RESULTS OF GROUND-WATER, SURFACE-WATER, AND WATER-QUALITY MONITORING, BLACK MESA AREA, NORTHEASTERN ARIZONA—1990-91

By G.R. Littin

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	***By***	***To obtain***
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
degree Fahrenheit (°F)	[°C=5/9(°F-32)]	degree Celsius

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.

RESULTS OF GROUND-WATER, SURFACE-WATER, AND WATER-QUALITY MONITORING, BLACK MESA AREA, NORTHEASTERN ARIZONA-1990-91

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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 water occurs under confined and unconfined conditions. Monitoring activities include continuous and periodic measurements of (1) ground-water levels in the confined and unconfined areas of the aquifer, (2) ground-water pumpage from the confined and unconfined areas of the aquifer, (3) surface-water discharge, (4) water quality of the aquifer, and (5) surface-water quality.

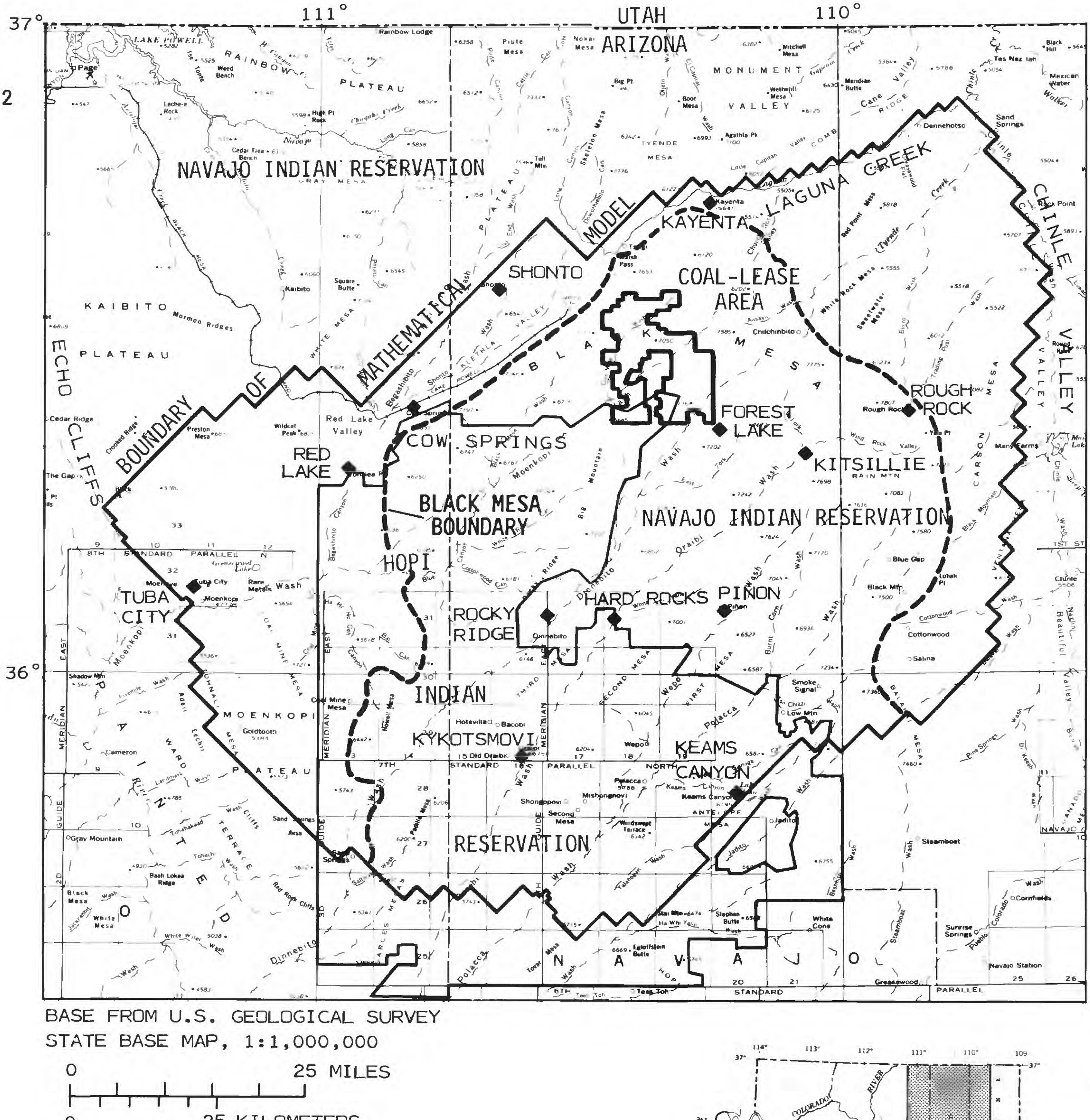
Since 1963, water levels in some wells completed in the confined area of the aquifer have declined as much as 70 feet. In contrast, however, water levels in many wells completed in the unconfined area of the aquifer have risen during the same period. Ground-water withdrawals for industrial and municipal use decreased slightly during January through December 1990. Chemical analyses to date generally indicate no major changes in water quality in the N aquifer.

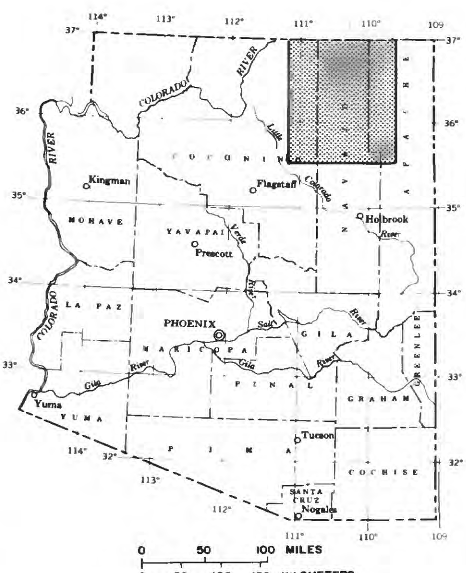
INTRODUCTION

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). 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 municipal and industrial use from the N aquifer in the Black Mesa area generally have increased during the last 25 years. Peabody Coal Company began operating a strip mine in

[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.





INDEX MAP SHOWING AREA OF REPORT (SHADED)

Figure 1.--Location of study area.

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 and has decreased to 3,430 acre-ft in 1990. Withdrawals from the N aquifer for municipal use have increased from an estimated 250 acre-ft in 1968 to about 2,380 acre-ft in 1990.

The Navajo and Hopi Tribes 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 by the U.S. Geological Survey (USGS) in cooperation with the Arizona Department of Water Resources in 1971; in 1983, the U.S. Bureau of Indian Affairs joined the cooperative effort. Since 1983, the Navajo Tribal Utility Authority; Peabody Coal Company; the Hopi Tribe; and the Western Navajo Agency, Chinle Agency, and Hopi Agency of the U.S. 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-quality monitoring in the Black Mesa area from October 1, 1989, to April 26, 1991. The monitoring is designed to determine the effects of industrial and municipal pumpage from the N aquifer. Data-collection efforts include continuous and periodic measurements of ground water and surface water in the Black Mesa area. Ground-water data were collected from wells completed in the confined and unconfined areas of the N aquifer and include data on water levels, pumpage, and chemical quality. Surface-water data include discharge measurements and chemical quality at selected springs and streamflow sites and discharge measurements at continuous-record sites.

Previous Investigations

Nine 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; and Sottilare, 1992). 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 prior to the 1986 water year; those data were published by the U.S. Geological Survey (1963-81; White and Garrett, 1984, 1986-88; Wilson and Garrett, 1988-89; and Boner and others, 1989-90). Eychaner (1983) showed the results of a mathematical model that was developed to simulate the flow of ground water in the N aquifer. The model was used to predict the effects of withdrawals through the year 2014. 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) provide data on water chemistry from many wells and springs in the area. Cooley and others (1969) provide a detailed description of the regional hydrogeology.

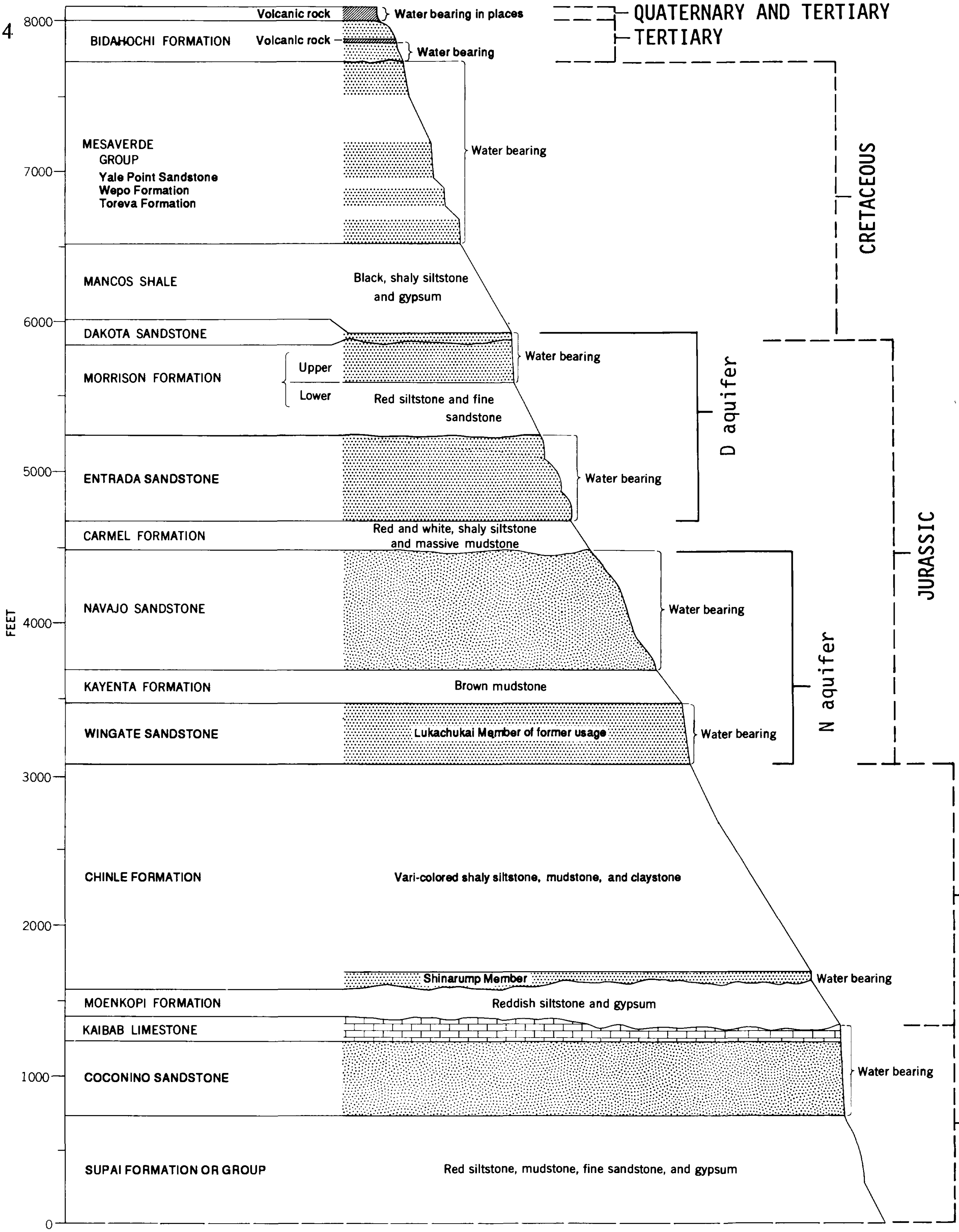


Figure 2.--Rock formations of the Black Mesa area.

HYDROLOGIC-DATA COLLECTION, 1989-91

Activities of the monitoring program include measurements of ground-water levels, metered and estimated ground-water withdrawals, flow measurements of springs and surface water, and collection of water-quality samples to detect changes in the hydrologic conditions in the N aquifer. Data presented in this report were collected from October 1989 through April 1991. Measurements of annual ground-water levels were made between February and April 1991; continuous-record observation-well water levels and ground-water withdrawals were from January to December 1990. Surface-water discharge data were collected from October 1989 to April 1991. Ground-water quality data were collected from December 1990 to February 1991. Surface-water quality data were collected in April 1991.

Ground-Water Levels

Annual ground-water levels were obtained from a network of 38 municipal and stock wells (table 1). In 1991, the maximum annual recorded water-level decline in the Black Mesa area was 18.7 ft at the Forest Lake well. The maximum annual recorded rise in water level was 8.4 ft at the Keams Canyon No. 2 well (table 1).

A mathematical model of the N aquifer was developed on the basis of available information about the aquifer (Eychaner, 1983). Water-level changes were simulated in several municipal wells and continuous-record observation wells that penetrate the N aquifer. During 1985, the model was rerun with measured withdrawals for 1980-84 to check the continued agreement of measured and simulated water levels (Hill and Sottilare, 1987). Brown and Eychaner (1988) recalibrated the 1983 model using a new model program that provided a finer grid and more detailed hydrologic characteristics near Kayenta, Tuba City, Keams Canyon, Oraibi, and the coal-lease area. As part of the recalibration process, the model was used to simulate water-level changes from 1965 to 1984. Hydrographs of the results of this simulation indicated general agreement between measured and simulated water-level changes observed in six continuous-record observation wells (BM1-6; Brown and Eychaner, 1988). The model for 1988 was rerun in 1989 by using measured withdrawals from 1985-88 to check agreement between measured and simulated water levels (Hart and Sottilare, 1989). The 1988 model was again rerun in 1990 by using measured withdrawals from 1965-89 (Sottilare, 1992). Although the model was not run in 1991, water-level measurements in the six observation wells for 1990-91 have been used to extend the hydrographs (fig. 3). The hydrographs of the measured water levels are based on annual and continuous-record data beginning about 1963 with well BM3. 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 BM1 and BM4, completed in the unconfined areas of the N aquifer, have risen by 0.5 and 0.9 ft, respectively (figs. 3 and 4). Water levels in wells BM2, BM3, and BM5, completed in the confined areas of the N aquifer, have declined from about 40 ft in well BM3 to about 60 ft in well BM2 during that same period. Well BM6, completed in a confined area of the N aquifer, has recorded a 69-foot decline in water level since 1977.

Table 1.--*Water-level changes in wells completed in the N aquifer, 1988-91*

Well system or location name	U.S. Bureau of Indian Affairs field number	Change in water level from preceding water year, in feet								Water level as depth below land surface, in feet, 1991
		1988		1989		1990		1991		
		Confined	Unconfined	Confined	Unconfined	Confined	Unconfined	Confined	Unconfined	
Tuba City	3T-333		+2.8		+0.2		+1.5		+0.8	29.5
Do.	3K-325		+1.2		-.2		-.1		-.5	202.9
Do.	Rare Metals 2		+.3		-.2		+.4		+.8	55.8
Tuba NTUA 1	3T-508		[1]+9.7		-----		[1]-13.7		+2.5	60.4
Tuba NTUA 4	3T-546		-----		[1]-9.3		-3.7		+5.6	62.3
Gold Tooth	3A-28		+3.4		0.0		+.3		-.1	229.7
White Mesa Arch	1K-214		-.9		+1.1		-.3		+.8	220.6
Cow Spring	1K-225		+.7		+.3		0.0		-.5	48.9
Shonto	3K-300		-.5		+1.1		0.0		+.6	171.8
Rough Rock	9Y-95		+3.6		+2.4		-.7		----	-----
Do.	9Y-92		+1.6		-1.4		+.1		-1.4	169.8
Northeast Rough Rock	8A-180		+5.4		-5.1		+.2		-.1	43.4
Shonto Southeast	2K-301		-.5		-.4		-.6		+.6	286.3
BM4	2T-514		-.1		0.0		+.3		0	216.1
BM1	8T-537		-.1		+.2		+.3		0	373.5
Long House Valley	8T-510		-1.4		+.8		-.6		-.2	117.3
Shonto Southeast	2T-502		+1.8		-1.5		-.2		+.1	414.3
Marsh Pass	8T-522		-.3		+0.2		-.6		-1.0	124.8
BM3	8T-500	+4.6		-3.6		+4.6		-0.4		130.0
Kayenta West	8T-541	-12.6		+7.3		-8.7		+3.6		272.2
BM2	8T-538	-2.0		-3.7		-3.4		-3.7		184.6
Sweetwater Mesa	8K-443	0.0		([2])		([2])		[1]-1.8		535.4
BM5	4T-519	-2.8		-4.0		-3.5		-4.0		377.6
BM6	BM6	-2.7		-2.6		-9.5		-4.0		804.6
Rough Rock	10R-119	-0.9		+.3		+.6		+.6		254.7
Do.	10T-258	+6.7		+1.8		-1.0		([2])		-------
Do.	10R-111	+3.1		+.1		-.1		+.2		197.7
Chilchinbito	PM3	+1.6		-9.9		+40.2		+1.5		427.0
Forest Lake	4T-523	-.8		-12.2		-6.2		-18.7		1,153.5
Pinon	PM6	([2])		([2])		[1]-41.7		([2])		-------
Low Mountain	PM2	-1.0		-19.7		([2])		([2])		-------
Keams Canyon	2	+18.9		-17.2		-1.5		+8.4		397.9
Kykotsmovi	PM1	-1.5		-1.4		------		+1.5		259.3
Do.	PM3	([2])		[1]-3.6		-.7		([2])		-------
Rocky Ridge	PM2	-2.1		-3.2		-5.1		-5.4		491.9
Howell Mesa	3K-311	([2])		[1]+.5		([2])		([2])		-------
Do.	6H-55	-.2		-.5		+0.3		-4.6		270.8

[1]Change in water level from last measurement of 2 years or more.
[2]Unable to measure.

Withdrawals from the N Aquifer

Withdrawals from the N aquifer are separated into three categories: (1) industrial use from the confined area, (2) municipal use from the confined area, and (3) municipal use from the unconfined areas (tables 2 and 3). The industrial category includes eight wells at the Peabody Coal Company well field in northern Black Mesa (fig. 5). The U.S. 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.

Tables 2, 3, and 4 are based on a compilation of metered and estimated data. In some areas, only partial data were available because of meter malfunctions and pumpage was either prorated 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, 1991) for areas without commercial water use.

Total ground-water withdrawal decreased slightly from about 5,920 acre-ft in 1989 to about 5,810 acre-ft in 1990. Most of the decrease in pumpage occurred in the municipal category for the unconfined areas (table 2) where fluctuations in total pumpage are largely affected by withdrawals from the areas of Tuba City and Kayenta (tables 3 and 4). Although industrial pumpage showed a slight decrease of about 20 acre-ft in 1990, municipal pumpage in the confined area increased about 100 acre-ft and resulted in a net increase of about 80 acre-ft from the confined area.

Surface-Water Discharge

Outflow from the N aquifer appears 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 station, Moenkopi Wash at Moenkopi (09401260; fig. 6, table 5). Low flow in Moenkopi Wash during November through February has remained fairly constant at about 3 ft^3/s since the streamflow station was established in 1976. Daily mean discharges for previous water years have been published by U.S. Geological Survey (1963-81; White and Garrett, 1984, 1986-88; Wilson and Garrett, 1988-89; and Boner and others, 1989-90). Measurements formerly made on Laguna Creek have been discontinued because variable amounts of snowmelt and sewage effluent are often included in the flow, and the data did not represent discharge from the N aquifer.

On April 26, 1991, nine base-flow measurements were made along a 20-mile reach of Moenkopi Wash between Blue Canyon and Moenkopi to determine the discharge from the confined area of the N aquifer (fig. 6, table 6). No flow was observed upstream from base-flow measurement site 1 (MSI-1). Although discharges downstream from MSI-1 varied, a general increase from less than 0.005 ft^3/s at MSI-1 to 2.02 ft^3/s at MSI-7 was measured. Downstream from MSI-7, the flow rate decreased to 0.86 ft^3/s at Moenkopi and may have been due to irrigation in or near Moenkopi. The extent to which evapotranspiration affected base flow is unknown.

Four springs were selected for discharge measurements as part of the monitoring program during 1990-91 (fig. 6, table 7). The springs were Moenkopi School Spring (3GS-77-6, Navajo Sandstone tongue in Kayenta Formation), an unnamed spring near Rough Rock (10R-158, Dakota Sandstone), Whisky Spring (5M-4, Navajo Sandstone), and Burro Spring (6M-31, Navajo Sandstone).

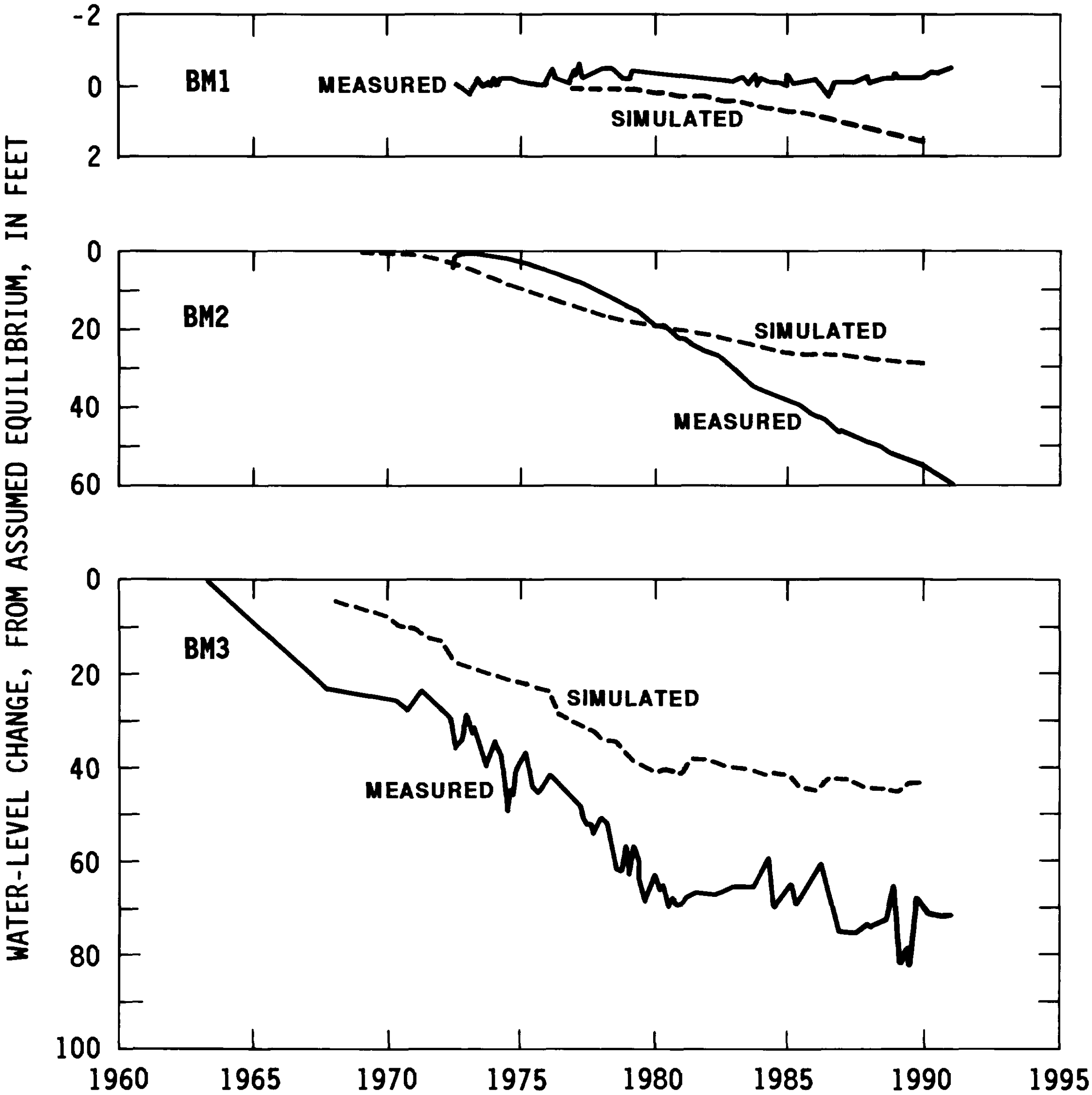


Figure 3.--Measured and simulated water-level changes in observation wells, BM 1-6, 1963-91 (modified from Brown and Eychaner, 1989; and Sottilare, 1992).

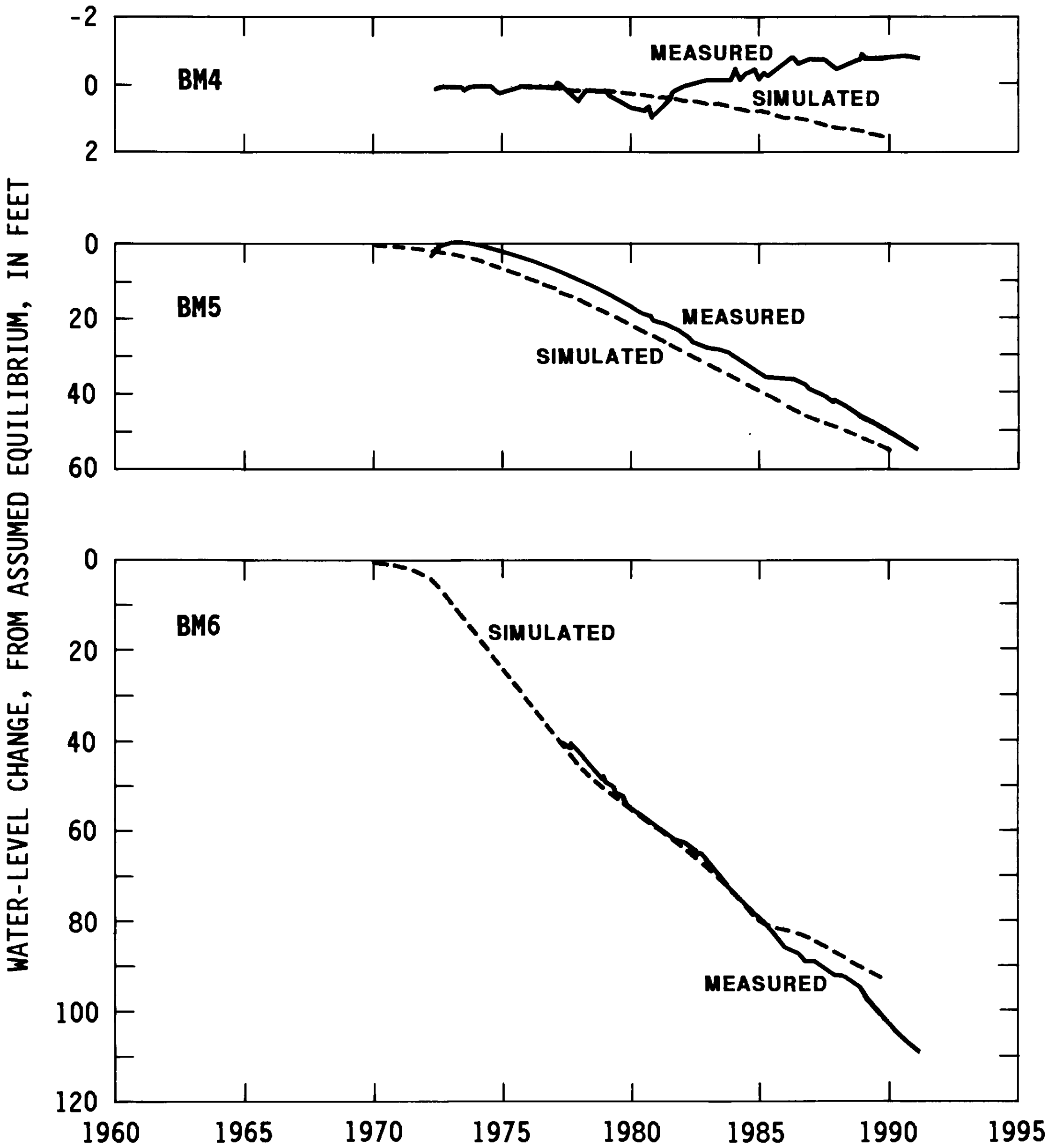
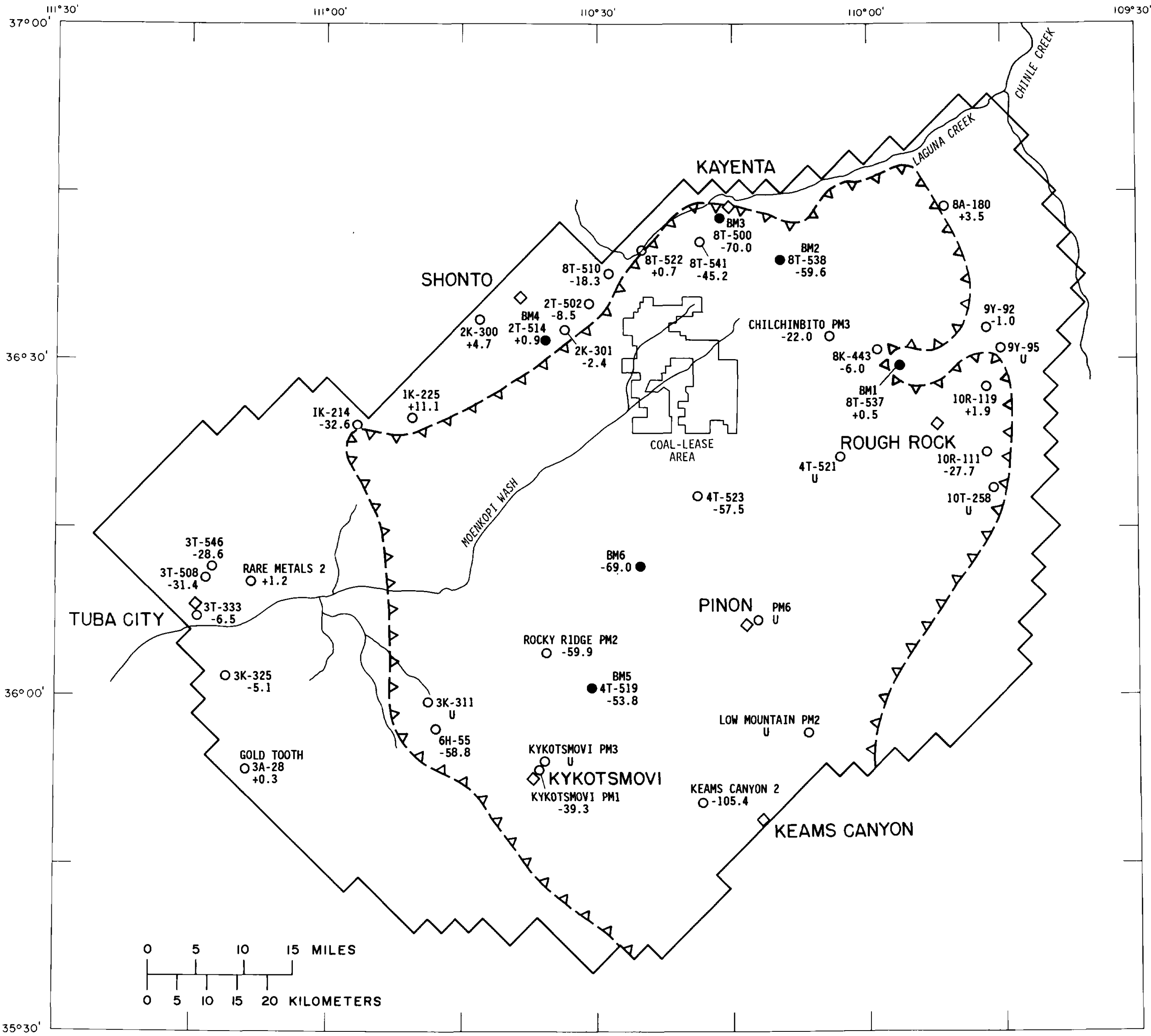


Figure 3.--Continued.



Base from U.S. Geological Survey Flagstaff 1:250,000, 1954-70; Gallup, 1:250,000, 1950-70; Marble Canyon, 1:250,000, 1956-70; and Shiprock, 1:250,000, 1954-69.

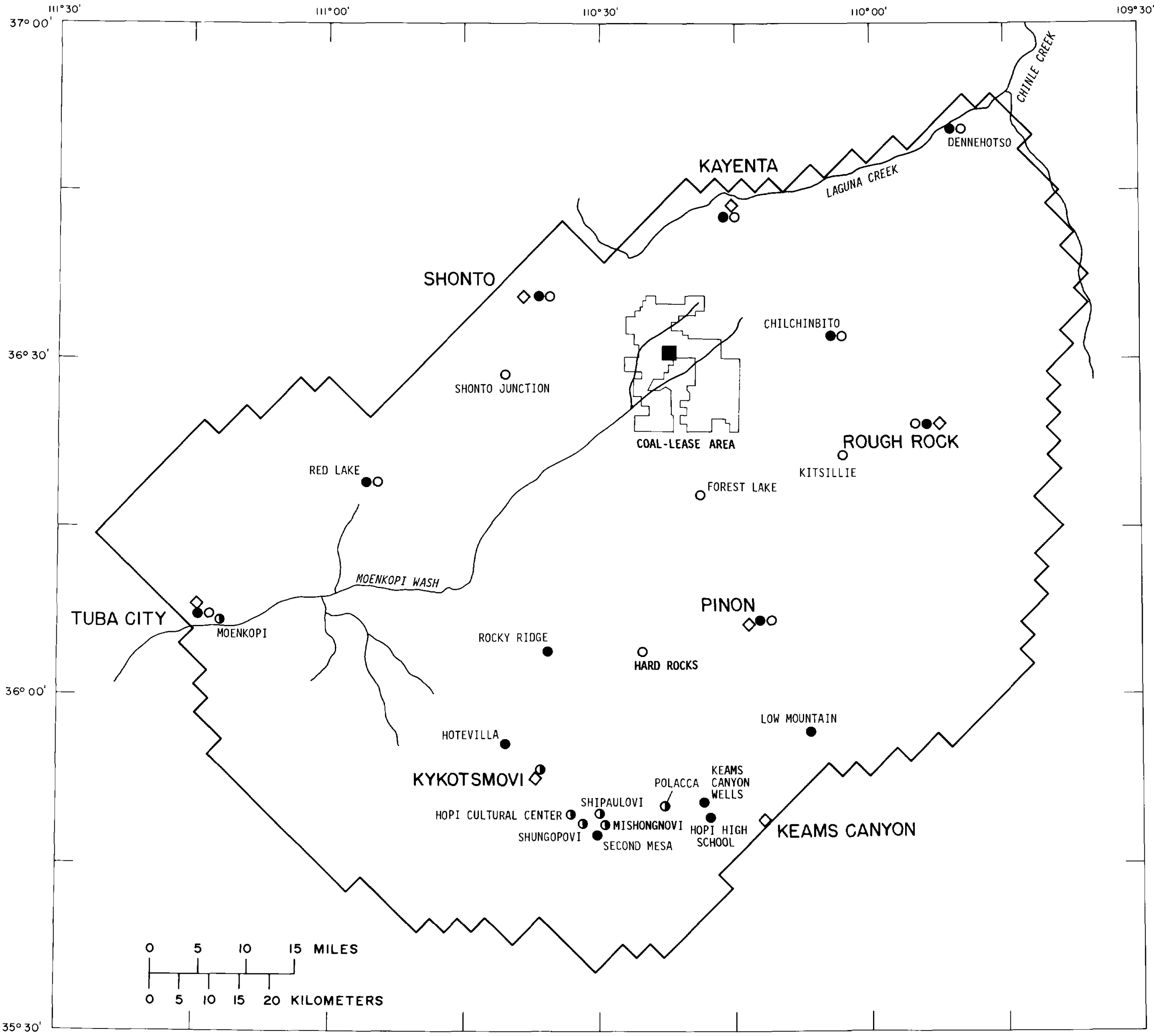
Modified from Brown and Eychaner, 1988

Figure 4.--Water-level changes in wells completed in the N aquifer, 1953-91.

EXPLANATION

CONFINED / UNCONFINED	APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS—From Eychaner (1983)
———	BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)
○ 4T-523 / -57.5	WELL IN WHICH DEPTH TO WATER WAS MEASURED ANNUALLY—First entry, 4T-523, is Bureau of Indian Affairs identification number; second entry, -57.5, is change in water level, in feet, between measurements made during the prestress period and measurements made during 1990-91. U, unable to measure
● BM3 / 8T-500 / -70.0	CONTINUOUS WATER-LEVEL RECORDING SITE (OBSERVATION WELL) MAINTAINED BY THE U.S. GEOLOGICAL SURVEY—First entry, BM3, is U.S. Geological Survey identification number; second entry, 8T-500, is Bureau of Indian Affairs identification number; third entry, -70.0, is change in water level, in feet, from 1953 to 1990-91
◇	COMMUNITY

Figure 4.--Continued.



Base from U.S. Geological Survey
Flagstaff 1:250,000, 1954-70;
Gallup, 1:250,000, 1950-70;
Marble Canyon,1:250,000, 1956-70;
and Shiprock, 1:250,000, 1954-69

Modified from Brown and Eychaner, 1988

Figure 5.--Location of well systems monitored for withdrawals from the N aquifer, 1990.

E X P L A N A T I O N

WELL-SYSTEM OWNER

● U.S. Bureau of Indian Affairs

○ Navajo Tribal Utility Authority

◑ Hopi Tribe

■ Peabody Coal Company

◇ COMMUNITY

Figure 5.--Continued.

Table 2.--*Withdrawals from the N aquifer, 1965-90*

[Measurements are in acre-feet. Data for 1965-79 from Eychaner, 1983]

Year	Industrial[1]	Municipal[2,3] Confined	Municipal[2,3] Unconfined
1965	0	50	20
1966	0	110	30
1967	0	120	50
1968.	95.	150	100
1969	43	200	100
1970	740	280	150
1971	1,900	340	150
1972	3,680	370	250
1973	3,520	530	300
1974	3,830	580	362
1975	3,550	600	508
1976	4,180	690	645
1977	4,090	750	726
1978	3,000	830	930
1979	3,500	860	930
1980	3,540	910	880
1981	4,010	960	1,000
1982	4,740	870	965
1983	4,460	1,360	1,280
1984	4,170	1,070	1,400
1985	2,520	1,040	1,160
1986	4,480	970	1,260
1987	3,830	1,130	1,280
1988	4,090	1,250	1,310
1989	3,450	1,070	1,400
1990	3,430	1,170	1,210

[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, Pinon, Keams Canyon, and Kykotsmovi prior to 1980; metered and estimated pumpage furnished by the Navajo Tribal Utility Authority and the U.S. 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 U.S. Bureau of Indian Affairs, various Hopi Village Administrations, and the U.S. Geological Survey, 1986-90.

Table 3.--*Withdrawals from the N aquifer by well system, 1990*

[Measurements, in acre-feet, are flowmeter data. BIA, U.S. Bureau of Indian Affairs; NTUA, Navajo Tribal Utility Authority; USGS, U.S. Geological Survey; Hopi, Hopi Village Administrations]

Location	Owner	Source of data	Confined aquifer well systems	Unconfined aquifer well systems
Tuba City	BIA	USGS/BIA		251.3
Red Lake	BIA	USGS/BIA		10.0
Shonto	BIA	USGS/BIA		175.6
Dennehotso	BIA	USGS/BIA		[1]25.0
Kayenta	BIA	USGS/BIA	77.0	
Rocky Ridge	BIA	USGS/BIA	14.3	
Chilchinbito	BIA	USGS/BIA	7.0	
Pinon	BIA	USGS/BIA	35.5	
Rough Rock	BIA	USGS/BIA	[1]40.0	
Hotevilla	BIA	USGS/BIA	[1]25.0	
Second Mesa	BIA	USGS/BIA	9.5	
Hopi High School	BIA	USGS/BIA	13.0	
Keams Canyon	BIA	USGS/BIA	64.2	
Low Mountain	BIA	USGS/BIA	8.3	
Tuba City	NTUA	NTUA		631
Red Lake	NTUA	NTUA		44.4
Shonto	NTUA	NTUA		17.9
Shonto Junction	NTUA	NTUA		29.3
Dennehotso	NTUA	NTUA		25.5
Forest Lake	NTUA	NTUA	12.8	
Chilchinbito	NTUA	NTUA	35.7	
Kayenta	NTUA	NTUA	527	
Rough Rock	NTUA	NTUA	12.0	
Pinon	NTUA	NTUA	66.5	
Kitsillie	NTUA	NTUA	10.4	
Hard Rocks	NTUA	NTUA	22.9	
Mine Well Field	Peabody	Peabody	3,430	
Polacca	Hopi	USGS	[1]30.0	
Kykotsmovi	Hopi	USGS/Hopi	[1]69.0	
Shungopovi	Hopi	USGS/Hopi	18.9	
Shipaulovi	Hopi	USGS	22.7	
Mishongnovi	Hopi	USGS/Hopi	3.1	
Hopi Cultural Center	Hopi	USGS/Hopi	[1]11.2	
Hopi Civic Center	Hopi	([2])	([2])	
Moenkopi	Hopi	([2])	[1]25.0	

[1]Includes some estimated data because of temporary 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.

[2]Data not available.

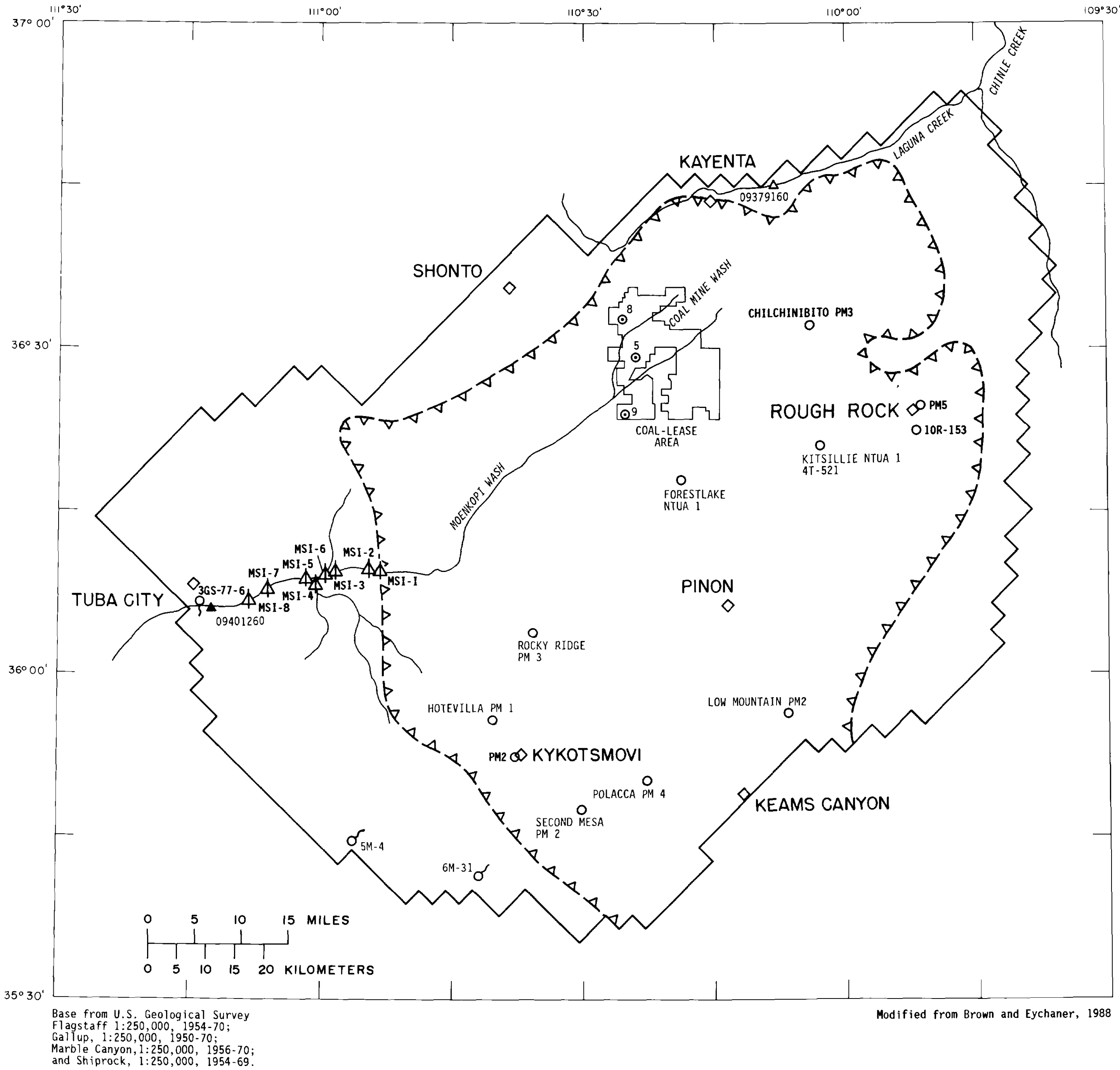


Figure 6.--Surface-water and water-quality data-collection sites, 1990-91.

E X P L A N A T I O N

CONFINED △△△△△△△△△ UNCONFINED	APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS—From Eychaner (1983)
————————	BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)
○ POLACCA PM 4	MUNICIPAL WELL FROM WHICH WATER-QUALITY SAMPLE WAS COLLECTED—Polacca PM4 is well name
⊙5	WELL OWNED BY PEABODY COAL COMPANY FROM WHICH WATER-QUALITY SAMPLE WAS COLLECTED—Number, 5, is well number
♂ 5M-4	SPRING AT WHICH DISCHARGE WAS MEASURED AND WATER-QUALITY SAMPLE WAS COLLECTED—Letter and number, 5M-4, is spring identification number
▲ 09401260	STREAMFLOW-GAGING STATION OPERATED BY THE U.S. GEOLOGICAL SURVEY AT WHICH SURFACE-WATER DATA WERE COLLECTED—Number, 09401260, is station identification number
△ 09379160	LOW-FLOW MEASUREMENT SITE—Number, 09379160, is site identification number
⍋ MSI-1	MISCELLANEOUS MEASUREMENT SITE—Number, MSI-1, is site identification number
◇	COMMUNITY

Figure 6.--Continued.

Table 4.--*Withdrawals from the N aquifer by well system, 1989*

[Measurements, in acre-feet, are flowmeter data. BIA, U.S. Bureau of Indian Affairs; NTUA, Navajo Tribal Utility Authority; USGS, U.S. Geological Survey; Hopi, Hopi Village Administrations]

Location	Owner	Source of data	Confined aquifer well systems	Unconfined aquifer well systems
Tuba City	BIA	USGS/BIA		[1]233
Red Lake	BIA	USGS/BIA		11.9
Shonto	BIA	USGS/BIA		199.0
Dennehotso	BIA	USGS/BIA		[1]39.7
Kayenta	BIA	USGS/BIA	87.7	
Rocky Ridge	BIA	USGS/BIA	12.1	
Chilchinbito	BIA	USGS/BIA	7.6	
Pinon	BIA	USGS/BIA	37.7	
Rough Rock	BIA	USGS/BIA	46.2	
Hotevilla	BIA	USGS/BIA	30.0	
Second Mesa	BIA	USGS/BIA	8.5	
Hopi High School	BIA	USGS/BIA	22.6	
Keams Canyon	BIA	USGS/BIA	84.6	
Low Mountain	BIA	USGS/BIA	9.2	
Tuba City	NTUA	NTUA		803
Red Lake	NTUA	NTUA		43.2
Shonto	NTUA	NTUA		17.9
Shonto Junction	NTUA	NTUA		28.3
Dennehotso	NTUA	NTUA		25.7
Forest Lake	NTUA	NTUA	11.3	
Chilchinbito	NTUA	NTUA	32.4	
Kayenta	NTUA	NTUA	443	
Rough Rock	NTUA	NTUA	12.4	
Pinon	NTUA	NTUA	72.6	
Kitsillie	NTUA	NTUA	7.4	
Hard Rocks	NTUA	NTUA	19.4	
Mine Well Field	Peabody	Peabody	3,450	
Polacca	Hopi	USGS	31.3	
Kykotsmovi	Hopi	USGS/Hopi	55.6	
Shungopovi	Hopi	USGS/Hopi	19.3	
Shipaulovi	Hopi	USGS	18.5	
Mishongnovi	Hopi	USGS/Hopi	2.8	
Hopi Cultural Center	Hopi	([2])	([2])	
Hopi Civic Center	Hopi	([2])	([2])	
Moenkopi	Hopi	([2])	([2])	

[1]Includes some estimated data because of temporary meter malfunction during the calendar year on one or more wells in this municipal well system. Estimate based on electrical usage or the typical average daily pumpage prior to meter malfunction for the well in question. Does not include possible estimated data provided by cooperating agencies.

[2]Data not available.

Table 5.--*Discharge data, Moenkopi Wash at Moenkopi, water year 1990*

[Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1990, is called "water year 1990." Dashes indicate no data]

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR 1990
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.00	1.1	1.8	1.8	3.2	5.6	1.1	3.1	0.34	0.00	0.00	0.00
2	.00	.92	1.6	3.1	3.9	5.4	1.7	2.1	.17	.00	.00	.00
3	.00	1.1	1.8	4.7	4.1	3.8	2.8	2.1	.24	.00	.00	.00
4	8.8	1.5	1.8	2.7	3.6	3.6	3.4	2.2	.59	9.1	.00	67
5	45.00	1.9	1.9	5.3	5.4	3.5	2.8	2.3	.07	8.9	.00	101
6	6.5	1.9	2.3	6.0	6.1	2.9	3.0	1.9	.00	2.8	.00	105
7	2.5	1.7	[1]1.9	7.3	3.8	3.6	2.5	2.3	.00	60	.00	20
8	1.5	1.7	1.7	5.2	4.7	2.8	1.6	.71	.00	182	.00	15
9	.94	1.6	[1]1.2	5.8	3.7	3.4	2.6	.94	.00	157	.00	8.9
10	.44	1.4	[1]1.5	6.2	3.9	2.8	2.5	1.3	.00	18	.00	6.7
11	.35	1.7	1.5	5.1	4.4	2.8	3.0	.78	19	8.9	.00	6.5
12	.35	1.7	1.6	4.6	4.4	2.8	3.1	.79	18	15	.00	5.1
13	.27	1.7	1.7	5.8	4.9	2.7	2.2	.92	5.6	6.5	.00	5.6
14	.06	1.9	2.2	3.7	4.3	2.2	2.1	.81	.23	20	166	4.9
15	.01	1.9	2.3	3.8	3.6	2.8	2.1	.70	.01	233	187	8.6
16	.01	1.7	2.8	2.5	4.7	2.0	2.1	.87	.00	54	120	100
17	.02	1.9	2.0	2.7	6.1	1.6	1.8	1.1	.00	12	20	38
18	.04	2.8	2.7	2.1	6.4	2.1	1.6	1.0	.00	70	3.5	214
19	.06	2.3	2.2	3.0	8.9	1.6	2.3	.66	.00	22	1.2	320
20	.11	2.3	1.8	[1]2.3	5.2	1.9	2.7	.63	.00	8.9	.48	181
21	.18	1.8	2.4	[1]2.3	4.6	2.1	2.0	.86	.00	4.8	.15	206
22	.50	1.8	2.1	[1]2.1	4.5	2.1	1.6	.51	.00	10	.30	25
23	.27	1.7	2.4	[1]2.4	3.7	2.1	2.3	.17	.00	5.0	.11	14
24	.46	1.6	2.4	[1]1.6	3.6	1.0	7.3	.20	.00	4.5	.10	19
25	.51	1.8	2.6	[1]2.2	3.6	1.0	7.3	.11	.00	3.7	.00	4.6
26	.56	1.7	2.6	[1]1.8	3.6	1.0	4.2	.05	.00	5.2	.00	2.7
27	.68	1.3	1.7	[1]1.6	4.1	1.0	2.7	.25	.00	1.4	.00	2.0
28	.55	1.3	3.0	[1]1.9	4.9	1.2	3.2	1.3	.00	.13	.00	1.5
29	.55	1.1	4.7	[1]1.7	--	1.4	2.4	.54	.00	.13	.00	1.5
30	.80	1.7	3.4	[1]1.6	--	1.3	3.0	.50	.00	.01	.00	1.5
31	1.0	--	1..7	3.3	--	1.5	--	56	--	.00	.00	--
TOTAL	73.02	50.52	67.3	106.2	127.9	75.6	83.0	32.26	44.25	922.97	498.84	1,485.10
MEAN	2.36	1.68	2.17	3.43	4.57	2.44	2.77	1.04	1.47	29.8	16.1	49.5
MAX	45	2.8	4.7	7.3	8.9	5.6	7.3	3.1	19	233	187	320
MIN.	0.00	.9	1.2	1.6	3.2	1.0	1.1	.05	.00	.00	.00	.00
AC-FT	145	100	133	211	254	150	165	64.	88	1,830	989.00	2,950

WATER YEAR 1990 TOTAL 3,566.96 MEAN 9.77 MAXIMUM 320 MINIMUM 0.00 ACRE-FEET 7, 080

[1]Estimated.

Table 6.--*Discharge data from seepage investigations along Moenkopi Wash, 1991*

[MSI, Moenkopi seepage investigation. <, less than]

Base-flow measurement site number[1]	Stream name	Date of measurement	Discharge, in cubic feet per second	Remarks
MSI-1	Moenkopi Wash	04-26-91	<0.005	300 feet above entrance to water caves.
MSI-2	Do.	Do.	<.1	0.5 mile below water caves.
MSI-3	Do.	Do.	1.28	150 feet above confluence with Begashibito Wash.
MSI-4	Begashibito Wash	Do.	.63	30 feet above confluence with Moenkopi Wash.
	Moenkopi Wash	Do.	1.81	25 feet below Begashibito Wash.
MSI-5	Do.	Do.	1.58	125 feet above Coal Mine Wash.
MSI-6	Coal Mine Wash	Do.	<.1	50 feet above confluence with Moenkopi Wash.
	Moenkopi Wash	Do.	1.89	200 feet above water falls; 0.6 miles below confluence.
MSI-7	Do.	Do.	2.02	75 feet below point of rock above Shonto Well.
MSI-8	Do.	Do.	1.54	30 feet above control at discontinued station 09401250.
MSI-9	Do.	Do.	.86	600 feet below gage at station 09401260.

[1]Measurement site numbers correlate to locations plotted on figure 7.

Table 7.--*Discharge measurements of selected springs, 1952-91*

Spring name	U.S. Bureau of Indian Affairs well number	Year	Discharge, in gallons per minute
Moenkopi School	3GS-77-6	1952	40
		1987	[1]16.0
		1988	[1]12.5
		1991	[1]13.5
Unnamed spring near Rough Rock	10R-158	1986	.2
		1990	.3
Whisky Spring	5M-4	1989	.1
		1990	.2
Burro Spring	6M-31	1989	.4
		1990	.4

[1]Discharge measured at sampling site only and does not represent the total discharge at Moenkopi School spring system.

Chemical Quality

Water from Wells Completed in the N Aquifer

Water from the N aquifer is monitored to detect effects of withdrawals on the chemical quality. The hydraulic head in the overlying D aquifer in 1964 averaged about 300 ft higher than that in the N aquifer. This higher head may cause water to move downward through the confining beds from the D aquifer to the N aquifer (Eychaner, 1983). Differences in the chemical composition of the water from the D aquifer and the N aquifer, however, indicate that the quantity of downward leakage must be small. On the average, the concentration of dissolved solids in water from the D aquifer is about 7 times greater than that of water from the N aquifer, concentration of chloride ions is about 11 times greater, and the concentration of sulfate ions is about 30 times greater (Eychaner, 1983). Any increase in the leakage rate as a result of pumping from the N aquifer probably would become evident as an increase in concentrations of sulfate, chloride, and dissolved solids in the most heavily pumped wells.

In general, water in the N aquifer is a calcium bicarbonate type in the part of the study area northwest of Black Mesa and a sodium bicarbonate type elsewhere throughout the area (Davis and others, 1963; Kister and Hatchett, 1963; Cooley and others, 1964). Locally, however, some wells penetrating the N aquifer may contain large concentrations of sulfate, chloride, and other ions. The large concentrations of sulfate, chloride, and other ions may result from the movement of water downward from the D aquifer to the N aquifer through wells not adequately sealed to prevent vertical movement of water through the well bore or by drawdown leakage through confining beds (Eychaner, 1983). Water-quality data to date, however, do not substantiate leakage through confining beds because of drawdown in the N aquifer.

All the wells sampled in 1991 penetrate the confined area of the N aquifer. All the wells except Peabody Well 8 and PM3 at Chilchinbito contained a sodium bicarbonate type water (fig. 7). Historically, water from Peabody Well 8 has been a sodium sulfate type. Water from well PM3 at Chilchinbito, however, indicated a marked change from a sodium bicarbonate type water in 1988 to a sodium sulfate type water in 1991. Sulfate concentrations increased from 31 to 620 milligrams per liter (mg/L). This change is believed to be caused by failure of the cement seal around the casing because the change was sudden rather than gradual and because other nearby wells were not affected.

Dissolved-solids concentrations in water from the N aquifer ranged from 83 mg/L at Peabody well 9 to 952 mg/L at the Chilchinbito well (tables 8 and 9; fig. 7). In the N aquifer, dissolved-solids concentrations in the sodium bicarbonate waters generally ranged from about 100 to 400 mg/L. Wells at Rough Rock and Low Mountain, however, had dissolved-solids concentrations of 574 and 812 mg/L, respectively.

Arsenic concentrations ranged from 1 to 79 micrograms per liter (μg/L). Most samples contained from 1 to 4 μg/L of arsenic. At Rough Rock and Low Mountain, concentrations of arsenic were 46 and 79 μg/L, respectively. The U.S. Environmental Protection Agency (EPA) has established 50 μg/L as the maximum contaminant level (MCL) for the safe drinking water standard for arsenic.

Surface Water

Chemical analyses were made on water samples from three sites along Moenkopi Wash (table 10). The samples were collected in April 1991 as part of a seepage investigation to determine the quality of water discharged into Moenkopi Wash from the N aquifer; however, the samples were taken from the stream channel and may have been affected by alluvium deposited from the upstream erosion of rocks of the D aquifer. At each site, the water was a sodium sulfate type, and dissolved-solids concentrations ranged from 1,080 mg/L at MSI-1 to 582 mg/L at MSI-3. Sulfate concentrations ranged from 690 mg/L at MSI-1 to 280 mg/L at MSI-3. Arsenic concentrations were 2 μg/L or less.

Four springs were selected for water-quality analyses as part of the monitoring program during 1990-91 (figs. 6 and 7; table 11). The springs were Moenkopi School Spring, an unnamed spring near Rough Rock, Whisky Spring, and Burro Spring.

Water from the unnamed spring near Rough Rock issues from a sedimentary unit that is part of the D aquifer and is not part of the N aquifer. Dissolved-solids concentrations in water from the four springs ranged from 157 to 451 mg/L, and arsenic concentrations were 2 μg/L or less. On the basis of previous data, the quality of water in the springs has not changed (table 11).

Table 8.--*Chemical analyses of water from selected industrial and municipal wells completed in the N aquifer, 1991*

Well name	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)
Peabody Well 5	362901110234101	01-25-91	32.1	264	9.3	106	0.9
Peabody Well 8	363130110254501	01-25-91	30.2	452	8.3	99	1.6
Peabody Well 9	362333110250001	01-25-91	32.4	163	9.1	78	.7
Rocky Ridge PM3	360422110353501	01-23-91	26.2	248	9.5	115	1.3
Polacca PM4	354950110231501	01-22-91	22.0	746	9.5	327	.1
Rough Rock PM5	362418109514601	01-11-91	20.9	1,060	8.9	219	1.0
Second Mesa PM2	354749110300101	01-24-91	20.6	613	9.7	287	.1
Low Mountain PM2	355638110064001	01-18-91	20.6	1,500	9.0	373	.1

Well name	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	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)
Peabody Well 5	0.01	3.5	0.11	55	0.7	3.0	18
Peabody Well 8	.01	24	3.2	67	2.7	6.1	109
Peabody Well 9	.03	3.9	.14	32	.6	2.7	3.1
Rocky Ridge PM3	.02	.46	.03	59	.4	.7	6.8
Polacca PM4	.01	.64	.11	170	.6	29	27
Rough Rock PM5	.01	2.0	.32	230	1.4	130	109
Second Mesa PM2	.01	.5	.01	140	0.4	10	15
Low Mountain PM2	.01	1.6	.5	330	1.1	210	75

Well name	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)
Peabody Well 5	0.2	20	3	40	3	178
Peabody Well 8	.2	19	2	40	6	280
Peabody Well 9	.1	19	3	20	28	83
Rocky Ridge PM3	.1	20	3	20	7	248
Polacca PM4	.6	14	16	230	4	431
Rough Rock PM5	1.7	12	46	400	39	374
Second Mesa PM2	.3	20	15	90	3	242
Low Mountain PM2	2.8	11	79	1,200	14	812

Table 8.--*Chemical analyses of water from selected industrial and municipal wells completed in the N aquifer, 1991--Continued*

Well name	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)
Kitsillie NTUA1	362035110032201	01-21-91	27.4	435	9.7	205	1.2
Forest Lake NTUA1	361737110180301	01-21-91	29.4	321	9.5	127	.6
Chilchinbito PM3	363137110044702	02-07-91	19.0	1,500	8.2	143	.1
Hotevilla PM1	355518110400301	01-24-91	26.3	304	9.7	142	1.1
Kykotsmovi PM2	355215110375001	02-21-91	22.3	372	9.9	164	1.2

Well name	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	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)
Kitsillie NTUA1	0.01	0.76	0.14	98	0.6	6.6	4.9
Forest Lake NTUA1	.01	.85	.09	76	.6	10	24
Chilchinbito PM3	.01	17	7.3	280	4.5	11	620
Hotevilla PM1	.02	.72	.01	68	.5	.7	5.4
Kykotsmovi PM2	.02	.51	.10	80	.4	4.4	7.9

Well name	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)
Kitsillie NTUA1	0.1	24	4	50	5	232
Forest Lake NTUA1	.1	21	3	60	44	183
Chilchinbito PM3	.5	8.5	1	200	20	952
Hotevilla PM1	.1	22	3	20	3	208
Kykotsmovi PM2	.1	23	3	30	3	203

Table 9.--*Selected properties of water from industrial and municipal wells completed in the N aquifer, 1968 and 1980-91*

Well name	Year	Specific conductance (µS/cm)	Dissolved-solids concentrations residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Peabody Well 5	1968	224	[1]149	3.5	16
	1980	210	134	2.9	9.5
	1986	398	---	8.0	28
	[2]1986	602	338	12.0	62
	1987	270	168	4.6	21
	1988	270	184	5.1	22
	1988	263	174	4.1	26
	1990	262	152	4.1	18
	1991	264	178	3.0	18
Peabody Well 8	1980	420	283	4.8	100
	1983	440	278	4.8	100
	1984	436	264	4.7	100
	1986	445	---	4.9	110
	[3]1988	790	516	7.2	250
	[4]1988	438	300	4.8	120
	1988	418	308	4.5	120
	1990	440	287	4.3	109
	1991	452	280	6.1	110
Peabody Well 9	1986	181	---	3.1	4.9
	1987	148	102	2.8	4.1
	1990	158	106	1.6	3.0
	1991	163	83	2.7	3.1
Rocky Ridge PM3	1982	255	---	1.4	6.0
	1990	222	126	1.5	6.0
	1991	248	164	.7	6.8
Polacca PM4	1990	830	424	30	25
	1991	746	431	29	27
Rough Rock PM5	1983	1,090	628	130	110
(BIA #2)	1984	1,090	613	130	99
	1986	1,010	633	140	120
	1988	1,120	624	130	109
	[2]1991	1,060	574	130	110
Second Mesa	1990	590	364	6.5	16
PM2	1991	613	292	10.0	15
Kykotsmovi	1988	368	212	3.2	8.6
PM2	1990	355	255	3.2	9.0
	1991	372	203	4.4	7.9
Low Mountain	1988	1,580	851	200	75
PM2	1990	1,480	837	200	61
	1991	1,500	812	210	75
Kitsillie	1982	580	365	5.4	84
NTUA1	1983	505	291	4.4	37
	1984	460	258	5.2	20
	1988	418	241	3.7	5.7
	1990	410	268	3.6	5.0
	1991	435	232	6.6	4.9
Forest Lake	1982	470	---	11	67
NTUA1	1990	375	226	8.2	38
	1991	321	183	10	24
Hotevilla PM1	1990	290	192	1.6	5.0
	1991	304	208	.7	5.4
Chilchinbito PM3	1986	390	231	2.4	11
	1988	414	256	2.7	31
	1991	1,500	952	11.0	620

[1]Dissolved-solids concentration in 1974.
[2]Volume of well bore not completely displaced prior to sampling.
[3]Well pumped for 16 hours at 470 gallons per minute.
[4]Well pumped for 20 hours at 600 gallons per minute.

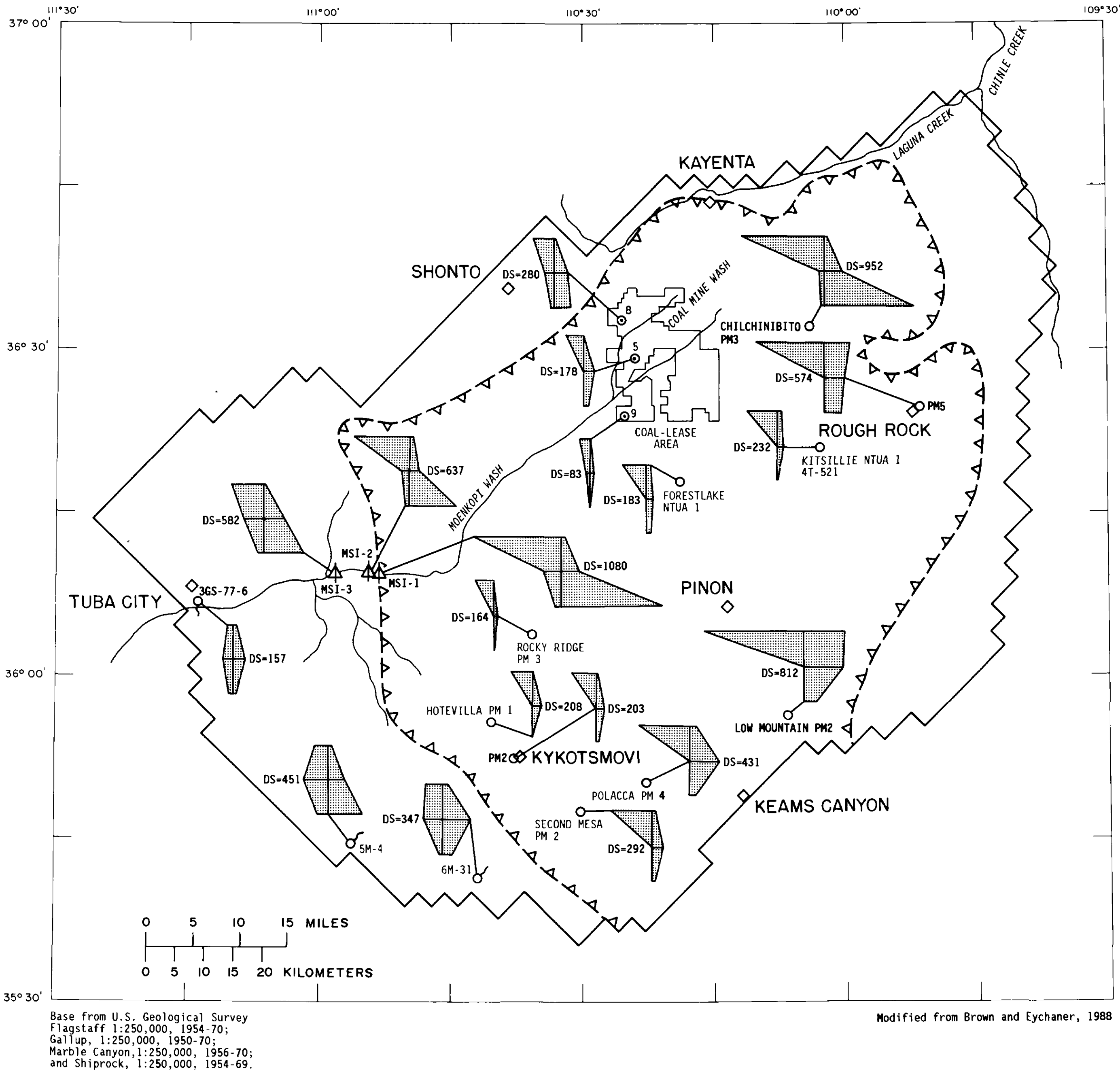
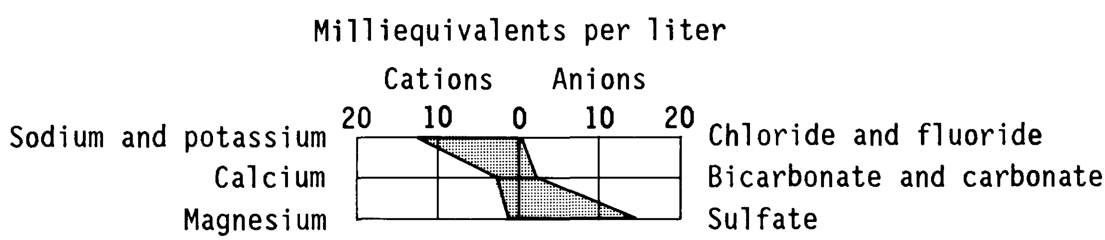


Figure 7.--Water quality and distribution of dissolved solids in the N aquifer, 1990-91.

EXPLANATION

CONFINED / UNCONFINED	APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS—From Eychaner (1983)
	BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)
POLACCA PM 4	MUNICIPAL WELL FROM WHICH WATER-QUALITY SAMPLE WAS COLLECTED—Polacca PM4 is well name
5	WELL OWNED BY PEABODY COAL COMPANY FROM WHICH WATER-QUALITY SAMPLE WAS COLLECTED—Number, 5, is well number
5M-4	SPRING AT WHICH DISCHARGE WAS MEASURED AND WATER-QUALITY SAMPLE WAS COLLECTED—Letter and number, 5M-4, is spring identification number
	CHEMICAL-QUALITY DIAGRAM—Shows major chemical constituents in milliequivalents per liter. The diagrams are in a variety of shapes and sizes, and they provide a means of comparing, correlating, and characterizing types of water



DS=952	DISSOLVED SOLIDS—Number, 952, is dissolved-solids concentrations, in milligrams per liter
MSI-1	MISCELLANEOUS MEASUREMENT SITE—Number, MSI-1, is site identification number
◇	COMMUNITY

Figure 7.--Continued.

Table 10.--*Chemical analyses of water from base-flow measurement sites along Moenkopi Wash, 1991*

Site name	Site 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)
Moenkopi Wash above water caves, near Red Lake....	MSI-1	4-26-91	18	1,590	8.2	126	0.087
Moenkopi Wash below water caves, near Red Lake....	MSI-2	4-26-91	21.5	977	9.2	143	.05
Moenkopi Wash above Begashibito Wash, near Tonalea............	MSI-3	4-26-91	19.5	846	8.4	161	.05

Site name	Phosphorus, ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	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)
Moenkopi Wash above water caves, near Red Lake......	0.01	53	13	290	2.4	17	690
Moenkopi Wash below water caves, near Red Lake.....	.01	20	5.1	190	2.0	9.1	330
Moenkopi Wash above Begashibito Wash, near Tonalea......	.01	62	12	110	3.4	6.9	280

Site name	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)
Moenkopi Wash above water caves, near Red Lake.....	0.5	11	2	40	12	1,080
Moenkopi Wash below water caves,. near Red Lake.....	.5	11	2	30	23	637
Moenkopi Wash above Begashibito Wash, near Tonalea......	.5	10	1	40	12	682

Table 11.--*Chemical analyses of water from selected springs, 1952-91*

Spring name	U.S. 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)	Alkalinity (mg/L as $CaCO_3$)	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
Moenkopi School	3GS-77-6	360632111131101	Navajo Sandstone	05-16-52	----	222	---	92	----
			Tongue in the	04-22-87	16	270	7.4	101	1.7
			Kayenta Formation	11-29-88	18	270	7.2	98	1.9
				02-21-91	16.5	287	7.5	97	1.9
Spring near Rough Rock	10R-158	362410109521201	Dakota Sandstone	05-20-86	8.5	268	8.2	93	.98
				12-13-90	4.5	323	8.0	109	----
Whisky Spring	5M-4	354446110562001	Navajo Sandstone	05-13-54	20	639	---	---	----
				12-14-89	8	560	7.9	117	<.1
				12-14-90	7.5	676	7.9	121	----
Burro Spring	6M-31	354156110413701	Navajo Sandstone	12-15-89	3.5	485	7.6	180	<.1
				12-13-90	5.0	546	7.6	201	----

Spring name	Date of sample	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)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Percent sodium	Sodium+Potassium, dissolved (mg/L as Na+K)
Moenkopi School	05-16-52	-----	78	0	21	6.1	----	0.9	33	17
	04-22-87	.01	85	---	25	5.5	22	1.0	--	--
	11-29-88	<.01	---	---	27	5.9	22	---	--	--
	02-21-91	.01	---	---	27	5.7	22	---	--	--
Spring near Rough Rock	05-20-86	.01	109	---	34	7	5.7	.2	--	--
	12-13-90	-----	---	---	43	9.0	6.7	---	--	--
Whisky Spring	05-13-54	-----	270	144	---	----	----	.8	31	31
	12-14-89	<.01	---	---	72	17	45	---	--	--
	12-14-90	-----	---	---	72	17	44	---	--	--
Burro Spring	12-15-89	<.01	---	---	49	3.8	56	---	--	--
	12-13-90	-----	---	---	56	4.3	61	---	--	--

Spring name	Date of sample	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)
Moenkopi School	05-16-52	---	6	---	---	----	--	--	--	---
	04-22-87	1.3	12	19	0.2	13	--	40	5	161
	11-29-88	1.3	12	19	.1	14	--	30	6	155
	02-21-91	1.3	14	20	.1	13	2	30	3	157
Spring near Rough Rock	05-20-86	1.8	5	28	.3	7.8	--	30	12	---
	12-13-90	3.8	7	34	.6	6.9	1	30	3	173
Whisky Spring	05-13-54	---	10	189	.4	17	--	--	--	---
	12-14-89	2.6	7	219	.3	15	--	50	12	455
	12-14-90	2.8	10	240	.2	15	1	50	3	451
Burro Spring	12-15-89	.5	22	59	.3	15	--	50	10	308
	12-13-90	.5	23	65	.3	15	1	60	160	347

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. Combined ground-water withdrawals have increased from about 350 acre-ft in 1968 to 5,800 acre-ft in 1990. Outflow from the N aquifer is mainly surface flow along Moenkopi Wash and Laguna Creek and discharge from springs near the boundaries of the aquifer. In 1990, ground-water withdrawals from the N aquifer were used mainly for industrial (3,430 acre-ft) and municipal uses (2,380 acre-ft).

Calcium bicarbonate water and sodium bicarbonate water are the primary types of water that occur in the N aquifer. Calcium bicarbonate water occurs in the part of the study area northwest of Black Mesa. The sodium bicarbonate water generally occurs elsewhere throughout the area. Calcium sulfate and sodium sulfate waters have been found in a few wells. In 1990-91, dissolved-solids concentrations ranged from about 80 to 1,080 mg/L. Arsenic concentrations ranged from 1 to 79 μg/L.

Although a potential exists for downward movement of water from the D aquifer to the N aquifer, the water-quality data to date do not substantiate any leakage through confining beds because of drawdown in the N aquifer. In general, long-term water-quality data for wells and springs show no discernible change in water quality.

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