Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1996

By G.R. LITTIN and S.A. MONROE

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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 (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/d)	0.003785	cubic meter per day

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8(°C) + 32$$

ABBREVIATED WATER-QUALITY UNITS

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

VERTICAL DATUM

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum 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 areas of the aquifer, (3) surface-water discharge, and (4) chemistry of the ground water and surface water.

In 1996, ground-water withdrawals for industrial and municipal use totaled about 7,040 acre-feet, which is less than a 1-percent decrease from 1995. Pumpage from the confined part of the aquifer decreased by about 3 percent to 5,390 acre-feet, and pumpage from the unconfined part of the aquifer increased by about 9 percent to 1,650 acre-feet. Water-level declines in the confined area during 1996 were recorded in 11 of 13 wells, and the median change was a decline of about 2.7 feet as opposed to a decline of 1.8 feet for 1995. Water-level declines in the unconfined area were recorded in 11 of 18 wells, and the median change was a decline of 0.5 foot in 1996 as opposed to a decline of 0.1 foot in 1995.

The average low-flow discharge at the Moenkopi streamflow-gaging station was 2.3 cubic feet per second in 1996. Streamflow-discharge measurements also were made at Laguna Creek, Dinnebito Wash, and Polacca Wash during 1996. Average low-flow discharge was 2.3 cubic feet per second at Laguna Creek, 0.4 cubic foot per second at Dinnebito Wash, and 0.2 cubic foot per second at Polacca Wash. Discharge was measured at three springs. Discharge from Moenkopi School Spring decreased by about 2 gallons per minute from the measurement in 1995. Discharge from an unnamed spring near Dennehotso decreased by 1.3 gallons per minute from the measurement made in 1995; however, discharge increased slightly at Burro 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

[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.

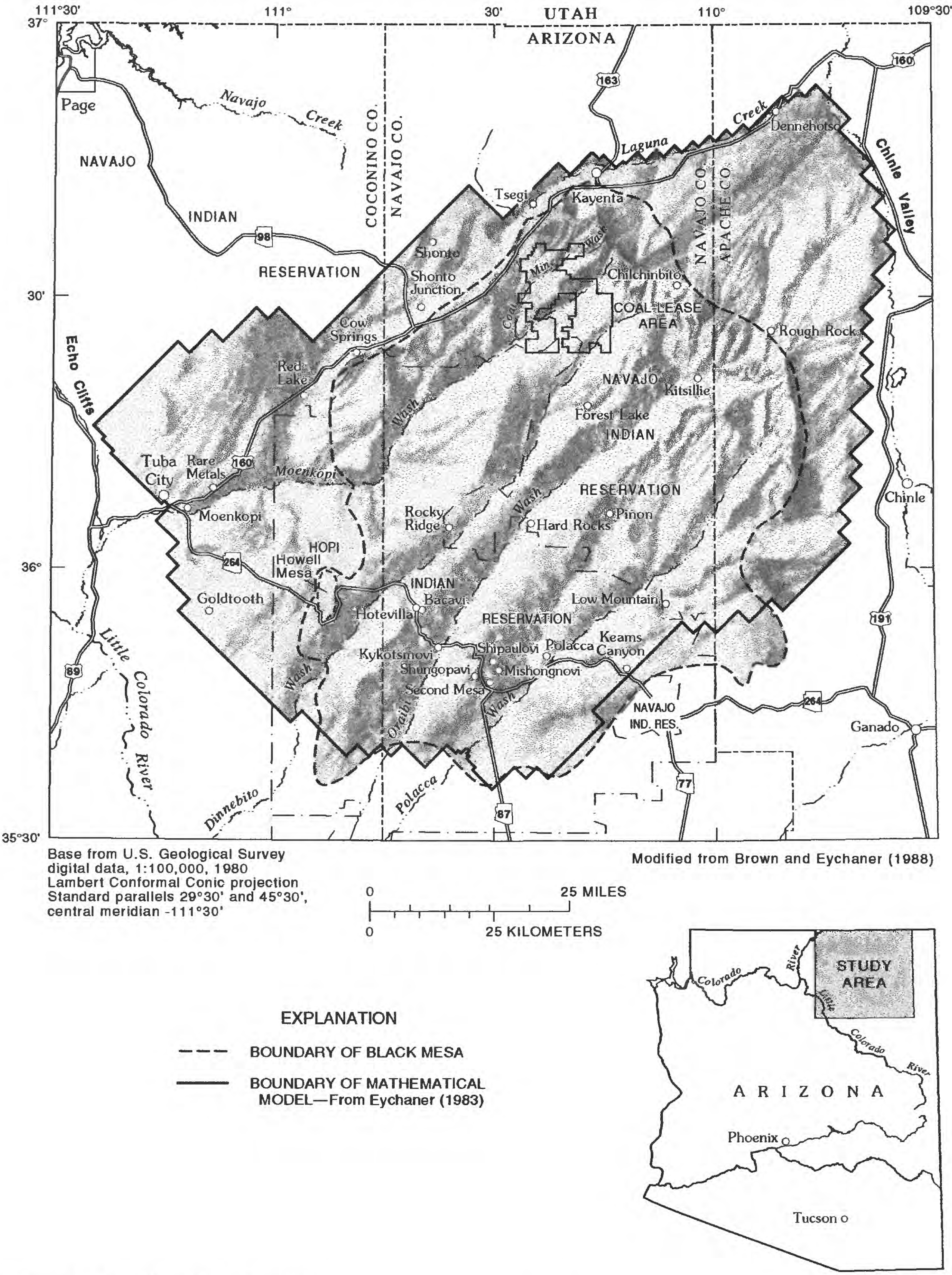


Figure 1. Location of study area.

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 28 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 95 acre-feet (acre-ft) in 1968 to a maximum of 4,740 acre-ft in 1982. The quantity of water pumped in 1996 was 4,010 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 decreased to about 3,030 acre-ft in 1996.

The Navajo Nation and Hopi Tribe have been concerned about the long-term effects of industrial withdrawals from the N aquifer on 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 1996. 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. Ground-water data from wells completed in the N aquifer include pumpage, water levels, and water chemistry. Surface-water data include discharge measurements at a continuous-record site.

Previous Investigations

Fourteen 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). 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; 1976–83; 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) 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.

HYDROLOGIC-DATA COLLECTION

In 1996, activities of the monitoring program included metered and estimated ground-water withdrawals, measurements of ground-water levels, flow measurements of springs and surface water, and collection of water-chemistry samples to detect changes in the hydrologic conditions in the N aquifer. Ground-water withdrawals, continuous-record water-level data from observation wells, and surface-water discharge data were collected from January to December 1996. Measurements of annual ground-water levels were made between November and December 1996. Chemical data are from ground-water samples collected in December 1996.

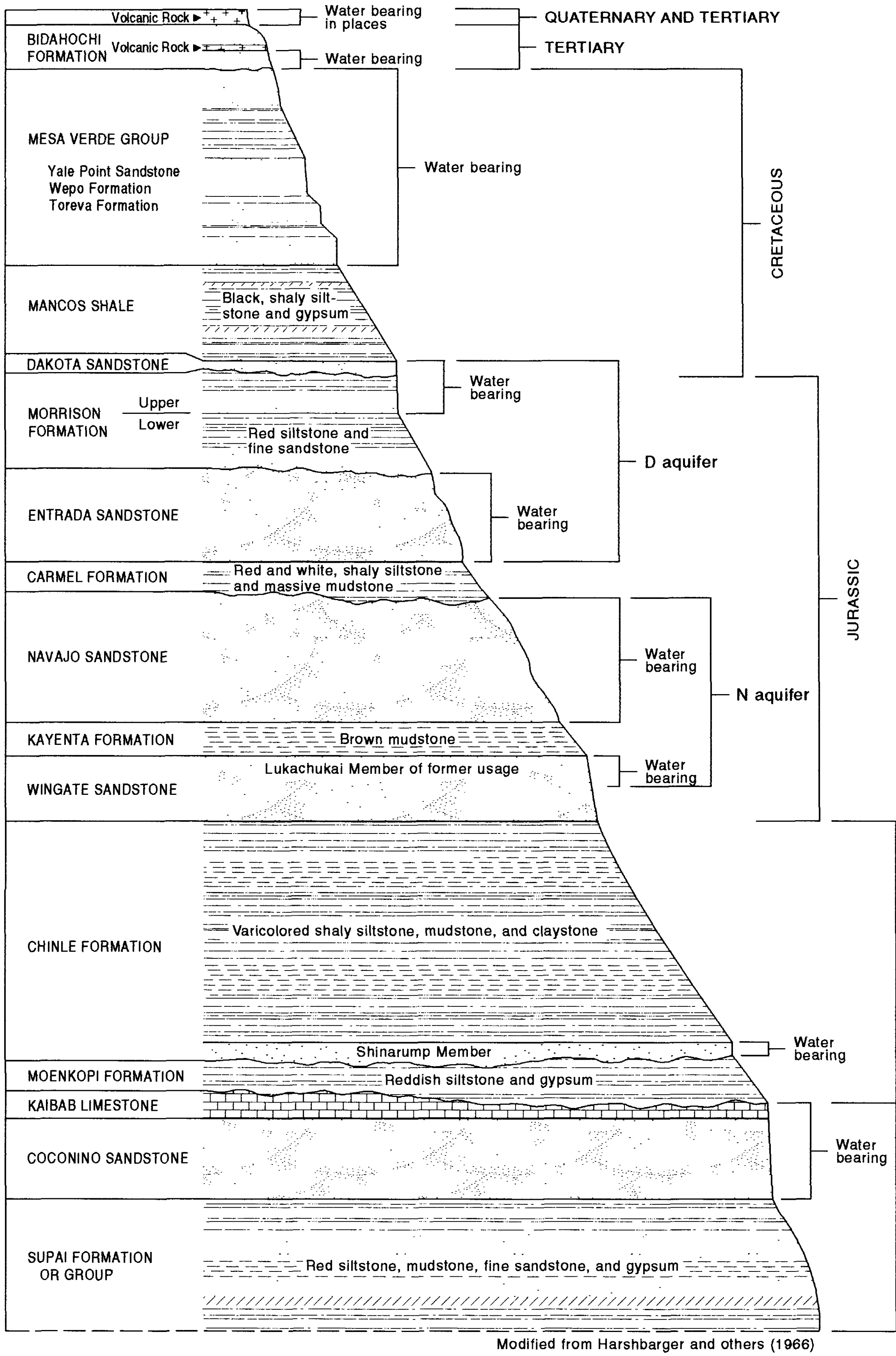


Figure 2. Rock formations of the Black Mesa area. The N aquifer is approximately 1,000 feet thick.

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 not measured or 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 1996 was about 7,040 acre-ft (table 1), which is less than a 1-percent decrease from total withdrawals in 1995. Pumpage from the confined part of the

Table 1. Withdrawals from the N aquifer, 1965–96

[Values are in 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	1981	4,010	960	1,000	5,970
1966	0	110	30	140	1982	4,740	870	965	6,575
1967	0	120	50	170	1983	4,460	1,360	1,280	7,100
1968	95	150	100	345	1984	4,170	1,070	1,400	6,640
1969	43	200	100	343	1985	2,520	1,040	1,160	4,720
1970	740	280	150	1,170	1986	4,480	970	1,260	6,710
1971	1,900	340	150	2,390	1987	3,830	1,130	1,280	6,240
1972	3,680	370	250	4,300	1988	4,090	1,250	1,310	6,650
1973	3,520	530	300	4,350	1989	3,450	1,070	1,400	5,920
1974	3,830	580	362	4,772	1990	3,430	1,170	1,210	5,810
1975	3,500	600	508	4,608	1991	4,020	1,140	3,360	8,520
1976	4,180	690	645	5,515	1992	3,820	1,180	1,410	6,410
1977	4,090	750	726	5,566	1993	3,700	1,250	1,570	6,520
1978	3,000	830	930	4,760	1994	4,080	1,210	1,600	6,890
1979	3,500	860	930	5,290	1995	4,340	1,220	1,510	7,070
1980	3,540	910	880	5,330	1996	4,010	1,380	1,650	7,040

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

[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, 1986–95.

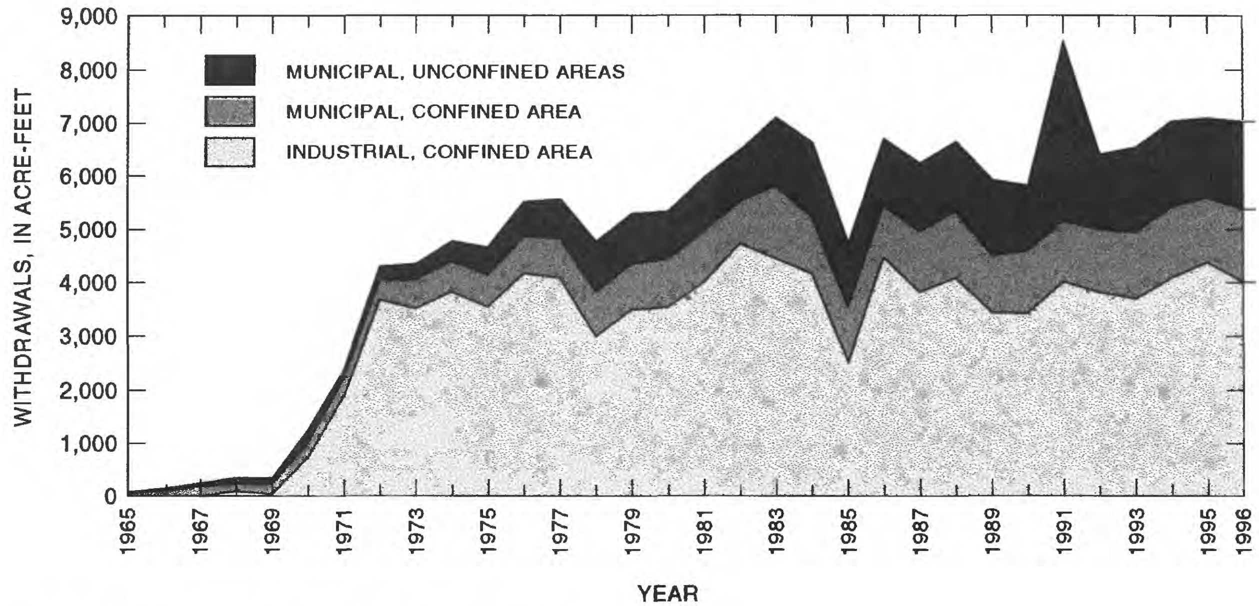


Figure 3. Withdrawals from the N aquifer, 1965–96.

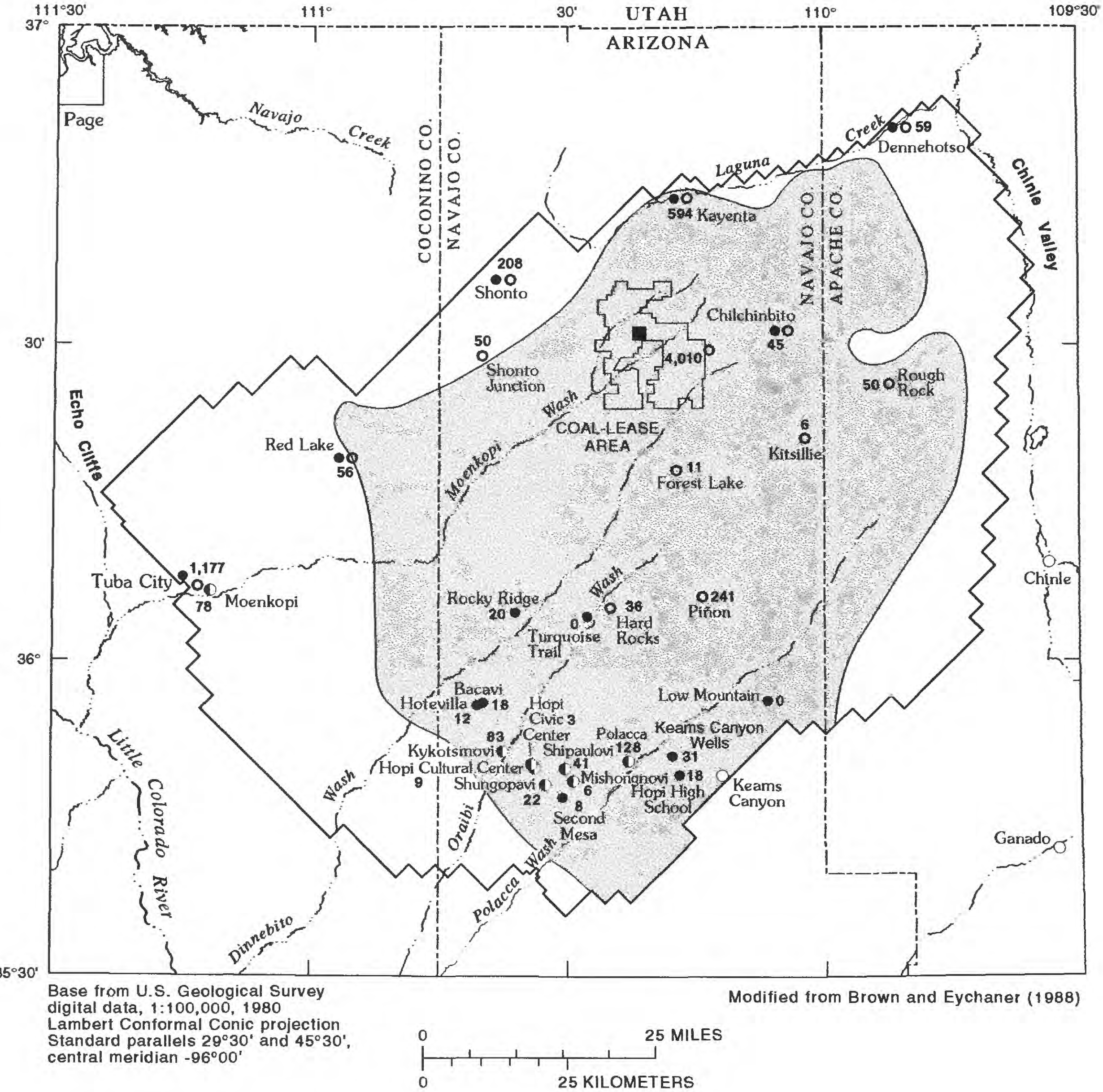
aquifer decreased by about 3 percent to 5,390 acre-ft and pumpage from the unconfined part of the aquifer increased by about 9 percent to 1,650 acre-ft. Industrial pumpage accounted for about 4,010 acre-ft, or about 57 percent of the total withdrawal, as compared to 61 percent in 1995. Municipal pumpage accounted for about 3,030 acre-ft and represents 43 percent of the total withdrawal as compared to 39 percent in 1995.

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 a network of 36 municipal and stock wells (table 3). Water-level changes from the earliest available data (prestress) through 1996 ranged from a rise of about 14 ft at well 1K-225 at Cow Springs to a decline of about 160 ft at Keams Canyon 2 well. In 1996, the maximum annual recorded rise in water level in the Black Mesa area was 10.7 ft at Keams Canyon 2 well. The maximum annual recorded water-level decline was 9.4 ft at well 10T-258 near Rough Rock. Piñon well PM6 recorded a decline of 13.8 ft over a 2-year period. Water-level declines from 1995 to 1996 were measured in 11 of 13 wells in the confined area, and the median change for all water levels was a decline of about 2.7 ft as compared with a decline of 1.8 ft from 1994 to 1995. Water-level declines from 1995 to 1996 in the unconfined area were measured in 11 of 18 wells, and the median change for all water levels was a decline of 0.5 ft as compared to a decline of 0.1 ft from 1994 to 1995.

Hydrographs of measured water levels in the six continuous-record observation wells (BM1 through BM6) are based on annual and continuous-record data beginning about 1963 at well BM3 (fig. 6). Water-level data for wells BM1, BM2, BM4, and BM5 began in 1972; water-level data for well BM6 began in 1977.

Since 1972, water levels in wells completed in the unconfined part of the N aquifer have risen by 0.1 ft in BM1 and 1.0 ft in BM4 (fig. 6). Water levels in wells completed in the confined part of the N aquifer have declined by about 70 ft in well BM2, 72 ft in well BM3, and 71 ft in well BM5 during that same period. Well BM6, also completed in the confined part of the N aquifer, has recorded a water-level decline of 87 ft since 1977. Records for the oldest well, BM3, indicate a water-level decline of 94 ft since 1963.



EXPLANATION

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

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

WELL-SYSTEM OWNER

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

Hotevilla ● 12 WITHDRAWALS FROM THE N AQUIFER—Hotevilla, is the village name; 12, is the total withdrawal in acre-feet for 1996. The total is cumulative at locations served by multiple well owners

Figure 4. Location of well systems monitored for withdrawals from the N aquifer, 1996.

Table 2. Withdrawals from the N aquifer by well system, 1996

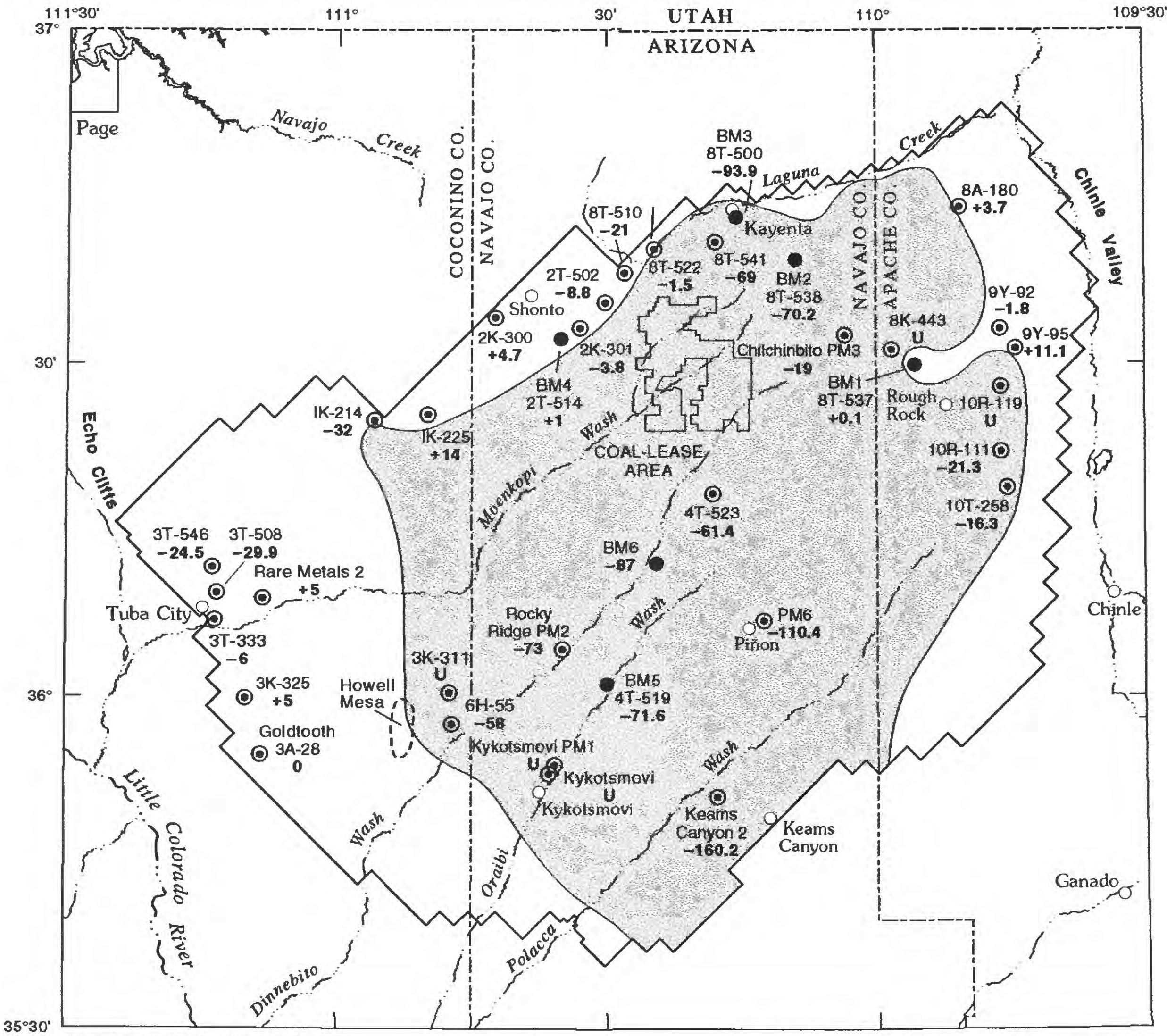
[Withdrawals, in acre-feet, are from flowmeter measurements. BIA, Bureau of Indian Affairs; NTUA, Navajo Tribal Utility Authority; USGS, U.S. Geological Survey; Peabody, Peabody Coal Company; Hopi, Hopi Village Administrations; BIA Roads]

Well system (one or more wells)	Owner	Source of data	Withdrawals: Confined aquifer	Withdrawals: Unconfined aquifer	Well system (one or more wells)	Owner	Source of data	Withdrawals: Confined aquifer	Withdrawals: Unconfined aquifer
Chilchinbito	BIA	USGS/BIA	4.3		Kayenta	NTUA	NTUA	514.1	
Dennehotso	BIA	USGS/BIA		27.8	Kitsillie	NTUA	NTUA	6.5	
Hopi High School	BIA	USGS/BIA	18		Piñon	NTUA	NTUA	241	
Hotevilla	BIA	USGS/BIA	12.4		Red Lake	NTUA	NTUA		48.7
Kayenta	BIA	USGS/BIA	80.2		Rough Rock	NTUA	NTUA	10.1	
Keams Canyon	BIA	USGS/BIA	31.3		Shonto	NTUA	NTUA		16.6
Low Mountain	BIA	USGS/BIA	[1]0		Shonto Junction	NTUA	NTUA		50.4
Piñon	BIA	USGS/BIA	[1]0		Tuba City	NTUA	NTUA		1,004.1
Red Lake	BIA	USGS/BIA		5.1	Mine Well Field	Peabody	Peabody	[2]4,013.1	
Rocky Ridge	BIA	USGS/BIA	20.4		Bacavi	Hopi	USGS/Hopi	18.3	
Rough Rock	BIA	USGS/BIA	39.4		Hopi Civic Center	Hopi	USGS/Hopi	2.8	
Second Mesa	BIA	USGS/BIA	7.9		Hopi Cultural Center	Hopi	USGS/Hopi	8.8	
Shonto	BIA	USGS/BIA		191.3	Kykotsmovi	Hopi	USGS/Hopi	82.8	
Tuba City	BIA	USGS/BIA		172.8	Mishongnovi	Hopi	USGS/Hopi	5.9	
Turquoise Trail	BIA	BIA Roads	0		Moenkopi	Hopi	USGS/Hopi		[3]77.5
Chilchinbito	NTUA	NTUA	40.5		Polacca	Hopi	USGS/Hopi	[4]128	
Dennehotso	NTUA	NTUA		59	Shipaulovi	Hopi	USGS/Hopi	40.7	
Forest Lake	NTUA	NTUA	11.1		Shungopovi	Hopi	USGS/Hopi	22.2	
Hard Rocks	NTUA	NTUA	35.8						

[1]Well taken out of service.
[2] Industrial pumpage.
[3]Total pumpage may be greater than that shown because of possible meter malfunction.
[4] Estimated. Well PM4 not metered. Total includes 88 acre-feet from wells 5 and 6 and may include water from the D aquifer.

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



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

Modified from Brown and Eychaner (1988)

0 — 25 MILES
0 — 25 KILOMETERS

EXPLANATION

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

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

4T-523
-61.4
WELL IN WHICH DEPTH TO WATER WAS MEASURED ANNUALLY—First entry, 4T-523, is Bureau of Indian Affairs site number; second entry, -61.4, is change in water level, in feet, between measurements made during the prestress period and measurements made during 1996. U, unable to measure

BM2
8T-538
-70.2
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, -70.2, is change in water level, in feet, from earliest available date to 1996

Figure 5. Water-level changes in wells completed in the N aquifer from the start of data collection through 1996.

Table 3. Water-level changes in wells completed in the N aquifer, 1995–96

[---, no data]

Well system or location name	U.S. Bureau of Indian Affairs site number	Change in water level from preceding water year, in feet		Water level, in feet below land surface, 1996	Prestress water level, in feet below land surface	Change in water level from prestress to 1996, in feet[1]
		1995	1996			
Unconfined						
BM1[2]	8T-537	-0.2	0	373.9	374.0	+0.1
BM4[2]	2T-514	-.1	0	216.0	217	+1
Cow Springs	1K-225	-.1	+.4	46.5	60	+14
Goldtooth	3A-28	-.1	-.5	130.1	230	0
Long House Valley	8T-510	-1.2	-.7	120.5	99	-21
Marsh Pass	8T-522	-1.0	-1.3	127.0	125.5	-1.5
Northeast Rough Rock	8A-180	0	0	43.2	46.9	+3.7
Rough Rock	9Y-95	+8.3	-2.9	108.4	119.5	+11.1
Do.	9Y-92	+1.8	-3.5	170.6	168.8	-1.8
Shonto	2K-300	+.4	-.2	171.8	176.5	+4.7
Shonto Southeast	2K-301	+.3	-.5	287.7	283.9	-3.8
Do.	2T-502	+2.1	-.5	414.6	405.8	-8.8
Tuba City	3T-333	+1.5	-1.2	29.0	23.0	-6
Do.	3K-325	-1.1	+.1	202.6	208	+5
Do.	Rare Metals 2	-1.1	+1.3	52.3	57	+5
Tuba NTUA 1	3T-508	-.5	-3.0	58.9	29.0	-29.9
Tuba NTUA 4	3T-546	+.3	-2.4	58.2	33.7	-24.5
White Mesa Arch	1K-214	-.5	+.5	220.4	188	-32
Confined						
BM2[2]	8T-538	-2.5	-1.6	195.2	125.0	-70.2
BM3[2]	8T-500	-12.3	-2.6	153.9	60.0	-93.9
BM5[2]	4T-519	-1.8	-2.7	395.4	323.8	-71.6
BM6[2]	BM6	-3.4	-3.8	822.6	735.6	-87
Chilchinbito	PM3	+3.6	-2.5	424.3	405	-19
Forest Lake NTUA 1	4T-523	-3.8	-5.1	1,157.4	1,096.0	-61.4
Howell Mesa	6H-55	-.3	-.9	269.5	212	-58
Do.	3K-311	[3]+2.9	([4])	([4])	463	---
Kayenta West	8T-541	+.4	-7.0	296.2	227	-69
Keams Canyon	2	-14.1	+10.7	452.7	292.5	-160.2
Kykotsmovi	PM1	([4])	([4])	([4])	220	---
Do.	PM3	([4])	([4])	([4])	210	---
Piñon	PM6	([4])	[3]-13.8	854.0	743.6	-110.4
Rocky Ridge	PM2	-2.1	-2.9	504.9	432	-73
Rough Rock	10R-119	-.2	([4])	([4])	256.6	---
Do.	10T-258	+.2	-9.4	317.3	301.0	-16.3
Do.	10R-111	-1.1	+8.2	191.3	170.0	-21.3
Sweetwater Mesa	8K-443	-2.4	([4])	([4])	529.4	---

[1]Change in water level is reported to the same precision as the prestress water level.
[2]Continuous recorder.
[3]Change in water level from last measurement two or more years earlier.
[4]Unable to measure.

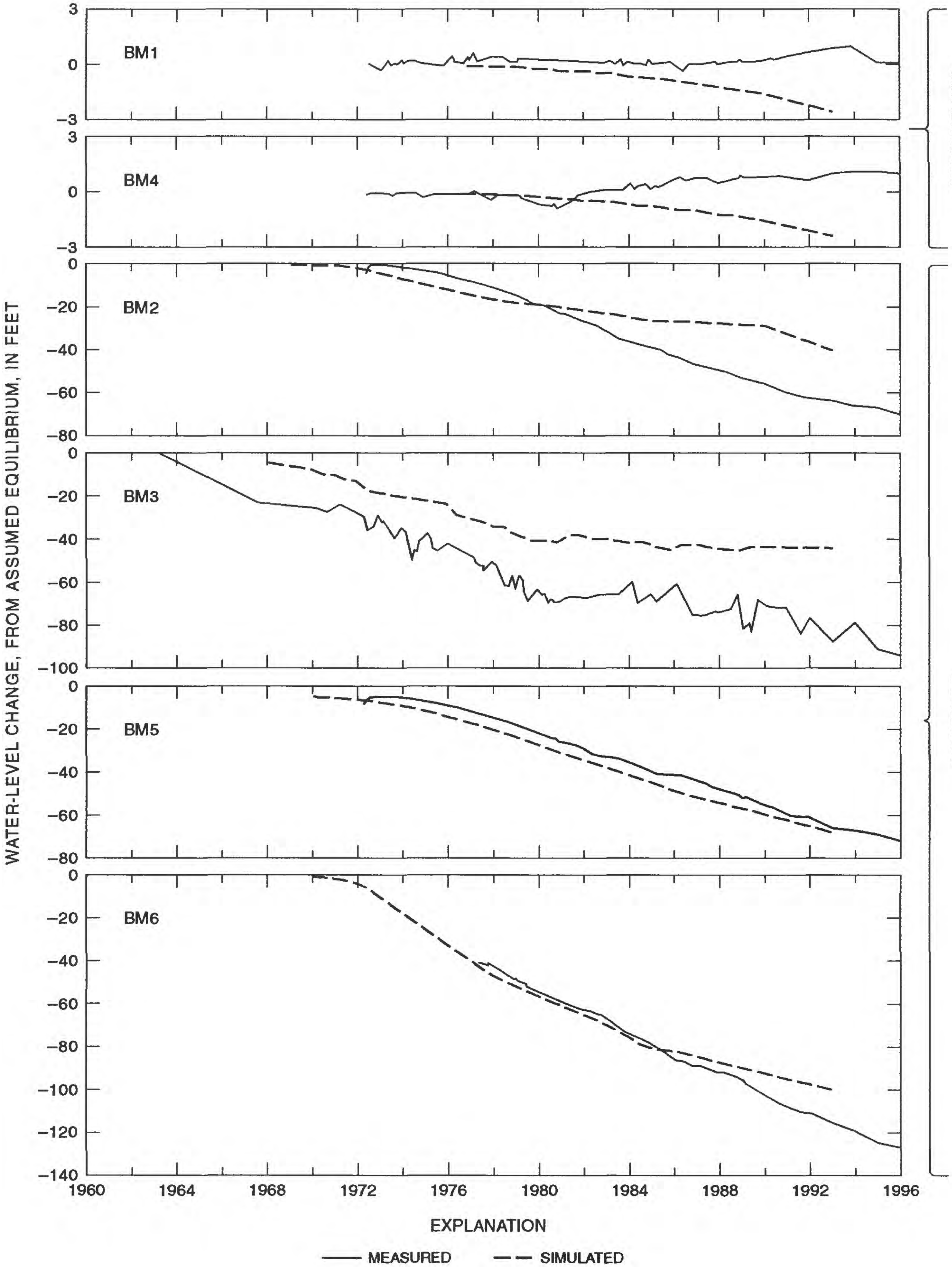


Figure 6. Measured water-level changes in continuous-record observation wells BM1 through BM6, 1963–96, and simulated water-level changes from Littin and Monroe (1996).

(09401260; fig. 7, table 4), Laguna Creek at Dennehotso (09379180; fig. 7, table 5), Dinnebito Wash near Sand Springs (09401110; fig. 7, table 6), and Polacca Wash near Second Mesa (09400568; fig. 7, table 7). The Dinnebito and Polacca Wash streamflow-gaging stations monitor spring discharge along the southern boundary of Black Mesa. Low-flow calculations for these streams are based on discharge measurements made during November through February. Discharge data collected during these months 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 average low-flow discharge at the Moenkopi station was 2.3 cubic feet per second (ft^3/s). The mean daily discharge for the same period was 2.2 ft^3/s and is based on continuous-record data. Mean daily discharges for previous water 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), and Smith and others (1993–96). On the basis of these data, the average mean daily discharge (as low flow) in Moenkopi Wash has remained at about 3 ft^3/s since the streamflow-gaging station was installed in 1976. The Laguna Creek station became operational in July 1996. The average low-flow discharge at this station was 2.3 ft^3/s, which was based on measurements made during November and December[2] 1996. The mean daily discharge for the same period was 2.5 ft^3/s, which was based on provisional data. The Dinnebito and Polacca 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 network in October 1996. The average low-flow discharge was 0.44 ft^3/s at the Dinnebito station and 0.16 ft^3/s at the Polacca station. The average mean daily discharge for Dinnebito Wash during November through February was 0.50 ft^3/s, which was based on continuous-record data for calendar years 1994 through 1996. The average mean daily discharge for Polacca Wash was 0.27 ft^3/s, which was based on continuous-record data for calendar years 1995 and 1996.

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 1996 (fig. 7, table 8). Discharge from Burro Spring was measured at 0.4 gallon per minute (gal/min). Discharge at the unnamed spring near Dennehotso was measured at 15.7 gal/min. Discharge from Moenkopi School Spring was 10 gal/min as compared with 12.1 gal/min measured in 1995. Discharge at Pasture Canyon Spring was measured volumetrically at 38 gal/min at the spring.

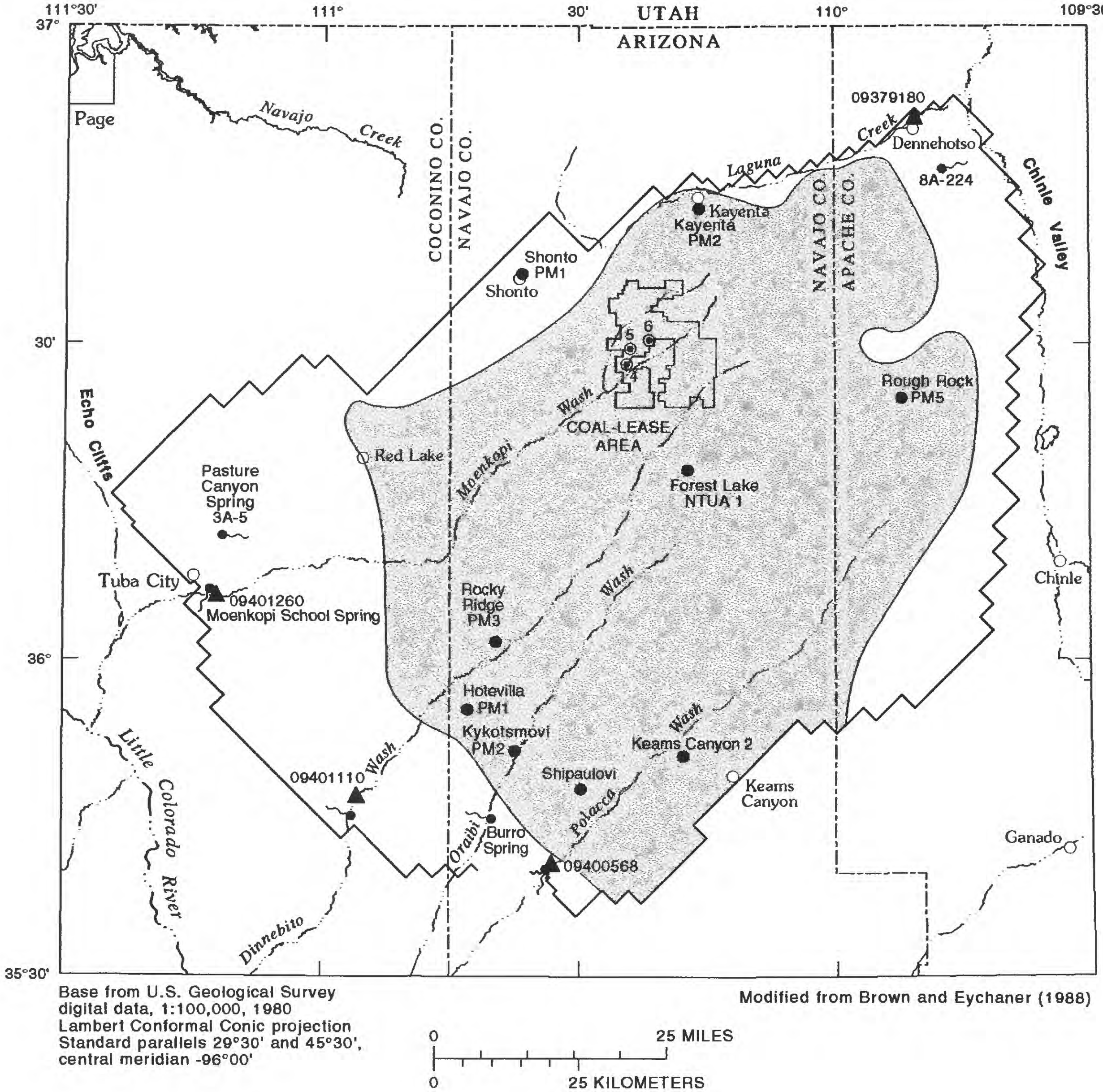
Water Chemistry

Water from Wells Completed in the N Aquifer

All but one well (Shonto PM2) sampled in 1996 are completed in the confined part of the N aquifer (fig. 7). 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. Sodium bicarbonate water generally occurs elsewhere throughout the area. All but two (Shonto PM2 and Kayenta PM2) of the 12 wells sampled contained a sodium bicarbonate water. Historically, water from Shonto PM2 and Kayenta PM2 have been a calcium bicarbonate type (Littin, 1993). Although the Kayenta PM2 well penetrates the confined part of the N aquifer, the water is chemically similar to water from wells and springs associated with the unconfined areas of the N aquifer (fig. 8).

Dissolved-solids concentrations in water from wells completed in the N aquifer ranged from 122 milligrams per liter (mg/L) at Peabody well No. 6 to 634 mg/L at the Rough Rock well PM5 (fig. 9; tables 9 and 10). Long-term comparison of dissolved-solids concentrations in water collected

[2]Effluent is continuously discharged into Laguna Creek at Kayenta during the winter months according to the Navajo Tribal Utility Authority. Discharge was 0.53 cubic foot per second in November 1994.



EXPLANATION

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

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Shonto PM1 — MUNICIPAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—Shonto PM1 is well name

4 — INDUSTRIAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—4 is well number

Pasture Canyon Spring 3A-5 — SPRING AT WHICH DISCHARGE WAS MEASURED AND (OR) WATER-CHEMISTRY SAMPLE WAS COLLECTED—Number is spring identification number

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

Figure 7. Surface-water and water-chemistry data-collection sites, 1996.

Table 4. Discharge data, Moenkopi Wash at Moenkopi, calendar year 1996

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1996 DAILY MEAN VALUES												
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	2.5	2.6	[2]2.0	2.1	1.6	0.00	0.00	0.00	[2]0.00	0.23	1.6	3.9
2	2.1	2.3	[2]2.0	2.1	1.7	.00	.00	.00	[2].00	[2].09	1.3	4.3
3	2.8	[2]2.3	2.1	2.1	1.6	.00	.00	.00	[2].00	.12	1.3	[2]3.5
4	2.8	[2]2.3	2.1	2.1	1.4	.00	.00	.00	.00	1.8	1.1	2.8
5	2.5	[2]2.3	2.1	2.1	1.2	.00	.00	.00	.00	.91	.91	3.1
6	[2]2.0	2.3	2.1	2.1	1.2	.00	.00	.00	.00	.58	.91	2.8
7	[2]2.0	2.2	2.1	1.9	1.2	.00	.00	.00	.00	.46	.91	2.4
8	1.7	2.3	2.4	2.0	.99	.00	.00	.00	.00	.35	.91	2.1
9	1.9	2.5	2.4	2.4	.92	.00	.00	.00	.00	.35	.74	1.8
10	2.4	2.4	2.4	1.8	.95	.00	.00	.00	.00	.23	[2].74	[2]1.8
11	[2]2.2	2.4	2.2	1.8	1.1	.00	.00	.00	.00	.23	.91	2.1
12	[2]2.2	2.6	2.1	1.8	1.0	.00	.00	.00	.00	.35	.91	2.4
13	[2]2.2	2.6	2.1	1.8	1.1	.00	.00	.00	9.2	.23	1.6	2.4
14	[2]2.2	2.4	1.9	1.8	.87	.00	.00	.00	187	.35	[2]1.6	2.4
15	[2]2.2	2.6	1.8	1.8	.62	.00	.00	.00	57	.58	1.8	2.1
16	[2]2.2	2.9	1.8	1.8	.41	.00	.00	.00	4.6	.58	2.1	1.6
17	2.3	2.7	2.0	1.8	.22	.00	.00	.00	2.0	.35	[2]2.1	1.6
18	2.3	2.6	1.9	1.8	.24	.00	.00	.00	1.5	.12	[2]2.1	1.1
19	2.0	2.4	1.8	2.0	[2].00	.00	.00	.00	1.4	.35	2.4	1.6
20	[2]2.3	2.5	1.9	2.1	[2].00	.00	.00	.00	.91	.35	2.4	1.1
21	2.6	2.2	2.1	1.8	[2].00	.00	.00	.00	.77	[2].35	[2]3.1	1.8
22	2.2	2.2	2.1	1.8	[2].00	.00	.00	.00	.59	.23	3.5	2.4
23	2.9	1.9	2.1	1.7	[2].00	.00	.00	.00	.37	.35	4.7	3.1
24	1.7	2.0	1.9	1.8	[2].00	.00	.00	.00	.18	.46	2.8	1.6
25	2.5	2.1	1.8	1.7	[2].00	.00	.00	13	.14	.46	2.4	1.3
26	[2]2.2	2.1	2.0	1.9	.53	.00	.00	36	.32	.46	2.4	1.3
27	1.8	[2]2.1	2.1	1.9	.99	.00	.00	19	.72	.58	2.4	[2]1.6
28	2.3	2.1	2.1	1.6	.74	.00	.00	3.0	.35	.74	2.4	2.1
29	[2]2.5	[2]2.0	2.1	1.3	.54	.00	.00	[2].60	.22	.91	1.8	3.5
30	[2]2.5	---	2.1	1.4	.18	.00	.00	[2].40	.35	1.1	2.1	2.0
31	3.1	---	2.1	---	[2].00	---	.00	[2].20	---	.74	---	.91
TOTAL	71.1	67.9	63.7	56.1	21.3	0.00	0.00	72.20	267.62	15.04	56.0	68.87
MEAN	2.29	2.34	2.05	1.87	.69	.00	.00	2.33	8.92	.49	1.87	2.21
MAX	3.1	2.9	2.4	2.4	1.7	.00	.00	36	187	1.8	4.7	4.3
MIN	1.7	1.9	1.8	1.3	[2].00	.00	.00	.00	.00	.12	.74	.91
AC-FT	141	135	126	111	42	.00	.00	143	531	29.9	110.9	135.6

CALENDAR YEAR 1996 TOTAL 759.48 MEAN 2.08 MAXIMUM 187 MINIMUM 0.00 ACRE-FT 1,506

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

[2]Estimated.

Table 5. Discharge data, Laguna Creek at Dennehotso, calendar year 1996

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1996 DAILY MEAN VALUES												
Day	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July[1]**	**Aug.[1]**	**Sept.[1]**	**Oct.[1]**	**Nov.[1]**	**Dec.[1]**
1	---	---	---	---	---	---	---	0.0	1.0	0.0	3.5	2.4
2	---	---	---	---	---	---	---	0.0	.44	0.0	2.4	.08
3	---	---	---	---	---	---	---	0.0	[2].23	1.6	2.6	.30
4	---	---	---	---	---	---	---	0.0	[2].34	2.0	2.4	.23
5	---	---	---	---	---	---	---	0.0	.12	5.5	4.6	.03
6	---	---	---	---	---	---	---	0.0	.07	2.4	5.0	.97
7	---	---	---	---	---	---	---	0.0	1.2	1.6	2.6	.61
8	---	---	---	---	---	---	---	0.0	.12	1.0	1.7	11
9	---	---	---	---	---	---	---	0.0	.05	.47	1.8	4.8
10	---	---	---	---	---	---	---	0.0	.01	.16	1.7	2.2
11	---	---	---	---	---	---	---	0.0	0.0	.54	2.7	3.0
12	---	---	---	---	---	---	---	0.0	[2]13.2	.37	2.3	4.6
13	---	---	---	---	---	---	---	0.0	[2]44.4	.31	2.8	3.0
14	---	---	---	---	---	---	---	0.0	68	.22	3.4	1.0
15	---	---	---	---	---	---	---	0.0	[2]62.2	.17	3.7	.16
16	---	---	---	---	---	---	---	0.0	36	.22	4.7	.06
17	---	---	---	---	---	---	---	0.0	5.3	.33	6.0	0.0
18	---	---	---	---	---	---	---	0.0	1.1	.43	8.0	0.0
19	---	---	---	---	---	---	---	0.0	[2]1.6	.36	4.3	0.0
20	---	---	---	---	---	---	---	0.0	[2]1.8	.24	1.2	0.0
21	---	---	---	---	---	---	---	0.0	1.2	.27	.95	0.0
22	---	---	---	---	---	---	---	5.4	.89	.10	1.2	0.0
23	---	---	---	---	---	---	---	1.9	.33	.21	13	0.0
24	---	---	---	---	---	---	---	2.1	.22	.72	20	0.0
25	---	---	---	---	---	---	0.0	[2]14.5	0.1	.64	3.2	0.0
26	---	---	---	---	---	---	0.0	[2]37.4	0.0	1.7	.91	0.0
27	---	---	---	---	---	---	0.0	[2]9.7	0.0	1.1	.51	1.1
28	---	---	---	---	---	---	0.0	3.9	0.0	32	.26	.22
29	---	---	---	---	---	---	0.0	2.3	0.0	43	.39	.83
30	---	---	---	---	---	---	0.0	1.4	0.0	14	2.7	.73
31	---	---	---	---	---	---	0.0	1.9	---	4.1	---	1.4
TOTAL	---	---	---	---	---	---	---	80.5	239.92	115.76	110.52	38.72
MEAN	---	---	---	---	---	---	---	2.6	8	3.73	3.68	1.25
MAX	---	---	---	---	---	---	---	37.4	68	43	20	11
MIN	---	---	---	---	---	---	---	.00	.00	.00	.26	.00
AC-FT	---	---	---	---	---	---	---	159.9	477	230	219	77

CALENDAR YEAR 1996 TOTAL MEAN MAXIMUM MINIMUM 0.00 ACRE-FT

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

Table 6. Discharge data, Dinnebito Wash near Sand Springs, calendar year 1996

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1996 DAILY MEAN VALUES												
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	0.45	0.49	0.45	0.43	0.36	0.31	0.23	0.25	0.40	[2]0.25	0.32	0.42
2	.40	.46	.45	.41	.35	.27	.24	.26	.44	[2].25	.34	.44
3	.41	.45	.49	.44	.33	.28	.25	.29	10	[2].26	.35	.38
4	.46	.45	.49	.45	.33	.27	.24	.27	1.3	.37	.35	.39
5	.43	.47	.44	.45	.34	.27	.25	.27	.46	.25	.34	.37
6	.42	.48	.45	.42	.35	.26	.26	.30	.33	.38	.34	.39
7	.42	.48	.47	.42	.31	.28	5.4	.33	.30	.30	.32	.39
8	.43	.47	.50	.42	.29	.29	1.3	.34	.30	[2].28	.33	.37
9	.43	.47	.49	.41	.29	.26	.34	1.0	.30	[2].34	.42	.37
10	.47	.47	.49	.39	.31	.25	.28	.51	.33	[2].36	.37	.38
11	.43	.47	.47	.38	.32	.26	.26	.42	.42	.33	.36	.40
12	.45	.47	.46	.41	.32	.27	.27	.38	28	.32	.37	.35
13	.45	.48	.54	.39	.32	.30	.28	.37	56	.30	.37	.37
14	.46	.47	.50	.39	.31	.31	.27	.40	98	.30	.37	.37
15	.48	.47	.49	.41	.32	.28	.25	.44	308	[2].31	.36	.31
16	.49	.47	.47	.40	.33	.25	.26	.45	20	[2].31	.39	.33
17	.51	.47	.44	.37	.33	.23	.29	.43	8.4	[2].32	.34	.32
18	.41	.46	.45	.37	.33	.22	.28	1.0	3.6	[2].31	.39	.24
19	.47	.45	.48	.39	.28	.22	.27	.68	1.6	[2].32	.39	.26
20	.43	.44	.48	.38	.30	.22	.26	.50	.46	[2].30	.38	.29
21	.42	.43	.49	.37	.32	.22	.23	.54	.45	[2].32	.38	.37
22	.46	.40	.47	.39	.30	.21	.23	.50	.52	[2].32	.53	.39
23	.39	.43	.43	.39	.31	.21	.23	.50	.28	.31	.44	.42
24	.44	.44	.46	.38	.32	.20	.24	2.4	[2].25	.33	.24	.37
25	.45	.44	.47	.36	.34	.20	.25	65	[2].25	.32	.24	.35
26	.41	.52	.47	.37	.36	.23	.30	39	[2].25	.35	5.1	.35
27	.44	.46	.46	.37	.35	.25	.28	8.3	[2].25	.35	3.0	.42
28	.50	.49	.42	.34	.32	.25	.26	3.3	[2].25	.34	.47	.43
29	.48	.48	.46	.36	.32	.26	.26	.95	[2].25	.33	.54	.41
30	.49	---	.46	.39	.31	.23	.28	.45	[2].25	.33	.48	.42
31	.50	---	.45	---	.32	---	.27	.71	---	.32	---	.41
TOTAL	13.88	13.43	14.54	11.85	9.99	7.56	14.31	130.54	541.64	9.78	18.62	11.48
MEAN	.45	.46	.47	.39	.32	.25	.46	4.21	18.1	.32	.62	.37
MAX	.51	.52	.54	.45	.36	.31	5.4	65	308	.38	5.1	.44
MIN	.39	.40	.42	.34	.28	.20	.23	.25	.25	.25	.24	.24
AC-FT	28	27	29	24	20	15	28	259	1,070	20	37	23

CALENDAR YEAR 1996 TOTAL 797.62 MEAN 2.20 MAXIMUM 308 MINIMUM 0.20 ACRE-FT 1,580

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

Table 7. Discharge data, Polacca Wash near Second Mesa, calendar year 1996

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1996 DAILY MEAN VALUES												
Day	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**[1]	**Nov.**[1]	**Dec.**[1]
1	[2]0.40	0.24	0.23	0.24	0.19	0.10	0.05	0.03	0.04	0.06	0.09	0.14
2	[2].35	.20	.22	.22	.19	.10	.05	.03	.04	.06	.09	.13
3	[2].35	.17	.23	.23	.19	.09	.05	.03	24	.07	.09	.13
4	[2].35	[2].15	.23	.26	.17	.09	.05	.03	2.3	11	.09	.13
5	[2].30	.19	.20	.27	.18	.08	.05	.04	1.2	3.1	.08	.12
6	[2].30	.18	.21	.25	.18	.08	.05	.04	.97	.58	.08	.14
7	[2].30	.19	.20	.25	.17	.08	.05	.05	3.0	.08	.08	.13
8	[2].25	.18	.23	.27	.15	.08	.04	.05	1.8	.07	.09	.13
9	[2].25	.19	.22	.26	.15	.07	.04	.06	.85	.07	.09	.13
10	.28	.19	.22	.25	.15	.07	.04	.23	.10	.08	.10	.14
11	[2].20	.20	.21	.22	.16	.07	.04	[2].05	.16	.07	.10	.14
12	.27	.21	.22	.25	.16	.07	.04	[2].05	.44	.07	.10	.14
13	.28	.21	.27	.22	.15	.08	.04	[2].05	10	.08	.10	.13
14	[2].25	.21	.27	.23	.15	.08	.04	[2].05	40	.08	.10	.12
15	.22	.21	.25	.25	.14	.08	.04	[2].05	[2]206	.08	[2].10	.13
16	.29	.21	.25	.26	.12	.07	.04	[2].05	5.9	.08	.11	.16
17	.28	.21	.23	.22	.11	.06	.04	[2].05	2.2	.08	.10	.12
18	.22	.22	.22	.23	.12	.06	.05	[2].05	34	.08	.10	.10
19	[2].20	.20	.23	.22	.10	.07	.04	[2].05	11	.08	.11	.12
20	.22	.20	.25	.21	.10	.07	.04	[2].05	2.1	.09	[2].11	.13
21	[2].20	.20	.24	.20	.10	.06	.03	[2].05	.64	.08	.11	.19
22	[2].20	.21	.26	.21	.10	.06	.03	[2].05	.17	.08	.16	.23
23	.19	.20	.23	.22	.09	.06	.03	[2].05	.06	.08	.17	.21
24	.25	.23	.26	.22	.10	.05	.03	.04	.06	.08	.10	.15
25	[2].20	.23	.26	.20	.13	.05	.03	.07	.06	.08	.10	.16
26	[2].20	.20	.25	.20	.13	.06	.03	7.0	.16	.09	.39	.17
27	[2].20	.26	.25	.19	.14	.06	.03	1.0	.06	.09	.16	.17
28	[2].20	.24	.24	.18	.12	.06	.03	2.3	.06	.10	.12	.16
29	.25	.25	.26	.18	.10	.06	.03	7.2	.06	.09	.23	.17
30	.24	---	.27	.19	.10	.05	.03	1.4	.06	.09	.16	.17
31	.21	---	.26	---	.10	---	.03	.08	---	.09	---	.17
TOTAL	17.90	6.00	7.37	6.80	4.24	2.12	1.23	20.33	347.49	16.91	3.61	4.56
MEAN	.25	.21	.24	.23	.14	.07	.04	.66	11.6	.55	.12	.15
MAX	.40	.26	.27	.27	.19	.10	.05	7.2	206	11	.39	.23
MIN	.19	.15	.20	.18	.09	.05	.03	.03	.04	.06	.08	.10
AC-FT	16	12	15	13	8.4	4.2	2.4	40	689	34	7.2	9.1

CALENDAR YEAR 1996 TOTAL 428.56 MEAN 1.19 MAXIMUM 206 MINIMUM 0.03 ACRE-FT 850.3

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

[2]Estimated.

Table 8. Discharge measurements of selected springs, 1952–96

[---, no data]

Spring name	U.S. Bureau of Indian Affairs site number	Rock Formations	Date of measurement	Discharge, in gallons per minute
Burro Spring	6M-31	Navajo Sandstone	12–15–89	0.4
			12–13–90	.4
			03–18–93	.3
			12–08–94	.2
			12–17–96	.4
Unnamed spring near Dennehotso	8A-224	Navajo Sandstone	10–06–54	[1]1
			06–27–84	[1].2
			11–17–87	.5
			03–26–92	.2
			10–22–93	14.4
			12–05–95	17
			12–19–96	15.7
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
Pasture Canyon Spring	3A-5	Navajo Sandstone and alluvium	08–10–54	174
			07–28–82	135
			05–19–86	166
			11–18–88	211
			03–24–92	[3]233
			10–12–93	[3]211
			12–04–95	[4]38
			12–16–96	[4]38

[1]Estimated.

[2]Discharge measured at water-quality sampling site only and does not represent the total discharge from the Moenkopi School Spring system.

[3]Discharge 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 of 38 gallons per minute 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.

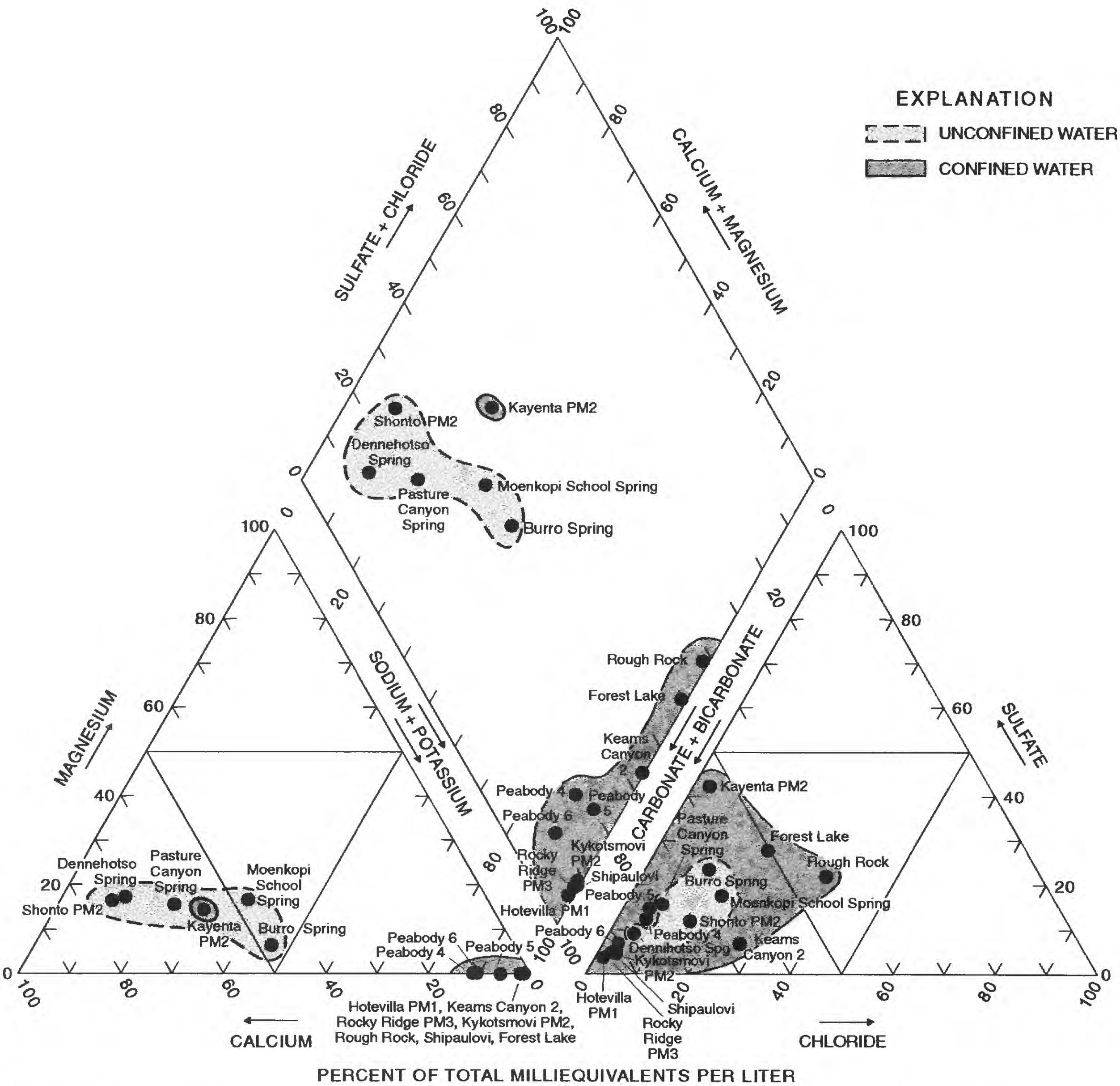


Figure 8. Relative compositions of ground water from the N aquifer in the Black Mesa area.

from Keams Canyon 2 and Kayenta PM2 wells[3] shows no significant change from 1983 to 1996 (fig. 10; table 10). From 1991 to 1993, an increase in concentrations of dissolved solids in water from the Forest Lake well NTUA 1 has been observed. Since 1993, dissolved-solids concentrations have averaged about 370 mg/L as compared to 250 mg/L before that time.

Surface Water

Four springs were selected for water-chemistry analyses as part of the monitoring program during 1996 (figs. 7, 8, and 9; table 11). The springs, all of which discharge from the Navajo Sandstone, are

[3]Well selection was based on sample frequency, length of record, consistency in sampling conditions, and representative spatiality.

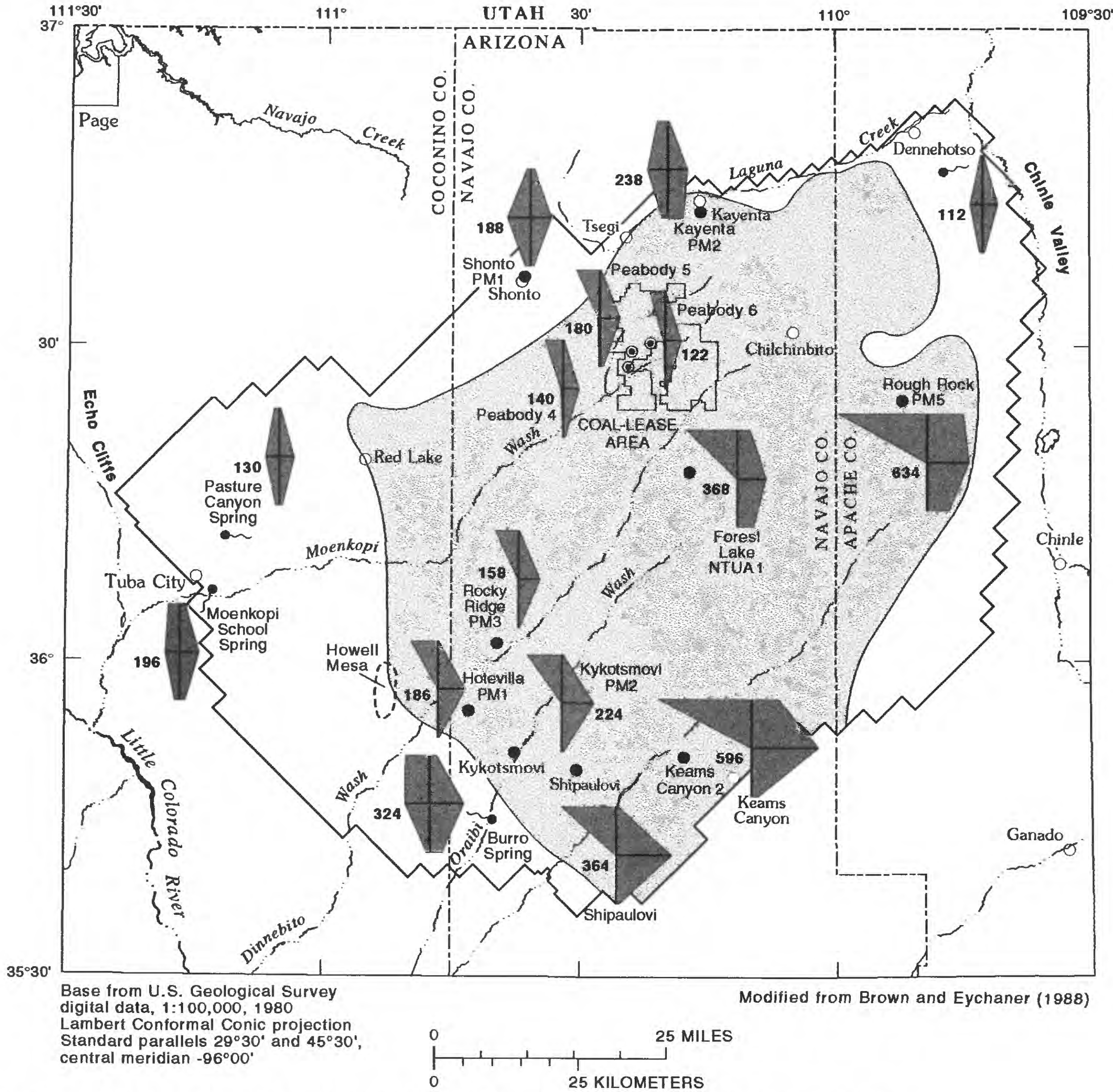


Figure 9. Water chemistry and distribution of dissolved solids in the N aquifer, 1996.

Burro Spring near Kykotsmovi, an unnamed spring near Dennehotso, Moenkopi School Spring at Moenkopi, and Pasture Canyon Spring near Tuba City.

Historically, the chemistry of water from these springs has not changed significantly although there has been some increase in dissolved-solids concentrations (table 12). Waters from Moenkopi School Spring, Pasture Canyon Spring, and the unnamed spring near Dennehotso have been calcium bicarbonate types; and water from Burro Spring has been a sodium bicarbonate type. In 1996, dissolved-solids concentrations in water from the four springs ranged from 112 mg/L at the unnamed spring near Dennehotso to 324 mg/L at Burro Spring.

SUMMARY

The N aquifer is a major source of water for industrial and municipal uses in the Black Mesa

EXPLANATION

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

CONFINED

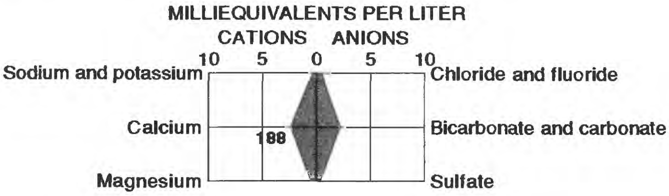
UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Shonto PM1 ● MUNICIPAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—Shonto PM1 is well name

◉ INDUSTRIAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED

Pasture Canyon Spring SPRING AT WHICH DISCHARGE WAS MEASURED AND OR WATER-CHEMISTRY SAMPLE WAS COLLECTED



WATER-CHEMISTRY DIAGRAM—Shows major chemical constituents in milliequivalents per liter. The diagrams are in a variety of shapes and sizes, and provide a means of comparing, correlating, and characterizing types of water. Number, **188**, is dissolved-solids concentration, in milligrams per liter

Figure 9. Continued.

area, and water occurs under confined and unconfined conditions. From 1995 to 1996, combined ground-water withdrawals decreased by less than 1 percent to about 7,040 acre-ft; pumpage from the confined part of the aquifer decreased by about 3 percent to 5,390 acre-ft; and pumpage from the unconfined part of the aquifer increased by about 9 percent to 1,650 acre-ft.

The median change in water levels in the confined area for 1996 was a decline of about 2.7 ft as opposed to a decline of 1.8 ft for 1995. In the unconfined area, the median change in water levels was a decline of 0.5 ft in 1996 as opposed to a decline of 0.1 ft for 1995.

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. Average measured low flow was about 2.3 ft^3/s along Moenkopi Wash and Laguna Creek, 0.4 ft^3/s at DinnebitoWash, and 0.2 ft^3/s at Polacca Wash in 1996. The Dinnebito and Polacca streamflow-gaging stations were recently added to the network to monitor spring discharge along the southern boundary of Black Mesa. Spring discharge decreased by 2.1 gal/min at Moenkopi School Spring and 1.3 gal/min at an unnamed spring near Dennehotso and increased slightly at Burro Spring.

Calcium bicarbonate water and sodium bicarbonate water are the primary types of water that occur in the N aquifer. The calcium bicarbonate type water occurs in the part of the study area north and northwest of Black Mesa. The sodium bicarbonate type water generally occurs elsewhere throughout the area. All but two (Shonto PM2 and Kayenta PM2) of the 12 wells sampled in 1996 contained a sodium bicarbonate type water. Historically, water from Shonto PM2 and Kayenta PM2 have been a calcium bicarbonate type (Littin, 1993). Dissolved-solids concentrations ranged from 122 mg/L at Peabody well No. 6 to 634 mg/L at Rough Rock well PM5 in 1996.

Recent increases in concentrations of dissolved solids in water from well Forest Lake NTUA 1 have been observed. Regionally, long-term water-chemistry data for wells and springs have remained stable.

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Table 9. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the confined part of the N aquifer, 1996

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

Well name	U.S. Geological Survey identification number	Date of sample	Temperature (°C)	Specific conductance (µS/cm)	pH (units)	Alkalinity (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 NTUA 1	361737110180301	12–18–96	28	684	9.3	149	0.45	0.01	1.1	0.10
Hotevilla PM1	355518110400301	12–17–96	25	328	9.8	139	1.1	.02	.62	.02
Kayenta PM2	364344110151201	12–19–96	16	370	8.1	102	.97	.01	42	6.5
Keams Canyon 2	355023110182701	12–17–96	18	1,030	9.2	346	.05	.01	.78	.15
Kykotsmovi PM2	355215110375001	12–18–96	18	365	9.9	164	1.2	.02	.49	.01
Peabody 4	362647110243501	12–19–96	32	214	9.2	83	1.0	.02	4.4	.04
Peabody 5	362901110234101	12–19–96	31	274	9.2	105	.94	.01	2.9	.04
Peabody 6	363007110221201	12–20–96	34	177	9.0	81	.69	.01	3.7	.03
Rocky Ridge PM3	360422110353501	12–20–96	26	256	9.5	112	1.3	.05	.41	.01
Rough Rock PM5	362418109514601	12–18–96	21	1,100	8.9	218	1.1	.01	1.9	.25
Shipaulovi	354742110294701	12–16–96	20	600	9.7	285	.05	.02	.46	.04
Shonto PM1	363558110392501	12–18–96	10	323	8.0	109	4.2	.01	47	6.4

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 NTUA 1	120	0.9	44	79	0.8	18	1	266	97	368
Hotevilla PM1	64	.5	1.3	5.3	.2	23	2	53	3	186
Kayenta PM2	24	1.2	3.8	76	.2	16	1	23	8	238
Keams Canyon 2	220	.8	96	34	1.4	12	27	647	4	596
Kykotsmovi PM2	82	.5	3.3	8.5	.7	25	4	37	3	224
Peabody 4	41	.7	3.8	12	.2	22	2	53	3	140
Peabody 5	54	.7	4.1	19	.3	21	2	36	3	180
Peabody 6	36	.7	1.5	6	.2	22	3	41	3	122
Rocky Ridge PM3	55	.4	2.0	5.8	.2	21	3	27	3	158
Rough Rock PM5	210	1.5	130.5	110	1.8	12	49	402	9	634
Shipaulovi	130	.6	7.5	14	.3	19	15	108	3	364
Shonto PM1	6.4	1.8	15	17	.1	15	1	19	4	188

Table 10. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, 1968–96

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

Year	Specific conductance (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	321	183	10	24
1993	693	352	35	88
1994	744	430	56	100
1995	470	274	13	60
Do.	1,030	626	86	160
Do.	488	316	16	71
1996	684	368	44	79
Hotevilla PM1				
1990	290	192	1.6	5
1991	304	208	.7	5.4
1993	305	180	1.2	5.5
1994	307	166	1.4	4.8
1995	282	196	1.4	3.7
1996	328	186	1.3	5.3
Kayenta PM2				
1982	360	228	4.5	58
1983	375	230	---	60
1984	365	209	4.2	51
1986	300	181	8.2	30
1988	358	235	3.8	74
1992	383	210	5.6	78
1993	374	232	3.7	78
1994	379	236	4.2	77
1995	371	250	4.2	72
1996	370	238	3.8	76
Keams Canyon 2				
1982	1,010	592	94	35
1983	1,120	636	120	42
1984	1,040	578	96	36
1988	1,040	591	97	34
1990	1,030	600	94	34
1992	1,008	570	93	36
1993	1,040	590	92	36
1994	991	562	88	32
1995	1,010	606	99	32
1996	1,030	596	96	34
Kykotsmovi PM2				
1988	368	212	3.2	8.6
1990	355	255	3.2	9
1991	372	203	4.4	7.9
1993	363	212	3.3	8.4
1994	372	212	3.6	8.5
1995	368	224	3.1	6.2
Kykotsmovi PM2—Continued				
1996	365	224	3.3	8.5
Peabody 4				
1980	230	139	4.3	13
1986	205	---	4.2	12
1987	194	135	5	13
1992	224	125	4.3	12
1993	214	124	3	12
1996	214	140	3.8	12
Peabody 5				
1980	210	134	2.9	9.5
1986	398	---	8	28
1987	270	168	4.6	21
1988	270	183	5.1	22
1988	263	174	4.1	26
1990	262	152	4.1	18
1991	260	178	3	18
1993	257	112	2.3	4.8
1994	281	170	4.7	20
1996	274	180	4.1	19
Peabody 6				
1968	201	---	3.0	13
1980	260	160	3.5	15
1986	182	---	2.3	9.6
1988	173	127	2.4	9.1
1996	177	122	1.5	6
Rocky Ridge PM3				
1982	255	---	1.4	6
1990	222	126	1.5	6
1993	254	146	1.3	5.5
1994	247	152	1.4	5.5
1995	242	166	1.3	4
1996	256	158	2.0	5.8
Rough Rock PM5				
1983	1,090	628	130	110
1984	1,090	613	130	99
1986	1,010	633	140	120
1988	1,120	624	130	109
1991	1,060	574	130	110
1993	1,040	614	130	110
1994	1,180	626	130	110
1995	1,110	648	140	110
1996	1,100	634	130	110
Shipaulovi				
1992	621	354	12	17
1996	600	364	7.5	14

Table 10. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, 1968–96—Continued

Year	Specific conductance (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Year	Specific conductance (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Shonto PM2					**Shonto PM2—Continued**				
1986	290	---	10	14	1993	324	197	17	16
1988	285	171	13	14	1996	323	188	15	17
1992	321	186	22	19					

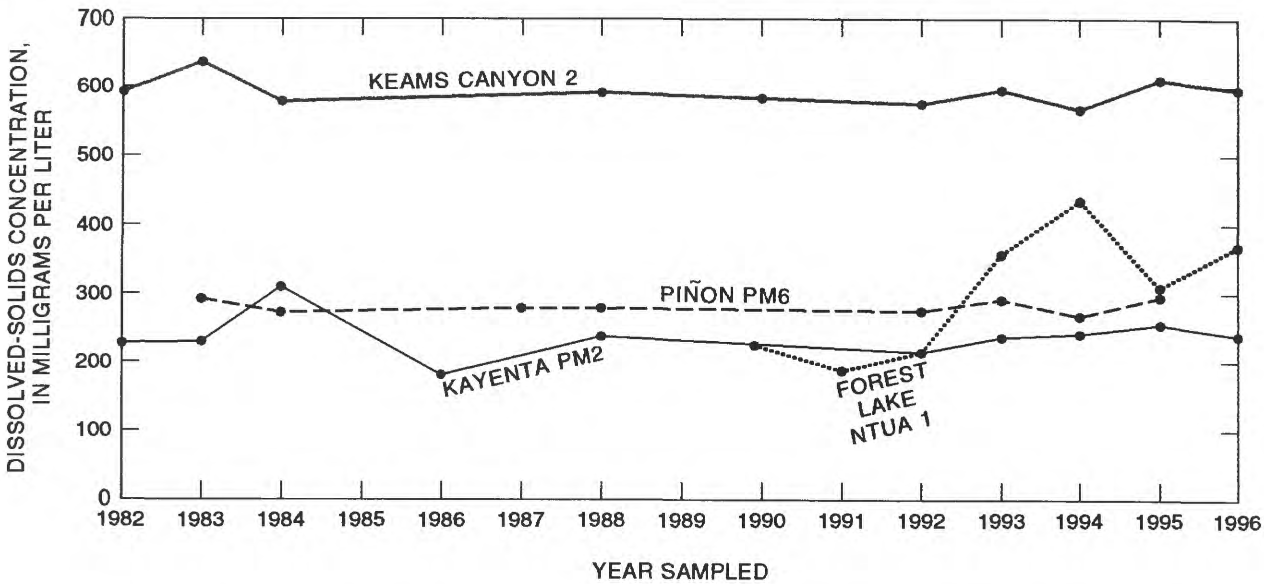

Figure 10. Comparison of dissolved-solids concentrations in water from wells, Keams Canyon 2, Piñon PM6, Forest Lake NTUA 1, and Kayenta PM2, 1982–96.

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Table 11. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, 1996

[°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 field number	U.S. Geological Survey identification number	Rock formation	Date of sample	Temperature (°C)	Specific conductance (µS/cm)	pH (units)
Burro Spring	6M-31	354156110413701	Navajo Sandstone	12–17–96	6	525	7.9
Unnamed spring near Dennehotso	8A-224	364656109425400	Navajo Sandstone	12–19–96	16	189	7.9
Moenkopi School Spring	3GS-77-6	360632111131101	Navajo Sandstone tongue in the Kayenta Formation	12–16–96	18	332	7.7
Pasture Canyon Spring	3A-5	361021111115901	Navajo Sandstone	12–16–96	16	238	7.8

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	0.05	0.01	140	---	51	4.2
Unnamed spring near Dennehotso	77	1.7	.02	81	---	26	4
Moenkopi School Spring	99	2.5	.01	100	---	30	6.5
Pasture Canyon Spring	77	4.8	.01	88	---	28	4.3

Spring name	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Percent sodium	Sodium plus potassium, dissolved (mg/L as Na+K)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)
Burro Spring	57	2	47	57.3	0.3	23
Unnamed spring near Dennehotso	4.6	.2	11	5.5	.9	2.8
Moenkopi School Spring	26	1	36	27.5	1.5	19
Pasture Canyon Spring	11	.5	22	12.4	1.4	4.7

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	62	0.6	15	1	60	11	324
Unnamed spring near Dennehotso	8.2	.1	12	2	34	3	112
Moenkopi School Spring	26	.2	14	2	24	3	196
Pasture Canyon Spring	15	.2	9.1	1	23	3	130

Table 12. Specific conductance and concentrations of selected chemical constituents in water from springs that discharge from the N aquifer, 1984–96

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

Spring name	Year	Specific conductance (μS/cm)	Dissolved solids, residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Burro	1989	485	308	22	59
	1990	546	347	23	65
	1993	595	368	30	85
	1994	601	368	26	80
	1996	525	324	23	62
Unnamed spring near Dennehotso	1984	195	112	2.8	7.1
	1987	178	108	3.4	7.5
	1992	178	108	3.6	7.3
	1993	184	100	3.2	8
	1995	184	124	2.6	5.7
	1996	189	112	2.8	8.2
Moenkopi School	1952	222	----	6	----
	1987	270	161	12	19
	1988	270	155	12	19
	1991	297	157	14	20
	1993	313	204	17	27
	1994	305	182	17	23
	1995	314	206	18	22
	1996	332	196	19	26
Pasture Canyon	1948	199	123	5	13
	1982	240	----	5.1	18
	1986	257	----	5.4	19
	1988	232	146	5.3	18
	1992	235	168	7.1	17
	1993	242	134	5.3	17
	1995	235	152	4.8	14
	1996	238	130	4.7	15

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