Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona—1995

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

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ARIZONA DEPARTMENT OF WATER RESOURCES
and the BUREAU OF INDIAN AFFAIRS

Tucson, Arizona
1996

CONTENTS

FIGURES

TABLES

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 1995, ground-water withdrawals for industrial and municipal use totaled about 7,070 acre-feet, which is about a 3-percent increase from 1994. Pumpage from the confined part of the aquifer increased by about 5 percent to 5,560 acre-feet, and pumpage from the unconfined part of the aquifer decreased by about 6 percent to 1,510 acre-feet. Water-level declines in the confined area during 1995 were recorded in 11 of 15 wells, and the median change was a decline of about 1.8 feet as opposed to a decline of 2.3 feet for 1994. The median change in water levels in the unconfined area was a decline of 0.1 foot in 1995 as opposed to a rise of 0.1 foot in 1994.

The average low-flow discharge at the Moenkopi streamflow-gaging station was 3.1 cubic feet per second in 1995. Discharge was measured at three springs. Discharge from Moenkopi School Spring decreased by about 0.8 gallon per minute from the measurement in 1994. Discharge from an unnamed spring near Dennehotso increased by 2.6 gallons per minute from the measurement made in 1993. 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 27 years. 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-ft in 1968 to a maximum of 4,740 acre-ft in 1982. The quantity of water pumped in 1995 was 4,340 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 2,730 acre-ft in 1995.

[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.

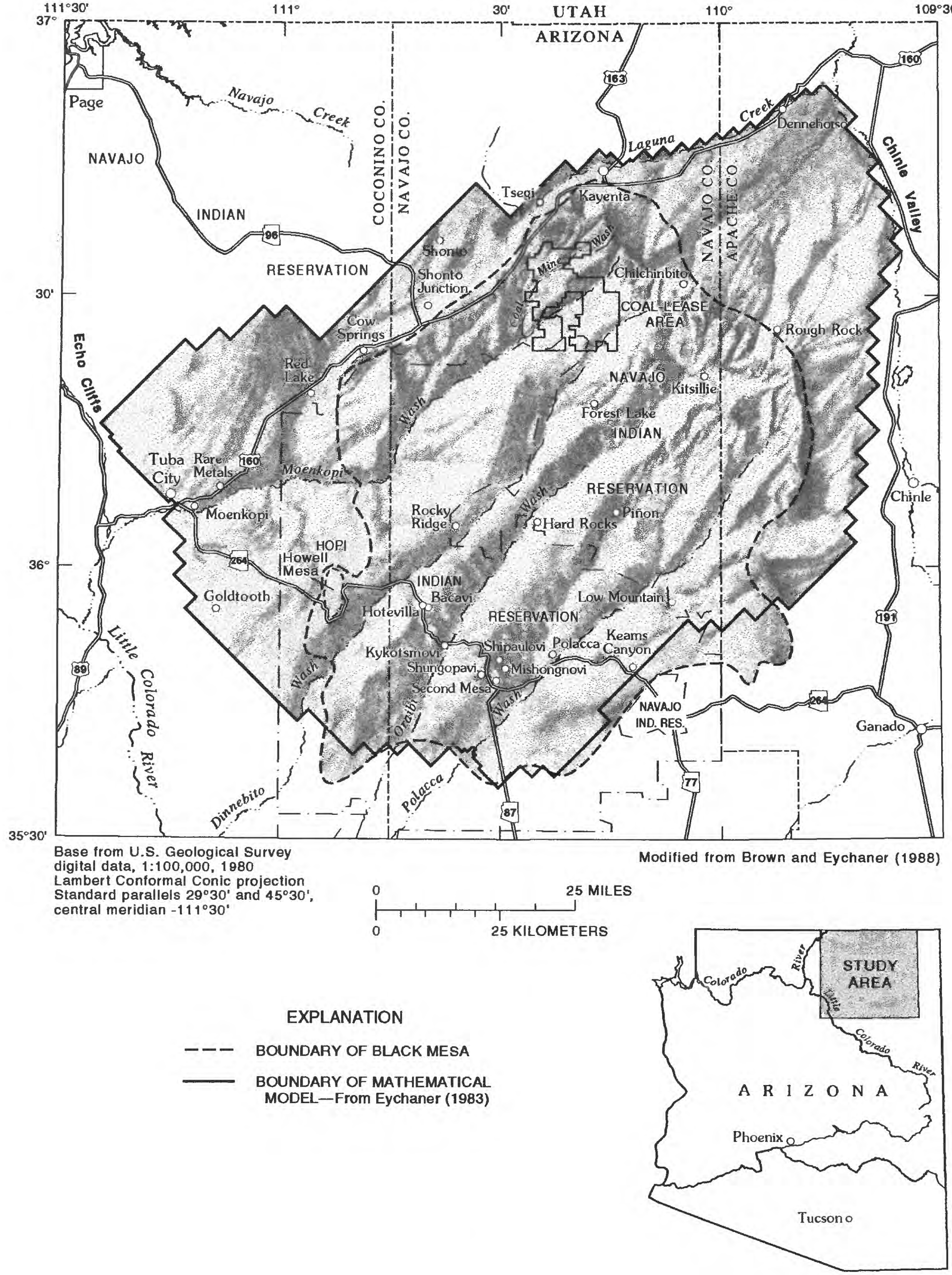


Figure 1. Location of study area.

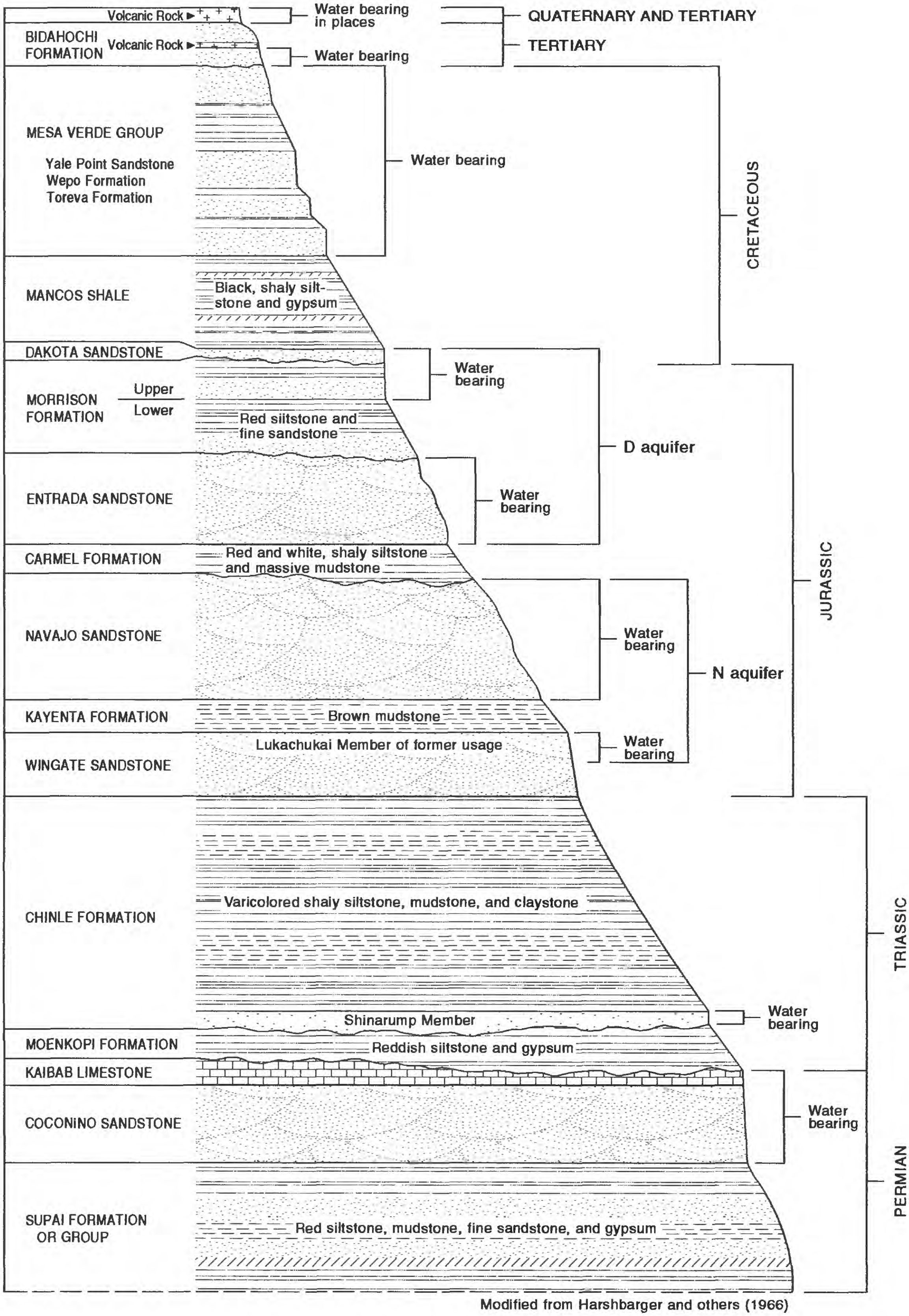


Figure 2. Rock formations of the Black Mesa area. The N aquifer is approximately 1,000 feet thick.

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 1995. 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

Thirteen 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; and Littin and Monroe, 1995a, b). 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 1995, 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 1995. Measurements of annual ground-water levels were made between November and December 1995. Chemical data are from ground-water samples collected in December 1995.

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 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 1995 was about 7,070 acre-ft (table 1), which is a 3-percent increase from total withdrawals in 1994. Pumpage from the confined part of the aquifer increased by about 5 percent to 5,560 acre-ft and pumpage from the unconfined part of the aquifer decreased by about 6 percent to 1,510 acre-ft. Industrial pumpage accounted for about 4,340 acre-ft, or about 61 percent of the total withdrawal, as compared to 59 percent in 1994. Municipal pumpage accounted for about 2,730 acre-ft and represents 39 percent of the total withdrawal as compared to 41 percent in 1994.

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

Table 1. Withdrawals from the N aquifer, 1965–95

[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 per year	Year	Industrial[1]	Municipal[2,3] Confined	Municipal[2,3] Unconfined	Total withdrawals per year
1965	0	50	20	50	1981	4,010	960	1,000	4,970
1966	0	110	30	110	1982	4,740	870	965	5,610
1967	0	120	50	120	1983	4,460	1,360	1,280	5,820
1968	95	150	100	245	1984	4,170	1,070	1,400	5,240
1969	43	200	100	243	1985	2,520	1,040	1,160	3,560
1970	740	280	150	1,020	1986	4,480	970	1,260	5,450
1971	1,900	340	150	2,240	1987	3,830	1,130	1,280	4,960
1972	3,680	370	250	4,050	1988	4,090	1,250	1,310	5,340
1973	3,520	530	300	4,050	1989	3,450	1,070	1,400	4,520
1974	3,830	580	362	4,410	1990	3,430	1,170	1,210	4,600
1975	3,500	600	508	4,100	1991	4,020	1,140	3,360	5,160
1976	4,180	690	645	4,870	1992	3,820	1,180	1,410	5,000
1977	4,090	750	726	4,840	1993	3,700	1,250	1,570	4,950
1978	3,000	830	930	3,830	1994	4,080	[4]1,210	1,600	5,290
1979	3,500	860	930	4,360	1995	4,340	1,220	1,510	5,560
1980	3,540	910	880	4,450					

[1]Metered pumpage 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.

[4]Total municipal pumpage in 1994 was erroneously reported as 1,340 acre-feet in Littin and Monroe (1995b).

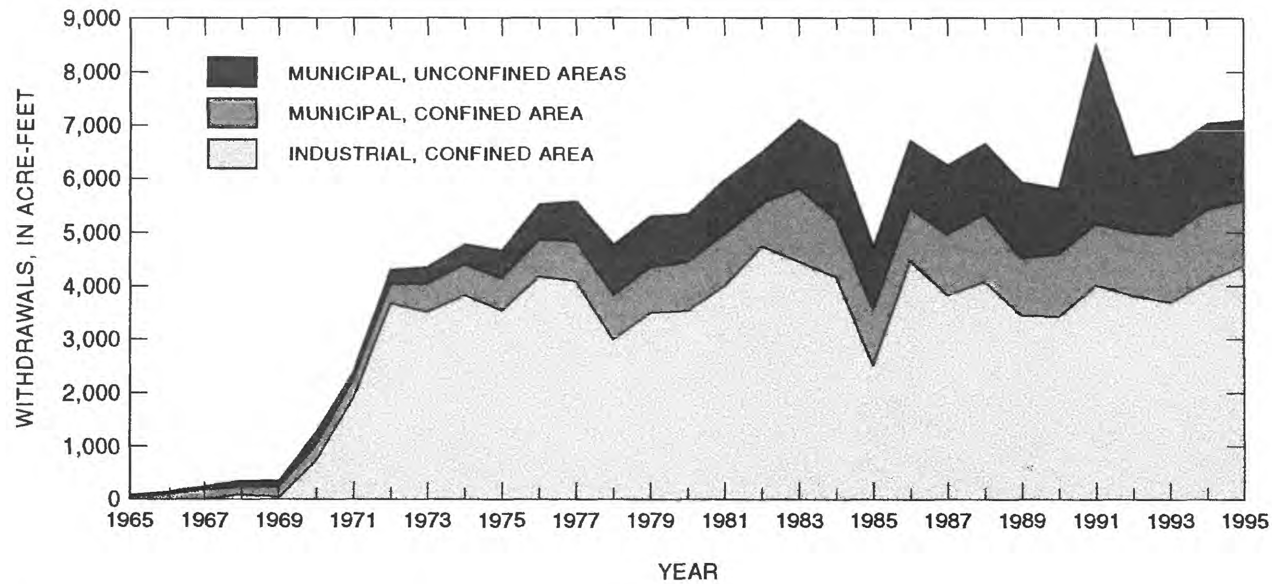


Figure 3. Withdrawals from the N aquifer, 1965–95.

stock wells (table 3). Water-level changes from the earliest available data (pre-stress) through 1995 ranged from a rise of about 14 ft at wells 3K-311 near Howell Mesa and 9Y-95 near Rough Rock to a decline of about 171 ft at Keams Canyon 2 well (fig. 5). In 1995, the maximum annual recorded rise in water level in the Black Mesa area was 8.3 ft at well 9Y-95 near Rough Rock. The maximum annual recorded water-level decline was 14.1 ft at the Keams Canyon 2 well. Water-level declines from 1994 to 1995 were measured in 11 of 15 wells in the confined area, and the median change for all water levels was a decline of about 1.8 ft as compared with a decline of 2.3 ft from 1993 to 1994. Water-level declines from 1994 to 1995 in the unconfined area were measured in 10 of 18 wells, and the median change for all water levels was a decline of 0.1 ft as compared to a rise of 0.1 ft from 1993 to 1994.

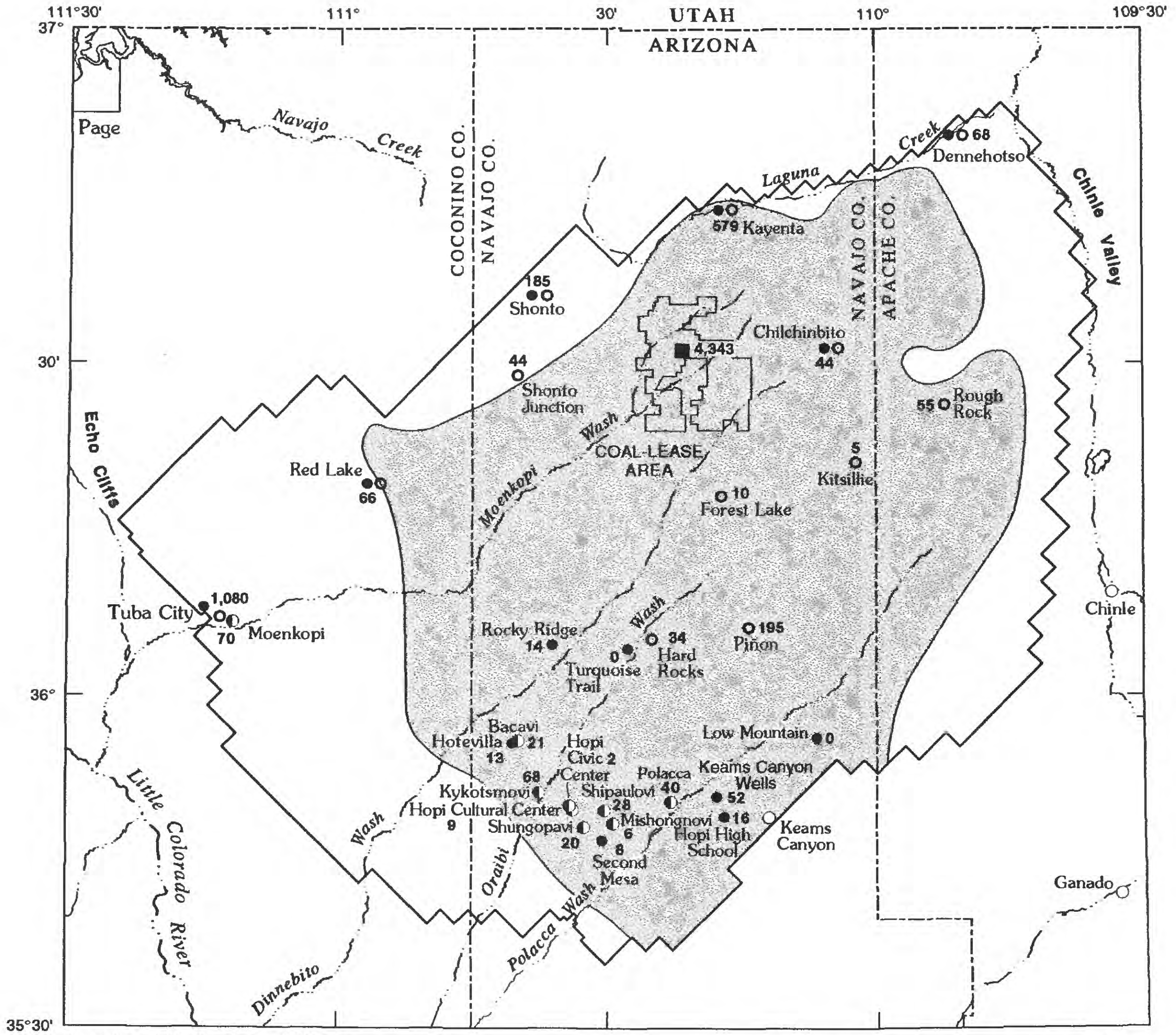
Hydrographs of measured water levels in the six continuous-record observation wells (BM1 through BM6) are based on annual and continuous-record data beginning about 1963 at well BM3 (fig. 6). Water-level data for wells BM1, BM2, BM4, and BM5 began in 1972; water-level data for well BM6 began in 1977.

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 68 ft in wells BM2, BM3, and BM5 during that same period. Well BM6, also completed in a confined part of the N aquifer, has recorded a water-level decline of 83 ft since 1977. Records for the oldest well, BM3, indicate a water-level decline of 91 ft since 1963. A water-level decline of 23 ft was recorded at well BM3 from 1963 to 1967 even though there was no significant pumpage.

Surface-Water Discharge

Outflow from the N aquifer occurs mainly as surface flow in Moenkopi Wash and Laguna Creek[2] and as springs near the boundaries of the aquifer (Davis and others, 1963). Discharge data were collected at the continuous-record streamflow-gaging station, Moenkopi Wash at Moenkopi (09401260; fig. 7, table 4). Low-flow calculations for Moenkopi Wash historically are based on discharge measurements made during November through February. Discharge data collected during

[2]Measurements formerly made on Laguna Creek have been discontinued because variable amounts of snowmelt and sewage effluent often are included in the flow, and the data did not represent discharge solely from the N aquifer.



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

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

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

WELL-SYSTEM OWNER

● Bureau of Indian Affairs

○ Navajo Tribal Utility Authority

◐ Hopi Tribe

■ Peabody Coal Company

Hotevilla ● 13 WITHDRAWALS FROM THE N AQUIFER—Hotevilla, is the village name; 13, is the total withdrawal in acre-feet for 1995 location. The total is cumulative at locations served by multiple wells

Figure 4. Location of well systems monitored for withdrawals from the N aquifer, 1995.

Table 2. Withdrawals from the N aquifer by well system, 1995

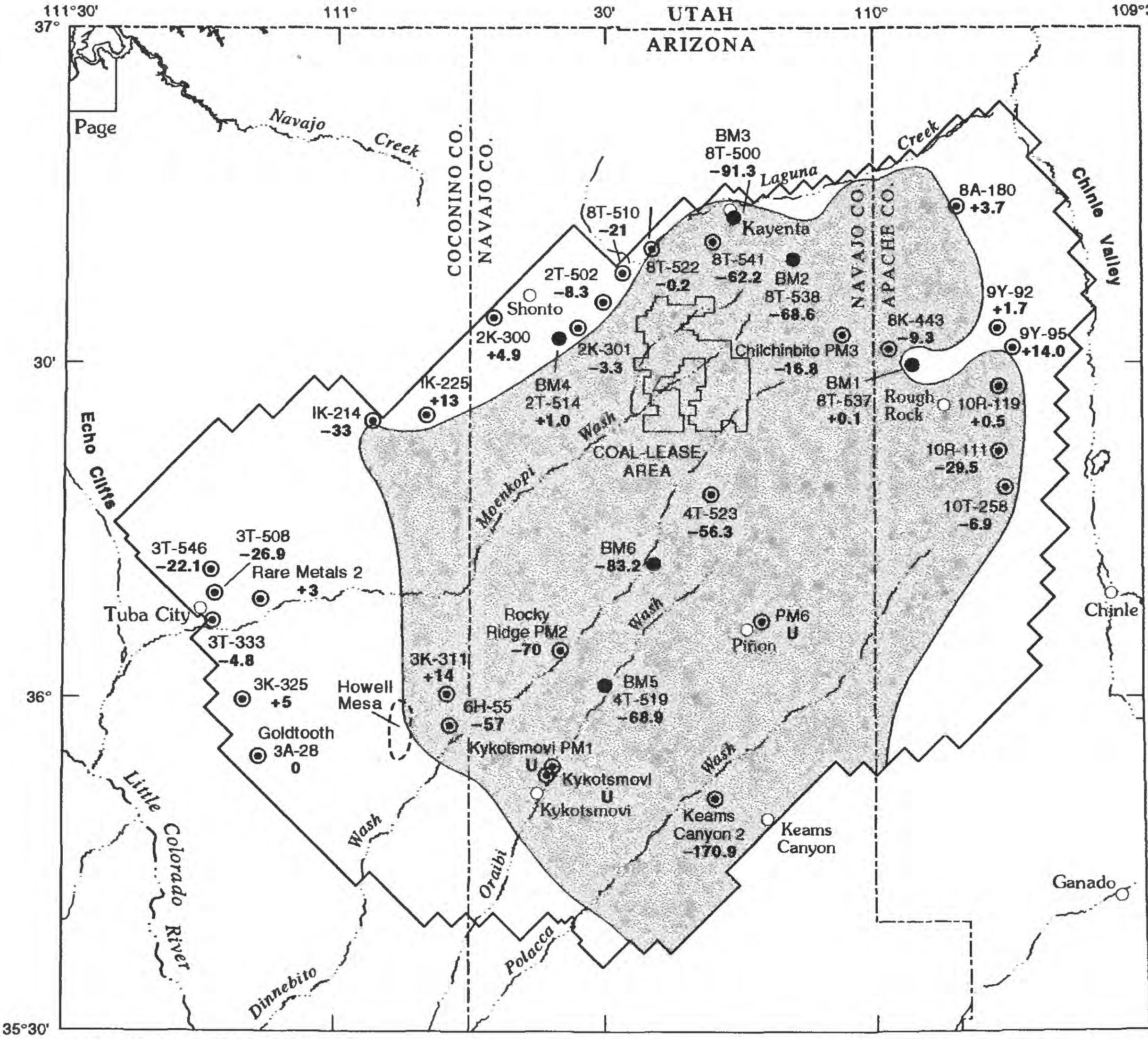
[Withdrawals, in acre-feet, are from flowmeter measurements. BIA, Bureau of Indian Affairs; NTUA, Navajo Tribal Utility Authority; USGS, U.S. Geological Survey; Peabody, Peabody Coal Company; Hopi, Hopi Village Administrations; Blaze, Blaze Construction Company]

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	5.1		Kayenta	NTUA	NTUA	504.8	
Dennehotso	BIA	USGS/BIA		28.2	Kitsillie	NTUA	NTUA	4.7	
Hopi High School	BIA	USGS/BIA	16.2		Piñon	NTUA	NTUA	173.7	
Hotevilla	BIA	USGS/BIA	13.2		Red Lake	NTUA	NTUA		48.2
Kayenta	BIA	USGS/BIA	73.9		Rough Rock	NTUA	NTUA	20.8	
Keams Canyon	BIA	USGS/BIA	51.7		Shonto	NTUA	NTUA		15.9
Low Mountain	BIA	USGS/BIA	0		Shonto Junction	NTUA	NTUA		44.2
Piñon	BIA	USGS/BIA	20.9		Tuba City	NTUA	NTUA		942.9
Red Lake	BIA	USGS/BIA		17.4	Mine Well Field	Peabody	Peabody	[2]4,343.4	
Rocky Ridge	BIA	USGS/BIA	13.8		Bacavi	Hopi	USGS/Hopi	21.1	
Rough Rock	BIA	USGS/BIA	34.2		Hopi Civic Center	Hopi	USGS/Hopi	1.8	
Second Mesa	BIA	USGS/BIA	8.2		Hopi Cultural Center	Hopi	USGS/Hopi	8.8	
Shonto	BIA	USGS/BIA		169.5	Kykotsmovi	Hopi	USGS/Hopi	67.9	
Tuba City	BIA	USGS/BIA		137.0	Mishongnovi	Hopi	USGS/Hopi	5.8	
Turquoise Trail	BIA	Blaze	0		Moenkopi	Hopi	USGS/Hopi		[3]70.1
Chilchinbito	NTUA	NTUA	38.8		Polacca	Hopi	USGS/Hopi	[4]40	
Dennehotso	NTUA	NTUA		39.7	Shipaulovi	Hopi	USGS/Hopi	27.8	
Forest Lake	NTUA	NTUA	9.9		Shungopovi	Hopi	USGS/Hopi	19.5	
Hard Rocks	NTUA	NTUA	[1]33.6						

[1]Total pumpage in 1994 was erroneously reported as 161.7 acre-feet in Littin and Monroe (1995b). Actual pumpage for 1994 was 33 acre-feet.
[2]Industrial pumpage.
[3]Includes some estimated data because of meter malfunction during the calendar year on one or more wells in this municipal well system. Estimate based on electrical usage, the typical average daily pumpage prior to meter malfunction for the well in question, or on per capita use of 40 gallons per day. Does not include possible estimated data provided by cooperating agencies.
[4]Estimated. Well not metered.

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 3.1 ft^3/s and is based on low-flow measurements of 3.97 and 2.17 ft^3/s made during January and November 1995. The mean daily discharge for the same months was 3.71 and



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

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

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

4T-523
-56.3
WELL IN WHICH DEPTH TO WATER WAS MEASURED ANNUALLY—First entry, 4T-523, is Bureau of Indian Affairs site number; second entry, -56.3, is change in water level, in feet, between measurements made during the prestress period and measurements made during 1995. U, unable to measure

BM2
8T-538
-68.6
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, -68.6, is change in water level, in feet, from earliest available date to 1995

Figure 5. Water-level changes in wells completed in the N aquifer from the start of data collection through 1995.

Table 3. Water-level changes in wells completed in the N aquifer, 1992–95

[---, 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, 1995	Pre-stress water level, in feet below land surface	Change in water level from pre-stress period to 1995, in feet[1]
		1994	1995			
Unconfined						
BM1[2]	8T-537	+0.1	-0.2	373.9	374.0	+0.1
BM4[2]	2T-514	+.1	-.1	216.0	217	+1
Cow Springs	1K-225	+.3	-.1	46.9	60	+13
Goldtooth	3A-28	+3.2	-.1	229.6	230	0
Long House Valley	8T-510	+.4	-1.2	119.8	99	-21
Marsh Pass	8T-522	-.6	-1.0	125.7	125.5	-.2
Northeast Rough Rock	8A-180	+.1	0	43.2	46.9	+3.7
Rough Rock	9Y-95	-5.7	+8.3	105.5	119.5	+14.0
Do.	9Y-92	-.5	+1.8	167.1	168.8	+1.7
Shonto	2K-300	-.3	+.4	171.6	176.5	+4.9
Shonto Southeast	2K-301	-.7	+.3	287.2	283.9	-3.3
Do.	2T-502	-1.5	+2.1	414.1	405.8	-8.3
Tuba City	3T-333	[3]-.5	+1.5	27.8	23.0	-4.8
Do.	3K-325	+.3	-1.1	202.7	208	+5
Do.	Rare Metals 2	[3]+3.3	-1.1	53.6	57	+3
Tuba NTUA 1	3T-508	-2.5	-.5	55.9	29.0	-26.9
Tuba NTUA 4	3T-546	+1.8	+.3	55.8	33.7	-22.1
White Mesa Arch	1K-214	+.5	-.5	220.9	188	-33
Confined						
BM2[2]	8T-538	-2.3	-2.5	193.6	125.0	-68.6
BM3[2]	8T-500	+8.8	-12.3	151.3	60.0	-91.3
BM5[2]	4T-519	-4.9	-1.8	392.7	323.8	-68.9
BM6[2]	BM6	-3.2	-3.4	818.8	735.6	-83.2
Chilchinbito	PM3	+1.2	+3.6	421.8	405	-17
Forest Lake NTUA 1	4T-523	-4.6	-3.8	1,152.3	1,096.0	-56.3
Howell Mesa	6H-55	-.5	-.3	268.6	212	-57
Do.	3K-311	([4])	[3]+2.9	448.8	463	+14
Kayenta West	8T-541	+4.9	+.4	289.2	227	-62.2
Keams Canyon	2	-9.2	-14.1	463.4	292.5	-170.9
Kykotsmovi	PM1	+18.0	([4])	([4])	220	---
Do.	PM3	[3]-7.2	([4])	([4])	210	---
Piñon	PM6	([4])	([4])	([4])	743.6	---
Rocky Ridge	PM2	-3.4	-2.1	502.0	432	-70
Rough Rock	10R-119	-6.1	-.2	256.1	256.6	+.5
Do.	10T-258	+4.1	+.2	307.9	301.0	-6.9
Do.	10R-111	0	-1.1	199.5	170.0	-29.5
Sweetwater Mesa	8K-443	-.1	-2.4	538.7	529.4	-9.3

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

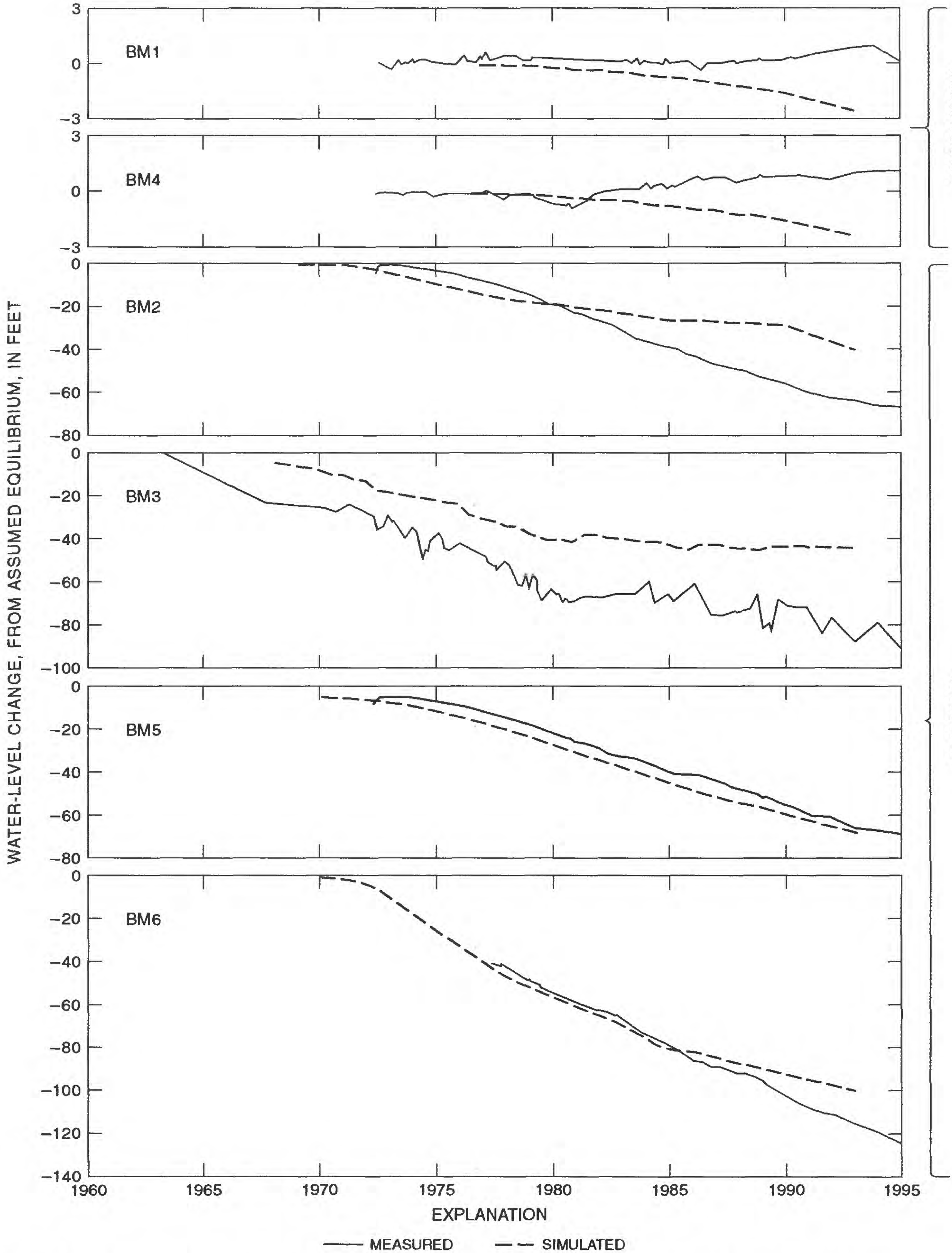
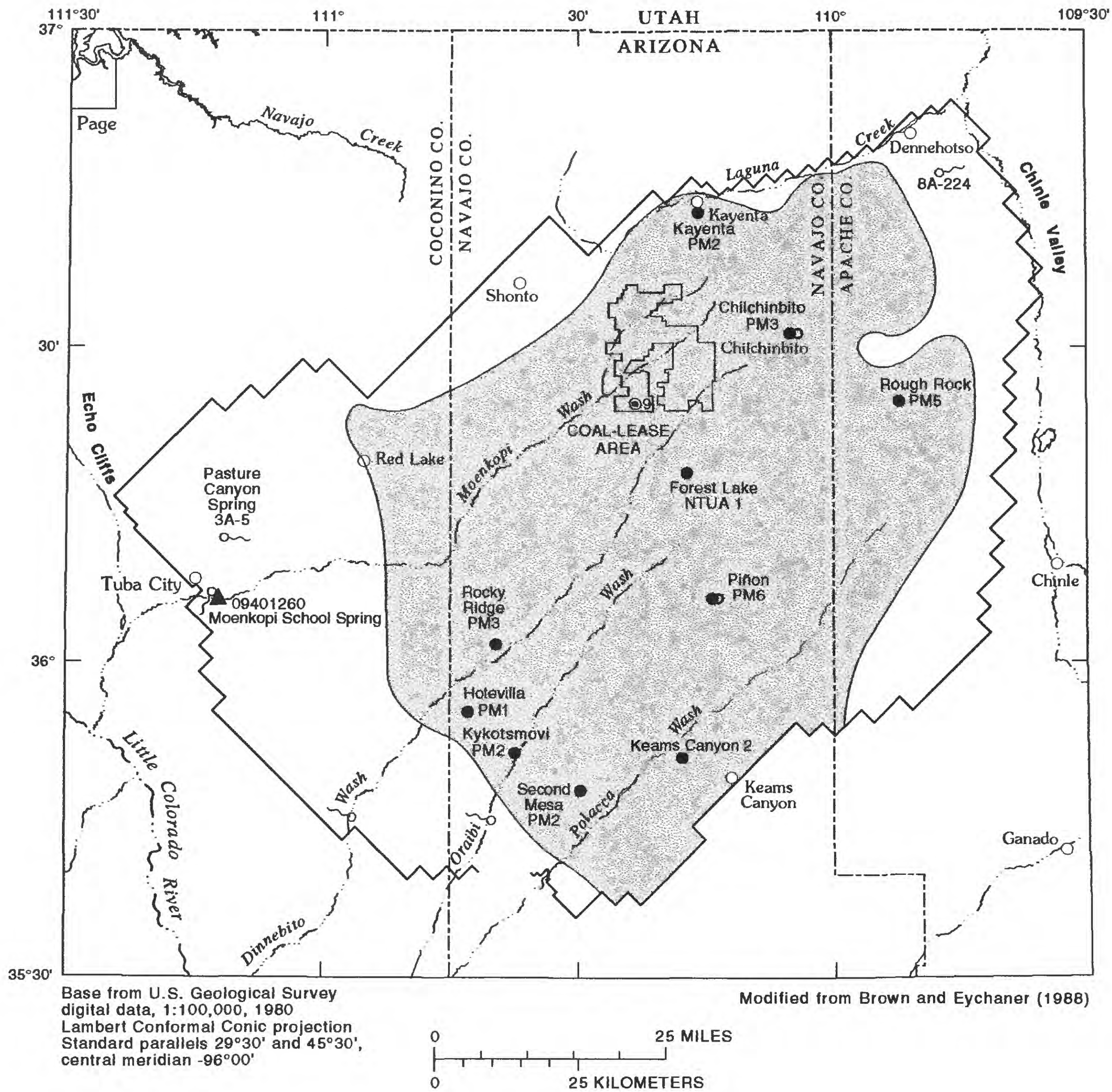


Figure 6. Measured water-level changes in continuous-record observation wells BM1 through BM6, 1963–95, and simulated water-level changes from Littin and Monroe, 1995.



EXPLANATION

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

CONFINED

UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Piñon PM6 — MUNICIPAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—Piñon PM6 is well name

9 — INDUSTRIAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—9 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, 1995.

Table 4. Discharge data, Moenkopi Wash at Moenkopi, calendar year 1995

[---, no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1995 DAILY MEAN VALUES												
Day	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug**	**Sept.**	**Oct.[1]**	**Nov.[1]**	**Dec.[1]**
1	[2]3.4	2.5	4.2	1.8	1.6	1.6	.00	.00	.00	.68	7.6	2.2
2	[2]3.4	2.4	4.8	1.8	1.6	1.1	.00	.00	.00	.69	18	1.9
3	[2]3.4	2.3	4.8	1.8	1.6	.84	.00	.00	.00	.60	3.4	2.4
4	3.8	2.2	4.2	2.4	1.6	1.3	.00	.00	.00	.45	2.1	1.9
5	4.2	2.3	4.3	2.1	1.5	1.1	.00	.00	.00	.24	1.9	1.7
6	7.0	2.5	11	2.1	1.3	.59	.00	.00	.08	.24	1.8	1.6
7	3.7	2.5	8.9	2.1	1.7	.16	.00	.00	61	.60	1.8	1.6
8	4.7	1.8	4.0	2.1	2.1	.13	.00	.00	12	.73	1.8	2.3
9	4.5	2.1	3.5	2.1	2.0	.68	.00	.00	24	.54	2.1	1.8
10	3.4	2.9	3.4	2.2	1.7	1.1	.00	.00	30	.58	2.1	1.9
11	3.1	2.3	3.9	2.4	1.7	.87	.00	.00	3.7	.58	2.1	2.6
12	4.1	2.1	3.9	2.4	1.3	.77	.00	.00	2.0	.74	2.1	1.8
13	5.0	2.1	3.6	2.4	1.1	.55	.00	.00	1.0	.59	2.1	2.5
14	3.5	2.1	3.9	2.4	1.1	.13	278	.00	.73	.51	2.4	3.3
15	3.7	2.1	3.6	2.4	1.3	.00	87	.00	.34	.52	2.7	2.0
16	3.8	2.3	5.1	2.5	1.1	.00	[2]47	.00	.22	.72	2.7	2.4
17	3.7	2.2	5.9	2.7	1.3	.00	[2]25	[2].00	.16	.91	2.7	2.0
18	3.5	2.0	4.5	2.7	1.7	.00	[2]8.5	.00	.22	.91	2.7	2.6
19	3.2	1.8	6.2	2.7	1.8	.00	[2]3.1	.00	.00	.91	2.7	3.3
20	[2]3.8	1.8	3.9	2.7	1.5	.00	[2]1.6	.88	.00	.74	2.7	2.3
21	[2]3.8	1.8	3.7	3.1	1.2	.00	[2].74	13	.00	.83	2.7	1.9
22	[2]3.8	2.3	2.9	3.7	1.1	.00	.09	5.4	.00	.77	2.7	3.0
23	[2]3.5	3.1	2.6	3.2	.91	.00	.00	72	.00	.74	2.7	4.6
24	3.2	3.1	2.7	3.2	.94	.00	.00	15	.00	.88	2.7	1.9
25	3.1	2.7	3.0	2.7	1.1	.00	.00	40	.00	1.1	2.7	2.5
26	3.3	3.6	2.9	2.7	1.1	.00	.00	16	.00	1.1	2.7	2.5
27	3.2	3.7	2.9	2.7	1.5	.00	.00	5.4	.00	1.1	2.2	2.4
28	3.0	3.4	2.4	2.5	1.6	.00	.00	2.9	.00	1.1	2.0	3.4
29	3.0	---	2.1	2.0	3.3	.00	.00	1.8	1.9	1.1	2.3	2.6
30	2.7	---	2.1	1.6	3.6	.00	.00	.96	1.1	1.3	2.4	2.8
31	3.4	---	1.9	---	1.9	---	.00	.28	---	1.3	---	2.7
TOTAL	114.9	68.0	126.8	73.2	48.85	10.92	451.03	173.62	138.45	23.80	92.6	74.4
MEAN	3.71	2.43	4.09	2.44	1.58	.36	14.5	5.60	4.61	.77	3.09	2.40
MAX	7.0	3.7	11	3.7	3.6	1.6	278	72	61	1.3	18	4.6
MIN	2.7	1.8	1.9	1.6	.91	.00	.00	.00	.00	.24	1.8	1.6
AC-FT	228	135	252	145	97	22	895	344	275	47	184	148

CALENDAR YEAR 1995 TOTAL 1396.57 MEAN 3.80 MAXIMUM 278 MINIMUM 0.00 ACRE-FT 2772

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

[2]Estimated.

3.09 ft^3/s. 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, low flow in Moenkopi Wash has remained fairly constant at about 3 ft^3/s since the streamflow-gaging station was installed in 1976.

Four springs—an unnamed spring near Dennehotso, Moenkopi School Spring, Pasture Canyon Spring, and Rock Ledge Spring—were selected for discharge measurements as part of the monitoring program during 1995 (fig. 7; table 5). Discharge at the unnamed spring near Dennehotso was measured at 17 gal/min. Discharge from Moenkopi School Spring was 12.1 gal/min as compared with 12.9 gal/min measured in 1994. Discharge at Pasture Canyon Spring was measured volumetrically at 38 gal/min from a pipe at the spring. Diversions for irrigation precluded sampling at or near the previously measured downstream site. Discharge at Rock Ledge Spring was estimated to be less than 0.1 gal/min.

Table 5. Discharge measurements of selected springs, 1952–95

[---, no data]

Spring name	U.S. Bureau of Indian Affairs site number	Rock Formations	Date of measurement	Discharge, in gallons per minute
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	.16
			10–22–93	14.4
			12–05–95	17
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
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
Rock Ledge Spring	6M-114	Navajo Sandstone	04–15–93	[1]2
			12–07–95	[1]<1

[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.

Water Chemistry

Water from Wells Completed in the N Aquifer

All wells sampled in 1995 are completed in the confined part of the N aquifer (figs. 7 and 8; tables 6 and 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 one (Kayenta PM2) of the 10 wells sampled, generally in upgradient areas of Black Mesa between the Peabody mine, Piñon, and Kykotsmovi, contained a sodium bicarbonate water. 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 122 mg/L at Peabody well No. 9 to 648 mg/L at the Rough Rock well PM5 (fig. 8; tables 6 and 7). Long-term comparison of dissolved-solids concentrations in water collected from Keams Canyon 2, Piñon PM6, and Kayenta PM2 wells[3] shows no significant change from 1983 to 1995 (fig. 9; table 7). Since 1991, a gradual increase in concentrations of dissolved solids, sulfate, and chloride in water from the Forest Lake well NTUA 1 has been observed.[4]

Surface Water

Four springs were selected for water-chemistry analyses as part of the monitoring program during 1995 (figs. 7 and 8; tables 8 and 9). The springs, all of which discharge from the Navajo Sandstone, are an unnamed spring near Dennehotso, Moenkopi School Spring at Moenkopi, Pasture Canyon Spring near Tuba City, and Rock Ledge Spring near Second Mesa.

Historically, the chemistry of water from these springs has not changed significantly although there has been some increase in dissolved-solids concentrations[5] (table 9). Waters from Moenkopi School Spring, Pasture Canyon Spring, and the unnamed spring near Dennehotso have been calcium bicarbonate types; and water from Rock Ledge Spring has been a calcium sulfate type. In 1995, dissolved-solids concentrations in water from the four springs ranged from 124 mg/L at the unnamed spring near Dennehotso to 3,140 mg/L at Rock Ledge Spring.

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 1994 to 1995, combined ground-water withdrawals increased by 3 percent to about 7,070 acre-ft; pumpage from the confined part of the aquifer increased by about 5 percent to 5,560 acre-ft and pumpage from the unconfined part of the aquifer decreased by about 6 percent to 1,510 acre-ft.

The median change in water levels in the confined area for 1995 was a decline of about 1.8 ft as opposed to a decline of 2.3 ft for 1994. In the unconfined area, the median change in water levels was a decline of 0.1 ft in 1995 as opposed to a rise of 0.1 ft for 1994.

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 along Moenkopi Wash was about 3.1 ft^3/s in 1995. Spring discharge decreased by 0.8 gal/min at Moenkopi School Spring and increased by 2.6 gal/min at the unnamed spring near Dennehotso.

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 one (Kayenta PM2) of

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

[4]Multiple water samples were collected from Forest Lake well NTUA 1 in August and December 1995. Dissolved-solids concentrations ranged from 626 to 274 milligrams per liter.

[5]Increase in chloride at Moenkopi Spring may be caused by chlorination of water at municipal wells upgradient from the spring.

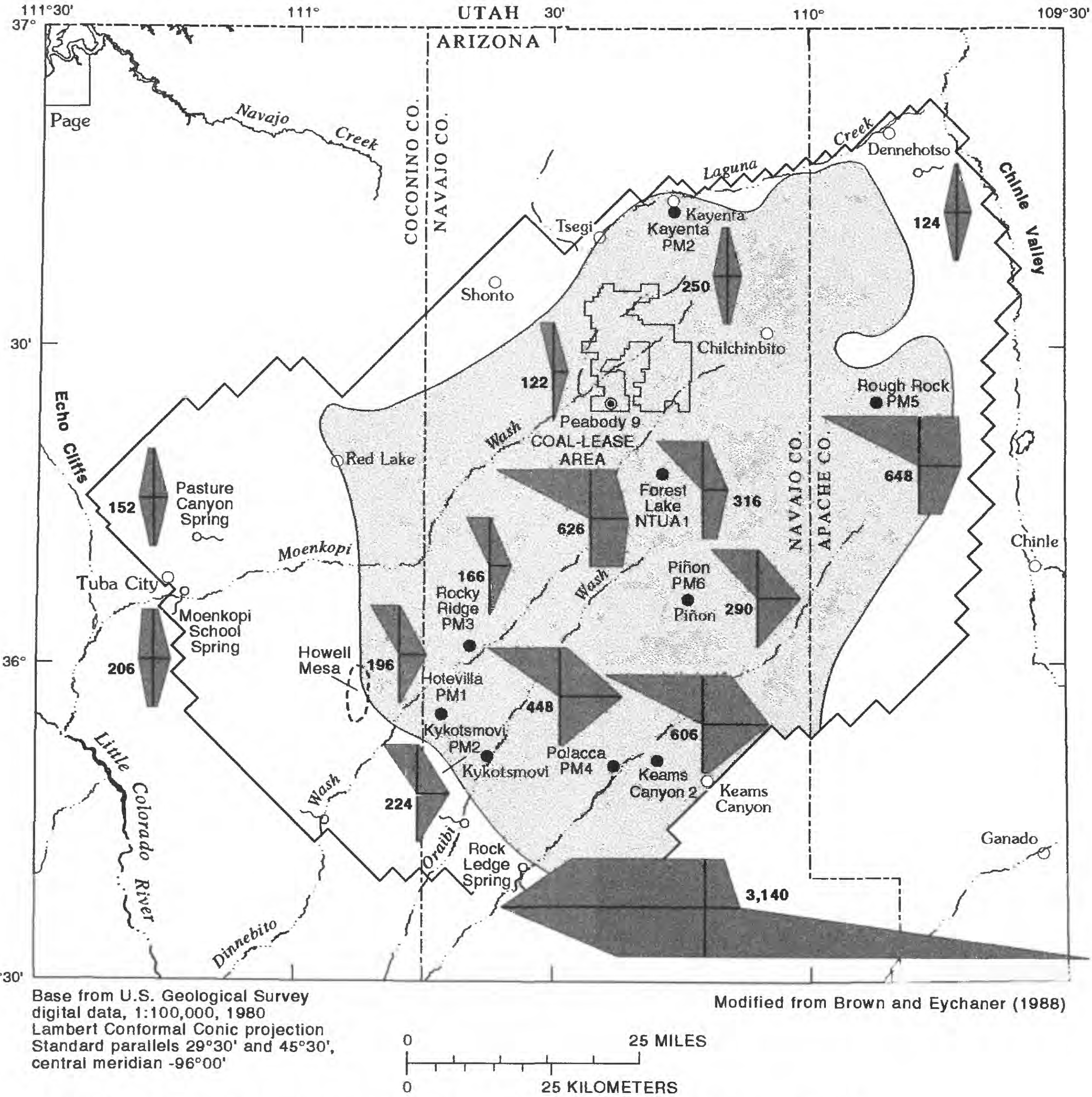


Figure 8. Water chemistry and distribution of dissolved solids in the N aquifer, 1995.

the 10 wells sampled in 1995 contained a sodium bicarbonate type water. Historically, water from Kayenta PM2 has been a calcium bicarbonate type (Littin, 1993). Dissolved-solids concentrations ranged from 122 to 648 mg/L in 1995.

Recent gradual increases in concentrations of dissolved solids, sulfate, and chloride 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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EXPLANATION

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

CONFINED

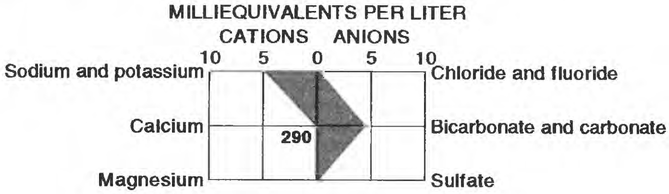
UNCONFINED

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Piñon PM6 MUNICIPAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—Piñon PM6 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, **290**, is dissolved-solids concentration, in milligrams per liter

Figure 8. Continued.

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Table 6. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the confined part of the N aquifer, 1995

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

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	08–09–95	29	470	9.4	132	0.60	0.01	1.1	0.12
Do.	361737110180301	12–06–95	26	1,030	9.0	194	.31	.01	2.5	.3
Do.	361737110180301	12–06–95	27	488	9.3	131	.58	.01	.96	.12
Hotevilla PM1	355518110400301	12–07–95	25	282	9.8	138	1.1	.02	.62	.03
Kayenta PM2................	364344110151201	12–04–95	15	371	8.2	101	.94	.01	42	7.1
Keams Canyon 2	355023110182701	12–07–95	19	1,010	9.3	342	.05	.01	.85	.17
Kykotsmovi PM2	355215110375001	12–07–95	21	368	9.8	163	1.2	.03	.45	.01
Peabody 9.....................	362901110234101	12–06–95	32	154	9	73	.76	.01	3.6	.03
Piñon PM6....................	360614110130801	12–06–95	26	476	10	222	1.4	.01	.5	.01
Polacca PM4.................	354950110231501	12–08–95	21	753	9.6	322	.05	.02	.56	.07
Rocky Ridge PM3........	360422110353501	12–06–95	27	242	9.6	111	1.3	.02	.41	.01
Rough Rock PM5.........	362418109514601	12–05–95	20	1,110	9	216	1.1	.02	2.0	.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)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids, residue at 180°C (mg/L)
Forest Lake NTUA 1....	98	0.7	13	60	0.4	21	110	30	274
Do.	220	1.7	86	160	1.7	17	510	100	626
Do.	110	.7	16	71	.4	21	130	25	316
Hotevilla PM1	67	.5	1.4	3.7	.2	23	30	4	196
Kayenta PM2................	24	1.2	4.2	72	.2	16	20	3	250
Keams Canyon 2	230	.8	99	32	1.5	13	630	3	606
Kykotsmovi PM2	80	.4	3.1	6.2	.2	25	30	3	224
Peabody 9.....................	32	.6	1.6	1.6	.2	21	20	3	122
Piñon PM6....................	110	.4	4	3.3	.3	28	40	3	290
Polacca PM4.................	170	.5	25	19	.6	15	240	3	448
Rocky Ridge PM3........	55	.4	1.3	4	.2	21	30	3	166
Rough Rock PM5.........	230	1.4	140	110	1.9	13	410	15	648

Table 7. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, 1982–95

[μS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; °C, degrees Celsius; --- 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
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
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
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
Kykotsmovi PM2				
1988	368	212	3.2	8.6
1990	355	255	3.2	9
1991	372	203	4.4	7.9
Kykotsmovi PM2				
1993	363	212	3.3	8.4
1994	372	212	3.6	8.5
1995	368	224	3.1	6.2
Peabody 9				
1986	181	----	3.1	4.9
1987	148	102	2.8	4.1
1990	158	106	1.6	3.0
1995	154	122	1.6	1.6
Piñon PM6				
1982	485	---	3.7	5
1983	505	293	3.6	3.5
1984	495	273	3.7	5.4
1987	500	279	3.7	3.8
1988	455	278	3.5	5.2
1992	488	270	7	8.6
1993	488	287	3.6	4.5
1994	488	262	3.9	4.7
1995	476	290	4	3.3
Polacca PM4				
1990	830	424	30	25
1991	746	431	29	27
1993	755	422	27	23
1995	753	448	25	19
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
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	1,080	626	130	110
1995	1,110	648	140	110

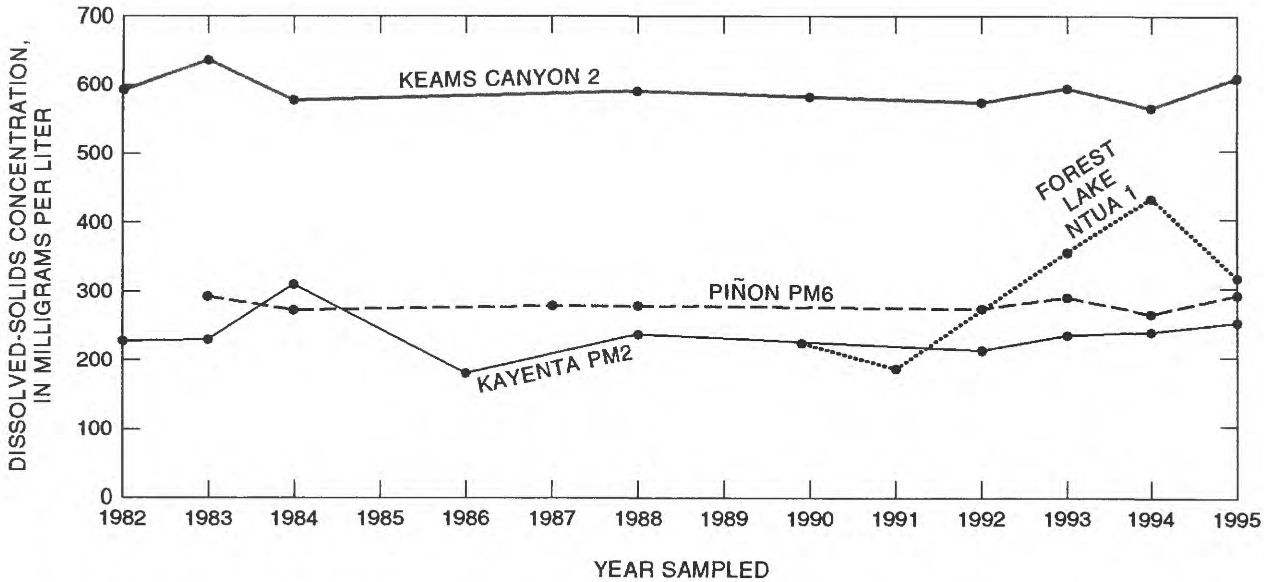

Figure 9. Comparison of dissolved-solids concentrations in water from wells, Keams Canyon 2, Piñon PM6, Forest Lake NTUA 1, and Kayenta PM2, 1982–95.

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Table 8. Physical properties and chemical analyses of water from selected springs that discharge from the N aquifer, 1995

[°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)
Unnamed spring near Dennehotso.	8A-224	364656109425400	Navajo Sandstone	12–05–95	11.5	184	7.8
Moenkopi School Spring.	3GS–77–6	360632111131101	Navajo Sandstone tongue in the Kayenta Formation	12–04–95	16	314	7.6
Pasture Canyon Spring.	3A-5	361021111115901	Navajo Sandstone	12–04–95	16	235	7.7
Rock Ledge Spring......	6M-114	354011110331501	Navajo Sandstone	12–07–95	6	3,440	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)
Unnamed spring near Dennehotso.	74	1.6	0.02	81	---	26	3.9
Moenkopi School Spring.	91	2.4	.01	98	---	29	6.3
Pasture Canyon Spring.	75	4.5	.02	91	---	29	4.4
Rock Ledge Spring	179	4	.01	1,500	---	420	110

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)
Unnamed spring near Dennehotso.	4.4	0.2	11	5.4	1.0	2.6
Moenkopi School Spring.	24	1	35	25.3	1.3	18
Pasture Canyon Spring.	11	.5	21	12.3	1.3	4.8
Rock Ledge Spring	310	3	31	315.2	5.2	68

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)
Unnamed spring near Dennehotso.	5.7	0.2	13	---	20	3	124
Moenkopi School Spring.	22	.2	14	---	40	3	206
Pasture Canyon Spring.	14	.2	10	---	30	3	152
Rock Ledge Spring	1,900	.5	15	---	140	9	3,140

Table 9. Specific conductance and concentrations of selected chemical constituents in water from springs that discharge from the N aquifer, 1984–95

[μS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; °C, degrees Celsius; ---, 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)
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
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
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
Rock Ledge	1993	3,480	3,030	74	1,700
	1995	3,440	3,140	68	1,900

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Littin and
Monroe

GROUND-WATER, SURFACE-WATER, AND WATER-CHEMISTRY DATA,
BLACK MESA AREA, NORTHEASTERN ARIZONA—1995

U.S. Geolgical Survey
OFR 96—616