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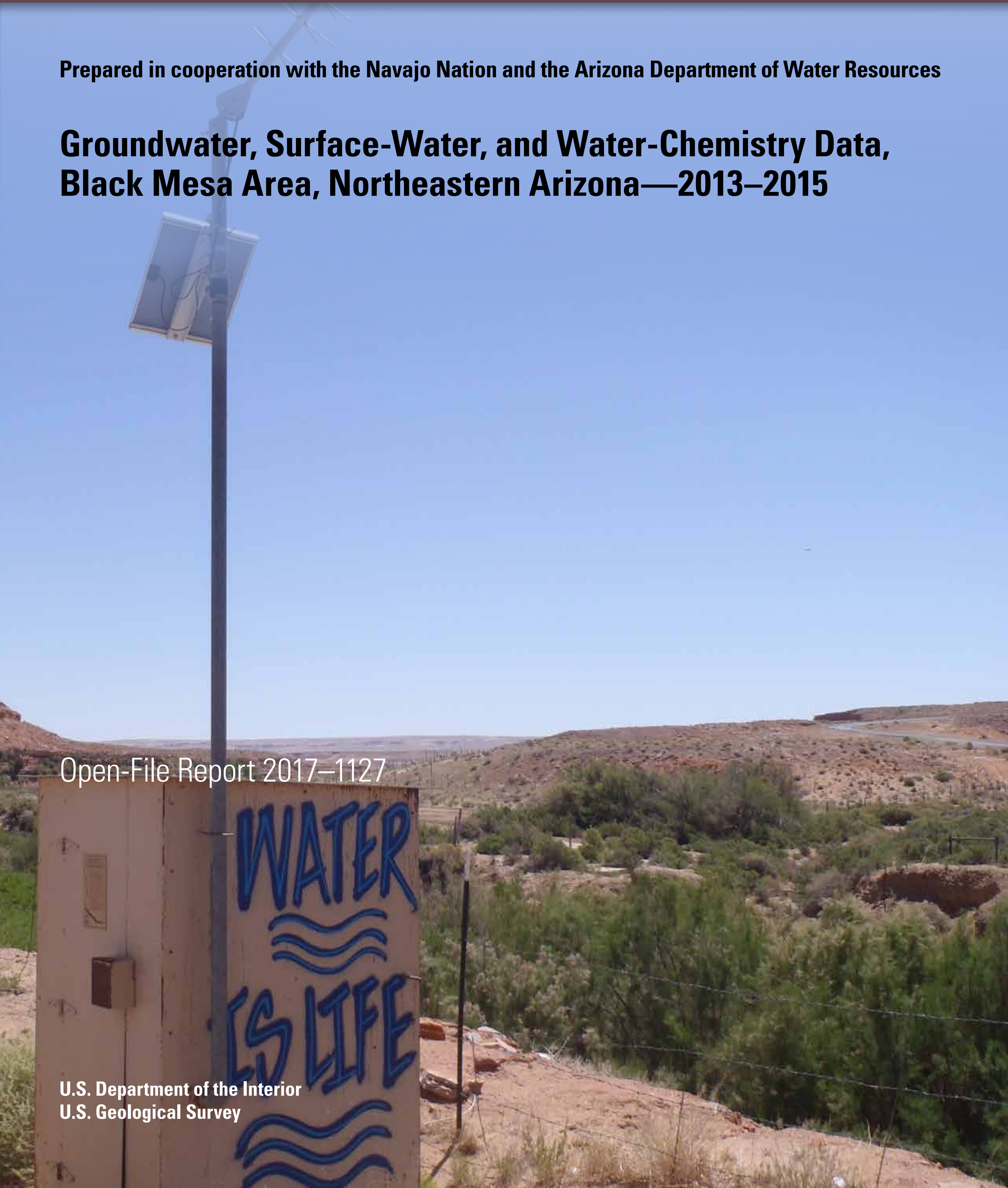
Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2013–2015



Open-File Report 2017–1127

U.S. Department of the Interior
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Cover: U.S. Geological Survey streamgaging station at Moenkopi Wash at Moenkopi, AZ (09401260). Photograph by Jeff Balmat, USGS.

Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2013–2015

By Jamie P. Macy and Jon P. Mason

Prepared in cooperation with the Navajo Nation and the Arizona Department of Water Resources

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U.S. Department of the Interior
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Conversion Factors

[U.S. customary units to International System of Units]

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).

Groundwater, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—2013–2015

By Jamie P. Macy and Jon P. Mason

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 16 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 2013 to December 2015. The monitoring program includes measurements of (1) groundwater withdrawals (pumping), (2) groundwater levels, (3) spring discharge, (4) surface-water discharge, and (5) groundwater chemistry.

In 2013, total groundwater withdrawals were 3,980 acre-feet (ft), in 2014 total withdrawals were 4,170 acre-ft, and in 2015 total withdrawals were 3,970 acre-ft. From 2013 to 2015 total withdrawals varied by less than 5 percent.

From 2014 to 2015, annually measured water levels in the Black Mesa area declined in 9 of 15 wells that were available for comparison in the unconfined areas of the N aquifer, and the median change was -0.1 feet. Water levels declined in 3 of 16 wells measured in the confined area of the aquifer. The median change for the confined area of the aquifer was 0.6 feet. From the prestress period (prior to 1965) to 2015, the median water-level change for 34 wells in both the confined and unconfined areas was -13.2 feet; the median water-level changes were -1.7 feet for 16 wells measured in the unconfined areas and -42.3 feet for 18 wells measured in the confined area.

Spring flow was measured at four springs in 2014. Flow fluctuated during the period of record for Burro Spring and Unnamed Spring near Dennehotso, but a decreasing trend was statistically significant ($p<0.05$) 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. Trend analysis for discharge at Moenkopi and Pasture Canyon Springs yielded a slope significantly different ($p<0.05$) from zero.

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 2015), Dinnebito Wash near Sand Springs 09401110 (1993 to 2015), Polacca Wash near Second Mesa 09400568 (1994 to 2015), and Pasture Canyon Springs 09401265 (2004 to 2015). Median winter flows (November through February) of each water year were used as an index of the amount of groundwater discharge at the above-named sites. 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 2014, water samples collected from four springs in the Black Mesa area were analyzed for selected chemical constituents, and the results were compared with previous analyses. Dissolved solids, chloride, and sulfate concentrations increased at Moenkopi School Spring during the more than 25 years of record at that site. Concentrations of dissolved solids, chloride, and sulfate at Pasture Canyon Spring have not varied significantly ($p>0.05$) since the early 1980s, and there is no increasing or decreasing trend in those data. Concentrations of dissolved solids, chloride, and sulfate at Burro Spring and Unnamed Spring near Dennehotso have varied for the period of record, but there is no increasing or decreasing statistical trend in the data.

Introduction

The 5,400-square mile (mi^2) 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 mi^2. 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 from 6 to 16 in (U.S. Department of Agriculture, 2010). 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)(Eychaner, 1983).

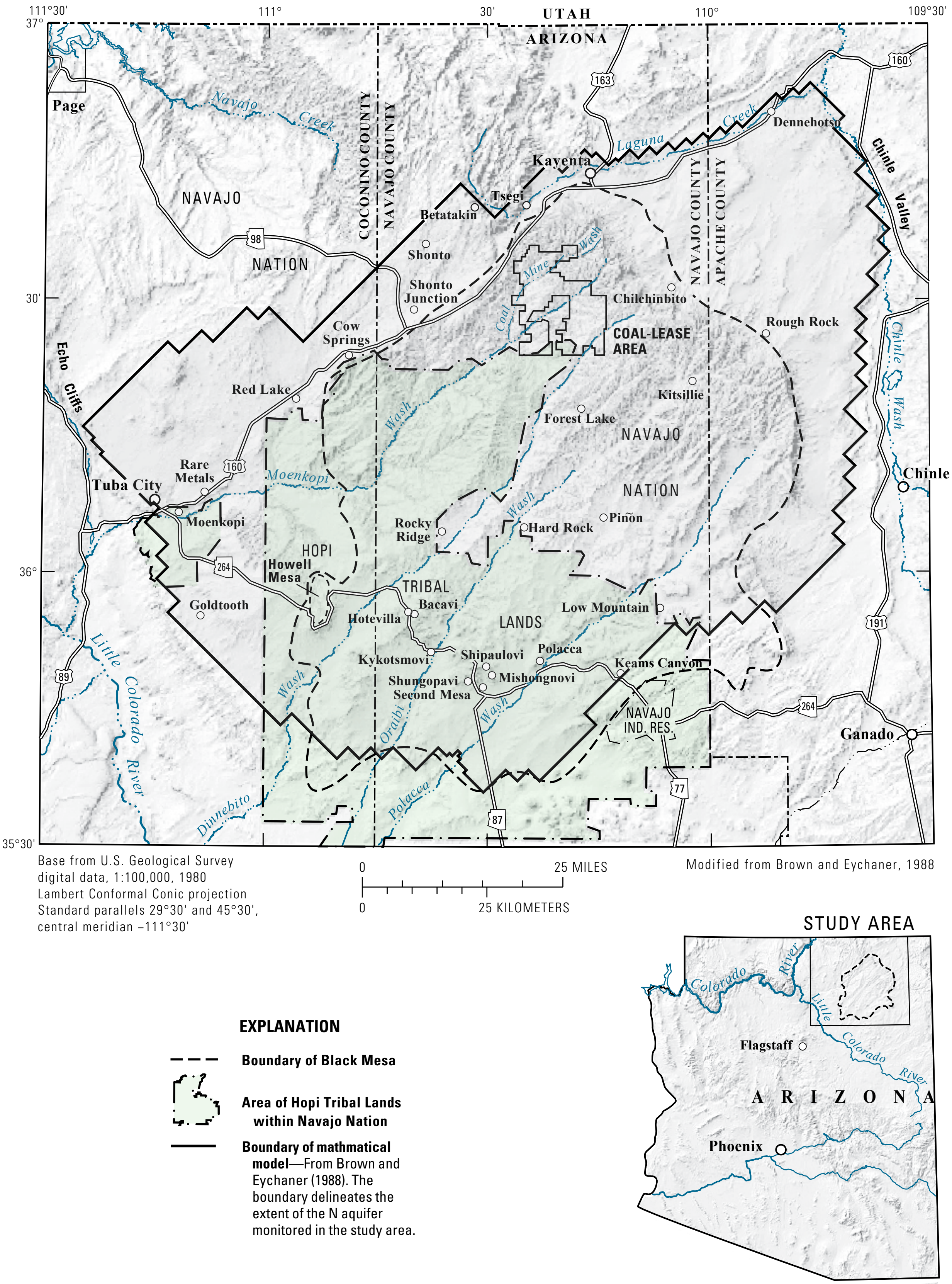


Figure 1. Map showing location of study area, Black Mesa area, northeastern Arizona.

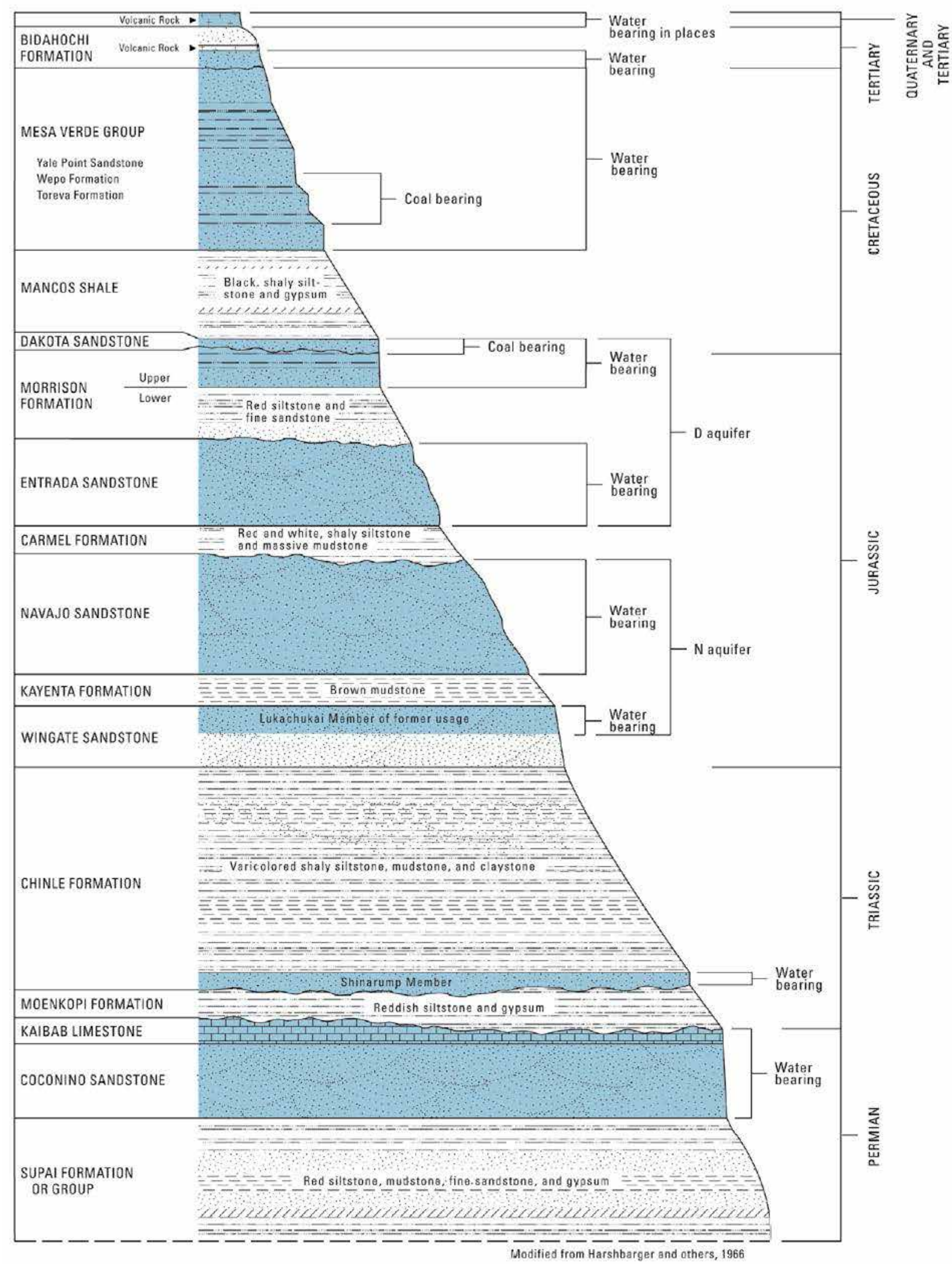


Figure 2. Stratigraphic section showing rock formations and hydrogeologic units of the Black Mesa area, northeastern Arizona (not to scale). The N aquifer is approximately 1,000 feet thick.

The N aquifer is confined under most of Black Mesa, and the overlying stratigraphy limits recharge to this part of the aquifer. The N aquifer is unconfined in areas surrounding Black Mesa, and most recharge occurs where the Navajo Sandstone is exposed in the area near Shonto (fig. 1) (Lopes and Hoffmann, 1997). 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. 3). 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).

Within the Black Mesa study area, the Navajo Nation and Hopi Tribe are the principal municipal water users, and Peabody Western Coal Company (PWCC) is the principal industrial water user. Withdrawals from the N aquifer in the Black Mesa area increased fairly consistently from 1965 through 2002 (table 1). PWCC began operating a strip mine in the northern part of the study area in 1968 (fig. 1). PWCC's mining operation consisted of two mines on Black Mesa—the Kayenta mine, which transported coal to the Navajo Generating Station by train, and the Black Mesa mine, which transported coal 275 miles to the Mohave Generating Station by a coal slurry pipeline. In 1982, the PWCC sold the largest amount of moisture-adjusted tons of

Table 1. Withdrawals from the N aquifer, Black Mesa area, northeastern Arizona, 1965–2015.

[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
2013	1,460	[4]1,410	[4]1,110	[4]3,980
2014	1,580	[4]1,280	[4]1,310	[4]4,170
2015	1,340	[4]1,370	[4]1,260	[4]3,970

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

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

[3]Includes estimated pumpage 1965–73 and metered pumpage 1974–79 at Tuba City; metered pumpage at Kayenta and estimated pumpage at Chilchinbito, Rough Rock, Piñon, Keams Canyon, and Kykotsmovi before 1980; metered and estimated pumpage furnished by the Navajo Tribal Utility Authority and the Bureau of Indian Affairs and collected by the U.S. Geological Survey, 1980–85; and metered pumpage furnished by the Navajo Tribal Utility Authority, the Bureau of Indian Affairs, various Hopi Village Administrations, and the U.S. Geological Survey, 1986–2011.

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

[5]Confined and unconfined totals were reversed in previous reports.

[6]Confined withdrawals are about 90 acre-feet greater than previously reported.

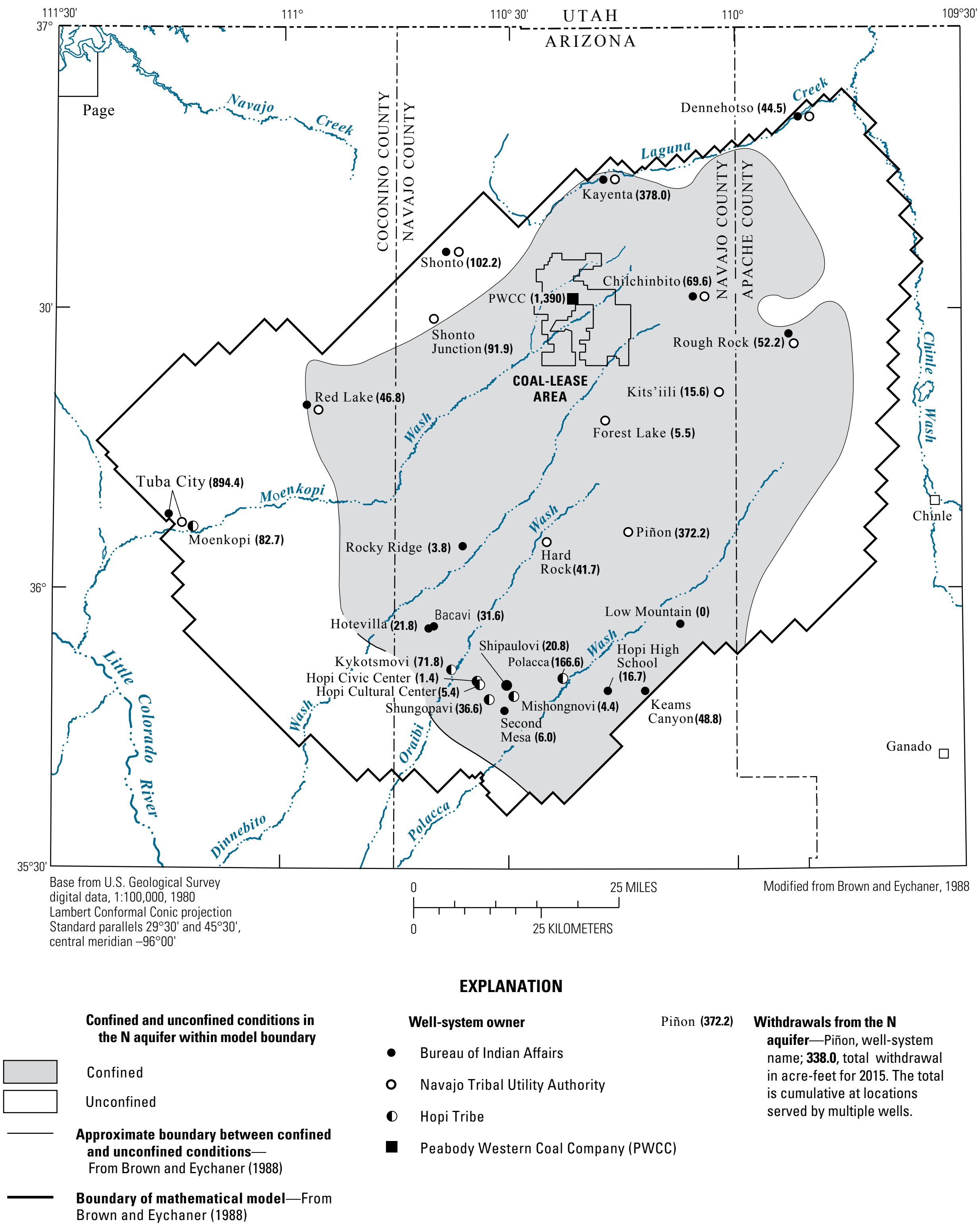


Figure 3. Locations of well systems monitored for annual withdrawals from the N aquifer, Black Mesa area, northeastern Arizona, calendar year 2015.

coal to the Mohave Generating Station and the quantity of water pumped by the PWCC increased from about 100 acre-feet (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). During the same time period, municipal withdrawals grew from about 250 acre-ft in 1968 to 1,830 acre-ft in 1982.

PWCC operated both mines on Black Mesa from the 1970s until about 2005, when the Mohave Generating Station ceased operations. On December 31, 2005, PWCC reduced pumping of the N aquifer by approximately 70 percent as a result of discontinued use of the coal slurry pipeline that delivered water, in addition to coal, to the Mohave Generating Station. The two mines at PWCC have since been combined into the Black Mesa complex, which still delivers coal to the Navajo Generating Station by an electric train. PWCC planned to continue to pump approximately 1,000 to 1,500 acre-ft per year after 2005, 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 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 2013 to December 2015. 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 groundwater withdrawals (pumping), water levels, spring-discharge rates, and water chemistry. Surface-water data include discharge rates at four continuous-record streamflow-gaging stations. Together, these data are compared with groundwater and surface-water data from 1965 to 2013 to describe the overall status of 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-nine progress reports on the Black Mesa area monitoring program have been prepared by the USGS, and these progress reports are summarized in table 2. The groundwater-level, surface-water discharge, and water chemistry 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/). Water-withdrawal data are presented in tables in the progress reports.

Stream-discharge and periodic water-quality data collected from Moenkopi Wash before the 1982 water year were published by the USGS (1963–64a,b; 1965–74a,b; and 1976–83). Stream-discharge data from water years 1983 to 2005 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), 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. GeoTrans, Inc. (1987) also developed a two-dimensional numerical model of the N aquifer in the 1980s. In the late 1990s, HSIGeoTrans, 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. HSIGeoTrans, 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 Longsworth (2003) described the hydrogeology of the D aquifer and the movement and ages of groundwater in the Black Mesa area by using data from

Table 2. Tabulated list of progress reports for the Black Mesa monitoring program 1978–2015.

Year published	Author(s)	Title	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.	Progress report on Black Mesa monitoring program—1984	Open-File Report 85–483
1986	Hill, G.W., and Whetten, M.I.	Progress report on Black Mesa monitoring program—1985–86	Open-File Report 86–414
1987	Hill, G.W., and Sottilare, 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 Sottilare, J.P.	Progress report on the ground-water, surface-water, and quality-of-water monitoring program, Black Mesa area, northeastern Arizona—1987–88	Open-File Report 88–467
1989	Hart, R.J., and Sottilare, J.P.	Progress report on the ground-water, surface-water, and quality-of-water monitoring program, Black Mesa area, northeastern Arizona—1988–89	Open-File Report 89–383
1992	Sottilare, 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.	Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1990–91	Water-Resources Investigations Report 92–4045
1993	Littin, G.R.	Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1991–92	Water-Resources Investigations Report 93–4111
1995	Littin, G.R., and Monroe, S.A.	Results of ground-water, surface-water, and water-quality monitoring, Black Mesa area, northeastern Arizona—1992–93	Water-Resources Investigations Report 95–4156
1995	Littin, G.R., and Monroe, S.A.	Results of ground-water, surface-water, and water-chemistry monitoring, Black Mesa area, northeastern Arizona—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.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1996	Open-File Report 97–566
1999	Littin, G.R., Baum, B.M., and Truini, Margot	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1997	Open-File Report 98–653
2000	Truini, Margot, Baum, B.M., Littin, G.R., and Shingoitewa-Honanie, Gayl	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—1998	Open-File Report 00–66
2000	Thomas, B.E., and Truini, Margot	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona–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	Water-Resources Investigations Report 02–4211

Table 2.—Continued

Year published	Author(s)	Title	USGS report type and number
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, Margot, and Thomas, B.E.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2002–03	Open-File Report 03–503
2005	Truini, Margot, Macy, J.P., and Porter T.J.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2003–04	Open-File Report 2005–1080
2006	Truini, Margot, and Macy, J.P.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2004–05	Open-File Report 2006–1058
2007	Truini, Margot, and Macy, J.P.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2005–06	Open-File Report 2007–1041
2008	Truini, Margot, and Macy, J.P.	Ground-water, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2006–07	Open-File Report 2008–1324
2009	Macy, Jamie P.	Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2007–2008	Open-File Report 2009–1148
2010	Macy, Jamie P.	Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2008–2009	Open-File Report 2010–1038
2011	Macy, Jamie P., and Brown, C.R.	Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2009–2010	Open-File Report 2011–1198
2012	Macy, Jamie P., Brown, C.R., and Anderson, J.R.	Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2010–2011	Open-File Report 2012–1102
2014	Macy, Jamie P. and Unema, Joel A.	Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2011–2012	Open-File Report 2013–1304
2015	Macy, Jamie P. and Truini, Margot.	Groundwater, surface-water, and water-chemistry data, Black Mesa area, northeastern Arizona—2012–2013	Open-File Report 2015–1221

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 2013–15, activities of the Black Mesa area monitoring program included metered groundwater withdrawals, measurements of groundwater levels, spring-discharge measurements, streamflow gaging, and the collection of water-chemistry samples from wells and springs. 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, 6 are continuous-recording observation wells that have been outfitted for real-time data telemetry (referred to as "BM observation well" in table 3). The water-level data from these six continuous-recording observation wells are available on the NWIS website (http://waterdata.usgs.gov/az/nwis/gw). Groundwater-withdrawal data were compiled during January 2015. Spring discharges and groundwater levels were measured between March and

Table 3. Identification numbers and names of monitoring program study wells, 2013–15, 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	---

September. Groundwater samples were collected from four springs from August to September 2014 and were analyzed for chemical constituents. Annual groundwater-withdrawal data are collected from 36 well systems within the NTUA, BIA, and Hopi municipal systems, as well as the PWCC industrial well field. Water-level measurements are collected from 34 wells and well identification information 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. The period before appreciable groundwater withdrawals began for mining or municipal purposes (about 1965) is referred to in this report as the "prestress period."

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. Within the study area there are no industrial withdrawals from the unconfined area. 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 D, N, Toreva (T), and alluvial aquifers, primarily for livestock. The estimated total withdrawal by the windmills from the N aquifer is about 65 acre-ft/yr (HSIGeoTrans, Inc. and Waterstone Environmental Hydrology and Engineering, Inc., 1999). The total withdrawal by the windmills is less than 1 percent of the total annual withdrawal from the N aquifer.

Table 4. Withdrawals from the N aquifer by well system, Black Mesa area, northeastern Arizona, calendar year 2013–15.

[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	2013 Withdrawals		2014 Withdrawals		2015 Withdrawals	
			Confined aquifer	Unconfined aquifer	Confined aquifer	Unconfined aquifer	Confined aquifer	Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	3.0		2.1		1.7	
Dennehotso	BIA	USGS/BIA		11.6		[2]12.4		[2]12.4
Hopi High School	BIA	USGS/BIA	20.1		[2]15.0		[2]16.7	
Hotevilla	BIA	USGS/BIA	43.5		[2]21.8		[2]21.8	
Kayenta	BIA	USGS/BIA	19.3		17.3		17.3	
Keams Canyon	BIA	USGS/BIA	[2]48.6		[2]57.0		48.8	
Low Mountain	BIA	USGS/BIA	[1]0		[1]0		[1]0	
Piñon	BIA	USGS/BIA	[1]0		[1]0		[1]0	
Red Lake	BIA	USGS/BIA		5.5		4.0		3.0
Rocky Ridge	BIA	USGS/BIA	6.7		3.7		3.8	
Rough Rock	BIA	USGS/BIA	13.6		11.9		14.3	
Second Mesa	BIA	USGS/BIA	4.2		5.0		6.0	
Shonto	BIA	USGS/BIA		96.3		97.2		79.8
Tuba City	BIA	USGS/BIA		78.1		78.4		74.6
Chilchinbito	NTUA	USGS/NTUA	75.1		84.7		67.9	
Dennehotso	NTUA	USGS/NTUA		44.1		[2]52.2		41.8
Forest Lake	NTUA	USGS/NTUA	12.3		10.8		5.5	
Hard Rock	NTUA	USGS/NTUA	53.8		41.5		41.7	
Kayenta	NTUA	USGS/NTUA	421.8		[2]322.3		[2]360.7	
Kits'iili	NTUA	USGS/NTUA	25.2		20.3		15.6	
Piñon	NTUA	USGS/NTUA	310.3		324.5		372.2	
Red Lake	NTUA	USGS/NTUA		59.9		48.8		43.7
Rough Rock	NTUA	USGS/NTUA	40.6		38.7		38.0	
Shonto	NTUA	USGS/NTUA		13.9		17.6		22.3
Shonto Junction	NTUA	USGS/NTUA		63.0		81.0		91.9
Tuba City	NTUA	USGS/NTUA		669.2		[2]855.2		819.8
Mine Well Field	Peabody	Peabody	1,464		1,584		1,341	
Bacavi	Hopi	USGS/Hopi	25.4		27.2		31.6	
Hopi Civic Center	Hopi	USGS/Hopi	1.6		1.1		1.4	
Hopi Cultural Center	Hopi	USGS/Hopi	6.6		5.5		5.4	
Kykotsmovi	Hopi	USGS/Hopi	62.6		61.8		[2]71.8	
Mishongnovi	Hopi	USGS/Hopi	4.7		4.2		4.4	
Moenkopi	Hopi	USGS/Hopi		66.6		69.7		82.7
Polacca	Hopi	USGS/Hopi	157.9		148.2		166.6	
Shipaulovi	Hopi	USGS/Hopi	22.6		19.7		20.8	
Shungopovi	Hopi	USGS/Hopi	33.6		34.6		36.6	

[1]Well taken out of service.

[2]Estimated value due to partial record.

Withdrawals in Calendar Year 2013–15

In 2013, 2014, and 2015 total groundwater withdrawal from the N aquifer was about 3,980, 4,170, and 3,970 acre-ft respectively (table 1). Total withdrawals for municipal use from 2013 to 2015 were about 2,600 acre-ft per year; municipal withdrawals from the confined area averaged about 1,350 acre-ft per year, while withdrawals from the unconfined areas averaged about 1,200 acre-ft. Withdrawals for industrial use averaged about 1,460 acre-ft from 2013 to 2015 (tables 1 and 5).

Withdrawals from the N aquifer have varied annually from 1965 to the present but generally increased from 1965 to 2005 and decreased from 2006 to 2015. 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. 4). Total withdrawal for the period of record (1965–2015) totaled 259,790 acre-ft; industrial withdrawals were 58 percent and municipal withdrawals were 42 percent of total withdrawals (table 5). Total annual withdrawals increased from close to 70 acre-ft in 1965 to about 4,300 acre-ft in 1972, then more slowly increased to about 7,100 acre-ft in 1983, and then a maximum of about 8,000 acre-ft in 2002 (table 1). From 1965–2005 industrial withdrawals were 63 percent and municipal withdrawals were 37 percent of total withdrawals (table 5). A 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 during the previous period (table 5). From 2006 to 2015, withdrawals totaled 41,490 acre-ft; industrial withdrawals were 32 percent and municipal withdrawals were 68 percent of total withdrawals (table 5). Total withdrawals in 2015 were 3,970 acre-ft, with 34 percent from industrial withdrawals and 66 percent from municipal withdrawals (table 5).

Groundwater Levels in the N Aquifer

Groundwater levels are monitored at wells that are screened in the N aquifer to determine the effects of withdrawals 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. 3).

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.

Table 5. Total, industrial, and municipal withdrawals from the N aquifer for discrete time periods from 1965 to 2015, Black Mesa area, northeastern Arizona.

Period	Total withdrawals (acre-feet)	Industrial withdrawals (acre-feet)	Municipal withdrawals (acre-feet)	Percent industrial	Percent municipal
1965–2015	259,790	151,380	108,410	58	42
1965–2005	218,300	138,100	80,200	63	37
2006–2015	41,490	13,280	28,210	32	68
2013	3,980	1,460	2,520	37	63
2014	4,170	1,580	2,590	38	62
2015	3,970	1,340	2,630	34	66

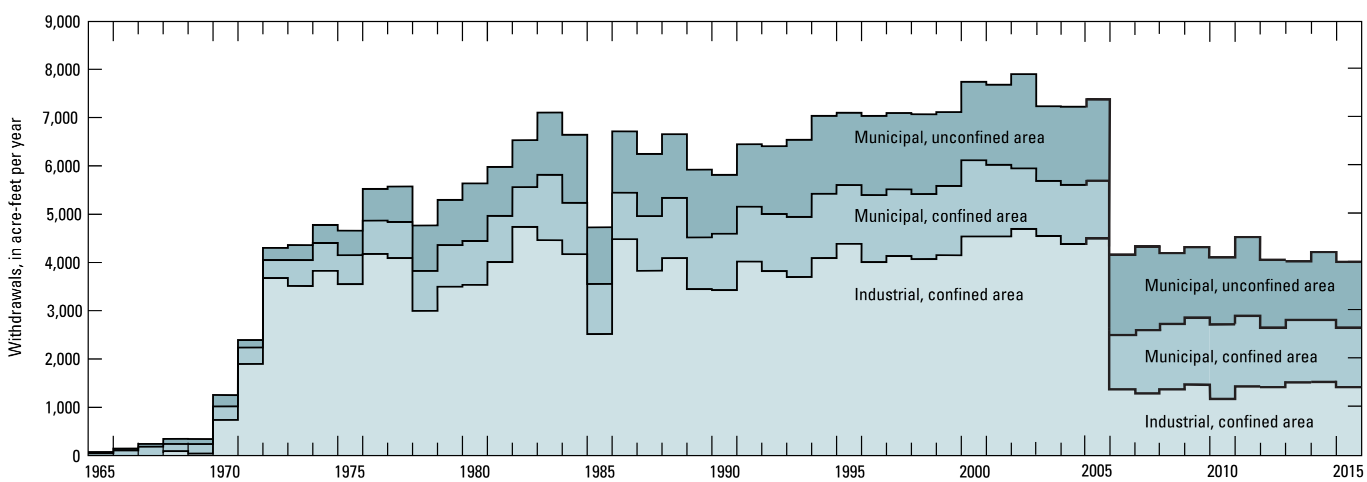


Figure 4. Annual withdrawals from the N aquifer, Black Mesa area, northeastern Arizona, 1965–2015.

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. During March and June in 2014 and 2015, water-levels were measured in 34 wells and water-level comparisons were made between years (table 6). Of the 34 wells, 6 are continuous-recording observation wells. Water levels were measured quarterly using electric tape in these six wells during water years 2013–15 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

Table 6. Water-level changes in monitoring program wells completed in the N aquifer, Black Mesa area, northeastern Arizona, prestress period to calendar year 2015.

[---, no data; R, reported from driller's log]

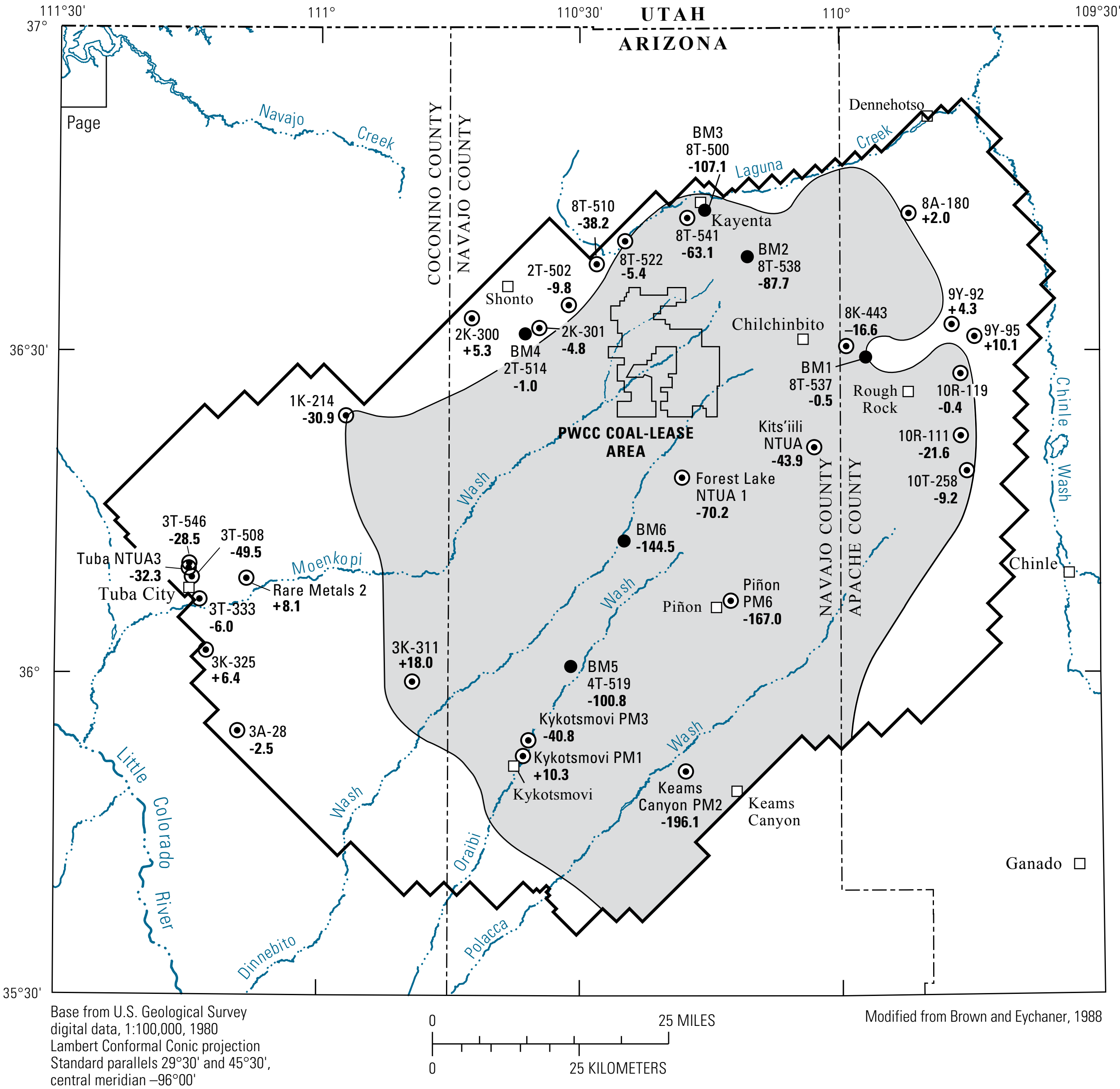
Common name or location	Bureau of Indian Affairs site number	Change in water level from preceding year (feet)			Water level (feet below land surface), 2015	Prestress period water level		Change in water level from prestress period to 2015 (feet)
		2013	2014	2015		Feet below land surface	Date	
Unconfined areas								
BM observation well 1[1]	8T-537	0.4	-0.4	-0.1	374.5	374.0	([1])	-0.5
BM observation well 4[1]	2T-514	0.4	-0.3	0.1	217.0	216.0	([1])	-1.0
Goldtooth	3A-28	2.3	0.0	1.6	232.5	230.0	10–29–53	-2.5
Long House Valley	8T-510	-0.3	-0.2	1.1	137.6	99.4	08–22–67	-38.2
Northeast Rough Rock	8A-180	0	-0.3	0.0	44.9	46.9	11–13–53	2.0
Rough Rock	9Y-95	0.3	-3.5	-0.8	109.4	119.5	08–03–49	10.1
Rough Rock	9Y-92	0.4	-1.2	-1.1	164.5	168.8	12–13–52	4.3
Shonto	2K-300	0.1	-1.2	-1.3	171.2	176.5	06–13–50	5.3
Shonto Southeast	2K-301	0.5	-0.3	-0.4	288.7	283.9	12–10–52	-4.8
Shonto Southeast	2T-502	1.6	-0.7	-0.1	415.6	405.8	08–22–67	-9.8
Tuba City	3T-333	-0.4	-1.2	-0.8	29.0	23.0	12–02–55	-6.0
Tuba City	3K-325	-1.1	([2])	([2])	201.6	208.0	06–30–55	6.4
Tuba City Rare Metals 2	---	0.1	0.3	0.1	48.9	57.0	09–24–55	8.1
Tuba City NTUA 1	3T-508	-9.4	16.8	-17.3	78.5	29.0	02–12–69	-49.5
Tuba City NTUA 3	---	-1.2	-1.0	-0.9	66.5	34.2	11–08–71	-32.3
Tuba City NTUA 4	3T-546	-0.1	-5.1	7.1	62.2	33.7	08–06–71	-28.5
Confined area								
BM observation well 2[1]	8T-538	1.4	1.4	1.1	212.7	125.0	([1])	-87.7
BM observation well 3[1]	8T-500	-3.4	-0.3	0.6	162.1	55.0	04–29–63	-107.1
BM observation well 5[1]	4T-519	1.5	0.0	1.0	424.8	324.0	([1])	-100.8
BM observation well 6[1]	---	3.6	1.8	1.1	841.5	697.0	([1])	-144.5
Forest Lake NTUA 1	4T-523	0.2	([2])	([2])	1,166.2	1,096R	05–21–82	-70.2
Howell Mesa	3K-311	([2])	([2])	3.9	445.0	463.0	11–03–53	18
Kayenta West	8T-541	8.3	-4.2	0.9	293.1	230.0	03–17–76	-63.1
Keams Canyon PM2	---	-2.6	([2])	([2])	488.6	292.5	06–10–70	-196.1
Kits'iili NTUA 2	---	-4.5	-1.2	-0.6	1,341.8	[3]1,297.9	01–14–99	-43.9
Kykotsmovi PM1	---	1.4	0.8	0.2	209.7	220.0	05–20–67	10.3
Kykotsmovi PM3	---	([2])	([2])	0.2	250.8	210.0	08–28–68	-40.8
Marsh Pass	8T-522	-0.9	-1.3	-1.1	[4]130.9	125.5	02–07–72	-5.4
Piñon PM6	---	3.0	0.3	3.1	910.6	743.6	05–28–70	-167.0
Rough Rock	10R-119	0.4	-1.8	1.3	257.0	256.6	12–02–53	-0.4
Rough Rock	10T-258	-1.0	2.5	0.1	310.2	301.0	04–14–60	-9.2
Rough Rock	10R-111	6.9	0.3	0.0	191.6	170.0	08–04–54	-21.6
Sweetwater Mesa	8K-443	0.9	-0.8	-0.7	546.0	529.4	09–26–67	-16.6
White Mesa Arch	1K-214	0.7	-0.4	0.6	218.9	188.0	06–04–53	-30.9

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

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

[3]Water level is the first water level measured after completion of well.

[4]Well was recently pumped.



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)

2K-300 +5.3 **Well in which depth to water was measured annually**—First entry, 2K-300, is Bureau of Indian Affairs site number; second entry, **+5.3**, is change in water level, in feet, between measurement made during the prestress period and measurement made during 2015

BM2 8T-538 –87.7 **Continuous water-level recording site (observation well) maintained by the U.S. Geological Survey**—First entry, BM2, is U.S. Geological Survey well number; second entry, 8T-538, is Bureau of Indian Affairs site number; third entry, **-87.7**, is change in water level, in feet, from simulated prestress period to 2015

Figure 5. Map showing water-level changes in N-aquifer wells from the prestress period (prior to 1965) to 2015, Black Mesa area, northeastern Arizona.

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 2,205 ft at Kits'iili NTUA 2 (fig. 5; table 7).

From 2014 to 2015, water levels decreased in 12 of the 31 wells for which comparisons could be made (table 6). The median water-level change in the 31 wells was 0.1 ft (table 8). In the unconfined parts of the aquifer, water levels declined in 9 of the 15 wells measured (table 6), and the median water-level change was -0.1 ft (table 8). Water-level changes ranged from -17.3 ft at Tuba City NTUA 1 (3T-508) to +7.1 ft at Tuba City NTUA 4 (3T-546) (table 6). In the confined parts of the aquifer, water levels declined in 3 of 16 wells measured in 2015. The median water-level change was 0.6 ft (table 8). Water-level changes ranged from -1.1 ft at Marsh Pass 8T-522 to +3.9 ft at Howell Mesa (3K-311) (table 6).

Table 7. Well-construction characteristics and depth to top of N aquifer for wells used in annual water-level measurements and for continuous-record observation wells from 2013 to 2015, 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 (feet below land-surface)	Screened/open interval(s) (feet below land surface)	Depth to top of N aquifer (feet below land surface[1])
8T-537 (BM observation well 1)	02–01–72	5,864	851	300–360; 400–420; 500–520; 600–620; 730–780	290
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
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])
8A-180	01–20–39	5,200	107	60–107	[2]40
8K-443	08–15–57	6,024	720	619–720	590
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
Keams Canyon PM2	[3]05–00–70	5,809	1,106	906–1,106	900

From the prestress period (before 1965) to 2015, the median water-level change in 34 wells measured in 2015 was -13.2 ft (table 8). Water levels in 16 unconfined wells had a median change of -1.7 ft (table 8), and water-level changes ranged from -49.5 ft at Tuba City NTUA 1(3T-508) to +10.1 ft at Rough Rock (9Y-95) (fig. 5 and table 6). Water levels in 18 wells in the confined part of the aquifer had a median change of -42.3 ft (table 8), and water-level changes ranged from -196.1 ft at Keams Canyon PM2 to +18.0 ft at Howell Mesa (3K-311) (fig. 5 and table 6).

Hydrographs of groundwater levels in the network of wells observed annually show the temporal changes from the 1950s to present (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 well 8T-510 (Longhouse Valley) has declined 38.2 ft (figs. 5 and 6; table 6). Water levels

Table 7.—Continued

Bureau of Indian Affairs site number, and (or) common name	Date well was completed	Land-surface elevation (feet)	Well depth (feet below land-surface)	Screened/open interval(s) (feet below land surface)	Depth to top of N aquifer (feet below land surface[1])
Kits'iili NTUA 2	10–30–93	6,780	2,549	2,217–2,223	2,205
				2,240–2,256	
				2,314–2,324	
				2,344–2,394	
				2,472–2,527	
Kykotsmovi PM1	02–20–67	5,657	995	655–675	880
				890–990	
Kykotsmovi PM3	08–07–68	5,618	1,220	850–1,220	840
Piñon PM6	[3]02–00–70	6,397	2,248	1,895–2,243	1,870
Tuba City NTUA 3	[3]10–00–71	5,176	442	142–442	34
Tuba City Rare Metals 2	[3]09–00–55	5,108	705	100–705	255

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

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

[3]00, indicates day is unknown.

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

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

Table 8. Median changes in water levels in monitoring-program wells from 2013 to 2015 and prestress period (prior to 1965) to 2015, N aquifer, Black Mesa area, northeastern Arizona.

Years	Aquifer conditions	Number of wells	Median change in water level (feet)
2013–2014	All	29	-0.3
	Unconfined	15	-0.4
	Confined	14	-0.2
2014–2015	All	31	0.1
	Unconfined	15	-0.1
	Confined	16	0.6
Prestress–2015	All	34	-13.2
	Unconfined	16	-1.7
	Confined	18	-42.3

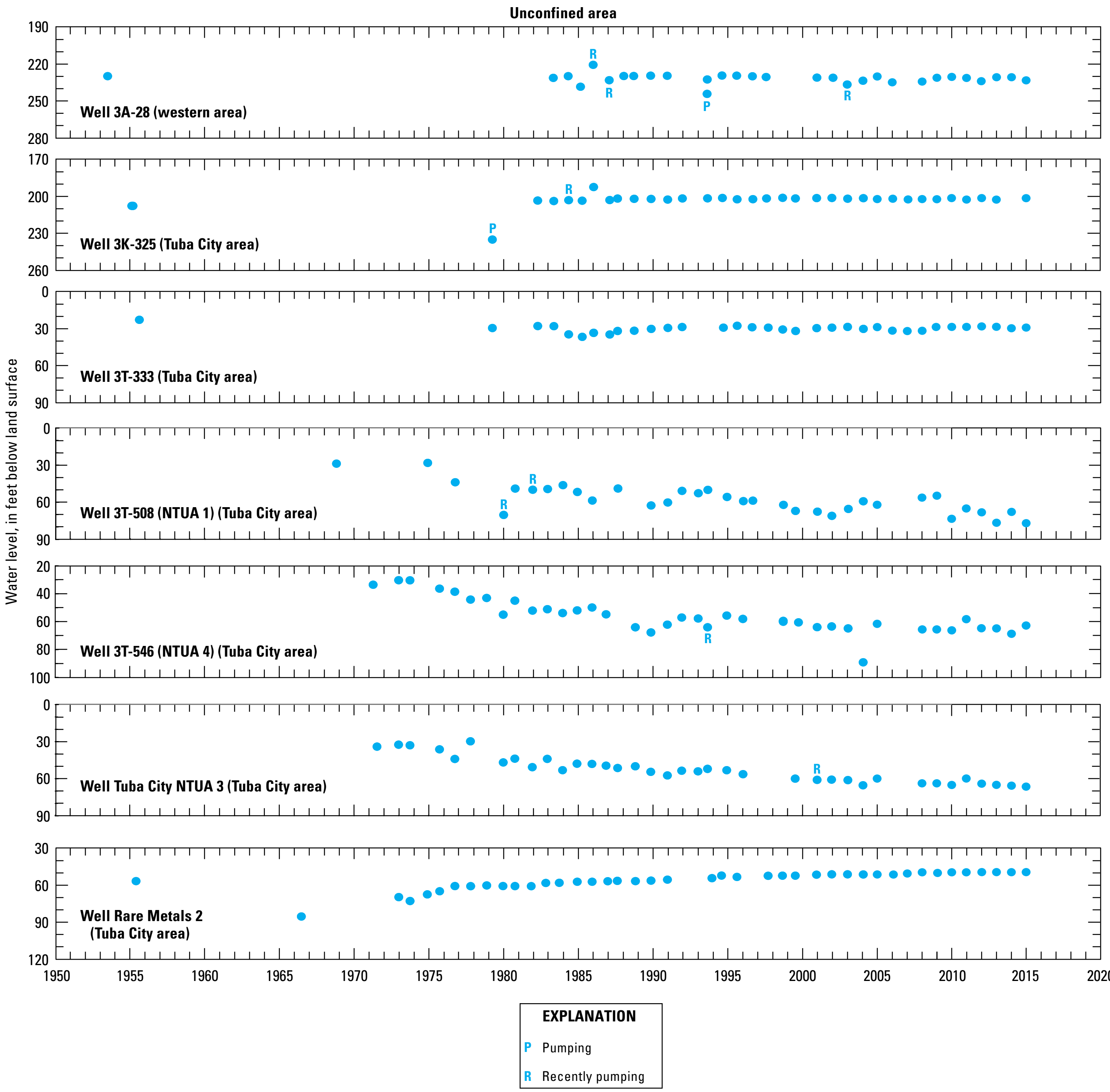


Figure 6. Plots of observed water levels (1950–2015) in annual observation-well network, N aquifer, Black Mesa area, northeastern Arizona.

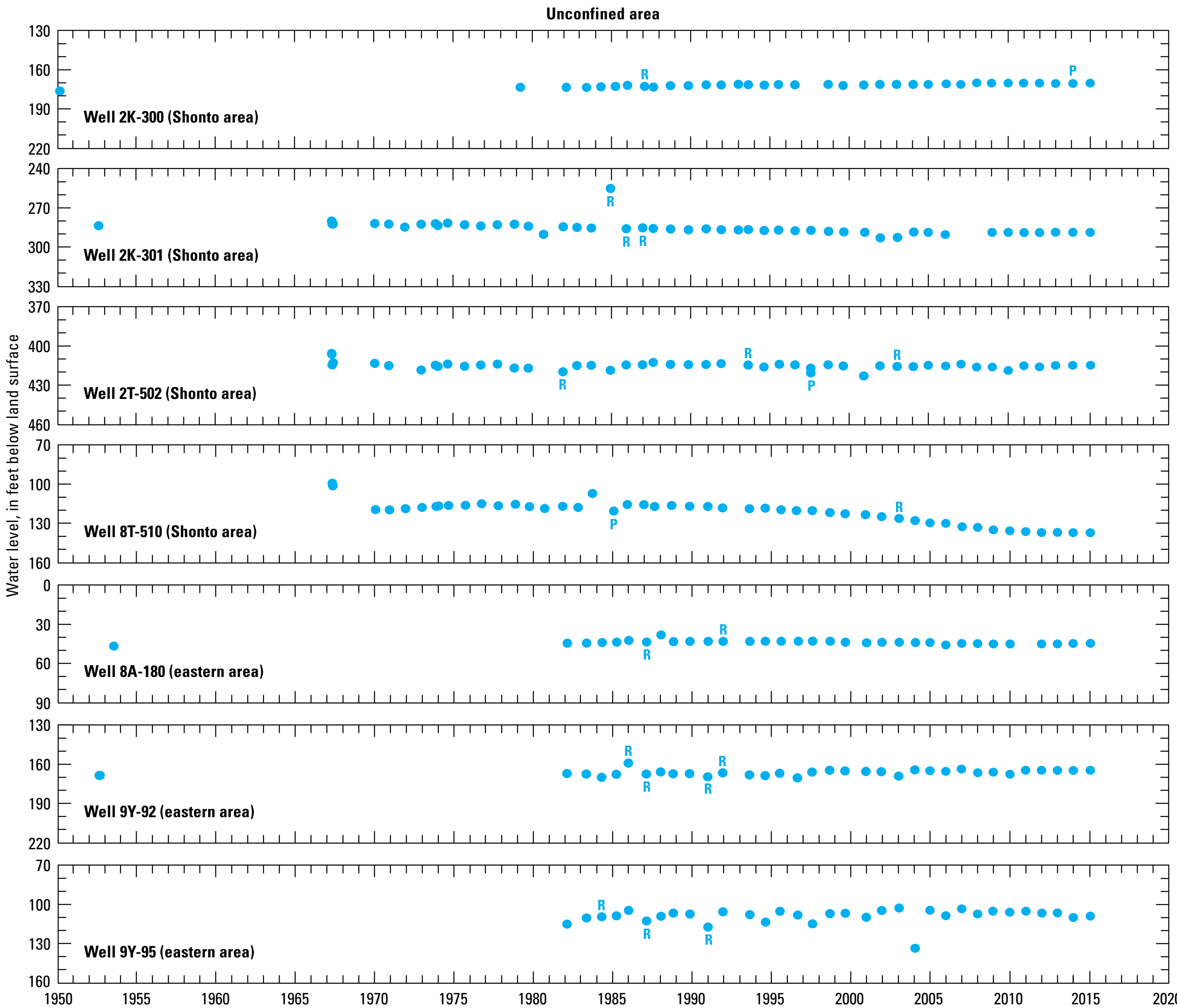


Figure 6.—Continued

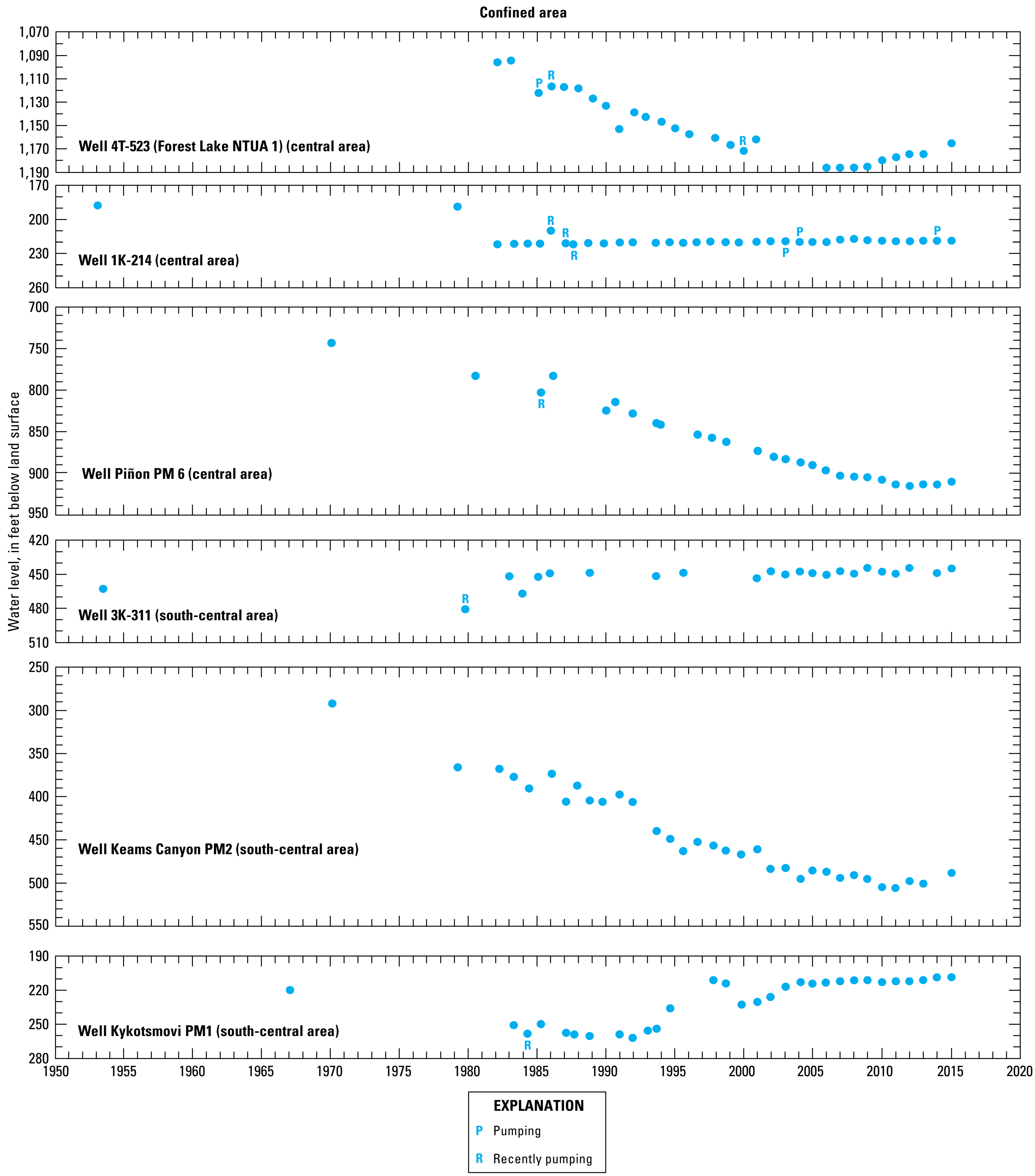


Figure 6.—Continued

Figure 6.—Continued

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 and Keams Canyon PM2) and near the wells for PWCC (BM6). Smaller declines occurred away from the pumping centers found 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 found in figure 7 show water levels since the early 1970s. 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 decline. In the confined area, water levels (not corrected for barometric pressure effects or seasonal effects) in wells BM2, BM3, and BM5 have consistently declined since the early 1970s (fig. 7). Since October 2009, water levels in BM2 have not declined and have leveled off. Water levels in BM6 in the confined area had consistently declined from the mid-1970s to 2007, when the water level trend abruptly switched from decreasing to increasing. A maximum depth to water of 861.2 ft below land surface was reached in well BM6 on December 4, 2006, and recovered to a water level of 839.9 ft below land surface on September 9, 2015, demonstrating about 21 feet of total recovery to date.

Spring Discharge from the N Aquifer

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 2014.

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). As in previous years, discharge from Moenkopi School Spring was measured in August 2014 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 2014, the measured discharge from Moenkopi School Spring was 6.3 gal/min (table 9). From 2013 to 2014, discharge was about the same; 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). A discharge measurement was not made in 2015.

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. As in previous years, the 2014 discharge measurement and water-quality sampling point was from 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 2014, the measured discharge was 0.3 gal/min, the same as the previous year (fig. 9 and table 9).

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. As in previous years, discharge was measured at Pasture Canyon Spring at its emergence point in August 2014 using the volumetric method and showed an increase in discharge of about 3.6 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. In 2014, the measured discharge was 39.3 gal/min (table 9).

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. As in previous years, measurements at Unnamed Spring near Dennehotso are made using a flume. There have been marked decreases in discharge at Unnamed Spring near Dennehotso since 2005. That year, the discharge at the spring was 21.5 gal/min, in 2010 the discharge was 9.0 gal/min, in 2012 the measured discharge was only 4.5 gal/min, in 2013 the measured discharge slightly increased to 6.7 gal/min, and there was also an increase in 2014 to about 8.1 gal/min. From 2013 to 2014 the discharge increased 1.4 gal/min (table 9). 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.

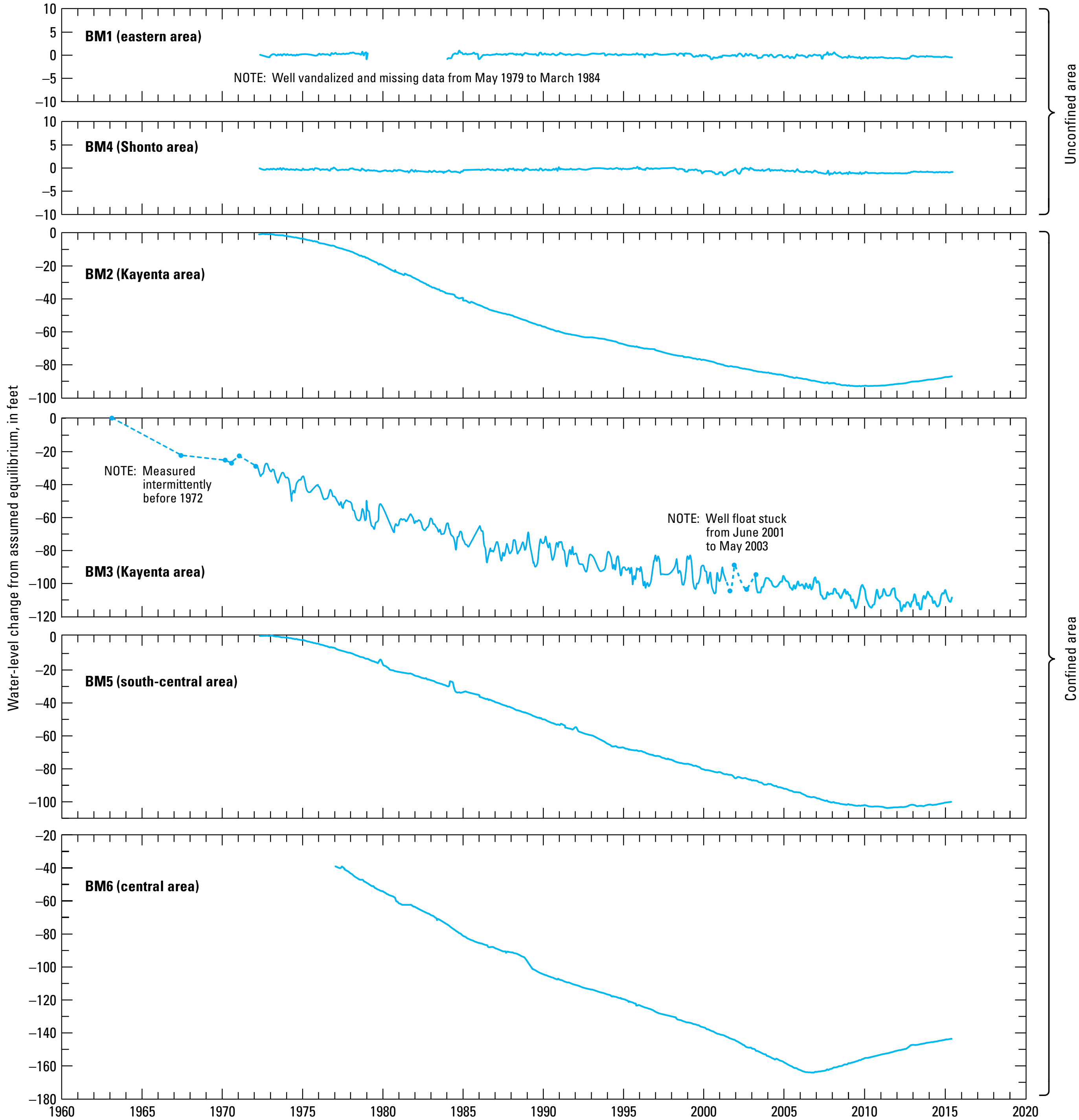
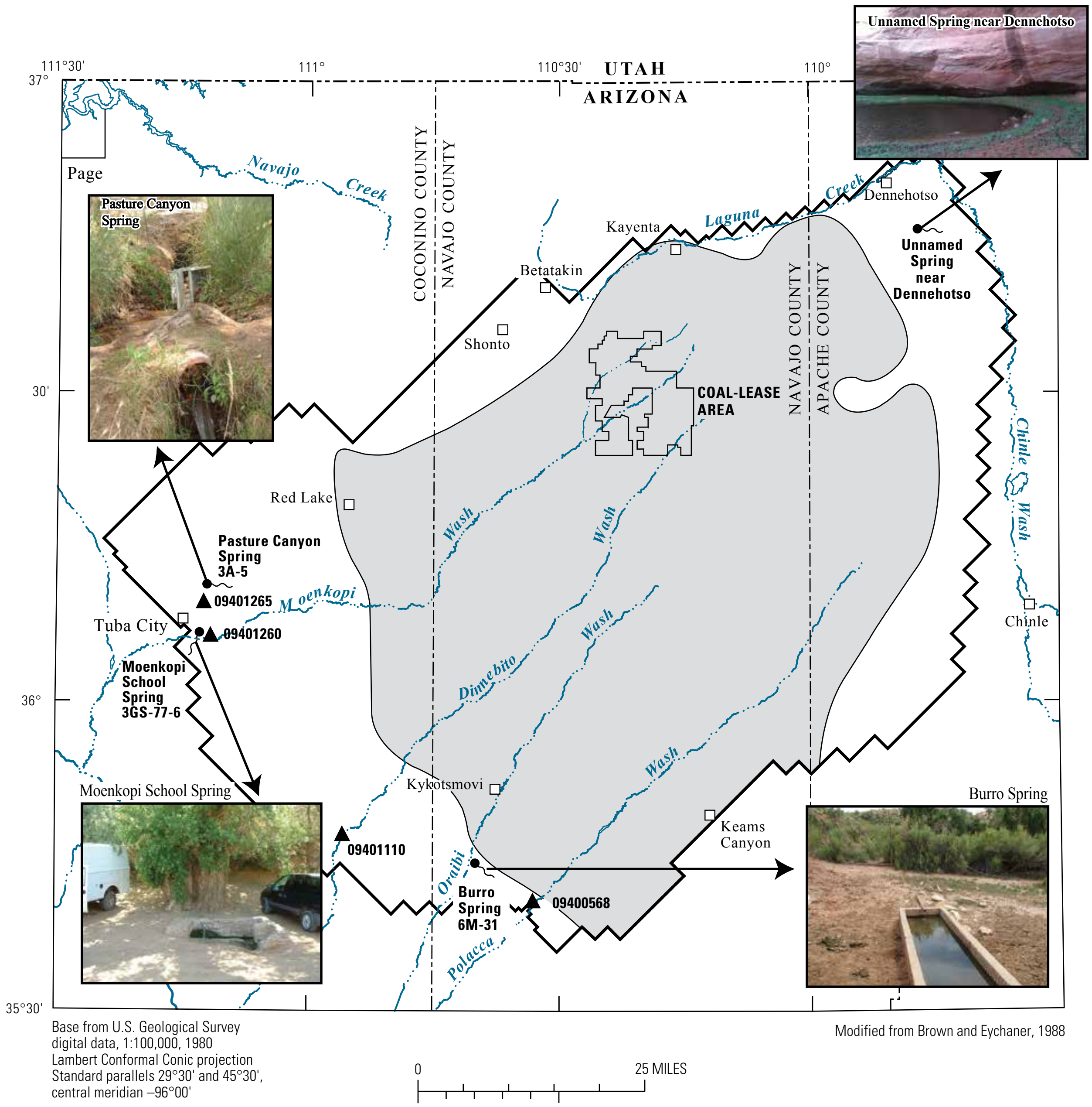


Figure 7. Plots of observed water-level changes in continuous-record observation wells BM1–BM6 from 1963 to 2015 in the N aquifer, Black Mesa area, northeastern Arizona.



EXPLANATION

Confined and unconfined conditions in the N aquifer within model boundary

Confined

Unconfined

Approximate boundary between confined and unconfined conditions From Brown and Eychaner (1988)

Boundary of mathematical model—From Brown and Eychaner (1988)

Moenkopi School Spring 3GS-77-6 — **Spring at which discharge was measured and water-chemistry sample was collected**—Number is spring identification

09401260 — **Streamflow-gaging station operated by the U.S. Geological Survey**—Number is station identification

Figure 8. Map of surface-water and water-chemistry data-collection sites, N aquifer, Black Mesa area, northeastern Arizona, 2013–14.

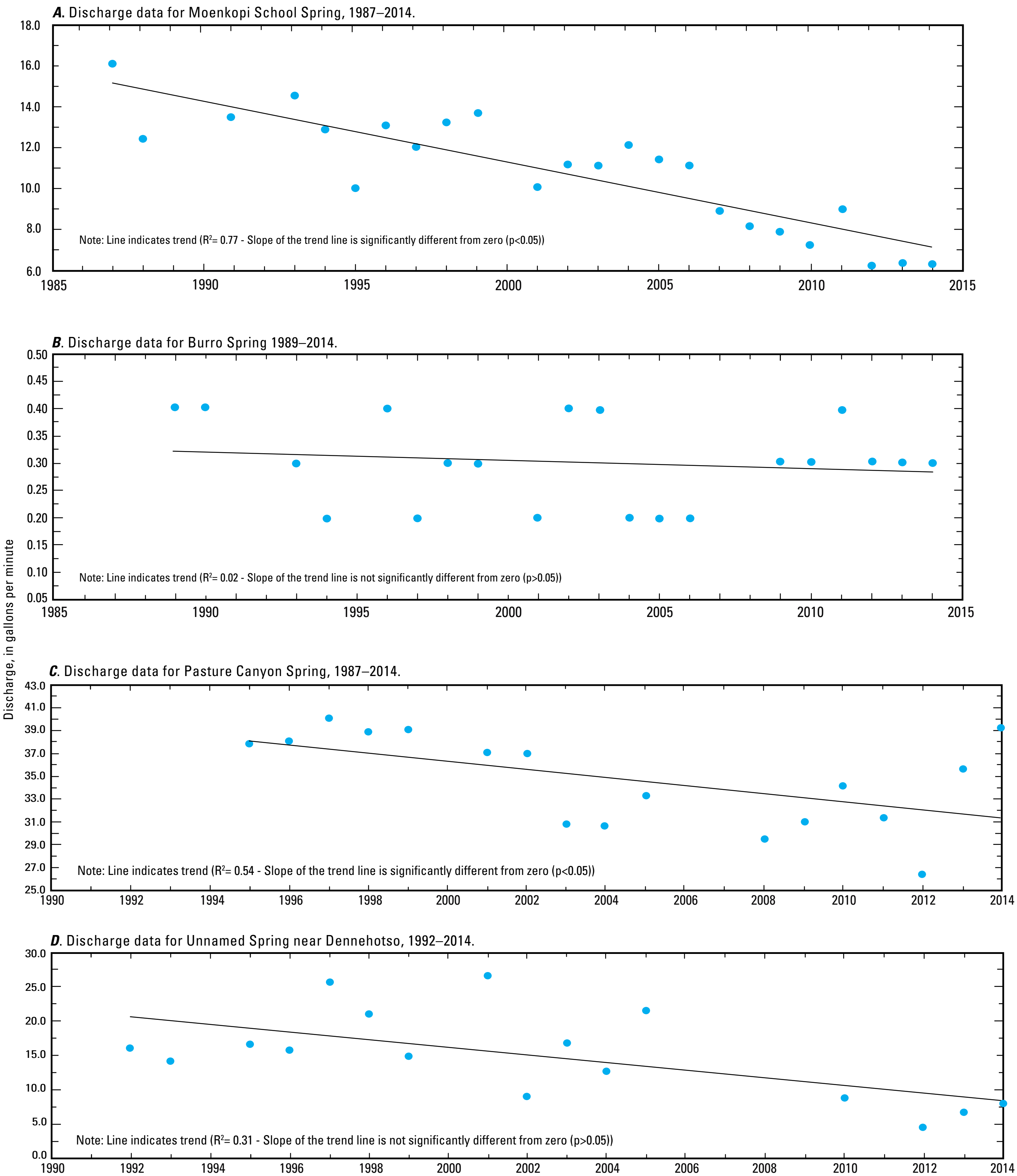


Figure 9. Plots of discharge from *A*, Moenkopi School Spring; *B*, Burro Spring; *C*, Pasture Canyon Spring; and *D*, Unnamed Spring near Dennehotso, N Aquifer, Black Mesa area, northeastern Arizona, 1987–2014. Data from 1952 measurement at Moenkopi School Spring are not shown because measurement was from a different measuring location. Data from 1988 to 1993 measurements at Pasture Canyon Spring are not shown because they were taken from a different measuring location. Trend lines were generated using method of least squares.

Table 9. Discharge from Moenkopi School Spring, Burro Spring, Pasture Canyon Spring, and Unnamed Spring near Dennehotso, N Aquifer, Black Mesa area, northeastern Arizona, 1952–2014.

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

Bureau of Indian Affairs site number	Rock formation(s)	Date of measurement	Discharge, in gallons per minute
Moenkopi School Spring[1]			
3GS-77-6	Navajo Sandstone[2]	05–16–52	40.0
		04–22–87	[3]16.0
		11–29–88	[3]12.5
		02–21–91	[3]13.5
		04–07–93	[3]14.6
		12–07–94	[3]12.9
		12–04–95	[3]10.0
		12–16-96	[3]13.1
		12–17–97	[3]12.0
		12–08–98	[3]13.3
		12–13–99	[3]13.7
		03–12–01	[3]10.2
		06–19–02	[3]11.2
		05–01–03	[3]11.2
		03–29–04	[3]12.2
		04–04–05	[3]11.5
		03–13–06	[3]11.1
		05–31–07	[3]9.0
		06–03–08	[3]8.3
		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
		08–27–14	[3]6.3
Pasture Canyon Spring[1]			
3A-5	Navajo Sandstone, alluvium	11–18–88	[4]211
		03–24–92	[4]233
		10–12–93	[4]211
		12–04–95	[5]38.0
		12–16–96	[5]38.0
		12–17–97	[5]40.0
		12–10–98	[5]39.0
		12–21–99	[5]39.0
		06–12–01	[5]37.0
		04–04–02	[5]37.0
		05–01–03	[5]30.9
		04–26–04	[5]30.6
		04–27–05	[5]33.3
		06–03–08	[5]29.4
		06–03–09	[5]31.1
		06–14–10	[5]34.3
		06–09–11	[5]31.4
		06–07–12	[5]26.5
		07–29–13	[5]35.7
		08–27–14	[5]39.3
Burro Spring[1]			
6M-31	Navajo Sandstone	12–15–89	0.4
		12–13–90	0.4
		03–18–93	0.3
		12–08–94	0.2
		12–17–96	0.4
		12–30–97	0.2
		12–08–98	0.3
		12–07–99	0.3
		04–02–01	0.2
		04–04–02	0.4
		04–30–03	0.4
		04–06–04	[6]0.2
		03–28–05	0.2
		03–28–06	0.2
		06–04–09	0.3
		06–07–10	0.3
		06–08–11	0.4
		06–14–12	0.3
		07–30–13	0.3
		09–02–14	0.3
Unnamed Spring near Dennehotso[4]			
8A-224	Navajo Sandstone	10–06–54	[7]1
		06–27–84	[7]2
		11–17–87	[7]5
		03–26–92	16.0
		10–22–93	14.4
		12–05–95	17.0
		12–19–96	15.7
		12–30–97	25.6
		12–14–98	21.0
		12–15–99	14.8
		03–14–01	26.8
		04–03–02	5.8
		07–15–02	9.0
		05–01–03	17.1
		04–01–04	12.6
		04–06–05	21.5
		06–17–10	9.0
		06–04–12	4.5
		08–06–13	6.7
		09–03–14	8.1

[1]Volumetric discharge measurement.

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

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

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

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

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

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

Surface-Water Discharge, Calendar Year 2013–15

Continuous surface-water discharge data have been collected at selected streams since the monitoring program began in 1971. 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 runoff depend on the intensity and duration of thunderstorms during the summer and cyclonic storms during the fall, winter, and spring.

In 2013–15, 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; table 14).

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. 10). Groundwater discharge was assumed to be constant throughout the year, and the median winter flow was assumed to represent constant annual groundwater discharge. Most flow that occurs during the winter is groundwater discharge; 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. Rather than the average flow, 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. Nonetheless, the median flow for November, December, January, and February is an 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 2015 water year were 2.5 ft^3/s for Moenkopi Wash at Moenkopi, 0.28 ft^3/s for Dinnebito Wash near Sand Springs, 0.13 ft^3/s for Polacca Wash near Second Mesa, and 0.30 ft^3/s for Pasture Canyon Springs (fig. 10*A-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 methods of least squares and Kendall's tau ($p>0.05$; fig. 10*A-D*).

Table 10. Discharge data (daily mean values), Moenkopi Wash at Moenkopi, Arizona (09401260). *A*, calendar year 2013; *B*, calendar year 2014; and *C*, calendar year 2015.

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

***A*. Discharge, in cubic feet per second, calendar year 2013**
Daily mean values

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.2	2.7	2.6	2	1.3	0.26	0.08	9.6	78	e0.88	1.5	1.9
2	1.2	2.7	2.5	1.9	1.3	0.25	0.09	69	2.6	e1.1	1.5	2
3	1.3	2.8	2.5	1.9	1.2	0.25	0.02	10	2	e1.2	1.5	e2.1
4	0.96	2.9	2.6	1.9	1.2	0.23	0.00	6.5	1.9	e1.0	1.5	e1.8
5	e0.90	2.9	2.5	1.9	1.2	0.24	0.00	5.1	1.8	e1.1	1.5	1.4
6	e0.90	3.1	2.5	1.8	1.2	0.26	0.00	4.6	1.7	e0.96	1.5	e1.4
7	e0.90	3.1	2.5	1.8	1.2	0.26	0.00	5	1.7	e0.95	1.5	1.4
8	e1.0	3	2.5	1.8	1.3	0.23	0.00	4.8	1.7	e1.2	1.5	1.5
9	e0.88	3.1	2.9	1.9	1.2	0.22	0.00	4.3	27	e1.2	1.5	2
10	e0.90	3	2.7	1.8	1.2	0.22	0.00	4.1	5.5	e1.3	1.5	2.2
11	0.67	2.9	2.6	1.7	1.2	0.2	0.00	4	21	e1.3	1.5	2.3
12	0.36	2.9	2.5	1.7	1.2	0.15	0.00	46	5.6	1.3	1.5	2.3
13	0.38	2.9	2.5	1.7	1.1	0.13	0.00	4.6	2.1	1.3	1.5	2.1
14	0.31	2.8	2.5	1.6	1.1	0.16	0.00	3.3	1.6	1.2	1.5	2.1
15	0.61	2.8	2.5	1.6	1	0.08	0.00	2.7	18	1.3	1.5	2.1
16	0.47	2.7	2.5	1.6	0.97	0.09	0.00	2.8	3.2	1.3	1.5	2.1
17	0.59	2.8	2.4	1.6	0.93	0.08	0.00	2.7	86	1.3	1.5	2.1
18	0.62	2.7	2.4	1.6	0.92	0.07	12	7.7	144	1.3	1.5	2.1
19	0.66	2.7	2.3	1.6	0.92	0.04	1.2	6.8	1.9	1.3	1.6	e1.8
20	e0.75	2.8	2.3	1.6	0.89	0.02	118	3.4	1.5	1.3	1.6	e1.5
21	0.69	2.8	2.3	1.6	0.82	0.01	0.11	2.7	1.4	1.4	1.6	e1.4
22	e0.83	2.7	2.2	1.5	0.68	0.18	565	3.2	e1.3	1.4	11	e1.3
23	0.61	2.6	2.2	1.5	0.68	0.23	48	4.6	e1.2	1.4	e46	e1.3
24	1	2.7	2.1	1.5	0.55	0.24	31	4.8	e1.3	1.4	e5.4	e1.6
25	1.3	2.6	2.1	1.5	0.41	0.15	25	7.9	e1.2	1.4	e1.8	e1.5
26	4.3	2.6	2.1	1.5	0.25	0.1	50	19	e1.2	1.5	1.3	e1.4
27	34	2.5	2.1	1.4	0.22	0.08	104	543	e1.1	1.5	1.1	e1.5
28	e5.0	2.5	2	1.4	0.3	0.06	83	740	e1.1	1.4	1.1	e1.7
29	e3.2	---	2	1.4	0.3	0.04	15	4.4	e1.0	1.4	1	e1.8
30	e2.9	---	2	1.4	0.35	0.05	12	2.1	e0.88	1.4	1.5	e1.6
31	e2.8	---	2	---	0.3	---	9.6	353	---	1.4	---	e1.6
Total	72.19	78.3	73.4	49.7	27.39	4.58	1,074.1	1,891.7	420.48	39.39	102	54.9
Mean	2.33	2.8	2.37	1.66	0.88	0.15	34.6	61	14	1.27	3.4	1.77
Max	34	3.1	2.9	2	1.3	0.26	565	740	144	1.5	46	2.3
Min	0.31	2.5	2	1.4	0.22	0.01	0.00	2.10	0.9	0.88	1	1.3
Med	0.9	2.8	2.5	1.6	0.97	0.16	0.08	4.8	1.8	1.3	1.5	1.8
Acre-ft	143	155	146	99	54	9.10	2,130	3,750	834	78	202	109
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.01	0.00	0.00	0.00
Calendar year 2013	Total 3,888		Mean 10.7		Max 740	Min 0.00	Median 1.5		Acre-ft 7,710		CFSM 0.01	

Table 10.—Continued

B. Discharge, in cubic feet per second, calendar year 2014 Daily mean values												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	e1.6	e2.2	3.1	2.0	1.2	0.31	0.00	0.86	0.00	e0.60	0.72	1.0
2	e1.6	e2.0	3.2	2.0	1.2	0.01	0.00	0.97	0.00	e0.55	0.91	1.1
3	e1.7	e2.2	3.0	2.0	1.2	0.00	0.00	14	0.00	e0.50	0.97	1.1
4	e1.7	e2.2	3.1	2.0	1.1	0.00	0.00	2.1	e0.27	0.6	1.1	1.1
5	e2.0	e2.2	3.1	2.0	1.1	0.00	0.00	1.8	0.00	0.86	1.2	1.1
6	e1.7	e2.2	3.2	2.0	1.0	0.00	0.00	1.7	0.00	1.0	1.0	1.1
7	e1.5	e2.3	3.1	1.9	1.0	0.00	0.00	1.5	0.03	0.9	0.84	1.2
8	e1.6	e2.3	3.0	1.8	1.0	0.00	0.00	1.6	e60	0.82	0.84	1.2
9	e1.6	e2.3	2.8	1.8	1.0	0.00	0.00	2.2	13	0.99	0.85	1.1
10	e1.7	e2.3	2.7	1.8	0.93	0.00	0.00	1.7	e25	0.98	0.92	1.1
11	e1.8	e2.1	2.7	1.8	0.87	0.00	0.00	1.2	e25	0.88	0.91	1.1
12	e1.8	e2.4	2.6	1.8	0.92	0.00	0.00	1.6	9.1	0.7	0.92	1.1
13	e1.8	e2.3	2.6	1.7	0.86	e0.00	0.00	67	e5.0	0.67	0.92	1.1
14	e1.9	2.4	2.6	1.6	0.8	e0.00	0.00	71	e4.1	0.6	0.92	1.1
15	e1.8	2.5	2.6	1.6	0.81	0.00	0.94	e25	3.8	0.76	0.98	1.1
16	e1.8	2.5	2.5	1.6	0.79	0.00	0.96	e21	6.4	0.71	0.95	1.1
17	e1.8	2.5	2.5	1.6	0.79	0.00	0.58	e23	29	0.78	0.93	1.1
18	e1.8	2.5	2.4	1.6	0.76	0.00	0.52	18	18	0.92	0.92	1.1
19	e2.0	2.5	2.4	1.6	0.69	0.00	0.14	13	11	0.84	0.92	1.1
20	e2.0	2.5	2.4	1.5	0.61	0.00	0.00	e12	e4.4	0.74	0.94	1.2
21	e2.2	2.6	2.4	1.5	0.61	0.00	0.00	e8.8	e1.9	0.64	0.96	1.3
22	e2.1	2.6	2.4	1.4	0.43	0.00	0.00	4.3	e1.5	0.63	0.97	1.4
23	e2.0	2.6	2.3	1.4	0.57	0.00	0.00	4.2	e1.1	0.59	0.97	1.5
24	e1.9	2.7	2.3	1.4	0.65	0.00	0.00	e0.31	e0.90	0.65	0.95	1.6
25	e1.9	2.7	2.2	1.4	0.78	0.00	0.00	e0.00	e0.85	0.53	0.96	1.7
26	e1.8	2.7	2.2	1.4	0.74	0.00	e0.00	0.00	e0.80	0.59	1.0	1.8
27	e1.9	2.7	2.2	1.4	0.69	0.00	e0.00	e0.03	e0.75	0.65	1.0	1.9
28	e2.0	2.9	2.2	1.3	0.6	0.00	e0.00	0.01	e0.70	0.74	1.0	2
29	e2.0	---	2.2	1.2	0.54	0.00	0.00	0.00	e0.60	0.75	1.0	2.1
30	e2.0	---	2.1	1.2	0.56	0.00	0.05	0.00	e0.60	0.83	1.0	2.2
31	e2.1	---	2.1	---	0.53	---	0.00	0.00	---	0.86	---	2.3
Total	57.1	67.9	80.2	49.3	25.33	0.32	3.19	298.88	223.8	22.86	28.47	42
Mean	1.84	2.42	2.59	1.64	0.82	0.01	0.1	9.64	7.46	0.74	0.95	1.35
Max	2.2	2.9	3.2	2.0	1.2	0.31	0.96	71	60	1.0	1.2	2.3
Min	1.5	2.0	2.1	1.2	0.43	0.00	0.00	0.00	0.00	0.5	0.72	1.0
Med	1.8	2.5	2.5	1.6	0.79	0.00	0.00	1.7	1.3	0.74	0.95	1.1
Acre-ft	113	135	159	98	50	0.6	6.3	593	444	45	56	83
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Calendar year 2014	Total 899.35		Mean 2.46		Max 71	Min 0.00	Median 1.1		Acre-ft 1,780		CFSM 0.00	

Table 10.—Continued

C. **Discharge, in cubic feet per second, calendar year 2015** **Daily mean values**												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	2.4	e4.1	e8.2	2.1	1.3	0.65	0.07	0.67	e14	e1.6	3.4	e2.8
2	2.5	e4.1	e69	2.1	1.2	0.5	179	286	e8.5	e1.4	2.0	e2.9
3	2.6	e4.2	e36	2.1	1.3	0.35	5.2	2080	e7.1	e1.3	e1.7	e2.9
4	2.8	e4.2	e4.2	2.1	1.3	0.00	1.50	31	e132	e1.4	2.4	e2.9
5	e3.1	e4.2	e3.1	2.1	1.3	0.17	7.90	7.2	44	4.2	20	e2.9
6	e3.2	e4.2	e2.9	2.0	1.4	1.4	21.00	4.7	e25	602	8.8	e3.0
7	e3.2	e4.3	e2.8	1.9	1.3	1.6	6.60	e4.0	e5.6	586	4.2	e2.9
8	e3.3	e4.3	e2.7	1.9	1.3	1.3	3.40	206	e1.6	e32	3.4	e2.9
9	e3.3	e4.4	e2.6	1.9	1.3	0.81	7.70	45	e1.1	e11	3.3	e2.8
10	e3.3	e4.4	e2.6	1.9	1.3	0.84	13.00	9.5	e1.1	9.1	3.1	e2.7
11	e3.4	e4.4	e2.6	1.9	1.3	1.4	2.80	12	e1.1	8.2	3.0	2.7
12	e3.3	e4.5	e2.6	1.9	1.2	1.2	1.20	2590	e1.1	7.3	3.0	2.6
13	e3.4	e4.5	e2.6	1.8	1.2	0.86	0.68	43	e1.4	6.9	3.0	e2.3
14	e3.4	e4.6	e2.6	1.8	1.1	1.1	0.57	12	e1.4	6.3	3.0	e2.8
15	e3.5	e4.6	e2.6	1.8	1.3	1.1	11.00	7.8	e1.5	6.2	3.2	e2.3
16	e3.5	e4.7	e2.6	1.7	1.3	0.64	3.00	6.2	e1.6	6.0	3.3	e2.6
17	e3.5	e4.6	e2.6	1.8	1.2	0.23	1.80	e4.7	1.5	6.5	3.1	e2.1
18	e3.6	e4.7	2.5	1.8	1.1	0.00	e1.5	e4.2	1.5	28	2.8	e3.0
19	e3.6	e4.7	2.6	1.7	0.99	0.00	e1.5	e4.1	1.7	10	2.8	3.0
20	e3.7	e4.7	2.6	1.7	1.1	0.00	e1.5	e4.1	1.7	507	3.1	3.2
21	e3.7	e4.8	2.5	1.6	1.0	0.00	e44	e4.0	1.6	499	3.0	3.0
22	e3.8	e4.8	2.5	1.6	0.98	0.00	7.1	e4.2	2	236	2.4	2.6
23	e3.7	e5.6	2.5	1.6	1.0	0.00	e2.2	e3.9	1.8	38	2.7	2.1
24	e3.7	e16	2.5	1.6	1.1	0.00	e1.2	e3.6	1.8	18	2.9	e1.6
25	e3.8	5.3	2.5	1.6	1.1	0.00	e0.69	e4.1	2	18	3.1	e1.5
26	e3.8	4.5	2.5	1.8	0.99	0.00	0.4	e14	1.7	18	2.9	e1.7
27	e3.9	4.4	2.5	1.6	0.91	0.00	0.47	e38	1.7	19	3.1	e1.1
28	e3.9	5.7	2.5	1.5	0.81	0.00	0.6	e11	1.7	19	2.9	e1.4
29	e3.9	---	2.5	1.4	0.78	0.00	0.66	7.2	1.7	19	3.0	e2.0
30	e3.9	---	2.5	1.4	0.75	0.00	0.67	6.4	1.6	31	3.0	e2.9
31	e4.0	---	2.3	---	0.69	---	0.72	e47	---	8.7	---	e2.6
Total	106.7	139.5	187.3	53.7	34.9	14.15	329.63	5,505.57	272.1	2,766.1	111.6	77.8
Mean	3.44	4.98	6.04	1.79	1.13	0.47	10.6	178	9.07	89.2	3.72	2.51
Max	4	16	69	2.1	1.4	1.60	179	2,590	132	602	20	3.2
Min	2.4	4.1	2.3	1.4	0.69	0.00	0.07	0.67	1.1	1.3	1.7	1.1
Med	3.5	4.5	2.6	1.8	1.2	0.20	1.5	7.2	1.7	11	3.0	2.7
Acre-ft	212	277	372	107	69	28.00	654	10,920	540	5,490	221	154
CFSM	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11	0.01	0.05	0.00	0.00
Calendar year 2015	Total 9,599		Mean 26.3		Max 2590	Min 0.00	Median 2.7		Acre-ft 19,040		CFSM 0.02	

Table 11. Discharge data (daily mean values), Dinnebito Wash near Sand Springs, Arizona (09401110). *A*, calendar year 2013; *B*, calendar year 2014; and *C*, calendar year 2015.

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

***A*. Discharge, in cubic feet per second, calendar year 2013**
Daily mean values

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.36	0.47	0.25	0.35	0.44	0.18	0.18	0.57	e110	0.18	0.26	0.3
2	0.31	0.38	0.25	0.35	0.4	0.18	0.17	23	e76	0.18	0.26	0.27
3	0.29	0.39	0.25	0.36	0.37	0.17	0.18	4.4	e6.8	0.18	0.26	0.26
4	0.27	0.39	0.25	0.36	0.36	0.15	0.17	0.47	0.28	0.17	0.27	0.34
5	0.27	0.38	0.28	0.34	0.35	0.15	0.18	0.23	0.21	0.18	0.26	0.22
6	0.27	1.2	0.29	0.33	0.35	0.15	0.19	0.22	0.19	0.19	0.26	0.22
7	0.31	0.5	0.29	0.32	0.37	0.14	0.19	0.24	0.19	0.19	0.28	0.22
8	0.31	0.44	0.41	0.36	0.38	0.13	0.18	0.21	0.21	0.19	0.29	0.26
9	0.33	0.48	0.31	0.41	0.4	0.14	0.18	0.2	0.37	0.18	0.29	0.22
10	0.37	0.44	0.28	0.35	0.41	0.14	0.18	0.2	0.29	0.21	0.3	0.19
11	0.37	0.4	0.28	0.37	0.39	0.15	0.19	2.6	e124	0.19	0.3	0.18
12	0.32	0.42	0.27	0.38	0.38	0.15	0.23	0.32	e27	0.19	0.29	0.21
13	0.32	0.42	0.26	0.29	0.4	0.17	0.22	3.4	e0.69	0.19	0.22	0.26
14	0.31	0.41	2.2	0.28	0.44	0.14	0.2	1.5	e6.6	0.19	0.08	0.27
15	0.26	0.41	0.43	0.27	0.4	0.15	0.23	0.26	0.39	0.2	0.56	0.27
16	0.27	0.39	0.45	0.26	0.36	0.16	e22	0.22	0.22	0.2	0.37	0.27
17	0.27	0.4	0.38	0.28	0.31	0.15	42	15	0.2	0.2	0.33	0.27
18	0.27	0.39	0.36	0.28	0.37	0.16	122	4.3	0.17	0.2	0.33	0.28
19	0.23	0.4	0.34	0.3	0.39	0.21	85	0.23	0.17	0.3	0.35	0.32
20	0.2	0.44	0.38	0.3	0.35	0.22	78	0.19	0.2	0.34	0.39	0.48
21	0.23	0.43	0.36	0.29	0.33	0.22	29	0.19	0.2	0.34	0.42	0.33
22	0.25	0.42	0.33	0.29	0.29	0.17	129	0.2	0.17	0.24	8.6	0.28
23	0.28	0.41	0.37	0.28	0.27	0.2	13	0.2	0.18	0.24	29	0.27
24	0.41	0.48	0.49	0.29	0.24	0.2	2.9	0.21	0.19	0.24	9.8	0.27
25	0.56	0.3	0.87	0.31	0.22	0.16	0.29	0.24	0.18	0.24	3.3	0.27
26	4	0.26	0.62	0.33	0.22	0.18	144	5.3	0.16	0.24	0.37	0.26
27	1.3	0.68	0.46	0.4	0.22	0.18	12	e454	0.16	0.25	0.07	0.27
28	0.61	0.26	0.41	0.43	0.22	0.17	3.1	e362	0.17	0.24	0.07	0.28
29	0.52	---	0.39	0.42	0.22	0.17	7.1	e208	0.18	0.25	0.07	0.27
30	0.4	---	0.37	0.46	0.2	0.18	0.32	e287	0.18	0.27	0.86	0.27
31	0.34	---	0.37	---	0.2	---	0.2	e541	---	0.26	---	0.28
Total	14.81	12.39	13.25	10.04	10.25	5.02	692.78	1,916.1	355.95	6.86	58.51	8.36
Mean	0.48	0.44	0.43	0.33	0.33	0.17	22.3	61.8	11.9	0.22	1.95	0.27
Max	4	1.2	2.2	0.46	0.44	0.22	144	541	124	0.34	29	0.48
Min	0.2	0.26	0.25	0.26	0.2	0.13	0.17	0.19	0.16	0.17	0.07	0.18
Med	0.31	0.41	0.36	0.33	0.36	0.16	0.23	0.32	0.2	0.2	0.3	0.27
Acre-ft	29	25	26	20	20	10	1,370	3,800	706	14	116	17
CFSM	0	0	0	0	0	0	0.05	0.13	0.03	0.00	0.00	0.00
Calendar year 2013	Total 3,104.32		Mean 8.5		Max 541	Min 0.07	Median 0.28		Acre-ft 6,160		CFSM 0.02	

Table 11.—Continued

B. Discharge, in cubic feet per second, calendar year 2014 Daily mean values												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.29	0.31	0.46	0.26	0.26	0.2	0.1	0.2	0.2	0.56	0.27	0.33
2	0.28	0.29	0.36	0.29	0.24	0.19	0.13	0.2	0.2	0.28	0.3	0.34
3	0.27	0.3	0.33	0.31	0.23	0.18	0.13	0.29	0.18	0.25	0.3	0.31
4	0.29	0.29	0.33	0.29	0.22	0.17	0.09	4.5	0.2	0.25	0.29	0.52
5	0.23	0.29	0.32	0.3	0.23	0.17	0.09	0.39	0.22	0.25	0.29	0.39
6	0.22	0.3	0.32	0.28	0.33	0.16	0.1	0.22	0.2	0.24	0.29	0.38
7	0.24	0.32	0.32	0.28	0.28	0.15	0.09	0.2	0.19	0.25	0.29	0.4
8	0.25	0.3	0.3	0.29	0.28	0.14	0.09	0.19	0.2	0.27	0.29	0.4
9	0.26	0.3	0.3	0.29	0.26	0.14	0.08	0.19	0.21	0.32	0.3	0.39
10	0.26	0.3	0.31	0.29	0.26	0.16	0.07	0.19	0.21	0.28	0.3	0.4
11	0.28	0.3	0.3	0.08	0.13	0.14	0.09	0.19	0.19	0.26	0.29	0.41
12	0.28	0.3	0.3	0.08	0.08	0.14	0.08	0.19	0.18	0.25	0.3	0.41
13	0.26	0.29	0.31	0.09	0.08	0.13	0.08	2	0.19	0.24	0.3	0.49
14	0.27	0.3	0.32	e2.1	0.08	0.12	17	246	0.19	0.26	0.31	0.41
15	0.27	0.3	0.28	0.27	0.09	0.13	0.38	9.1	0.19	0.26	0.31	0.39
16	0.27	0.3	0.28	0.35	0.08	0.14	e42	0.57	5.1	0.26	0.3	0.42
17	0.27	0.3	0.37	0.31	0.08	0.14	2.8	0.25	15	0.27	0.27	0.45
18	0.27	0.31	0.46	0.31	2	0.15	0.24	0.23	8	0.28	0.29	0.42
19	0.26	0.29	0.47	0.32	0.34	0.16	0.16	0.23	0.69	0.3	0.31	0.4
20	0.28	0.27	0.49	0.3	0.31	0.14	0.15	0.23	0.28	0.32	0.34	0.42
21	0.28	0.3	0.51	0.3	0.28	0.13	0.15	0.24	0.23	0.3	0.33	0.41
22	0.28	0.31	0.51	0.28	0.28	0.13	0.15	0.24	0.21	0.3	0.31	0.42
23	0.27	0.31	0.52	0.28	0.32	0.13	0.14	0.22	0.21	0.31	0.33	0.38
24	0.27	0.31	0.52	0.28	0.33	0.12	0.16	0.21	0.2	0.32	0.29	0.36
25	0.28	0.32	0.5	0.26	0.33	0.11	0.17	0.21	0.2	0.3	0.28	0.41
26	0.28	0.31	0.54	0.3	0.3	0.1	48	0.23	0.2	0.3	0.32	0.37
27	0.23	0.3	0.56	0.28	0.28	0.11	0.84	0.35	0.21	0.28	0.33	0.34
28	0.22	0.3	0.55	0.26	0.27	0.12	0.24	0.22	5.3	0.29	0.34	0.3
29	0.22	---	0.54	0.25	0.25	0.11	0.2	0.21	22	0.29	0.31	0.23
30	0.32	---	0.41	0.25	0.26	0.1	0.19	0.21	1.9	0.28	0.34	0.23
31	0.36	---	0.26	---	0.23	---	0.2	0.21	---	0.27	---	0.26
Total	8.31	8.42	12.35	9.83	8.99	4.21	114.39	268.11	62.68	8.89	9.12	11.79
Mean	0.27	0.3	0.4	0.33	0.29	0.14	3.69	8.65	2.09	0.29	0.3	0.38
Max	0.36	0.32	0.56	2.1	2	0.2	48	246	22	0.56	0.34	0.52
Min	0.22	0.27	0.26	0.08	0.08	0.1	0.07	0.19	0.18	0.24	0.27	0.23
Med	0.27	0.3	0.36	0.29	0.26	0.14	0.15	0.22	0.21	0.28	0.3	0.4
Acre-ft	16	17	24	19	18	8.4	227	532	124	18	18	23
CFSM	0	0	0	0	0	0	0.01	0.02	0	0	0	0
Calendar year 2014	Total 527		Mean 1.4		Max 246	Min 0.07	Median 0.28		Acre-ft 1,050		CFSM 0.00	

Table 11.—Continued

C. Discharge, in cubic feet per second, calendar year 2015 Daily mean values												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.31	0.36	0.62	0.28	0.21	e0.20	2.1	0.22	0.71	0.57	0.26	e0.19
2	0.29	0.34	0.54	0.29	0.21	e0.20	1.1	16	0.65	0.56	0.24	0.16
3	0.25	0.34	0.44	0.29	0.2	0.22	0.4	213	0.84	0.54	0.22	0.17
4	0.25	0.34	0.39	0.3	0.21	0.21	e119	10	5.7	0.57	28	0.18
5	0.33	0.32	0.35	0.29	0.2	0.28	e30	5.4	15	1.4	12	0.19
6	0.42	0.33	0.34	0.29	e0.20	0.54	e4.1	3.7	9.3	121	1.9	0.19
7	0.44	0.33	0.34	0.31	e0.20	23	1.7	3.3	6.8	79	0.52	0.19
8	0.43	0.32	0.33	0.36	0.28	3.9	0.55	32	3.4	14	0.18	0.19
9	0.36	0.32	0.26	0.36	e0.20	e0.20	0.35	13	1.1	e4.0	0.16	0.19
10	0.33	0.31	0.21	0.38	e0.20	e0.19	0.3	4.7	0.83	e2.6	0.16	0.2
11	0.43	0.33	0.42	0.37	e0.20	e0.19	0.29	3.2	0.78	e1.3	0.17	0.2
12	0.43	0.34	0.34	0.36	e0.20	e0.19	0.29	134	0.76	e0.79	0.16	0.21
13	0.53	0.34	0.34	0.35	e0.20	e0.19	0.29	7.6	0.76	e0.56	0.16	0.2
14	0.42	0.33	0.34	0.34	e0.20	e0.19	0.29	4.1	0.79	e0.38	0.16	0.2
15	0.35	0.32	0.32	0.33	e0.20	e0.19	0.3	1.7	1.5	0.37	0.16	0.19
16	0.33	0.31	0.31	0.33	e0.20	e0.19	63	1.2	0.9	0.46	0.18	0.19
17	0.33	0.31	0.29	0.34	e0.20	e0.19	4.3	0.97	0.72	0.82	0.16	0.19
18	0.32	0.33	0.28	0.35	e0.20	e0.19	0.87	0.87	0.71	0.64	0.16	0.2
19	0.32	0.33	0.3	0.34	e0.20	e0.19	0.29	0.82	0.72	0.55	0.16	0.21
20	0.32	0.33	0.31	0.34	e0.20	e0.19	0.31	0.79	0.7	21	0.16	0.22
21	0.34	0.32	0.32	0.34	0.62	e0.19	0.25	0.79	0.7	42	0.15	0.21
22	0.3	0.27	0.3	0.33	e0.20	e0.19	0.23	0.79	0.74	65	0.15	0.23
23	0.29	0.53	0.28	0.32	e0.20	e0.19	0.22	0.74	0.76	24	0.15	0.23
24	0.31	0.51	0.29	0.34	e0.20	e0.19	0.23	0.71	0.71	11	0.16	0.22
25	0.31	0.38	0.31	0.41	e0.20	0.22	0.23	0.78	0.67	2.8	0.15	0.22
26	0.32	0.37	0.33	0.47	e0.20	0.21	0.22	0.89	0.62	0.73	0.16	0.24
27	0.33	0.38	0.32	0.37	e0.20	0.21	0.21	9.8	0.62	0.47	e0.19	0.27
28	0.32	0.39	0.3	0.35	e0.20	0.21	0.21	4.5	0.62	0.38	e0.19	0.29
29	0.35	---	0.29	0.24	e0.20	0.22	0.21	1.4	0.63	0.57	e0.19	0.3
30	0.51	---	0.29	0.22	e0.20	3.5	0.22	0.83	0.65	0.91	e0.19	0.29
31	0.44	---	0.27	---	e0.20	---	0.22	0.87	---	0.28	---	0.29
Total	11.01	9.73	10.37	9.99	6.73	36.17	232.28	478.67	59.39	399.25	46.95	6.65
Mean	0.36	0.35	0.33	0.33	0.22	1.21	7.49	15.4	1.98	12.9	1.56	0.21
Max	0.53	0.53	0.62	0.47	0.62	23	119	213	15	121	28	0.3
Min	0.25	0.27	0.21	0.22	0.2	0.19	0.21	0.22	0.62	0.28	0.15	0.16
Med	0.33	0.33	0.32	0.34	0.2	0.2	0.29	1.7	0.75	0.79	0.16	0.2
Acre-ft	22	19	21	20	13	72	461	949	118	792	93	13
CFSM	0	0	0	0	0	0	0.02	0.03	0	0.03	0	0
Calendar year 2015	Total 1,307		Mean 3.6		Max 213	Min 0.15	Median 0.32		Acre-ft 2,590		CFSM 0.01	

Table 12. Discharge data (daily mean values), Polacca Wash near Second Mesa, Arizona (09400568). *A*, calendar year 2013; *B*, calendar year 2014; and *C*, calendar year 2015.

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

***A*. Discharge, in cubic feet per second, calendar year 2013 Daily mean values**												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	e0.33	0.06	0.1	0.12	0.15	0.06	0.01	0.03	487	e0.11	e0.18	0.13
2	e0.31	0.07	0.11	0.11	0.15	0.06	0.01	0.03	13	e0.03	e0.24	0.14
3	e0.26	0.07	0.12	0.15	0.15	0.05	0.01	0.03	1.6	0.00	e0.21	0.17
4	e0.18	0.08	0.11	0.19	0.15	0.05	0.01	0.03	0.22	0.02	e0.06	0.2
5	e0.18	0.08	0.12	0.19	0.16	0.05	0.02	0.03	0.23	0.02	e0.07	0.2
6	e0.19	0.11	0.12	0.17	0.17	0.05	0.02	0.04	0.21	0.04	e0.08	0.18
7	e0.16	0.12	0.12	0.18	0.15	0.04	0.03	0.04	0.19	0.02	e0.07	0.2
8	e0.19	0.13	0.73	0.24	0.12	0.04	0.01	0.03	0.27	0.02	e0.10	0.19
9	e0.12	0.15	0.24	0.28	0.12	0.04	0	0.03	52	0.02	0.11	0.17
10	0.09	0.13	0.11	0.26	0.13	0.04	0	0.04	26	0.05	0.11	0.14
11	e0.18	0.14	0.11	0.29	0.13	0.03	0	3.6	75	0.06	0.12	0.14
12	e0.23	0.14	0.1	0.3	0.11	0.03	0	7.9	43	0.08	0.11	0.16
13	e0.17	0.14	0.1	0.29	0.11	0.03	0.01	8.4	6.9	0.04	0.13	0.17
14	e0.16	0.14	0.1	0.27	0.11	0.03	0	0.65	1.9	0.04	0.15	0.13
15	e0.19	0.15	0.12	0.31	0.11	0.04	0.01	0.09	12	0.02	0.15	0.1
16	e0.19	0.15	0.14	0.35	0.1	0.03	59	0.08	103	0.03	0.13	0.09
17	e0.22	0.14	0.13	0.35	0.1	0.02	10	0.08	146	0.02	0.12	0.1
18	e0.31	0.13	0.13	0.34	0.11	0.02	0.59	0.08	7.4	e0.03	0.11	0.1
19	e0.34	0.13	0.14	0.34	0.12	0.02	0.05	0.05	5.3	e0.06	0.15	0.13
20	e0.27	0.14	0.15	e0.38	0.11	0.01	543	0.05	e2.3	e0.03	0.14	0.16
21	e0.16	0.12	0.15	e0.31	0.12	0.01	e134	0.04	e0.51	e0.03	0.12	0.12
22	e0.12	0.1	0.13	e0.31	0.11	0.01	41	77	e0.45	e0.04	0.77	0.11
23	e0.13	0.1	0.12	e0.22	0.1	0.01	4.1	43	e0.30	e0.12	0.39	0.11
24	e0.08	0.1	0.13	0.22	0.1	0.01	0.26	28	e8.2	e0.14	0.17	0.11
25	0.04	0.11	0.13	0.16	0.11	0.01	0.09	29	e1.2	e0.04	0.13	0.11
26	0.39	0.1	0.13	0.17	0.12	0.02	55	125	e0.38	0.03	0.13	0.12
27	0.08	0.09	0.11	0.16	0.12	0.02	e159	259	e0.12	e0.05	0.13	0.16
28	0.25	0.1	0.11	0.17	0.14	0.01	e7.5	303	e0.11	e0.07	0.13	0.16
29	e0.44	---	0.15	0.16	0.12	0.01	e2.6	e154	e0.08	e0.05	0.15	0.16
30	0.08	---	0.12	0.15	0.08	0.01	e2.7	e15	e0.09	e0.05	0.13	0.13
31	0.06	---	0.13	---	0.06	---	e0.39	e828	---	e0.05	---	0.14
Total	6.1	3.22	4.51	7.14	3.74	0.86	1,019.42	1,882.35	994.96	1.41	4.79	4.43
Mean	0.2	0.12	0.15	0.24	0.12	0.03	32.9	60.7	33.2	0.05	0.16	0.14
Max	0.44	0.15	0.73	0.38	0.17	0.06	543	828	487	0.14	0.77	0.2
Min	0.04	0.06	0.1	0.11	0.06	0.01	0	0.03	0.08	0	0.06	0.09
Med	0.18	0.12	0.12	0.23	0.12	0.03	0.05	0.08	1.7	0.04	0.13	0.14
Acre-ft	12	6.4	8.9	14	7.4	1.7	2,020	3,730	1,970	2.8	9.5	8.8
CFSM	0	0	0	0	0	0	0.04	0.07	0.04	0	0	0
Calendar year 2013	Total 3,932.93		Mean 10.8		Max 828	Min 0.00	Median 0.12		Acre-ft 7,800		CFSM 0.01	

Table 12.—Continued

***B*. Discharge, in cubic feet per second, calendar year 2014 Daily mean values**												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.16	0.41	0.7	0.12	0.11	0.03	0	0.06	e0.10	0.93	0.26	0.16
2	0.16	0.37	0.35	0.13	0.1	0.02	0	0.07	e0.08	0.07	0.17	0.17
3	0.14	0.39	0.28	0.11	0.09	0.02	0	0.22	0.05	0.04	0.17	0.22
4	0.14	0.39	0.21	0.12	0.08	0.02	0	1.1	0.09	0.05	0.17	1.1
5	0.13	0.4	0.18	0.15	0.07	0.02	0.01	0.11	0.11	0.04	0.14	0.33
6	0.12	0.47	0.18	0.16	0.08	0.03	0.03	0.07	0.08	0.03	0.15	0.2
7	0.13	0.61	0.19	0.15	0.08	0.03	0.04	0.06	0.07	0.03	0.15	0.16
8	0.14	0.54	0.18	0.14	0.08	0.03	0.11	0.06	0.08	0.04	0.14	0.17
9	0.14	0.6	0.17	0.16	0.07	0.03	0.16	0.06	0.1	0.05	0.15	0.17
10	0.14	0.74	0.19	0.14	0.07	0.03	0.05	0.07	0.08	0.04	0.16	0.18
11	0.15	0.71	0.21	0.13	0.07	0.03	0.04	0.07	0.06	0.04	0.17	0.18
12	0.17	0.54	0.17	0.12	0.07	0.02	0.05	0.08	0.05	0.04	0.16	0.19
13	0.19	0.51	0.2	0.11	0.06	0.02	0.1	2.9	0.06	0.04	0.15	0.52
14	0.19	0.52	0.19	0.1	0.06	0	0.08	0.81	0.06	0.04	0.15	0.25
15	0.2	0.64	0.18	0.11	0.06	0	0.07	0.2	0.04	0.05	0.16	0.2
16	0.21	0.67	0.16	0.12	0.06	0	0.1	0.17	0.05	0.05	0.16	0.21
17	0.2	0.59	0.18	0.11	0.06	0	0.05	89	0.07	0.05	0.15	0.29
18	0.21	0.7	0.15	0.12	0.05	0	0.05	7.9	0.15	0.06	0.16	0.23
19	0.22	0.79	0.13	0.13	0.05	0	0.04	2.3	0.06	0.06	0.17	0.16
20	0.23	0.6	0.14	0.1	0.05	0	0.04	63	0.04	0.06	0.19	0.17
21	0.23	0.35	0.15	0.08	0.05	0.01	0.04	24	0.03	0.11	0.19	0.17
22	0.24	0.59	0.17	0.08	0.05	0	0.04	2.4	0.04	0.13	e0.18	0.18
23	0.24	0.46	0.2	0.07	0.05	0	0.03	0.08	0.04	0.14	e0.16	0.16
24	0.23	0.24	0.15	0.08	0.06	0	0.03	0.07	0.04	0.16	0.15	0.15
25	0.3	0.19	0.16	0.07	0.07	0	0.04	0.1	0.03	0.13	0.13	0.18
26	0.33	0.23	0.19	0.15	0.07	0	0.04	e1.2	0.03	0.17	0.15	0.17
27	0.34	0.27	0.17	0.12	0.06	0	0.06	e32	0.05	0.17	0.17	0.15
28	0.35	0.22	0.15	0.1	0.05	0	0.1	e41	0.11	0.2	0.17	0.17
29	0.38	---	0.13	0.09	0.05	0	0.07	e5.7	2.1	0.24	0.16	0.19
30	0.46	---	0.13	0.1	0.05	0	0.06	e0.68	9.2	0.21	0.17	0.14
31	0.43	---	0.11	---	0.04	---	0.06	e0.10	---	0.23	---	0.14
Total	6.9	13.74	6.05	3.47	2.02	0.34	1.59	275.64	13.15	3.7	4.91	7.06
Mean	0.22	0.49	0.2	0.12	0.07	0.01	0.05	8.89	0.44	0.12	0.16	0.23
Max	0.46	0.79	0.7	0.16	0.11	0.03	0.16	89	9.2	0.93	0.26	1.1
Min	0.12	0.19	0.11	0.07	0.04	0.00	0.00	0.06	0.03	0.03	0.13	0.14
Med	0.2	0.51	0.18	0.12	0.06	0.00	0.04	0.2	0.06	0.06	0.16	0.18
Acre-ft	14	27	12	6.9	4	0.7	3.2	547	26	7.3	9.7	14
CFSM	0	0	0	0	0	0	0	0.01	0	0	0	0
Calendar year 2014	Total 338.57		Mean 0.93		Max 89	Min 0.00	Median 0.13		Acre-ft 672		CFSM 0.00	

Table 12.—Continued

***C.* Discharge, in cubic feet per second, calendar year 2015**
Daily mean values

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.16	0.23	0.84	0.1	0.1	0.05	0	0.00	0.02	0.03	e0.40	e0.17
2	0.38	0.18	0.59	0.1	0.09	0.04	0	21	0.00	0.04	e0.35	e0.18
3	0.36	0.17	0.52	0.08	0.07	0.04	0	188	0.01	0.01	e0.30	e0.18
4	0.29	0.17	0.26	0.1	0.08	0.04	0	581	0.03	0.76	e0.25	e0.19
5	0.21	0.13	0.19	0.11	0.08	0.18	0.55	26	0.34	3.4	3.2	e0.20
6	0.19	0.14	0.21	0.1	0.08	4.6	3.8	2.5	0.35	349	e0.25	e0.21
7	0.17	0.15	0.23	0.1	0.06	28	0.24	0.08	99	357	e0.20	e0.22
8	0.17	0.16	0.26	0.1	0.07	e23	e2.3	226	7.9	432	e0.15	e0.23
9	0.17	0.19	0.25	0.09	0.08	e2.1	e2.7	549	0.54	19	e0.10	e0.24
10	0.18	0.15	0.24	0.11	0.08	e0.32	e0.74	53	0.12	1.5	e0.09	0.25
11	0.31	0.15	0.25	0.11	0.07	e0.12	e0.21	11	0.09	0.1	e0.07	0.1
12	0.23	0.14	0.29	0.12	0.07	0.09	e0.01	447	0.07	0.06	e0.05	0.11
13	0.83	0.15	0.3	0.11	0.06	0.13	0	261	0.01	e0.06	e0.03	0.06
14	0.48	0.16	0.3	0.13	0.06	0.14	0	28	1.3	e0.06	e0.05	0.07
15	0.2	0.18	0.32	0.12	0.06	0.09	0	6.4	0.1	e0.06	e0.05	0.06
16	0.17	0.16	0.32	0.14	0.11	0.07	0.02	8.3	0.44	e0.06	e0.06	0.06
17	0.16	0.14	0.23	0.19	0.08	0.04	0.34	1.9	0.23	e0.06	e0.06	0.09
18	0.17	0.15	0.21	0.17	0.07	0.03	1.1	0.34	2.9	e0.06	e0.07	0.09
19	0.18	0.16	0.22	0.07	0.07	0.03	0.17	0.23	27	e0.06	e0.08	0.08
20	0.19	0.15	0.22	0.14	0.06	0.02	0.01	0.95	6.8	e79	e0.08	0.07
21	0.31	0.12	0.22	0.16	0.07	0.02	15	1.2	0.46	12	e0.09	0.06
22	0.24	0.16	0.19	0.18	0.06	0.01	143	0.29	10	85	e0.10	0.07
23	0.2	0.32	0.18	0.16	0.07	0.01	9.3	0.13	4.6	197	e0.10	0.07
24	0.21	0.42	0.12	0.17	0.12	0.00	1.2	2.2	1.8	0.78	e0.11	0.06
25	0.17	0.19	0.13	0.2	0.14	0.00	0.28	0.13	0.6	e0.73	e0.12	0.05
26	0.17	0.14	0.11	0.83	0.1	0	0.31	0.55	0.3	e0.58	e0.13	0.04
27	0.21	0.14	0.11	0.24	0.08	0	0.04	0.55	0.22	e0.53	e0.14	e0.07
28	0.19	0.19	0.09	0.15	0.06	0	0	0.12	0.06	e0.48	e0.15	e0.11
29	0.2	---	0.07	0.11	0.06	0	0	0.03	0.03	e0.43	e0.15	e0.11
30	1.6	---	0.08	0.1	0.06	0	0	0.01	0.03	e0.50	e0.16	e0.12
31	0.8	---	0.1	---	0.05	---	0	0.03	---	e0.45	---	e0.24
Total	9.5	4.89	7.65	4.59	2.37	59.17	181.32	2,416.94	165.35	1,540.8	7.14	3.86
Mean	0.31	0.17	0.25	0.15	0.08	1.97	5.85	78	5.51	49.7	0.24	0.12
Max	1.6	0.42	0.84	0.83	0.14	28	143	581	99	432	3.2	0.25
Min	0.16	0.12	0.07	0.07	0.05	0	0	0	0	0.01	0.03	0.04
Med	0.2	0.16	0.22	0.12	0.07	0.04	0.17	1.9	0.32	0.5	0.1	0.1
Acre-ft	19	9.7	15	9.1	4.7	117	360	4,790	328	3,060	14	7.7
CFSM	0	0	0	0	0	0	0.01	0.09	0.01	0.05	0	0
Calendar year 2015	Total 4,403.58		Mean 12.1		Max 581	Min 0.00	Median 0.15		Acre-ft 8,730		CFSM 0.01	

Table 13. Discharge data (daily mean values), Pasture Canyon Springs near Tuba City, Arizona (09401265). *A*, calendar year 2013; *B*, calendar year 2014; and *C*, calendar year 2015.

[e, estimated; ---, no data]

***A*. Discharge, in cubic feet per second, calendar year 2013 Daily mean values**												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.36	0.34	0.34	0.33	0.32	0.33	0.32	0.32	0.32	0.28	0.28	0.25
2	0.36	0.34	0.34	0.33	0.32	0.33	0.32	0.32	0.32	0.28	0.27	0.25
3	0.36	0.34	0.34	0.33	0.32	0.32	0.32	0.32	0.3	0.28	0.27	0.25
4	0.36	0.36	0.34	0.33	0.32	0.32	0.32	0.32	0.3	0.28	0.27	0.25
5	0.36	0.36	0.34	0.34	0.34	0.32	0.33	0.32	0.3	0.28	0.27	0.25
6	0.36	0.36	0.34	0.34	0.34	0.32	0.36	0.32	0.3	0.28	0.26	0.25
7	0.35	0.36	0.34	0.34	0.34	0.32	0.36	0.34	0.3	0.28	0.26	0.25
8	0.34	0.36	0.37	0.37	0.34	0.32	0.35	0.32	0.3	0.28	0.25	0.24
9	0.34	0.36	0.41	0.37	0.34	0.32	0.35	0.32	0.38	0.28	0.25	0.23
10	0.36	0.36	0.4	0.32	0.34	0.32	0.35	0.32	0.37	0.31	0.24	0.23
11	0.36	0.36	0.36	0.32	0.34	0.32	0.36	0.32	0.33	0.32	0.25	0.23
12	0.36	0.36	0.35	0.33	0.34	0.32	0.36	0.32	0.32	0.32	0.26	0.23
13	0.36	0.36	0.35	0.33	0.34	0.32	0.34	0.32	0.31	0.32	0.26	0.23
14	0.36	0.36	0.35	0.32	0.34	0.32	0.33	0.31	0.3	0.32	0.26	0.23
15	0.35	0.36	0.35	0.31	0.34	0.32	0.32	0.32	0.3	0.32	0.25	0.25
16	0.34	0.36	0.34	0.3	0.34	0.32	0.33	0.32	0.3	0.3	0.25	0.25
17	0.34	0.36	0.35	0.3	0.34	0.32	0.33	0.3	0.3	0.32	0.25	0.25
18	0.34	0.36	0.35	0.33	0.34	0.32	0.35	0.3	0.3	0.32	0.25	0.25
19	0.34	0.36	0.34	0.33	0.34	0.32	0.34	0.3	0.3	0.32	0.25	0.25
20	0.34	0.38	0.35	0.34	0.34	0.32	0.32	0.3	0.29	0.32	0.25	0.25
21	0.34	0.38	0.34	0.33	0.34	0.32	0.31	0.3	0.29	0.32	0.25	0.25
22	0.34	0.37	0.35	0.33	0.33	0.32	0.3	0.3	0.3	0.32	0.34	0.25
23	0.34	0.36	0.36	0.34	0.33	0.32	0.3	0.3	0.3	0.32	0.35	0.25
24	0.36	0.36	0.35	0.33	0.33	0.32	0.28	0.3	0.3	0.31	0.29	0.25
25	0.37	0.34	0.35	0.33	0.33	0.32	0.28	0.3	0.3	0.3	0.27	0.24
26	0.61	0.34	0.35	0.33	0.33	0.32	0.29	0.33	0.3	0.3	0.27	0.24
27	0.41	0.34	0.34	0.32	0.33	0.33	0.28	e0.44	0.3	0.3	0.27	0.23
28	0.38	0.34	0.33	0.32	0.34	0.32	0.28	0.34	0.29	0.31	0.27	0.23
29	0.36	---	0.33	0.32	0.33	0.32	0.3	0.32	0.28	0.31	0.26	0.24
30	0.36	---	0.32	0.32	0.33	0.32	0.3	0.32	0.28	0.29	0.25	0.24
31	0.34	---	0.32	---	0.33	---	0.3	0.32	---	0.28	---	0.23
Total	11.25	9.99	10.79	9.88	10.37	9.63	9.98	9.9	9.18	9.37	7.97	7.52
Mean	0.36	0.36	0.35	0.33	0.33	0.32	0.32	0.32	0.31	0.3	0.27	0.24
Max	0.61	0.38	0.41	0.37	0.34	0.33	0.36	0.44	0.38	0.32	0.35	0.25
Min	0.34	0.34	0.32	0.3	0.32	0.32	0.28	0.3	0.28	0.28	0.24	0.23
Med	0.36	0.36	0.35	0.33	0.34	0.32	0.32	0.32	0.3	0.31	0.26	0.25
Acre-ft	22	20	21	20	21	19	20	20	18	19	16	15
Calendar year 2013	Total 115.83		Mean 0.32		Max 0.61	Min 0.23	Median 0.32		Acre-ft 230			

Table 13.—Continued

***B.* Discharge, in cubic feet per second, calendar year 2014 Daily mean values**												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.23	0.27	0.25	0.25	0.25	0.22	0.2	0.22	0.23	0.23	0.26	0.24
2	0.24	0.27	0.27	0.25	0.25	0.22	0.2	0.22	0.23	0.23	0.27	0.23
3	0.24	0.27	0.27	0.25	0.25	0.22	0.19	0.25	0.23	0.23	0.27	0.23
4	0.24	0.27	0.27	0.25	0.25	0.21	0.19	0.26	0.23	0.23	0.27	0.24
5	0.23	0.26	0.27	0.25	0.25	0.2	0.19	0.23	0.23	0.23	0.28	0.24
6	0.23	0.26	0.27	0.25	0.25	0.2	0.19	0.23	0.23	0.23	0.27	0.26
7	0.25	0.26	0.27	0.25	0.26	0.2	0.19	0.22	0.23	0.25	0.27	0.25
8	0.26	0.26	0.27	0.24	0.25	0.2	0.19	0.22	0.23	0.25	0.27	0.24
9	0.25	0.27	0.27	0.24	0.24	0.2	0.19	0.22	0.23	0.25	0.26	0.23
10	0.25	0.26	0.27	0.24	0.23	0.2	0.2	0.22	0.23	0.25	0.27	0.23
11	0.25	0.26	0.27	0.24	0.24	0.2	0.2	0.22	0.22	0.25	0.27	0.23
12	0.25	0.25	0.26	0.25	0.24	0.2	0.2	0.23	0.22	0.25	0.27	0.23
13	0.25	0.25	0.25	0.25	0.24	0.2	0.2	0.27	0.23	0.25	0.27	0.23
14	0.25	0.25	0.25	0.25	0.24	0.2	0.2	0.25	0.23	0.25	0.27	0.24
15	0.25	0.26	0.25	0.25	0.23	0.2	0.21	0.25	0.23	0.26	0.27	0.24
16	0.25	0.27	0.25	0.24	0.23	0.21	0.2	0.25	0.22	0.27	0.25	0.25
17	0.25	0.26	0.25	0.24	0.23	0.22	0.2	0.25	0.22	0.27	0.24	0.25
18	0.24	0.26	0.25	0.25	0.23	0.21	0.2	0.25	0.22	0.26	0.24	0.25
19	0.24	0.25	0.25	0.24	0.23	0.2	0.2	0.25	0.22	0.25	0.25	0.25
20	0.24	0.25	0.25	0.24	0.23	0.2	0.21	0.25	0.22	0.25	0.25	0.24
21	0.25	0.25	0.25	0.24	0.22	0.2	0.2	0.25	0.22	0.24	0.25	0.23
22	0.25	0.25	0.25	0.26	0.22	0.2	0.18	0.25	0.22	0.23	0.25	0.23
23	0.24	0.25	0.25	0.26	0.22	0.2	0.19	0.25	0.22	0.23	0.25	0.23
24	0.25	0.25	0.25	0.26	0.22	0.2	0.21	0.26	0.22	0.25	0.24	0.24
25	0.24	0.25	0.25	0.26	0.22	0.2	0.21	0.27	0.22	0.25	0.23	0.23
26	0.25	0.25	0.25	0.27	0.22	0.2	0.21	0.26	0.22	0.25	0.23	0.23
27	0.24	0.25	0.25	0.28	0.22	0.2	0.22	0.25	0.22	0.25	0.24	0.23
28	0.24	0.25	0.25	0.25	0.22	0.2	0.22	0.23	0.22	0.25	0.25	0.22
29	0.25	---	0.25	0.25	0.22	0.2	0.22	0.23	0.22	0.25	0.25	0.22
30	0.27	---	0.25	0.25	0.22	0.2	0.22	0.23	0.23	0.25	0.25	0.22
31	0.27	---	0.25	---	0.22	---	0.22	0.23	---	0.25	---	0.22
Total	7.64	7.21	7.96	7.5	7.24	6.11	6.25	7.47	6.74	7.64	7.71	7.3
Mean	0.25	0.26	0.26	0.25	0.23	0.2	0.2	0.24	0.22	0.25	0.26	0.24
Max	0.27	0.27	0.27	0.28	0.26	0.22	0.22	0.27	0.23	0.27	0.28	0.26
Min	0.23	0.25	0.25	0.24	0.22	0.2	0.18	0.22	0.22	0.23	0.23	0.22
Med	0.25	0.26	0.25	0.25	0.23	0.2	0.2	0.25	0.22	0.25	0.26	0.23
Acre-ft	15	14	16	15	14	12	12	15	13	15	15	14
Calendar year 2014	Total 86.77		Mean 0.24		Max 0.28	Min 0.18	Median 0.24		Acre-ft 172			

Table 13.—Continued

C. Discharge, in cubic feet per second, calendar year 2015 Daily mean values												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.23	0.32	0.44	0.41	0.36	0.28	e0.25	e0.25	e0.21	0.19	e0.28	e0.30
2	0.22	0.32	0.44	0.43	0.36	0.28	e0.25	e0.25	e0.21	0.19	e0.28	0.3
3	0.22	0.32	0.46	0.42	0.38	0.28	e0.26	e0.25	e0.23	0.19	e0.28	e0.30
4	0.22	0.33	0.47	0.41	0.38	0.27	e0.27	e0.25	e0.21	0.19	e0.27	e0.30
5	0.22	0.34	0.48	0.41	0.37	0.27	e0.27	e0.25	e0.22	0.2	e0.28	e0.30
6	0.22	0.34	0.48	0.41	0.36	0.27	e0.26	e0.24	e0.22	0.26	e0.28	e0.30
7	0.22	0.34	0.48	0.4	0.36	0.26	e0.25	e0.23	e0.22	0.24	e0.28	e0.30
8	0.23	0.36	0.46	0.38	0.36	0.25	e0.27	e0.23	e0.22	0.24	e0.28	e0.30
9	0.23	0.36	0.44	0.38	0.36	0.25	e0.27	e0.24	e0.21	0.23	e0.28	e0.30
10	0.23	0.36	0.45	0.38	0.33	0.25	e0.26	e0.25	e0.20	0.23	e0.28	e0.30
11	0.25	0.38	0.45	0.38	0.32	0.25	e0.26	e0.25	e0.21	0.23	e0.28	e0.30
12	0.25	0.38	0.45	0.38	0.32	0.25	e0.26	e0.23	e0.22	0.23	e0.28	e0.30
13	0.25	0.38	0.47	0.36	0.31	0.25	e0.26	e0.23	e0.22	0.22	e0.28	e0.30
14	0.24	0.39	0.48	0.37	0.32	0.27	e0.25	e0.23	e0.21	0.23	e0.28	e0.29
15	0.25	0.4	0.49	0.38	0.33	0.25	e0.26	e0.23	e0.20	0.24	e0.28	e0.30
16	0.25	0.38	0.46	0.38	0.34	0.25	e0.26	e0.23	e0.20	0.23	e0.28	e0.30
17	0.25	0.38	0.45	0.38	0.34	0.25	e0.26	0.23	e0.20	0.25	e0.28	e0.30
18	0.27	0.4	0.45	0.38	0.32	0.24	e0.27	e0.23	e0.20	0.25	e0.28	e0.30
19	0.27	0.41	0.44	0.37	0.32	0.23	e0.27	e0.23	e0.21	0.25	e0.28	e0.30
20	0.27	0.41	0.43	0.36	0.34	0.23	e0.25	e0.23	e0.21	0.24	e0.28	e0.30
21	0.28	0.41	0.43	0.37	0.32	0.23	e0.25	e0.23	e0.20	0.25	e0.28	e0.30
22	0.28	0.43	0.43	0.38	0.32	0.22	e0.24	e0.23	e0.20	0.27	e0.30	e0.30
23	0.28	0.43	0.43	0.36	0.3	0.22	e0.23	e0.22	e0.20	0.27	e0.30	e0.30
24	0.29	0.41	0.43	0.35	0.3	0.22	e0.25	e0.22	0.18	0.28	e0.30	e0.30
25	0.3	0.39	0.43	0.35	0.3	e0.25	e0.26	e0.22	0.18	0.28	e0.30	e0.30
26	0.3	0.38	0.41	0.34	0.3	e0.27	e0.25	e0.23	0.18	0.28	e0.30	e0.30
27	0.3	0.39	0.41	0.37	0.29	e0.27	e0.25	e0.23	0.17	0.28	e0.30	e0.30
28	0.31	0.44	0.41	0.38	0.3	e0.27	e0.25	e0.23	0.18	e0.27	e0.30	e0.30
29	0.32	---	0.41	0.38	0.3	e0.26	e0.25	e0.22	0.18	e0.28	e0.30	e0.30
30	0.3	---	0.41	0.36	0.3	e0.26	e0.25	e0.22	0.19	e0.28	e0.30	e0.30
31	0.29	---	0.41	---	0.3	---	e0.24	e0.22	---	e0.28	---	e0.30
Total	8.04	10.58	13.78	11.41	10.21	7.6	7.93	7.23	6.09	7.55	8.57	9.29
Mean	0.26	0.38	0.44	0.38	0.33	0.25	0.26	0.23	0.2	0.24	0.29	0.3
Max	0.32	0.44	0.49	0.43	0.38	0.28	0.27	0.25	0.23	0.28	0.3	0.3
Min	0.22	0.32	0.41	0.34	0.29	0.22	0.23	0.22	0.17	0.19	0.27	0.29
Med	0.25	0.38	0.44	0.38	0.32	0.25	0.26	0.23	0.2	0.24	0.28	0.3
Acre-ft	16	21	27	23	20	15	16	14	12	15	17	18
Calendar year 2015	Total 108.28		Mean 0.3		Max 0.49	Min 0.17	Median 0.28		Acre-ft 215			

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	---

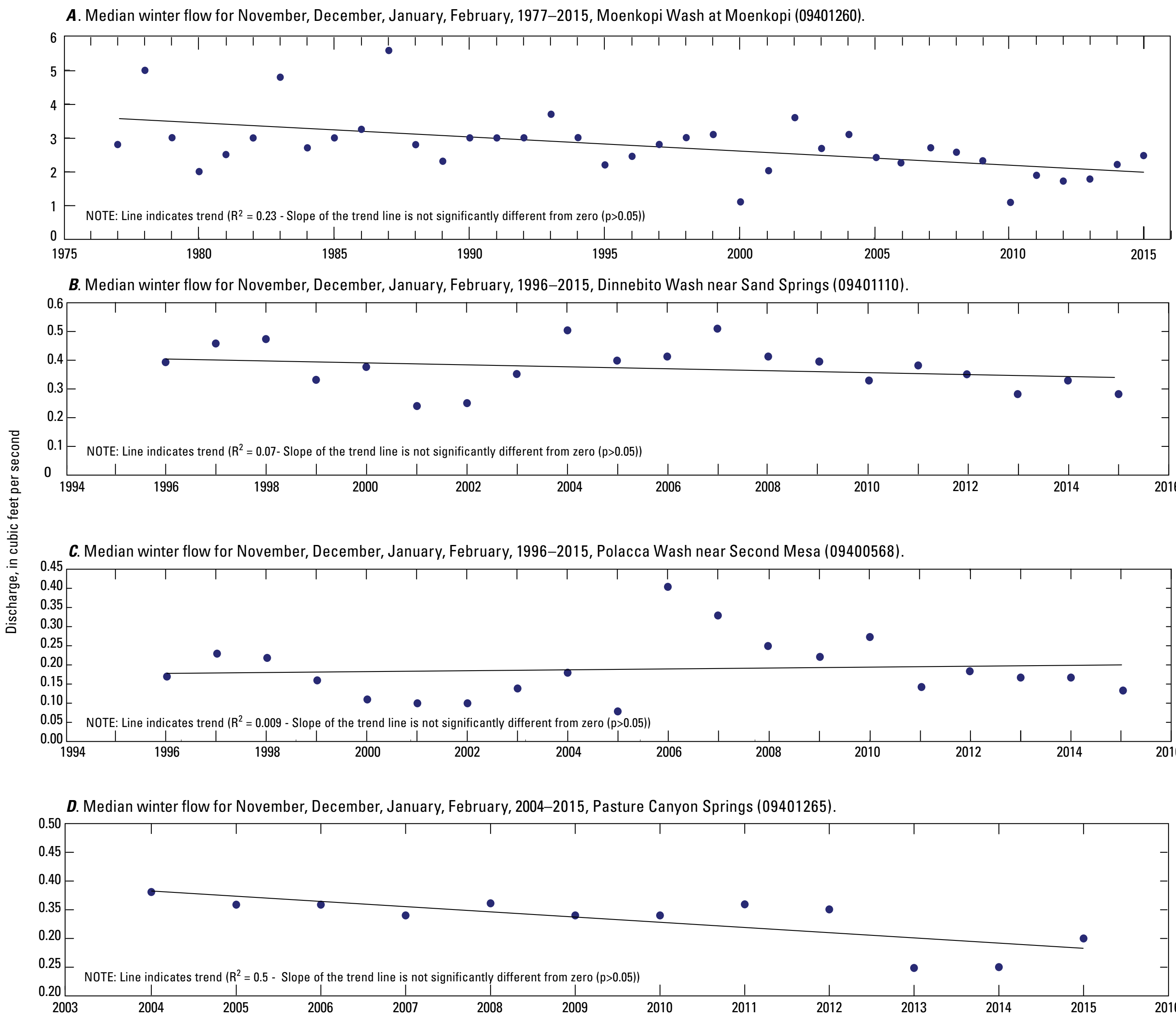


Figure 10. Plots of median winter flow for November, December, January, and February for water years 1977–2015 for *A*, Moenkopi Wash at Moenkopi (09401260); *B*, Dinnebito Wash near Sand Springs (09401110); *C*, Polacca Wash near Second Mesa (09400568); and *D*, Pasture Canyon Springs (09401265), Black 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. Trend lines were generated by using the method of least squares.

Water Chemistry

Water samples for water-chemistry analyses are mostly collected each year from selected wells and springs as part of the Black Mesa monitoring program. Field measurements are made and water samples are analyzed for major ions, trace elements, nutrients, 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, 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, trace element, 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.

Quality control samples were collected as part of the water-quality sampling of the Black Mesa monitoring program in 2014. A field blank sample was collected during collection of field water-quality samples. The field blank was processed at Moenkopi School Spring during the collection of an environmental sample. Concentrations of analytes in the field blank were below the NWQL reporting limit with the exception of fluoride which was right at the reporting limit (table 15).

Water-chemistry samples have been collected from the same four springs annually (Moenkopi School Spring, Pasture Canyon Spring, Unnamed spring near Dennehotso, and Burro Spring), and in 2014 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 available 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. 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.

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

In 2014, water samples were collected from Burro Spring, Moenkopi School Spring, Pasture Canyon Spring, and Unnamed Spring near Dennehotso (figs. 8 and 11). Geologic maps and field observations indicate that 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

Table 15. Physical properties and chemical analyses of a field blank water sample from the Black Mesa monitoring program, 2014.

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

U.S. Geological Survey identification number— 360632111131101
Common well name—Moenkopi School Spring
August 27, 2014

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)
--	E10	E6.4	--	<0.04	<0.004	[1]0.03	<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 (µg/L as As)	Boron (µg/L as B)	Iron (µg/L as Fe)	Solids, residue at 180°C (mg/L)
<0.06	<0.02	0.02	[1]0.07	<0.02	<0.10	[1]3.8	<4.0	<20

[1]Below lab reporting level above minimum detection level.

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. 11 and table 16). Dissolved solid concentrations measured 360 mg/L at Burro Spring, 226 mg/L at Moenkopi School Spring, 149 mg/L at Pasture Canyon Spring, and 122 mg/L at Unnamed Spring near Dennehotso (tables 16 and 17). Concentration of chloride was highest at Moenkopi School Spring (28.5 mg/L; tables 16 and 17). Concentration of sulfate was highest at Burro Spring (64.6 mg/L; tables 16 and 17). Concentrations of all the analyzed constituents in samples from all four springs were less than current EPA maximum contaminant levels (MCLs) and secondary maximum contaminant levels (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 17 and fig. 12). Concentrations of the same constituents in Pasture Canyon Spring, Burro Spring, and Unnamed Spring near Dennehotso did not show any significant trends (table 17 and fig. 12). However, in 2010, 2011, and 2012, Unnamed Spring near Dennehotso showed an increase in dissolved solid concentrations which may be the result of sampling from an alternate sample location. In 2013 and 2014, Unnamed Spring near Dennehotso was sampled from the same location that was used prior to 2010 and the results for dissolved solids analysis returned to levels observed prior to 2010 (fig. 12).

Table 16. Physical properties and chemical analyses of water samples from four springs in the Black Mesa area, northeastern Arizona, in 2014.

[°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)	Orthophosphate (mg/L as P)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Potassium (mg/L as K)
354156110413701	6M-31	Burro Spring	9/2/14	24.0	549	7.7	192	<0.04	0.006	57.9	4.42	0.40
360632111131101	3GS-77-6	Moenkopi School Spring	8/27/14	19.1	382	6.9	103	2.22	0.005	37.2	8.25	1.48
361021111115901	3A-5	Pasture Canyon Spring	8/27/14	16.9	249	7.6	81.7	4.4	0.014	30.9	4.87	1.47
364656109425400	8A-224	Unnamed Spring near Dennehotso	9/3/14	15.0	160	7.4	75.8	1.9	0.030	28.2	4.30	1.20

U.S. Geological Survey identification number	Bureau of Indian Affairs site number	Common spring name	Date of samples	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 (µg/L as As)	Boron (µg/L as B)	Iron (µg/L as Fe)	Solids, residue at 180°C (mg/L)
354156110413701	6M-31	Burro Spring	9/2/14	61.2	22.8	0.37	17.1	64.6	0.92	79	14.4	360
360632111131101	3GS-77-6	Moenkopi School Spring	8/27/14	30.3	28.5	0.17	13.6	34.6	2.3	39	<4	226
361021111115901	3A-5	Pasture Canyon Spring	8/27/14	13.1	5.03	0.16	9.88	17.2	1.7	31	8.0	149
364656109425400	8A-224	Unnamed Spring near Dennehotso	9/3/14	4.85	2.68	0.14	12.9	7.4	2.5	16	11.5	122

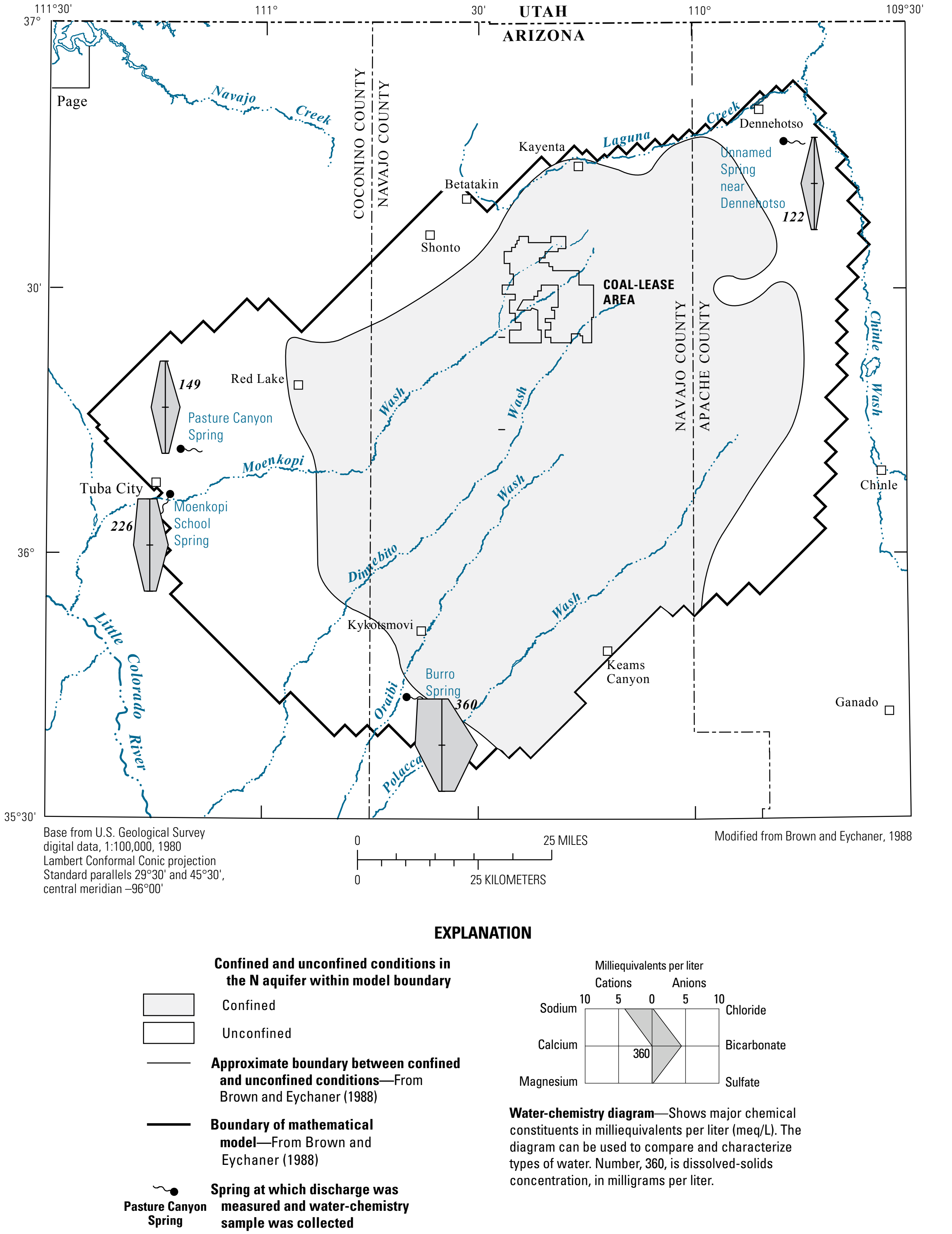


Figure 11. Map showing water chemistry and distribution of dissolved solids in the N aquifer, Black Mesa area, northeastern Arizona, 2014.

Table 17. Specific conductance and concentrations of selected chemical constituents in N-aquifer water samples from four springs in the Black Mesa area, northeastern Arizona, 1948–2014.

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

Year	Specific conductance, field (µS/cm)	Dissolved		
		Solids, residue at 180°C (mg/L)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)
		Burro Spring		
1989	485	308	22.0	59
1990	[1]545	347	23.0	65.0
1993	595	368	30.0	85.0
1994	[1]597	368	26.0	80.0
1996	525	324	23.0	62.0
1997	[1]511	332	26.0	75.0
1998	504	346	24.6	70.4
1999	545	346	24.8	69.2
2001	480	348	23.6	67.8
2002	591	374	30.6	77.0
2003	612	374	30.5	81.1
2004	558	337	24.9	63.6
2005	558	357	25.8	68.9
2006	576	359	25.0	68.2
2009	577	372	25.7	72.5
2010	583	355	25.9	71.5
2011	560	353	25.7	69.5
2012	553	330	23.1	64.7
2013	560	350	24.4	67.7
2014	549	360	22.8	64.6
		Moenkopi School Spring		
1952	222	---	6	---
1987	270	161	12.0	19.0
1988	270	155	12.0	19.0
1991	297	157	14.0	20.0
1993	313	204	17.0	27.0
1994	305	182	17.0	23.0
1995	314	206	18.0	22.0
1996	332	196	19.0	26.0
1997	[1]305	185	17.8	23.8
1998	296	188	17.6	23.7
1999	305	192	18.7	25.6
2001	313	194	18.3	25.5
2002	316	191	18.3	23.1
2003	344	197	18.6	23.4
2004	349	196	19.1	21.3
2005	349	212	23.3	29.6
2006	387	232	27.2	34.2
2007	405	238	30.6	39.9
2008	390	230	28.3	37.6
2009	381	240	27.0	35.4
2010	480	217	26.2	33.4
2011	374	216	28.5	36.2
2012	382	218	27.5	33.3
2013	370	220	27.2	33.3
2014	382	226	28.5	34.6

Table 17.—Continued

Year	Specific conductance, field (µS/cm)	Dissolved		
		Solids, residue at 180°C (mg/L)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)
Pasture Canyon Spring				
1948	[1]227	([2])	6.0	13
1982	240	---	5.1	18.0
1986	257	---	5.4	19.0
1988	232	146	5.3	18.0
1992	235	168	7.10	17.0
1993	242	134	5.3	17.0
1995	235	152	4.80	14.0
1996	238	130	4.70	15.0
1997	232	143	5.27	16.9
1998	232	147	5.12	16.2
1999	235	142	5.06	14.2
2001	236	140	5.06	17.0
2002	243	143	5.14	16.5
2003	236	151	5.09	16.1
2004	248	150	5.50	16.4
2005	250	149	5.07	16.3
2008	240	149	5.01	18.3
2009	241	160	5.10	18.6
2010	314	157	5.25	17.9
2011	236	146	5.47	18.5
2012	248	142	5.20	17.5
2013	245	145	5.16	17.7
2014	249	149	5.03	17.2
Unnamed Spring near Dennehotso				
1984	195	112	2.8	7.1
1987	178	[2]109	3.4	7.5
1992	178	108	3.60	7.30
1993	184	100	3.2	8.00
1995	184	124	2.60	5.70
1996	189	112	2.80	8.20
1997	[1]170	98	2.40	6.10
1998	179	116	2.43	5.36
1999	184	110	2.76	6.30
2001	176	116	2.61	5.96
2002	183	104	2.67	7.38
2003	180	118	2.95	7.16
2004	170	117	2.72	5.05
2005	194	114	2.65	8.67
2010	259	155	9.38	15.5
2011	292	172	14.5	24.1
2012	298	179	13.5	21.9
2013	196	127	3.06	8.24
2014	160	122	2.68	7.40

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

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

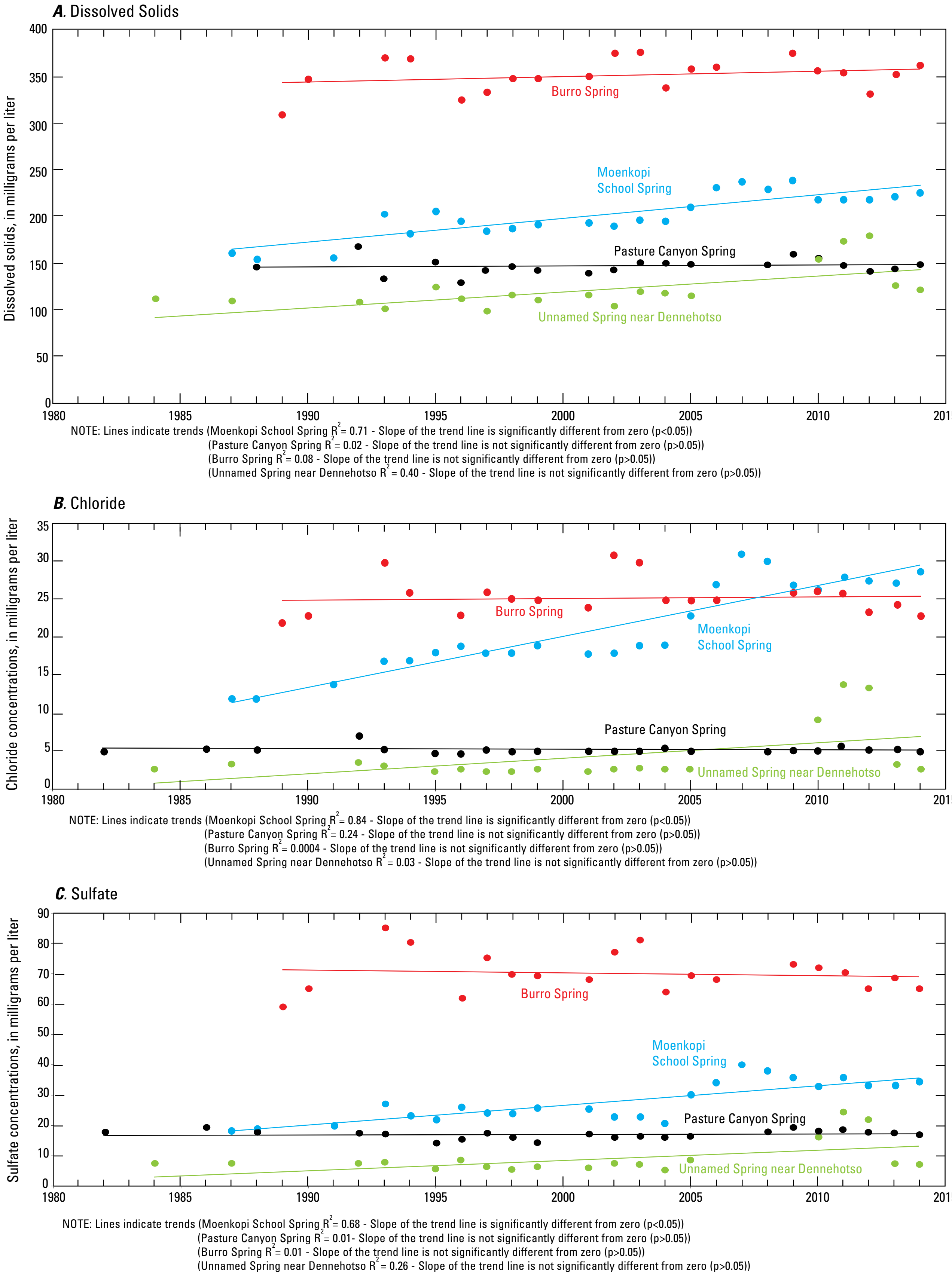


Figure 12. Plots of concentrations of dissolved solids, chloride, and sulfate for water samples from Moenkopi School Spring, Pasture Canyon Spring, Burro Spring, and Unnamed Spring near Dennehotso, which discharge from the N aquifer in Black Mesa area, northeastern Arizona, measured from 1982 to 2014. *A*, Dissolved solids; *B*, chloride; and *C*, sulfate. Trend lines were generated using the method of least squares.

Summary

The N aquifer is an extensive aquifer and 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 16 inches per year. This report presents results of groundwater, surface-water, and water-chemistry monitoring in the Black Mesa area from January 2013 to December 2015. The monitoring data for 2013–15 are compared to historical data from the 1950s to December 2015.

In 2013, total groundwater withdrawals were 3,980 acre-ft, in 2014 total withdrawals were 4,170 acre-ft, and in 2015 total withdrawals were 3,970 acre-ft. From 2013 to 2015 total withdrawals varied by less than 5 percent.

From 2014 to 2015, annually measured groundwater levels declined in 12 of 31 wells available for comparison. The median water-level change for the 31 wells was 0.1 ft. In unconfined areas of the N aquifer, water levels declined in 9 of 15 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 3 of 16 wells, and the median change was 0.6 ft. From the prestress period (before 1965) to 2015, the median groundwater-level change in 34 wells was -13.2 ft. Water levels in the 16 wells in the unconfined areas of the N aquifer had a median change of -1.7 ft, and the changes ranged from -49.5 ft to +10.1 ft. Water levels in the 18 wells in the confined area of the N aquifer had a median change of -42.3 ft, and the changes ranged from -196.1 ft to +18.0 ft.

Discharge has been measured annually at Moenkopi School Spring and Pasture Canyon Spring and intermittently at Burro Spring and Unnamed Spring near Dennehotso. 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.

Four streamflow-gaging stations—Moenkopi Wash, Dinnebito Wash, Pasture Canyon Springs, and Polacca Wash—varied during the periods of record and 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 2014, water samples were collected from four springs and analyzed for selected chemical constituents. Dissolved-solids concentrations in water samples from Burro Spring, Moenkopi School Spring, Pasture Canyon Spring, and Unnamed Spring near Dennehotso were 360 mg/L, 226 mg/L, 149 mg/L, and 122 mg/L, respectively. From the mid-1980s to 2014, long-term data from Moenkopi School Spring indicate increasing concentrations of dissolved solids, chloride, and sulfate. Concentrations of dissolved solids, chloride, and sulfate from Pasture Canyon Spring, Burro Spring, and Unnamed Spring near Dennehotso do not indicate a trend for the period of record.

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