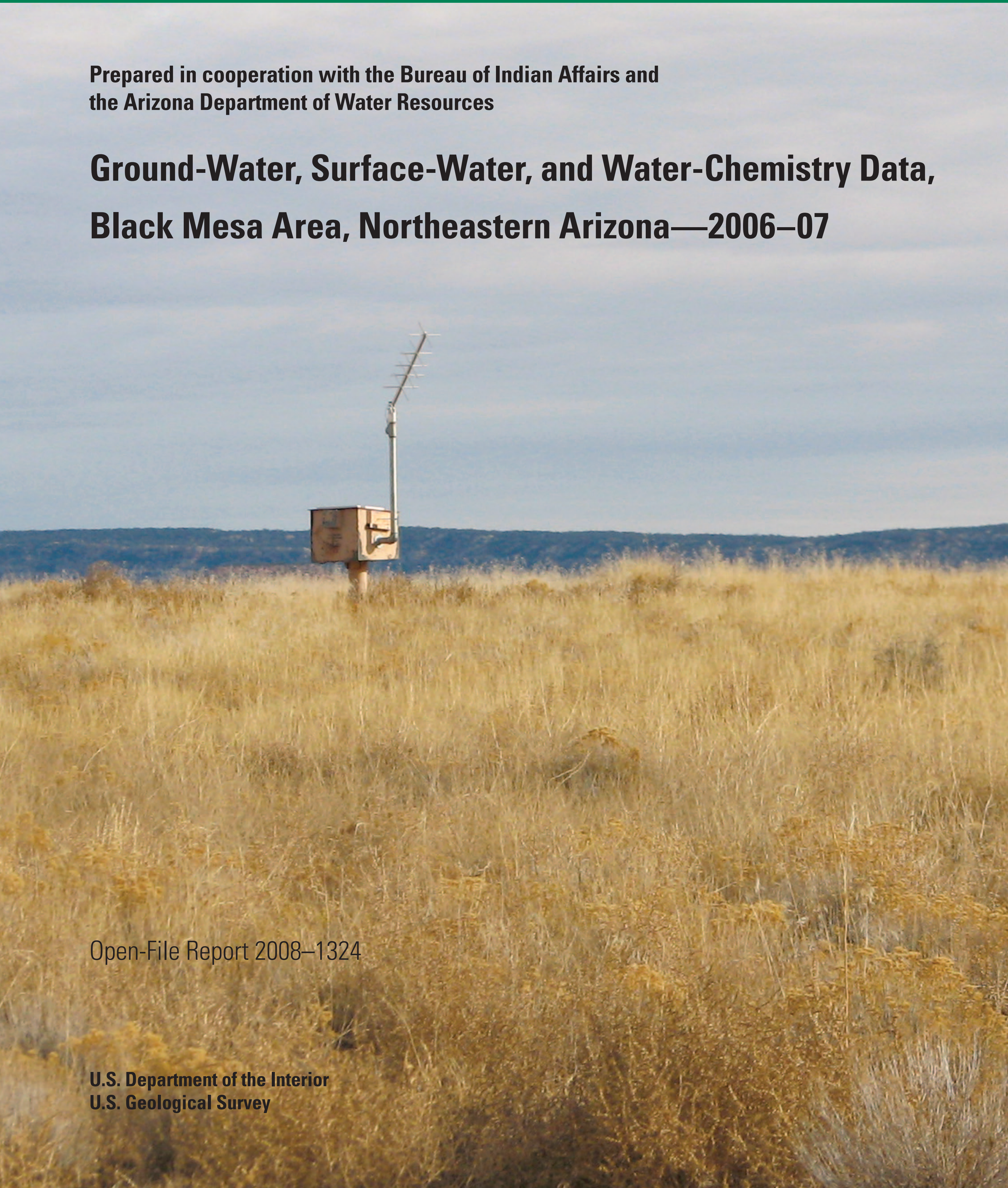
Prepared in cooperation with the Bureau of Indian Affairs and the Arizona Department of Water Resources

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2006–07



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By Margot Truini and J.P. Macy

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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FRONT COVER—Photograph of Black Mesa observation well number 1. Photo taken by Margot Truini.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi2)	2.590	square kilometer (km2)
Volume		
acre-foot (acre-ft)	0.001233	cubic hectometer (hm3)
	Flow rate	
cubic foot per second (ft3/s)	0.02832	cubic meter per second (m3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

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).

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—2006–07

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 is typically 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 2006 to September 2007. The monitoring program includes measurements of (1) ground-water withdrawals, (2) ground-water levels, (3) spring discharge, (4) surface-water discharge, and (5) ground-water chemistry. Periodic testing of ground-water withdrawal meters is completed every 4 to 5 years.

The Navajo Tribal Utility Authority (NTUA) yearly totals for the ground-water metered withdrawal data were unavailable in 2006 due to an up-grade within the NTUA computer network. Because NTUA data is often combined with Bureau of Indian Affairs data for the total withdrawals in a well system, withdrawals will not be published in this year's annual report.

From 2006 to 2007, annually measured water levels in the Black Mesa area declined in 3 of 11 wells measured in the unconfined areas of the N aquifer, and the median change was 0.0 feet. Measurements indicated that water levels declined in 8 of 17 wells measured in the confined area of the aquifer. The median change for the confined area of the aquifer was 0.2 feet. From the prestress period (prior to 1965) to 2007, the median water-level change for 30 wells was –11.1 feet. Median water-level changes were 2.9 feet for 11 wells measured in the unconfined areas and –40.2 feet for 19 wells measured in the confined area.

Spring flow was measured once in 2006 and once in 2007 at Moenkopi School Spring. Flow decreased by 18.9 percent at Moenkopi School Spring. During the period of record, flow fluctuated, and 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 at Moenkopi (1976 to 2006), Dinnebito Wash near Sand Springs (1993 to 2006), Polacca Wash near Second Mesa (1994 to 2006), and Pasture Canyon Springs (August 2004 to December 2006). 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 generally remained even, showing neither a significant increase nor decrease in flows. There is not a long enough period of record for Pasture Canyon Spring for a trend to be apparent.

In 2007, water samples were collected from 1 well and 1 spring in the Black Mesa area and were analyzed for selected chemical constituents. Concentrations of dissolved solids, chloride, and sulfate have varied at Peabody well 5 for the period of record, and there is an apparent increasing trend. Dissolved-solids, chloride, and sulfate concentrations increased at Moenkopi School Spring during the more than 12 years of record.

Introduction

The Black Mesa study area in northeastern Arizona includes of 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 precipitation rates that average about 6 to14 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 comprises 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).

The N aquifer is confined under most of Black Mesa, and the overlying stratigraphy prevents recharge to this part of the aquifer (fig. 2). 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 (fig. 3).

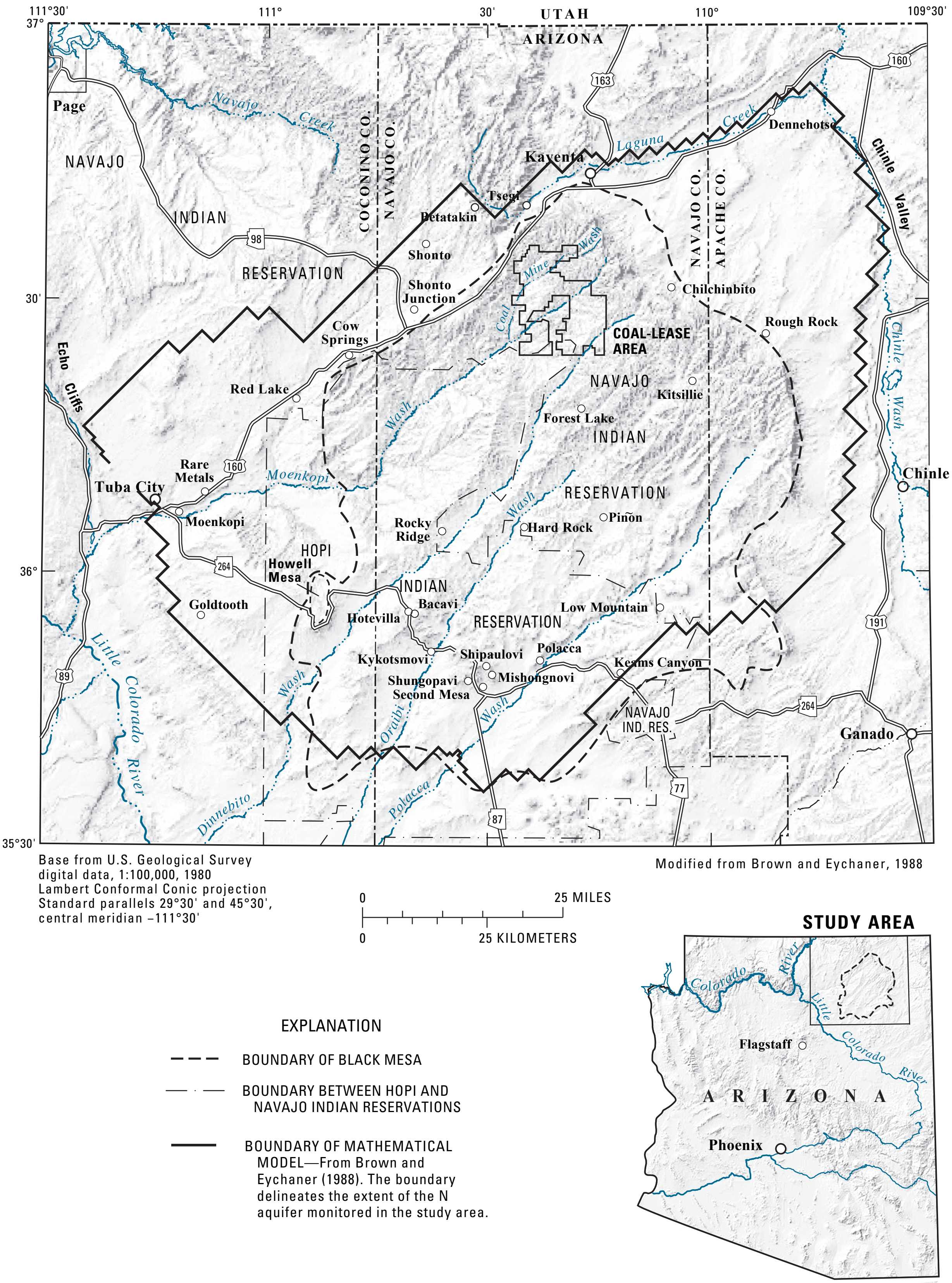


Figure 1. Location of water monitoring program study area, Black Mesa, northeastern Arizona.

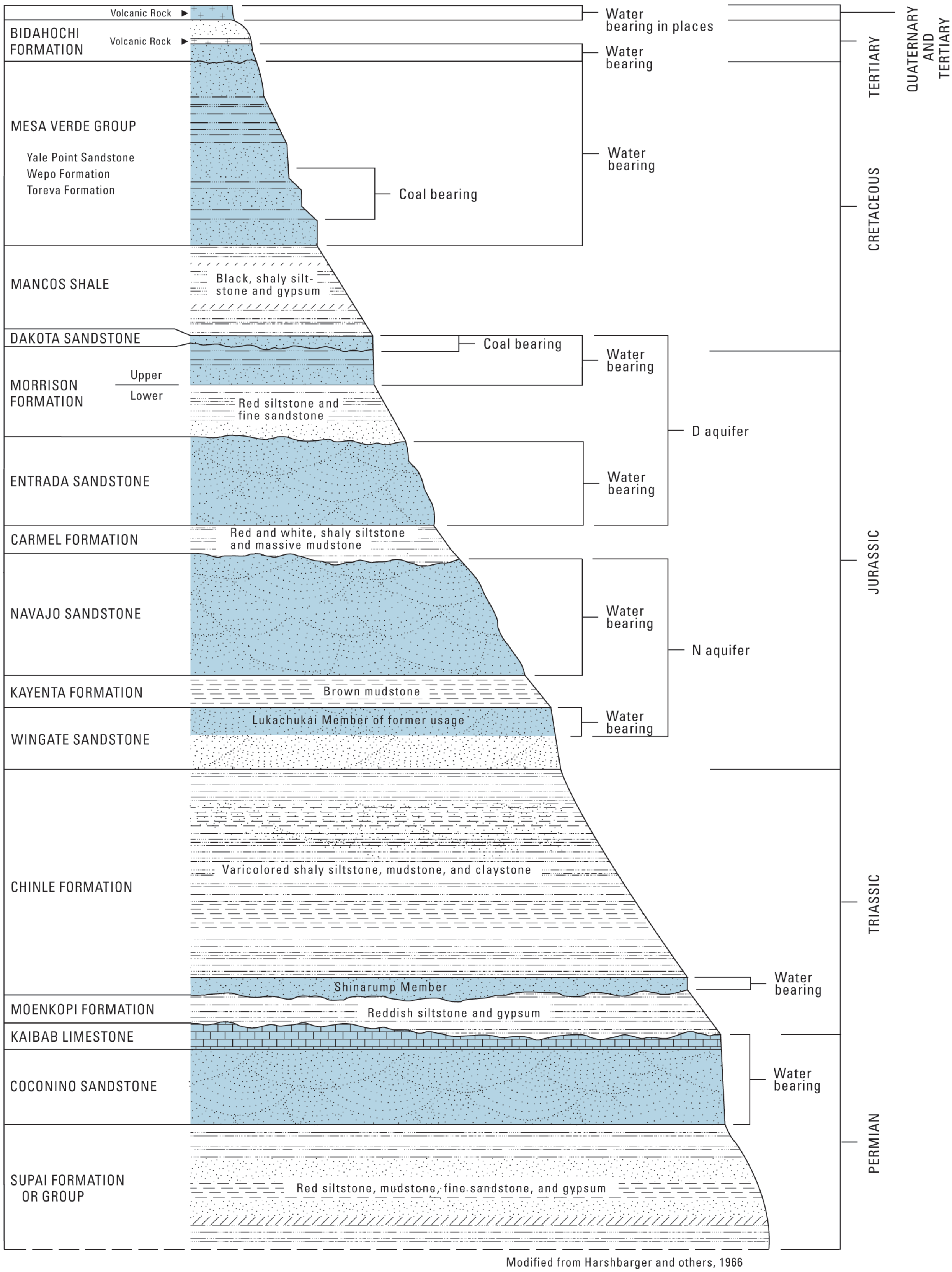


Figure 2. Rock formation and hydrogeologic units of the Black Mesa area, northeastern Arizona. The N aquifer is approximately 1,000 feet thick.

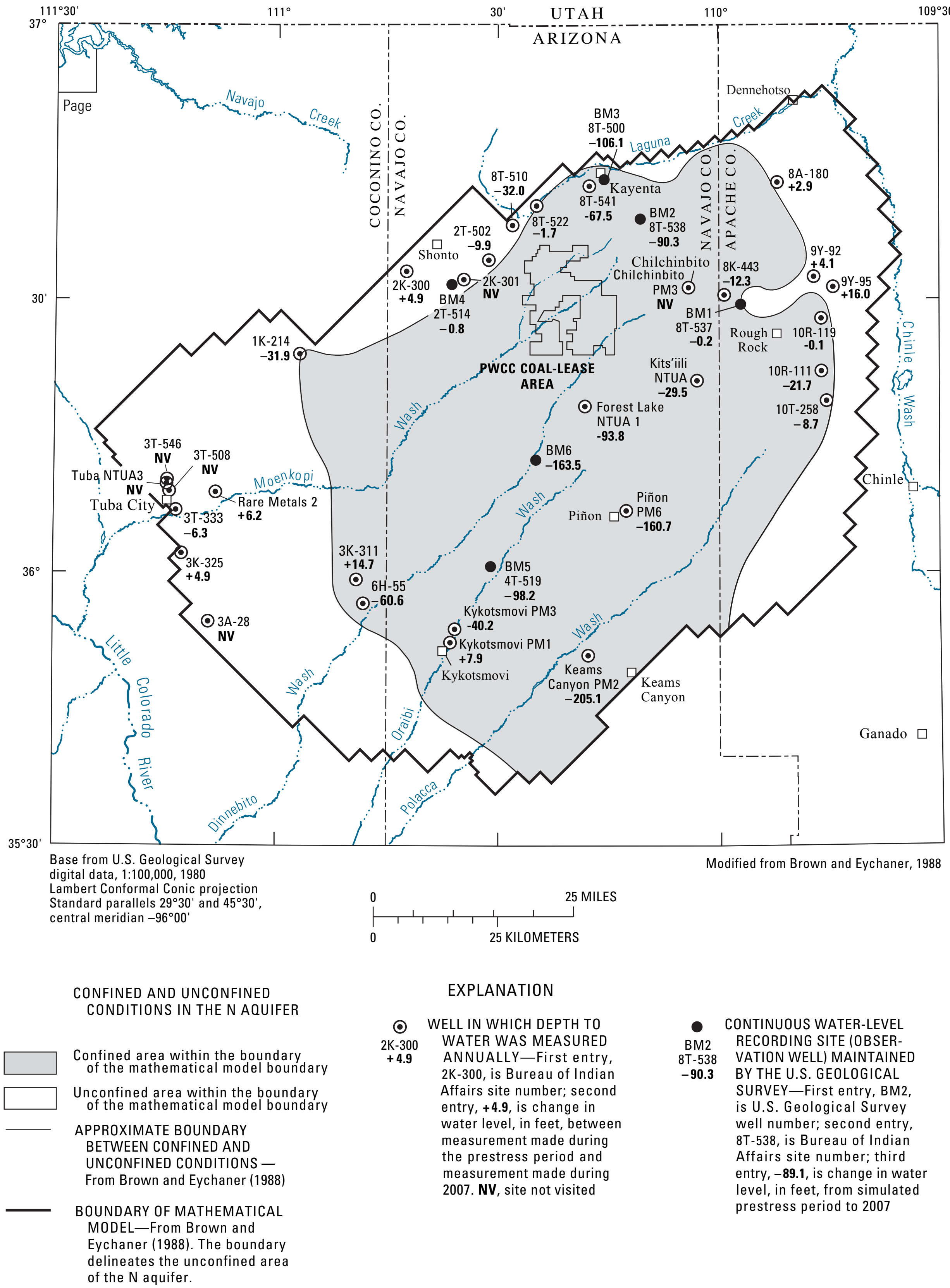


Figure 3. Water-level changes in N aquifer wells from the prestress period prior to 1965 to 2007, Black Mesa area, northeastern Arizona.

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. 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 PWCC pumped about 4,480 acre-ft of water. 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 pre-stress period. PWCC plans on pumping approximately 1,000 to 1,500 acre-ft per year, primarily for dust control. In 2006 PWCC pumped about 1,170 acre-ft.

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; 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 2006 to September 2007. 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 water levels, spring discharge rates, and water chemistry. Surface-water data include discharge rates at four continuous-record streamflow-gaging stations.

Previous Investigations

Twenty-four 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,b, 1996, 1997; Littin and others, 1999; Truini and others, 2000; Thomas and Truini, 2000; Thomas, 2002a,b; Truini and Thomas, 2004; Truini and others, 2005; Truini and Macy, 2006; and Truini and Macy, 2007). Most of the data from the Black Mesa area monitoring program are contained in these progress reports and in the USGS National Inventory System (NWIS) database (http://waterdata.usgs.gov/az/nwis/). 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 at Moenkopi, Dinnebito Wash near Sand Springs, Polacca Wash near Second Mesa, Laguna Creek, and Pasture Canyon Spring 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), and online at (http://wdr.water.usgs.gov/wy2006/search.jsp) in the 2006 annual data report. 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 investigated the hydrology of 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 collected 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 (2005) address leakage through the confining unit between the D aquifer and the N aquifer in a characterization of the Carmel Formation.

Hydrologic Data

In 2006–07, the Black Mesa area monitoring program included measuring depth to ground water, measuring discharge in streams and springs, and collecting and analyzing water samples from wells and springs. Annual discharge measurements were made at 1 spring, and annual ground-water level measurements were made at 30 wells. Six of the 30 annual wells are continuous-recording observation wells that have been upgraded for telemetry. The water-level data from these six continuous-recording observation 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 2007. Ground-water samples were collected from 1 well and 1 spring in April and May 2007 and were analyzed for chemical constituents. 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, however, the 2006 NTUA withdrawal data were unavailable. Identification information for the 35 wells used for water-level measurements and water-quality sampling is shown in table 1.

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. The industrial category includes eight wells in the PWCC well field in the northern Black Mesa area. The BIA, NTUA, and Hopi Tribe operate about 70 municipal wells that are combined into 28 well systems. Information about withdrawals from the N aquifer is compiled primarily on the basis of metered data from individual wells operated by the BIA, NTUA, and Hopi Tribe.

The total withdrawals are often a combination of meter readings from the agencies that operate the wells within the different systems. The NTUA annual withdrawal totals for the metered data were unavailable in 2006 due to an upgrade within the NTUA computer network. Because NTUA data is often combined with BIA data for the total withdrawals in a well system, withdrawals will not be published in this year's annual report.

Table 1. Identification numbers and names of monitoring program study wells, 2006–07, Black Mesa area, northeastern Arizona.

[Dashes indicate no data]

U.S. Geological Survey identification number	Common name or location	Bureau of Indian Affairs site number
355023110182701	Keams Canyon 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
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
362901110234101	Peabody 5	—
362406110563201	White Mesa Arch	1K-214
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
363423110305501	Shonto Southeast	2T-502
363309110420501	Shonto	2K-300
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

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. 3). From the recharge areas near Shonto, the ground water moves radially to the southwest toward Tuba City, to the south toward the Hopi Reservation, and to the east toward Rough Rock and Dennehotso (Eychaner, 1983).

Ground-water levels are measured once a year and compared with levels from previous years to determine changes over time. Only water levels from municipal and stock wells that were not considered to have been recently pumped, influenced by nearby pumping, or blocked or obstructed were used for comparison. During January 2007 to June 2007, water levels in 28 of 30 wells that were visited for annual measurements met these criteria (table 2). Six of the 30 wells are continuous-recording observation wells, and water levels were measured manually in these 6 wells twice between April 2006 and June 2007. Twenty-eight of 30 water levels measured in 2007 were compared with water levels for the same wells

Table 2. Water-level changes in monitoring program wells completed in the N aquifer, Black Mesa area, northeastern Arizona, prestress period (prior to 1965) to 2007.

Common name or location	Bureau of Indian Affairs site number	Change in water level from preceding year, in feet		Water level 2007[1], in feet below land surface	Prestress period water level		Change in water level from prestress period to 2007, in feet
		2006	2007		Feet below land surface	Date	
Unconfined areas							
BM observation well 1[3]	8T-537	+0.2	0.0	374.2	374.0	([1])	–0.2
BM observation well 4[3]	2T-514	–0.1	0.0	216.8	216.0	([1])	–0.8
Goldtooth	3A-28	–4.0	([3])	([3])	230.0	10–29–53	([3])
Long House Valley	8T-510	–0.3	–1.4	131.4	99.4	08–22–67	–32.0
Northeast Rough Rock	8A-180	–0.4	+0.4	44.0	46.9	11–13–53	+2.9
Rough Rock	9Y-95	–4.9	+5.9	103.5	119.5	08–03–49	+16.0
Rough Rock	9Y-92	–0.6	+0.9	164.7	168.8	12–13–52	+4.1
Shonto	2K-300	+0.0	–0.3	171.6	176.5	06–13–50	+4.9
Shonto Southeast	2K-301	–0.8	([3])	([3])	283.9	12–10–52	([3])
Shonto Southeast	2T-502	–1.4	+0.5	415.7	405.8	08–22–67	–9.9
Tuba City	3T-333	–0.6	0.0	29.3	23.0	12–02–55	–6.3
Tuba City	3K-325	–0.5	–0.4	203.1	208.0	06–30–55	+4.9
Tuba City Rare Metals 2	—	+0.6	+0.2	50.8	57.0	09–24–55	+6.2
Tuba City NTUA 1	3T-508	([2])	([3])	([3])	29.0	02–12–69	([3])
Tuba City NTUA 3	—	([2])	([3])	([3])	34.2	11–08–71	([3])
Tuba City NTUA 4	3T-546	([2])	([3])	([3])	33.7	08–06–71	([3])
Confined area							
BM observation well 2[3]	8T-538	–1.5	–2.5	215.3	125.0	(1)	–90.3
BM observation well 3[3]	8T-500	–3.5	–2.5	161.1	55.0	04–29–63	–106.1
BM observation well 5[3]	4T-519	–3.2	–3.9	422.2	324.0	(1)	–98.2
BM observation well 6[3]	—	–3.6	–1.8	860.5	697.0	(1)	–163.5
Forest Lake NTUA 1	4T-523	([2])	+0.3	1189.8	1,096[R]	05–21–82	–93.8
Howell Mesa	3K-311	–1.4	+2.1	448.3	463.0	11–03–53	+14.7
Howell Mesa	6H-55	–1.1	+0.3	272.6	212.0	07–08–54	–60.6
Kayenta West	8T-541	([2])	+8.2	297.5	230.0	03–17–76	–67.5
Keams Canyon PM2	—	–2.9	–8.9	497.6	292.5	06–10–70	–205.1
Kitsillie NTUA 2	—	–3.5	–3.4	1327.4	1,297.9	01–14–99	–29.5
Kykotsmovi PM1	—	+1.7	+0.4	212.1	220.0	05–20–67	+7.9
Kykotsmovi PM3	—	([2])	([2])	250.2	210.0	08–28–68	–40.2
Marsh Pass	8T-522	+1.0	+0.2	127.2	125.5	02–07–72	–1.7
Piñon PM6	—	–8.0	–5.9	904.3	743.6	05–28–70	–160.7
Rough Rock	10R-119	([2])	([2])	256.7	256.6	12–02–53	–0.1
Rough Rock	10T-258	–0.1	–0.2	309.7	301.0	04–14–60	–8.7
Rough Rock	10R-111	+3.1	+0.3	191.7	170.0	08–04–54	–21.7
Sweetwater Mesa	8K-443	–0.9	+0.2	541.7	529.4	09–26–67	–12.3
White Mesa Arch	1K-214	–0.3	+0.4	219.9	188.0	06–04–53	–31.9

[1]Continuous recorder. Except for well BM3, prestress period 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 in 2006-07.
Note: Numbers with superscript R are reported.

Table 3. Well-construction characteristics, depth to top of N aquifer, and type of data collected for wells in monitoring program, Black Mesa area, northeastern Arizona, 2006–07.

Bureau of Indian Affairs site number and (or) common name	Date well was completed	Land-surface elevation, in feet	Well depth, in feet below land surface	Screened/open interval(s), in feet below land surface	Depth to top of N aquifer, in feet below land surface[1]	Type of data collected
8T-537 (BM observation well 1)	02–01–72	5,864	851	300–360; 400–420; 500–520; 600–620; 730-780	290	Water level
8T-538 (BM observation well 2)	01–29–72	5,656	1,338	470–1,338	452	Water level
8T-500 (BM observation well 3)	07–29–59	5,724	868	712–868	155	Water level
2T-514 (BM observation well 4)	02–15–72	6,320	400	250–400	160	Water level
4T-519 (BM observation well 5)	02–25–72	5,869	1,683	1,521–1,683	1,520	Water level
BM observation well 6	01–31–77	6,332	2,507	1,954–2,506	1,950	Water level
1K-214	05–26–50	5,771	356	168–356	250	Water level
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
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, withdrawals
6H-55[6]	12–08–44	5,635	361	310–335	[6]310	Water level
8A-180	01–20–39	5,200	107	60–107	[2]40	Water level
8K-443	08–15–57	6,024	720	619–720	590	Water level
8T-510	02–11–63	6,262	314	130–314	[2]125	Water level
8T-522	[3]07–00–63	6,040	933	180–933	480	Water level
8T-541	03–17–76	5,885	890	740–890	700	Water level
9Y-92	01–02–39	5,615	300	154–300	[2]50	Water level
9Y-95	11–05–37	5,633	300	145–300	[2]68	Water level
10R-111	04–11–35	5,757	360	267–360	210	Water level
10R-119	12-02-53	5,775	360	([4])	235	Water level
10T-258	04–12–60	5,903	670	465–670	460	Water level
Peabody 5	00–00–68	6,585	3,737	2,091–3,735	3,140	Water hemistry
Keams Canyon PM2	[3]05–00–70	5,809	1,106	906–1,106	900	Water level, withdrawals
Kits'iili NTUA 2	10–30–93	6,780	2,549	2,217–2,223; 2,240–2,256; 2,314–2,324; 2,344–2,394; 2,472–2,527	2,205	Withdrawals
Kykotsmovi PM1	02–20–67	5,657	995	655–675; 890–990	880	Water level, withdrawals
Kykotsmovi PM3	10–14–77	5,760	1,155	950–1,155	890	Withdrawals
Piñon PM6	[3]02–00–70	6,397	2,248	1,895–2,243	1,870	Water level, witdrawals
Tuba City Rare Metals 2	[3]09–00–55	5,108	705	100–705	255	Water level

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

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

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

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

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

[6]Developed into the D aquifer only.

measured in 2006. Water levels measured in 2007 in two of the wells, Kykotsmovi PM3 and 10R-119 at Rough Rock, could not be compared to 2006 water levels because measurements were not available for these wells in 2006.

The wells used for water-level measurements are distributed throughout the study area (fig. 3). All but one of the wells is completed in the N aquifer; however, the characteristics of the wells vary considerably. Well 6H-55 was previously thought to be completed in the N aquifer, but is actually completed in the D aquifer. Construction dates range from 1934 to 1993, total well depths range from 107 ft near Dennehotso (8A-107), to 3,735 ft near PWCC, and depths to the top of the N aquifer range from 0 ft near Tuba City, to 3,140 ft near PWCC, (table 3).

From 2006 to 2007, water levels decreased in 11 of the 28 wells for which comparisons could be made (table 2). The median water-level change in the 28 wells was 0.1 ft (table 4). From 2006 to 2007, water levels declined in 3 of the 11 wells measured in the unconfined parts of the aquifer (table 2). The median water-level change was 0.0 ft (table 4). Water-level changes in the unconfined part of the aquifer ranged from –1.4 ft at 8T-510 near Long House Valley to 5.9 ft at 9Y-95 in Rough Rock (table 2). In the confined area, water levels declined in 8 of 17 wells measured from 2006 to 2007. The median water-level change was 0.2 ft (table 4). Water-level changes in the confined part of the aquifer ranged from –8.9 ft at Keams Canyon PM2 to 8.2 ft at 8T-541 in Kayenta West (table 2).

From the pre-stress period (prior to 1965) to 2007, the median water-level change in 30 wells was –11.1 ft (table 4). Water levels in 11 unconfined wells had a median change of 2.9 ft. Water-level changes in the unconfined part of the aquifer ranged from –32.0 ft at 8T-510 near Long House Valley to 16.0 ft at 9Y-95 in Rough Rock (table 2). Water levels in 19 wells in the confined part of the aquifer had a median change of –40.2 ft (table 4). Water-level changes in the confined part of the aquifer ranged from –205.1 ft at Keams Canyon PM2 to 14.7 ft at 3K-311 (fig. 3 and table 2).

Table 4. Median changes in water levels in monitoring program wells, 2006-07 and prestress period (prior to 1965) to 2007, N aquifer, Black Mesa area, northeastern Arizona.

Years	Aquifer conditions	Number of wells	Median change in water level, in feet
2006–07	All	28	0.1
	Unconfined	11	0.0
	Confined	17	0.2
Prestress-2007	All	30	-11.1
	Unconfined	11	2.9
	Confined	19	-40.2

Hydrographs of ground-water levels in the annual-well network show the time trends of changes since the 1950s, 1960s, or 1970s (fig. 4). 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 32 ft (fig. 3). Water levels have declined in most of the confined area; however, the magnitudes of declines are varied. Larger declines have occurred near the municipal pumping centers (wells Piñon PM6, Keams Canyon PM2), or near the annual wells for PWCC (BM6). Smaller declines occur away from pumping centers in or near towns in the study area (wells 10T-258, 8K-443, 10R-111, 8T-522; fig. 3).

Hydrographs for the Black Mesa continuous-record observation wells show continuous water-levels since the early 1970s (fig. 5). Water levels in the two the wells in the unconfined areas (BM1 and BM4) have had small seasonal or year-to-year variation since 1972. Water levels in wells BM2, BM3, BM5, and BM6 in the confined area have consistently declined since the early to mid-1960s (fig. 5).

Spring Discharge from the N Aquifer

Ground water in the N aquifer discharges from many springs around the margins of Black Mesa. In 2007 one of four of the springs that have been measured annually was measured for discharge. Moenkopi School Spring is in the western part of the Black Mesa area (fig. 6). Discharge from Moenkopi School Spring was measured in April 2007 and compared to discharge data from previous years to determine changes over time (fig. 7). The measurements at Moenkopi School Spring are made volumetrically.

In 2007, measured discharge was 9.0 gal/min from Moenkopi School Spring (table 5). From 2006 to 2007, discharge decreased by 18.9 percent at Moenkopi School Spring. For the period of record, discharge measurements have fluctuated, indicating a decreasing trend (fig. 7).

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.

In 2006, discharge data were collected at four continuous-recording streamflow-gaging stations (tables 6–9). Data collection at these stations began in July 1976 (Moenkopi Wash at Moenkopi, 09401260), June 1993 (Dinnebito Wash near Sand Springs, 09401110), April 1994 (Polacca Wash near Second Mesa, 09400568), and August 2004 (Pasture Canyon Spring, 09401265; fig. 8 and table 10). The annual average discharges at the four streamflow-gaging stations vary during the periods of record (fig. 9*A*), and no trends are apparent for Moenkopi Wash, Polacca Wash, and Dinnebito Wash. No trends can be determined for Pasture Canyon Wash because the length of record in insufficient to calculate a trend. In 2006, annual average flows for Moenkopi Wash, Polacca Wash, and Dinnebito Wash increased (fig. 8).

The ground-water discharge component of total flow at the four streamflow-gaging stations was estimated by computing the median flow for 120 consecutive daily mean flows for four winter months—November, December, January, and February (fig. 9). 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 ground-water 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 2007 water year; thus, daily mean flows for November and December 2006 were combined with daily mean flows for January and February 2007. These median winter flows were 2.3 ft^3/s for Moenkopi Wash at Moenkopi, 0.41 ft^3/s for Dinnebito Wash near Sand Springs, and 0.41 ft^3/s for Polacca Wash near Second Mesa (fig. 9*A–C*). For the period of record at each streamflow-gaging station, the median winter flows have generally remained constant as indicated by trends calculated by using the method of least squares (fig. 9*A–C*).

The annual average for precipitation measured at Betatakin National Park (Betatakin; fig. 1) from 1976 to 2006 is 12.6 in. (fig. 8*B*). Annual precipitation at Betatakin has been mostly less than average from 1995 through 2002 (11.4 in.); it was incomplete for 2003, above average for calendar year 2004 and 2005 (17.4), and below the average for calendar year 2006 (11.24 in.; fig. 8*B*).

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 have been collected from 12 wells during each year of the program. Eight of the wells have been sampled every year, and the other four wells have been selected on the basis of a sampling rotation. In 2007 the well sampling sites were reduced, and a sample was collected only from Peabody 5. Since 1989, samples have been collected from the same 4 springs (Moenkopi School Spring, Pasture Canyon Spring, Unnamed spring near Dennehotso, and Burro Spring); however, in 2007, samples were collected only from Moenkopi School 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 and unconfined areas of the northern and northwestern parts of the Black Mesa study area, and sodium bicarbonate water is generally in the area that is confined and downgradient to the south and east (Lopes and Hoffmann, 1997). In 2007, a water sample was collected from 1 well, Peabody 5 (fig. 6).

The sample from Peabody 5 yielded a sodium-bicarbonate type water and had a dissolved-solids concentration of 198 mg/L (fig. 10 and table 11). Concentrations of dissolved solids, chloride, and sulfate have varied for the period of record at Peabody 5 and indicate an increasing trend from 1968 to 2007 (fig. 11 and table 12). Concentrations of all the analyzed constituents in samples from Peabody 5 were less than current United States Environmental Protection Agency (USEPA) Maximum Contaminate Levels (MCLs) and Suggested Maximum Contaminate Levels (SMCLs; U.S. Environmental Protection Agency, 2002).

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

In 2007, water samples were collected from Moenkopi School Spring in the southwestern part of the Black Mesa study area (fig. 7). Moenkopi School Spring discharges water from the unconfined part of the N aquifer. At Moenkopi School Spring, samples were collected from a horizontal metal pipe that is developed into the hillside to collect water from the spring.

The Moenkopi School Spring sample yielded a calcium-bicarbonate-type water (fig. 10). The sample from the Moenkopi School Spring had a dissolved solids concentration of 238 mg/L (table 13). Concentrations of all the analyzed constituents in samples from Moenkopi School Spring were less than current USEPA MCLs and SMCLs (U.S. Environmental Protection Agency, 2002).

Increasing trends in concentrations of dissolved solids, chloride, and sulfate are evident in data from Moenkopi School Spring (table 14 and figs. 12A–C). Trend lines in figure 13 were generated by applying the statistical least squares method and are significantly different from zero.

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 2006 to September 2007. The monitoring data for 2006–07 are compared with data for 2005–06 and with historical data from the 1950s to September 2007.

The total ground-water withdrawals are often a combination of meter readings from the agencies that operate the wells within the different systems. The NTUA yearly totals for the metered data were unavailable in 2006 due to an upgrade within the NTUA computer network. Because NTUA data is often combined with BIA data for the total withdrawals in a well system, withdrawals were not published in this year's annual report.

From 2006 to 2007, annually measured ground-water levels declined in 11 of 28 wells. The median water-level change for the 28 wells was 0.1 ft. In unconfined areas of the N aquifer, water levels declined in 3 of 11 annual wells, and the median change was 0.0 ft. In the confined area of the N aquifer, water levels declined in 8 of 16 wells, and the median change was 0.2 ft.

From the prestress period (prior to 1965) to 2007, the median ground-water level change in 30 wells was –11.1 ft. Water levels in the 11 wells in the unconfined areas of the N aquifer had a median change of 2.9 ft, and the changes ranged from –32.0 ft to 16.0 ft. Water levels in the 19 wells in the confined area of the N aquifer had a median change of –40.2 ft, and the changes ranged from –205.1 ft to 14.7 ft.

Discharge was measured annually at Moenkopi School Spring. Between 2006 and 2007, spring flow decreased by 18.9 percent. For about the past 12 years, discharge at Moenkopi School Spring has fluctuated, and the data indicates a decreasing trend.

Annual average discharges at four streamflow-gaging stations—Moenkopi Wash, Dinnebito Wash, Pasture Canyon Spring, and Polacca Wash—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. For the period of record at each streamflow-gaging station, the median winter flows have generally remained even, showing neither a significant increase nor decrease in flows.

In 2007, water samples were collected from Peabody 5 well and analyzed for selected chemical constituents. Concentrations of dissolved solids, chloride, and sulfate have varied for the period of record, and the data indicate an increasing trend.

Dissolved-solids concentrations in water samples from Moenkopi School Spring were 238 mg/L. From the mid-1980s to 2007, long-term data indicate increasing trends in concentrations of dissolved solids, chloride, and sulfate.

Selected References

Boner, F.C., Davis, R.G., and Duet, N.R., 1992, Water-resources data for Arizona, water year 1991: U.S. Geological Survey Water-Data Report AZ–91–1, 411 p.

Boner, F.C., Garrett, W.B., and Konieczki, A.D., 1989, Water-resources data for Arizona, water year 1988: U.S. Geological Survey Water-Data Report AZ–88–1, 391 p.

Boner, F.C., Konieczki, A.D., and Davis, R.G., 1991, Water-resources data for Arizona, water year 1990: U.S. Geological Survey Water-Data Report AZ–90–1, 381 p.

Boner, F.C., Smith, C.F., Garrett, W.B., and Konieczki, A.D., 1990, Water-resources data for Arizona, water year 1989: U.S. Geological Survey Water-Data Report AZ–89–1, 383 p.

Brown, J.G., and Eychaner, J.H., 1988, Simulation of five ground-water withdrawal projections for the Black Mesa area, Navajo and Hopi Indian Reservations, Arizona: U.S. Geological Survey Water-Resources Investigations Report 88–4000, 51 p.

Cooley, M.E., Harshbarger, J.W., Akers, J.P., and Hardt, W.F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521–A, 61 p.

Davis, G.E., Hardt, W.F., Thompson, L.K., and Cooley, M.E., 1963, Records of ground-water supplies, part 1 of geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: Arizona State Land Department Water-Resources Report 12–A, 159 p.

Eychaner, J.H., 1983, Geohydrology and effects of water use in the Black Mesa area, Navajo and Hopi Indian Reservations, Arizona: U.S. Geological Survey Water-Supply Paper 2201, 26 p.

Fisk, G.G., Duet, N.R., Evans, D.W., Angeroth, C.E., Castillo, N.K., and Longsworth, S.A., 2004, Water-resources data for Arizona, water year 2003: U.S. Geological Survey Water-Data Report AZ–03–1, 326 p.

Fisk, G.G., Duet, N.R., McGuire, E.H., Angeroth, C.E., Castillo, N.K., and Smith, C.F., 2005, Water-resources data for Arizona, water year 2004: U.S. Geological Survey Water-Data Report AZ–04–1 p. 415

GeoTrans, Inc., 1987, A two-dimensional finite-difference flow model simulating the effects of withdrawals to the N aquifer, Black Mesa area, Arizona: Boulder, Colorado, GeoTrans, Inc., report prepared for Peabody Western Coal Company.

Harshbarger, J.W., Lewis, D.D., Skibitzke, H.E., Heckler, W.L., and Kister, L.R., 1966, Arizona water: U.S. Geological Survey Water-Supply Paper 1648, 85 p.

Hart, R.J., and Sottilare, J.P., 1988, Progress report on the ground-water, surface-water, and quality-of-water monitoring program, Black Mesa area, northeastern Arizona—1987–88: U.S. Geological Survey Open-File Report 88–467, 27 p.

Hart, R.J., and Sottilare, J.P., 1989, Progress report on the ground-water, surface-water, and quality-of-water monitoring program, Black Mesa area, northeastern Arizona—1988–89: U.S. Geological Survey Open-File Report 89–383, 33 p.

Hill, G.W., 1985, Progress report on Black Mesa monitoring program—1984: U.S. Geological Survey Open-File Report 85–483, 24 p.

Hill, G.W., and Sottilare, J.P., 1987, Progress report on the ground-water, surface-water, and quality-of-water monitoring program, Black Mesa area, northeastern Arizona—1987: U.S. Geological Survey Open-File Report 87–458, 29 p.

Hill, G.W., and Whetten, M.I., 1986, Progress report on Black Mesa monitoring program—1985–86: U.S. Geological Survey Open-File Report 86–414, 23 p.

HSIGeoTrans, Inc., 1993, Investigation of the N- and D-aquifer geochemistry and flow characteristics using major ion and isotopic chemistry, petrography, rock stress analyses, and dendrochronology in the Black Mesa area, Arizona: Boulder, Colorado, HSIGeoTrans, Inc., report prepared for Peabody Coal Company, 400 v.p.

HSIGeoTrans, Inc., and Waterstone Environmental Hydrology and Engineering, Inc., 1999, A three-dimensional flow model of the D and N aquifers, Black Mesa Basin, Arizona: Boulder, Colorado, HSIGeoTrans, Inc., and Waterstone Environmental Hydrology and Engineering, Inc., report prepared for Peabody Western Coal Company, 75 p.

Kister, L.R., and Hatchett, J.L., 1963, Selected chemical analyses of the ground water, part 2 of Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: Arizona State Land Department Water-Resources Report 12–B, 58 p.

Littin, G.R., 1992, Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1990–91: U.S. Geological Survey Water-Resources Investigations Report 92–4045, 32 p.

Littin, G.R., 1993, Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1991–92: U.S. Geological Survey Water-Resources Investigations Report 93–4111, 23 p.

Littin, G.R., Baum, B.M., and Truini, Margot, 1999, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1999: U.S. Geological Survey Open-File Report 98–653, 27 p.

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

Littin, G.R., and Monroe, S.A., 1995b, Results of ground-water, surface-water, and water-chemistry monitoring, Black Mesa area, northeastern Arizona—1994: U.S. Geological Survey Water-Resources Investigations Report 95–4238, 25 p.

Littin, G.R., and Monroe, S.A., 1996, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1995: U.S. Geological Survey Open-File Report 96–616, 22 p.

Littin, G.R., and Monroe, S.A., 1997, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1996: U.S. Geological Survey Open-File Report 97–566, 27 p.

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

McCormack, H.F., Fisk, G.G., Duet, N.R., Evans, D.W., and Castillo, N.K., 2002, Water-resources data for Arizona, water year 2001: U.S. Geological Survey Water-Data Report AZ–01–1, 399 p.

McCormack, H.F., Fisk, G.G., Duet, N.R., Evans, D.W., Roberts, W.P., and Castillo, N.K., 2003, Water-resources data for Arizona, water year 2002: U.S. Geological Survey Water-Data Report AZ–02–1, 337 p.

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

Smith, C.F., Boner, F.C., Davis, R.G., Duet, N.R., and Rigas, P.D., 1993, Water-resources data for Arizona, water year 1992: U.S. Geological Survey Water-Data Report AZ–92–1, 360 p.

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

Smith, C.F., Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 1997, Water-resources data for Arizona, water year 1996: U.S. Geological Survey Water-Data Report AZ–96–1, 328 p.

Smith, C.F., Rigas, P.D., Ham, L.K., Duet, N.R., and Anning, D.W., 1994, Water-resources data for Arizona, water year 1993: U.S. Geological Survey Water-Data Report AZ–93–1, 360 p.

Sottilare, J.P., 1992, Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1989–90: U.S. Geological Survey Water-Resources Investigations Report 92–4008, 38 p.

Tadayon, Saeid, Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 1999, Water-resources data for Arizona, water year 1998: U.S. Geological Survey Water-Data Report AZ–98–1, 454 p.

Tadayon, Saeid, Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 2000, Water-resources data for Arizona, water year 1999: U.S. Geological Survey Water-Data Report AZ–99–1, 389 p.

Tadayon, Saeid, Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 2001, Water-resources data for Arizona, water year 2000: U.S. Geological Survey Water-Data Report AZ–00–1, 390 p.

Tadayon, Saeid, Duet, N.R., Fisk, G.G., McCormack, H.F., Pope, G.L., and Rigas, P.D., 1998, Water-resources data for Arizona, water year 1997: U.S. Geological Survey Water-Data Report AZ–97–1, 416 p.

Thomas, B.E., 2002a, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2000–2001, and performance and sensitivity of the 1988 USGS numerical model of the N aquifer: U.S. Geological Survey Water-Resources Investigations Report 02–4211, 75 p.

Thomas, B.E., 2002b, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2001–02: U.S. Geological Survey Open-File Report 02–485, 43 p.

Thomas, B.E., and Truini, Margot, 2000, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona–1999: U.S. Geological Survey Open-File Report 00–453, 42 p.

Truini, Margot, Baum, B.M., Littin, G.R., and Shingoitewa-Honanie, Gayl, 2000, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1998: U.S. Geological Survey Open-File Report 00–66, 37 p.

Truini, Margot, and Longsworth, S.A., 2003, Hydrogeology of the D aquifer and movement and ages of ground water determined from geochemical and isotopic analyses, Black Mesa area, northeastern Arizona: U.S. Geological Survey Water-Resources Investigations Report 03–4189, 38 p.

Truini, Margot and Macy, J.P., 2005, Lithology and thickness of the Carmel Formation as related to leakage between the D and N aquifer, Black Mesa, Arizona: U.S. Geological Survey Scientific Investigation Report 2005-5187, 7 p.

Truini, Margot, and Macy, J.P., 2006, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2004–05: U.S. Geological Survey Open-File Report 2006–1058, 42 p.

Truini, Margot, and Macy, J.P., 2007, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2005–06: U.S. Geological Survey Open-File Report 2007–1041, 42 p.

Truini, Margot, Macy, J.P., and Porter T.J., 2005, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2003–04: U.S. Geological Survey Open-File Report 2005–1080, 44 p.

Truini, Margot, and Thomas, B.E., 2004, Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2002–03: U.S. Geological Survey Open-File Report 03–503, 43 p.

U.S. Department of Agriculture, Natural Resources Conservation Service, 1999, Arizona annual precipitation: Fort Worth, Texas, USDA–NRCS National Cartography & Geospatial Center, scale 1:1,300,000.

U.S. Environmental Protection Agency, 2002, Current drinking water standards, national primary and secondary drinking water regulations: Washington, D.C., U.S. Environmental Protection Agency [http://www.epa.gov/safewater/mcl.html 05:00P, last accessed January 31, 2006].

U.S. Geological Survey, 1963–64a, Surface-water records of Arizona: U.S. Geological Survey report, 191 p.

U.S. Geological Survey, 1963–64b, Ground-water records of Arizona: U.S. Geological Survey report, 80, p.

U.S. Geological Survey, 1965–74a, Water-resources data for Arizona—Part 1, surface-water records: U.S. Geological Survey Water-Resources Data Report, 212, p.

U.S. Geological Survey, 1965–74b, Water-resources data for Arizona—Part 2, ground-water records: U.S. Geological Survey Water-Resources Data Report, 89, p.

U.S. Geological Survey, 1976–83, Water-resources data for Arizona, water years 1975–81: U.S. Geological Survey Water-Resources Data Reports AZ–75–1 to AZ–81–1, 440 p .

U.S. Geological Survey, 1978, Progress report on Black Mesa monitoring program—1977: U.S. Geological Survey Open-File Report 78–459, 38 p.

White, N.D., and Garrett, W.B., 1984, Water resources data for Arizona, water year 1982: U.S. Geological Survey Water-Data Report AZ–82–1, 440 p.

White, N.D., and Garrett, W.B., 1986, Water resources data for Arizona, water year 1983: U.S. Geological Survey Water-Data Report AZ–83–1, 387 p.

White, N.D., and Garrett, W.B., 1987, Water resources data for Arizona, water year 1984: U.S. Geological Survey Water-Data Report AZ–84–1, 381 p.

White, N.D., and Garrett, W.B., 1988, Water resources data for Arizona, water year 1985: U.S. Geological Survey Water-Data Report AZ–85–1, 343 p.

Wilson, R.P., and Garrett, W.B., 1988, Water resources data for Arizona, water year 1986: U.S. Geological Survey Water-Data Report AZ–86–1, 341 p.

Wilson, R.P., and Garrett, W.B., 1989, Water-resources data for Arizona, water year 1987: U.S. Geological Survey Water-Data Report AZ–87–1, 385 p.

Zhu, Chen, Waddell, R.K., Star, I., and Ostrander, M., 1998, Responses of ground water in the Black Mesa Basin, northeastern Arizona, to paleoclimatic changes during the late Pleistocene and Holocene: Geology, v. 26, no. 2, p. 127–130.

Zhu, Chen, 2000, Estimate of recharge from radiocarbon dating of groundwater and numerical flow and transport modeling: Water Resources Research, v. 36, no. 9, p. 2607–2620.

Figures 4 through 12 and Tables 5 through 14

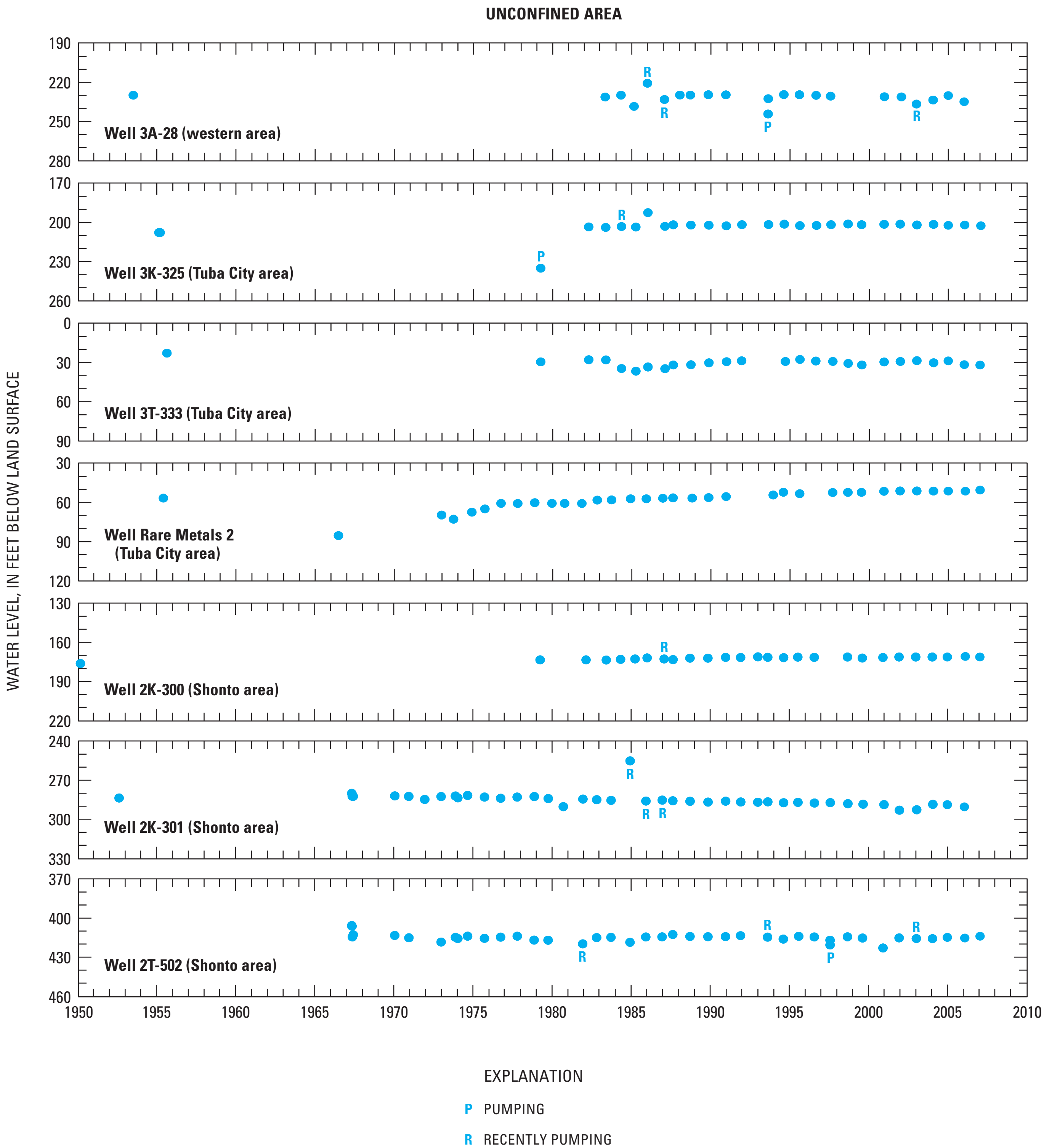


Figure 4. Observed water levels (1950–2007) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona.

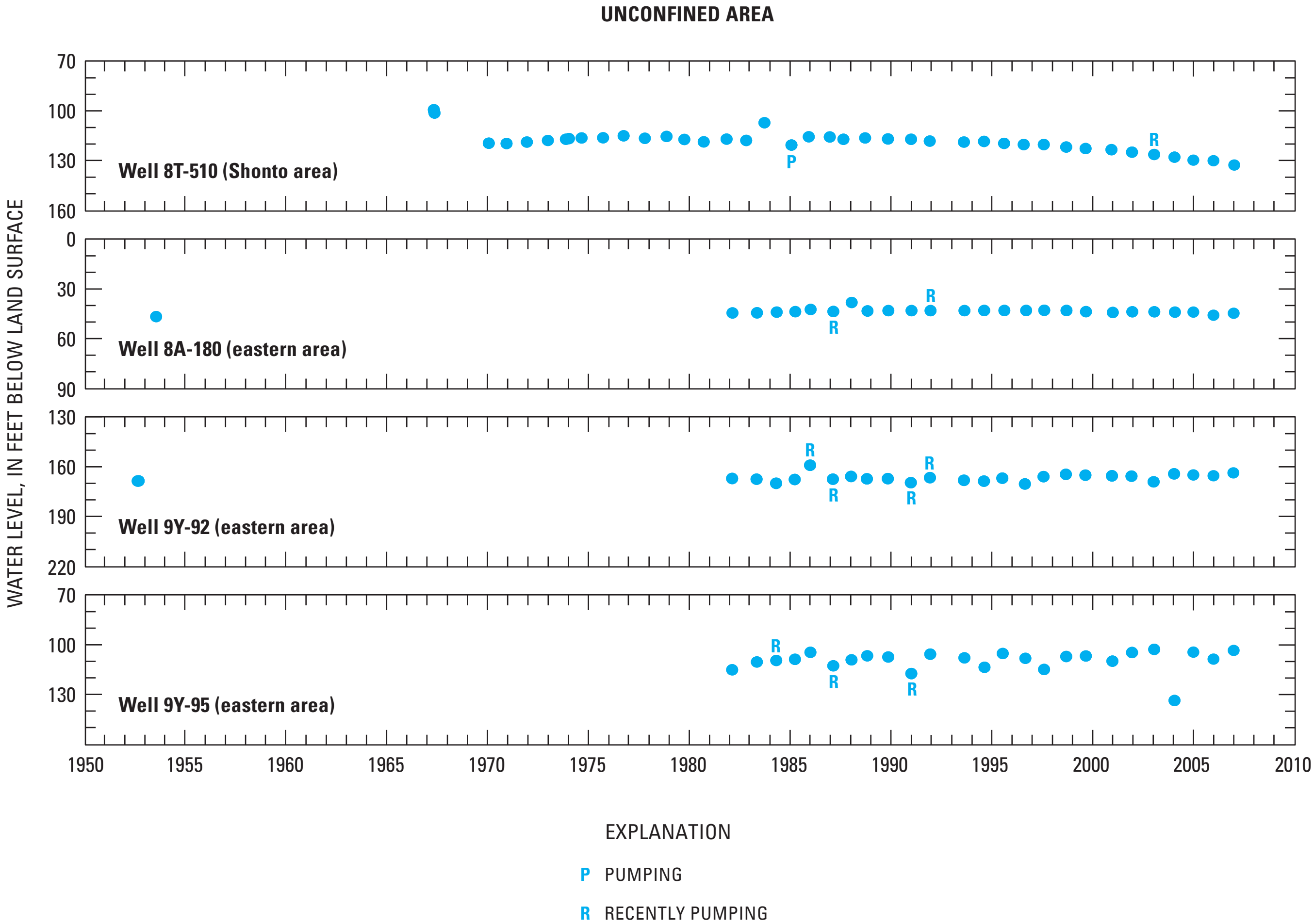


Figure 4. Observed water levels (1950–2007) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona—Continued.

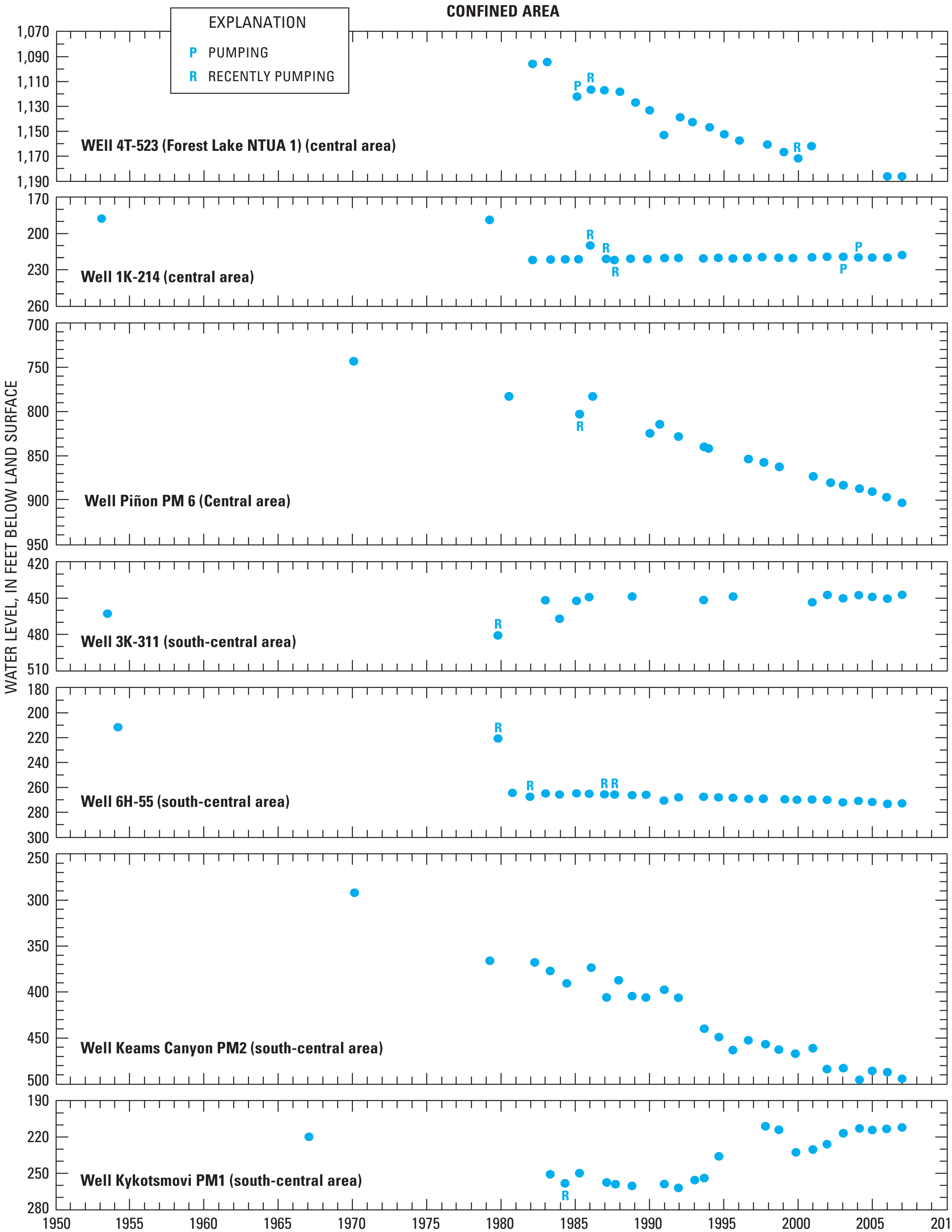


Figure 4. Observed water levels (1950–2007) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona—Continued.

Figure 4. Observed water levels (1950–2007) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona—Continued.

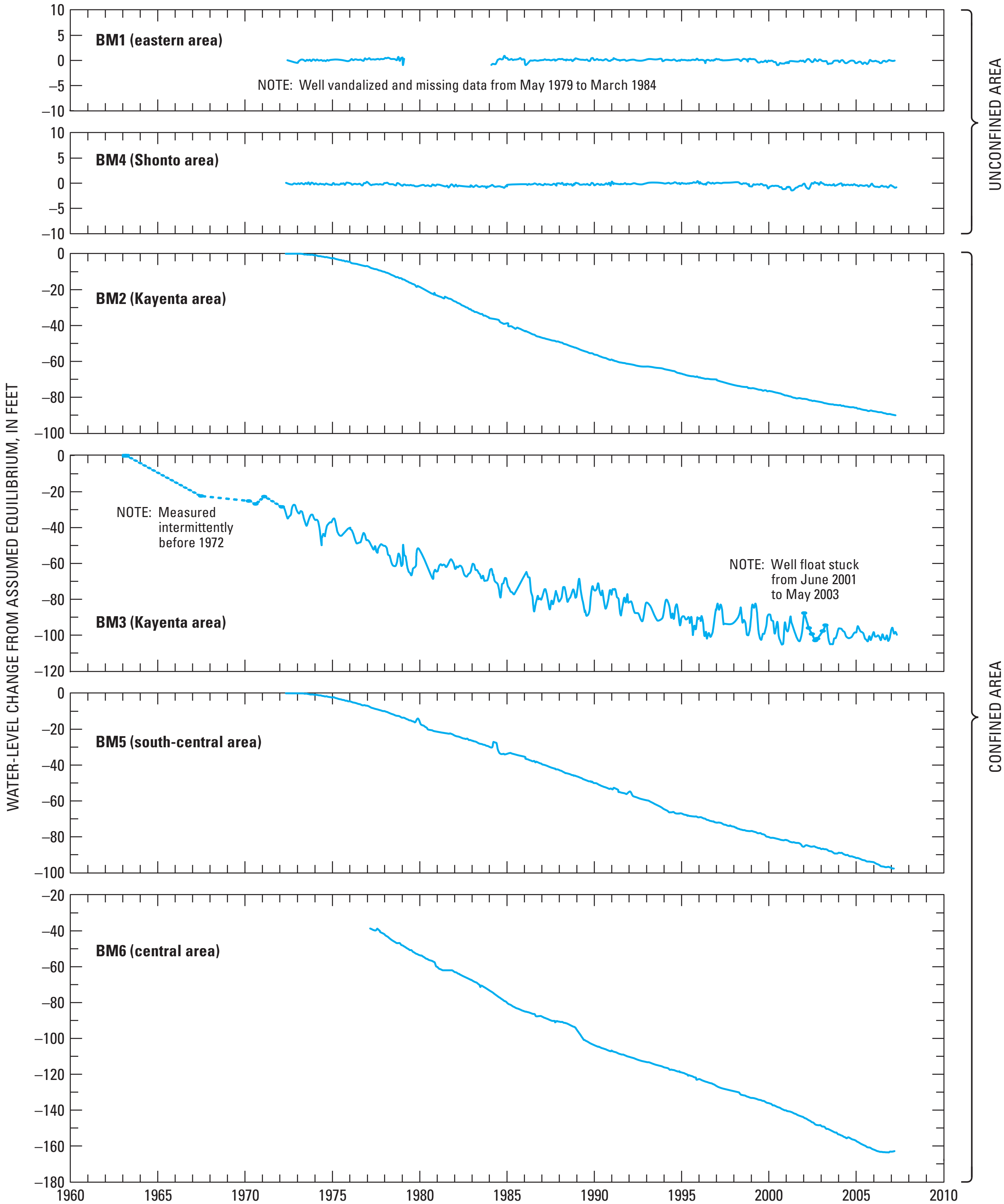
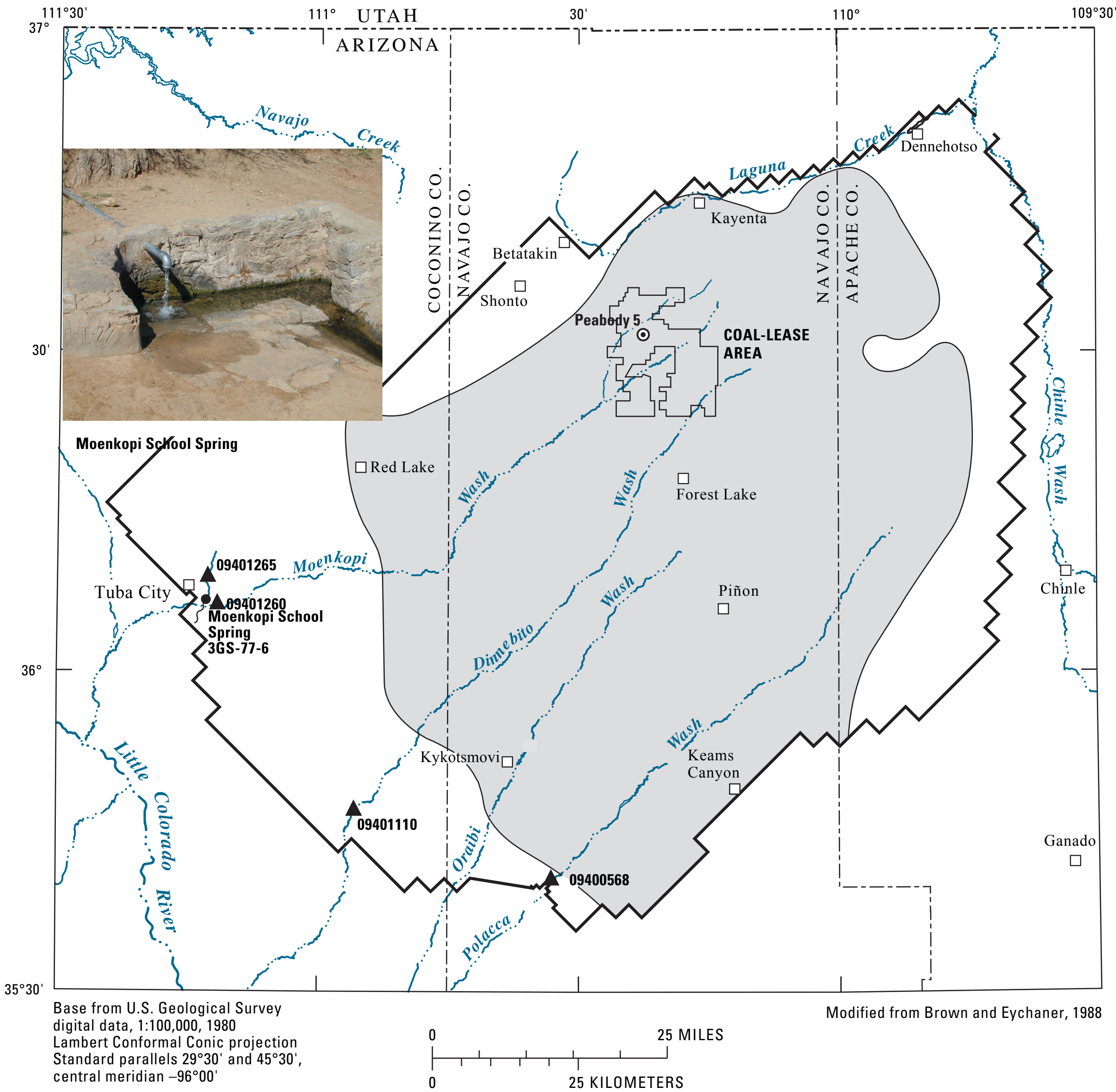


Figure 5. Observed water levels changes in continuous-record observation, wells, BM1-BM6, 1963–2007, N aquifer, Black Mesa area, northeastern Arizona.



EXPLANATION

CONFINED AND UNCONFINED CONDITIONS IN THE N AQUIFER WITHIN MODEL BOUNDARY

Confined within the boundary of the mathematical model

Unconfined within the boundary of the mathematical model

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

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

Peabody 5 INDUSTIAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—**Peabody 5** is a well number

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

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

Figure 6. Surface-water and water-chemistry data-collection sites, N aquifer, Black Mesa area, northeastern Arizona, 2006–07.

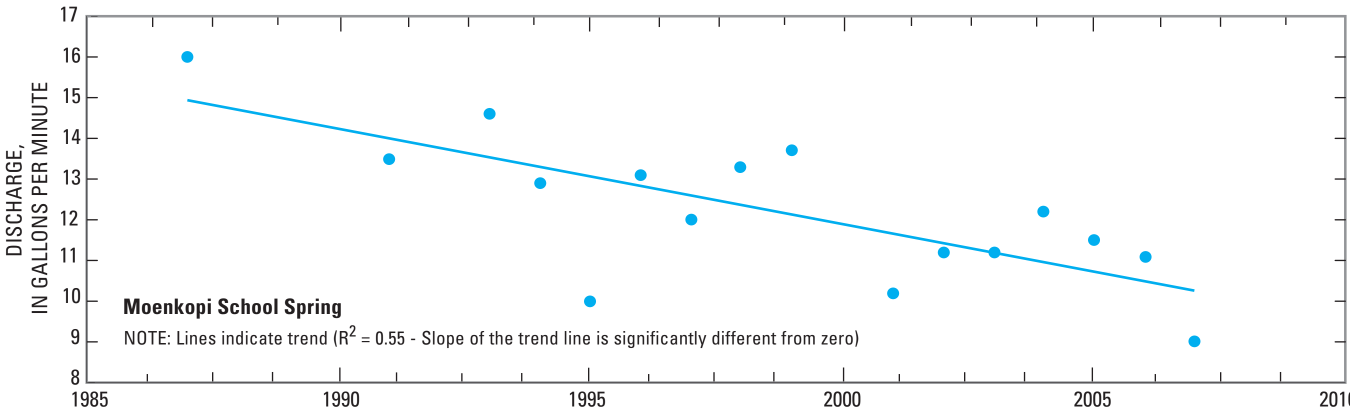


Figure 7. Discharge from Moenkopi School Spring, N aquifer, northeastern Black Mesa area, northeastern Arizona, 1987–2006. Data from earlier measurements at Moenkopi School Spring are not shown because different measuring locations were used. (Trend lines were generated by using the method of least squares).

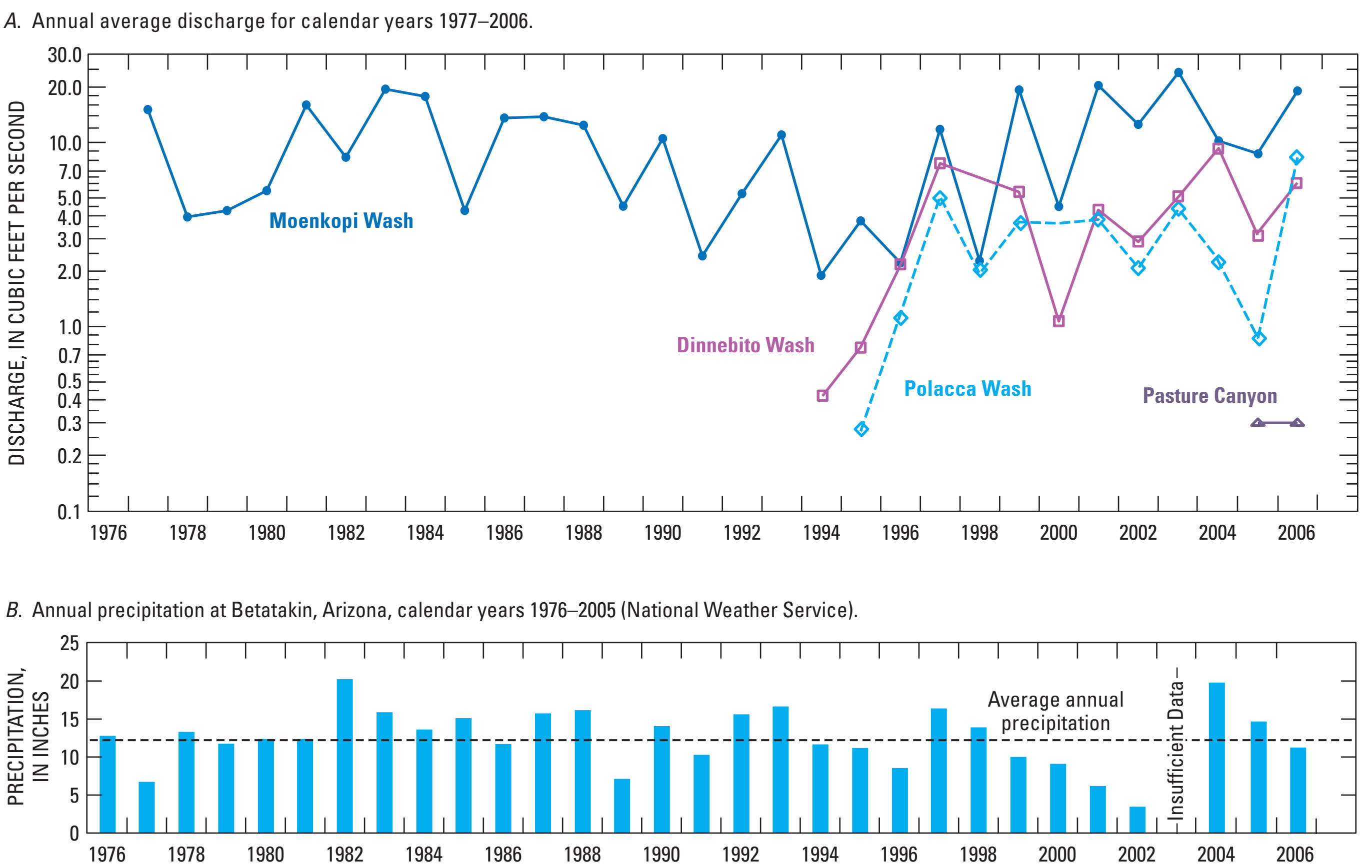
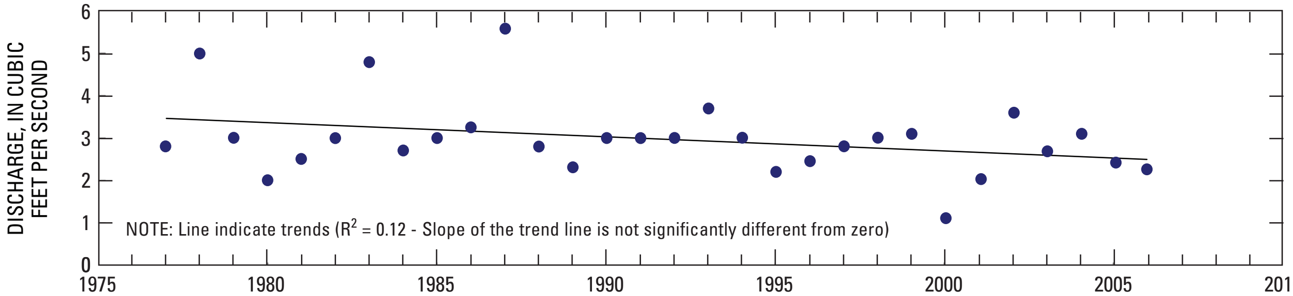
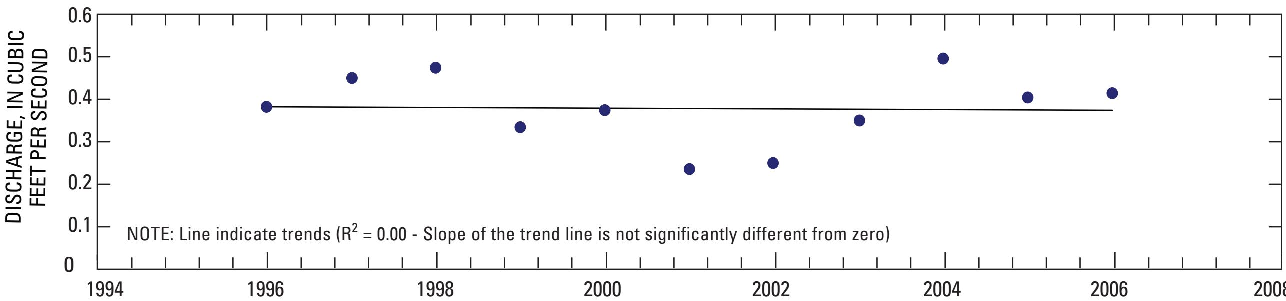


Figure 8. Streamflow characteristics at Moenkopi Wash at Moenkopi (09401260), Pasture Canyon Springs near Tuba City (09401265), Dinnebito Wash near Sand Spring (09401110), and Polacca Wash near Second Mesa (09400568), and annual precipitation at Betatakin, Arizona, Black Mesa area, northeastern Arizona. *A*, Annual average discharge for calendar years 1977–2006; *B*, Annual precipitation at Betatakin, Arizona, calendar years 1976–2006 (National Park Service, Betatakin National Monument, written commun., 2006).

A, Daily median discharge for November, December, January, February, 1977–2006, for Moenkopi Wash at Moenkopi (09401260).



B, Daily median discharge for November, December, January, February, 1996–2006, Dinnebito Wash near Sand Spring (09401110).



C, Daily median discharge for November, December, January, February, 1996–2006, Polacca Wash near Second Mesa (09400568).

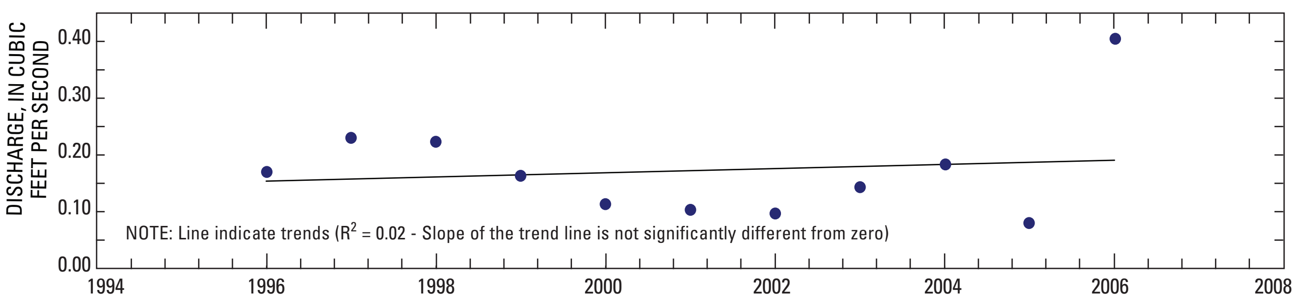


Figure 9. Median discharge for November, December, January, and February for water years 1977–2006 for Moenkopi Wash at (*A*) Moenkopi (09401260), (*B*) Dinnebito Wash near Sand Springs (09401110), and (*C*) Polacca Wash near Second Mesa (09400568), Black Mesa area, northeastern Arizona. Note: Trend lines were generated using the method of least squares.

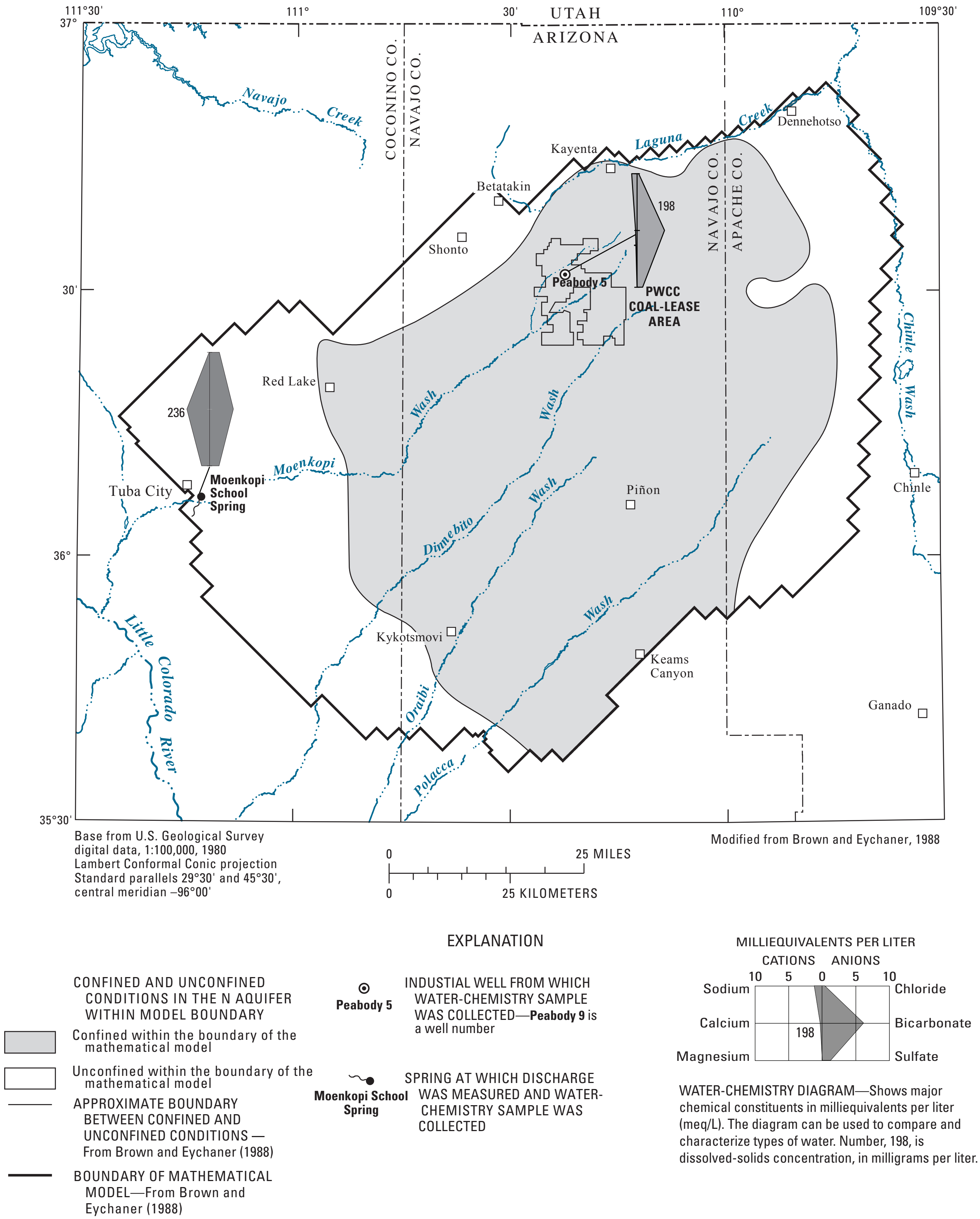


Figure 10. Water chemistry and distribution of dissolved solids in the N aquifer, Black Mesa area, northeastern Arizona, 2007.

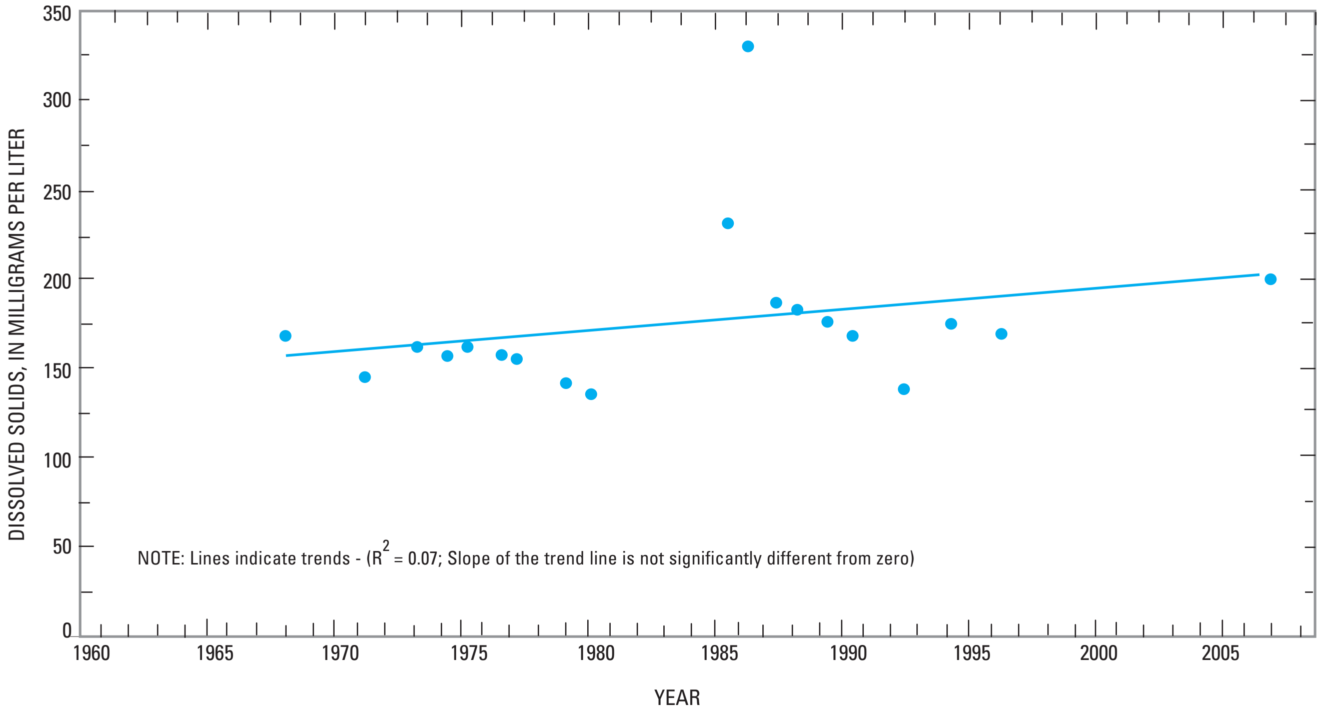


Figure 11. Dissolved-solids concentrations with linear trend line for water samples from industrial well Peabody 5, N aquifer, Black Mesa area, northeastern Arizona, 1980–2007. (Trend lines were generated by using the method of least squares).

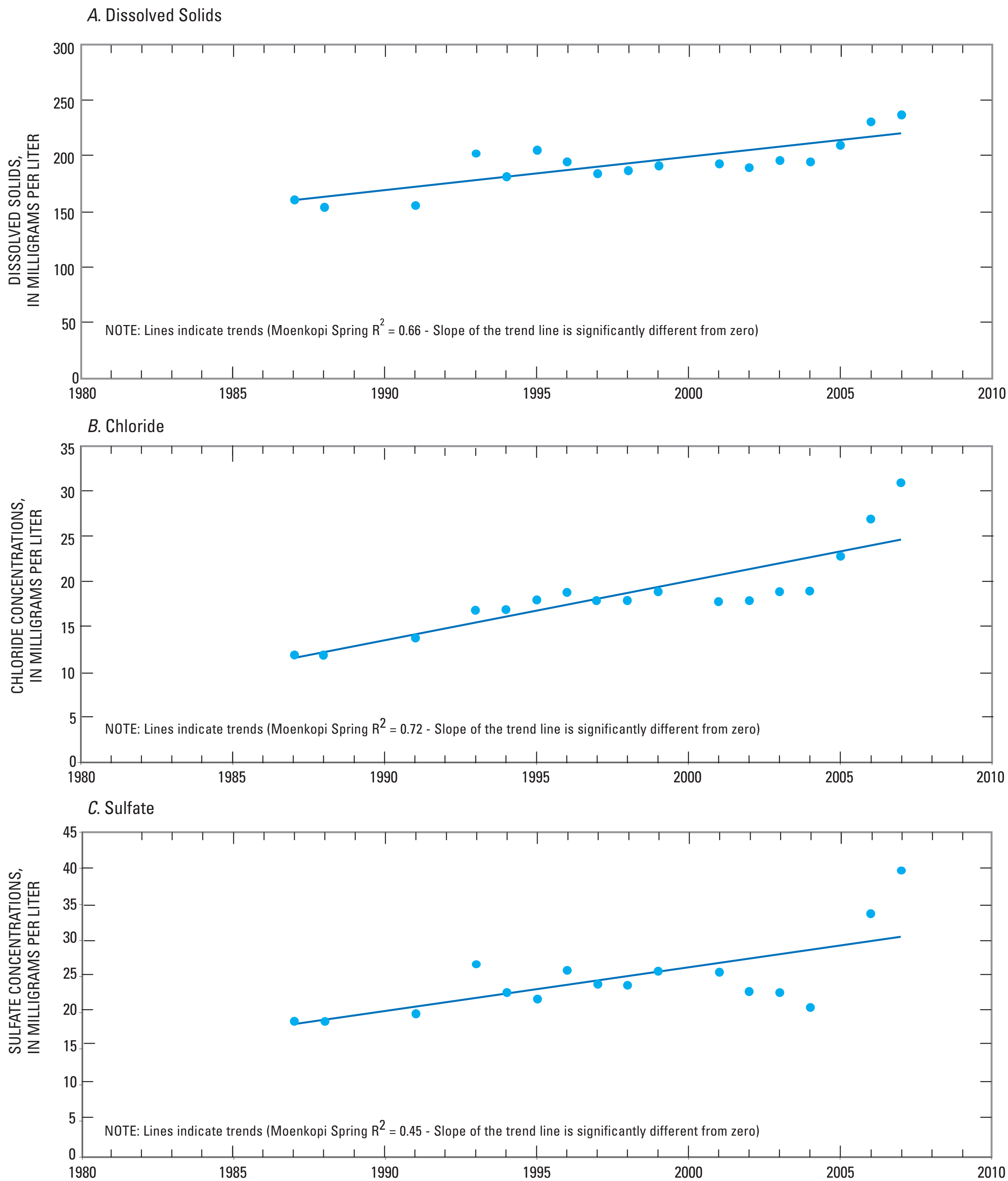


Figure 12. Concentrations of dissolved solids, chloride, and sulfate for water samples from Moenkopi School Spring, N aquifer Black Mesa area, northeastern Arizona, 1984–2007. *A*, Dissolved solids; *B*, Chloride; *C*, Sulfate. (Trend lines were generated by using the method of least squares).

Table 5. Discharge measurements for Moenkopi School Spring, Black Mesa area, northeastern Arizona, 1952–2007.

[Measured discharges may not represent the total discharge from the spring]

Bureau of Indian Affairs site number	Rock formation(s)	Date of measurement	Discharge, in gallons per minute
Moenkopi School Spring[1]			
3GS-77-6	Navajo Sandstone[2]	05–16–52	40.0
		04–22–87	[3]16.0
		11–29–88	[3]43.6
		02–21–91	[3]13.5
		04–07–93	[3]14.6
		12–07–94	[3]12.9
		12–04–95	[3]10.0
		12–16–96	[3]13.1
		12–17–97	[3]12.0
		12–08–98	[3]13.3
		12–13–99	[3]13.7
		03–12–01	[3]10.2
		06–19–02	[3]11.2
		05–01–03	[3]11.2
		03–29–04	[3]12.2
		04–04–05	[3]11.5
		03–13–06	[3]11.1
		05–31–07	[3]9.0

[1]Volumetric discharge measurement.

[2]Interfingering with the Kayenta Formation at this site.

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

Table 6. Discharge data, Moenkopi Wash at Moenkopi, Arizona (09401260), calendar year 2006.

[Dashes indicate no data; e, estimated; units in cubic feet per second (cfs); cfsm, cubic feet per second per square mile]

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.36	0.42	0.41	0.37	0.34	0.28	0.28	0.28	0.27	0.23	0.30	0.32
2	0.36	0.43	0.40	0.38	0.34	0.28	0.28	0.28	0.27	0.23	0.30	0.32
3	0.35	0.42	0.39	0.37	0.34	0.28	0.27	0.28	0.27	0.23	0.30	0.32
4	0.34	0.41	0.41	0.36	0.34	0.28	0.28	0.31	0.27	0.23	0.30	0.32
5	0.35	0.43	0.39	0.36	0.34	0.28	0.28	0.30	0.27	0.25	0.29	0.32
6	0.36	0.43	0.38	0.36	0.33	0.28	0.28	0.28	0.27	0.30	0.30	0.32
7	0.36	0.43	0.38	0.38	0.34	0.27	0.28	0.27	0.27	0.30	0.30	0.32
8	0.36	0.43	0.38	0.37	0.34	0.27	0.29	0.27	0.27	0.30	0.30	0.34
9	0.36	0.43	0.38	0.36	0.34	0.27	0.32	0.27	0.27	0.30	0.30	0.34
10	0.36	0.43	0.38	0.36	0.32	0.27	0.30	0.27	0.27	0.30	0.30	0.34
11	0.36	0.43	0.40	0.36	0.30	0.27	0.30	0.27	0.27	0.28	0.30	0.34
12	0.36	0.43	0.42	0.36	0.30	0.27	0.29	0.29	0.27	0.28	0.30	0.34
13	0.37	0.43	0.42	0.36	0.30	0.26	0.29	0.28	0.27	0.28	0.30	0.34
14	0.37	0.43	0.41	0.36	0.30	0.26	0.29	0.28	0.31	0.29	0.30	0.34
15	0.36	0.41	0.41	e0.35	0.30	0.25	0.29	0.28	e0.28	0.30	0.30	0.35
16	0.36	0.42	e0.35	0.41	0.30	0.25	0.29	0.28	0.26	0.30	0.30	0.36
17	0.36	0.43	e0.35	0.40	0.30	0.25	0.28	0.28	0.25	0.30	0.30	0.36
18	0.36	0.43	e0.35	0.38	0.30	0.25	0.27	0.28	0.25	0.30	0.30	0.36
19	0.38	0.41	e0.35	0.38	0.30	0.25	0.27	0.27	0.25	0.30	0.30	0.36
20	0.38	0.42	e0.35	0.38	0.30	0.25	0.28	0.27	0.25	0.30	0.30	0.36
21	0.38	0.41	e0.35	0.40	0.30	0.25	0.28	0.27	0.23	0.30	0.30	0.36
22	0.37	0.38	0.43	0.33	0.30	0.25	0.28	0.27	0.23	0.30	0.31	0.36
23	0.36	0.38	0.40	0.33	0.30	0.25	0.28	0.27	0.24	0.30	0.32	0.36
24	0.38	0.38	0.38	0.33	0.30	0.25	0.28	0.27	0.24	0.30	0.32	0.36
25	0.38	0.38	0.38	0.34	0.30	0.25	0.28	0.27	0.24	0.30	0.32	0.36
26	0.38	0.38	0.39	0.34	0.30	0.25	0.28	0.27	0.23	0.30	0.32	0.36
27	0.38	0.38	0.38	0.34	0.29	0.26	0.28	0.27	0.23	0.30	0.32	0.36
28	0.38	0.40	0.37	0.34	0.28	0.28	0.28	0.27	0.23	0.30	0.32	0.36
29	0.38	—	0.40	0.34	0.29	0.29	0.29	0.27	0.23	0.30	0.32	0.36
30	0.40	—	0.38	0.34	0.29	0.29	0.30	0.27	0.23	0.30	0.32	0.36
31	0.42	—	0.36	—	0.29	—	0.30	0.27	—	0.30	—	0.36
TOTAL	11.43	11.59	12.18	10.59	9.61	7.94	8.84	8.56	7.69	8.90	9.16	10.73
MEAN	0.37	0.41	0.39	0.35	0.31	0.26	0.29	0.28	0.26	0.29	0.31	0.35
MAX	0.42	0.43	0.43	0.38	0.34	0.29	0.32	0.31	0.31	0.30	0.32	0.36
MIN	0.34	0.38	0.36	0.33	0.28	0.25	0.27	0.27	0.23	0.23	0.29	0.32
MED	0.36	0.42	0.39	0.35	0.30	0.26	0.28	0.27	0.26	0.30	0.30	0.36
AC-FT	23	23	24	21	19	16	18	17	15	18	18	21
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	<0.01	<0.04	<0.01	<0.07	0.00	0.00

	Total	Mean	Max	Min.	Med.	Acre-ft	CFSM
Calendar year 2006	117.22	.32	.43	.23	.32	23.23	.0002

Table 7. Discharge data, Dinnebito Wash near Sand Springs, Arizona (09401110), calendar year 2006.

[Dashes indicate no data; e, estimated; units in cubic feet per second (cfs); cfsm, cubic feet per second per square mile]

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	e0.41	0.45	0.47	0.44	0.36	0.23	0.15	5.8	0.24	0.24	0.36	0.35
2	e0.41	0.46	0.47	0.41	0.34	0.22	0.14	0.79	5.9	0.22	0.35	0.36
3	e0.41	0.44	0.43	0.41	0.31	0.21	0.14	0.45	95	0.23	0.37	0.33
4	0.41	0.43	0.52	0.41	0.31	0.20	0.14	0.80	14	0.23	0.33	0.32
5	0.41	0.43	0.49	0.45	0.32	0.20	0.14	2.3	1.0	0.25	0.32	0.32
6	0.41	0.40	0.44	0.46	0.34	0.19	0.15	7.6	11	122	0.33	0.34
7	0.42	0.42	0.42	0.41	0.34	0.24	0.16	2.5	19	411	0.40	0.37
8	0.42	0.42	0.46	0.40	0.31	0.28	2.0	6.0	85	16	0.39	0.40
9	0.38	0.42	0.43	0.38	0.30	0.21	28	12	7.4	36	0.37	0.44
10	0.36	0.42	0.62	0.35	0.31	0.18	11	7.3	3.2	17	0.35	0.48
11	0.39	0.74	0.56	0.38	0.31	0.17	0.77	2.1	0.68	1.4	0.36	0.44
12	0.42	0.48	0.50	0.38	0.31	0.16	0.23	30	0.28	0.44	0.40	0.41
13	0.40	0.45	0.42	0.38	0.30	0.14	0.17	38	0.26	0.36	0.38	0.42
14	0.43	0.46	0.43	0.39	0.29	0.15	0.16	1.3	137	0.49	0.38	0.43
15	0.43	0.39	0.42	0.43	0.28	0.16	0.14	36	209	220	0.36	0.44
16	0.38	0.44	0.40	0.39	0.28	0.17	0.14	20	7.7	4.7	0.37	0.45
17	0.36	0.43	0.40	0.35	0.28	0.17	0.13	5.3	0.83	0.57	0.38	0.44
18	0.44	0.42	0.39	0.33	0.27	0.16	0.12	0.90	0.32	0.43	0.38	0.46
19	0.44	0.44	0.40	0.37	0.25	0.16	0.14	0.39	0.27	0.39	0.37	0.54
20	0.39	0.46	0.41	0.37	0.25	0.15	0.17	0.26	0.24	0.38	0.38	0.43
21	0.38	0.45	0.45	0.37	0.25	0.14	0.15	1.4	0.23	0.37	0.38	0.42
22	0.39	0.44	0.54	0.35	0.25	0.14	0.14	0.34	0.24	0.36	0.39	0.38
23	0.39	0.45	0.43	0.33	0.25	0.14	41	0.19	0.24	0.36	0.40	0.39
24	0.40	0.44	0.42	0.36	0.26	0.14	6.3	0.18	0.23	0.37	0.41	0.44
25	0.46	0.45	0.41	0.38	0.25	0.14	1.2	170	0.24	e0.39	0.39	0.40
26	0.47	0.43	0.39	0.36	0.22	0.14	2.0	8.2	0.24	0.36	0.38	0.45
27	0.45	0.45	0.40	0.36	0.20	0.14	1.3	1.0	0.23	0.36	0.39	0.51
28	0.43	0.46	0.51	0.38	0.20	0.15	2.9	0.41	0.23	0.38	0.39	0.56
29	0.44	—	0.67	0.34	0.23	0.15	0.70	0.24	0.23	0.38	0.43	0.72
30	0.44	—	0.55	0.35	0.24	0.15	0.56	0.22	0.23	0.36	0.30	0.48
31	0.45	—	0.45	—	0.23	—	241	0.22	—	0.36	—	0.45
TOTAL	12.82	12.57	14.30	11.47	8.64	5.18	341.44	362.19	600.66	836.38	11.19	13.37
MEAN	0.41	0.45	0.46	0.38	0.28	0.17	11.0	11.7	20.0	27.0	0.37	0.43
MAX	0.47	0.74	0.67	0.46	0.36	0.28	241	170	209	411	0.43	0.72
MIN	0.36	0.39	0.39	0.33	0.20	0.14	0.12	0.18	0.23	0.22	0.30	0.32
MED	0.41	0.44	0.43	0.38	0.28	0.16	0.17	1.4	0.30	0.38	0.38	0.43
AC-FT	25	25	28	23	17	10	677	718	1190	1660	22	27
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	< 0.02	< 0.02	< 0.04	< 0.06	0.00	0.00

	Total	Mean	Max	Min.	Med.	Acre-ft	CFSM
Calendar year 2006	2230	6.0	411	.12	.43	4422	.01

Table 8. Discharge data, Polacca Wash near Second Mesa, Arizona (09400568), calendar year 2006.

[Dashes indicate no data; e, estimated; units in cubic feet per second (cfs); cfsm, cubic feet per second per square mile]

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.09	0.08	0.09	0.13	0.27	<0.01	0.00	39	0.25	e0.13	e0.38	e0.19
2	0.10	0.09	0.09	0.11	0.26	<0.01	0.00	2.9	0.28	e0.13	e0.36	e0.21
3	0.08	0.08	0.09	0.12	0.23	<0.01	0.00	0.34	0.26	e0.13	e0.36	e0.20
4	0.07	0.08	0.07	0.13	0.23	<0.01	0.00	0.01	0.26	e0.13	e0.34	e0.21
5	0.07	0.08	0.07	0.17	0.21	<0.01	0.00	30	0.24	e0.13	e0.33	e0.20
6	0.07	0.05	0.08	0.23	0.27	<0.01	0.00	1.8	0.23	191	e0.33	e0.21
7	0.08	0.07	0.10	0.14	0.29	<0.01	0.00	0.68	e0.23	747	e0.33	0.25
8	0.08	0.08	0.08	0.13	0.25	<0.01	0.00	0.21	e0.23	73	0.74	e0.24
9	0.06	0.08	0.09	0.12	0.23	<0.01	0.00	0.03	e0.23	239	0.54	0.19
10	0.02	0.07	0.18	0.13	0.24	<0.01	0.00	6.3	e0.22	63	0.51	e0.18
11	0.05	0.07	0.19	0.13	0.22	<0.01	0.00	4.0	e0.22	29	0.42	0.25
12	0.10	0.06	0.17	0.14	0.21	0.00	0.00	e99	e0.21	20	0.40	0.26
13	0.11	0.08	0.14	0.15	0.20	0.00	0.00	e50	e0.20	18	0.32	0.24
14	0.13	0.09	0.12	0.20	0.19	0.00	0.00	e44	e0.18	39	0.28	e0.25
15	0.13	0.14	0.11	0.18	0.19	0.00	0.00	e83	e0.18	34	0.31	e0.24
16	0.09	0.08	0.10	0.19	0.19	0.00	0.00	e43	e0.17	e26	0.27	e0.24
17	0.04	0.11	0.10	0.20	0.19	0.00	0.00	e20	e0.16	e19	0.23	0.22
18	0.17	0.09	0.11	0.16	0.20	0.00	0.00	e6.6	e0.16	104	0.21	e0.23
19	0.12	0.09	0.09	0.18	0.18	0.00	0.00	e0.70	e0.16	e18	0.19	e0.25
20	0.08	0.09	0.11	0.20	0.15	0.00	0.00	e0.50	e0.16	e2.1	0.19	e0.27
21	0.03	0.09	0.11	0.20	0.11	0.00	0.00	e0.25	e0.16	e1.1	0.17	e0.28
22	0.06	0.09	0.12	0.23	0.14	0.00	0.00	e0.25	e0.15	e1.1	0.17	e0.33
23	0.07	0.09	0.10	0.21	0.09	0.00	0.00	e0.25	e0.15	e0.73	0.15	e0.33
24	0.06	0.09	0.10	0.20	0.10	0.00	0.46	e0.25	e0.15	e0.57	0.13	e0.34
25	0.17	0.08	0.11	0.29	0.09	0.00	0.83	e134	e0.15	e0.42	0.09	e0.33
26	0.17	0.09	0.08	0.29	0.07	0.00	4.4	e38	e0.14	e0.40	0.08	e0.34
27	0.10	0.09	0.09	0.25	0.05	0.00	0.42	e4.6	e0.14	e0.40	0.08	e0.33
28	0.10	0.10	0.15	0.32	0.02	0.00	0.13	e1.1	e0.14	e0.40	0.09	e0.34
29	0.11	—	0.18	0.28	<0.01	0.00	0.30	e9.9	e0.13	e0.40	0.09	e0.35
30	0.10	—	0.17	0.26	<0.01	0.00	0.49	0.27	e0.13	e0.40	0.23	e0.37
31	0.09	—	0.14	—	<0.01	—	761	0.23	—	e0.38	—	e0.37
TOTAL	2.80	2.38	3.53	5.67	5.10	0.11	768.03	621.17	5.67	1629.05	8.32	8.24
MEAN	0.09	0.09	0.11	0.19	0.16	0.00	24.8	20.0	0.19	52.5	0.28	0.27
MAX	0.17	0.14	0.19	0.32	0.29	0.01	761	134	0.28	747	0.74	0.37
MIN	0.02	0.05	0.07	0.11	0.01	0.00	0.00	0.01	0.13	0.13	0.08	0.18
MED	0.09	0.09	0.10	0.18	0.19	0.00	0.00	2.9	0.17	1.1	0.28	0.25
AC-FT	5.6	4.7	7.0	11	10	0.2	1520	1230	11	3230	17	16
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	0.03	<0.02	0.00	< 0.06	0.00	0.00

	Total	Mean	Max	Min.	Med.	Acre-ft	CFSM
Calendar year 2006	3060.07	8.2	761	.01	.18	6062.5	.009

Table 9. Discharge data, Pasture Canyon Springs near Tuba City, Arizona (09401265), calendar year 2006.

[Dashes indicate no data; e, estimated; units in cubic feet per second (cfs)]

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.36	0.42	0.41	0.37	0.34	0.28	0.28	0.28	0.27	0.23	0.30	0.32
2	0.36	0.43	0.40	0.38	0.34	0.28	0.28	0.28	0.27	0.23	0.30	0.32
3	0.35	0.42	0.39	0.37	0.34	0.28	0.27	0.28	0.27	0.23	0.30	0.32
4	0.34	0.41	0.41	0.36	0.34	0.28	0.28	0.31	0.27	0.23	0.30	0.32
5	0.35	0.43	0.39	0.36	0.34	0.28	0.28	0.30	0.27	0.25	0.29	0.32
6	0.36	0.43	0.38	0.36	0.33	0.28	0.28	0.28	0.27	0.30	0.30	0.32
7	0.36	0.43	0.38	0.38	0.34	0.27	0.28	0.27	0.27	0.30	0.30	0.32
8	0.36	0.43	0.38	0.37	0.34	0.27	0.29	0.27	0.27	0.30	0.30	0.34
9	0.36	0.43	0.38	0.36	0.34	0.27	0.32	0.27	0.27	0.30	0.30	0.34
10	0.36	0.43	0.38	0.36	0.32	0.27	0.30	0.27	0.27	0.30	0.30	0.34
11	0.36	0.43	0.40	0.36	0.30	0.27	0.30	0.27	0.27	0.28	0.30	0.34
12	0.36	0.43	0.42	0.36	0.30	0.27	0.29	0.29	0.27	0.28	0.30	0.34
13	0.37	0.43	0.42	0.36	0.30	0.26	0.29	0.28	0.27	0.28	0.30	0.34
14	0.37	0.43	0.41	0.36	0.30	0.26	0.29	0.28	0.31	0.29	0.30	0.34
15	0.36	0.41	0.41	e0.35	0.30	0.25	0.29	0.28	e0.28	0.30	0.30	0.35
16	0.36	0.42	0.41	e0.35	0.30	0.25	0.29	0.28	0.26	0.30	0.30	0.36
17	0.36	0.43	0.40	e0.35	0.30	0.25	0.28	0.28	0.25	0.30	0.30	0.36
18	0.36	0.43	0.38	e0.35	0.30	0.25	0.27	0.28	0.25	0.30	0.30	0.36
19	0.38	0.41	0.38	e0.35	0.30	0.25	0.27	0.27	0.25	0.30	0.30	0.36
20	0.38	0.42	0.38	e0.35	0.30	0.25	0.28	0.27	0.25	0.30	0.30	0.36
21	0.38	0.41	0.40	e0.35	0.30	0.25	0.28	0.27	0.23	0.30	0.30	0.36
22	0.37	0.38	0.43	0.33	0.30	0.25	0.28	0.27	0.23	0.30	0.31	0.36
23	0.36	0.38	0.40	0.33	0.30	0.25	0.28	0.27	0.24	0.30	0.32	0.36
24	0.38	0.38	0.38	0.33	0.30	0.25	0.28	0.27	0.24	0.30	0.32	0.36
25	0.38	0.38	0.38	0.34	0.30	0.25	0.28	0.27	0.24	0.30	0.32	0.36
26	0.38	0.38	0.39	0.34	0.30	0.25	0.28	0.27	0.23	0.30	0.32	0.36
27	0.38	0.38	0.38	0.34	0.29	0.26	0.28	0.27	0.23	0.30	0.32	0.36
28	0.38	0.40	0.37	0.34	0.28	0.28	0.28	0.27	0.23	0.30	0.32	0.36
29	0.38	—	0.40	0.34	0.29	0.29	0.29	0.27	0.23	0.30	0.32	0.36
30	0.40	—	0.38	0.34	0.29	0.29	0.30	0.27	0.23	0.30	0.32	0.36
31	0.42	—	0.36	—	0.29	—	0.30	0.27	—	0.30	—	0.36
TOTAL	11.43	11.59	12.18	10.59	9.61	7.94	8.84	8.56	7.69	8.90	9.16	10.73
MEAN	0.37	0.41	0.39	0.35	0.31	0.26	0.29	0.28	0.26	0.29	0.31	0.35
MAX	0.42	0.43	0.43	0.38	0.34	0.29	0.32	0.31	0.31	0.30	0.32	0.36
MIN	0.34	0.38	0.36	0.33	0.28	0.25	0.27	0.27	0.23	0.23	0.29	0.32
MED	0.36	0.42	0.39	0.35	0.30	0.26	0.28	0.27	0.26	0.30	0.30	0.36
AC-FT	23	23	24	21	19	16	18	17	15	18	18	21

	Total	Mean	Max	Min.	Med.	Acre-ft
Calendar year 2006	117.2	.32	.43	.23	.30	233

Table 10. Date that monitoring program data collection began and drainage areas for streamflow-gaging stations, Black Mesa area, northeastern Arizona.

[Dashes indicate area not determined]

Station name	Station number	Date data collection began	Drainage area, in square miles
Moenkopi Wash at Moenkopi	9401260	July 1976	1,629
Dinnebito Wash near Sand Springs	9401110	June 1993	473
Polacca Wash near Second Mesa	9400568	April 1994	905
Pasture Canyon Spring	9401265	August 2004	—

Table 11. Physical properties and chemical analyses of water from industrial well Peabody 5 completed in the N and D aquifers, Black Mesa area, northeastern Arizona, 2007.

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

Common well name	Peabody 5
U.S. Geological Survey identification number	362901110234101
Date of samples	04-19-2007
Temperature, field (degrees Celsius)	30.9
Specific conductance, field (µS/cm)	331
pH, field, units	9.5
Alkalinity, field, dissolved (mg/L as $CaCO_3$)	121.1
Nitrogen, $NO_2 + NO_3$, dissolved (mg/L as N)	1
Ortho-phosphate, dissolved (mg/L as P)	0.035
Calcium, dissolved (mg/L as Ca)	2.62
Magnesium dissolved (mg/L as Mg)	0.032
Potassium, dissolved (mg/L as K)	0.7
Sodium, dissolved (mg/L as Na)	67.4
Chloride, dissolved, in mg/L as Cl	4.97
Fluoride, dissolved, in mg/L as F	0.26
Silica, dissolved, in mg/L as SiO2	21
Sulfate, dissolved, in mg/L as SO4	23.4
Arsenic, dissolved, in µg/L as As	2.7
Boron, dissolved, in µg/L as B	36
Iron, dissolved, in µg/L as Fe	<6
Dissolved solids residue at 180°C, in mg/L	198

Table 12. Specific conductance and concentrations of selected chemical constituents in water from industrial well Peabody 5 completed in the N and D aquifers, Black Mesa area, northeastern Arizona, 1974–2007.

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

Year	Specific conductance, field, in µS/cm	Dissolved solids, residue at 180°C, in mg/L	Chloride, dissolved, in mg/L as Cl	Sulfate dissolved, in mg/L as SO_4
Peabody 5				
1968	224	168	3.5	16.0
1971	226	145	2.1	12.0
1973	–	162	–	–
1974	210	157	2.7	12.0
1975	240	162	4.0	18.0
1977	220	158	3.0	13.0
1977	220	155	3.0	12.0
1979	220	142	2.9	15.0
1980	210	135	2.9	9.5
1986	398	231	8.0	28.0
1986	602	330	12.0	62.0
1987	270	–	4.6	21.0
1988	270	187	5.1	22.0
1988	263	183	4.1	26.0
1990	262	176	4.1	18.0
1991	260	168	3.0	18.0
1993	257	138	2.3	4.8
1994	279	175	4.7	20.0
1996	–	–	4.1	18.0
1996	274	169	4.1	19.0
2007	331	198	5.0	23.4

Table 13. Physical properties and chemical analyses of N-aquifer water samples from Moenkopi School Spring,Black Mesa area, northeastern Arizona, 2007.

[°C, degree Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Common well name	Peabody 5
U.S. Geological Survey identification number	360632111131101
Bureau of Indian Affairs site number	3GS-77-6
Common spring name	Moenkopi School Spring
Date of samples	05-13-2007
Temperature, field (degrees Celsius)	17.9
Specific conductance, field (µS/cm)	405.3
pH, field, units	7.2
Alkalinity, field, dissolved (mg/L as $CaCO_3$)	105.1
Nitrogen, NO_2 + NO_3, dissolved (mg/L as N)	2.7
Ortho-phosphate, dissolved (mg/L as P)	0.019
Calcium, dissolved (mg/L as Ca)	40.2
Magnesium dissolved (mg/L as Mg)	8.61
Potassium, dissolved (mg/L as K)	1.49
Sodium, dissolved (mg/L as Na)	31.8
Chloride, dissolved, in mg/L as Cl	30.6
Fluoride, dissolved, in mg/L as F	0.18
Silica, dissolved, in mg/L as SiO2	13.2
Sulfate, dissolved, in mg/L as SO4	39.9
Arsenic, dissolved, in µg/L as As	2.5
Boron, dissolved, in µg/L as B	41
Iron, dissolved, in µg/L as Fe	<6
Dissolved solids residue at 180°C, in mg/L	238

Table 14. Specific conductance and concentrations of selected chemical constituents in N-aquifer water samples from Moenkopi School Spring, Black Mesa area, northeastern Arizona, 1948–2007.

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

Year	Specific conductance, field, in µS/cm	Dissolved solids, residue at 180°C, in mg/L	Chloride, dissolved, in mg/L as Cl	Sulfate, dissolved, in mg/L as SO_4
Moenkopi School Spring				
1952	222	–	6	–
1987	270	161	12	19
1988	270	155	12	19
1991	297	157	14	20
1993	313	204	17	27
1994	305	182	17	23
1995	314	206	18	22
1996	332	196	19	26
1997	[1]305	185	18	24
1998	296	188	18	24
1999	305	192	19	26
2001	313	194	18	26
2002	316	191	18	23
2003	344	197	19	23
2004	349	196	19	21
2005	349	212	23	30
2006	387	232	27	34
2007	405	238	31	40

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

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