

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

Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2012–2013

Open-File Report 2015–1221

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

COVER

Photograph of summer flowers on the Navajo Nation with Black Mesa Observation Well #4 in the background. Photograph by J.P. Macy, U.S. Geological Survey.

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By Jamie P. Macy and Margot Truini

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Conversion Factors and Datums

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 (mi ²)	2.590	square kilometer (km ²)
Volume		
acre-foot (acre-ft)	0.001233	cubic hectometer (hm ³)
Flow rate		
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 year (gal/yr)	3.785	liter per year (L/yr)

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).

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

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

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).

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Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2012–2013

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Abstract

The Navajo (N) aquifer is an extensive aquifer and the primary source of groundwater 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 by a growing population and because of low precipitation in the arid climate of the Black Mesa area. Precipitation in the area typically is between 6 and 14 inches per year.

The U.S. Geological Survey water-monitoring program in the Black Mesa area began in 1971 and provides information about the long-term effects of groundwater withdrawals from the N aquifer for industrial and municipal uses. This report presents results of data collected as part of the monitoring program in the Black Mesa area from January 2012 to September 2013. The monitoring program includes measurements of (1) groundwater withdrawals, (2) groundwater levels, (3) spring discharge, (4) surface-water discharge, and (5) groundwater chemistry.

In calendar year 2012, total groundwater withdrawals were 4,010 acre-ft, industrial withdrawals were 1,370 acre-ft, and municipal withdrawals were 2,640 acre-ft. Total withdrawals during 2012 were about 45 percent less than total withdrawals in 2005 because of Peabody Western Coal Company's discontinued use of water to transport coal in a coal slurry pipeline. From 2011 to 2012 total withdrawals decreased by 10 percent; industrial withdrawals decreased by approximately 1 percent, and total municipal withdrawals decreased by 15 percent.

From 2012 to 2013, annually measured water levels in the Black Mesa area declined in 6 of 16 wells that were available for comparison in the unconfined areas of the N aquifer, and the median change was 0.8 feet. Water levels declined in 5 of 16 wells measured in the confined area of the aquifer. The median change for the confined area of the aquifer was 0.3 feet. From the prestress period (prior to 1965) to 2013, the median water-level change for 34 wells in both the confined and unconfined areas was -13.5 feet; the median water-level changes were -0.8 feet for 16 wells measured in the unconfined areas and -51.0 feet for 16 wells measured in the confined area.

Spring flow was measured at four springs in 2013; Burro, Unnamed Spring near Dennehotso, Moenkopi School, and Pasture Canyon Springs. Flow fluctuated during

the period of record for Burro and Unnamed Springs near Dennehotso, but a decreasing trend was apparent at Moenkopi School Spring and Pasture Canyon Spring. Discharge at Burro Spring has remained relatively constant since it was first measured in the 1980s and discharge at Unnamed Spring near Dennehotso has fluctuated for the period of record at each spring. Trend analysis for discharge at Moenkopi School and Pasture Canyon Springs showed a decreasing trend.

Continuous records of surface-water discharge in the Black Mesa area were collected from streamflow-gaging stations at the following sites: Moenkopi Wash at Moenkopi 09401260 (1976 to 2013), Dinnebito Wash near Sand Springs 09401110 (1993 to 2013), Polacca Wash near Second Mesa 09400568 (1994 to 2013), and Pasture Canyon Springs 09401265 (2004 to 2013). Median winter flows (November through February) from these sites for each water year were used as an index of the amount of groundwater discharge. For the period of record of each streamflow-gaging station, the median winter flows have generally remained constant, which suggests no change in groundwater discharge.

In 2013, water samples collected from 12 wells and 4 springs in the Black Mesa area were analyzed for selected chemical constituents, and the results were compared with previous analyses. Concentrations of dissolved solids, chloride, and sulfate have varied at all 12 wells for the period of record, but neither increasing nor decreasing trends over time were found. Dissolved solids, chloride, and sulfate concentrations increased at Moenkopi School Spring during the more than 13 years of record at that site. Concentrations of dissolved solids, chloride, and sulfate at Pasture Canyon Spring have not varied significantly since the early 1980s. Concentrations of dissolved solids, chloride, and sulfate at Burro Spring and Unnamed Spring near Dennehotso have varied for the period of record with no increasing or decreasing trend in the data.

Introduction

The 5,400-mi² Black Mesa study area in northeastern Arizona contains diverse topography that includes flat plains, mesas, and incised drainages (fig. 1). Black Mesa, a topographic high at the center of the study area, encompasses

about 2,000 mi². It has 2,000-foot-high cliffs on its northern and northeastern sides, but it slopes gradually down to the south and southwest. Availability of water is an important issue in the study area because of continued groundwater withdrawals, the growing population, and an arid to semiarid climate with average annual precipitation ranging between 6 and 14 in. (U.S. Department of Agriculture, 1999). The Navajo (N) aquifer is the major source of water for industrial and municipal uses in the Black Mesa area. The N aquifer is composed of three hydraulically connected formations—the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Member of the Wingate Sandstone—that function as a single aquifer (fig. 2).

The N aquifer is confined by overlying stratigraphic units that limit recharge under most of the Black Mesa area. The N aquifer is unconfined in areas surrounding Black Mesa with most of the recharge occurring where the Navajo Sandstone is exposed in the area near Shonto (fig. 1) (Lopes and Hoffmann, 1997).

Within the Black Mesa study area, the Navajo Nation and the Hopi Tribe are the principal municipal water users, and the Peabody Western Coal Company (PWCC) is the principal industrial water user. Total withdrawals of groundwater from the N aquifer in the Black Mesa area increased fairly consistently from 1965 through 2002 (table 1). During the same time period, municipal withdrawals grew from about 70 acre-ft to 3,360 acre-ft. From 2002 to 2012, municipal withdrawals have varied, ranging from 2,640 to 3,100 ac-ft while total withdrawals have declined from 8,000 to 4,010 ac-ft.

The PWCC began operating a strip mine in the northern part of the study area in 1968 (fig. 1). The PWCC's mining operation consisted of two mines on Black Mesa—the Kayenta mine, which supplies coal to the Navajo Generating Station by train, and the Black Mesa mine, which supplied coal to the Mohave Generating Station by a coal slurry pipeline 275 miles away. In 1982, the PWCC sold the largest amount of moisture-adjusted tons of coal to the Mohave Generating Station and the quantity of water pumped by the PWCC increased from about 100 acre-ft in 1968 to a maximum of 4,740 acre-ft in 1982 (John Cochran, Manager of Environmental Hydrology, Peabody Investments Corporation, written commun., 2010).

In 2005 the Mohave Generating Station ceased operations and on December 31, 2005, the PWCC reduced its withdrawals from the N aquifer by approximately 70 percent as a result of discontinued use of a coal slurry pipeline. The two mines at the PWCC have since been combined into the Black Mesa complex, which still delivers coal to the Navajo Generating Station by way of an electric train. From 2006 to 2012, PWCC continued to pump 1,170 to 1,370 acre-ft per year primarily for dust control (table 1).

The members of the Navajo Nation and the Hopi Tribe have been concerned about the long-term effects of groundwater withdrawals from the N aquifer on available groundwater supplies, on stream and spring discharge, and on groundwater 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 Water Commission, which was the predecessor to the present 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), the PWCC, the Hopi Tribe, and the Western Navajo, Chinle, and Hopi Agencies of the BIA have assisted in the collection of hydrologic data.

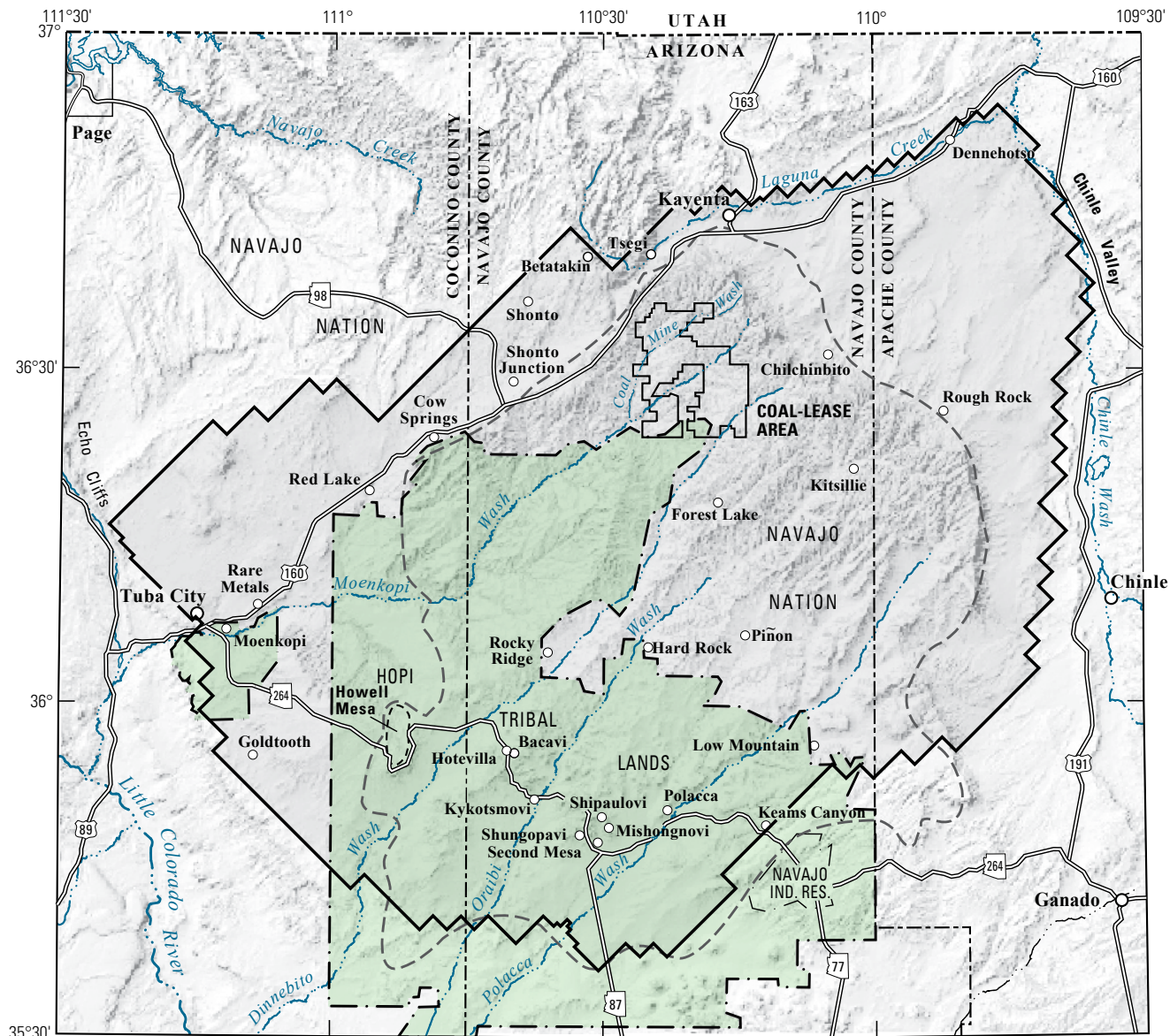
Purpose and Scope

This report presents results of groundwater, surface-water, and water-chemistry monitoring in the Black Mesa area from January 2012 to September 2013. One water level was measured at Kitsillie NTUA 2 in November of 2013, and is the one exception to all data presented from January 2012 to September 2013. Continuous and periodic groundwater and surface-water data are collected to determine the effects of industrial and municipal withdrawals from the N aquifer on groundwater levels, stream and spring discharge, and groundwater chemistry. Groundwater data include water levels, spring-discharge rates, and water chemistry. Surface-water data include discharge rates at four continuous-record streamflow-gaging stations: Moenkopi Wash at Moenkopi (09401260), Dinnebito Wash near Sand Springs (09401110), Polacca Wash near Second Mesa (09400568), and Pasture Canyon Springs (09401265). Together, these data are compared with data from 1965 to 2011 to describe the overall status and change over time of groundwater conditions in the N aquifer, as well as information on how the aquifer responds to groundwater development stresses. Some statistical analyses of the data are included in this report to examine trends in the data that identify groundwater conditions in the N aquifer.

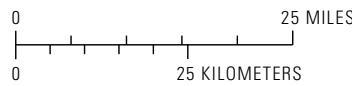
Previous Investigations

Twenty-eight progress reports on the Black Mesa area monitoring program have been prepared by the USGS, and they are summarized in table 2. Most of the data from the Black Mesa area monitoring program are contained in these progress reports and in the USGS National Water Information System (NWIS) database (<http://waterdata.usgs.gov/az/nwis/>).

Stream-discharge and periodic water-quality data collected from Moenkopi Wash at Moenkopi 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 2009 for Moenkopi Wash at Moenkopi (09401260), Dinnebito Wash near Sand Springs (09401110), Polacca Wash near Second Mesa (09400568), Laguna Creek at Dennehotso (09379180), and Pasture Canyon Spring (09401265) in the Black Mesa area were published in White and Garrett (1984, 1986, 1987, 1988), Wilson and Garrett (1988, 1989), Boner and others (1989, 1990, 1991, 1992), Smith and others (1993, 1994, 1995, 1996, 1997), Tadayon and others (1998, 1999, 2000, 2001), McCormack and others (2002, 2003), Fisk and others (2004, 2005, 2006,



Base from U.S. Geological Survey digital data, 1:100,000, 1980
 Lambert Conformal Conic projection Standard parallels 29°30'
 and 45°30', central meridian -111°30'



Modified from Brown and Eychaner, 1988

EXPLANATION




-  **Boundary of Black Mesa**
-  **Area of Hopi Tribal Lands within Navajo Nation**
-  **Boundary of mathematical model**—From Brown and Eychaner (1988). The boundary delineates the extent of the N aquifer monitored in the study area.



Figure 1. Map showing location of study area, Black Mesa area, northeastern Arizona.

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Table 1. Groundwater withdrawals from the N aquifer, Black Mesa area, northeastern Arizona, 1965–2012.

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

Calendar Year	Industrial ¹	Municipal ^{2,3}		Total withdrawals
		Confined	Unconfined	
1965	0	50	20	70
1966	0	110	30	140
1967	0	120	50	170
1968	100	150	100	350
1969	40	200	100	340
1970	740	280	150	1,170
1971	1,900	340	150	2,390
1972	3,680	370	250	4,300
1973	3,520	530	300	4,350
1974	3,830	580	360	4,770
1975	3,500	600	510	4,610
1976	4,180	690	640	5,510
1977	4,090	750	730	5,570
1978	3,000	830	930	4,760
1979	3,500	860	930	5,290
1980	3,540	910	880	5,330
1981	4,010	960	1,000	5,970
1982	4,740	870	960	6,570
1983	4,460	1,360	1,280	7,100
1984	4,170	1,070	1,400	6,640
1985	2,520	1,040	1,160	4,720
1986	4,480	970	1,260	6,710
1987	3,830	1,130	1,280	6,240
1988	4,090	1,250	1,310	6,650
1989	3,450	1,070	1,400	5,920
1990	3,430	1,170	1,210	5,810
1991	4,020	1,140	1,300	6,460
1992	3,820	1,180	1,410	6,410
1993	3,700	1,250	1,570	6,520
1994	4,080	1,210	1,600	6,890
1995	4,340	1,220	1,510	7,070
1996	4,010	1,380	1,650	7,040
1997	4,130	1,380	1,580	7,090
1998	4,030	1,440	1,590	7,060
1999	4,210	1,420	1,480	7,110
2000	4,490	1,610	1,640	7,740
2001	4,530	1,490	1,660	7,680
2002	4,640	1,500	1,860	8,000
2003	4,450	1,350	1,440	7,240
2004	4,370	1,240	1,600	7,210
2005	4,480	1,280	1,570	7,330
2006	1,200	⁴ 1,300	⁴ 1,600	⁴ 4,100
2007	1,170	1,460	1,640	4,270
2008	1,210	^{5,6} 1,430	⁵ 1,560	⁶ 4,200
2009	1,390	1,440	1,400	4,230
2010	1,170	⁴ 1,450	1,420	⁴ 4,040
2011	1,390	⁴ 1,460	1,630	⁴ 4,480
2012	1,370	⁴ 1,380	1,260	⁴ 4,010

¹Metered pumpage from the confined part of the aquifer by Peabody Western Coal Company.

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

³Includes 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, 1986–2011.

⁴Navajo Tribal Utility Authority meter data were incomplete; therefore, municipal withdrawals are estimated, and total withdrawal uses an estimation in the calculation.

⁵Confined and unconfined totals were reversed in previous reports.

⁶Confined withdrawals are about 90 acre-ft greater than previously reported.

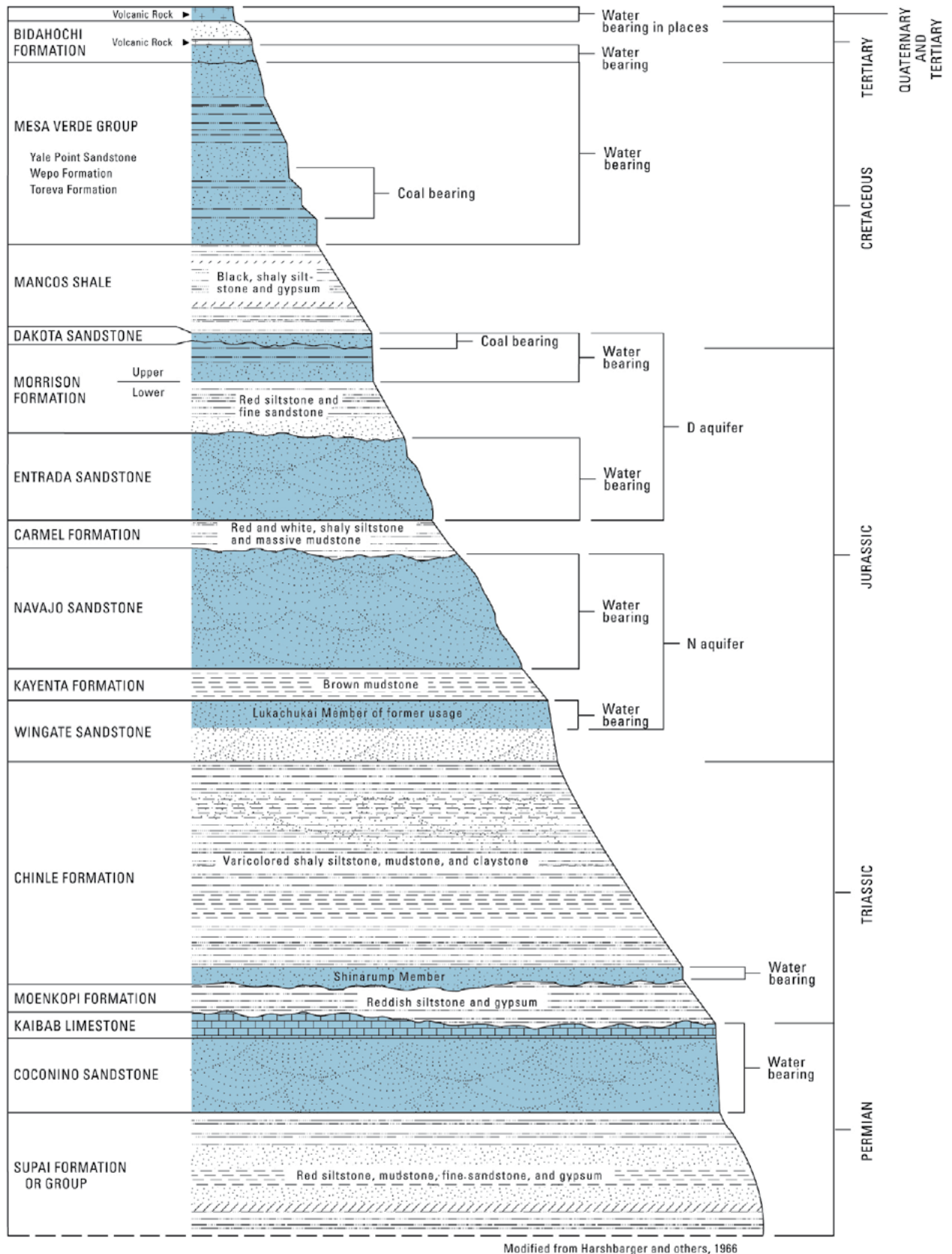


Figure 2. Stratigraphic section showing rock formations and hydrogeologic units of the Black Mesa area, northeastern Arizona (not to scale). The N aquifer is approximately 1,000 feet thick.

Table 2. Tabulated list of progress reports for the Black Mesa monitoring program 1978–2013.

Year Published	Author(s)	Title and year		USGS Report Type and Number
1978	U.S. Geological Survey	Progress report on Black Mesa monitoring program	1977	Open-File Report 78–459
1985	Hill, G.W.		1984	Open-File Report 85–483
1986	Hill, G.W., and Whetten, M.I.		1985–86	Open-File Report 86–414
1987	Hill, G.W., and Sottolare, J.P.	Progress report on the ground-water, surface-water, and quality-of-water monitoring program, Black Mesa area, northeastern Arizona	1987	Open-File Report 87–458
1988	Hart, R.J., and Sottolare, J.P.		1987–88	Open-File Report 88–467
1989	Hart, R.J., and Sottolare, J.P.		1988–89	Open-File Report 89–383
1992	Sottolare, J.P.	Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona	1989–90	Water-Resources Investigations Report 92–4008
1992	Littin, G.R.		1990–91	Water-Resources Investigations Report 92–4045
1993	Littin, G.R.		1991–92	Water-Resources Investigations Report 93–4111
1995	Littin, G.R., and Monroe, S.A.		1992–93	Water-Resources Investigations Report 95–4156
1995	Littin, G.R., and Monroe, S.A.		1994	Water-Resources Investigations Report 95–4238
1996	Littin, G.R., and Monroe, S.A.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona	1995	Open-File Report 96–616
1997	Littin, G.R., and Monroe, S.A.		1996	Open-File Report 97–566
1999	Littin, G.R., Baum, B.M., and Truini, M.		1997	Open-File Report 98–653
2000	Truini, M., Baum, B.M., Littin, G.R., and Shingoitewa-Honanie, G.		1998	Open-File Report 00–66
2000	Thomas, B.E., and Truini, M.		1999	Open-File Report 00–453
2002	Thomas, B.E.	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	2000–01	Water-Resources Investigations Report 02–4211
2002	Thomas, B.E.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona	2001–02	Open-File Report 02–485
2004	Truini, M., and Thomas, B.E.		2002–03	Open-File Report 03–503
2005	Truini, M., Macy, J.P., and Porter T.J.		2003–04	Open-File Report 2005–1080
2006	Truini, M., and Macy, J.P.		2004–05	Open-File Report 2006–1058
2007	Truini, M., and Macy, J.P.		2005–06	Open-File Report 2007–1041
2008	Truini, M., and Macy, J.P.		2006–07	Open-File Report 2008–1324
2009	Macy, J.P.		2007–2008	Open-File Report 2009–1148
2010	Macy, J.P.		2008–2009	Open-File Report 2010–1038
2011	Macy, J.P., and Brown, C.R.		2009–2010	Open-File Report 2011–1198
2012	Macy, J.P., Brown, C.R., and Anderson, J.R.		2010–2011	Open-File Report 2012–1102
2013	Macy, J.P. and Unema, J.A.		2011–2012	Open-File Report 2013–1304

2007, 2008, 2009, 2010, and 2011), and online for year 2006 to present at (<http://wdr.water.usgs.gov>). 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 groundwater flow in the N aquifer. Brown and Eychaner (1988) recalibrated Eychaner's model by using a finer grid and by using revised estimates of selected aquifer characteristics. Sottolare (1992) updated the simulated effects of pumping through 1992 with the revised model. Thomas (2002a) completed a performance-and-sensitivity analysis of the revised USGS model. GeoTrans, Inc. (1987) also developed a two-dimensional numerical model of the N aquifer in the 1980s. In the late 1990s, HSI GeoTrans, Inc., and Waterstone Environmental Hydrology and Engineering (1999) developed a three-dimensional numerical model of the N aquifer and the overlying Dakota (D) aquifer.

Kister and Hatchett (1963) made the first comprehensive evaluation of the chemistry of water collected from wells and springs in the Black Mesa area. HSI GeoTrans, Inc. (1993) evaluated the major-ion and isotopic chemistry of the D and N aquifers. Lopes and Hoffmann (1997) analyzed groundwater ages, recharge, and hydraulic conductivity of the N aquifer by using geochemical techniques. Zhu and others (1998) estimated groundwater recharge in the Black Mesa area by using isotopic data and flow estimates from the N-aquifer model developed by GeoTrans, Inc. (1987). Zhu (2000) estimated recharge using advective transport modeling and the same isotopic data from the GeoTrans model. Truini and Longworth (2003) described the hydrogeology of the D aquifer and the movement and ages of groundwater in the Black Mesa area by using data from geochemical and isotopic analyses. Truini and Macy (2005) addressed leakage through the confining unit between the D aquifer and the N aquifer as part of an investigation of the Carmel Formation.

Hydrologic Data

In 2012–13, activities of the Black Mesa area monitoring program included metered groundwater withdrawals, measurements of groundwater levels, spring-discharge measurements from the N aquifer, streamflow gaging, and the collection of water-chemistry samples from wells and springs developed in or discharging from the N aquifer. All data were collected by the USGS except withdrawal data from NTUA wells, which were compiled by NTUA personnel. Linear regression and Kendall's tau trend analyses were applied to streamflow data, spring-discharge measurements, and water-chemistry samples by using TIBCO Spotfire S+ statistical software (TIBCO Software, Inc.; Sommerville, MA). Annual discharge measurements were

made at 4 springs, and annual groundwater-level measurements were attempted at 34 wells. Of the 34 wells, six are continuous-recording observation wells that have been outfitted for real-time data telemetry (referred to as "BM" in table 3). Table 3 contains well names and site identification numbers for wells where annual water-level measurements are made and where water-quality samples are collected. The water-level data from these six continuous-recording observation wells are available online (<http://waterdata.usgs.gov/az/nwis/gw>). Groundwater-withdrawal data were compiled during January 2013. The period before appreciable groundwater withdrawals began for mining or municipal purposes (about 1965) is referred to in this report as the "prestress period." Spring discharges and groundwater levels were measured in March 2013 except a measurement from Kitsillie NTUA 2, which was measured in November 2013. Groundwater samples were collected from 12 wells and 4 springs in August 2013 and were analyzed for chemical constituents. Annual groundwater-withdrawal data are collected from 36 well systems within the NTUA, BIA, and Hopi municipal systems and the PWCC industrial well field. Identification information for the 34 wells used for water-level measurements as well as identification information for wells used for water-quality sampling is shown in table 3. Streamflow data are collected at four USGS gaging stations and are available online (<http://waterdata.usgs.gov/az/nwis/rt>). All annual data reported in this document are for calendar years beginning January 1 and ending December 31; however, streamflow data are reported in water years beginning October 1 and ending September 30, with the exception of tables 10–13, which are reported in calendar years.

Groundwater Withdrawals from the N Aquifer

Total annual withdrawals from the N aquifer are monitored on a continuing basis to determine the effects from industrial and municipal pumping. 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 36 well systems. Information about withdrawals from N aquifer is compiled primarily on the basis of metered data from individual wells operated by the BIA, NTUA, and Hopi Tribe (table 4).

Withdrawals from wells equipped with windmills are not measured in this monitoring program and are not included in total withdrawal values reported here. About 270 windmills in the Black Mesa area withdraw water from the Coconino (C), D, N, Toreva (T), Bidahochi, and alluvial aquifers, primarily for watering livestock. The estimated total withdrawal by the windmills from the N aquifer is about 65 acre-ft/yr (HSI GeoTrans, Inc., and Waterstone Environmental Hydrology and Engineering, Inc., 1999). The total withdrawal by the windmills is less than 1 percent of the total annual withdrawal from the N aquifer.

8 Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2012–2013

Table 3. Identification numbers and names of monitoring program study wells, 2012–13, Black Mesa area, northeastern Arizona.

[---, 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	---
355215110375001	Kykotsmovi PM2	---
355230110365801	Kykotsmovi PM1	---
355236110364501	Kykotsmovi PM3	---
355428111084601	Goldtooth	3A-28
355924110485001	Howell Mesa	3K-311
360055110304001	BM observation well 5	4T-519
360217111122601	Tuba City	3K-325
360527110122501	Piñon NTUA 1	---
360614110130801	Piñon PM6	---
360734111144801	Tuba City	3T-333
360904111140201	Tuba City NTUA 1	3T-508
360918111080701	Tuba City Rare Metals 2	---
360924111142201	Tuba City NTUA 3	---
360953111142401	Tuba City NTUA 4	3T-546
361225110240701	BM observation well 6	---
361737110180301	Forest Lake NTUA 1	4T-523
361832109462701	Rough Rock	10T-258
362043110030501	Kits'iili NTUA 2	---
362149109463301	Rough Rock	10R-111
362418109514601	Rough Rock PM5	---
362406110563201	White Mesa Arch	1K-214
362823109463101	Rough Rock	10R-119
362936109564101	BM observation well 1	8T-537
363005110250901	Peabody 2	---
363013109584901	Sweetwater Mesa	8K-443
363103109445201	Rough Rock	9Y-95
363143110355001	BM observation well 4	2T-514
363213110342001	Shonto Southeast	2K-301
363232109465601	Rough Rock	9Y-92
363309110420501	Shonto	2K-300
363423110305501	Shonto Southeast	2T-502
363558110392501	Shonto PM2	---
363727110274501	Long House Valley	8T-510
363850110100801	BM observation well 2	8T-538
364034110240001	Marsh Pass	8T-522
364226110171701	Kayenta West	8T-541
364248109514601	Northeast Rough Rock	8A-180
364338110154601	BM observation well 3	8T-500
364344110151201	Kayenta PM2	8A-295
365045109504001	Dennehotso PM2	---

Table 4. Groundwater withdrawals from the N aquifer by well system, Black Mesa area, northeastern Arizona, calendar year 2012.

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

Well system (one or more wells)	Owner	Source of data	Withdrawals	
			Confined aquifer	Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	2.9	
Dennehotso	BIA	USGS/BIA		13.7
Hopi High School	BIA	USGS/BIA	24.8	
Hotevilla	BIA	USGS/BIA	24.8	
Kayenta	BIA	USGS/BIA	24.8	
Keams Canyon	BIA	USGS/BIA	29.3	
Low Mountain	BIA	USGS/BIA	10	
Piñon	BIA	USGS/BIA	10	
Red Lake	BIA	USGS/BIA		4.2
Rocky Ridge	BIA	USGS/BIA	6.0	
Rough Rock	BIA	USGS/BIA	12.7	
Second Mesa	BIA	USGS/BIA	6.0	
Shonto	BIA	USGS/BIA		128.8
Tuba City	BIA	USGS/BIA		89.1
Chilchinbito	NTUA	USGS/NTUA	69.0	
Dennehotso	NTUA	USGS/NTUA		46.5
Forest Lake	NTUA	USGS/NTUA	12.5	
Hard Rock	NTUA	USGS/NTUA	46.5	
Kayenta	NTUA	USGS/NTUA	2402.2	
Kits'iili	NTUA	USGS/NTUA	19.6	
Piñon	NTUA	USGS/NTUA	338.0	
Red Lake	NTUA	USGS/NTUA		50.6
Rough Rock	NTUA	USGS/NTUA	42.1	
Shonto	NTUA	USGS/NTUA		13.3
Shonto Junction	NTUA	USGS/NTUA		85.0
Tuba City	NTUA	USGS/NTUA		757.7
Mine Well Field	Peabody	Peabody	1,370	
Bacavi	Hopi	USGS/Hopi	26.5	
Hopi Civic Center	Hopi	USGS/Hopi	1.8	
Hopi Cultural Center	Hopi	USGS/Hopi	5.6	
Kykotsmovi	Hopi	USGS/Hopi	67.6	
Mishongnovi	Hopi	USGS/Hopi	3.8	
Moenkopi	Hopi	USGS/Hopi		67.9
Polacca	Hopi	USGS/Hopi	162.1	
Shipaulovi	Hopi	USGS/Hopi	23.1	
Shungopovi	Hopi	USGS/Hopi	32.4	

¹Well taken out of service.

²Estimated value due to partial record.

Withdrawals in Calendar Year 2012 Compared to Previous Years

In 2012, the total groundwater withdrawal from the N aquifer was about 4,010 acre-ft (tables 1 and 4). Total withdrawals for municipal use in 2012 was about 2,640 acre-ft; withdrawals from the confined area totaled about 1,380 acre-ft, while withdrawals from the unconfined areas totaled about 1,260 acre-ft. Withdrawals for industrial use totaled about 1,370 acre-ft, a 1-percent decrease from 2011 (tables 1 and 5). Total withdrawals in 2012 for municipal use decreased by about 15 percent from the previous year; this equates to a 5-percent decrease in withdrawals for municipal use from the confined areas of the aquifer, and a 23-percent decrease in withdrawals from the unconfined areas.

Groundwater withdrawals from the N aquifer have varied from 1965 to the present, generally increased from 1965 to 2005 and decreased from 2006 to 2012. Beginning in 2006, the Peabody Western Coal Company reduced their pumping by 70 percent, a reduction that is reflected by a decrease in total annual withdrawals from 2005 by about 42 percent (tables 1 and 5, fig. 3). Total withdrawal for the period of record (1965–2012) totaled 247,670 acre-ft; industrial withdrawals represent 59 percent and municipal withdrawals represent 41 percent of the total (table 5). From 1965 to 2005, total annual withdrawals increased from 70 acre-ft to a maximum of 8,000 acre-ft (table 1); industrial withdrawals were 63 percent and municipal withdrawals were 37 percent of the total (table 5). A significant change in the amount of water being pumped from the N aquifer occurred in 2006; industrial withdrawals accounted for only about 30 percent of the total withdrawals compared to 63 percent the previous year (table 5). From 2006 to 2012, withdrawals totaled 29,370 acre-ft; industrial withdrawals were 30 percent and municipal withdrawals were 70 percent of total withdrawals (table 5). Total withdrawals in 2012 were 4,010 acre-ft, with 34 percent from industrial withdrawals and 66 percent from municipal withdrawals (table 5).

Table 5. Total, industrial, and municipal groundwater withdrawals from the N aquifer for discrete time periods from 1965 to 2012, Black Mesa area, northeastern Arizona.

Period	Withdrawals (acre-feet)			Percent	
	Total	Industrial	Municipal	Industrial	Municipal
1965–2012	247,670	147,000	100,670	59	41
1965-2005	218,300	138,100	80,200	63	37
2006-2012	29,370	8,900	20,470	30	70
2012	4,010	1,370	2,640	34	66

Groundwater Levels in the N Aquifer

Groundwater levels are monitored in the N aquifer to determine the effects that withdrawals have on the potentiometric surface of the aquifer. Groundwater 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. 4). From the recharge areas near Shonto, groundwater 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).

Groundwater levels are measured once a year at the same time of year to limit the effect of seasonal variability. Groundwater levels are compared with levels from previous years to determine short-term changes and also are compared to prestress water levels to determine long-term changes. Only water levels from municipal and stock wells that were not considered to have been recently pumped, affected by nearby pumping, or blocked or obstructed are compared. Water levels in 32 of the 34 wells having annual measurements from both 2012 and 2013 met these criteria (table 6).

All of the well measurements were taken in March 2013 except for the measurement at Kitsillie NTUA 2, which was measured in November 2013 because of issues with accessibility to the well. Of the 32 wells sampled, 6 are

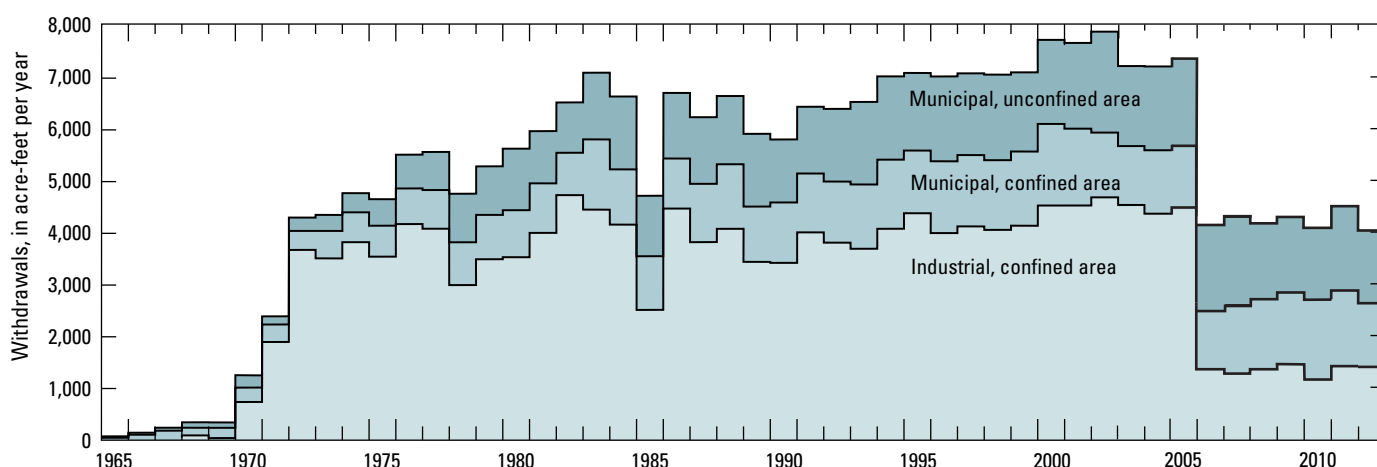
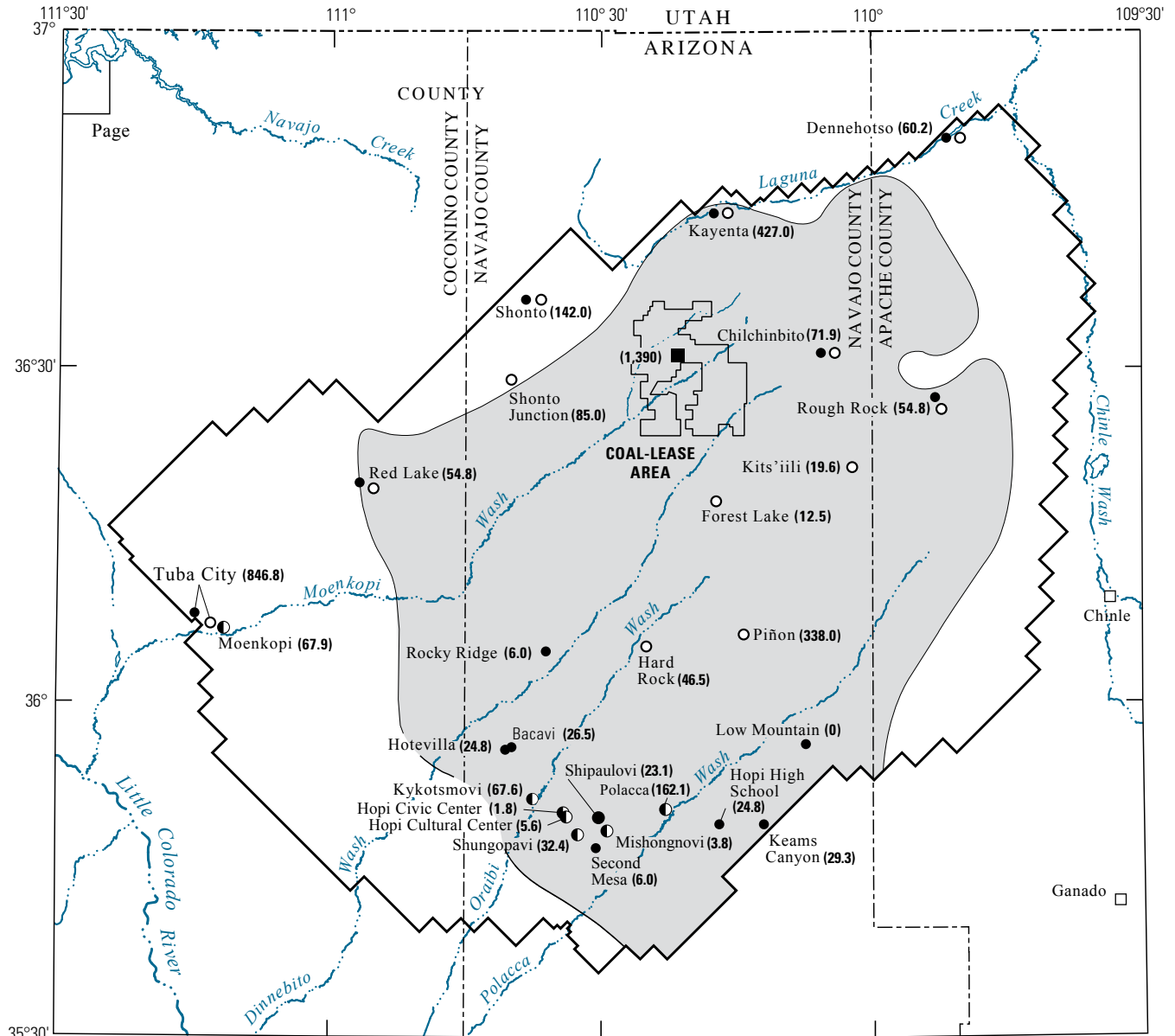


Figure 3. Plot of annual groundwater withdrawals from the N aquifer. Black Mesa area, northeastern Arizona, 1965–2012.

10 Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2012–2013



Base from U.S. Geological Survey digital data, 1:100,000, 1980 Lambert Conformal Conic projection Standard parallels 29°30' and 45°30', central meridian -96°00'



Modified from Brown and Eychaner, 1988

EXPLANATION

Confined and unconfined conditions in the N aquifer within model boundary



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

Withdrawals from the n aquifer—Piñon, well-system name; 338.0, total withdrawal in acre-feet for 2012. The total is cumulative at locations served by multiple wells

Figure 4. Map showing locations of well systems monitored for annual withdrawals from the N aquifer, Black Mesa area, northeastern Arizona, calendar year 2012.

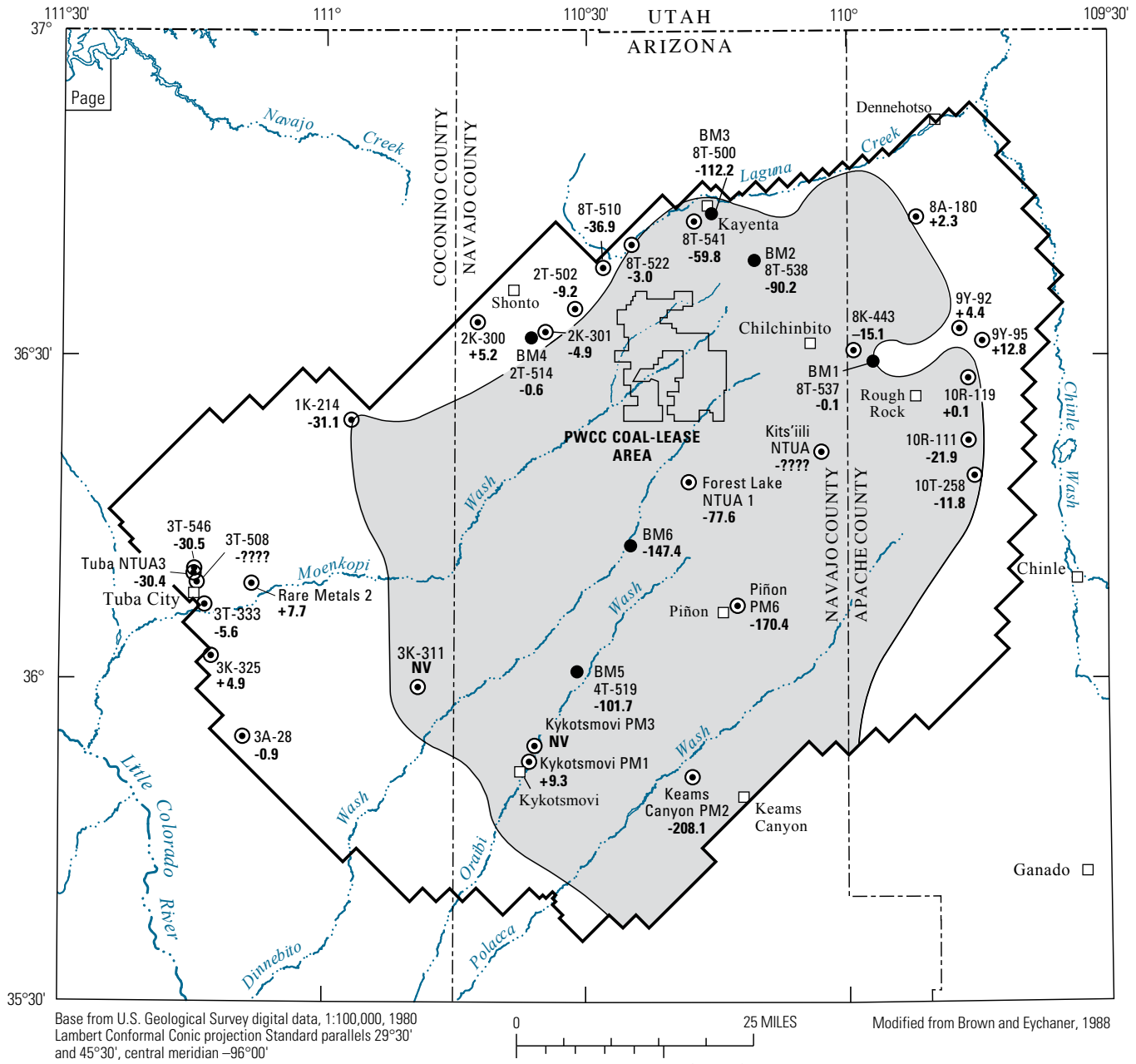
Table 6. Water-level changes in monitoring program wells completed in the N aquifer, Black Mesa area, northeastern Arizona, prestress period to calendar year 2013.

[---, no data; 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), 2013	Prestress period water level		Change in water level from prestress period to 2013 (feet)
		2012	2013		Feet below land surface	Date	
Unconfined areas							
BM observation well 1 ¹	8T-537	-0.1	0.4	374.1	374.0	(¹)	-0.1
BM observation well 4 ¹	2T-514	0.2	0.4	216.6	216.0	(¹)	-0.6
Goldtooth	3A-28	-2.3	2.3	230.9	230.0	10-29-53	-0.9
Long House Valley	8T-510	-1.0	-0.3	136.3	99.4	08-22-67	-36.9
Northeast Rough Rock	8A-180	(²)	0.0	44.6	46.9	11-13-53	2.3
Rough Rock	9Y-95	-1.4	0.3	106.7	119.5	08-03-49	12.8
Rough Rock	9Y-92	0.3	0.4	164.4	168.8	12-13-52	4.4
Shonto	2K-300	0.2	0.1	171.3	176.5	06-13-50	5.2
Shonto Southeast	2K-301	0.3	0.5	288.8	283.9	12-10-52	-4.9
Shonto Southeast	2T-502	-1.4	1.6	415.0	405.8	08-22-67	-9.2
Tuba City	3T-333	0.6	-0.4	28.6	23.0	12-02-55	-5.6
Tuba City	3K-325	1.1	-1.1	203.1	208.0	06-30-55	4.9
Tuba City Rare Metals 2	---	0.2	0.1	49.3	57.0	09-24-55	7.7
Tuba City NTUA 1	3T-508	-4.2	-9.4	78.0	29.0	02-12-69	-49.0
Tuba City NTUA 3	---	-4.6	-1.2	64.6	34.2	11-08-71	-30.4
Tuba City NTUA 4	3T-546	-7.1	-0.1	64.2	33.7	08-06-71	-30.5
Confined areas							
BM observation well 2 ¹	8T-538	1.1	1.4	215.2	125.0	(¹)	-90.2
BM observation well 3 ¹	8T-500	0.2	-3.4	167.2	55.0	04-29-63	-112.2
BM observation well 5 ¹	4T-519	-0.3	1.5	425.7	324.0	(¹)	-101.7
BM observation well 6 ¹	---	2.5	3.6	844.4	697.0	(¹)	-147.4
Forest Lake NTUA 1	4T-523	4.6	0.2	1,173.6	1,096R	05-21-82	-77.6
Howell Mesa	3K-311	6.4	(²)	---	463.0	11-03-53	(²)
Kayenta West	8T-541	-1.9	8.3	289.8	230.0	03-17-76	-59.8
Keams Canyon PM2	---	8.4	-2.6	500.6	292.5	06-10-70	-208.1
Kits'iili NTUA 2	---	4.2	-4.5	1,340.1	³ 1,297.9	01-14-99	-42.2
Kykotsmovi PM1	---	-0.1	1.4	210.7	220.0	05-20-67	9.3
Kykotsmovi PM3	---	-0.1	(²)	---	210.0	08-28-68	(²)
Marsh Pass	8T-522	-0.5	-0.9	128.5	125.5	02-07-72	-3.0
Piñon PM6	---	-4.0	3.0	914.0	743.6	05-28-70	-170.4
Rough Rock	10R-119	1.5	0.4	256.5	256.6	12-02-53	0.1
Rough Rock	10T-258	0.8	-1.0	312.8	301.0	04-14-60	-11.8
Rough Rock	10R-111	-6.1	6.9	191.9	170.0	08-04-54	-21.9
Sweetwater Mesa	8K-443	-1.0	0.9	544.5	529.4	09-26-67	-15.1
White Mesa Arch	1K-214	-0.1	0.7	219.1	188.0	06-04-53	-31.1

¹Continuous recorder. Prestress water levels were estimated from a ground-water model, except for well BM3 (Brown and Eychaner, 1988).²Cannot be determined because at least one of the water-level measurements is not available.³Water level is the first water level measured after completion of well.

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EXPLANATION

- Confined and unconfined conditions in the N aquifer**
- Confined area within the boundary of the mathematical boundary
- Unconfined area within the boundary of the mathematical boundary
- Approximate boundary between confined and unconfined conditions—**
From Brown and Eychaner (1988)
- Boundary of mathematical model—**
From Brown and Eychaner (1988)
- Well in which depth to water was measured annually—**
First entry, 2K-300, is Bureau of Indian Affairs site number; second entry, +5.2, is change in water level, in feet, between measurement made during the prestress period and measurement made during 2013
- Continuous water-level recording site (observation well) maintained by the U.S. Geological Survey—**
First entry, BM2, is U.S. Geological Survey well number; second entry, 8T-538, is Bureau of Indian Affairs site number; third entry, -90.2, is change in water level, in feet, from simulated prestress period to 2013

Figure 5. Map showing water-level changes in N-aquifer wells from the prestress period (prior to 1965) to 2013, Black Mesa area, northeastern Arizona.

Table 7. Well-construction characteristics, depth to top of N aquifer, and type of data collected for wells in monitoring program 2012–13, Black Mesa area, northeastern Arizona.

Bureau of Indian Affairs site number, and (or) common name	Date well was completed	Land-surface elevation (feet)	Well depth	Screened/open interval(s)	Depth to top of N aquifer ¹	Type of data collected
				(feet below land surface)		
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	
8T-500 (BM observation well 3)	07-29-59	5,724	868	712–868	155	
2T-514 (BM observation well 4)	02-15-72	6,320	400	250–400	160	
4T-519 (BM observation well 5)	02-25-72	5,869	1,683	1,521–1,683	1,520	
BM observation well 6	01-31-77	6,332	2,507	1,954–2,506	1,950	
1K-214	05-26-50	5,771	356	168–356	250	
2K-300	³ 06-00-50	6,264	300	260–300	0	
2K-301	06-12-50	6,435	500	318–328; 378–500	² 30	
2T-502	08-10-59	6,670	523	12–523	25	
3A-28	04-19-35	5,381	358	(⁴)	60	
3K-311	³ 11-00-34	5,855	745	380–395; 605–745	615	
3K-325	06-01-55	5,250	450	75–450	² 30	
3T-333	12-02-55	4,940	229	63–229	24	
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	
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
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
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	
8T-522	³ 07-00-63	6,040	933	180–933	480	
8T-541	03-17-76	5,885	890	740–890	700	
9Y-92	01-02-39	5,615	300	154–300	² 50	
9Y-95	11-05-37	5,633	300	145–300	² 68	
10R-111	04-11-35	5,757	360	267–360	210	
10R-119	01-09-35	5,775	360	(⁴)	310	
10T-258	04-12-60	5,903	670	465–670	460	
Dennehotsos PM2	06-05-64	5,005	675	475–675	8	
Keams Canyon PM2	³ 05-00-70	5,809	1,106	906–1,106	900	Water level, withdrawals, water chemistry
Kits'iili NTUA 2	10-30-93	6,780	2,549	2,217–2,223; 2,240–2,256 2,314–2,324; 2,344–2,394 2,472–2,527	2,205	Water level, withdrawals
Kykotsmovi PM1	02-20-67	5,657	995	655–675; 890–990	880	
Kykotsmovi PM2	10-14-77	5,760	1,155	950–1,155	890	Water chemistry, withdrawals
Kykotsmovi PM3	08-07-68	5,618	1,220	850–1,220	840	Water level, withdrawals
Low Mountain PM2	³ 04-00-72	6,123	1,343	1,181–1,262	1,153	Withdrawals
Peabody 2	³ 06-00-67	6,530	3,636	1,816–3,603	728	Water chemistry, withdrawals
Peabody 9	³ 00-00-83	6,385	3,510	2,332–3,505	2,400	
Piñon NTUA 1	02-25-80	6,336	2,350	1,860–2,350	1,850	
Rough Rock PM5	06-27-64	6,299	1,425	1,175–1,425	1,156	
Second Mesa PM2	³ 10-00-68	5,777	1,090	740–1,090	720	
Piñon PM6	³ 02-00-70	6,397	2,248	1,895–2,243	1,870	
Shonto PM2	05-05-61	6,465	554	485–510; 514–539	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

¹Depth to top of N aquifer from Eychaner (1983) and Brown and Eychaner (1988).²All material between land surface and top of the N aquifer is unconsolidated—soil, alluvium, or dune sand.³00, indicates day is unknown.⁴Screened and (or) open intervals are unknown.⁵Depth to top of N aquifer was not estimated.

Table 8. Median changes in water levels in monitoring-program wells, 2012–13 and prestress period (prior to 1965) to 2013, N aquifer, Black Mesa area, northeastern Arizona.

Years	Aquifer conditions	Number of wells	Median change in water level (feet)
2012–2013	All	32	0.1
	Unconfined	16	0.8
	Confined	16	0.3
Prestress–2013	All	32	-13.5
	Unconfined	16	-0.8
	Confined	16	-51.0

continuous-recording observation wells. Water levels were measured by electric tape in these six wells three times during water year 2013 to verify or update instrument calibration.

The wells used for water-level measurements are distributed throughout the study area (fig. 5). The wells were constructed between 1934 and 1993 and the total well depths range from 107 ft near Northeast Rough Rock (8A-180) to 3,636 ft near the PWCC. Depths to the top of the N aquifer range from 0 ft near Tuba City to 2,400 ft at Peabody 9 (table 7).

From 2012 to 2013, water levels decreased in 11 of the 32 wells for which comparisons could be made (table 6). The median water-level change in the 32 wells was 0.1 ft (table 8). In the unconfined parts of the aquifer, water levels declined in 6 of the 16 wells measured (table 6), and the median water-level change was 0.8 ft (table 8). Water-level changes ranged from -9.4 ft at Tuba City NTUA 1 (3T-508) to +2.3 ft at Goldtooth (3A-28) (table 6). In the confined parts of the aquifer, water levels declined in 5 of 16 wells measured from 2012 to 2013. The median water-level change was 0.3 ft (table 8). Water-level changes ranged from -4.5 ft at Kitsillie NTUA 2 to +83 ft at Kayenta West (8T-541) (table 6).

From the prestress period (before 1965) to 2013, the median water-level change in 32 wells measured in 2013 was -13.5 ft (tables 6 and 8). Water levels in 16 unconfined wells had a median change of -0.8 ft (table 8), and water-level changes ranged from -49.0 ft at Tuba City NTUA 1(3T-508) to +12.8 ft at Rough Rock (9Y-95) (fig. 5 and table 6). Water levels in 16 wells in the confined part of the aquifer had a median change of -51.0 ft (table 8), and water-level changes ranged from -208.1 ft at Keams Canyon PM2 to +9.3 ft at Kykotsmovi PM1 (fig. 5 and table 6).

Hydrographs of groundwater levels in the network of wells observed annually show the temporal changes from the 1950s to the March 2013 (fig. 6). In most of the unconfined area, water levels have changed only slightly (generally less than 10 ft). Near the Shonto area, however, the water level in Long House Valley well (8T-510) has declined about 36.9 ft (figs. 5 and 6; table 6). Water levels have declined in most of the confined area but the magnitudes of declines are varied. Larger declines have occurred near the municipal pumping centers (wells Piñon PM6, Keams Canyon PM2) and near the wells for PWCC (BM6). Smaller declines occurred away from pumping centers in or near towns in the study area (wells 10T-258, 8K-443, 10R-111, 8T-522; figs. 5 and 6).

Hydrographs for the Black Mesa continuous-record observation wells show water levels since the early 1970s (fig. 7). The two wells in the unconfined areas (BM1 and BM4) have shown small seasonal or year-to-year variation since 1972 but no apparent long-term change. In the confined area, water levels (that have not been corrected for barometric pressure effects or seasonal effects) in wells BM2, BM3, BM5, and BM6 have consistently declined since the early 1970s (fig. 7). Since October 2009, water levels in BM2 have flattened out and begun to rise. The water level trend in BM6 shows a distinct change from decreasing to increasing beginning in 2007. The water level in BM6 reached a maximum depth of 861.2 ft below land surface on December 4, 2006, and has recovered to 843.4 ft below land surface on September 11, 2013, about 18 feet of total recovery.

Spring Discharge from the N Aquifer

The effect of groundwater withdrawals from the N aquifer on the discharge of springs around Black Mesa is a concern of the cooperators of this program. Groundwater in the N aquifer discharges from many springs around the margins of Black Mesa, and changes to the discharge from those springs could indicate effects of withdrawals from the N aquifer. Moenkopi School Spring, Pasture Canyon Spring, Burro Spring, and Unnamed Spring near Dennehotso have been measured intermittently since the late 1980s and all four springs were measured for discharge in July and August 2013.

Moenkopi School Spring is in the western part of the Black Mesa area and is also called Susunova Spring by the Hopi Tribe (fig. 8). Discharge from Moenkopi School Spring was measured in July 2013 by the volumetric method and compared to discharge data from previous years to determine changes over time (fig. 9). The trend for discharge measurements at this spring is not corrected for seasonal variability, but discharge measurements are made annually at or close to the same time of year. In 2013, the measured discharge from Moenkopi School Spring was 6.4 gal/min (table 9). From 2012 to 2013, discharge increased by about 1 percent; for the period of record, discharge measurements have a significant ($p < 0.05$) decreasing trend, and linear regression analysis indicates that spring discharge decreases an average of about 0.3 gal/yr (fig. 9 and table 9).

Burro Spring is in the southwestern part of the study area and discharges from the Navajo Sandstone and alluvium (fig. 8). Burro Spring discharges from the aquifer through a metal pipe and into a cement trough for livestock. The July 2013 discharge measurement was made volumetrically at the end of the metal pipe before the livestock trough. Discharge at Burro Spring has fluctuated since 1989 between 0.2 and 0.4 gal/min, but there is no significant ($p > 0.05$) trend from linear regression and Kendall's tau analyses (fig. 9). In 2013, the measured discharge was 0.3 gal/min, the same as the previous year (fig. 9 and table 9). The trend in discharge data measured at this spring is not corrected for seasonal variability, but annual discharge measurements are made as close to the same time of year as is logistically possible.

Pasture Canyon Spring is in the western part of the study area and discharges from the Navajo Sandstone and alluvium (fig. 8). Discharge is measured at two locations: where the spring issues from the Navajo Sandstone (also the water-quality sampling point), and farther down the canyon at the USGS gaging station. The USGS gaging station at Pasture Canyon measures the discharge from Pasture Canyon Spring as well as additional discharge from seeps in Pasture Canyon. The discharge, 35.7 gal/min, at Pasture Canyon Spring was measured at its emergence point in July 2013 using the volumetric method, and showed an increase in discharge of about 9 gal/min from the previous year (fig. 9 and table 9). When compared to discharge in previous years, a decreasing trend ($p < 0.05$) is evident from

both linear regression and Kendall’s tau analyses. The trend in discharge data measured at this spring is not corrected for seasonal variability, but annual discharge measurements are made as close to the same time of year as is logistically possible.

Unnamed Spring near Dennehotso is the only spring in the northeastern part of the study area (fig. 8), and it discharges from the Navajo Sandstone. Measurements at Unnamed Spring near Dennehotso are made using a 3-inch flume. There have been marked decreases in discharge at Unnamed Spring near Dennehotso since April 2005. That year, the discharge at the spring was 21.5 gal/min, in June 2010 the discharge was 9.0 gal/min, in June 2012 the measured discharge was only 4.5 gal/min, and in August 2013 the measured discharge slightly

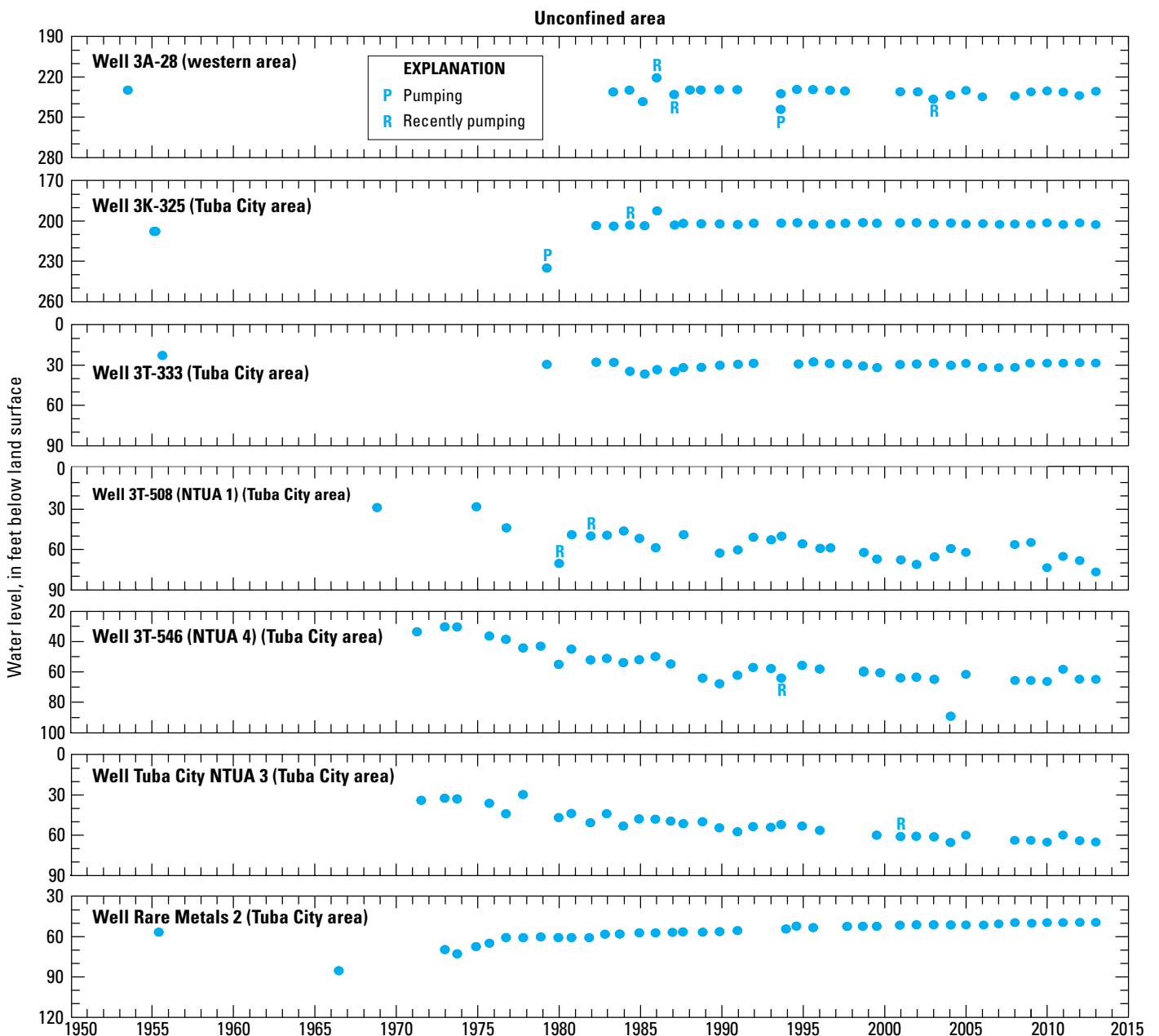


Figure 6. Plots of observed water levels (1950–2013) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona.

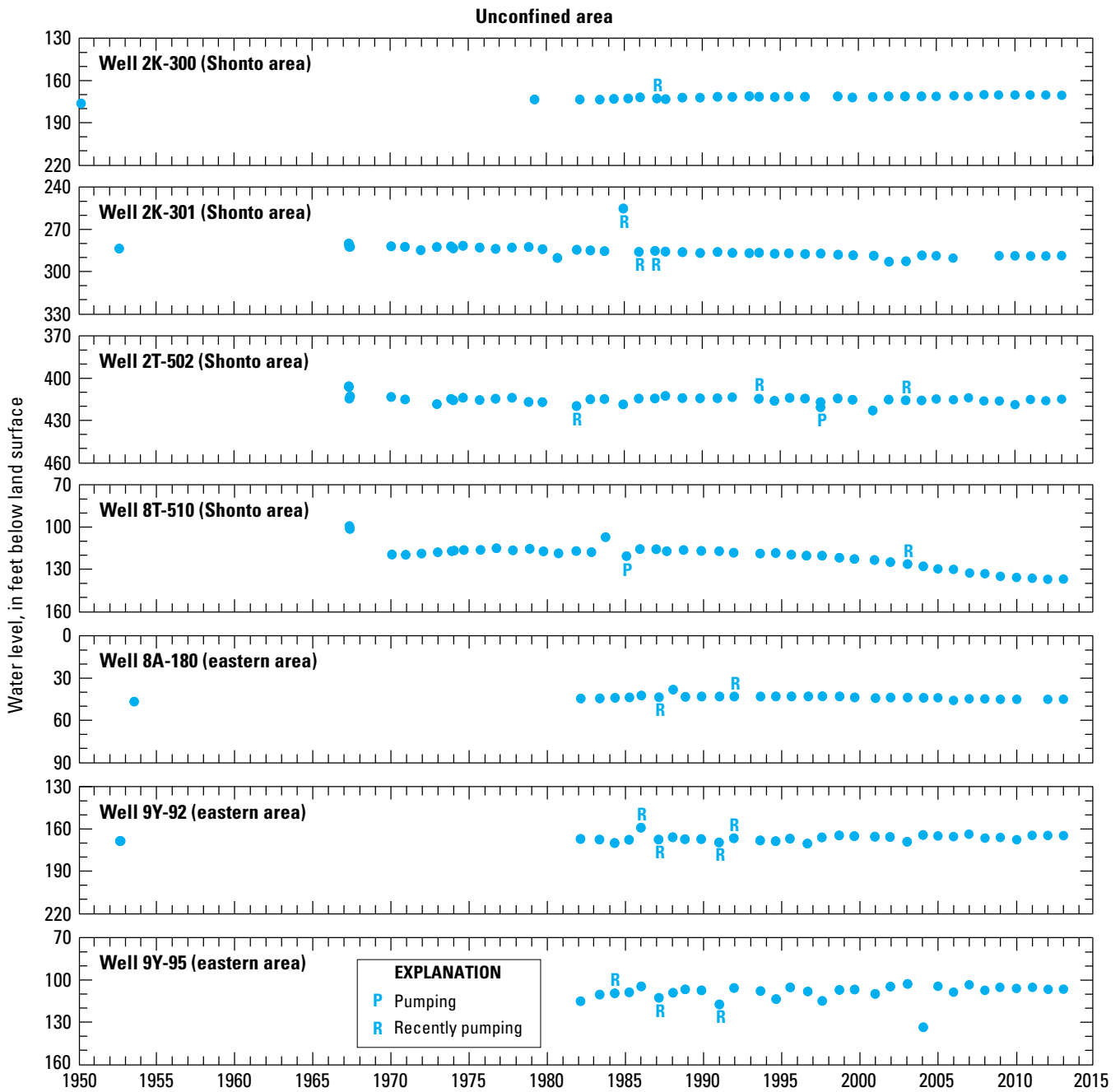


Figure 6. Plots of observed water levels (1950–2013) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona.—Continued

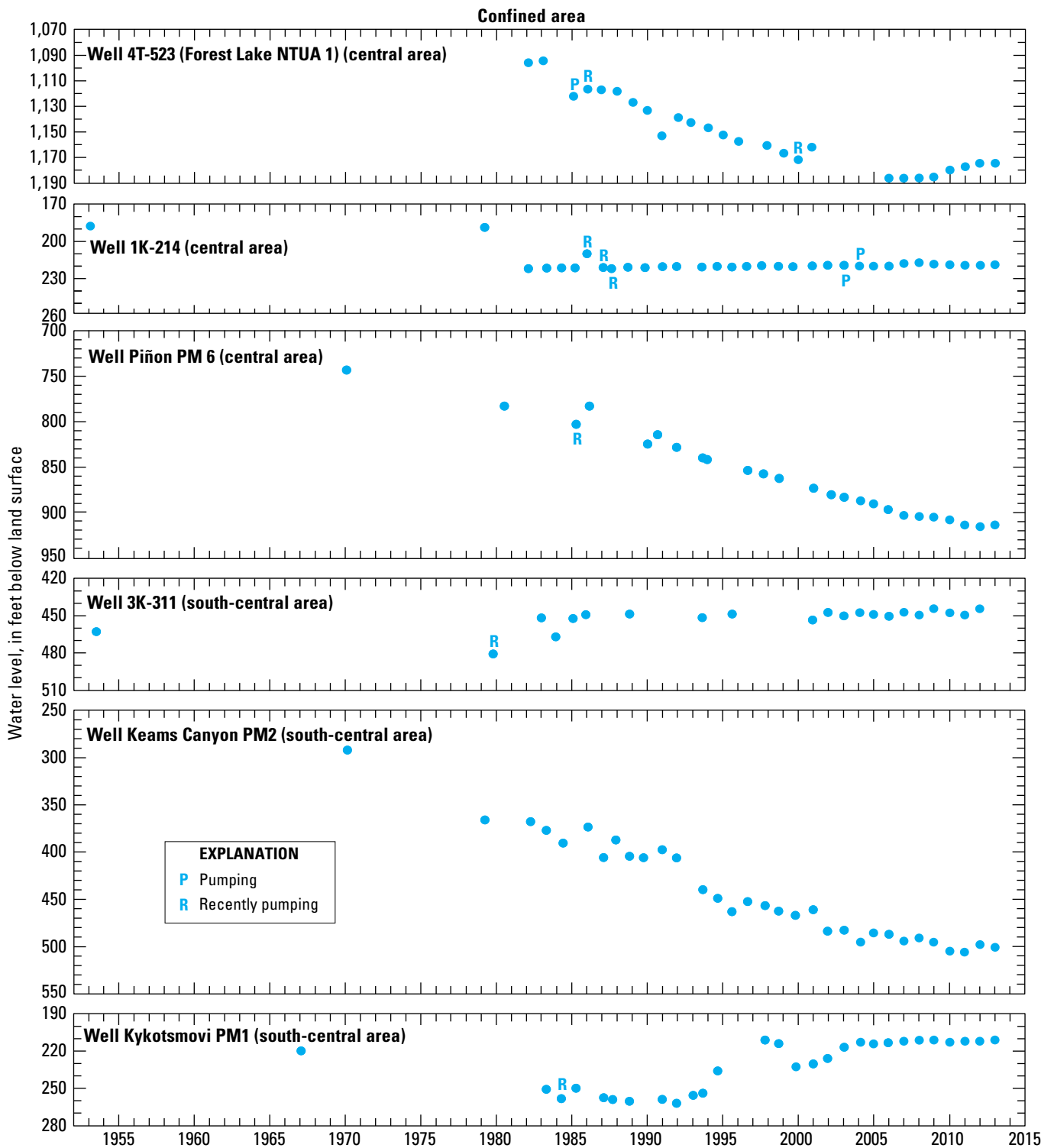


Figure 6. Plots of observed water levels (1950–2013) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona.—Continued

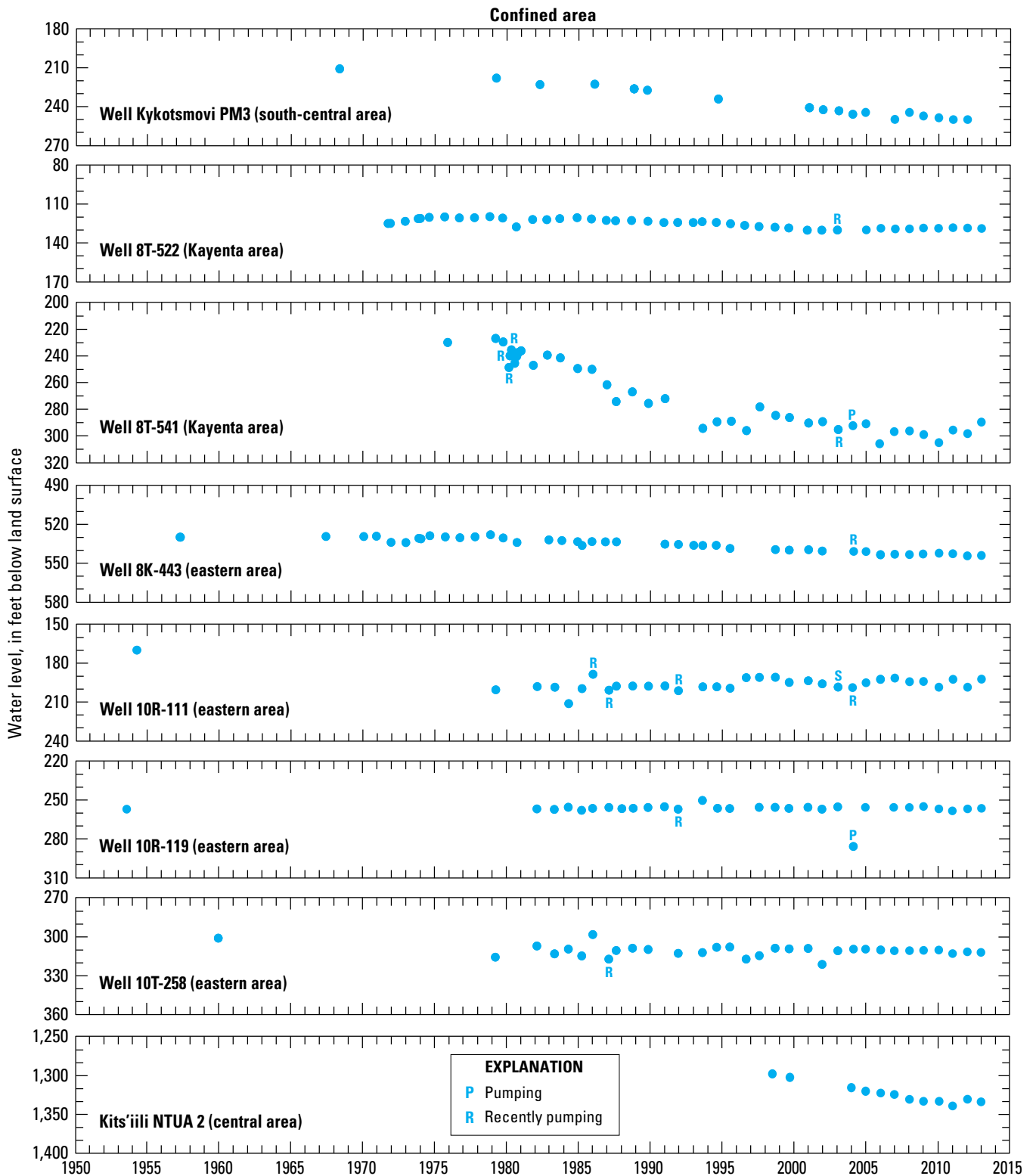


Figure 6. Plots of observed water levels (1950–2013) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona.—Continued

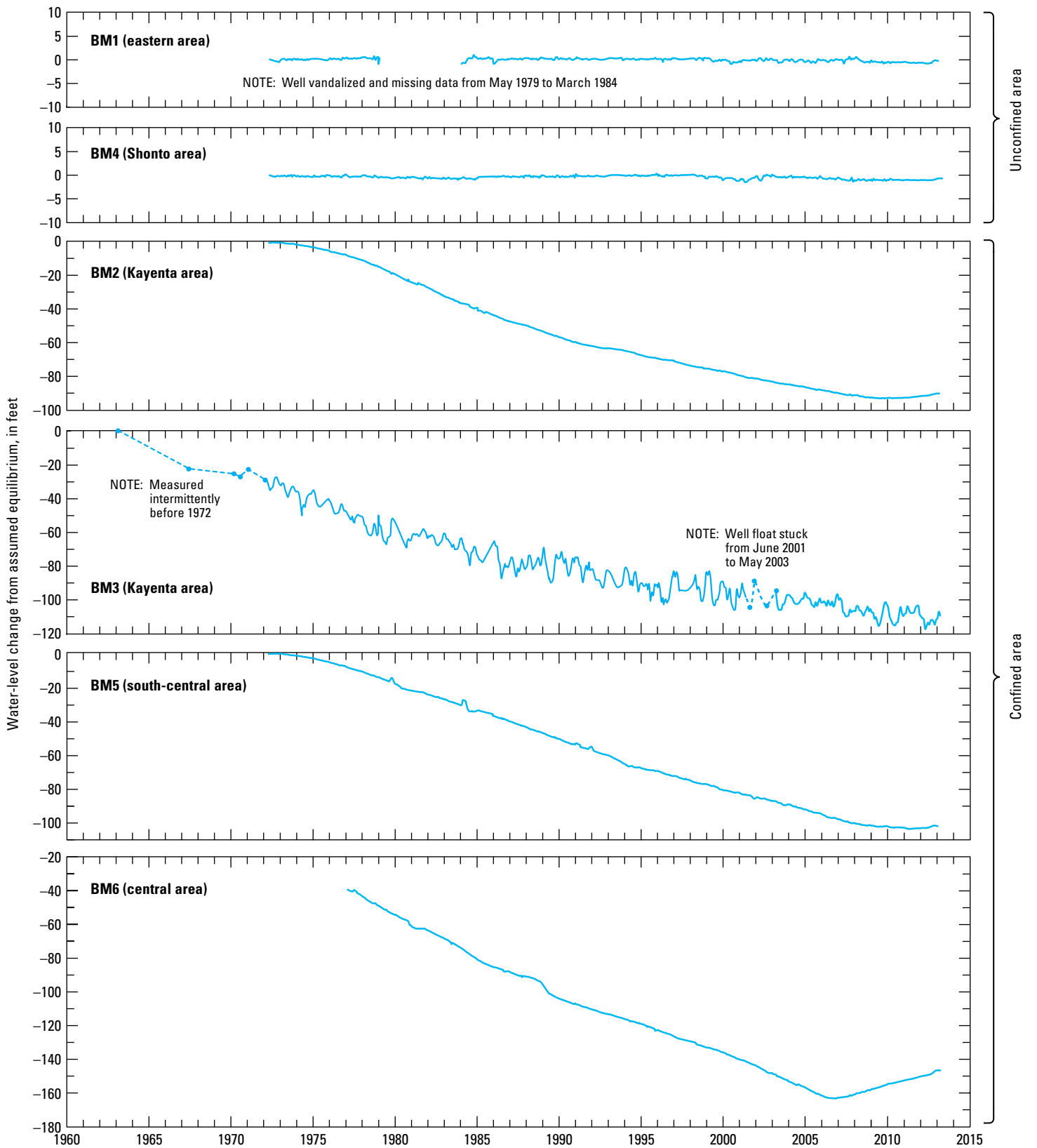
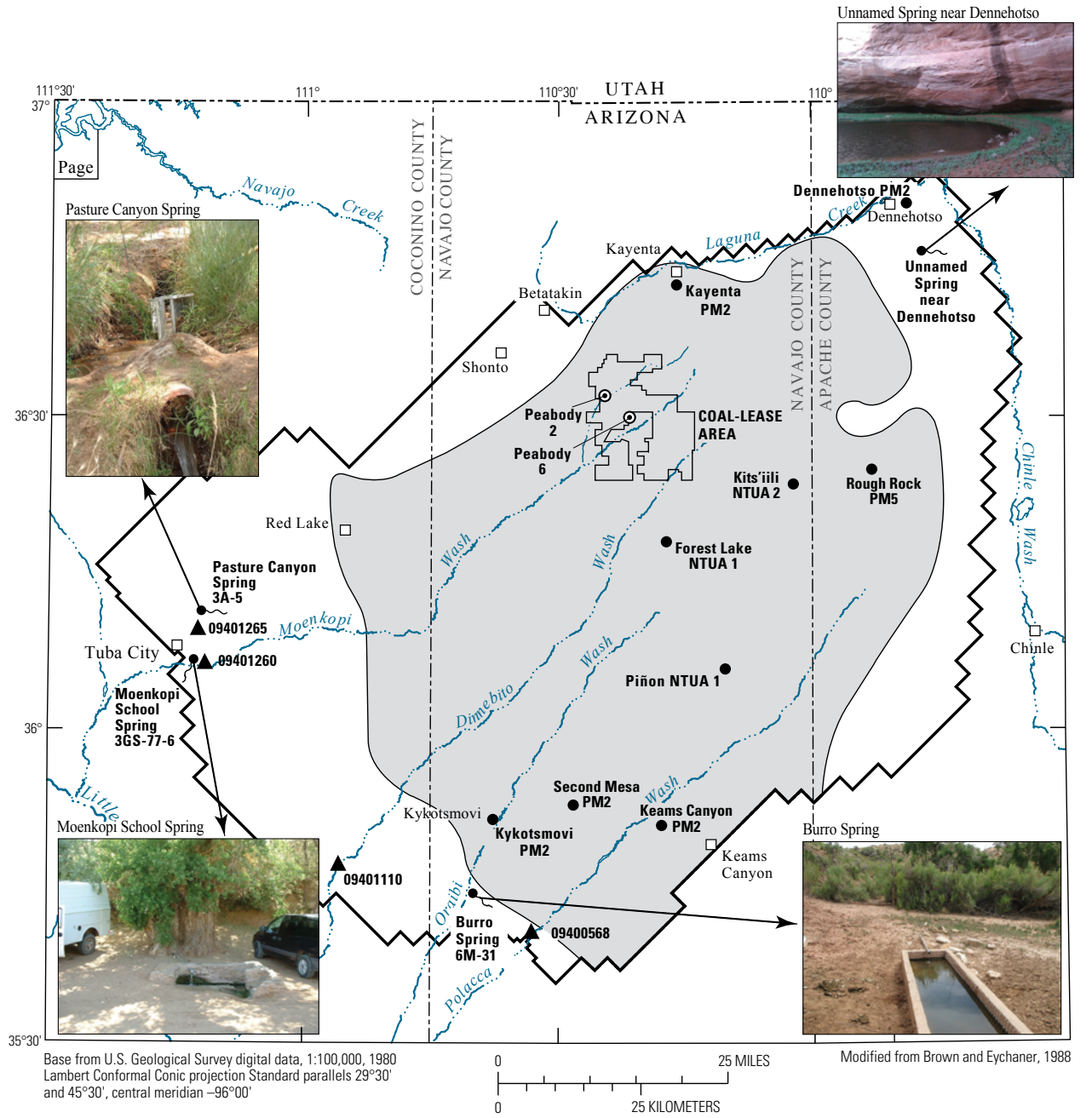


Figure 7. Plots of observed water-level changes in continuous-record observation wells BM1–BM6 over 1963–2013 in the N aquifer, Black Mesa area, northeastern Arizona.



EXPLANATION

- | | | |
|--|---|---|
| <p>Confined and unconfined conditions in the N aquifer within model boundary</p> <p> Confined
 Unconfined </p> <p> Approximate boundary between confined and unconfined conditions—From Brown and Eychaner (1988) </p> <p> Boundary of mathematical model—From Brown and Eychaner (1988) </p> | <p> Kykotsmovi PM2
 Peabody 2 </p> <p> Municipal well from which water-chemistry sample was collected—Kykotsmovi PM2 is well name

 Industrial well from which water-chemistry sample was collected—Peabody 2 is a well number </p> | <p> Moenkopi School Spring 3GS-77-6
 09401260 </p> <p> Spring at which discharge was measured and water-chemistry sample was collected—Number is spring identification

 Streamflow-gaging station operated by the U.S. Geological Survey—Number is station identification </p> |
|--|---|---|

Figure 8. Map of surface-water and water-chemistry data-collection sites, N aquifer, Black Mesa area, northeastern Arizona, 2012–13.

Table 9. Discharge from Moenkopi School Spring, Burro Spring, Pasture Canyon Spring, and Unnamed Spring near Dennehotso, N Aquifer, Black Mesa area, northeastern Arizona, 1987–2013.

[Measured discharges do not represent the total discharge from the springs]

Bureau of Indian Affairs site number 3GS-77-6			Bureau of Indian Affairs site number 6M-31			Bureau of Indian Affairs site number 3A-5			Bureau of Indian Affairs site number 8A-224		
Rock forma- tion(s)	Date of measure- ment	Discharge, in gallons per minute	Rock forma- tion(s)	Date of measure- ment	Discharge, in gallons per minute	Rock forma- tion(s)	Date of measure- ment	Discharge, in gallons per minute	Rock forma- tion(s)	Date of measure- ment	Discharge, in gallons per minute
Moenkopi School Spring ¹			Burro Spring ¹			Pasture Canyon Spring ¹			Unnamed spring near Dennehotso ⁴		
	05–16–52	40.0		12–15–89	0.4		11–18–88	⁴ 211		10–06–54	⁷ 1
	04–22–87	³ 16.0		12–13–90	0.4		03–24–92	⁴ 233		06–27–84	⁷ 2
	11–29–88	³ 12.5		03–18–93	0.3		10–12–93	⁴ 211		11–17–87	⁷ 5
	02–21–91	³ 13.5		12–08–94	0.2		12–04–95	⁵ 38.0		03–26–92	16.0
	04–07–93	³ 14.6		12–17–96	0.4		12–16–96	⁵ 38.0		10–22–93	14.4
	12–07–94	³ 12.9		12–30–97	0.2		12–17–97	⁵ 40.0		12–05–95	17.0
	12–04–95	³ 10.0		12–08–98	0.3		12–10–98	⁵ 39.0		12–19–96	15.7
	12–16–96	³ 13.1		12–07–99	0.3		12–21–99	⁵ 39.0		12–30–97	25.6
	12–17–97	³ 12.0		04–02–01	0.2		06–12–01	⁵ 37.0		12–14–98	21.0
	12–08–98	³ 13.3		04–04–02	0.4	Navajo	04–04–02	⁵ 37.0	Navajo	12–15–99	14.8
	12–13–99	³ 13.7		04–30–03	0.4	Sandstone,	05–01–03	⁵ 30.9	Sandstone	03–14–01	26.8
Navajo	03–12–01	³ 10.2	Navajo	04–06–04	⁶ 0.2	alluvium	04–26–04	⁵ 30.6		04–03–02	5.8
Sandstone ²	06–19–02	³ 11.2	Sandstone	03–28–05	0.2		04–27–05	⁵ 33.3		07–15–02	9.0
	05–01–03	³ 11.2		03–28–06	0.2		06–03–08	⁵ 29.4		05–01–03	17.1
	03–29–04	³ 12.2		06–04–09	0.3		06–03–09	⁵ 31.1		04–01–04	12.6
	04–04–05	³ 11.5		06–07–10	0.3		06–14–10	⁵ 34.3		04–06–05	21.5
	03–13–06	³ 11.1		06–08–11	0.4		06–09–11	⁵ 31.4		06–17–10	9.0
	05–31–07	³ 9.0		06–14–12	0.3		06–07–12	⁵ 26.5		06–04–12	4.5
	06–03–08	³ 8.3		07–30–13	0.3		07–29–13	⁵ 35.7		08–06–13	6.7
	06–03–09	³ 8.0									
	06–14–10	³ 7.4									
	06–10–11	³ 9.0									
	06–07–12	³ 6.3									
	07–29–13	³ 6.4									

¹Volumetric discharge measurement.

²Interfingering with the Kayenta Formation at this site.

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

⁴Discharge measured in an irrigation ditch about 0.25 mile below water-quality sampling point.

⁵Discharge measured at water-quality sampling point about 20 feet below upper spring on west side of canyon.

⁶Discharge is approximate because the container used for the volumetric measurement was not calibrated.

⁷Discharge measured at a different point than later measurements.

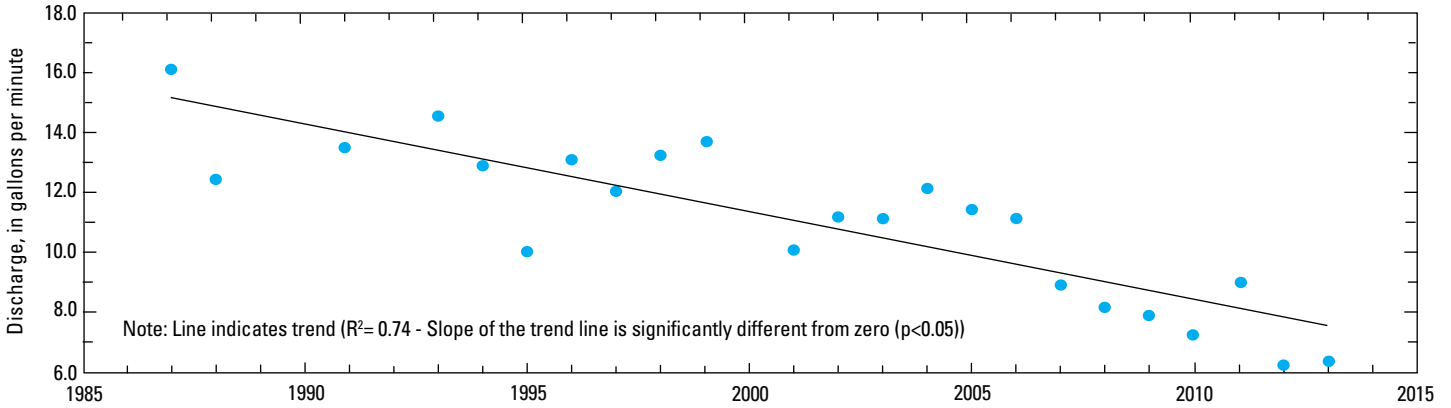
increased to 6.7 gal/min. From 2012 to 2013 the discharge increased almost 50 percent after decreasing significantly from 2005 to 2012 (table 10). For the period of record, which includes a gap in data from 2005 to 2010, there is no appreciable trend in the data based on linear regression ($p > 0.05$) and Kendall’s tau analyses. The trend in discharge data measured at this spring is not corrected for seasonal variability. Measurements made at this site from 1954 to 1999 were made in October, November, and December except for 1984 and 1992, which were made in June and March respectively. Measurements made from 2001 to 2005 were made in March, April, and May with the exception of 2002, when the measurements were made in July. Since 2010, measurements at this site have been made in June and August. Discharge measurements made in the winter and spring months are three times greater than those made in the summer (fig. 9).

Surface-Water Discharge, Calendar Year 2012

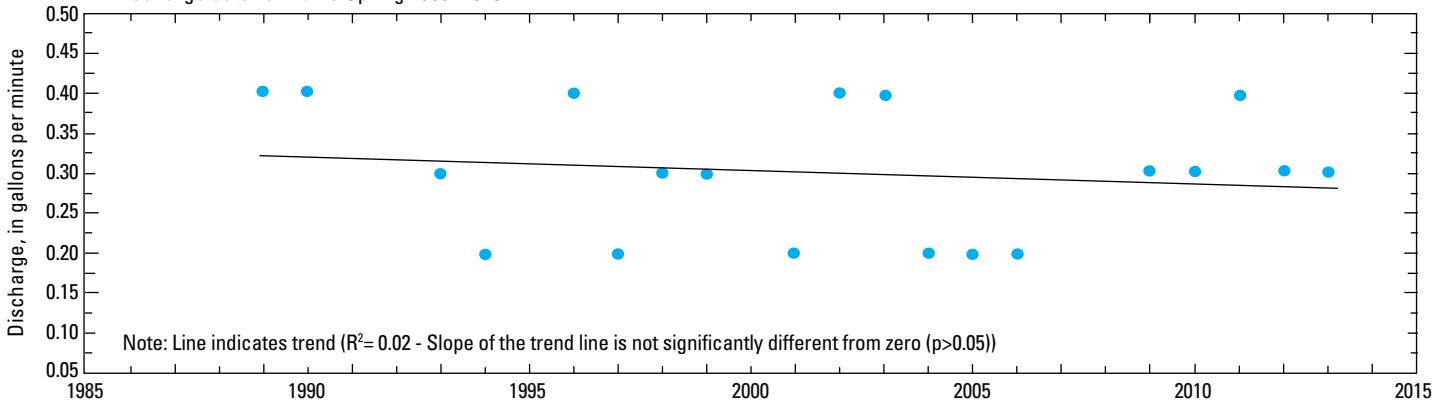
Continuous surface-water discharge data have been collected at selected streams since July 1976. Surface-water discharge in the study area generally originates as groundwater that discharges to streams and as surface runoff from rainfall or snowmelt. Groundwater discharges to some stream reaches at a fairly constant rate throughout the year; however, the amount of groundwater discharge that results in surface flow is affected by seasonal fluctuations in evapotranspiration (Thomas, 2002a). In contrast, the amount of rainfall or snowmelt runoff varies widely throughout the year. In the winter and spring, the amount and timing of snowmelt runoff are a result of the temporal variation in snow accumulation, air temperatures, and rate of snowmelt. Although rainfall can occur throughout the year, most occurs during the summer months. The amount and timing of rainfall

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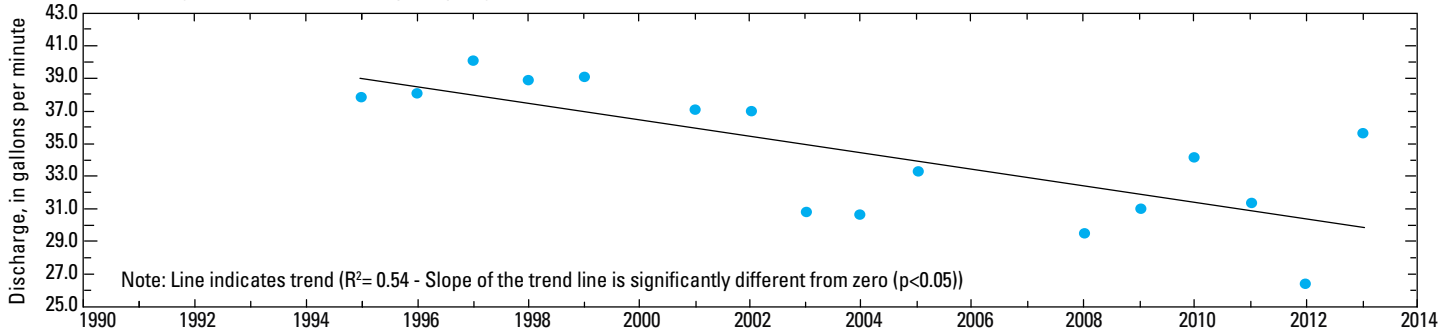
A. Discharge data for Moenkopi School Spring, 1987–2013.



B. Discharge data for Burro Spring 1989–2013.



C. Discharge data for Pasture Canyon Spring, 1987–2013.



D. Discharge data for Unnamed Spring near Dennehotso, 1992–2013.

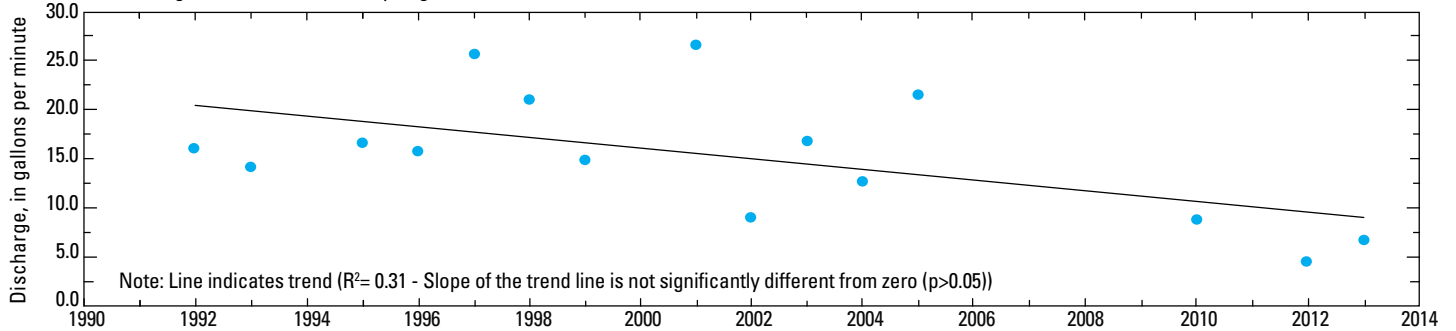


Figure 9. Plots of discharge from *A*, Moenkopi School Spring; *B*, Burro Spring; *C*, Pasture Canyon Spring; and *D*, Unnamed Spring near Dennehotso, N Aquifer, Black Mesa area, northeastern Arizona, 1987–2013. Data from the 1952 measurement at Moenkopi School Spring, and data from the 1988 to 1993 measurements at Pasture Canyon Spring are not shown because they were from different measuring locations. Trend lines were generated using method of least squares.

Table 10. Discharge data (daily mean values), Moenkopi Wash at Moenkopi, Arizona (09401260), calendar year 2012.

[e, estimated; CFSM, cubic feet per square mile; ---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 2012													
DAILY MEAN VALUES													
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
1	e2.4	2.0	2.5	1.8	0.79	0.00	0.00	935	11	0.86	1.8	2.0	
2	e2.8	2.2	2.5	1.8	0.78	0.00	0.00	9.2	452	0.85	1.8	1.9	
3	e2.3	2.9	2.5	2.0	0.72	0.00	0.00	0.00	15	0.87	1.8	1.9	
4	e1.3	2.4	2.7	1.8	0.61	0.00	e0.00	0.02	4.1	0.85	1.8	1.9	
5	e1.1	2.5	2.8	2.2	0.5	0.00	e0.00	0.00	2.8	0.84	1.7	1.8	
6	e1.1	2.2	2.6	2.1	0.49	0.00	0.00	236	2	0.88	1.6	1.7	
7	e0.95	1.9	2.8	2.2	0.43	0.00	0.00	6.1	1.6	0.89	1.5	1.6	
8	e0.99	2.8	2.9	2.0	0.34	0.00	0.00	29	1.4	0.91	1.5	1.5	
9	e0.90	2.1	2.6	2.1	0.41	0.00	0.00	0.18	1.1	0.95	1.5	1.5	
10	e0.90	2.0	2.7	2.1	0.45	0.00	0.00	0.00	1.0	0.98	1.5	1.4	
11	e0.90	1.7	2.7	1.7	0.44	0.00	0.00	0.00	634	1.0	1.6	1.5	
12	e0.95	2.0	2.7	1.5	0.34	0.00	5.5	0.00	e1830	3.3	1.6	1.5	
13	e1.5	2.0	2.8	1.8	0.3	0.00	0.44	0.00	74	1.9	1.6	1.8	
14	e1.4	1.9	2.6	1.8	0.21	0.00	1.6	0.00	18	1.2	1.7	2.0	
15	e2.0	2.4	2.3	2.0	0.21	0.00	0.56	0.00	8.8	1.1	1.7	1.9	
16	e2.9	2.1	2.2	1.7	0.17	0.00	239	0.00	7.4	1.1	1.8	1.5	
17	e1.4	2.2	2	1.6	0.15	0.00	17	0.00	5.9	1.1	1.8	1.6	
18	e1.4	2.2	3.2	1.6	0.08	0.00	1.0	0.00	5.9	1.1	1.8	2.0	
19	1.7	2.5	3.5	1.5	0.00	0.00	0.13	0.00	5.3	1.1	1.8	1.6	
20	1.7	2.2	2	1.2	0.05	0.00	0.00	87	4.8	1.2	1.9	1.3	
21	1.5	2.5	1.9	1.2	0.05	0.00	43	4.4	4.2	1.2	1.9	1.3	
22	1.8	2.8	2.3	1.2	0.00	0.00	367	560	3.7	1.2	1.9	1.5	
23	1.9	2.5	2.6	1.1	0.00	0.00	13	982	3.3	1.3	2.0	1.6	
24	2.5	2.8	2.5	1.0	0.00	0.00	0.58	227	3.0	1.6	2.0	1.6	
25	1.9	2.6	2.5	1.1	0.00	0.00	0.09	19	2.7	1.7	2.0	1.4	
26	2.5	2.6	1.8	1.0	0.00	0.00	0.01	2.7	2.4	1.7	2.1	1.5	
27	2.5	2.6	1.8	1.1	0.00	0.00	0.00	1.7	2.0	1.6	2.1	1.6	
28	1.9	2.7	1.8	1.1	0.00	0.00	0.00	19	1.8	1.7	2.1	1.3	
29	2.0	2.8	1.7	1.1	0.00	0.00	327	2.6	1.5	1.7	2.0	1.3	
30	e1.8	---	2.0	0.83	0.00	0.00	1,140	1.7	1.3	1.7	2.0	1.3	
31	e1.6	---	2.0	---	0.00	---	562	1.4	---	1.7	---	1.4	
TOTAL	52.49	68.1	75.5	47.23	7.52	0.00	2,717.91	3124	3,112	40.08	53.9	49.7	
MEAN	1.69	2.35	2.44	1.57	0.24	0.00	87.7	101	104	1.29	1.8	1.6	
MAX	2.9	2.9	3.5	2.2	0.79	0.00	1,140	982	1,830	3.3	2.1	2.0	
MIN	0.9	1.7	1.7	0.83	0.00	0.00	0.00	0.00	1.0	0.84	1.5	1.3	
MED	1.7	2.4	2.5	1.7	0.17	0.00	0.09	1.7	3.9	1.1	1.8	1.6	
AC-FT	104	135	150	94	15	0.00	5,390	6,200	6,170	79	107	99	
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.06	0.00	0.00	0.00	
Calendar year 2012	Total 9,348		Mean 25.5		Max 1,830		Min 0.00		Median 1.6		Acre-ft 18,543		CFSM 0.016

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Table 11. Discharge data (daily mean values), Dinnebito Wash near Sand Springs, Arizona (09401110), calendar year 2012.

[e, estimated; CFSM, cubic feet per square mile; ---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 2012												
DAILY MEAN VALUES												
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.38	0.38	0.38	0.34	0.69	0.22	0.15	757	133	0.22	0.29	0.36
2	0.38	0.38	0.38	0.36	0.36	0.2	0.16	3.1	107	0.21	0.29	0.36
3	0.37	0.37	0.38	0.37	0.35	0.2	0.16	0.34	0.86	0.2	0.3	0.36
4	0.37	0.38	0.39	0.37	0.32	0.2	0.16	2.3	0.32	0.2	0.3	0.36
5	0.37	0.37	0.39	0.39	0.32	0.19	0.17	14	0.3	0.21	0.3	0.35
6	0.39	0.37	0.37	0.4	0.34	0.19	0.17	10	0.22	0.21	0.31	0.09
7	0.38	0.36	0.38	0.4	0.34	0.19	0.16	3.2	0.21	0.21	0.31	0.69
8	0.38	0.37	0.4	0.41	0.34	0.18	0.17	3.4	0.21	0.21	0.31	0.36
9	0.37	0.37	0.41	0.41	0.35	0.18	0.18	e204	0.2	0.22	0.32	0.34
10	0.38	0.37	0.44	0.4	0.33	0.18	0.17	e44	0.22	0.22	0.33	0.28
11	0.37	0.37	0.41	0.39	0.31	0.19	0.17	e22	5.4	0.22	0.28	0.3
12	0.34	0.39	0.41	0.4	0.32	0.18	0.16	e2.4	144	3.3	0.29	0.35
13	0.34	0.4	0.41	0.41	0.31	0.17	0.16	e0.34	31	1.2	0.28	0.38
14	0.33	0.45	0.4	0.69	0.3	0.17	0.19	e0.17	6.2	0.26	0.41	1.5
15	0.35	0.41	0.4	0.5	0.28	0.17	0.18	e0.13	0.91	0.26	0.33	0.52
16	0.38	0.39	0.39	0.42	0.27	0.17	0.18	0.12	0.27	0.25	0.34	0.38
17	0.36	0.37	0.38	0.41	0.26	0.16	0.16	0.12	0.24	0.24	0.33	0.38
18	0.37	0.37	0.64	0.42	0.25	0.15	0.15	0.12	0.24	0.24	0.32	0.41
19	0.37	0.42	0.44	0.4	0.25	0.16	0.16	0.11	0.23	0.24	0.33	0.4
20	0.37	0.38	0.35	0.39	0.25	0.16	0.17	50	0.23	0.25	0.33	0.3
21	0.39	0.38	0.44	0.37	0.25	0.15	0.16	15	0.22	0.24	0.33	0.23
22	0.4	0.38	0.39	0.37	0.23	0.15	e236	55	0.22	0.25	0.34	0.47
23	0.39	0.39	0.39	0.38	0.21	0.15	44	e137	0.22	0.25	0.34	0.4
24	0.41	0.37	0.39	0.36	0.22	0.15	12	e29	0.22	0.24	0.34	0.45
25	0.38	0.39	0.38	0.36	0.2	0.17	0.69	0.43	0.22	0.24	0.34	0.4
26	0.38	0.38	0.38	0.43	0.21	0.16	0.29	0.54	0.24	0.25	0.34	0.39
27	0.39	0.38	0.38	0.34	0.22	0.16	0.21	0.5	0.24	0.27	0.34	0.37
28	0.36	0.37	0.38	0.33	0.38	0.16	1.3	0.93	0.23	0.27	0.34	0.33
29	0.36	0.38	0.38	0.32	0.25	0.16	4.1	0.24	0.23	0.28	0.35	0.32
30	0.37	---	0.38	0.31	0.23	0.15	126	0.22	0.23	0.4	0.36	0.34
31	0.38	---	0.37	---	0.23	---	71	0.21	---	0.29	---	0.41
TOTAL	11.56	11.09	12.41	11.85	9.17	5.17	499.08	1,355.92	433.53	11.55	9.72	12.58
MEAN	0.37	0.38	0.4	0.4	0.3	0.17	16.1	43.7	14.5	0.37	0.32	0.41
MAX	0.41	0.45	0.64	0.69	0.69	0.22	236	757	144	3.3	0.41	1.5
MIN	0.33	0.36	0.35	0.31	0.2	0.15	0.15	0.11	0.2	0.2	0.28	0.09
MED	0.37	0.38	0.39	0.39	0.28	0.17	0.17	2.3	0.23	0.24	0.33	0.36
AC-FT	23	22	25	24	18	10	990	2,690	860	23	19	25
CFSM	0	0	0	0	0	0	0.03	0.09	0.03	0	0	0
Calendar year 2012	Total 2,384		Mean 6.5		Max 757	Min 0.09	Median 0.34		Acre-ft 4,729		CFSM 0.014	

Table 12. Discharge data (daily mean values), Polacca Wash near Second Mesa, Arizona (09400568), calendar year 2012.

[e, estimated; CFSM, cubic feet per square mile; ---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 2012												
DAILY MEAN VALUES												
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.13	0.15	0.12	0.13	0.08	0.06	0.02	148	0.73	0.06	0.13	0.18
2	0.13	0.14	0.12	0.12	0.08	0.05	0.02	322	169	0.06	0.14	0.19
3	0.13	0.14	0.14	0.12	0.09	0.05	0.02	19	e191	0.06	0.15	0.19
4	0.14	0.15	0.13	0.11	0.09	0.05	0.02	55	e53	0.06	0.16	0.18
5	0.14	0.14	0.13	0.12	0.09	0.05	0.03	41	e20	0.07	0.16	0.19
6	0.13	0.14	0.16	0.12	0.09	0.05	0.03	3.1	e4.8	0.07	0.17	0.21
7	0.13	0.14	0.13	0.13	0.1	e0.04	0.02	0.41	e0.55	0.08	0.18	0.21
8	0.14	0.14	0.13	0.14	0.11	0.03	0.02	13	e0.03	0.08	0.19	0.21
9	0.16	0.14	0.14	0.14	0.1	0.02	0.02	19	e0.02	0.08	0.23	0.21
10	0.16	0.14	0.15	0.12	0.09	0.03	0.02	4.8	e0.02	0.09	0.26	0.2
11	0.15	0.14	0.15	0.12	0.07	0.03	0.02	1.3	e0.03	0.09	0.21	0.28
12	e0.14	0.15	0.14	0.11	0.07	0.03	0.05	0.16	3.6	0.12	0.21	0.3
13	e0.14	0.16	0.15	0.12	0.07	0.03	0.03	10	e19	0.12	0.22	0.29
14	e0.14	0.15	0.15	0.16	0.07	0.03	0.04	2.4	e8.0	0.12	0.23	0.48
15	e0.14	0.12	0.15	0.13	0.07	0.03	0.04	0.74	e1.3	0.13	0.23	0.37
16	0.16	0.12	0.14	0.12	0.06	0.03	0.04	0.07	0.05	0.12	0.16	0.25
17	0.15	0.11	0.15	0.13	0.06	0.03	0.03	0.06	e0.05	0.13	0.14	0.23
18	0.16	0.12	0.24	0.14	0.06	0.03	0.02	15	0.04	0.09	0.15	0.24
19	0.15	0.12	0.17	0.14	0.06	0.03	0.02	15	0.05	0.08	0.15	0.27
20	0.14	0.13	0.15	0.12	0.06	0.03	0.04	4.6	0.04	0.08	0.16	0.28
21	e0.13	0.12	0.16	0.1	0.06	0.02	0.09	2.4	0.04	0.09	0.16	0.27
22	0.16	0.12	0.13	0.09	0.06	0.02	0.04	23	0.04	0.09	0.16	0.25
23	0.16	0.12	0.13	0.09	0.06	0.02	1.3	8.5	0.04	0.1	0.16	0.24
24	0.15	0.12	0.13	0.09	0.06	0.02	0.3	5.1	0.04	0.1	0.17	0.27
25	0.15	0.12	0.13	0.09	0.06	0.02	0.05	4.9	0.05	0.1	0.17	0.28
26	0.15	0.12	0.14	0.14	0.07	0.02	0.04	1.2	0.06	0.11	0.17	0.28
27	0.14	0.13	0.12	0.11	0.06	0.02	0.04	0.05	0.05	0.11	0.18	0.27
28	e0.12	0.14	0.12	0.11	0.07	0.02	0.05	0.05	0.06	0.12	0.19	0.27
29	e0.12	0.12	0.11	0.11	0.07	0.02	0.08	2.1	0.06	0.12	0.17	0.32
30	e0.13	---	0.12	0.09	0.07	0.02	0.17	0.6	0.06	0.14	0.18	0.28
31	0.14	---	0.12	---	0.07	---	1.4	0.71	---	0.13	---	0.29
TOTAL	4.41	3.85	4.35	3.56	2.28	0.93	4.11	723.25	471.81	3	5.34	7.98
MEAN	0.14	0.13	0.14	0.12	0.07	0.03	0.13	23.3	15.7	0.1	0.18	0.26
MAX	0.16	0.16	0.24	0.16	0.11	0.06	1.4	322	191	0.14	0.26	0.48
MIN	0.12	0.11	0.11	0.09	0.06	0.02	0.02	0.05	0.02	0.06	0.13	0.18
MED	0.14	0.14	0.14	0.12	0.07	0.03	0.04	4.6	0.05	0.09	0.17	0.27
AC-FT	8.7	7.6	8.6	7.1	4.5	1.8	8.2	1,430	936	6	11	16
CFSM	0	0	0	0	0	0	0	0.03	0.02	0	0	0
Calendar year 2012	Total 1,235		Mean 3.4		Max 322	Min 0.02	Median 0.13		Acre-ft 2,446		CFSM 0.004	

Table 13. Discharge data (daily mean values), Pasture Canyon Springs near Tuba City, Arizona (09401265), calendar year 2012.

[e, estimated; CFSM, cubic feet per square mile; ---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 2012												
DAILY MEAN VALUES												
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.34	0.38	0.38	0.34	0.34	0.34	0.3	0.28	0.27	0.28	0.3	0.35
2	0.34	0.38	0.38	0.33	0.34	0.35	0.3	0.28	0.27	0.28	0.3	0.36
3	0.34	0.38	0.38	0.33	0.34	0.34	0.3	0.28	0.27	0.28	0.31	0.39
4	0.34	0.38	0.38	0.33	0.34	0.34	0.3	0.28	0.27	0.28	0.31	0.38
5	0.34	0.38	0.38	0.32	0.34	0.34	0.3	0.27	0.27	0.28	0.31	0.38
6	0.34	0.38	0.38	0.32	0.34	0.34	0.3	0.25	0.27	0.28	0.31	0.38
7	0.34	0.38	0.38	0.32	0.34	0.34	0.3	0.25	0.27	0.28	0.31	0.39
8	0.34	0.38	0.37	0.32	0.34	0.34	0.3	0.25	0.26	0.28	0.32	0.4
9	0.34	0.38	0.36	0.32	0.38	0.34	0.29	0.25	0.26	0.28	0.32	0.38
10	0.34	0.38	0.36	0.32	0.38	0.34	0.3	0.25	0.27	0.28	e0.32	0.38
11	0.34	0.38	0.36	0.33	0.37	0.34	0.3	0.25	e0.50	0.28	e0.33	0.38
12	0.34	0.38	0.36	0.34	0.37	0.34	0.3	0.25	0.37	0.32	e0.33	0.38
13	0.34	0.38	0.36	0.34	0.37	0.34	0.3	0.26	0.31	0.3	e0.34	0.38
14	0.34	0.38	0.36	0.34	0.37	0.34	0.31	0.28	0.3	0.3	0.34	0.44
15	0.34	0.38	0.36	0.34	0.35	0.34	0.36	0.27	0.3	0.3	0.34	0.43
16	0.34	0.36	0.36	0.34	0.34	0.34	0.35	0.27	0.3	0.3	0.34	0.41
17	0.34	0.36	0.36	0.34	0.34	0.34	0.33	0.27	0.3	0.3	0.34	0.41
18	0.34	0.36	0.45	0.34	0.34	0.33	0.32	0.27	0.29	0.3	0.34	0.41
19	0.34	0.38	0.43	0.34	0.34	0.33	0.32	0.27	0.28	0.3	0.34	0.4
20	0.34	0.38	0.4	0.32	0.34	0.33	0.31	0.28	0.29	0.3	0.34	0.38
21	0.36	0.38	e0.36	0.32	0.34	0.33	0.3	0.29	0.31	0.3	0.34	0.38
22	0.36	0.38	e0.36	0.32	0.34	0.34	0.3	0.28	0.3	0.3	0.34	0.38
23	0.36	0.38	e0.36	0.32	0.34	0.34	0.29	0.28	0.3	0.3	0.34	0.38
24	0.4	0.38	0.36	0.32	0.34	0.33	0.28	0.28	0.3	0.3	0.34	0.38
25	0.37	0.38	0.36	0.33	0.34	0.32	0.28	0.28	0.3	0.3	0.34	0.38
26	0.36	0.38	0.35	0.34	0.34	0.32	0.28	0.28	0.3	0.3	0.34	0.38
27	0.36	0.38	0.34	0.34	0.33	0.32	0.3	0.27	0.3	0.3	0.34	0.38
28	0.36	0.4	0.34	0.34	0.32	0.31	0.3	0.27	0.3	0.3	0.34	0.38
29	0.36	0.4	0.34	0.34	0.33	0.31	0.35	0.26	0.3	0.3	0.35	0.38
30	0.37	---	0.34	0.34	0.33	0.31	0.31	0.27	0.29	0.3	0.34	0.37
31	0.38	---	0.34	---	0.34	---	0.28	0.27	---	0.3	---	0.36
TOTAL	10.84	11	11.4	9.93	10.7	10.01	9.46	8.34	8.92	9.1	9.9	11.96
MEAN	0.35	0.38	0.37	0.33	0.35	0.33	0.31	0.27	0.3	0.29	0.33	0.39
MAX	0.4	0.4	0.45	0.34	0.38	0.35	0.36	0.29	0.5	0.32	0.35	0.44
MIN	0.34	0.36	0.34	0.32	0.32	0.31	0.28	0.25	0.26	0.28	0.3	0.35
MED	0.34	0.38	0.36	0.33	0.34	0.34	0.3	0.27	0.3	0.3	0.34	0.38
AC-FT	22	22	23	20	21	20	19	17	18	18	20	24
CFSM	0	0	0	0	0	0	0	0.03	0.02	0	0	0
Calendar year 2012	Total 121.6		Mean 0.33		Max 0.5	Min 0.25	Median 0.34		Acre-ft 244			

Table 14. Streamflow-gaging stations used in the Black Mesa monitoring program, their periods of record, and drainage areas. [---, not determined]

Station name	Station number	Date data collection began	Drainage area (square miles)
Moenkopi Wash at Moenkopi	09401260	July 1976	1,629
Dinnebito Wash near Sand Springs	09401110	June 1993	473
Polacca Wash near Second Mesa	09400568	April 1994	905
Pasture Canyon Springs	09401265	August 2004	---

runoff depend on the intensity and duration of thunderstorms during the summer and cyclonic storms during the fall, winter, and spring.

In 2012, discharge data were collected at four continuous-recording streamflow-gaging stations (tables 10–13). 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 Springs, 09401265; fig. 10A; table 14). The annual average discharges for a given water year at the four streamflow-gaging stations vary during the periods of record (fig. 10A), and there are no significant trends in annual average discharge for Moenkopi Wash, Polacca Wash, Dinnebito Wash, and Pasture Canyon Springs.

Annual average discharge can be influenced by precipitation; more precipitation generally results in greater annual average discharge at a streamflow-gaging station. The annual precipitation measured at Navajo National Monument (Betatakin; fig. 10) from 1976 to 2012 averaged 12.6 in. (fig. 10B). In 2012, total precipitation measured 12.0 in. (fig 10B; National Climatic Data Center, 2013).

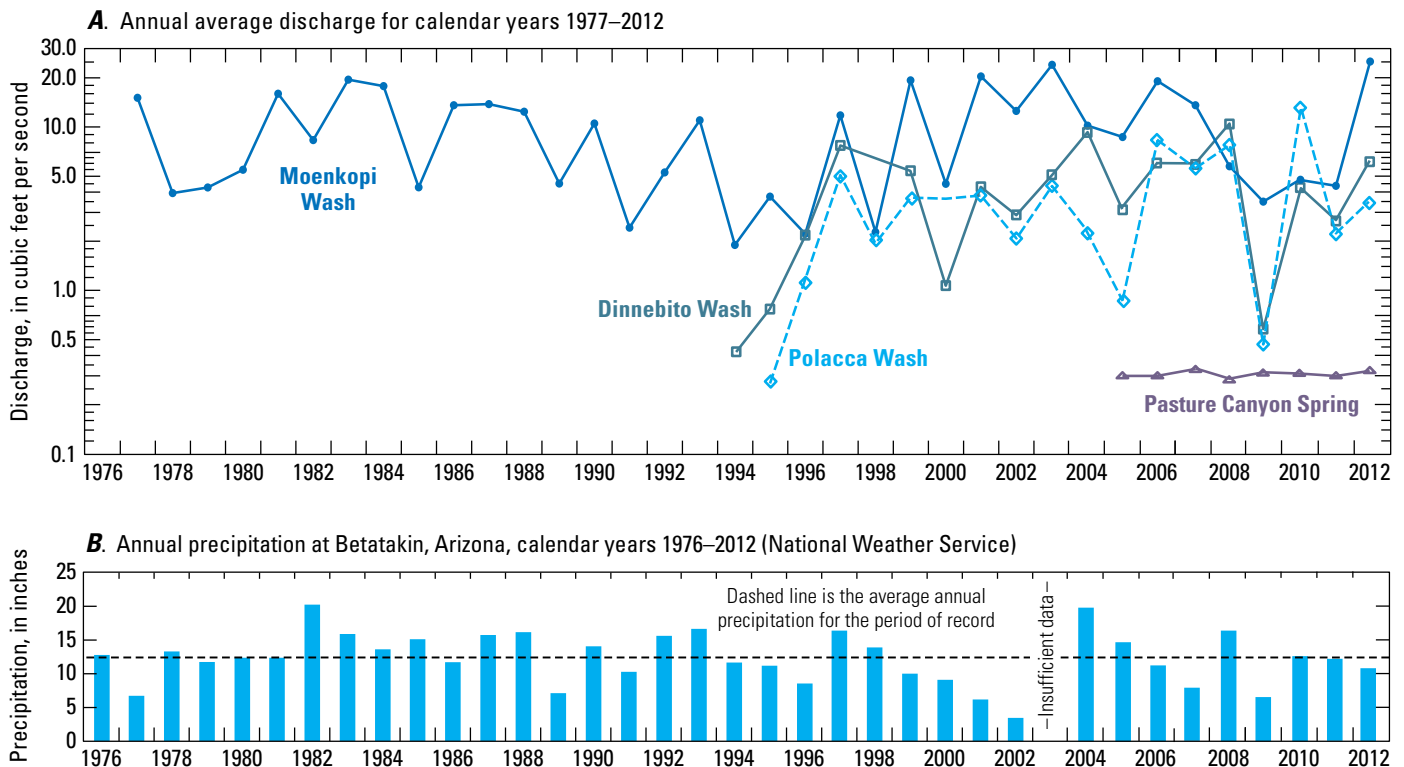


Figure 10. Plots of annual average discharge at Moenkopi Wash at Moenkopi (09401260), Pasture Canyon Springs (09401265), Dinnebito Wash near Sand Springs (09401110), and Polacca Wash near Second Mesa (09400568), and annual precipitation at Betatakin, Arizona, Black Mesa area, northeastern Arizona. A, Annual average discharge for calendar years 1977–2012; B, Annual precipitation at Betatakin, northeastern Arizona, calendar years 1976–2012 (National Climatic Data Center, 2013).

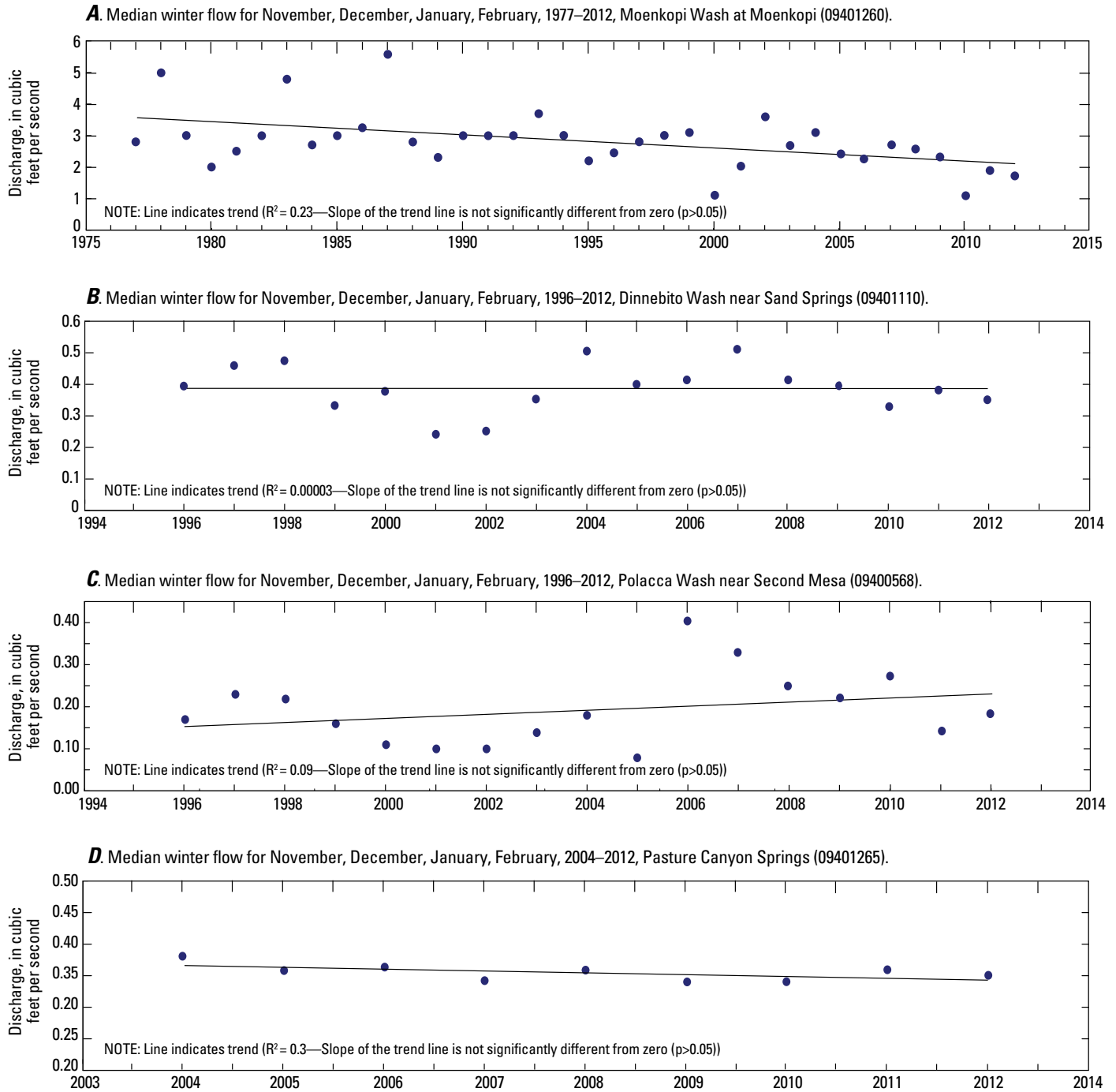


Figure 11. Plots of median winter flow for November, December, January, and February for water years 1977–2012 for *A*, Moenkopi Wash at Moenkopi (09401260); *B*, Dinnebito Wash near Sand Springs (09401110); *C*, Polacca Wash near Second Mesa (09400568); and *D*, Pasture Canyon Springs (09401265), Black Mesa area, northeastern Arizona. Median winter flow is calculated by computing the median flow for 120 consecutive daily mean flows for winter months—November, December, January, and February. Note: Trend lines were generated by using the method of least squares.

Table 15. Physical properties and chemical analyses of an equipment blank water sample from the Black Mesa monitoring program 2013. [$^{\circ}\text{C}$, degrees Celsius; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25°C ; mg/L , milligrams per liter; E, estimated; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than; --, no data]

U.S. Geological Survey identification number—333333111111110								
Common well name—Equipment Blank, July 26, 2013								
Temperature field ($^{\circ}\text{C}$)	Specific conductance, field ($\mu\text{S}/\text{cm}$)	pH, field (units)	Dissolved					
			Alkalinity, field, (mg/L as CaCO_3)	Nitrogen, $\text{NO}_2 + \text{NO}_3$, (mg/L as N)	Ortho-Phosphate, (mg/L as P)	Calcium, (mg/L as Ca)	Magnesium, (mg/L as Mg)	Potassium, (mg/L as K)
--	5	E6.3	<4.0	<0.04	<0.004	<0.022	<0.011	<0.03
Dissolved								
Sodium, (mg/L as Na)	Chloride, (mg/L as Cl)	Fluoride, (mg/L as F)	Silica, (mg/L as SiO_2)	Sulfate, (mg/L as SO_4)	Arsenic, ($\mu\text{g}/\text{L}$ as As)	Boron, ($\mu\text{g}/\text{L}$ as B)	Iron, ($\mu\text{g}/\text{L}$ as Fe)	Solids, residue at 180°C (mg/L)
<0.06	<0.06	<0.01	<0.06	<0.09	<0.04	<1.0	<4.0	<20

Table 16. Comparison of physical properties and chemical analyses of replicate and environmental water samples from Rough Rock PM5, Black Mesa area, northeastern Arizona, August 7, 2013.

[$^{\circ}\text{C}$, degrees Celsius; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25°C ; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than]

U.S. Geological Survey identification number—362418109514601			
Common well name	Rough Rock PM5		Percent difference
	Environmental	Replicate	
Temperature, field ($^{\circ}\text{C}$)	21.1	21.1	0
Specific conductance, field ($\mu\text{S}/\text{cm}$)	1090	1090	0
pH, field (units)	8.6	8.6	0
Alkalinity, field, dissolved (mg/L as CaCO_3)	212	212	0
Nitrogen, $\text{NO}_2 + \text{NO}_3$, dissolved (mg/L as N)	1.02	1.07	4.8
Ortho- Phosphate, dissolved (mg/L as P)	0.008	0.008	0
Calcium, dissolved (mg/L as Ca)	2.14	2.1	1.9
Magnesium, dissolved (mg/L as Mg)	0.293	0.284	3.1
Potassium, dissolved (mg/L as K)	1.21	1.19	1.7
Sodium, dissolved (mg/L as Na)	222	218	1.8
Chloride, dissolved (mg/L as Cl)	132	132	0
Fluoride, dissolved (mg/L as F)	1.8	1.8	0
Silica, dissolved (mg/L as SiO_2)	12.1	12.1	0
Sulfate, dissolved (mg/L as SO_4)	121	121	0
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	48.7	48.1	1.2
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	394	399	1.3
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	16.4	13.4	20
Dissolved solids, residue at 180°C (mg/L)	637	645	1.2

Trends in the groundwater-discharge component of total flow at the four streamflow-gaging stations were evaluated on the basis of the median of 120 consecutive daily mean flows for four winter months (November, December, January, and February) as a surrogate measure for base flow (fig. 11). Most flow to the streams that occurs during the winter is groundwater discharge from the N aquifer; rainfall and snowmelt runoff are infrequent. Most precipitation in the winter falls as snow, and the cold temperatures prevent appreciable snowmelt. Evapotranspiration is at a minimum during the winter. The median flow for November, December, January, and February is used to estimate groundwater discharge because the median is less affected by occasional winter runoff and is a better index of groundwater discharge rather than a calculation of base-flow groundwater discharge. A more rigorous and accurate calculation of base-flow 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 groundwater in the N aquifer with groundwater 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 groundwater discharge.

Median winter flows calculated for the 2012 water year were 1.9 ft³/s for Moenkopi Wash at Moenkopi, 0.38 ft³/s for Dinnebito Wash near Sand Springs, 0.14 ft³/s for Polacca Wash near Second Mesa, and 0.36 ft³/s for Pasture Canyon Springs (fig. 11A–D). For the period of record at each streamflow-gaging station, there have been no significant trends in median winter flows, as indicated by trends calculated using the method of least squares and Kendall's tau ($p > 0.05$; fig. 11A–D).

Water Chemistry

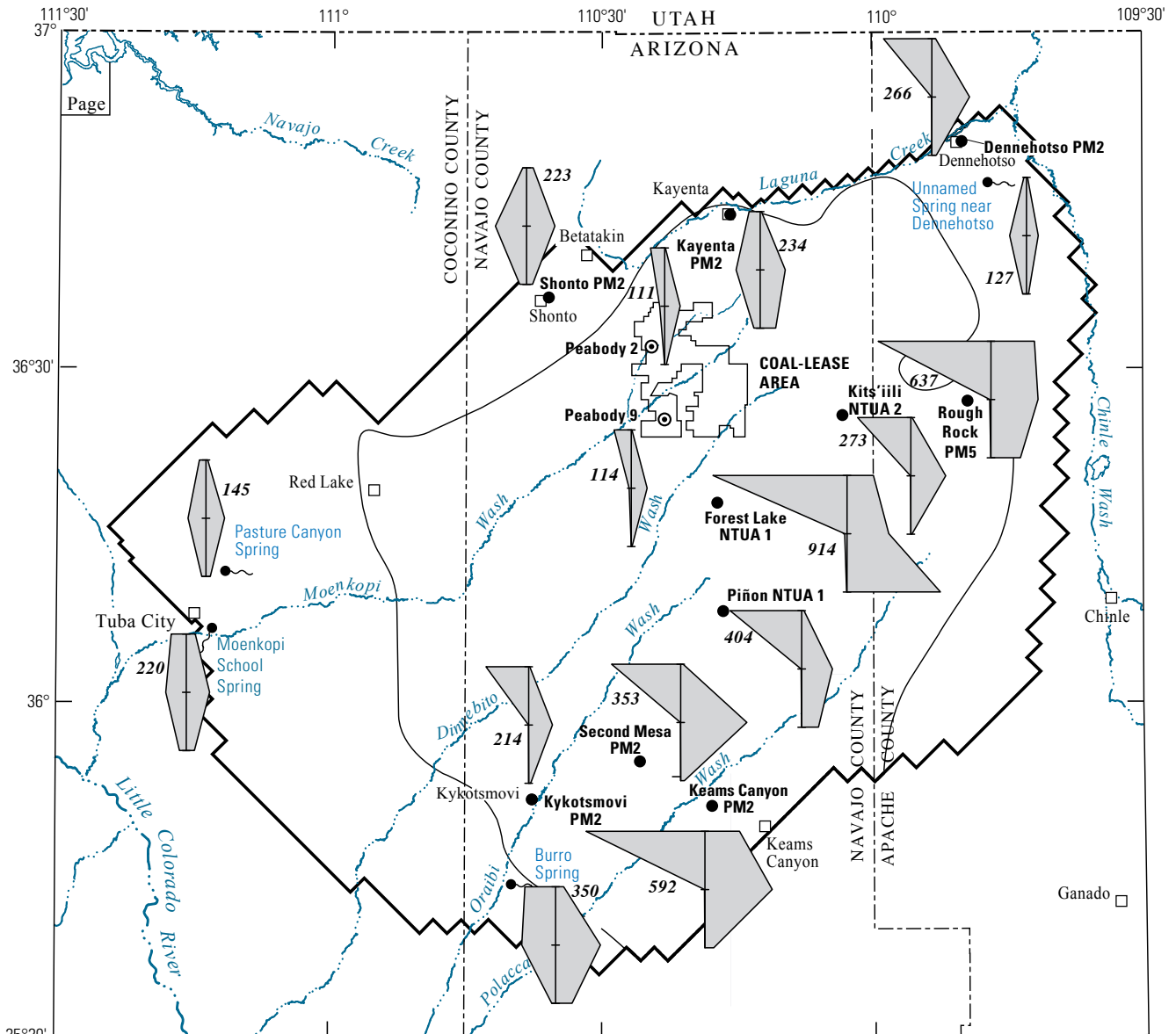
Water samples for water-chemistry analyses were collected in July and August 2013 from selected wells and springs as part of the Black Mesa monitoring program. Field measurements are made and the water samples are analyzed for major ions, nutrients, iron, boron, and arsenic. Field measurements are made in accordance with standard USGS protocols documented in the USGS National Field Manual for the Collection of Water-Quality Data and in several USGS Techniques of Water-Resources Investigations Reports (Friedman and Erdmann, 1982; Koterba and others, 1995; Wilde and others, 1998a,b,c; and Wilde and others, 1999). Field measurements include pH, specific conductance, temperature, dissolved oxygen, alkalinity, and discharge rates at springs. Field alkalinities were determined using incremental equivalence (Wilde, variously dated). Major ion, nutrient, iron, boron, arsenic, and alkalinity samples were filtered through a 0.45-micron pore size filter and preserved according to sampling and analytical protocols. Laboratory analyses for samples were done at the USGS National Water Quality Laboratory (NWQL) according to techniques described in Fishman and Friedman (1989), Fishman (1993), Struzeski and others (1996), and Garbarino and others (2006).

Quality assurance for this study was maintained through the use of proper training of field personnel, use of standard

USGS field and laboratory protocols, collection of quality control samples, and a thorough review of the analytical results. All USGS scientists involved with this study have participated in the USGS National Field Quality Assurance Program, which requires participants to successfully determine pH, specific conductance, and alkalinity of reference samples supplied by the USGS Branch of Quality Systems. Field personnel were trained in water-quality field methods by USGS personnel or through formal instruction at the USGS water-quality field-methods class.

Quality control samples were collected as part of the water-quality sampling of the Black Mesa monitoring program in 2013. An equipment blank sample was collected prior to collection of field water-quality samples and a replicate sample was taken during collection of field water-quality samples (tables 15 and 16). The equipment blank was processed at the Arizona Water Science Center Flagstaff field office water laboratory prior to the collection of any environmental samples. The equipment blank did not yield concentrations of any analytes above the NWQL reporting limit for any of constituents reported (table 15). A sequential replicate sample was collected during the 2013 field visit to the well Rough Rock PM5. The results of the comparison between the replicate sample and environmental sample are presented in table 16. Relative percent difference was used to evaluate variability between analytes of the replicate and environmental sample at Rough Rock PM5. Aside from iron, all other constituents were within +/- 5 percent of each other (table 16). The greatest variability was dissolved iron, with a 20 percent difference between replicate and environmental sample (table 16).

Water-chemistry samples have been collected from 12 different wells during the past 10 years of the project; 4 of the wells have been sampled every year, and the other 8 wells have been selected on the basis of a sampling rotation. In 2013, water samples were collected from 12 well sites: Second Mesa PM2, Keams Canyon PM2, Kykotsmobi PM2, Piñon NTUA 1, Forest Lake NTUA 1, Kitsillie NTUA 2, Rough Rock PM5, Peabody 2, Peabody 9, Shonto PM2, Kayenta PM2, and Dennehotso PM2. Since 1989, samples have been collected from the same four springs (Moenkopi School Spring, Pasture Canyon Spring, Unnamed Spring near Dennehotso, and Burro Spring), and in 2013 all four springs were sampled. Long-term data for specific conductance, dissolved solids, chloride, and sulfate for the wells and springs sampled each year are shown in the annual reports (table 2). These constituents are monitored on an annual basis because increased concentrations in the N aquifer could indicate leakage from the overlying D aquifer (Eychaner, 1983). On average, the concentrations of dissolved solids in water from the D aquifer is about 7 times greater than that of water from the N aquifer; concentration of chloride ions is about 11 times greater, and concentration of sulfate ions is about 30 times greater (Eychaner, 1983). 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>), and they can be found in monitoring reports cited in the "Previous Investigations" section of this report and listed in table 2.



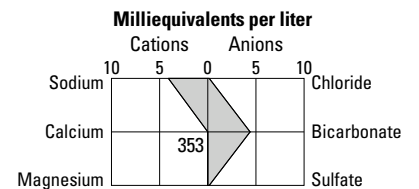
Base from U.S. Geological Survey digital data, 1:100,000, 1980 Lambert Conformal Conic projection Standard parallels 29°30' and 45°30', central meridian -96°00'



Modified from Brown and Eychaner, 1988

EXPLANATION

- Confined
- Unconfined
- Approximate boundary between confined and unconfined conditions—From Brown and Eychaner (1988)
- Boundary of mathematical model—From Brown and Eychaner (1988)
- Kykotsmovi PM2
- Municipal well from which water-chemistry sample was collected—Kykotsmovi PM2 is well name
- Peabody 2
- Industrial well from which water-chemistry sample was collected—Peabody 2 is a well number
- Pasture Canyon Spring
- Spring at which discharge was measured and water-chemistry sample was collected



Water-chemistry diagram—Shows major chemical constituents in milliequivalents per liter (meq/L). The diagram can be used to compare and characterize types of water. Number, 353, is dissolved-solids concentration, in milligrams per liter.

Figure 12. Map showing water chemistry and distribution of dissolved solids of selected wells in the N aquifer, Black Mesa area, northeastern Arizona, 2013.

Water-Chemistry Data for Selected Wells Completed in the N Aquifer

In July and August 2013, water samples were collected from 12 well sites: Second Mesa PM2, Keams Canyon PM2, Kykotsmovi PM2, Piñon NTUA 1, Forest Lake NTUA 1, Kitsillie NTUA 2, Rough Rock PM5, Peabody 2, Peabody 9, Shonto PM2, Kayenta PM2, and Dennehotso PM2 (table 16, figs. 12 and 13). The primary types of water in the N aquifer in the Black Mesa study area are calcium bicarbonate water and sodium bicarbonate water. Calcium bicarbonate water is mostly found in the recharge and unconfined areas of the northern and northwestern parts of the Black Mesa study area. Sodium bicarbonate water is mostly found in the area that is confined and downgradient to the south and east (Lopes and Hoffmann, 1997). Water-chemistry results from well samples in 2013 are presented in figures 12 and 13 and in table 17.

Forest Lake NTUA1, Rough Rock PM5, and Keams Canyon PM2 consistently yielded the highest dissolved-solids concentrations and the highest chloride concentrations of the 12 wells sampled, at 914 mg/L, 637 mg/L, and 592 mg/L dissolved solids, respectively (fig. 13 and table 17), and 80 mg/L, 132 mg/L, and 105 mg/L chloride (table 17). Dissolved-solids concentrations in the other 8 wells ranged from 111 mg/L at Peabody 2 to 404 mg/L at Piñon NTUA 1, and chloride concentrations ranged from 2.03 mg/L at Peabody 2 and Peabody 9 to 11.2 mg/L at Dennehotso PM2 (table 17). Forest Lake NTUA 1 and Rough Rock PM5 had the highest sulfate concentration 384 mg/l and 121 mg/L, respectively, of the 12 wells sampled, and the concentrations at the other wells ranged from 3.42 mg/L at Peabody 9 to 69 mg/L at Piñon NTUA 1 (table 17).

The water sample collected at Forest lake NTUA1 in August 2013 showed elevated specific conductance, dissolved calcium, magnesium, potassium, sodium, chloride, fluoride,

sulfate, boron, and total dissolved solids when compared to samples collected in the previous five years (tables 17 and 18). The 2013 sample at Forest Lake NTUA1 was more similar to a sample collected at Forest Lake NTUA1 in 1995 and 1997. Although there are no specific reasons as to why certain concentrations are elevated in the 2013 sample, it was significant enough to note.

Samples from 1998 to present at Piñon NTUA 1 have shown varying sulfate, chloride, and dissolved-solids concentrations (table 18). Purge times greater than 12 hours from Piñon NTUA 1 appear to induce leakage from the overlying D aquifer and result in higher concentrations in samples. The confining layer of the Carmel Formation, in the area of Piñon, is about 120 ft thick and composed of a more sandy siltstone rather than the clayey siltstone observed in the northern part of the study area, where leakage has not been detected (Truini and Macy, 2005). Areas where the Carmel Formation is 120 ft thick or less coincide with areas where isotopic ratios of $^{87}\text{Sr}/^{86}\text{Sr}$ and major-ion data for groundwater indicate that D aquifer water has mixed with N aquifer water as a result of leakage (Truini and Longworth, 2003). Both the lithologic difference in, and the thickness of, the Carmel Formation near Piñon indicate that leakage could be possible. Purge times may have an effect on samples taken from Piñon NTUA 1 and will be more closely monitored during future sampling.

Chemical constituents analyzed from the 12 wells were compared to the U.S. Environmental Protection Agency (USEPA) primary and secondary drinking water standards (U.S. Environmental Protection Agency, 2003). Maximum contaminant levels (MCLs), which are the primary regulations, are legally enforceable standards that apply to public water systems. They protect drinking-water quality by limiting the levels of specific contaminants that can adversely affect public health. Secondary maximum contaminant levels (SMCLs)

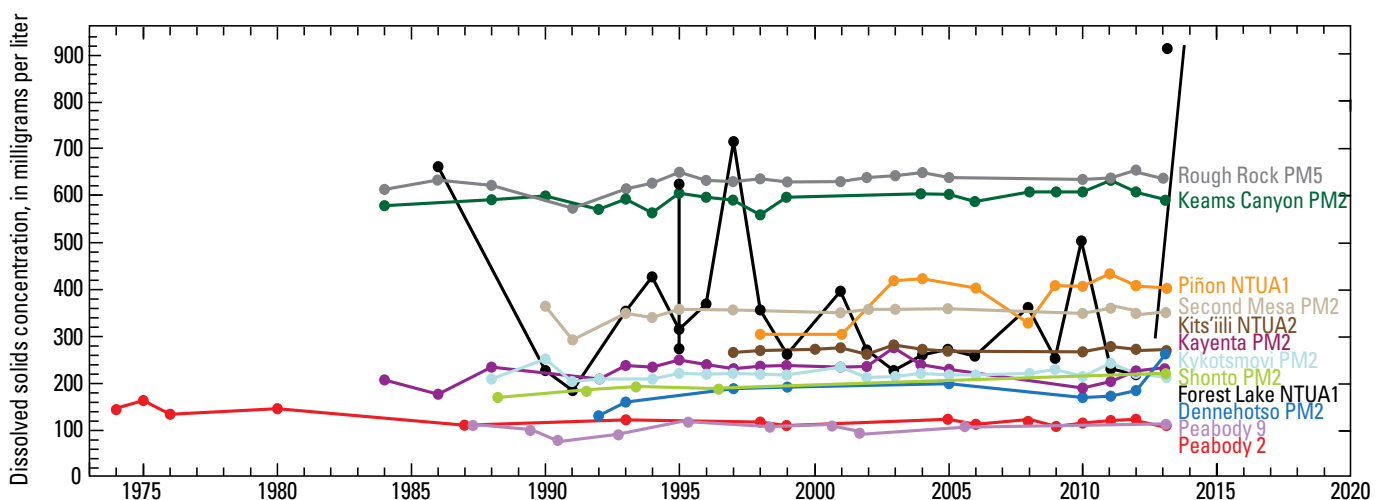


Figure 13. Plot of dissolved-solids concentrations for water samples from selected wells during 1974–2013, N aquifer, Black Mesa area, northeastern Arizona: Rough Rock PM5, 1984–2013; Keams Canyon PM2, 1984–2013; Forest Lake NTUA 1, 1986–2013; Piñon NTUA 1, 1998–2013; Second Mesa PM2, 1990–2013; Kitsillie NTUA 2, 1997–2013; Kykotsmovi, 1988–2013; Kayenta PM2, 1984–2013; Dennehotso PM2, 1992–2013; Shonto PM2, 1961–2013; Peabody 9, 1987–2013; and Peabody 2, 1974–2013.

Table 17. Physical properties and chemical analyses of water samples from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, northeastern Arizona, 2013.[°C, degrees Celsius; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than]

Common well name	U.S. Geological Survey identification number	Date of samples	Temperature, field (°C)	Specific conductance, field ($\mu\text{S}/\text{cm}$)	pH, field (units)	Dissolved					
						Alkalinity, field, (mg/L as CaCO_3)	Nitrogen, $\text{NO}_2 + \text{NO}_3$, (mg/L as N)	Ortho-Phosphate, (mg/L as P)	Calcium, (mg/L as Ca)	Magnesium, (mg/L as Mg)	Potassium, (mg/L as K)
Second Mesa PM2	354749110300101	7/31/13	19.2	558	6.9	284	<0.04	0.011	0.482	0.032	0.42
Keams Canyon PM2	355023110182701	7/31/13	20.2	1050	9.2	343	<0.04	0.008	0.847	0.16	0.75
Kykotsmovi PM2	355215110375001	7/30/13	22.9	369	9.5	164	1.16	0.032	0.478	0.013	0.4
Piñon NTUA 1	360527110122501	8/1/13	26.6	654	9.3	238	1.28	0.006	1.03	0.147	0.52
Forest Lake NTUA 1	361737110180301	8/9/13	28.6	1460	8.8	192	0.28	0.019	3.97	0.508	1.26
Kitsillie NTUA 2	362043110030501	8/1/13	28.9	452	9.2	237	1.36	0.01	0.515	0.012	0.53
Peabody 9	362333110250001	8/8/13	31.9	159	8.6	73.4	0.761	0.006	3.7	0.032	0.6
Rough Rock PM5	362418109514601	8/7/13	21.1	1090	8.6	212	1.02	0.008	2.14	0.293	1.21
Peabody 2	363005110250901	8/8/13	31.1	162	8.3	68.7	0.961	0.007	8.69	0.129	0.72
Shonto PM2	363558110392501	8/8/13	14	375	6.9	122	4.72	0.012	53.6	7.09	1.75
Kayenta PM2	364344110151201	8/7/13	16.6	352	7.5	108	0.881	0.006	41.4	6.62	1.21
Denehotso PM2	365045109504001	8/6/13	20.5	406	8.3	165	1.98	0.1	0.521	0.011	0.44

Common well name	U.S. Geological Survey identification number	Date of samples	Dissolved								Solids, residue at 180 °C (mg/L)
			Sodium, (mg/L as Na)	Chloride, (mg/L as Cl)	Fluoride, (mg/L as F)	Silica, (mg/L as SiO_2)	Sulfate, (mg/L as SO_4)	Arsenic, ($\mu\text{g}/\text{L}$ as As)	Boron, ($\mu\text{g}/\text{L}$ as B)	Iron, ($\mu\text{g}/\text{L}$ as Fe)	
Second Mesa PM2	354749110300101	7/31/13	136	7.08	0.31	19.3	15.2	17.1	93	<4	353
Keams Canyon PM2	355023110182701	7/31/13	234	105	1.5	12.4	36.2	41.1	623	9.3	592
Kykotsmovi PM2	355215110375001	7/30/13	83.9	3.05	0.17	23.6	8.01	4.9	32	<4	214
Piñon NTUA 1	360527110122501	8/1/13	141	6.99	0.29	26.3	69	4.3	76	<4	404
Forest Lake NTUA 1	361737110180301	8/9/13	264	80	1.58	15.6	384	1.1	523	21.8	914
Kitsillie NTUA 2	362043110030501	8/1/13	105	3.68	0.19	25.5	4.43	3.7	47	<4	273
Peabody 9	362333110250001	8/8/13	33.8	2.03	0.16	19.4	3.42	3	19	<4	114
Rough Rock PM5	362418109514601	8/7/13	222	132	1.8	12.1	121	48.7	394	16.4	637
Peabody 2	363005110250901	8/8/13	27.9	2.03	0.12	21.6	6.86	2.9	17	<4	111
Shonto PM2	363558110392501	8/8/13	7.43	20	0.03	14.2	24.5	0.65	16	<4	223
Kayenta PM2	364344110151201	8/7/13	22	3.67	0.15	16.3	63.7	2.4	29	4.7	234
Denehotso PM2	365045109504001	8/6/13	95.1	11.2	0.28	7.29	18.4	3.2	60	<4	266

Table 18. Specific conductance and concentrations of selected chemical constituents in water samples from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, northeastern Arizona, 1961–2013.[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligram per liter; ---, no data]

Year	Specific conductance, field ($\mu\text{S}/\text{cm}$)	Dissolved solids, residue at 180 °C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Year	Specific conductance, field ($\mu\text{S}/\text{cm}$)	Dissolved solids, residue at 180 °C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Second Mesa PM2					Piñon NTUA 1				
1968	670	---	14	35	1998	460	304	4.59	4.74
1990	590	364	6.5	16	2001	473	304	4.86	5.53
1991	595	292	10	15	2002	512	---	5.04	5.47
1993	630	350	7.5	15	2003	716	421	6.71	82.8
1994	605	342	7.6	15	2004	691	429	7.04	75.9
1995	610	357	7.2	14	2006	709	399	6.56	66.9
1997	646	356	7.08	14.4	2008	565	328	6.15	8.70
2001	597	352	7.11	14.9	2009	670	409	7.09	68.4
2002	608	357	7.53	14.4	2010	675	407	7.06	63.8
2003	601	359	6.26	14.2	2011	629	422	7.78	77.8
2005	615	361	6.83	13.4	2012	652	407	7.09	64.3
2010	553	349	7.02	15.3	2013	654	404	6.99	69
2011	550	355	7.71	16.3	Forest Lake NTUA 1				
2012	570	346	7.26	14.9	1982	470	---	11	67
2013	557	353	7.08	15.2	1986	---	660	35	300
Keams Canyon PM2					1990	375	226	8.2	38
1982	1,010	---	94	35	1991	¹ 350	183	10	24
1983	1,120	---	120	42	1993	693	352	35	88
1984	1,060	578	96	36	1994	¹ 734	430	56	100
1988	1,040	591	97	34	1995	470	274	13	60
1990	1,020	600	94	34	1995	1,030	626	86	160
1992	1,010	570	93	36	1995	488	316	16	71
1993	1,040	590	92	36	1996	684	368	44	79
1994	975	562	86	32	1997	¹ 1,140	714	77.8	247
1995	1,010	606	99	32	1998	489	350	37.3	70.8
1996	1,020	596	96	34	1999	380	259	15.7	48.5
1997	1,070	590	95.8	33.5	2001	584	398	49.6	83.9
1998	908	558	78.1	28.5	2002	452	268	21.7	49.5
1999	1,040	595	97.1	35.2	2003	385	228	10.5	39.8
2004	945	³ 603	96.7	32.4	2004	222	263	16.0	40.5
2005	828	601	97.4	33.6	2005	402	272	17.9	43.8
2006	1,070	588	98.9	34	2006	445	258	13.9	48.6
2008	1,080	607	95.1	34.5	2008	424	362	36.5	73.2
2009	1,030	609	100	35.5	2009	400	250	12.1	43.6
2010	965	607	104	34.9	2010	524	503	60.3	125
2011	1,080	629	117	39.6	2011	369	227	10.9	38.3
2012	1,060	608	102	35.2	2012	391	219	11.3	36.0
2013	1,050	592	105	36.2	2013	1,460	914	80	384
Kykotsmovi PM2					Kits'ivili NTUA 2				
1988	368	212	3.2	8.6	1997	¹ 524	269	3.6	4.3
1990	355	255	3.2	9.0	1998	379	270	3.8	4.07
1991	¹ 374	203	4.4	7.9	2000	454	274	4.0	4.11
1992	363	212	3.3	8.4	2001	409	276	5.0	4.52
1994	¹ 365	212	3.6	8.5	2002	439	264	4.5	4.38
1995	368	224	3.1	6.2	2003	445	275	4.2	4.42
1996	365	224	3.3	8.5	2004	367	73	4.0	4.60
1997	¹ 379	222	3.02	7.97	2005	424	271	3.67	3.70
1998	348	223	3.33	7.33	2010	457	269	3.81	4.65
1999	317	221	3.50	7.94	2011	449	274	3.89	4.85
2001	339	230	3.48	8.18	2012	443	270	3.77	4.94
2002	350	215	3.39	7.86	2013	452	273	3.68	4.43
2003	364	219	3.49	7.76					
2004	261	223	3.46	8.32					
2005	316	221	3.08	6.93					
2006	367	221	3.25	7.69					
2008	373	226	3.04	8.22					
2009	369	230	3.13	8.11					
2010	382	217	3.17	8.38					
2011	367	229	3.10	8.35					
2012	367	219	3.07	7.75					
2013	369	214	3.05	8.01					
2013	369	214	3.05	8.01					

¹Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports showed values determined by laboratory analysis.²Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports showed values determined by the sum of constituents.³Value is different in Black Mesa monitoring report printed in 2004.

Table 18. Specific conductance and concentrations of selected chemical constituents in water samples from selected industrial and municipal wells completed in the N aquifer, Black Mesa area, northeastern Arizona, 1961–2013.—Continued[$\mu\text{S/cm}$, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligram per liter; ---, no data]

Year	Specific conductance, field ($\mu\text{S/cm}$)	Dissolved solids, residue at 180 °C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Year	Specific conductance, field ($\mu\text{S/cm}$)	Dissolved solids, residue at 180 °C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Rough Rock PM5					Kayenta PM2				
1964	1,120	(²)	100	110	1982	360	(²)	4.5	58
1970	610	(²)	13	50	1983	375	(²)	5.9	60
1983	1,090	(²)	130	110	1984	¹ 370	209	4.2	51
1984	¹ 1,100	613	130	99	1986	300	181	8.2	30
1986	1,010	633	140	120	1988	358	235	3.8	74
1988	1,120	624	130	³ 110	1992	383	210	5.6	78
1991	¹ 1,210	574	130	110	1993	374	232	3.7	78
1993	1,040	614	130	110	1994	¹ 371	236	4.2	77
1994	¹ 1,180	626	130	110	1995	371	250	4.2	72
1995	1,110	648	140	110	1996	370	238	3.8	76
1996	1,100	634	130	110	1997	379	230	3.93	76.9
1997	¹ 1,060	628	130	112	1998	349	236	3.75	71.0
1998	894	637	133	112	1999	364	236	3.99	72.4
1999	1,050	630	129	110	2001	331	234	5.04	73.4
2001	980	628	125	110	2002	363	237	5.08	66.9
2002	1,120	636	129	109	2003	78	273	5.88	87.7
2003	1,080	642	127	110	2004	303	241	4.03	71.8
2004	653	49	128	109	2005	374	231	3.69	76.3
2005	1,050	639	128	113	2010	308	191	4.71	11.1
2010	1,100	635	129	114	2011	302	192	4.82	11.1
2011	1,090	629	135	119	2012	363	222	3.71	62.5
2012	1,080	649	130	116	2013	352	234	3.67	63.7
2013	1,090	637	132	121	Shonto PM2				
Peabody 2					1961	290	---	10	16
1967	221	---	5.0	21	1973	280	---	7.1	20
1971	211	---	2.8	18	1986	302	---	10	14
1974	210	144	2.8	17	1988	285	171	13	14
1975	230	163	5.0	20	1992	321	186	22	19
1976	260	133	3.6	16	1993	324	197	17	16
1979	220	---	3.4	24	1996	323	188	15	17
1980	225	145	11.0	20	2002	355	215	21.6	22.5
1986	172	---	2.6	8.1	2003	357	239	20.2	22.2
1987	149	113	5.0	9.1	2005	346	205	17.2	19.9
1993	163	124	1.7	8.9	2013	375	223	20	24.5
1998	93	119	2.22	7.87	Peabody 9				
1999	167	115	2.31	8.14	1986	181	---	3.1	4.9
2005	134	124	2.09	8.22	1987	148	102	2.8	4.1
2006	167	118	2.16	8.23	1990	158	106	1.6	3
2008	160	120	2.04	7.47	1991	155	83	2.7	3.1
2009	146	113	2.08	7.16	1993	157	94	1.6	2.9
2010	168	119	2.08	7.37	1994	---	---	1.7	---
2011	162	114	2.13	8.12	1995	154	122	1.6	1.6
2012	155	122	2.04	7.25	1998	109	109	1.68	2.48
2013	162	111	2.03	6.86	2001	88	112	1.83	2.72
Dennehotso PM2					2002	152	96	1.66	2.54
1964	350	---	12	31	2006	158	111	2.59	4.43
1992	226	131	9.8	19	2013	159	114	2.03	3.42
1993	298	164	8.2	16					
1997	¹ 305	190	10.9	14.3					
1999	314	196	13.7	15.3					
2005	339	205	10.5	14.4					
2010	279	173	7.41	13.2					
2011	279	178	7.64	13.9					
2012	295	184	7.59	13.6					
2013	406	266	11.2	18.4					

¹Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports showed values determined by laboratory analysis.²Value is different in Black Mesa monitoring reports printed before 2000. The earlier reports showed values determined by the sum of constituents.³Value is different in Black Mesa monitoring report printed in 2004.

Table 19. Physical properties and chemical analyses of water samples from Burro, Moenkopi School, Pasture Canyon springs, and Unnamed spring near Dennehotso in the Black Mesa area, northeastern Arizona, in July and August 2013.

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

U.S. Geological Survey identification number	Bureau of Indian Affairs site number	Common spring name	Date of samples	Temperature, field (°C)	Specific conductance, field (µS/cm)	pH, field (units)	Dissolved					
							Alkalinity, field, (mg/L as CaCO ₃)	Nitrogen, NO ₂ + NO ₃ , (mg/L as N)	Ortho-Phosphate, (mg/L as P)	Calcium, (mg/L as Ca)	Magnesium, (mg/L as Mg)	Potassium, (mg/L as K)
354156110413701	6M-31	Burro Spring	7/30/13	24.3	560	7.2	193	<0.04	0.005	58.2	4.06	0.36
360632111131101	3GS-77-6	Moenkopi School Spring	7/29/13	18.8	370	6.9	100	2.26	0.006	35.2	7.11	1.33
36102111115901	3A-5	Pasture Canyon Spring	7/29/13	17.3	245	7.4	79.9	4.58	0.014	30.9	4.45	1.27
364656109425400	8A-224	Unnamed Spring near Dennehotso	8/6/13	16.2	196	7.3	50.5	1.55	0.043	28.9	4.04	1.23

U.S. Geological Survey identification number	Bureau of Indian Affairs site number	Common spring name	Date of samples	Dissolved								Solids, residue at 180 °C (mg/L)
				Sodium, (mg/L as Na)	Chloride, (mg/L as Cl)	Fluoride, (mg/L as F)	Silica, (mg/L as SiO ₂)	Sulfate, (mg/L as SO ₄)	Arsenic, (µg/L as As)	Boron, (µg/L as B)	Iron, (µg/L as Fe)	
354156110413701	6M-31	Burro Spring	7/30/13	60.5	24.4	0.37	17.5	67.7	1.4	87	15.7	350
360632111131101	3GS-77-6	Moenkopi School Spring	7/29/13	29.7	27.2	0.17	13.3	33.3	2.3	41	<4	220
36102111115901	3A-5	Pasture Canyon Spring	7/29/13	13	5.16	0.16	9.98	17.7	1.6	34	<4	145
364656109425400	8A-224	Unnamed Spring near Dennehotso	8/6/13	5.17	3.06	0.15	13.2	8.24	2.5	19	4.9	127

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 enforced.

In 2013, most of the analyzed constituents from the 12 wells were below the USEPA MCL or SMCL for drinking water. Three of the 12 wells sampled exceeded the USEPA MCL for arsenic (10.0 µg/L): Second Mesa PM2 had a concentration of 17.1 µg/L, Rough Rock PM5 had a concentration of 48.7 µg/L, and Keams Canyon PM2 had a concentration of 41.1 µg/L (table 17). The USEPA SMCL for concentration of dissolved solids (500 mg/L) was exceeded at Keams Canyon PM2 (592 mg/L), Forest Lake NTUA 1 (914 mg/L), and Rough Rock MP5 (637 mg/L). In addition, the USEPA SMCL for pH (6.5 to 8.5) was exceeded at Keams Canyon PM2, Kykotsmovi PM2, Piñon NTUA 1, Forest Lake NTUA 1, Kitsillie NTUA 2, Rough Rock PM5, and Peabody 9 (U.S. Environmental Protection Agency, 2003; table 17). The USEPA SMCL for sulfate (250 mg/L) was exceeded at the Forest Lake NTUA 1 well (384 mg/L).

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

In July and August 2013, water samples were collected from Burro Spring, Moenkopi School Spring, Pasture Canyon Spring, and Unnamed Spring near Dennehotso (figs. 8 and 12, table 19). These four springs discharge water from the unconfined part of the N aquifer. At Moenkopi School Spring, samples were collected from a horizontal metal pipe built into the hillside to collect water from the spring. At Pasture Canyon Spring, samples were collected from a pipe at the end of a channel that is approximately 50 ft away from the spring. At Burro Spring, samples were collected from the end of a pipe that fills a trough for cattle. At Unnamed Spring near Dennehotso, samples were collected from a pool along the bedrock wall from which the spring discharges.

The samples from all four springs yielded calcium bicarbonate-type water (fig. 12 and table 19). Dissolved solid concentrations measured 350 mg/L at Burro Spring, 220 mg/L at Moenkopi School Spring, 145 mg/L at Pasture Canyon Spring,

Table 20. Specific conductance and concentrations of selected chemical constituents in N-aquifer water samples from four springs in the Black Mesa area, northeastern Arizona, 1948–2013.[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; °C, degrees Celsius; ---, no data]

Year	Specific conductance, field ($\mu\text{S}/\text{cm}$)	Dissolved solids, residue at 180 °C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Year	Specific conductance, field ($\mu\text{S}/\text{cm}$)	Dissolved solids, residue at 180 °C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Burro Spring					Pasture Canyon Spring				
1989	485	308	22.0	59	1948	¹ 227	(2)	6.0	13
1990	¹ 545	347	23.0	65.0	1982	240	---	5.1	18.0
1993	595	368	30.0	85.0	1986	257	---	5.4	19.0
1994	¹ 597	368	26.0	80.0	1988	232	146	5.3	18.0
1996	525	324	23.0	62.0	1992	235	168	7.10	17.0
1997	¹ 511	332	26.0	75.0	1993	242	134	5.3	17.0
1998	504	346	24.6	70.4	1995	235	152	4.80	14.0
1999	545	346	24.8	69.2	1996	238	130	4.70	15.0
2001	480	348	23.6	67.8	1997	232	143	5.27	16.9
2002	591	374	30.6	77.0	1998	232	147	5.12	16.2
2003	612	374	30.5	81.1	1999	235	142	5.06	14.2
2004	558	337	24.9	63.6	2001	236	140	5.06	17.0
2005	558	357	25.8	68.9	2002	243	143	5.14	16.5
2006	576	359	25.0	68.2	2003	236	151	5.09	16.1
2009	577	372	25.7	72.5	2004	248	150	5.50	16.4
2010	583	355	25.9	71.5	2005	250	149	5.07	16.3
2011	560	353	25.7	69.5	2008	240	149	5.01	18.3
2012	553	330	23.1	64.7	2009	241	160	5.10	18.6
2013	560	350	24.4	67.7	2010	314	157	5.25	17.9
Moenkopi School Spring					2011	236	146	5.47	18.5
1952	222	---	6	---	2012	248	142	5.20	17.5
1987	270	161	12.0	19.0	2013	245	145	5.16	17.7
1988	270	155	12.0	19.0	Unnamed Spring near Dennehotso				
1991	297	157	14.0	20.0	1984	195	112	2.8	7.1
1993	313	204	17.0	27.0	1987	178	² 109	3.4	7.5
1994	305	182	17.0	23.0	1992	178	108	3.60	7.30
1995	314	206	18.0	22.0	1993	184	100	3.2	8.00
1996	332	196	19.0	26.0	1995	184	124	2.60	5.70
1997	¹ 305	185	17.8	23.8	1996	189	112	2.80	8.20
1998	296	188	17.6	23.7	1997	¹ 170	98	2.40	6.10
1999	305	192	18.7	25.6	1998	179	116	2.43	5.36
2001	313	194	18.3	25.5	1999	184	110	2.76	6.30
2002	316	191	18.3	23.1	2001	176	116	2.61	5.96
2003	344	197	18.6	23.4	2002	183	104	2.67	7.38
2004	349	196	19.1	21.3	2003	180	118	2.95	7.16
2005	349	212	23.3	29.6	2004	170	117	2.72	5.05
2006	387	232	27.2	34.2	2005	194	114	2.65	8.67
2007	405	238	30.6	39.9	2010	259	155	9.38	15.5
2008	390	230	28.3	37.6	2011	292	172	14.5	24.1
2009	381	240	27.0	35.4	2012	298	179	13.5	21.9
2010	480	217	26.2	33.4	2013	196	127	3.06	8.24
2011	374	216	28.5	36.2					
2012	382	218	27.5	33.3					
2013	370	220	27.2	33.3					

¹Value is different in Black Mesa monitoring reports before 2000. Earlier reports showed values determined by laboratory analysis.²Value is different in Black Mesa monitoring reports before 2000. Earlier reports showed values determined by the sum of constituents.

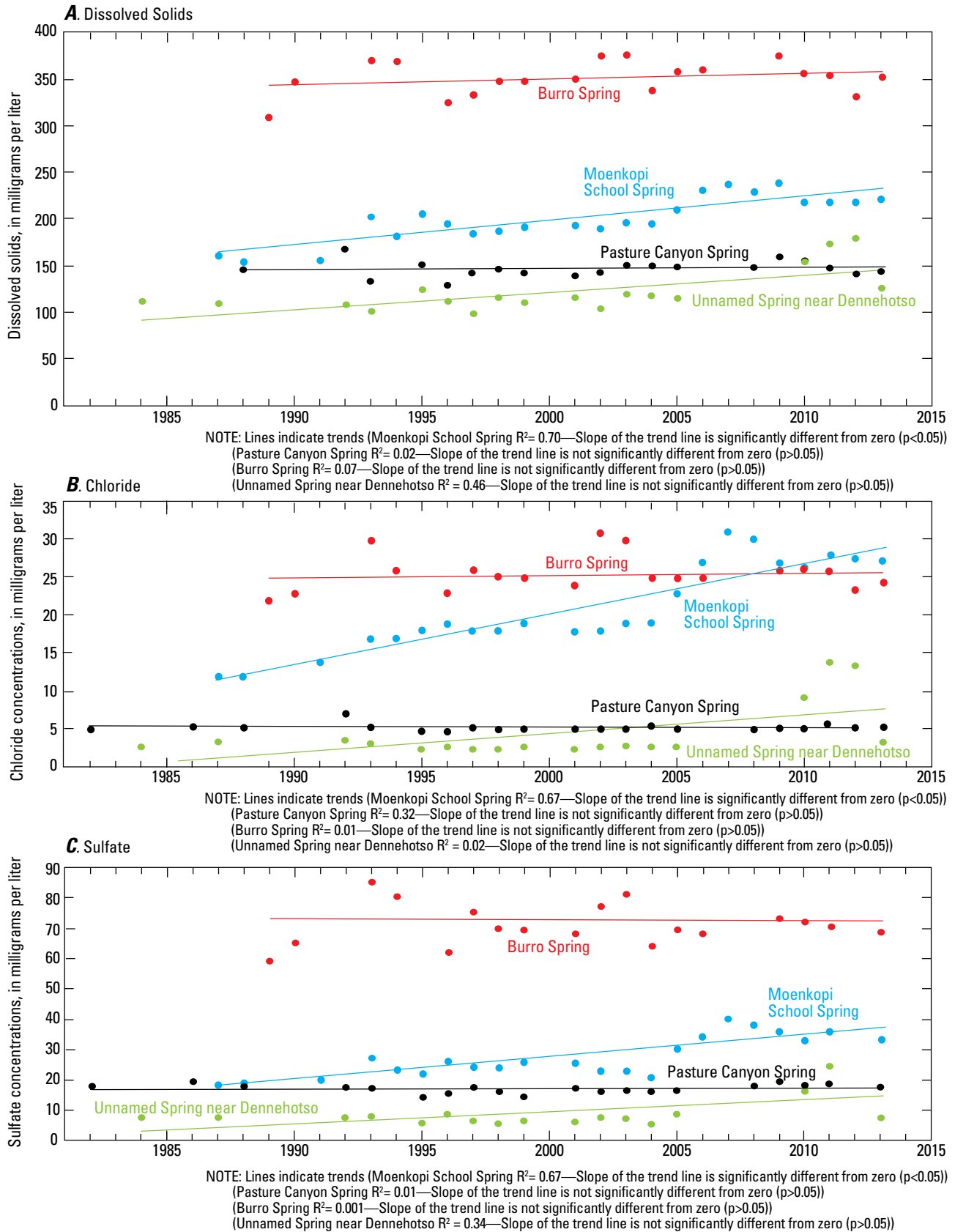


Figure 14. Plots showing concentrations of dissolved solids, chloride, and sulfate for water samples from Moenkopi School Spring, Pasture Canyon Spring, Burro Spring and Unnamed Spring near Dennehotso, which discharge from the N aquifer in Black Mesa area, northeastern Arizona, measured from 1982 to 2013. A, Dissolved solids; B, chloride; and C, sulfate. (Trend lines were generated using the method of least squares.)

and 127 mg/L at Unnamed Spring near Dennehotso (tables 19 and 20). Concentration of chloride was highest at Moenkopi School Spring (27.2 mg/L; tables 19 and 20). Concentration of sulfate was highest at Burro Spring (67.7 mg/L; tables 19 and 20). Concentrations of all the analyzed constituents in samples from all four springs were less than current USEPA MCLs and SMCLs (U.S. Environmental Protection Agency, 2003).

There are significant increasing trends in concentrations of dissolved solids, chloride, and sulfate in water from Moenkopi School Spring ($p < 0.05$; table 20 and fig. 14). Concentrations of the same constituents in Pasture Canyon Spring, Burro Spring, and Unnamed Spring near Dennehotso did not show any significant trends (table 20 and fig. 14). However, from 2010 to 2012, Unnamed Spring near Dennehotso showed an increase in dissolved solids, chloride, and sulfate concentrations, which may be the result of sampling from an alternate sample location. In 2013 Unnamed Spring near Dennehotso was sampled from the same pre-2010 location and the results for these constituents returned to pre-2010 levels (fig. 14 and table 20).

Summary

The N aquifer is the primary source of groundwater 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 limited precipitation of about 6 to 14 inches per year.

This report presents results of groundwater, surface-water, and water-chemistry monitoring in the Black Mesa area from January 2012 to September 2013. The monitoring data for 2012–13 are compared to historical data from 1948 to September 2011.

In 2012, total groundwater withdrawals were about 4,010 acre-ft; industrial withdrawals were about 1,370 acre-ft, and municipal withdrawals were about 2,640 acre-ft. From 2011 to 2012, total withdrawals from the N aquifer decreased by 10 percent, industrial withdrawals decreased by approximately 1 percent, and total municipal withdrawals decreased by 15 percent.

From 2012 to 2013, annually measured groundwater levels declined in 11 of 32 wells available for comparison. The median water-level change for the 34 wells measured was -0.1 ft. In unconfined areas of the N aquifer, water levels declined in 6 of 16 annual wells available for comparison, and the median change was 0.1 ft. In the confined area of the N aquifer, water levels declined in 5 of 16 wells, and the median change was 0.3 ft. From the prestress period (before 1965) to 2013, the median groundwater-level change in 34 wells was -13.5 ft. Water levels in the 16 wells in the unconfined areas of the N aquifer had a median change of -0.8 ft, and the changes ranged from -49.0 ft to $+12.8$ ft. Water levels in the 16 wells in the confined area of the N aquifer had a median change of -51.0 ft, and the changes ranged from -208.1 ft to $+9.3$ ft.

Discharge has been measured annually at Moenkopi School Spring and Pasture Canyon Spring and intermittently at Burro Spring and Unnamed Spring near Dennehotso. From 2012 to 2013, spring flow increased about one percent at Moenkopi School Spring, and by nine percent at Pasture Canyon Spring. Discharge at Burro Spring has remained relatively constant since it was first measured in 1989. For the period of record, discharge at Moenkopi School Spring and Pasture Canyon Spring has fluctuated, and the data indicate a decreasing trend in discharge for both springs; however, no trend is apparent for either Burro Spring or Unnamed Spring near Dennehotso.

The annual average discharge for a given water year at four streamflow-gaging stations—Moenkopi Wash, Dinnebito Wash, Pasture Canyon Springs, and Polacca Wash—has varied from 1977 to 2012. No trends are apparent in streamflow at the four streamflow-gaging stations. Median flows for November, December, January, and February of each water year are used as an indicator of groundwater discharge to those streams. For the period of record at each streamflow-gaging station, the median winter flows have generally remained constant, showing neither a significant increase nor decrease.

In 2013, water samples were collected from 12 wells and 4 springs and analyzed for selected chemical constituents. Quality assurance samples, one equipment blank and one replicate, indicate no sample bias owing to collection and processing of the water samples. In the 12 wells and 4 springs, concentrations of dissolved solids, chloride, and sulfate have varied from 1961 to 2013, except for Moenkopi School Spring which has an increasing trend from the mid-1980s to 2013, and the data do not indicate a trend.

Dissolved solids concentrations of the wells sampled in 2013 ranged from 111 mg/L (Peabody 2) to 914 mg/L (Forest Lake NTUA 1). Dissolved-solids concentrations in water samples from Burro Spring, Moenkopi School Spring, Pasture Canyon Spring, and Unnamed Spring near Dennehotso were 350 mg/L, 220 mg/L, 145 mg/L, and 127 mg/L, respectively. U.S. Environmental Protection Agency maximum contaminate levels were exceeded for arsenic in three of 12 wells samples in 2013; Second Mesa PM2, Keams Canyon PM2, and Rough Rock PM5. Secondary maximum contaminate levels were exceeded for dissolved solids at the Keams Canyon PM2, Forest Lake NTUA 1, and Rough Rock MP5, pH at Keams Canyon PM2, Kykotsmovi PM2, Piñon NTUA 1, Forest Lake NTUA 1, Kitsillie NTUA 2, Rough Rock PM5, and Peabody 9, and sulfate at Forest Lake NTUA 1.

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