U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1998

Open-File Report 00–66

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

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By Margot Truini, B.M. Baum, G.R. Littin, *and* Gayl Shingoitewa-Honanie

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Tucson, Arizona
2000

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/day)	0.003785	cubic meter per day

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the solute mass (milligrams) per unit of volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter.

For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C). Chemical concentrations in streambed sediment are given in micrograms per gram (μg/g) or micrograms per kilogram (μg/kg). Micrograms per gram is equal to parts per million (ppm). Micrograms per kilograms is equal to parts per billion (ppb).

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called “Sea Level Datum of 1929”.

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Abstract

The Black Mesa monitoring program is designed to document long-term effects of ground-water pumping from the N aquifer by industrial and municipal users. The N aquifer is the major source of water in the 5,400-square-mile Black Mesa area, and the ground water occurs under confined and unconfined conditions. Monitoring activities include continuous and periodic measurements of (1) ground-water pumpage from the confined and unconfined parts of the aquifer, (2) ground-water levels in the confined and unconfined parts of the aquifer, (3) surface-water discharge, (4) flowmeter tests, and (5) ground-water and surface-water chemistry.

In 1998, ground-water withdrawals for industrial and municipal use totaled about 7,060 acre-feet, which is less than a 1 percent decrease from 1997. Pumpage from the confined part of the aquifer decreased by less than 1 percent to 5,470 acre-feet, and pumpage from the unconfined part of the aquifer increased by less than 1 percent to 1,590 acre-feet. Water-level declines in the confined part of the aquifer were recorded in 10 of 14 wells during 1998, and the median change from 1997 was a decline of 3.0 feet as opposed to a rise of 0.2 feet for the change from 1996 to 1997. Water-level declines in the unconfined part of the aquifer were recorded in 9 of 16 wells, and the median change from 1997 was 0.0 feet, which is the same as the median change from 1996 to 1997.

Of the 35 pumpage meters on municipal wells that were tested, the difference between metered and tested discharge ranged from +6.3 to -19.6 percent. The average difference was about -3.4 percent. Five of the meters exceeded the allowable difference (10 percent) and should be repaired or replaced.

The low-flow discharge at the Moenkopi streamflow-gaging station ranged from 2.6 to 4.7 cubic feet per second in 1998. Streamflow-discharge measurements also were made at Laguna Creek, Dinnebito Wash, and Polacca Wash during 1998. The low-flow discharge ranged from 0.41 to 5.1 cubic feet per second at Laguna Creek, 0.32 to 0.44 cubic feet per second at Dinnebito Wash, and 0.13 to 0.36 cubic feet per second at Polacca Wash. Discharge was measured at four springs. Discharge from Moenkopi School Spring decreased by about 1.1 gallons per minute from the measurement in 1997. Discharge from an unnamed spring near Dennehotso decreased by 4.6 gallons per minute from the measurement made in 1997. Discharge increased slightly at Burro Spring and decreased by about 1 gallon per minute at Pasture Canyon Spring. Regionally, long-term water-chemistry data for wells and springs have remained stable.

INTRODUCTION

The N aquifer is the major source of water for industrial and municipal users in the 5,400-square-mile Black Mesa area (**fig. 1**) and the ground water occurs under confined and unconfined conditions. The aquifer consists of three rock formations—the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Member[1] of the Wingate Sandstone—which are all of early Jurassic age (Peterson, 1988). These formations are hydraulically connected and function as a single aquifer referred to as the N aquifer (**fig. 2**).

Total withdrawals for industrial and municipal use from the N aquifer in the Black Mesa area generally have increased during the last 33 years (**table 1**). Peabody Coal Company began operating a strip mine in the northern part of the mesa in 1968. The quantity of water pumped by the company increased from about 100 acre-feet (acre-ft) in 1968 to a maximum of 4,740 acre-ft in 1982. The quantity of water pumped in 1998 was 4,030 acre-ft. Withdrawals from the N aquifer for municipal use increased from an estimated 250 acre-ft in 1968 to a maximum of 4,500 acre-ft in 1991 and was 3,030 acre-ft in 1998.

The Navajo Nation and Hopi Tribe have been concerned about the long-term effects of industrial withdrawals from the N aquifer on water supplies for domestic and municipal purposes. These concerns led to an investigation of the water resources of the Black Mesa area in 1971 by the U.S. Geological Survey (USGS) in cooperation with the Arizona Department of Water Resources; in 1983, the Bureau of Indian Affairs joined the cooperative effort. Since 1983, the Navajo Tribal Utility Authority (NTUA); Peabody Coal Company; the Hopi Tribe; and the Western Navajo Agency, Chinle Agency, and Hopi Agency of the Bureau of Indian Affairs have assisted in the collection of ground-water data.

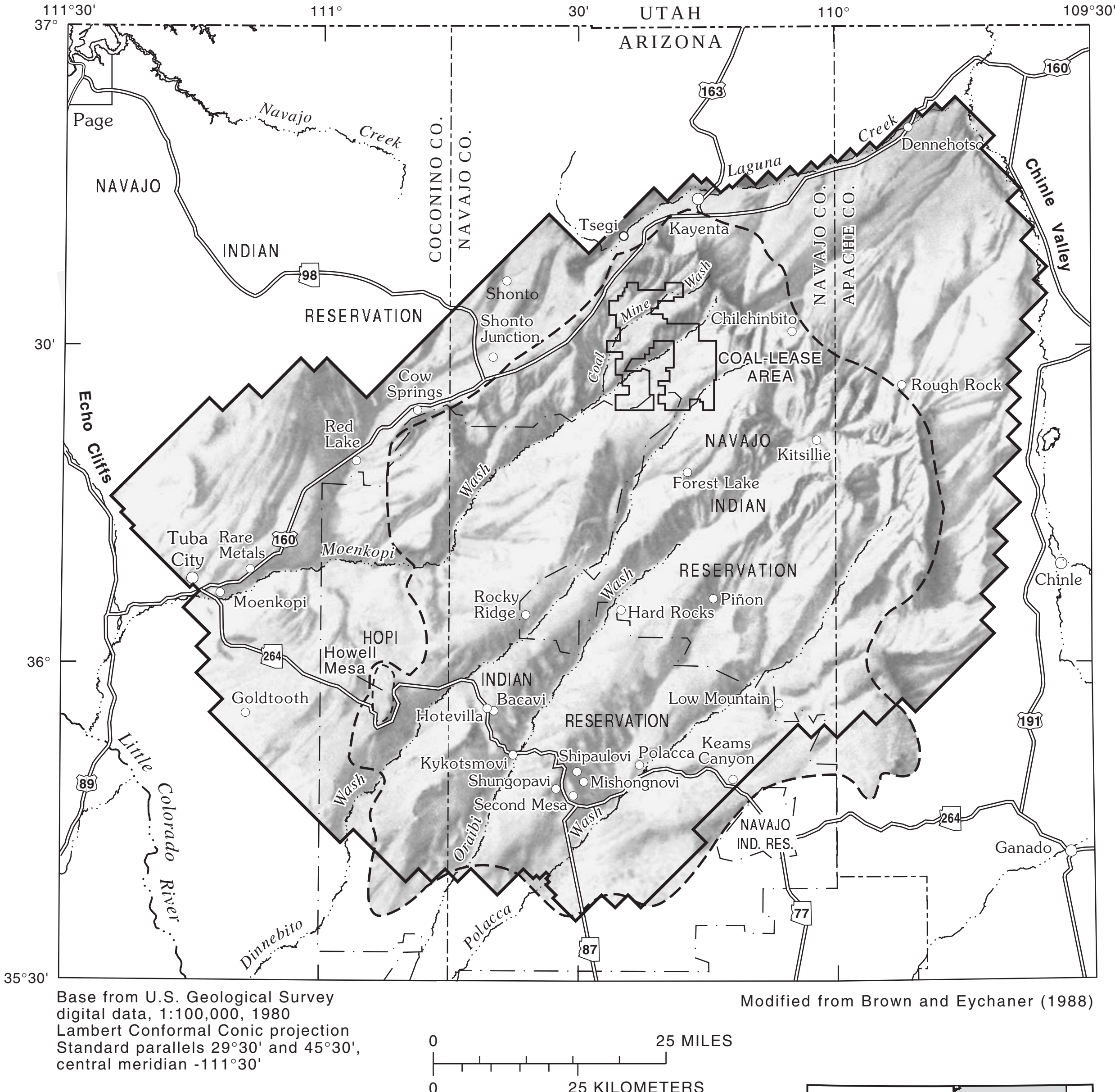
Purpose and Scope of the Report

This report describes the results of ground-water, surface-water, and water-chemistry monitoring in the Black Mesa area from January to December 1998. The monitoring is designed to determine the effects of industrial and municipal pumpage from the N aquifer on water levels, stream and spring discharge, and water chemistry. Data-collection efforts include continuous and periodic measurements of ground water and surface water in the Black Mesa area and periodic flowmeter tests. Every 3 years flowmeter tests are made to ensure the quality of reported and metered pumpage from wells. Ground-water data from wells completed in the N aquifer include pumpage, water levels, and water chemistry. Surface-water data include discharge measurements at four continuous-record streamflow-gaging stations and four springs, and water chemistry for selected springs.

Previous Investigations

Sixteen progress reports have been prepared by the U.S. Geological Survey on the monitoring phase of the program (U.S. Geological Survey, 1978; G.W. Hill, hydrologist, written commun., 1982, 1983; Hill, 1985; Hill and Whetten, 1986; Hill and Sottilare, 1987; Hart and Sottilare, 1988, 1989; Sottilare, 1992; Littin, 1992, 1993; Littin and Monroe, 1995a, b; and Littin and Monroe, 1996, 1997; and Littin, Baum, and Truini, 1999). Most of the data obtained from the monitoring program are contained in these reports except for stream-discharge and sediment-discharge data from Moenkopi Wash collected before the 1986 water year; those data were published in U.S. Geological Survey (1963–64a, b; 1965–74a, b; and 1976–83); and White and Garrett (1984, 1986, 1987, and 1988). Eychaner (1983) describes the results of mathematical-model simulations of the flow of ground water in the N aquifer. The model was converted to a new model program and recalibrated by using revised estimates of selected aquifer characteristics and a finer spatial grid (Brown and Eychaner, 1988). Kister and Hatchett (1963) and Lopes and Hoffman (1997) show selected chemical analyses of ground water from wells and springs throughout the Navajo and Hopi Indian Reservations. Cooley and others (1969) provide a detailed description of the regional hydrogeology.

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



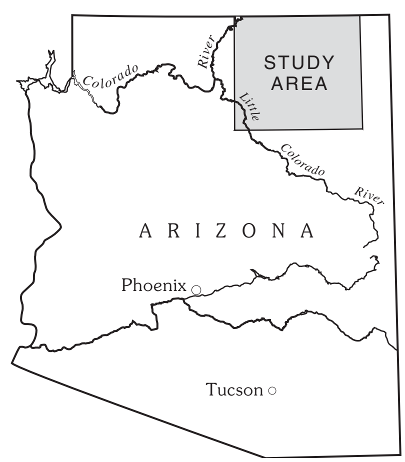


Figure 1. Location of study area.

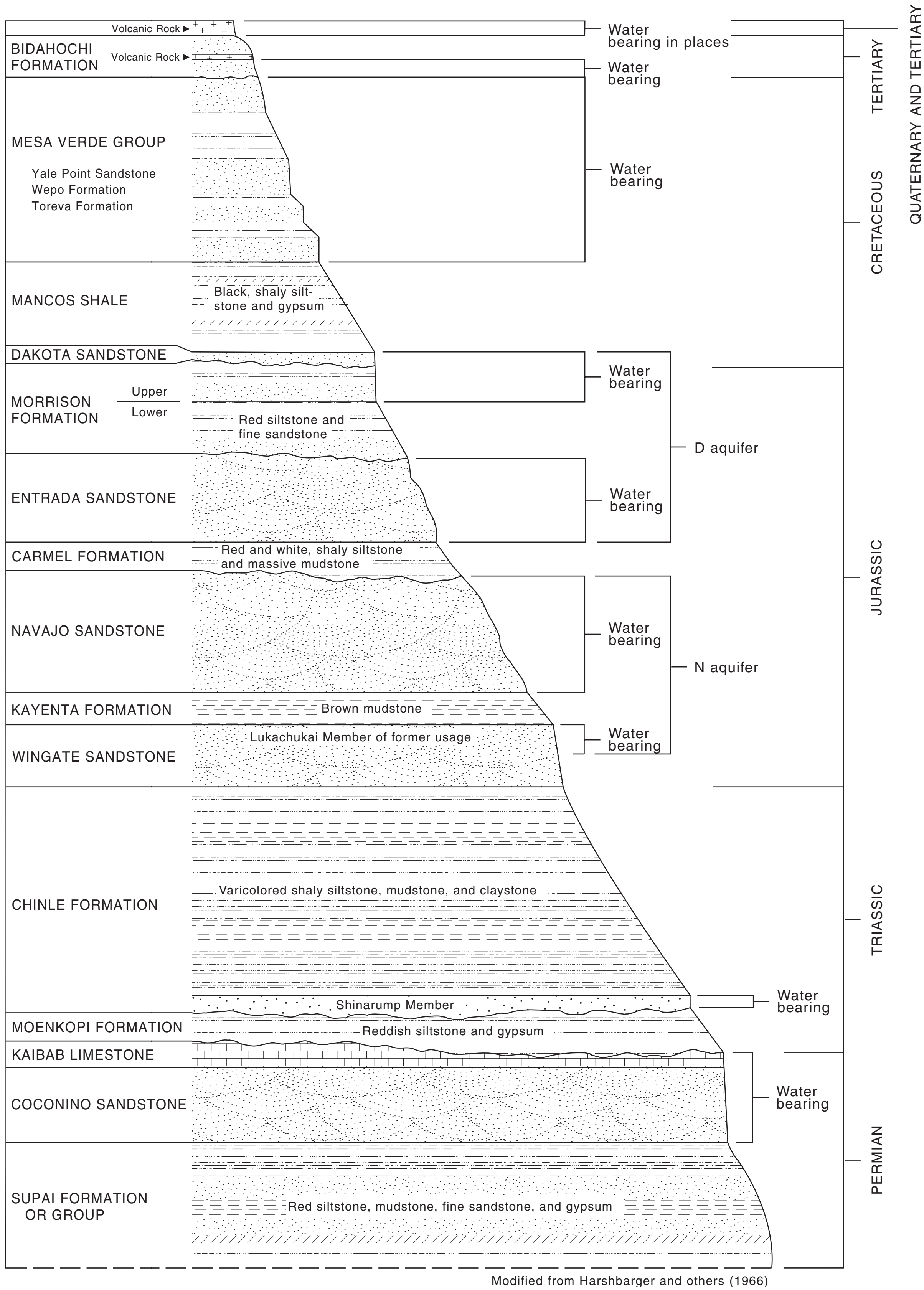


Figure 2. Rock formations of the Black Mesa area, Arizona. The N aquifer is approximately 1,000 feet thick.

Table 1. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–98

[Values are rounded to nearest 10 acre-feet. Data for 1965–79 from Eychaner (1983)]

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

NOTE: Total withdrawals in Littin and Monroe (1996) were for the confined part of the aquifer.

[1]Metered pumpage from the confined part of the aquifer by Peabody Coal Company at its mine on Black Mesa.

[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, 1986–98.

HYDROLOGIC-DATA COLLECTION

In 1998, activities of the monitoring program included metering and estimating ground-water withdrawals, measuring depth to ground water, measuring streamflow and spring flow, collecting and analyzing water samples from wells and springs, and checking the accuracy of metered discharge from municipal wells. Ground-water withdrawal data, continuous-record water-level data from observation wells, and surface-water discharge data were collected from January to December 1998. Annual ground-water levels generally were measured between November and December 1998. Some water levels were measured during the first quarter of 1999 because of adverse weather and field conditions. Chemical data are from ground-water and spring-flow samples collected in December 1998.

Withdrawals from the N Aquifer

Withdrawals from the N aquifer are separated into three categories—(1) industrial use from the confined part of the aquifer, (2) municipal use from the confined part of the aquifer, and (3) municipal use from the unconfined part of the aquifer (**table 1**, fig. 3). The industrial category includes eight wells at the Peabody Coal Company well field in northern Black Mesa (**fig. 4**). The Bureau of Indian Affairs, Navajo Tribal Utility Authority, and the Hopi Tribe operate about 70 municipal wells that are in categories 2 and 3. Withdrawals from wells equipped with windmills are neither measured nor estimated.

Withdrawals from the N aquifer were compiled on the basis of metered and estimated data (**tables 1** and **2**). In some areas, only partial data were available because of meter malfunctions, and pumpage was either prorated, based on electrical usage, or computed on a per capita basis of 40 gallons per day (gal/d). The per capita consumption is based on pumpage data and population figures (Arizona Department of Economic Security, Population statistics of the Navajo and Hopi Reservations, 1990 census, unpublished data, 1991) for areas without commercial water use.

The total ground-water withdrawal in 1998 was about 7,060 acre-ft (table 1), which is less than a 1 percent decrease from the total withdrawal in 1997. Pumpage from the confined part of the aquifer decreased by less then 1 percent to 5,470 acre-ft and pumpage from the unconfined part of the aquifer increased by less than 1 percent to 1,590 acre-ft. Industrial pumpage accounted for 4,030 acre-ft, or 57 percent of the total withdrawal, as compared to 58 percent in 1997. Municipal pumpage accounted for 3,030 acre-ft and represents 43 percent of the total withdrawal as compared to 42 percent in 1997.

In an effort to improve and ensure accuracy of withdrawal data, a quality-assurance program was begun in 1985 for data from industrial and municipal wells that penetrate the N aquifer. Nearly all industrial and municipal wells in the study area are equipped with totalizing flowmeters to measure ground-water withdrawals. Meters on all the municipal wells were tested using a Rockwell mechanical flowmeter. The flowmeter was attached to the discharge bypass at each site and the average was taken of three readings made after discharge stabilized. Results were compared with the permanent well flowmeter readings (**table 3**). Measurements made in December 1998 represent about one half of the municipal wells that need to be tested. Results from the remaining one half of the wells to be tested are planned for publication in a future report. For the purposes of the monitoring study, the allowable difference between the discharge measured by the permanent flowmeter and discharge measured by the test meter is 10 percent.

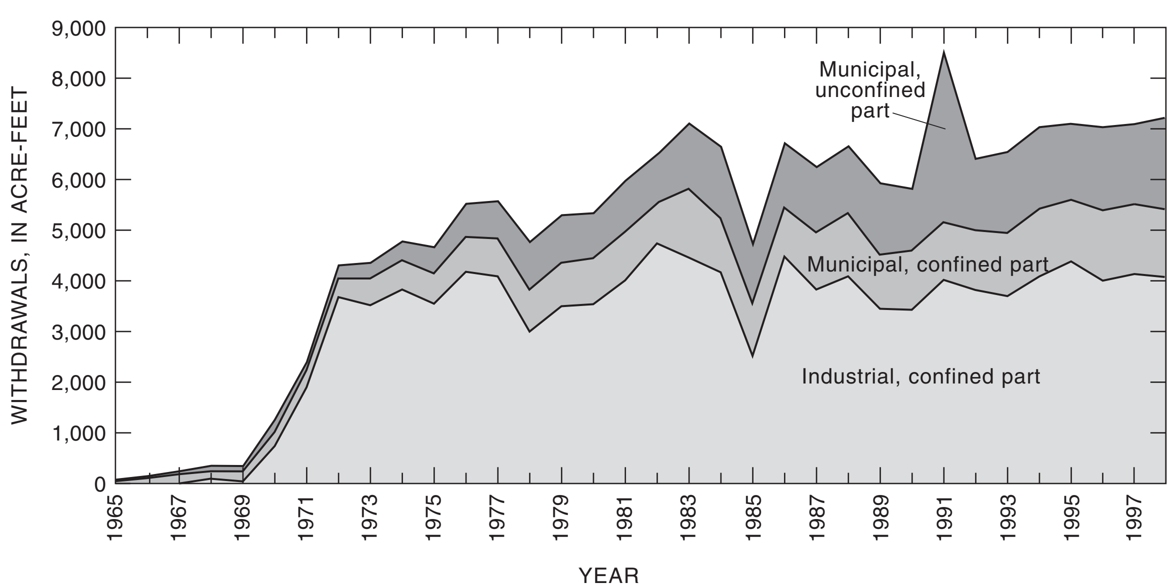


Figure 3. Withdrawals from the N aquifer, Black Mesa area, Arizona, 1965–98.

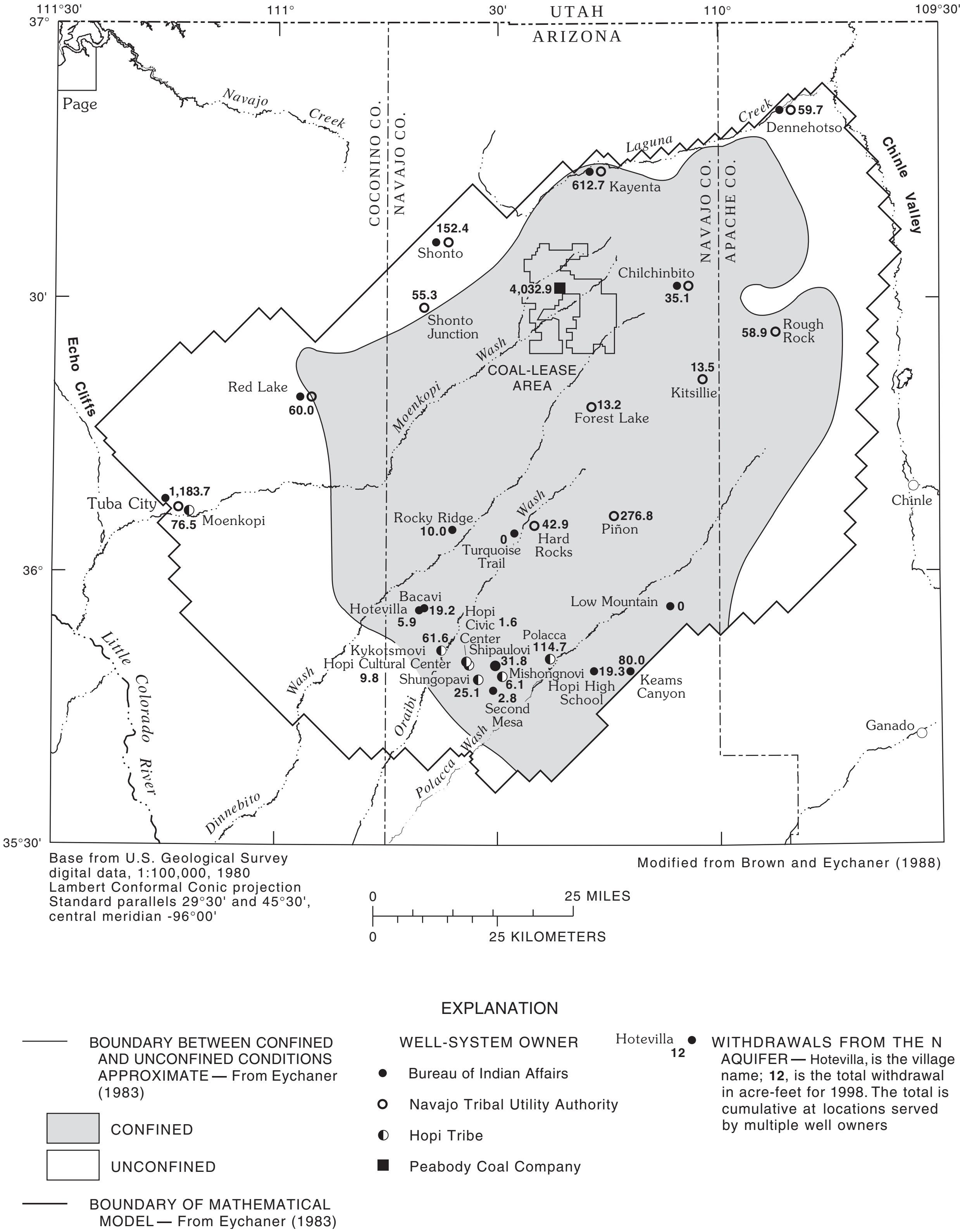


Figure 4. Location of well systems monitored for withdrawals from the N aquifer, Black Mesa area, Arizona, 1998.

Table 2. Withdrawals from the N aquifer by well system, Black Mesa area, Arizona, 1998

[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 Coal Company; Hopi, Hopi Village Administrations; BIA Roads, Bureau of Indian Affairs, Division of Roads]

Well system (one or more wells)	Owner	Source of data	Withdrawals		Well system (one or more wells)	Owner	Source of data	Withdrawals	
			Confined aquifer	Unconfined aquifer				Confined aquifer	Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	4.0		Kayenta	NTUA	NTUA	539.9	
Dennehotso	BIA	USGS/BIA		20.2	Kitsillie	NTUA	NTUA	13.5	
Hopi High School	BIA	USGS/BIA	19.3		Piñon	NTUA	NTUA	276.8	
Hotevilla	BIA	USGS/BIA	5.9		Red Lake	NTUA	NTUA		55.7
Kayenta	BIA	USGS/BIA	72.8		Rough Rock	NTUA	NTUA	27.4	
Keams Canyon	BIA	USGS/BIA	80.0		Shonto	NTUA	NTUA		14.4
Low Mountain	BIA	USGS/BIA	[1]0		Shonto Junction	NTUA	NTUA		55.3
Piñon	BIA	USGS/BIA	[1]0		Tuba City	NTUA	NTUA		968.7
Red Lake	BIA	USGS/BIA		6.3	Mine Well Field	Peabody	Peabody	[2]4,032.9	
Rocky Ridge	BIA	USGS/BIA	10.0		Bacavi	Hopi	USGS/Hopi	19.2	
Rough Rock	BIA	USGS/BIA	31.5		Hopi Civic Center	Hopi	USGS/Hopi	1.6	
Second Mesa	BIA	USGS/BIA	2.8		Hopi Cultural Center	Hopi	USGS/Hopi	9.8	
Shonto	BIA	USGS/BIA		138.0	Kykotsmovi	Hopi	USGS/Hopi	61.6	
Tuba City	BIA	USGS/BIA		215.0	Mishongnovi	Hopi	USGS/Hopi	6.1	
Turquoise Trail	BIA	BIA Roads	[1]0		Moenkopi	Hopi	USGS/Hopi		76.5
Chilchinbito	NTUA	NTUA	31.1		Polacca	Hopi	USGS/Hopi	[3]114.7	
Dennehotso	NTUA	NTUA		39.5	Shipaulovi	Hopi	USGS/Hopi	31.8	
Forest Lake	NTUA	NTUA	13.2		Shungopovi	Hopi	USGS/Hopi	25.1	
Hard Rocks	NTUA	NTUA	42.9						

1Well taken out of service.
[2] Industrial pumpage.
[3] Estimated. Well PM4 not metered. Total includes 74.7 acre-feet from wells 5 and 6 and may include D aquifer water. The 2.3 acre-feet from well 6 was used for construction purposes.

Table 3. Flowmeter-test results for municipal wells that tap the N aquifer, Black Mesa area, Arizona, 1998

[NA, not applicable]

Well name	Date tested	Pumping rate, in gallons per minute: Permanent meter	Pumping rate, in gallons per minute: Test meter[1]	Percent difference[2]	Name and number of permanent meter
Navajo Tribal Utility Authority					
Kayenta NTUA 2	01–06–99	95	98	-3.1	Rockwell 1312925
Kayenta NTUA 3	01–07–99	100	96	+4.2	Rockwell 1385421
Kayenta NTUA 4	01–07–99	278	273	+1.8	Rockwell (no serial number)
Kayenta NTUA 5	01–07–99	148	146	+1.4	Sensus 1412051
Red Lake NTUA 1	01–06–99	66	66	0.0	Sensus 1550832
Shonto NTUA 1	01–06–99	55	58	-5.2	Rockwell 28945149
Shonto Junction NTUA 1	01–06–99	103	103	0.0	Brooks 8403-23219-1-1
Shonto Junction NTUA 2	01–06–99	89	91	-2.2	Brooks 5044633
Tuba City NTUA 2	01–05–99	169	159	+6.3	Sparling 129709
Tuba City NTUA 3	01–05–99	162	162	0.0	Sparling 94420
Tuba City NTUA 4	01–05–99	182	192	-5.2	Sparling 126447
Tuba City NTUA 5	01–05–99	198	200	-1.0	Sparling 126189
Tuba City NTUA 6	01–05–99	375–380	Pumpage exceeded capacity of test meter		
Bureau of Indian Affairs					
Hopi High School #1	12–30–98	84	87	-3.4	Neptune 31625407
Hopi High School #2	12–30–98	56	58	-3.4	Neptune 31625415
Hopi High School #3	12–30–98	96	93	+3.2	Neptune 60067824
Hotevilla PM 1	01–04–99	44	44	0.0	Rockwell 36726381
Hotevilla PM 2	Well not in use				
Low Mountain PM 2	12–28–98	37	46	-19.6	Rockwell 3265870
Low Mountain PM 3	12–28–98	83	87	-4.6	Sparling 116800
Second Mesa PM 1	12–28–98	104	102	+2.0	Rockwell 32658703
Second Mesa PM 2	12–28–98	64	65	-1.5	Arad 029154
Tuba City PM 4	01–05–99	106	108	-1.9	Rockwell 1323857
Tuba City PM 5	01–05–99	83	92	-9.8	Rockwell 1305840
Tuba City PM 6	01–05–99	121	122	-0.8	Rockwell 1323856
Hopi Tribe					
Bacavi	12–23–98	68	68	0.0	Sensus 1403844
Hopi Civic Center	12–23–98	44	44	0.0	Rockwell 1323855
Cultural Center	12–17–98	49	50	-2.0	Rockwell 37078664
Hotevilla	12–21–98	40	48	-16.7	Sensus 1424710
Kykotsmovi PM 1	Well not in use				
Kykotsmovi PM 2	12–18–98	80	82	-2.4	Kent 77655836
Kykotsmovi PM 3	12–18–98	145	146	-0.7	Rockwell 1266317

See footnotes at end of table.

Table 3. Flowmeter-test results for municipal wells that tap the N aquifer, Black Mesa area, Arizona, 1998—Continued

Well name	Date tested	Pumping rate, in gallons per minute: Permanent meter	Pumping rate, in gallons per minute: Test meter[1]	Percent difference[2]	Name and number of permanent meter
Hopi Tribe—Continued					
Mishongnovi #1	12–28–98	10	12	-16.7	Precision E569880
Mishongnovi #2			Well not in use		
Moenkopi[3]	12–16–98	50	56	-10.7	Rockwell 36880398
Polacca PM5	01–04–99	170	198	-14.1	McCrometer 87-6-312
Polacca PM 6	01–04–99	175	188	-6.9	McCrometer 87-6-311
Polacca Day School	01–04–99	[4]72	Not tested	NA	No permanent meter
Shipaulovi	12–28–98	100	102	-2.0	Kent 88538743
Shungopovi	12–17–98	44	45	-2.2	Rockwell 25766390
Turquoise Trail			Well not in use		

[1]Sensus 125-W portable large meter tester.

[2]A positive difference indicates that the meter is registering more pumpage than is actually occurring, whereas a negative difference indicates less pumpage than is actually occurring.

[3]Three-well system. All discharges measured through a common meter.

[4]Estimated.

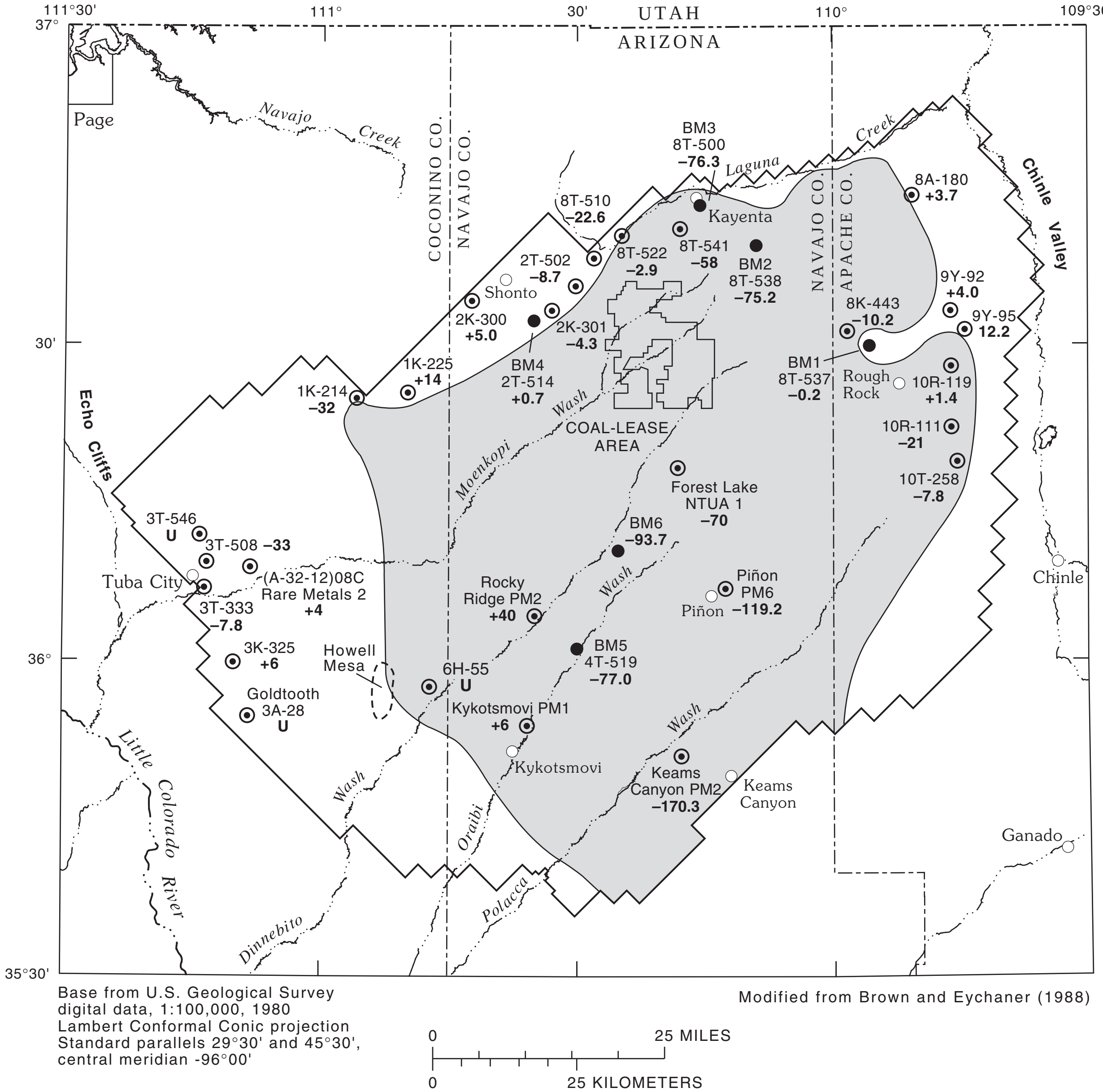
Of the 35 meters that were tested, the difference between metered and tested discharge ranged from +6.3 to -19.6 percent. The average difference was about -3.4 percent. Five of the permanent meters exceeded the allowable difference for the monitoring study.

Ground-Water Levels

Ground water occurs under confined or artesian conditions in the central part of the study area and under unconfined or water-table conditions around the periphery (**fig. 5**). Annual ground-water levels were obtained from 30 of 33 observation, municipal, and stock wells (**table 4**). Water-level changes from the earliest available data through 1998 ranged from a rise of about 40 ft at the Rocky Ridge PM2 well to a decline of about 170 ft at the Keams Canyon PM2 well. The maximum recorded rise in water level in the Black Mesa area in 1998 was 5.8 ft at the Rough Rock 10T-258 well. The maximum recorded decline in water level in 1998 was 33.2 ft at the Rocky Ridge PM2 well. Water-level declines in the confined area from 1997 to 1998 were measured in 10 of 14 wells, and the median change was a decline of about 3.0 ft as compared with a rise of 0.2 ft from 1996 to 1997. Water-level declines in the unconfined area from 1997 to 1998 were measured in 9 of 16 wells, and the median change for all 16 wells was 0.0 ft, which was also the median change from 1996 to 1997. Hydrographs of measured water levels for the 27 municipal and stock wells measured in 1998 are shown in **figure 6**. Well-construction data for these wells are given in **table 5**.

Hydrographs of measured water-level changes in the six continuous-record observation wells (BM1 through BM6) are based on annual and continuous-record data (**fig. 7**). Data have been collected at well BM3 since 1963. Data have been collected at wells BM1, BM2, BM4, and BM5 since 1972, and at well BM6 since 1977. Well-construction data for these wells are given in table 5.

Since 1972, the water level in the unconfined part of the N aquifer at well BM1 has declined by 0.2 ft and the water level at well BM4 has risen by 1.0 ft (fig. 7; table 4). The water level in the confined part of the N aquifer has declined by about 75.2 ft at well BM2, 93.4 ft at well BM3, and 77 ft at well BM5 during that same period. At well BM6, which also is completed in the confined part of the N aquifer, the water-level has declined 93.0 ft since 1977.



EXPLANATION

BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS APPROXIMATE—From Eychaner (1983)

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

4T-523
–65.1
WELL IN WHICH DEPTH TO WATER WAS MEASURED ANNUALLY—First entry, 4T-523, is Bureau of Indian Affairs site number; second entry, **–65.1**, is change in water level, in feet, between measurement made during the prestress period and measurement made during 1998. **U**, unable to measure

BM2
8T-538
–72.8
CONTINUOUS WATER-LEVEL RECORDING SITE (OBSERVATION WELL) MAINTAINED BY THE U.S. GEOLOGICAL SURVEY—First entry, BM2, is U.S. Geological Survey well number; second entry, 8T-538, is Bureau of Indian Affairs site number; third entry, **–72.8**, is change in water level, in feet, from earliest simulated period to 1998

Figure 5. Water-level changes in wells completed in the N aquifer from the prestress period to 1998, Black Mesa, Arizona. See **table 4**.

Table 4. Water-level changes in wells completed in the N aquifer, Black Mesa area, Arizona, 1992–98

[Do, ditto; ---, no data; R; reported]

Well system or location name	Bureau of Indian Affairs site number	Change in water level from preceding water year, in feet		Water level, in feet below land surface, 1998	Prestress water level[1]		Change in water level from prestress to 1998, in feet[2]
		1997	1998		Feet below land surface	Date	
Unconfined							
BM1[3]	8T-537	0	-0.3	374.2	374.0	([3])	-0.2
BM4[3]	2T-514	0	-0.3	216.3	217	([3])	+0.7
Cow Springs	1K-225	-0.5	+1.2	45.8	60	07–04–54	+14
Goldtooth	3A-28	-0.6	([6])	([6])	230	10–29–53	---
Long House Valley	8T-510	0	-1.5	122.0	99.4	08–22–67	-22.6
Marsh Pass	8T-522	-0.9	-0.5	128.4	125.5	02–07–72	-2.9
Northeast Rough Rock	8A-180	+0.1	-0.1	43.2	46.9	11–13–53	+3.7
Rough Rock	9Y-95	-6.7	+7.8	107.3	119.5	08–03–49	+12.2
Do.	9Y-92	+4.4	+1.4	164.8	168.8	12–31–52	+4.0
Shonto	2K-300	([4])	[5]+0.3	171.5	176.5	06–13–50	+5.0
Shonto Southeast	2K-301	+0.3	-0.8	288.2	283.9	06–13–50	-4.3
Do.	2T-502	-2.5	+2.6	414.5	405.8	08–22–67	-8.7
Tuba City	3T-333	-0.3	-1.5	30.8	23.0	12–02–55	-7.8
Do.	3K-325	+0.6	+0.5	201.5	208	06–30–55	+6
Do.	Rare Metals 2	-0.4	+0.1	52.6	57	09–24–55	+4
Tuba NTUA 1	3T-508	([4])	[5]-3.4	62.3	29	02–12–69	-33
Tuba NTUA 4	3T-546	([4])	([4])	([4])	33.7	08–06–71	---
White Mesa Arch	1K-214	+0.6	-0.5	220.3	188	06–04–53	-32
Confined							
BM2[3]	8T-538	-2.6	-2.4	200.2	125.0	([3])	-75.2
BM3[3]	8T-500	+4.3	-3.8	153.4	77.1	08–28–67	-76.3
BM5[3]	4T-519	-2.4	-3.0	400.8	323.8	([3])	-77.0
BM6[3]	BM6	-3.5	-3.2	829.3	735.6	([3])	-93.7
Forest Lake NTUA 1	4T-523	-3.7	-5.4	1,166.5	1,096R	05–21–82	-70
Howell Mesa	6H-55	+0.3	([6])	([6])	212	07–08–54	---
Kayenta West	8T-541	+17.8	-6.4	284.8	227	07–17–79	-58
Keams Canyon PM2	Keams Canyon PM2	([4])	[5]-10.1	462.8	292.5	06–10–79	-170.3
Kykotsmovi	Kykotsmovi PM1	([4])	[5]+22.0	214.2	220	05–20–67	+6
Piñon	Piñon PM6	-3.8	-5.0	862.8	743.6	05–28–70	-119.2
Rocky Ridge	Rocky Ridge PM2	+146.5	-33.2	391.6	432	06–26–63	+40
Rough Rock	10R-119	[5]+0.9	0	255.2	256.6	12–02–52	+1.4
Do.	10T-258	+2.7	+5.8	308.8	301.0	04–14–60	-7.8
Do.	10R-111	+0.2	+0.1	191.0	170	08–04–54	-21
Sweetwater Mesa	8K-443	([4])	[5]-0.9	539.6	529.4	09–26–67	-10.2

[1]Prestress refers to the period of record prior to ground-water withdrawals for mining purposes, circa 1968. The earliest water-level measurement is given, however, for wells in which the water-level was first measured after 1968.
[2]Change in water level is reported to the same precision as the prestress water level.
[3]Continuous recorder. Except for well BM3, prestress water levels are based on model simulation.
[4]Unable to measure because of obstruction in well or no access to well.
[5]Change in water level from last measurement 2 or more years earlier.
[6]Well not measured during reporting period.

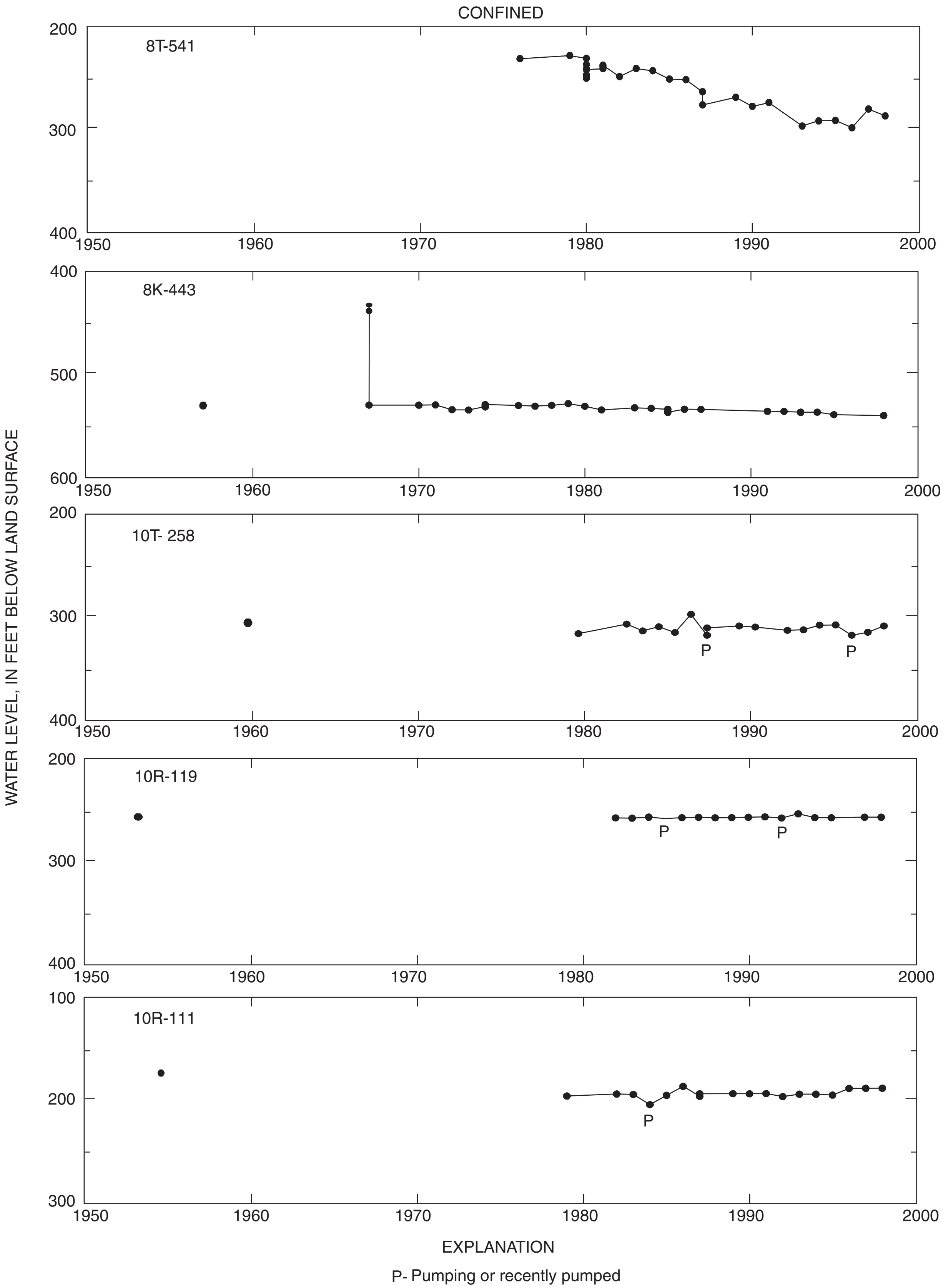


Figure 6. Water-level changes in wells used for annual water-level measurements, Black Mesa area, Arizona.

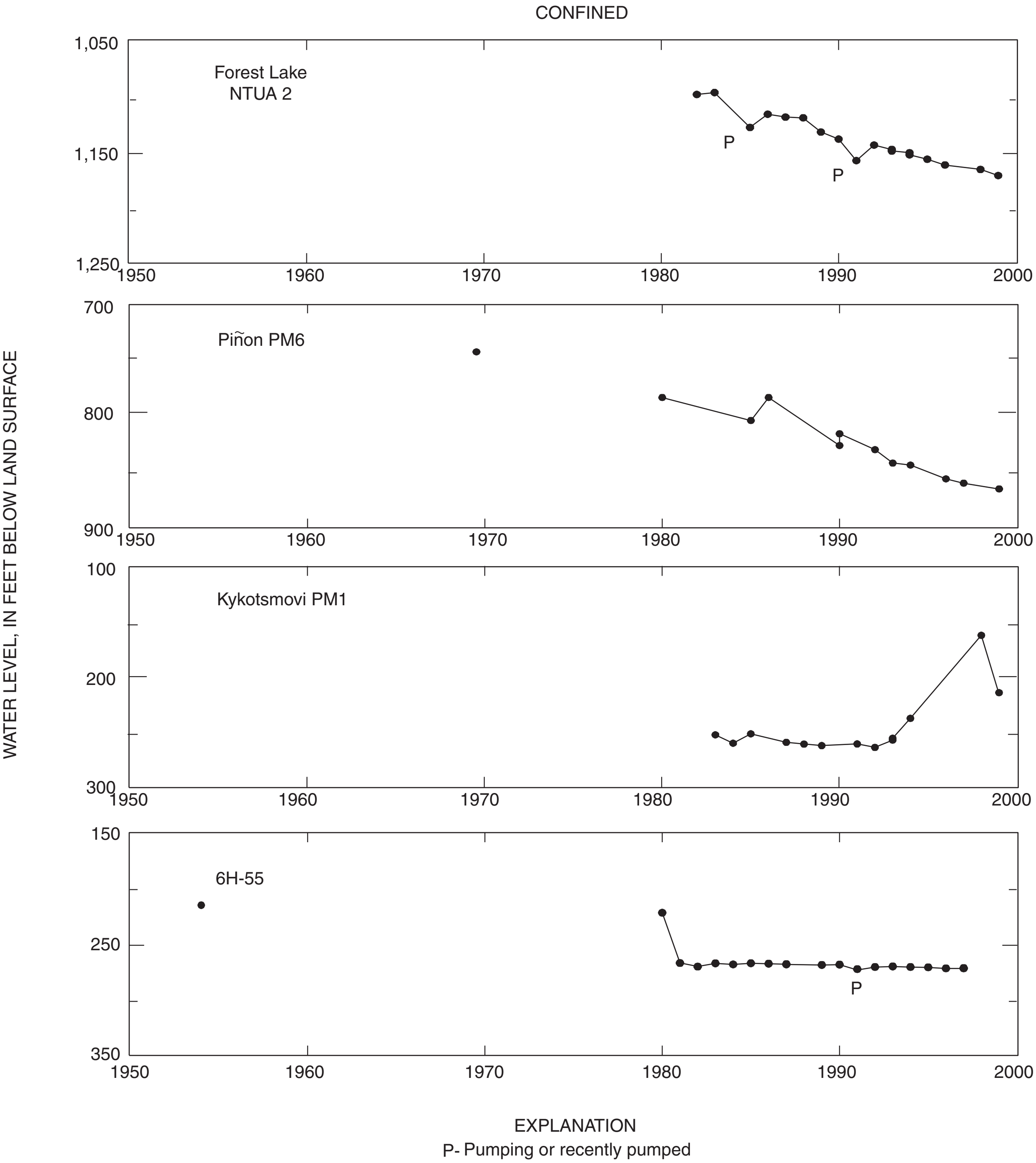


Figure 6. Continued.

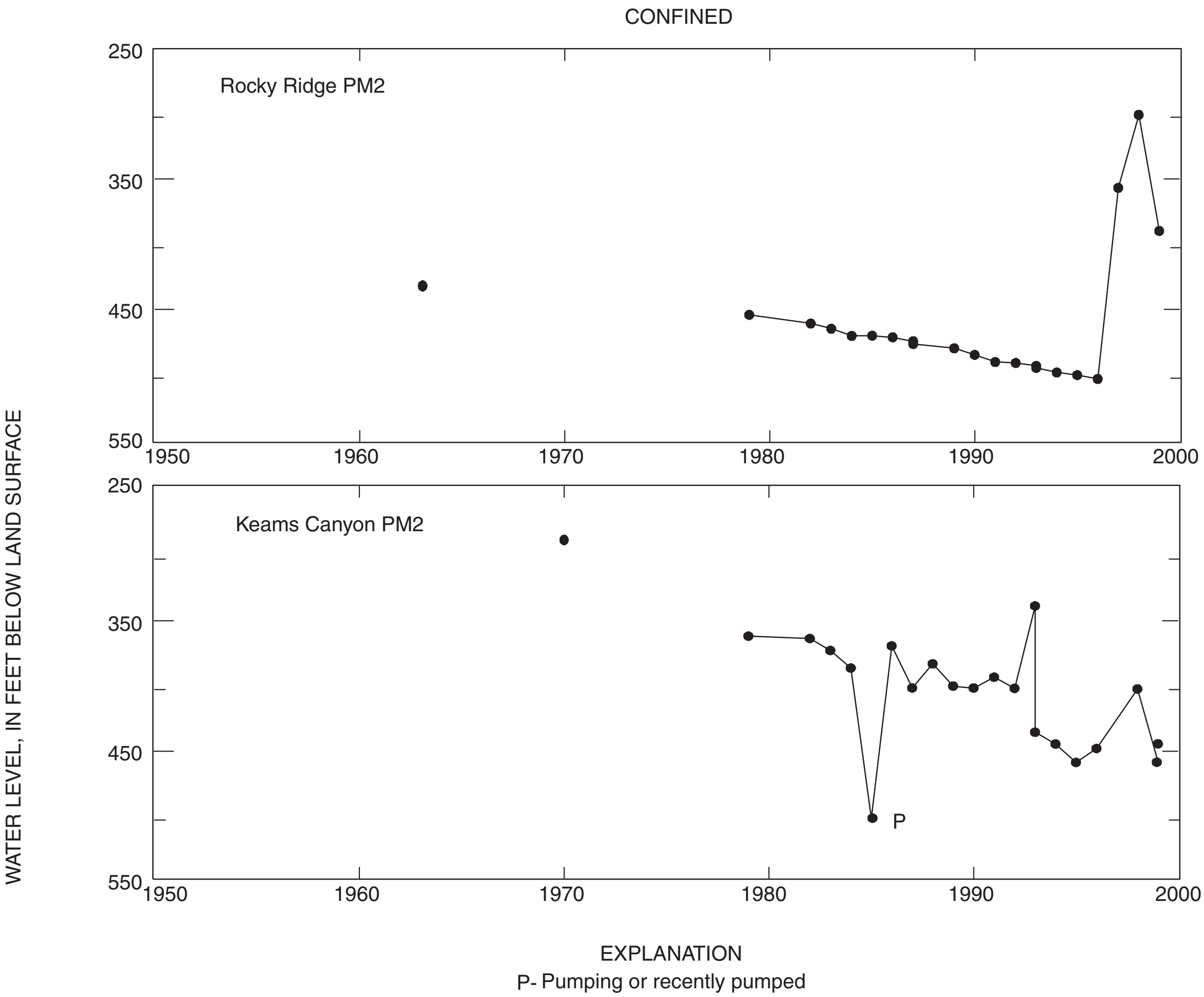


Figure 6. Continued.

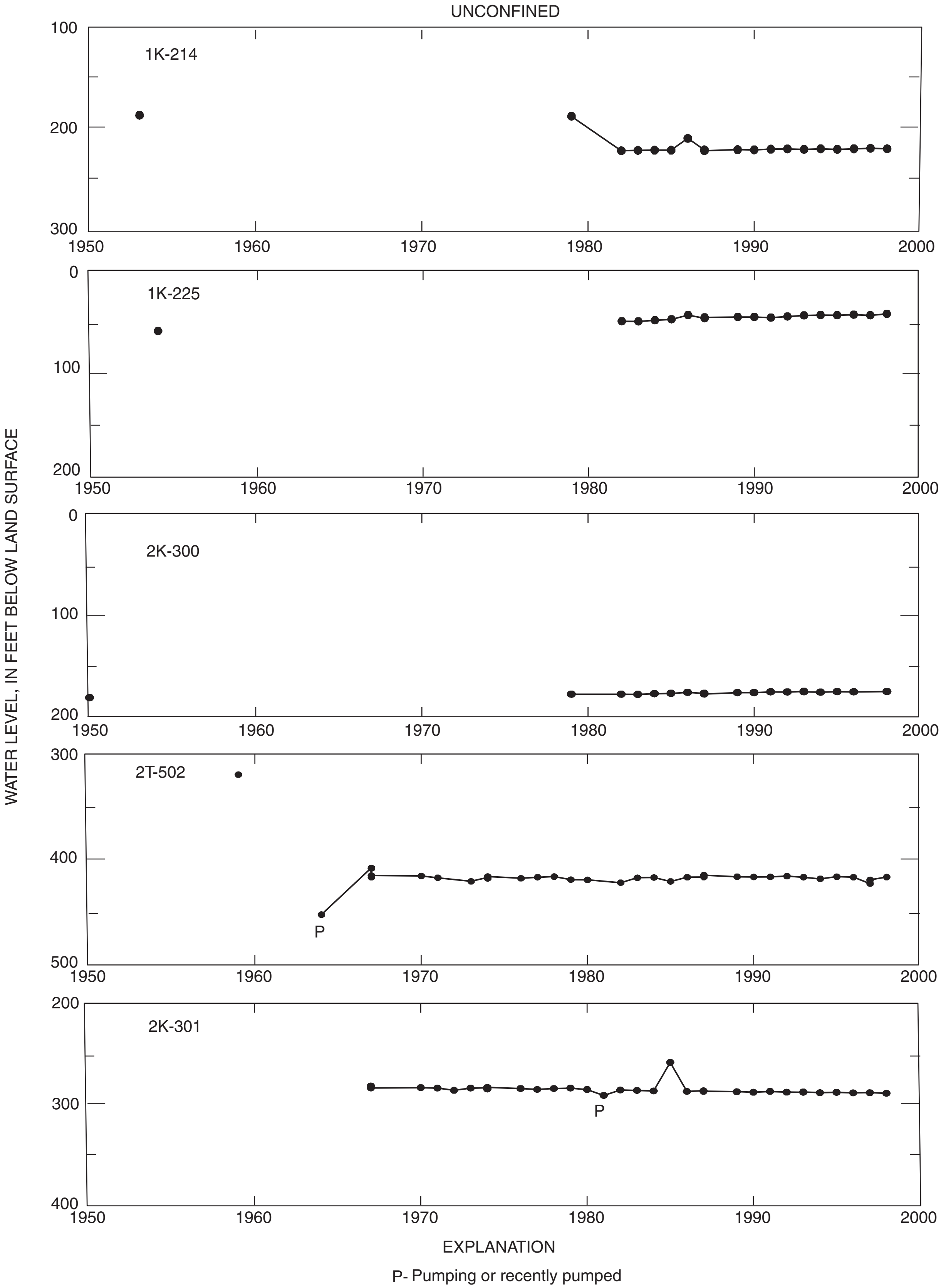


Figure 6. Continued.

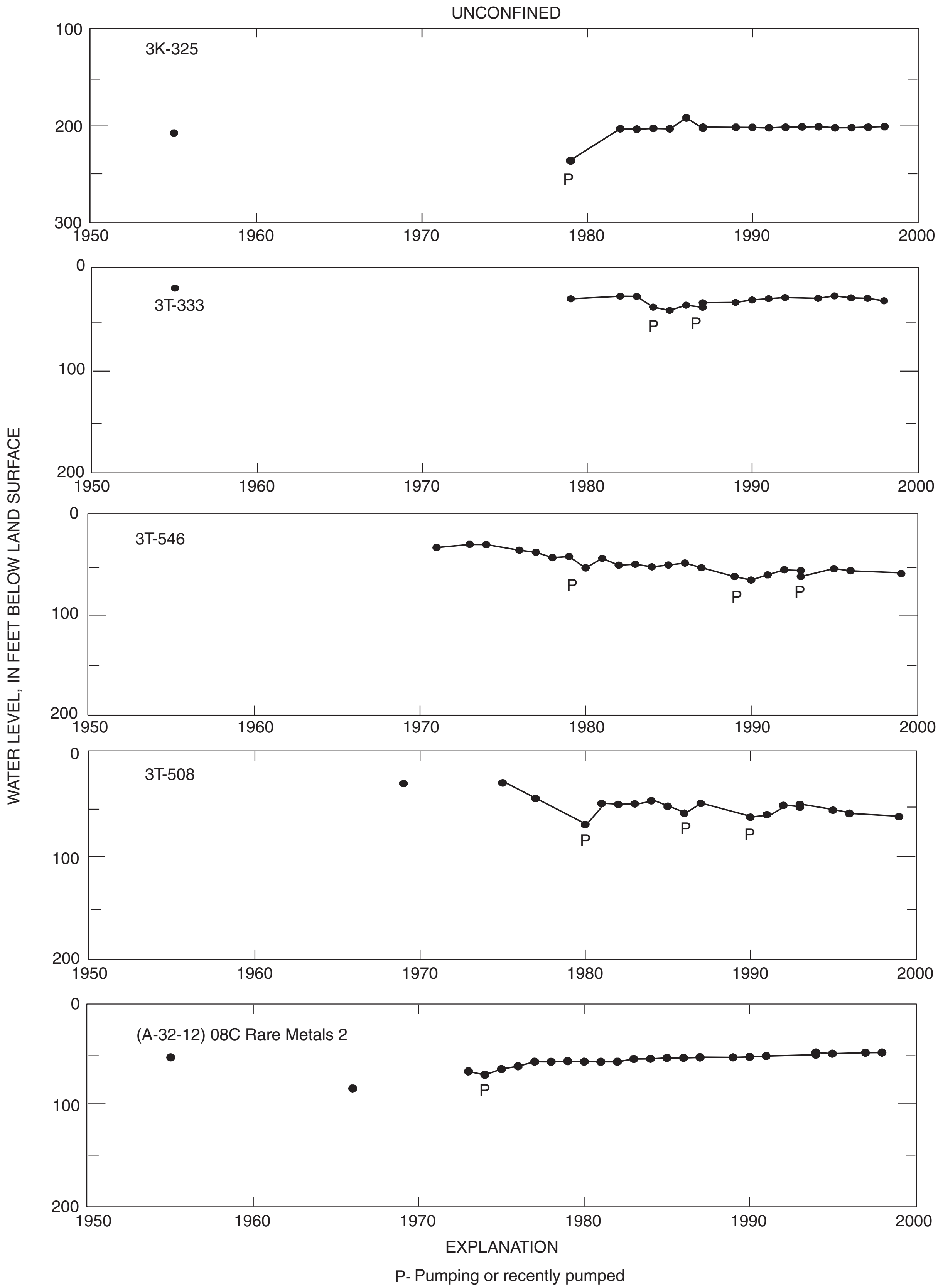


Figure 6. Continued.

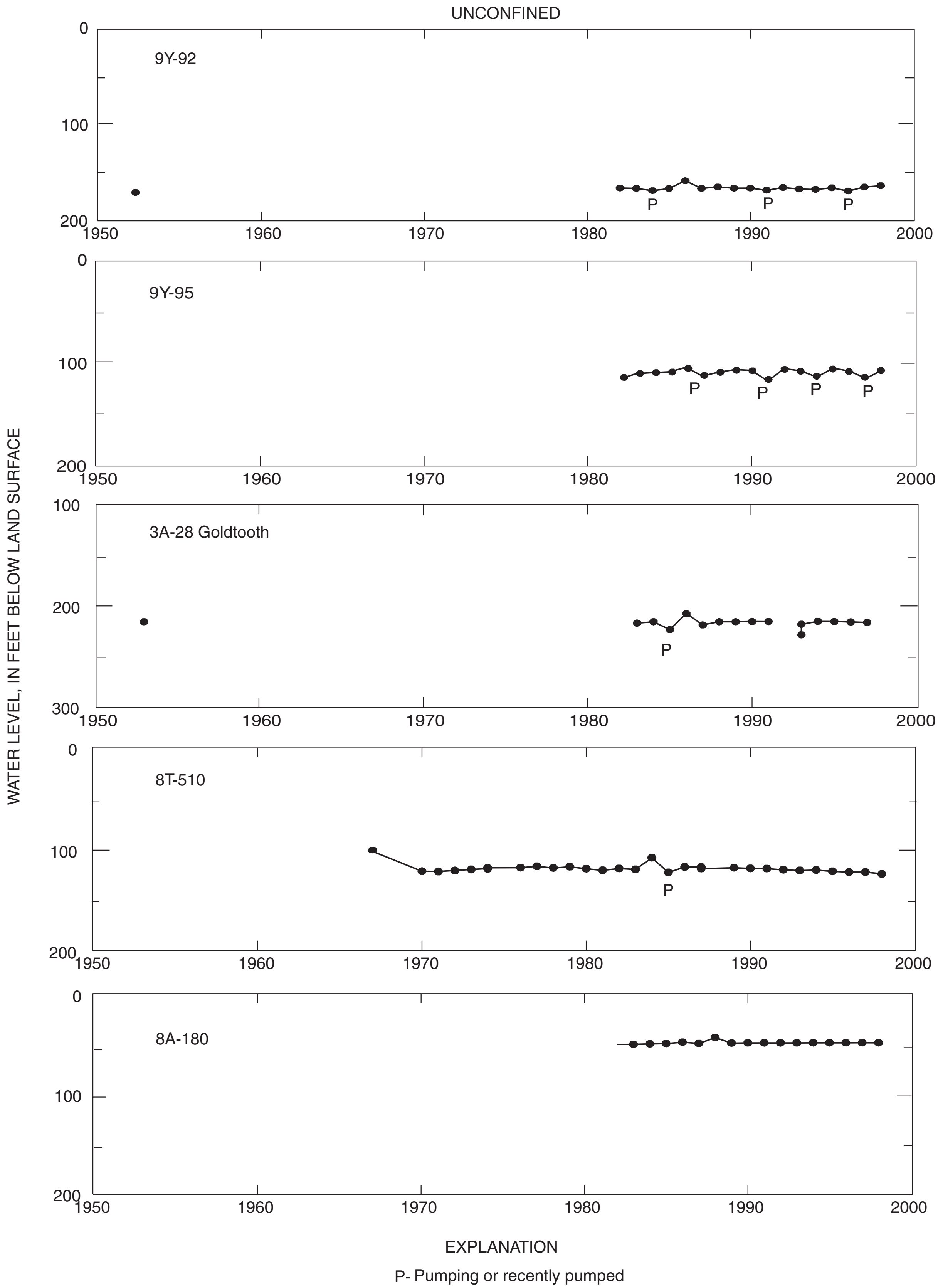


Figure 6. Continued.

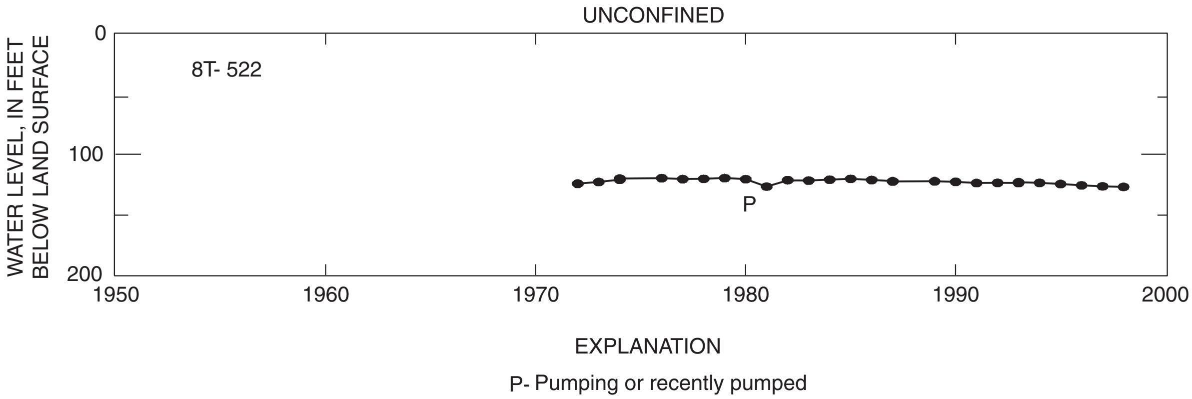


Figure 6. Continued.

Table 5. Well-construction data for municipal and livestock wells used for annual water-level measurements and for continuous-record observation wells BM1–BM6, Black Mesa area, Arizona

[Ss, Sandstone; Fm, Formation. Identifiers in parenthesis are observation well names]

Bureau of Indian Affairs site number	Date completed	Elevation, in feet	Depth, in feet below land surface	Screened/open interval(s), in feet below land surface	Lithology at indicated interval(s), in feet below land surface	Static water level, in feet below land surface
8T-537 (BM1)	02–01–72	5,865	850	300-360;400-420; 500-520;600-620; 730-780	Navajo Ss (290-640) Kayenta Fm (640-)[1]	374
8T-538 (BM2)	01–29–72	5,650	1,338	470-1,338	Navajo Ss (455-995) Kayenta Fm (995-1,145) Wingate Ss (1,145-)[1]	125
8T-500 (BM3)	07–29–59	5,735	868	712-868	Navajo Ss (155-860) Kayenta Fm (860-)[1]	60
2T-514 (BM4)	02–15–72	6,345	400	250-400	Navajo Ss (30-)[1]	217
4T-519 (BM5)	02–25–72	5,858	1,683	1,521-1,683	Navajo Ss (1,520-)[1]	323
BM6	01–31–77	6,340	2,507	1,954-2,506	Navajo Ss (1,950-)[1]	736
1K-225	07–04–54	5,722	251	19-251	Navajo Ss (19-190)	60
3A-28	04–19–35	5,381	358	(2)	(3)	230
8T-510	02–11–63	6,262	314	130-314	Navajo Ss (130-)[1]	99
8T-522	[4]07–00–63	6,040	933	180-933	Entrada Ss/Carmel Fm (180-480) Navajo Ss (480-930) Kayenta Fm (930-)[1]	126
8A-180	01–20–39	5,200	107	60-107	Navajo Ss (60-)[1]	47
9Y-95	11–05–37	5,633	300	145-300	Kayenta Fm (145-168) Wingate Ss (168-300)	120
9Y-92	01–02–39	5,615	300	154-300	Alluvium (154-180) Navajo Ss (180-300)	169

See footnotes at end of table.

Table 5. Well-construction data for municipal and livestock wells used for annual water-level measurements and for continuous-record observation wells BM1–BM6, Black Mesa area, Arizona—Continued

Bureau of Indian Affairs site number	Date completed	Elevation, in feet	Depth, in feet below land surface	Screened/open interval(s), in feet below land surface	Lithology at indicated interval(s), in feet below land surface	Static water level, in feet below land surface
2K-300	[4]06–00–50	6,264	300	260-300	Navajo Ss (260-300)	176
2K-301	06–12–50	6,435	500	318-328; 378-500	Navajo Ss (318-)[1]	284
2T-502	08–10–59	6,670	523	12-523	Navajo Ss (12-520) Kayenta Fm (520-)[1]	318
3T-333	12–02–55	4,940	229	63-229	Navajo Ss (63-176) Kayenta Fm (176-182) Navajo Ss (182-195) Kayenta Fm (195-)[1]	23
3K-325	06–01–55	5,260	450	75-450	Navajo Ss (75-)[1]	208
Rare Metals 2	[4]09–00–55	5,108	705	100-705	Navajo Ss (100-525) Kayenta Fm (525-575) Navajo Ss (575-705)	57
3T-508	08–25–59	5,120	475	(2)	(3)	29
3T-546	[4]08–00–71	5,220	612	556-756	Kayenta Fm (556-756)	34
1K-214	05–26–50	5,771	356	168-356	Carmel Fm (168-330) Navajo Ss (330-)[1]	188
4T-523	10–01–80	6,644	2,674	1,870-1,910 2,070-2,210 2,250-2,674	(3)	1,096
6H-55	12–08–44	5,623	361	310-335	Navajo Ss (310-335)	212
8T-541	03–17–76	5,885	890	740-890	Navajo Ss (740-)[1]	227
Keams Canyon 2	[4]05–00–70	5,809	1,106	906-1,106	Navajo Ss (906-1,035) Kayenta Fm (1,035-1,106)	292
Kykotsmovi PM 1	02–20–67	5,650	995	655-675 890-990	Entrada Ss (655-675) Navajo Ss (890-990)	220
Piñon PM 6	[4]02–00–70	6,397	2,248	1,895-2,243	Navajo Ss (1,895-2,243)	744
Rocky Ridge PM 2	06–26–63	5,985	1,780	1,480-1,780	Navajo Ss (1,480-1,780)	432
10R-119	01–09–35	5,775	360	(2)	(3)	257
10T-258	04–12–60	5,903	670	465-670	Navajo Ss (465-670)	301
10R-111	04–11–35	5,757	360	267-360	Navajo Ss (267-)[1]	170
8K-443	08–15–57	6,024	720	619-720	Navajo Ss (619-)[1]	530

[1]Total thickness is unknown.
[2]Open intervals are unknown.
[3]Borehole lithology was not described.
[4]00 = day unknown.

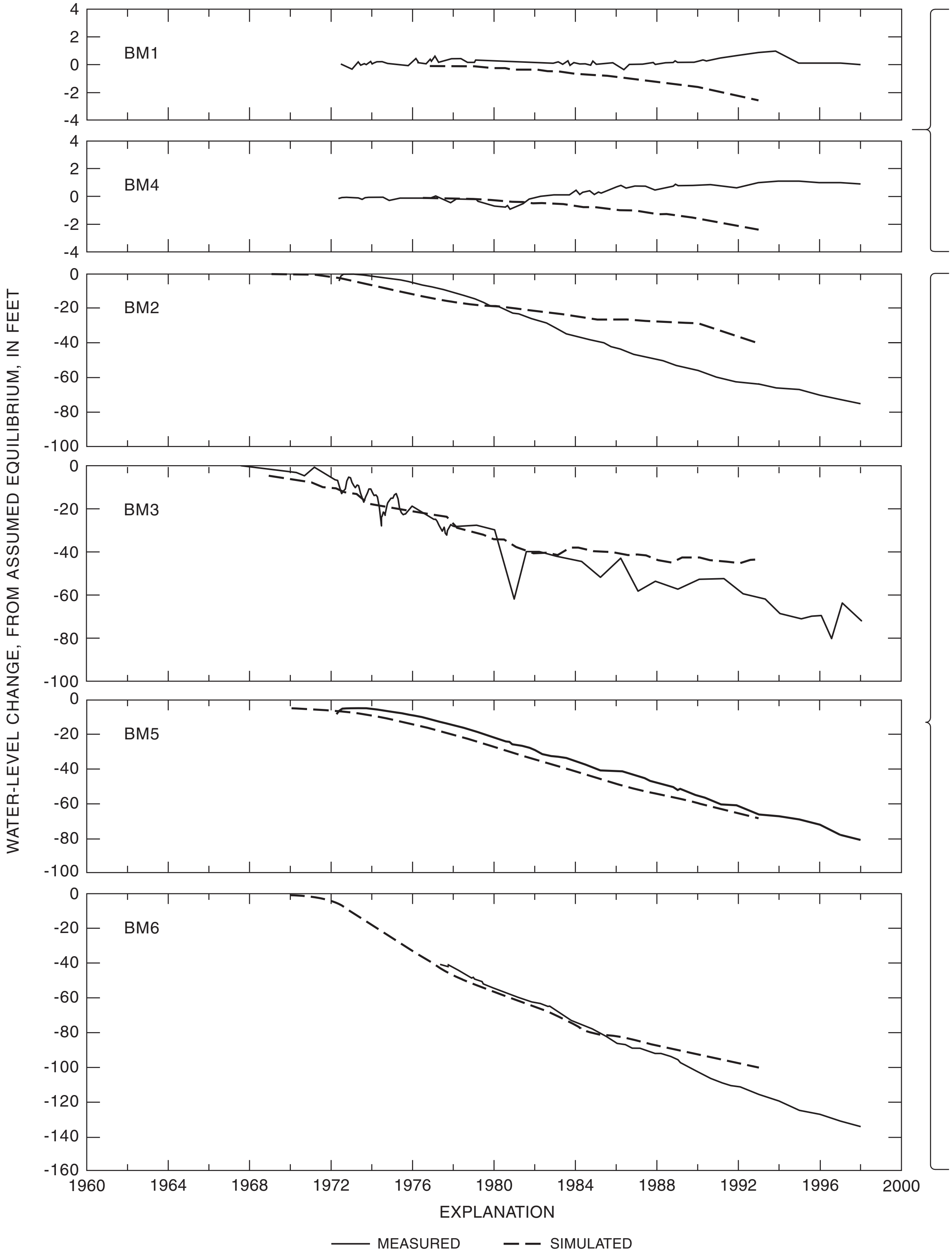


Figure 7. Measured water-level changes in continuous-record observation wells BM1 through BM6, 1963–98, and simulated water-level changes from Littin and Monroe (1995a), Black Mesa area, Arizona, 1998.

Surface-Water Discharge

Outflow from the N aquifer occurs mainly as surface flow in Moenkopi Wash and Laguna Creek, and as springs near the boundaries of the aquifer (Davis and others, 1963). Discharge data were collected at the continuous-record streamflow-gaging stations, Moenkopi Wash at Moenkopi (09401260; **fig. 8**, **table 6**), Laguna Creek at Dennehotso (09379180; fig. 8, **table 7**), Dinnebito Wash near Sand Springs (09401110; fig. 8, **table 8**), and Polacca Wash near Second Mesa (09400568; fig. 8, **table 9**). The Dinnebito and Polacca Wash stations monitor discharge from springs along the southern boundary of Black Mesa. Current-meter measurements of discharge during January, February, November, and December are considered representative of low flow because the effect of stream loss from evapotranspiration and gain from snowmelt and rainfall (which generally occurs during temperate months) is minimized.

The four low-flow discharge measurements made at the Moenkopi streamflow-gaging station ranged from 2.6 to 4.7 ft^3/s. The monthly mean discharge for the low-flow months in 1998 ranged from 1.08 to 6.47 ft^3/s on the basis of continuous-record data (table 6). Daily mean discharges for previous years have been published by the U.S. Geological Survey (1963–64a, b; 1965–74a, b; and 1976–83), White and Garrett (1984, 1986–88), Wilson and Garrett (1988–89), Boner and others (1989–92), Garrett and Gellenbeck (1991), Smith and others (1993–97), and Tadayon and others (1998). On the basis of these data, the daily mean discharge (as low flow) in Moenkopi Wash has remained at about 3 ft^3/s since the Moenkopi station was installed in 1976. Since 1992, the daily mean discharge (as low flow) is about 2.4 ft^3/s.

The Laguna Creek streamflow-gaging station became operational in July 1996. The two low-flow discharge measurements made at the Laguna station ranged from 0.41 to 5.1 ft^3/s. The monthly mean discharge for January, February, November, and December of 1998 ranged from 2.95 to 6.46 ft^3/s on the basis of continuous-record data (table 7).

The Dinnebito and Polacca streamflow-gaging stations became operational in June 1993 and April 1994, respectively, under contract with the Hopi Tribe, and were added to the Black Mesa streamflow-gaging station network in October 1996. The three low-flow discharge measurements at the Dinnebito station ranged from 0.32 to 0.44 ft^3/s. The monthly mean discharge for the low-flow months ranged from 0.41 to 0.60 ft^3/s on the basis of continuous-record data (table 8). The three low-flow discharge measurements from Polacca Wash ranged from 0.13 to 0.36 ft^3/s. The monthly mean discharge for the low-flow months ranged from 0.16 to 0.80 ft^3/s on the basis of continuous-record data (table 9).

Four springs—Burro Spring, an unnamed spring near Dennehotso, Moenkopi School Spring, and Pasture Canyon Spring—were selected for discharge measurements as part of the monitoring program during 1998 (fig. 8, **table 10**). Discharge at Burro Spring was 0.3 gal/min, which was a 0.1 gal/min increase since 1997. Discharge at the unnamed spring near Dennehotso was 21 gal/min, which was a decrease of 4.6 gal/min since 1997. Discharge from Moenkopi School Spring was 12 gal/min, a decrease of 1.1 gal/min since 1997. Discharge from Pasture Canyon Spring was 39 gal/min, which was a 1 gal/min decrease since 1997.

Water Chemistry

Water from Wells Completed in the N Aquifer

All wells sampled in 1998 are completed in the confined part of the N aquifer (fig. 8). The primary types of water that occur in the N aquifer are calcium bicarbonate and sodium bicarbonate. Calcium bicarbonate water occurs in the northern and northwestern part of the Black Mesa area and sodium bicarbonate water generally occurs elsewhere in the area. All but one (Kayenta PM2) of the 12 wells sampled contained a sodium bicarbonate water (**fig. 9**). Although Kayenta PM2 penetrates the confined part of the N aquifer, the water is chemically similar to water from springs associated with the unconfined areas of the N aquifer (fig. 9, **table 11**). Historically, water from Kayenta PM2 has been a calcium bicarbonate type (Littin, 1993).

Dissolved-solids concentrations in water from wells completed in the N aquifer ranged from 109 mg/L at Peabody 9 to 637 mg/L at Rough Rock PM5 (**fig. 10**; table 11). Long-term comparison of dissolved-solids concentrations in water collected from Keams Canyon PM2 and Kayenta PM2 wells shows no significant change from 1982 to 1998 (**fig. 11**; **table 12**). Since 1991, an occasional increase in concentrations of dissolved solids in water from the Forest Lake well NTUA 1 has been observed.

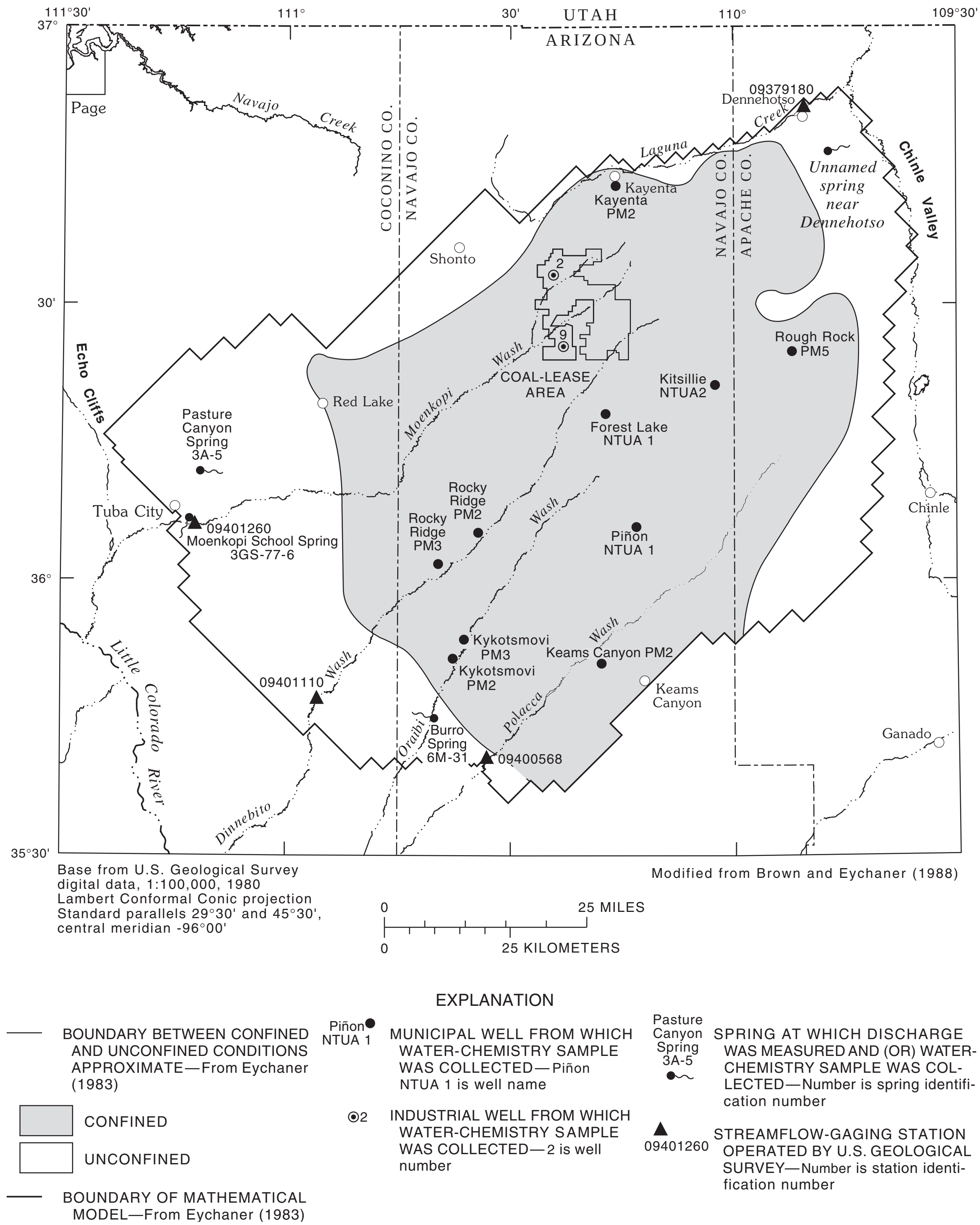


Figure 8. Surface-water and water-chemistry data-collection sites, Black Mesa area, Arizona, 1998.

Table 6. Discharge data, Moenkopi Wash at Moenkopi, Arizona (09401260), calendar year 1998

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1998
DAILY MEAN VALUES

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	3.7	2.9	16	2.9	2.6	0.37	0.00	2.2	0.00	0.18	1.1	1.1
2	3.7	3.0	8.8	2.7	2.7	.23	.00	2.2	.00	.12	1.1	1.1
3	3.7	2.7	9.2	2.7	2.8	.05	.00	2.3	.00	.17	1.1	1.1
4	3.1	2.7	5.5	2.5	2.8	.00	.00	2.2	.40	.10	1.1	1.1
5	2.8	2.7	4.6	2.6	2.2	.00	.00	2.3	2.3	.19	1.1	1.1
6	3.7	2.7	3.0	2.7	2.0	.09	.00	2.2	2.1	.28	1.1	1.3
7	3.5	2.7	2.9	2.6	2.1	.04	.00	2.1	1.9	.44	1.0	1.2
8	3.5	2.7	2.6	2.6	2.0	.00	.00	2.2	[2]1.4	.58	1.1	.80
9	3.1	2.9	2.5	2.5	1.9	.00	.00	.64	[2]1.4	.58	.97	1.0
10	3.2	2.9	2.3	2.5	1.7	.00	.00	.00	[2]1.4	.58	.93	1.2
11	2.6	2.7	2.3	2.6	1.7	.00	.00	.00	1.5	.58	.94	1.2
12	2.6	2.7	4.0	2.6	1.4	.00	.00	.00	1.8	.56	.98	1.2
13	2.0	2.9	6.1	2.7	1.6	.00	.00	.00	1.7	.73	1.0	1.2
14	2.3	2.8	5.0	2.7	2.0	.00	.00	.00	1.8	.72	.98	1.2
15	3.0	3.8	3.1	2.7	2.0	.00	.00	.00	1.7	.45	1.0	1.3
16	2.9	4.9	2.8	[2]2.7	1.6	.00	.00	.00	1.8	.84	1.0	1.3
17	2.9	7.6	2.6	[2]2.6	1.4	.00	.00	.00	1.6	.85	1.1	1.3
18	2.7	5.7	3.1	[2]2.5	1.2	.00	.00	.00	.00	.80	1.2	1.3
19	2.7	9.9	3.2	[2]2.4	1.2	.00	.00	.00	.00	.80	1.2	1.4
20	2.7	13	2.8	[2]2.3	1.1	.00	.00	.00	.00	.92	1.1	1.2
21	2.7	9.1	2.7	[2]2.3	1.6	.00	.00	.00	.08	1.1	1.2	1.3
22	2.8	7.2	2.6	2.4	1.5	.00	.00	.00	.00	1.2	1.3	.79
23	3.0	6.0	2.5	2.2	1.1	.00	4.5	.00	.54	1.1	1.1	1.0
24	3.0	9.1	2.5	2.2	.94	.00	2.7	.00	.70	1.1	1.1	1.1
25	3.4	12	2.4	2.2	.84	.00	2.6	.00	.55	1.1	1.1	1.2
26	3.5	21	2.6	2.9	.91	.00	2.5	.00	.47	1.1	1.1	1.1
27	3.0	18	3.0	4.1	.65	.00	2.3	.00	.40	1.0	1.1	1.2
28	3.1	15	3.0	2.9	.64	.00	2.3	.00	.36	1.1	1.1	1.2
29	2.9	---	3.9	2.8	.50	.00	2.4	.00	.38	1.1	1.1	1.2
30	3.1	---	3.7	2.7	.38	.00	2.3	.00	.37	1.1	1.1	1.2
31	2.8	---	3.1	---	.34	---	2.2	.00	---	1.1	---	1.2
TOTAL	93.7	181.3	124.4	78.8	47.40	0.78	23.80	18.34	26.65	22.57	32.40	36.09
MEAN	3.02	6.47	4.01	2.63	1.53	.026	.77	.59	.89	.73	1.08	1.16
MAX	3.7	21	16	4.1	2.8	.37	4.5	2.3	2.3	1.2	1.3	1.4
MIN	2.0	2.7	2.3	2.2	.34	.00	.00	.00	.00	.10	.93	.79
AC-FT	186	360	247	156	94	1.5	47	36	53	45	64	72

CALENDAR YEAR 1998 TOTAL 686.23 MEAN 1.88 MAXIMUM 21 MINIMUM 0.00 ACRE-FT 1,360

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

Table 7. Discharge data, Laguna Creek at Dennehotso, Arizona (09379180), calendar year 1998

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1998
DAILY MEAN VALUES

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	[2]1.0	1.6	3.2	7.1	3.0	0.00	0.00	2.5	0.00	1.7	14	4.5
2	[2]1.0	2.2	3.1	4.0	1.8	.00	.00	.99	.00	2.6	5.4	4.5
3	[2]1.0	2.5	3.3	3.6	1.0	.00	.00	.20	.00	1.5	5.5	3.9
4	[2]1.0	2.6	2.3	3.1	.51	.00	.00	.02	[2].20	.83	4.3	3.9
5	[2]2.0	2.8	.94	2.9	.05	.00	.00	.00	[2].50	.59	3.6	3.7
6	[2]3.0	2.2	3.5	1.1	.00	.00	.00	.00	[2]1.0	3.1	3.6	3.1
7	[2]5.0	3.7	4.6	.20	.00	.00	.00	.00	[2]1.5	2.2	3.7	3.6
8	[2]8.0	4.7	3.1	.17	.26	.00	.00	.00	[2]2.0	1.9	4.5	1.2
9	[2]10	6.4	3.4	1.1	1.2	.00	2.4	.00	[2]2.0	2.3	45	1.2
10	[2]6.0	6.9	2.5	3.3	.40	.00	2.4	.00	[2]2.4	1.9	22	.75
11	[2]5.0	5.2	1.4	.88	.06	.00	.04	.00	267	1.6	7.6	1.6
12	[2]4.0	7.1	.13	1.6	.02	.00	.00	.00	139	.98	5.6	1.1
13	[2]4.0	6.1	.00	.26	.00	.00	.00	.00	514	.33	6.0	.23
14	3.2	7.2	.00	.07	.00	.00	.00	.00	21	.07	5.4	.06
15	2.7	8.5	.00	.52	.00	.00	.00	[2]3.0	7.9	.21	4.3	.01
16	2.1	9.4	.00	1.6	.00	.00	.00	[2].80	3.8	.22	4.2	.27
17	3.7	9.6	.00	.34	.22	.00	.00	[2].20	3.0	.31	4.4	1.3
18	[2]3.0	9.8	.00	.07	.00	.00	.00	.57	2.7	1.6	3.7	31
19	2.7	8.6	.00	.00	.00	.00	.00	.85	2.1	.87	3.3	8.3
20	3.5	7.4	.00	.00	.00	.00	.00	.03	1.7	.27	2.6	12
21	2.0	8.3	.00	.00	.00	.00	.00	.00	.97	2.9	2.1	9.9
22	1.1	9.3	.00	.00	.00	.00	47	.00	.38	208	2.3	4.2
23	1.8	6.3	.00	.14	.00	.00	24	.00	.87	25	3.5	2.3
24	1.7	6.8	.00	.03	.00	.00	12	.04	1.2	10	4.7	1.6
25	1.7	7.2	.00	.93	.00	.00	11	.01	1.5	8.3	4.4	4.6
26	1.7	6.8	.00	1.7	.00	.00	4.5	.00	1.4	197	3.6	.72
27	1.9	6.6	.10	16	.00	.00	2.6	.00	1.1	27	3.0	1.2
28	[2]2.0	6.2	.41	14	.00	.00	23	.00	1.0	10	3.6	.38
29	1.6	---	9.9	8.8	.00	.00	14	.00	1.1	5.7	4.0	.42
30	1.8	---	14	5.2	.00	.00	5.4	.00	1.0	4.8	3.9	3.7
31	2.4	---	12	---	.00	---	3.6	.00	---	48	---	2.3
TOTAL	91.6	172.0	67.88	78.71	8.52	0.00	151.94	9.21	982.32	571.78	193.8	117.54
MEAN	2.95	6.14	2.19	2.62	.27	.000	4.90	.30	32.7	18.4	6.46	3.79
MAX	10	9.8	14	16	3.0	.00	47	3.0	514	208	45	31
MIN	1.0	1.6	.00	.00	.00	.00	.00	.00	.00	.07	2.1	.01
AC-FT	182	341	135	156	17	.00	301	18	1950	1130	384	233

CALENDAR YEAR 1998 TOTAL 2445.3 MEAN 6.70 MAXIMUM 514 MINIMUM 0.00 ACRE-FT 4,850

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

Table 8. Discharge data, Dinnebito Wash near Sand Springs, Arizona (09401110), calendar year 1998

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1998 DAILY MEAN VALUES												
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.52	0.35	0.39	0.39	0.34	0.22	0.15	2.9	0.21	0.17	0.97	0.54
2	.55	.39	.41	.39	.32	.20	.14	.36	.20	.20	.64	.54
3	.59	.36	.40	.39	.31	.16	.15	.31	.18	.18	.34	.55
4	.76	.44	.39	.35	.30	.19	.14	.63	33	.18	.10	.54
5	.48	.37	10	.39	.29	.22	.17	.31	103	.19	.07	.54
6	.36	.37	[2]20	.40	.33	.21	.17	.24	[2]15	.22	.27	.52
7	.56	.36	[2]10	.51	.34	.17	.15	.22	[2]10	.24	.50	.48
8	.45	.40	[2]7.0	.42.	.31	.20	.15	.22	[2]7.0	.25	.48	.47
9	.44	.45	[2]3.0	.40	.31	.21	.15	.23	[2]5.0	.25	1.9	.55
10	.55	.40	[2]2.0	.37	.28	.20	.15	.22	[2]2.0	.27	1.7	.53
11	.46	.38	.56	.32	.30	.19	.15	45	[2]1.0	.27	.69	.52
12	.44	.37	.42	.36	.28	.19	.15	[2]20	[2].40	.29	.60	.60
13	.44	.40	3.5	.38	.29	.18	.13	[2]10	[2].30	.29	.53	.60
14	.43	.42	12	.36	.34	.20	.13	[2]3.0	[2].20	.29	.54	.67
15	.43	.62	[2]6.8	.40	.31	.19	.15	[2]1.0	[2].20	.27	.53	.67
16	.45	.54	[2].41	.42	.26	.17	.15	[2].50	[2].20	.28	.53	.66
17	.43	.39	[2].39	.43	.24	.17	.15	[2].30	[2].20	.33	.49	.65
18	.43	.44	[2].31	.40	.25	.23	.15	[2].30	.19	.33	.51	.62
19	.41	.37	[2].30	.40	.24	.23	.15	[2].20	.17	.35	.52	.55
20	.43	.44	[2].30	.39	.33	.20	.16	.18	.15	.35	.51	.53
21	.40	.44	[2].30	.35	.38	.19	.16	.18	.14	9.0	.53	.47
22	.38	.43	[2].30	.43	.26	.17	.14	.19	.17	21	.56	.42
23	.38	.41	[2].30	.29	.24	.15	49	.19	.18	8.6	.54	.42
24	.38	.45	[2].30	.26	.25	.15	[2]2.0	.19	.16	7.6	.50	.43
25	.37	.44	.33	.31	.23	.15	.32	.18	.24	17	.41	.46
26	.36	.36	.58	.36	.19	.17	.14	.19	.17	193	.42	.50
27	.36	.37	.45	.32	.20	.18	[2]47	.18	.16	12	.90	.52
28	.36	.37	.72	.31	.21	.18	[2]85	.16	.18	4.0	.57	.59
29	.35	---	.68	.71	.20	.18	[2]10	.16	.20	1.5	.69	.61
30	.40	---	.44	.43	.21	.18	[2]3.0	.17	.17	.66	.54	.65
31	.35	---	.40	---	.23	---	1.5	.16	---	1.2	---	.62
TOTAL	13.70	11.53	83.38	11.64	8.57	5.63	201.25	88.07	180.37	280.76	18.08	17.02
MEAN	.44	.41	2.69	.39	.28	.19	6.49	2.84	6.01	9.06	.60	.55
MAX	.76	.62	20	.71	.38	.23	85	45	103	193	1.9	.67
MIN	.35	.35	.30	.26	.19	.15	.13	.16	.14	.17	.07	.42
AC-FT	27	23	165	23	17	11	399	175	358	557	36	34

CALENDAR YEAR:1998 TOTAL 920.00 MEAN 2.52 MAXIMUM 193 MINIMUM 0.07 ACRE-FT 1,820

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

Table 9. Discharge data, Polacca Wash near Second Mesa, Arizona (09400568), calendar year 1998

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1998 DAILY MEAN VALUES												
Day	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**[1]	**Nov.**[1]	**Dec.**[1]
1	0.28	0.23	0.24	0.23	0.21	0.13	0.06	0.02	0.02	0.02	16	0.14
2	.29	.24	.23	.23	.20	.12	.05	.02	.03	.02	3.7	.14
3	.34	.24	.23	.23	.19	.11	.06	.02	.03	.02	.69	.13
4	.33	.27	.22	.22	.19	.12	.06	.02	.02	.02	.12	.14
5	.30	.24	.22	.22	.19	.12	.06	.02	.03	.02	.11	.14
6	.22	.25	.27	.22	.19	.12	.08	.02	.02	.02	.11	.13
7	.21	.24	.51	.50	.20	.10	.07	.02	.02	.03	.11	.13
8	.21	.32	.31	.26	.19	.10	.07	.01	.01	.02	.13	.11
9	.28	.31	.25	.24	.19	.10	.13	.01	.01	.02	.28	.15
10	.42	.26	.23	.23	.18	.10	.10	.02	.01	.02	.11	.16
11	.30	.23	.23	.21	.18	.10	.07	.02	.02	.03	.12	.15
12	.24	.24	.23	.26	.18	.10	.07	.02	.02	.03	.13	.16
13	.24	.27	.23	.23	.18	.10	.06	.01	.02	.03	.11	.17
14	.22	.30	.38	.21	.20	.10	.06	.02	.02	.03	.11	.18
15	.23	.81	.37	.23	.19	.10	.05	.02	.02	.03	.12	.17
16	.23	.52	.25	.25	.18	.09	.05	.01	.02	.03	.12.	.17
17	.23	.29	.23	.25	.17	.08	.05	.01	.02	.03	.11	.17
18	.24	.29	.26	.23	.16	.09	.05	.02	.02	.03	.11	.17
19	.24	.25	.23	.23	.17	.09	.05	.01	.01	.03	.12	.18
20	.22	.30	.23	.22	.17	.08	.05	.01	.01	.04	.12	.17
21	.23	.29	.23	.22	.18	.08	.05	.02	.01	.16	.13	.15
22	.22	.27	.22	.22	.16	.07	.05	17	.02	.12	.13	.14
23	.23	.27	.23	.21	.16	.07	181	1.4	.02	.13	.13	.14
24	.22	.34	.22	.20	.16	.07	23	.05	.02	.05	.13	.13
25	.22	.29	.20	.20	.16	.07	1.5	.02	.02	.76	.13	.15
26	.23	.25	.46	.44	.15	.07	.26	.02	.02	197	.14	.17
27	.23	.23	.29	.34	.14	.07	2.4	.02	.02	175	.14	.18
28	.23	.23	.35	.24	.14	.07	.71	.01	.02	16	.16	.21
29	.23	---	.50	.24	.13	.07	1.4	.01	.02	1.7	.17	.20
30	.24	---	.29	.22	.13	.06	.13	.01	.02	.33	.14	.21
31	.24	---	.25	---	.14	---	.03	.02	---	.15	---	.21
TOTAL	7.79	8.27	8.59	7.43	5.36	2.75	211.83	18.91	0.57	391.92	23.93	4.95
MEAN	.25	.30	.28	.25	.17	.092	6.83	.61	.019	12.6	.80	.16
MAX	.42	.81	.51	.50	.21	.13	181	17	.03	197	16	.21
MIN	.21	.23	.20	.20	.13	.06	.03	.01	.01	.02	.11	.11
AC-FT	15	16	17	15	11	5.5	420	38	1.1	777	47	9.8
CALENDAR YEAR 1998			TOTAL 692.3		MEAN 1.90		MAXIMUM 197		MINIMUM 0.01		ACRE-FT 1,370	

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

Table 10. Discharge measurements of selected springs, Black Mesa area, Arizona, 1952–98

Spring name	U.S. Bureau of Indian Affairs site number	Rock Formation(s)	Date of measurement	Discharge, in gallons per minute
Burro Spring	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
Unnamed spring near Dennehotso	8A-224	Navajo Sandstone	10–06–54	[1]1
			06–27–84	[1]0.2
			11–17–87	0.5
			03–26–92	0.2
			10–22–93	14.4
			12–05–95	17
			12–19–96	15.7
			12–31–97	25.6
			12–14–98	21.0
Moenkopi School Spring	3GS-77-6	Navajo Sandstone tongue in the Kayenta Formation	05–16–52	40
			04–22–87	16
			11–29–88	12.5
			02–21–91	[2]13.5
			04–07–93	[2]14.6
			12–07–94	[2]12.9
			12–04–95	[2]12.1
			12–16–96	[2]10
			12–17–97	[2]13.1
			12–08–98	[2]12.0
Pasture Canyon Spring	3A-5	Navajo Sandstone and alluvium	11–18–88	[3]211
			03–24–92	[3]233
			10–12–93	[3]211
			12–04–95	[4]38
			12–16–96	[4]38
			12–17–97	[4]40
			12–10–98	[4]39

[1]Estimated.
[2]Discharge was measured at water-quality sampling site only and does not represent the total discharge from the Moenkopi School Spring system.
[3]Discharge was measured in an irrigation ditch about 0.25 mile below water-quality sampling point and does not represent the total discharge from Pasture Canyon Spring.
[4]Discharge was measured volumetrically from pipe at water-quality sampling point 20 feet below uppermost spring. Water was being diverted for irrigation upstream of previous points of measurement.

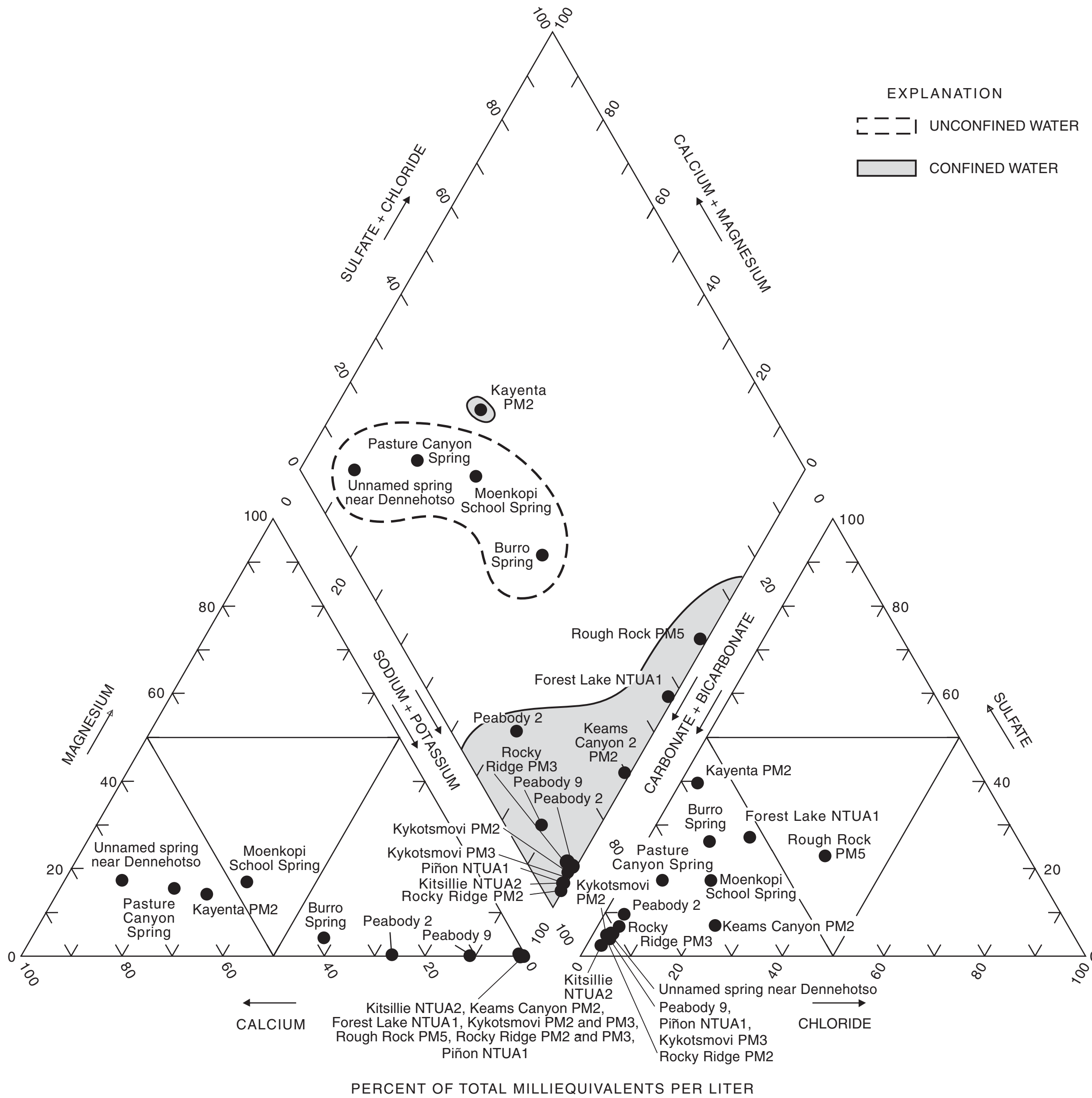


Figure 9. Relative compositions of ground water from the N aquifer, Black Mesa area, Arizona, 1998.

Table 11. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the confined part of the N aquifer, Black Mesa area, Arizona, 1998

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

Well name	U.S. Geological Survey identification number	Date of sample	Temperature, field (°C)	Specific conductance, field (µS/cm)	pH, field (units)	Alkalinity, field (mg/L as $CaCO_3$)	Nitrogen NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Forest Lake NTUA1	361737110180301	12–02–98	27.5	489	9.4	145	0.46	<0.01	0.86	0.10
Kayenta PM2	364344110151201	12–01–98	15.5	349	8.0	106	.95	<.01	40	6.5
Keams Canyon PM2	355023110182701	12–04–98	18.1	908	9.4	341	<.05	.02	.70	.14
Kitsillie NTUA 2	362043110030501	12–02–98	28.0	379	9.8	206	1.38	.01	.50	.01
Kykotsmovi PM2	355215110375001	12–03–98	21.9	348	9.9	169	---	---	.45	.01
Kykotsmovi PM3	355236110364501	12–03–98	21.6	341	9.9	166	1.19	.03	.32	.01
Peabody 2	363005110250901	11–30–98	30.8	93	8.6	78	.95	<.01	8.2	.13
Peabody 9	362901110234101	11–30–98	30.3	109	9.0	68	.75	<.01	3.4	.03
Piñon NTUA 1	360527110122501	12–15–98	23.6	460	10.0	227	1.29	.02	.48	.01
Rocky Ridge PM2	360418110352701	12–03–98	24.4	215	9.6	110	1.26	.02	.40	.01
Rocky Ridge PM3	360422110353501	12–04–98	11.2	222	9.9	112	1.27	.02	.96	.01
Rough Rock PM5	362418109514601	12–01–98	20.9	894	9.1	207	1.02	.01	1.8	.27

Well name	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L as As	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids, residue at 180°C, (mg/L)
Forest Lake NTUA1	120	0.72	37	71	0.75	20	2	226	45	350
Kayenta PM2	23	1.2	3.7	71	.17	17	2	26	<10	236
Keams Canyon PM2	210	.65	78	29	1.2	13	36	537	<10	558
Kitsillie NTUA 2	98	.55	3.8	4.1	.24	26	4	49	<10	270
Kykotsmovi PM2	79	.34	3.3	7.3	.22	25	5	28	<10	223
Kykotsmovi PM3	81	.35	4.6	8.4	.23	25	6	37	<10	219
Peabody 2	26	.69	2.2	7.9	.13	24	3	18	<10	119
Peabody 9	31	.61	1.7	2.5	.17	20	3	20	<10	109
Piñon NTUA 1	110	.40	4.6	4.7	.23	28	4	56	<10	304
Rocky Ridge PM2	54	.36	1.4	<.10	.10	22	3	22	<10	140
Rocky Ridge PM3	55	.37	3.2	5.0	.12	22	3	23	<10	164
Rough Rock PM5	220	1.2	130	110	1.7	13	47	403	[1]7.7	637

[1]Estimated value.

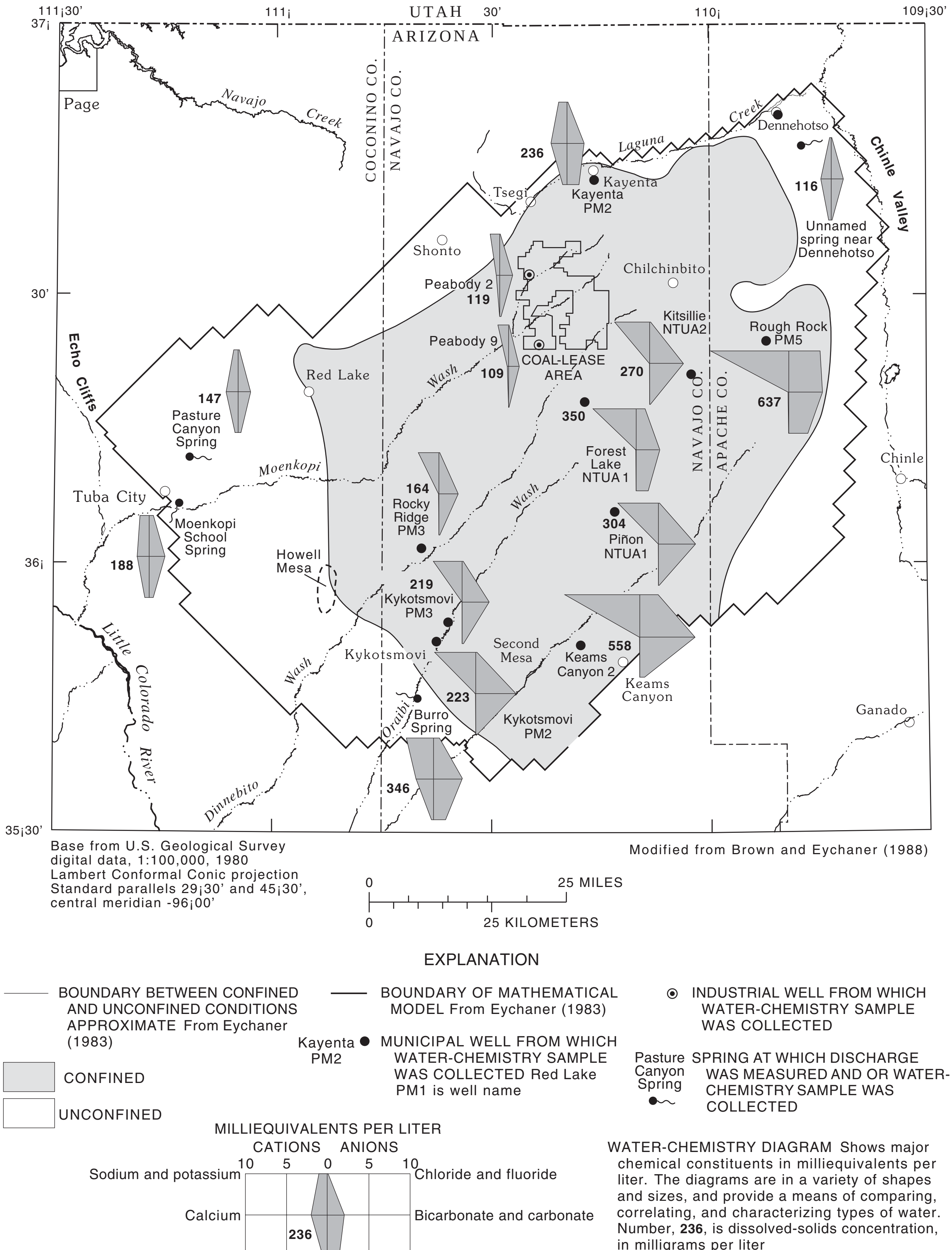


Figure 10. Water chemistry and distribution of dissolved solids in the N aquifer, Black Mesa area, Arizona, 1998.

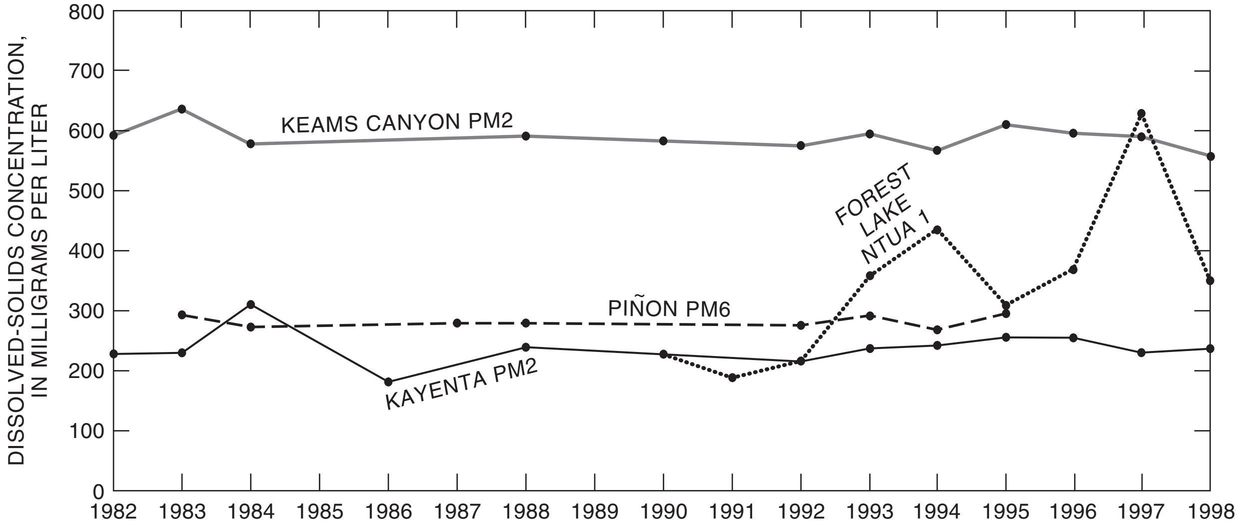


Figure 11. Comparison of dissolved-solids concentrations in water from wells Keams Canyon PM2, Piñon PM6, Forest Lake NTUA 1, and Kayenta PM2, Black Mesa area, Arizona, 1982–98.

Table 12. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, Black Mesa area, Arizona, 1968–98

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

Year	Specific conductance, field (µS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Forest Lake NTUA 1				
1982	470	---	11	67
1990	375	226	8.2	38
1991	[1]350	183	10	24
1993	693	352	35	88
1994	[1]734	430	56	100
1995	470	274	13	60
Do	1,030	626	86	160
Do	488	316	16	71
1996	684	368	44	79
1997	[1]1,140	714	78	250
1998	489	350	37	71
Kayenta PM2[2]				
1982	360	(2)	4.5	58
1983	375	(2)	5.9	60
1984	[1]370	209	4.2	51
1986	300	181	8.2	30
1988	358	235	3.8	74
Kitsillie NTUA 2				
1997	[1]524	269	3.6	4.3
1998	379	270	3.8	4.1
Kykotsmovi PM2				
1988	368	212	3.2	8.6
1990	355	255	3.2	9.0
1991	[1]374	203	4.4	7.9
1992	363	212	3.3	8.4
1994	[1]365	212	3.6	8.5
1995	368	224	3.1	6.2
1996	365	224	3.3	8.5
1997	[1]379	222	3.0	8.0
1998	348	223	3.3	7.3
Kykotsmovi PM3				
1998	341	219	4.6	8.4
Peabody 2				
1980	225	145	11	20
1986	172	---	2.6	8.1

See footnotes at end of table.

Table 12. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, Black Mesa area, Arizona, 1968–98

Year	Specific conductance, field (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Kayenta PM2[2]—Continued				
1992	383	210	5.6	78
1993	374	232	3.7	78
1994	[1]371	236	4.2	77
1995	371	250	4.2	72
1996	370	238	3.8	76
1997	[1]379	230	3.9	77
1998	349	236	3.7	71
Keams Canyon PM2				
1982	1,010	(2)	94	35
1983	1,120	(2)	120	42
1984	[1]1,060	578	96	36
1988	1,040	591	97	34
1990	1,030	600	94	34
1992	[1]1,010	570	93	36
1993	1,040	590	92	36
1994	[1]975	562	[1]86	32
1995	1,010	606	99	32
1996	1,030	596	96	34
1997	[1]1,070	590	96	33
1998	908	558	78	29
Rough Rock PM5				
1983	1,090	(2)	130	110
1984	[1]1,100	613	130	99
1986	1,010	633	140	120
1988	1,120	624	130	[3]110
1991	[1]1,210	574	130	110
1993	1,040	614	130	110
1994	[1]1,070	626	130	110
1995	1,110	648	140	110
1996	1,100	634	130	110
1997	[1]1,060	628	130	110
1998	894	637	130	110

Year	Specific conductance, field (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Peabody 2—Continued				
1987	149	113	5.0	9.1
1993	163	124	1.7	8.9
1998	93	119	2.2	7.9
Peabody 9				
1986	181	---	3.1	4.9
1987	148	102	2.8	4.1
1990	158	106	1.6	3.0
1991	155	83	2.7	3.1
1993	157	94	1.6	2.9
1994	---	---	1.7	---
1995	154	122	1.6	1.6
1998	109	109	1.7	2.5
Piñon NTUA 1				
1998	460	304	4.6	4.7
Rocky Ridge PM2				
1986	247	164	2.4	6.4
1998	215	140	1.4	<.10
Rocky Ridge PM3				
1982	255	---	1.4	6.0
1990	222	126	1.5	6.0
1993	254	146	1.3	5.5
1994	[1]248	152	1.4	5.5
1995	242	166	1.3	4.0
1996	256	[2]156	2.0	5.8
1997	[1]238	159	2.5	5.0
1998	222	164	3.2	5.0

[1]Value shown in reports from previous years for this date was determined by laboratory analysis.
[2]Value shown in reports from previous years for this date represented the sum of constituents.
[3]Value shown in reports from previous years for this date was reported with a different rounding definition.

In 1994, 1995, and 1997, dissolved-solids concentrations at the Forest Lake NTUA1 well were measured at 430, 316, and 714 mg/L, respectively. The concentrations for dissolved solids decreased from 714 mg/L in 1997 to 350 mg/L in 1998. Specific conductance at the well was above 1,000 μS/cm on two occasions (table 12), however, long-term water-chemistry data for this well has remained stale. On a regional basis, the long-term chemistry for the Black Mesa area has remained stable.

Surface Water

Four springs were selected for water-chemistry analyses as part of the monitoring program during 1998. The springs, all of which discharge from the Navajo Sandstone, are Burro Spring near Kykotsmovi, an unnamed spring near Dennehotso, Moenkopi School Spring at Moenkopi, and Pasture Canyon Spring near Tuba City (figs. 8, 9, and 10; table 13). Water from Burro Spring is more of a sodium bicarbonate type than water from the unnamed spring near Dennehotso, Moenkopi School Spring, and Pasture Canyon Spring, which is a calcium bicarbonate type (fig. 9).

Long-term data for these springs indicate predominately stable concentrations of total dissolved solids (**table 14**). Concentrations at Burro Spring ranged from 308 mg/L in 1989 to 368 mg/L in 1993 and 1994. Concentrations at Moenkopi Spring increased from 161 mg/L in 1987 to 206 mg/L in 1995 and decreased to 188 mg/L in 1998.

Table 13. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 1998

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

Spring name	Bureau of Indian Affairs site number	U.S. Geological Survey identification number	Rock formation	Date of sample	Temperature (°C)	Specific conductance (field) (μS/cm)	pH (units)
Burro Spring	6M-31	354156110413701	Navajo Sandstone	12–08–98	5.0	504	8.4
Unnamed spring near Dennehotso	8A-224	364656109425400	Navajo Sandstone	12–14–98	9.8	179	7.8
Moenkopi School Spring	3GS–77–6	360632111131101	Navajo Sandstone tongue in the Kayenta Formation	12–08–98	17.2	296	7.4
Pasture Canyon Spring	3A-5	361021111115901	Navajo Sandstone	12–10–98	15.0	232	7.7

Spring name	Alkalinity (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Burro Spring	176	0.28	<0.01	120	---	43	3.1
Unnamed spring near Dennehotso	77	1.57	.03	82	---	27	3.9
Moenkopi School Spring	96	---	---	100	---	29	6.5
Pasture Canyon Spring	75	4.45	.02	90	---	29	4.5

Table 13. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, Black Mesa area, Arizona, 1998—Continued

Spring name	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Percent sodium	Sodium plus postassium, dissolved (mg/L as Na+K)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)
Burro Spring	76	3	58	77	0.61	25
Unnamed spring near Dennehotso	4.1	.2	10	5.1	1.0	2.4
Moenkopi School Spring	25	1	35	26	1.3	18
Pasture Canyon Spring	11	.5	21	12	1.5	5.1

Spring name	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Dissolved solids, residue at 180°C (mg/L)
Burro Spring	70	0.44	13	<1	69	<10	346
Unnamed spring near Dennehotso	5.4	.12	12	3	<16	<10	116
Moenkopi School Spring	24	.19	14	3	34	<10	188
Pasture Canyon Spring	16	.17	10	2	24	<10	147

Table 14. Specific conductance and concentrations of selected chemical constituents in water from springs that discharge from the N aquifer, Black Mesa area, Arizona, 1948–98

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

Spring name	Year	Specific conductance (field) (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Spring name	Year	Specific conductance (field) (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Burro Spring	1989	485	308	22	59	Moenkopi School Spring	1952	222	---	6	---
	1990	[1]545	347	23	65		1987	270	161	12	19
	1993	595	368	30	85		1988	270	155	12	19
	1994	[1]597	368	26	80		1991	297	157	14	20
	1996	525	324	23	62		1993	313	204	17	27
	1997	[1]511	332	26	75		1994	305	182	17	23
	1998	504	346	25	70		1995	314	206	18	22
							1996	332	196	19	26
							1997	[1]305	185	18	24
							1998	296	188	18	24
Unnamed spring near Dennehotso	1984	195	112	2.8	7.1	Pasture Canyon Spring	1948	[1]227	(2)	5	13
	1987	178	[2]109	3.4	7.5		1982	240	---	5.1	18
	1992	178	108	3.6	7.3		1986	257	---	5.4	19
	1993	184	100	3.2	8		1988	232	146	5.3	18
	1995	184	124	2.6	5.7		1992	235	168	7.1	17
	1996	189	112	2.8	8.2		1993	242	134	5.3	17
	1997	[1]170	98	2.4	6.1		1995	235	152	4.8	14
	1998	179	116	2.4	5.4		1996	238	130	4.7	15
							1997	232	143	5.3	17
							1998	232	147	5.1	16

[1]Value shown in reports from previous years for this date was determined by laboratory analysis.
[2]Value shown in reports from previous years for this date represented the sum of constituents.

SUMMARY

The N aquifer is a major source of water for industrial and municipal uses in the Black Mesa area, and water occurs under confined and unconfined conditions. From 1997 to 1998, combined ground-water withdrawals decreased by less than 1 percent to about 7,060 acre-ft; pumpage from the confined part of the aquifer decreased by less than 1 percent to 5,470 acre-ft and pumpage from the unconfined part of the aquifer increased by less than 1 percent to 1,590 acre-ft.

Water-level declines in the confined area during 1998 were recorded in 10 of 14 wells, and the median change from 1997 was a decline of about 3.0 ft as opposed to a rise of 0.2 ft for 1996–97. Water-level declines in the unconfined area were recorded in 9 of 16 wells, and the median change was 0.0 ft in 1998. The change from 1996–97 was also 0.0 ft.

Natural discharge from the N aquifer is mainly surface flow along Moenkopi Wash and Laguna Creek and discharge from springs near the boundaries of the aquifer. Measured low flow ranged from 2.6 to 4.7 ft^3/s along Moenkopi Wash, 0.41 to 5.1 ft^3/s at Laguna Creek, 0.32 to 0.44 ft^3/s at Dinnebito, and 0.13 to 0.36 ft^3/s at the Polacca streamflow-gaging stations in 1998. The Dinnebito and Polacca stations were recently added to the network to monitor spring discharge along the southern boundary of Black Mesa. Spring discharge in 1998 decreased by 1.1 gal/min at Moenkopi School Spring, 4.6 gal/min at the spring near Dennehotso, and 1 gal/min at Pasture Canyon, and increased 0.1 gal/min at Burro Spring as compared to discharges measured in 1997.

Of the 36 pumpage meters on municipal wells that were tested, the difference between metered and tested discharge ranged from +6.3 to -19.6 percent. The average difference was about -3.4 percent. Five of the meters exceeded the allowable difference (10 percent) for the monitoring study.

Calcium bicarbonate water and sodium bicarbonate water are the primary types of water in the N aquifer. The calcium bicarbonate type water occurs in the northern and northwestern parts of the Black Mesa area. The sodium bicarbonate type water generally occurs elsewhere in the area. All but one (Kayenta PM2) of the 12 wells sampled in 1998 contained a sodium bicarbonate type water. Historically, water from Kayenta PM2 has been a calcium bicarbonate type (Littin, 1993). Dissolved-solids concentrations ranged from 109 to 637 mg/L in 1998.

The concentration of dissolved solids in water from Forest Lake well NTUA 1 had increased during the last several years prior to 1998, however, the concentration decreased from 714 mg/L in 1997 to 350 mg/L in 1998. In general, long-term water-chemistry data for wells and springs have remained stable.

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