Results of Ground-Water, Surface-Water, and Water-Chemistry Monitoring, Black Mesa Area, Northeastern Arizona—1994

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

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CONTENTS

CONVERSION FACTORS

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

Temperatures are given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{\circ}F = 1.8(^{\circ}C) + 32$$

ABBREVIATED WATER-CHEMISTRY UNITS

Chemical concentration is 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 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 (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 areas 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 1994, ground-water withdrawals for industrial and municipal use totaled about 7,000 acre-feet, which is an 8-percent increase from the previous year. Pumpage from the confined part of the aquifer increased by about 9 percent to 5,400 acre-feet, and pumpage from the unconfined part of the aquifer increased by about 2 percent to 1,600 acre-feet. Water-level declines in the confined area during 1994 were recorded in 10 of 16 wells, and the median change was a decline of about 2.3 feet as opposed to a decline of 3.3 feet for the previous year. The median change in water levels in the unconfined area was a rise of 0.1 foot in 1994 as opposed to a decline of 0.5 foot in 1993.

Measured low-flow discharge along Moenkopi Wash decreased from 3.0 cubic feet per second in 1993 to 2.9 cubic feet per second in 1994. Eleven low-flow measurements were made along Laguna Creek between Tsegi, Arizona, and Chinle Wash to determine the amount of discharge that would occur as seepage from the N aquifer under optimal base-flow conditions. Discharge was 5.6 cubic feet per second near Tsegi and 1.5 cubic feet per second above the confluence with Chinle Wash. Maximum discharge was 5.9 cubic feet per second about 4 miles upstream from Dennehotso. Discharge was measured at three springs. The changes in discharge at Burro and Whisky Springs were small and within the uncertainty of measurement. Discharge at Moenkopi School Spring decreased from 14.6 gallons per minute in 1993 to 12.9 gallons per minute in 1994.

Regionally long-term water-chemistry data for wells and springs have shown no discernible change. A recent gradual increase in concentrations of dissolved solids, sulfate, and chloride in water from Forest Lake NTUA 1, however, indicates that, locally, water from the D aquifer may be mixing with water from 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), and the ground water occurs under confined and unconfined conditions. The aquifer consists of three rock formations—Navajo Sandstone, Kayenta Formation, and 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 that is 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 26 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 1994 was 4,080 acre-ft. Withdrawals from the N aquifer for municipal use increased from an estimated 250 acre-ft in 1968 to a maximum of about 4,500 acre-ft in 1991 and decreased to about 2,940 acre-ft in 1994.

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.

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[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.

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 1994. 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 were collected from wells completed in the N aquifer and include data on pumpage, water levels, and chemistry. Surface-water data include discharge measurements at a continuous-record site, and discharge measurements and chemistry at sites along Laguna Creek and at selected springs.

Previous Investigations

Twelve progress reports have been prepared by the USGS on the monitoring phase of the program (USGS, 1978; G.W. Hill, hydrologist, USGS, 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, 1995). 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 USGS (1975–81), White and Garrett (1984–88), Wilson and Garrett (1988–89), Boner and others (1989–92), and Smith and others (1992–94). Eychaner (1983) described the results of mathematical-model simulations of 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) 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.

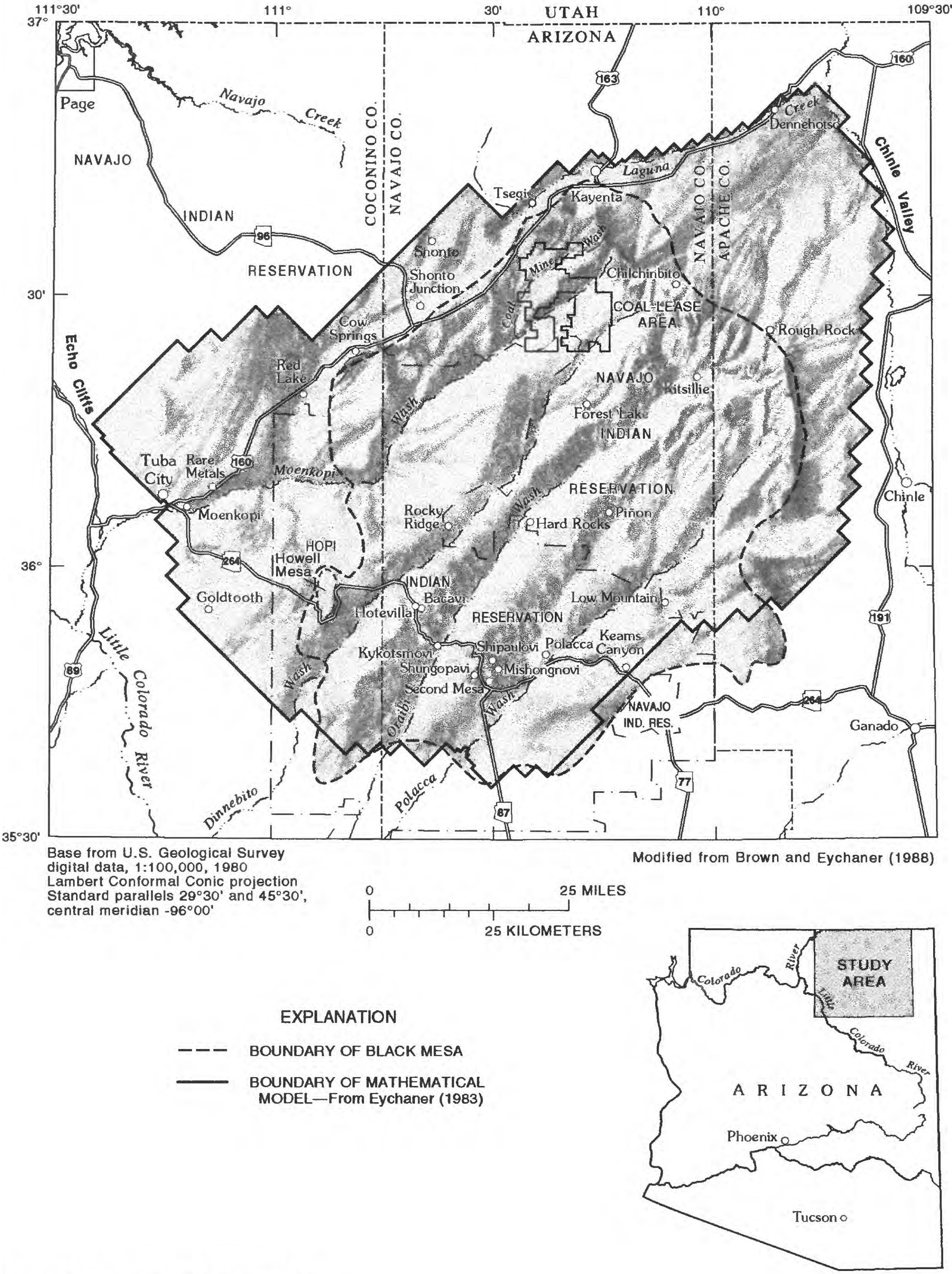


Figure 1. Location of study area.

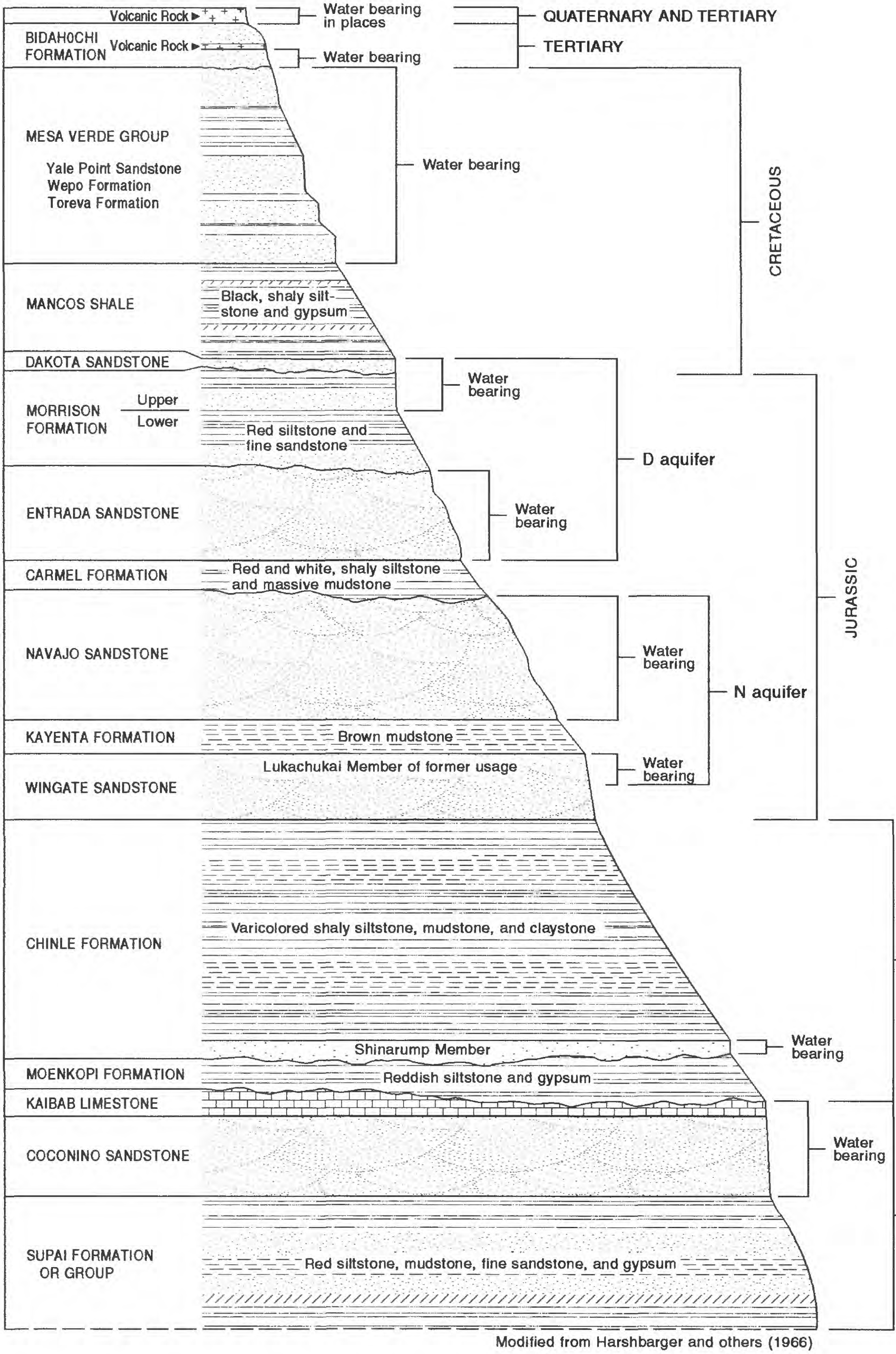


Figure 2. Rock formations of the Black Mesa area. The N aquifer is approximately 1,000 feet thick.

HYDROLOGIC DATA

Activities of the monitoring program in 1994 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 through December 1994. Measurements of annual ground-water levels were made during November and December 1994. Chemical data are from ground-water samples collected during November and December 1994.

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 (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

Table 1. Withdrawals from the N aquifer, 1965–94

[Values are in acre-feet. Data for 1965–79 from Eychaner (1983)]

Year	Industrial[1]	Municipal[2,3]		Total withdrawals per year	Year	Industrial[1]	Municipal[2,3]		Total withdrawals per year
		Confined	Unconfined				Confined	Unconfined	
1965	0	50	20	70	1980	3,540	910	880	5,330
1966	0	110	30	140	1981	4,010	960	1,000	5,970
1967	0	120	50	170	1982	4,740	870	965	6,575
1968	95	150	100	345	1983	4,460	1,360	1,280	7,100
1969	43	200	100	343	1984	4,170	1,070	1,400	6,640
1970	740	280	150	1,170	1985	2,520	1,040	1,160	4,720
1971	1,900	340	150	2,390	1986	4,480	970	1,260	6,710
1972	3,680	370	250	4,300	1987	3,830	1,130	1,280	6,240
1973	3,520	530	300	4,350	1988	4,090	1,250	1,310	6,650
1974	3,830	580	362	4,772	1989	3,450	1,070	1,400	5,920
1975	3,500	600	508	4,608	1990	3,430	1,170	1,210	5,810
1976	4,180	690	645	5,515	1991	4,020	1,140	3,360	8,520
1977	4,090	750	726	5,566	1992	3,820	1,180	1,410	6,410
1978	3,000	830	930	4,750	1993	3,700	1,250	1,570	6,520
1979	3,500	860	930	5,290	1994	4,080	1,340	1,600	7,020

[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 prior to 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, 1986–94.

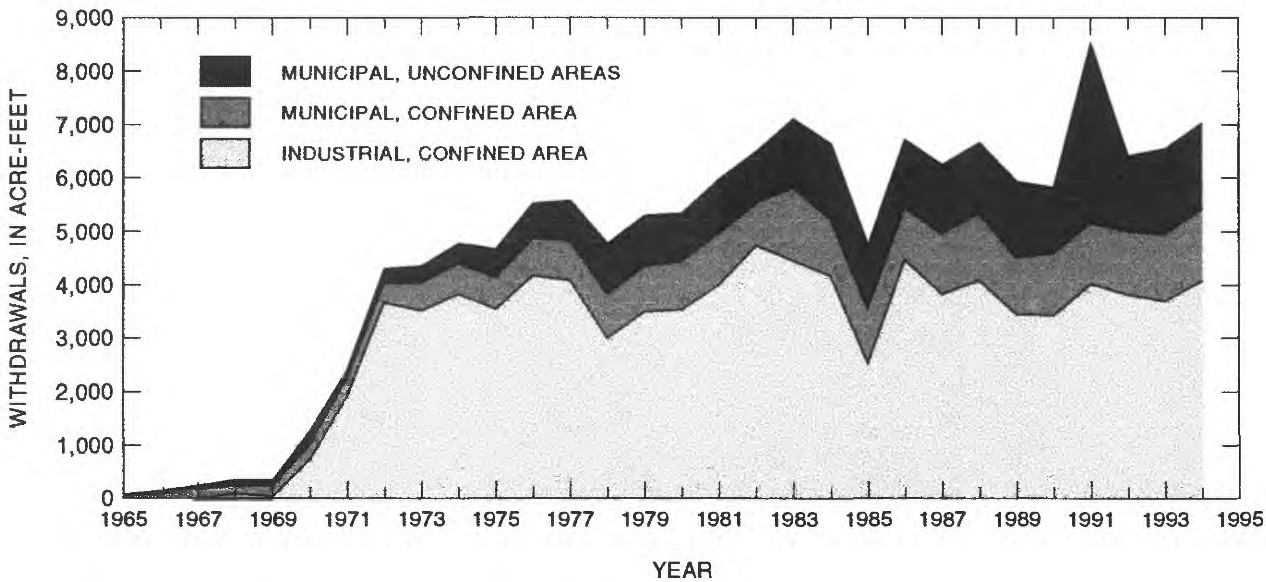


Figure 3. Withdrawals from the N aquifer, 1965–94.

available because of meter malfunctions, and pumpage was either prorated, on the basis of 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, 1991) for areas without commercial water use.

The total ground-water withdrawal in 1994 was about 7,000 acre-ft (table 1), which is an 8-percent increase in withdrawals compared with total withdrawals in 1993. Pumpage from the confined part of the aquifer increased by about 9 percent to 5,400 acre-ft, and pumpage from the unconfined part of the aquifer increased by about 2 percent to 1,600 acre-ft. Industrial pumpage accounted for about 4,100 acre-ft or about 58 percent of the total withdrawal, as compared to 57 percent in 1993. Municipal pumpage accounted for about 2,900 acre-ft and represents 42 percent of the total withdrawal as compared to 43 percent in 1993.

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 through 1994 ranged from a rise of 6.4 ft at well 3K-325 near Tuba City to a decline of 156.8 ft at Keams Canyon 2 well (fig. 5). In 1994, the maximum annual recorded rise in water level in the Black Mesa area was 18 ft at the Kykotsmovi PM1 well. The maximum annual recorded water-level decline was 9.2 ft at the Keams Canyon 2 well. Water-level declines in the confined area were measured in 10 of 16 wells and the median change was a decline of about 2.3 ft as opposed to a decline of 3.3 ft for the previous year. The median change in water levels in the unconfined area was a rise of 0.1 ft in 1994 as opposed to a decline of 0.4 ft in 1993.

Hydrographs of measured water levels in the six continuous-record observation wells (BM1 through BM6) are based on annual and continuous-record data beginning in about 1963 with 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 area of the N aquifer have risen by

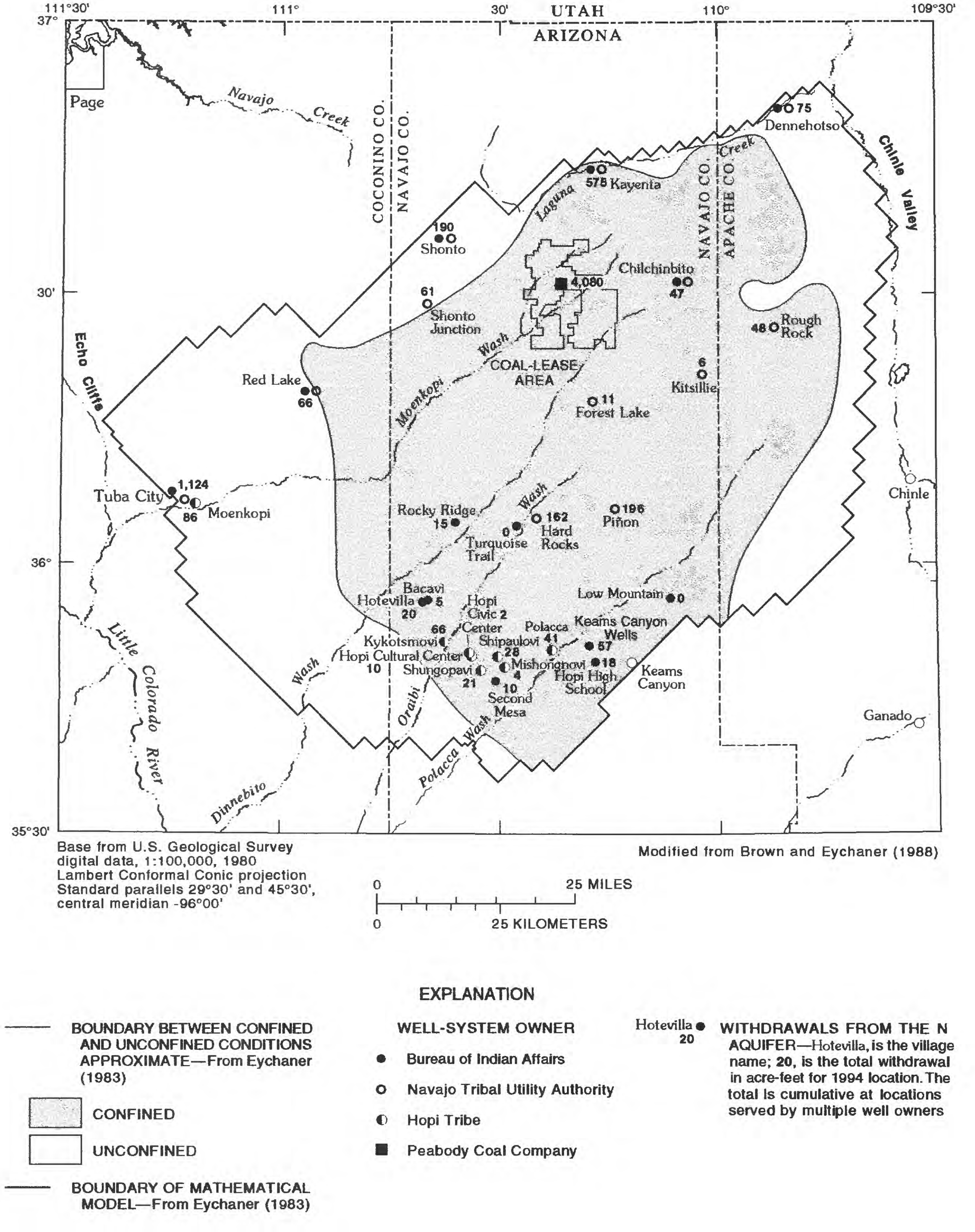


Figure 4. Location of well systems monitored for withdrawals from the N aquifer, 1994.

Table 2. Withdrawals from the N aquifer by well system, 1994

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

Location	Owner	Source of data	Confined aquifer well systems	Unconfined aquifer well systems
Chilchinbito	BIA	USGS/BIA	7.0	
Dennehotso	BIA	USGS/BIA		40.2
Hopi High School	BIA	USGS/BIA	17.8	
Hotevilla	BIA	USGS/BIA	19.8	
Kayenta	BIA	USGS/BIA	77.5	
Keams Canyon	BIA	USGS/BIA	57.2	
Low Mountain	BIA	USGS/BIA	.2	
Piñon	BIA	USGS/BIA	34.1	
Red Lake	BIA	USGS/BIA		17.8
Rocky Ridge	BIA	USGS/BIA	14.6	
Rough Rock	BIA	USGS/BIA	27.2	
Second Mesa	BIA	USGS/BIA	9.6	
Shonto	BIA	USGS/BIA		175.1
Tuba City	BIA	USGS/BIA		131.5
Turquoise Trail	BIA	Contractor	.1	
Chilchinbito	NTUA	NTUA	39.6	
Dennehotso	NTUA	NTUA		34.5
Forest Lake	NTUA	NTUA	10.6	
Hard Rocks	NTUA	NTUA	161.7	
Kayenta	NTUA	NTUA	497.6	
Kitsillie	NTUA	NTUA	5.5	
Pinon	NTUA	NTUA	161.4	
Red Lake	NTUA	NTUA		48.4
Rough Rock	NTUA	NTUA	20.4	
Shonto	NTUA	NTUA		14.4
Shonto Junction	NTUA	NTUA		61.0
Tuba City	NTUA	NTUA		992.0
Mine Well Field	Peabody	Peabody	4,078.8	
Bacavi	Hopi	USGS/Hopi	4.7	
Hopi Civic Center	Hopi	USGS/Hopi	1.7	
Hopi Cultural Center	Hopi	USGS/Hopi	10.0	
Kykotsmovi	Hopi	USGS/Hopi	65.9	
Mishongnovi	Hopi	USGS/Hopi	4.4	
Moenkopi	Hopi	USGS/Hopi		[1]86.2
Polacca	Hopi	USGS/Hopi	[2]41	
Shipaulovi	Hopi	USGS/Hopi	27.6	
Shungopovi	Hopi	USGS/Hopi	20.8	

[1]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.

[2]Estimated. Well not metered.

0.3 ft in BM1 and 1.1 ft in BM4 (fig. 6). Water levels in wells completed in the confined area of the N aquifer have declined from about 58 ft in well BM3 to 67.1 ft in well BM5 since 1972. The water level of well BM6, which is completed in the confined area of the N aquifer, has declined 79.8 ft since 1977. Records for the oldest well, BM3, indicate a water-level decline of 79 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 is mainly surface flow in Moenkopi Wash and Laguna Creek[2] and springs near the boundaries of the aquifer (Davis and others, 1963). Discharge data were collected at

[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.

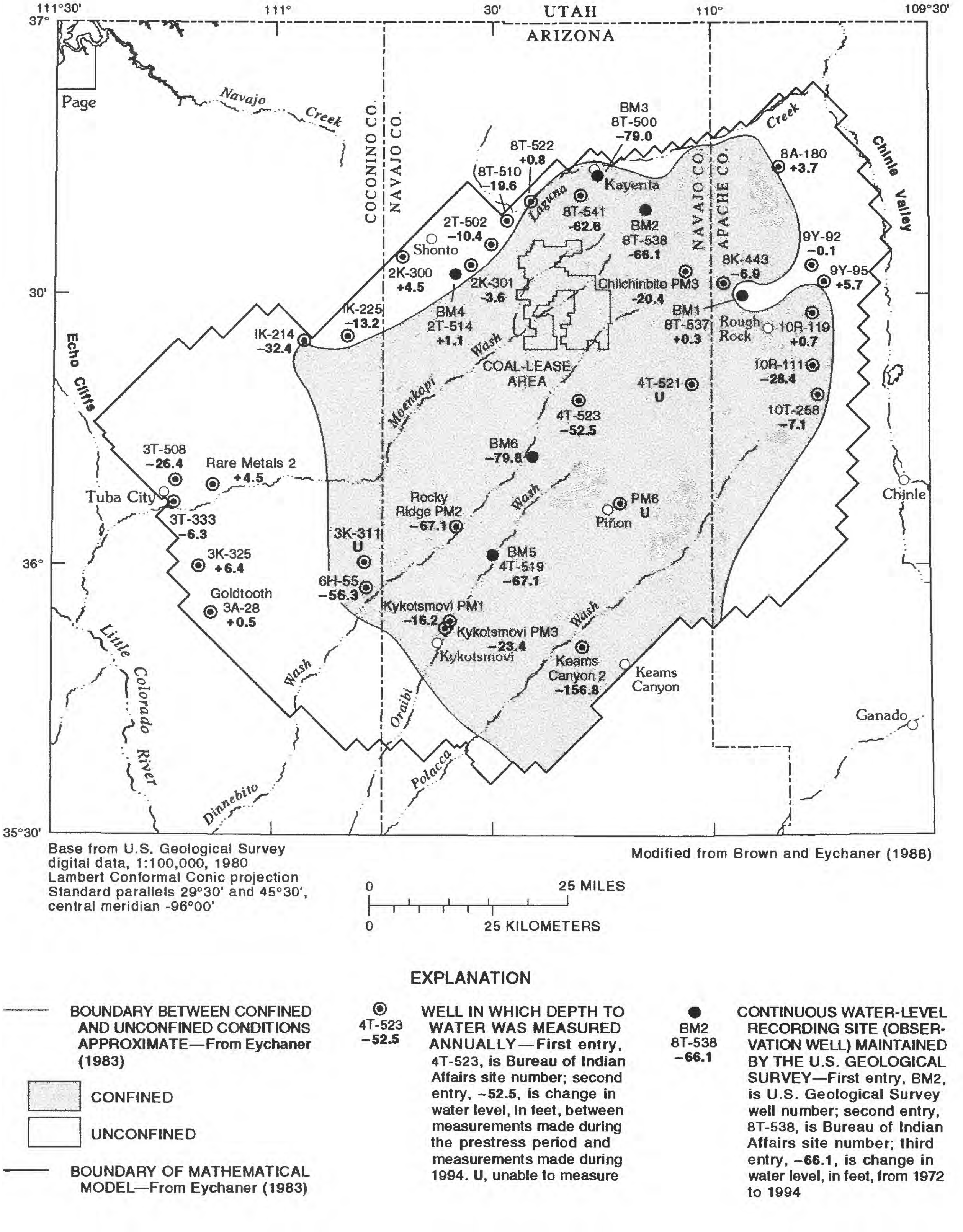


Figure 5. Water-level changes in wells completed in the N aquifer from the start of data collection through 1994.

Table 3. Water-level changes in wells completed in the N aquifer, 1991–94

[Dashes indicate no data]

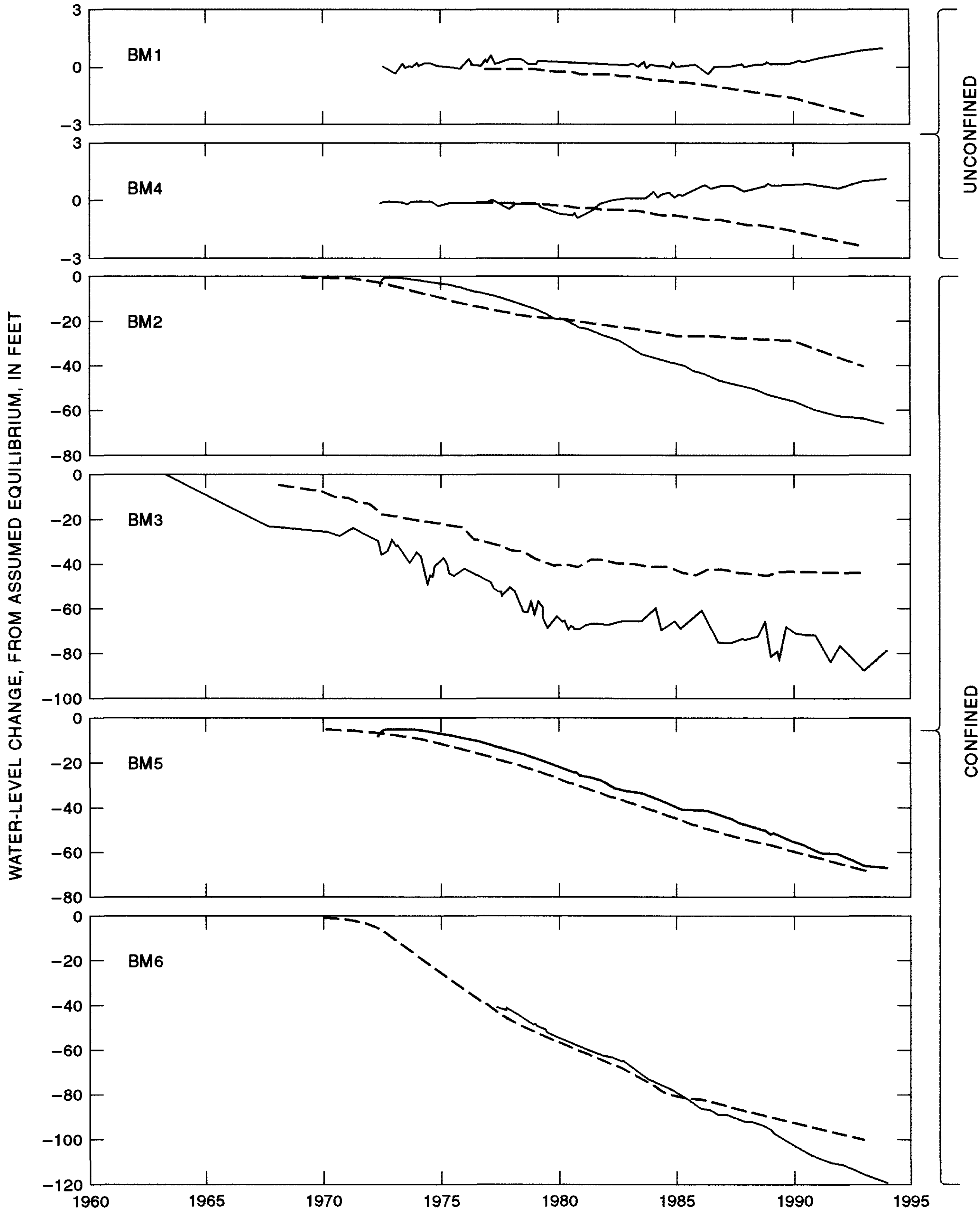
Well system or location name	Bureau of Indian Affairs site number	Change in water level from preceding water year, in feet				Water level, in feet, below land surface, 1994
		1991	1992	1993	1994	
Unconfined						
BM1[1]	8T-537	0	+0.4	+0.2	+0.1	373.7
BM4[1]	2T-514	0	-.2	+.3	+.1	215.9
Cow Springs	1K-225	-.5	+.9	+.9	+.3	46.8
Goldtooth	3A-28	-.1	(2)	[3]-3.0	+3.2	229.5
Long House Valley	8T-510	-.2	+1.1	-.6	+.4	118.6
Marsh Pass	8T-522	-1.0	+.1	+.6	-.6	124.7
Northeast Rough Rock	8A-180	-.1	0	0	+.1	43.2
Rough Rock	9Y-95	--	[3]+1.7	-2.2	-5.7	113.8
Do.	9Y-92	-1.4	+3.0	-1.6	-.5	168.9
Shonto	2K-300	+.6	-.1	+.2	-.3	172.0
Shonto Southeast	2K-301	+.6	-.6	+.1	-.7	287.5
Do.	2T-502	+.1	+.7	-1.1	-1.5	416.2
Tuba City	3T-333	+.8	+.7	(2)	[3]-.5	29.3
Do.	3K-325	-.5	+.9	+.1	+.3	201.6
Do.	Rare Metals 2	+.8	(2)	(2)	[3]+3.3	52.5
Tuba NTUA 1	3T-508	+2.5	+9.4	-1.9	-2.5	55.4
Tuba NTUA 4	3T-546	+5.6	+5.1	-.7	+1.8	56.1
White Mesa Arch	1K-214	+.8	+.1	-.4	+.5	220.4
Confined						
BM2[1]	8T-538	-3.7	-2.2	-1.1	-2.3	191.1
BM3[1]	8T-500	-.4	-7.1	-4.1	+8.8	139.0
BM5[1]	4T-519	-4.0	-1.3	-3.9	-4.9	390.9
BM6[1]	BM6	-4.0	-3.4	-4.2	-3.2	815.4
Chilchinbito	PM3	+1.5	-2.8	+3.2	+1.2	425.4
Forest Lake NTUA 1	4T-523	-18.7	+13.5	-3.9	-4.6	1,148.5
Howell Mesa	6H-55	-4.6	+2.5	+.5	-.5	268.3
Kayenta West	8T-541	+3.6	(2)	[3]-22.3	+4.9	289.6
Keams Canyon	2	+8.4	-8.6	[4]-33.6	-9.2	449.3
Kykotsmovi	PM1	[3]+1.5	-3.1	+8.2	+18.0	236.2
Do.	PM3	(2)	(2)	(2)	[3]-7.2	233.4
Piñon	PM6	(2)	[3]-3.6	-11.6	(2)	--
Do.	3K-311	(2)	(2)	[3]-7.1	(2)	--
Rocky Ridge	PM2	-5.4	-.8	-3.8	-3.4	499.9
Rough Rock	10R-119	+.6	-1.9	+6.8	-6.1	255.9
Do.	10T-258	(2)	[3]-3.0	+.6	+4.1	308.1
Do.	10R-111	+.2	-3.7	+3.0	0	198.4
Sweetwater Mesa	8K-443	[3]-1.8	-.2	-.8	-.1	536.3

[1]Continuous recorder.

[2]Unable to measure.

[3]Change in water level from last measurement 2 or more years earlier.

[4]Measurement may have been affected by obstructions in well and (or) nearby pumping.



EXPLANATION

—— MEASURED — — SIMULATED

Figure 6. Measured water-level changes in continuous-record observation wells BM1 through BM6, 1963–94, and simulated water-level changes from Littin and Monroe, 1995.

the continuous-record streamflow station, Moenkopi Wash at Moenkopi (09401260; fig. 7, table 4). Low flow in Moenkopi Wash historically is 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.

A low-flow measurement of 2.9 ft^3/s was made at the Moenkopi gage in November 1994. The mean daily discharge for the same month was 2.6 ft^3/s. Measurements made in December through February were affected by snowmelt and are not included. The mean daily discharge for those months, however, was 3.6 ft^3/s. Mean daily discharges for previous water years have been published by the USGS (1963–81), White and Garrett (1984, 1986–88), Wilson and Garrett (1988–89), Boner and others (1989–92), Garrett and Gellenbeck (1991), and Smith and others, (1993–94). These data indicate that low flow in Moenkopi Wash during November through February has remained fairly constant at about 3 ft^3/s since the streamflow-gaging station was installed in 1976.

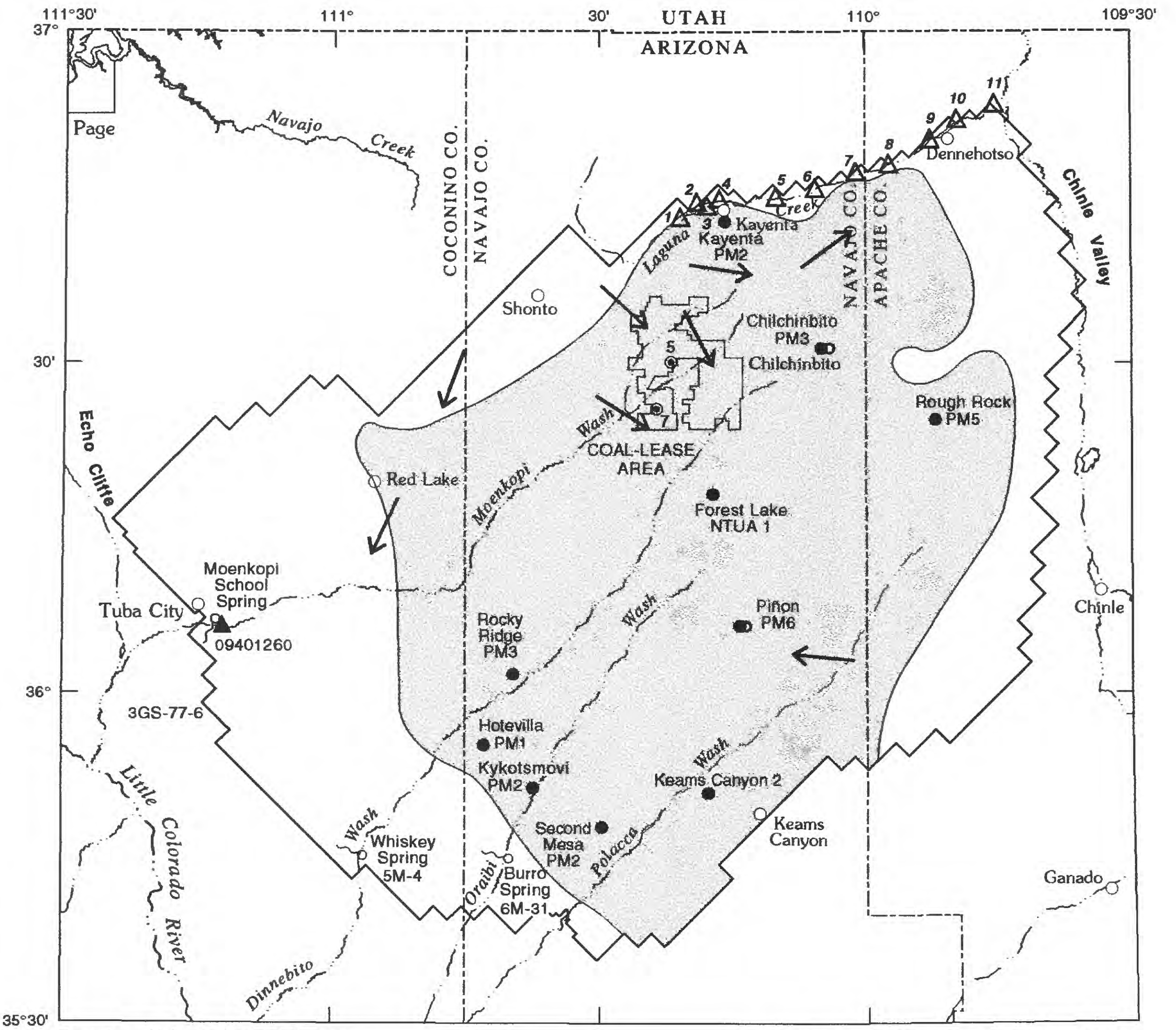
On November 16, 1994, 11 low-flow measurements were made as a part of a seepage investigation along a 40-mile reach of Laguna Creek between Tsegi and its confluence with Chinle Wash (fig. 7, table 5). The measurements were made to determine the amount of discharge that would occur (under optimal base-flow conditions) as seepage from the N aquifer. Measurements were made in November to reduce the chance of stream loss from evapotranspiration or gain from snowmelt. No measurable precipitation was reported in the weeks before the measurements were made. Air temperatures ranged from 8°C to 13°C throughout the day. Although discharge decreased from 5.6 ft^3/s at LSI-1 near Tsegi, Arizona, to 1.5 ft^3/s at LSI-11, above the confluence with Chinle Wash, the maximum discharge measured was 5.9 ft^3/s at LSI-8, about 4 mi west of Dennehotso. The minimum discharge was 0.7 ft^3/s at LSI-3, which is below a diversion dam about 3 mi west of Kayenta. Much of the variation in measured discharge along Laguna Creek probably was due to variations in underflow as a function of alluvial geometry. Other contributing sources included fringe ice and discharge from sewage lagoons at Kayenta and Dennehotso. The sewage discharge provided an additional 0.53 ft^3/s of flow to the stream at Kayenta during the investigation (Freddy Bosley, NTUA, oral commun., 1994). Discharge from the Dennehotso lagoon was estimated to be less than 0.1 ft^3/s.

Burro, Moenkopi, and Whisky Springs were selected for discharge measurements as part of the monitoring program during 1994 (fig. 6, table 6). The discharge from Burro Spring was 0.25 gal/min as compared with 0.3 gal/min measured in 1993. Because no discrete point of discharge could be located at Whisky Spring, discharge was estimated to be about 0.1 gal/min—the same as in 1993. Discharge from Moenkopi School Spring decreased by about 1.7 gal/min from the measurement of the previous year. The changes in discharge at Burro and Whisky Springs were small and within the uncertainty of measurement. At Moenkopi, the change in spring discharge probably is caused by the cumulative effect of local recharge in addition to the regional ground-water flow; however, discharge does not appear to be affected by changes in local or regional pumping from the previous year.

Water Chemistry

Water from Wells Completed in the N Aquifer

Water from the N aquifer is analyzed for selected chemical constituents to determine if declining hydraulic heads are inducing vertical leakage from overlying formations. The hydraulic head in the overlying D aquifer in 1964 averaged about 300 ft higher than the hydraulic head 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 concentration of dissolved constituents in 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,



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)

GENERALIZED DIRECTION OF GROUND-WATER FLOW—From Brown and Eychaner (1988)

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

5 — INDUSTRIAL WELL FROM WHICH WATER-CHEMISTRY SAMPLE WAS COLLECTED—5 is well number

Burro Spring 6M-31 — 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

9 — SITE ALONG LAGUNA CREEK AT WHICH DISCHARGE WAS MEASURED AND WATER-CHEMISTRY SAMPLE WAS COLLECTED—Full site identification would be LSI-9; number is abbreviated site identification

Figure 7. Surface-water and water-chemistry data-collection sites, 1994.

Table 4. Discharge data, Moenkopi Wash at Moenkopi, calendar year 1994

[Dashes indicate no data]

DISCHARGE, IN CUBIC FEET PER SECOND, CALENDAR YEAR 1994 DAILY MEAN VALUES												
Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct.[1]	Nov.[1]	Dec.[1]
1	4.2	4.5	3.2	2.5	1.8	0.00	0.00	0.00	0.00	0.00	2.8	2.4
2	3.9	4.3	3.2	2.1	1.8	.00	.00	.00	.00	.09	2.7	2.4
3	3.9	4.1	3.3	2.3	1.9	.00	.00	.00	.00	.23	2.5	2.8
4	4.0	4.2	3.4	2.5	1.8	.00	.00	.00	.00	.34	2.6	3.3
5	4.7	3.4	3.3	2.1	1.7	.00	.00	.00	.00	.21	3.0	3.2
6	4.5	3.5	3.3	1.9	1.5	.00	.00	.00	.00	.49	3.5	4.3
7	3.4	3.0	2.8	1.8	1.4	.00	.00	.00	.00	1.0	3.5	5.4
8	3.7	3.5	3.7	1.9	1.2	.00	.00	.00	.00	1.3	3.5	2.7
9	5.1	3.8	3.4	2.4	1.3	.00	.00	.00	.00	1.3	2.9	1.9
10	4.6	3.3	3.1	2.8	1.5	.00	.00	.00	.00	1.3	3.1	3.2
11	4.4	3.1	2.7	2.4	1.7	.00	.00	.00	.00	1.3	2.8	2.2
12	4.3	3.3	3.0	2.0	4.1	.00	.00	.00	.00	1.3	3.3	2.5
13	4.2	3.0	3.0	2.0	2.1	.00	.00	.00	.00	1.2	3.8	3.2
14	3.9	[2]3.0	2.9	2.0	1.8	.00	.00	.00	.00	1.2	2.8	3.1
15	3.8	[2]3.5	2.9	2.0	1.7	.00	.00	.00	.00	1.4	2.7	2.9
16	4.4	3.6	2.9	2.0	1.3	.00	.00	.00	.00	1.9	2.3	4.0
17	4.2	3.3	3.0	1.8	.97	.00	.00	.00	.00	1.9	2.3	2.8
18	4.2	3.3	2.5	2.0	.81	.00	.00	40	.00	1.3	2.2	3.0
19	3.8	3.1	2.5	2.0	.76	.00	.00	2.1	.00	1.3	2.2	3.1
20	4.4	3.3	3.7	1.9	.81	.00	.00	1.4	.00	1.5	2.1	3.0
21	4.6	3.0	3.7	1.9	1.0	.00	.00	21	.00	1.6	2.1	3.0
22	4.5	2.9	2.8	1.8	1.1	.00	.00	3.1	.00	1.6	2.2	3.6
23	4.3	3.0	2.6	1.7	1.1	.00	.00	.36	.00	1.6	2.1	4.2
24	4.5	3.1	2.3	1.5	.91	.00	.00	.00	.00	1.5	2.3	3.8
25	4.7	3.3	2.1	1.6	1.1	.00	.00	.00	.00	1.7	2.5	3.5
26	4.0	3.2	2.9	2.5	1.6	.00	.00	.00	.00	1.9	2.7	3.1
27	4.3	3.2	4.6	3.2	1.6	.00	.00	.00	.00	1.8	2.4	3.2
28	3.9	3.8	2.5	2.2	1.3	.00	.00	.00	.00	1.9	2.2	3.3
29	4.0	---	2.3	2.1	1.1	.00	.00	.24	.00	2.1	1.9	3.1
30	4.0	---	2.2	1.8	.84	.00	.00	.02	.00	2.2	2.1	2.7
31	[2]4.0	---	2.2	---	.49	---	.00	.00	---	2.7	---	3.2
TOTAL	130.4	95.6	92.0	62.7	44.09	0.00	0.00	68.22	0.00	41.16	79.1	98.1
MEAN	4.21	3.41	2.97	2.09	1.42	.00	.00	2.20	.00	1.33	2.64	3.16
MAX	5.1	4.5	4.6	3.2	4.1	.00	.00	40	.00	2.7	3.8	5.4
MIN	3.4	2.9	2.1	1.5	.49	.00	.00	.00	.00	.00	1.9	1.9
AC-FT	259	190	182	124	87	.00	.00	135	.00	82	157	194

CALENDAR YEAR 1994 TOTAL 711.37 MEAN 1.95 MAXIMUM 40 MINIMUM 0.00 ACRE-FT 1,410

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

[2] Estimated.

Table 5. Discharge data from seepage investigation along Laguna Creek, 1994

[LSI, Laguna seepage investigation]

Base-flow measurement site number[1]	Discharge (cubic feet per second)	Remarks[2]
LSI-1	5.65	Laguna Creek near Tsegi, Arizona, 10 feet below Tsegi gage (09379120)
LSI-2	2.00	Parrish Creek at bridge above confluence with Laguna Creek
LSI-3	.71	Laguna Creek below diversion dam, 3 miles west of Kayenta, Arizona
LSI-4	4.51	Laguna Creek, 250 feet above bridge on Highway 464 at Kayenta, Arizona
LSI-5	2.16	Laguna Creek near Lion Rock, 3.5 miles northeast of Kayenta, Arizona
LSI-6	2.08	Laguna Creek near Church Rock, 7 miles northeast of Kayenta, Arizona, at miscellaneous measurement site (09379160)
LSI-7	3.25	Laguna Creek near Baby Rocks, 500 feet below falls, 14 miles northeast of Kayenta, Arizona
LSI-8	5.88	Laguna Creek near Red Point, 4 miles west of Dennehotso, Arizona
LSI-9	3.32	Laguna Creek above Dennehotso, 200 feet above diversion spillway gates
LSI-10	1.12	Laguna Creek below Dennehotso, 50 feet below bridge on Highway 164
LSI-11	1.47	Laguna Creek, 300 feet above confluence with Chinle Wash

[1]Measurement-site numbers correlate to locations plotted on figure 6.

[2]All measurements were made on November 16, 1994.

Table 6. Discharge measurements of selected springs, 1952–94

Spring name	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	.25
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	[1]13.5
			04–07–93	[1]14.6
			12–07–94	[1]12.9
Whisky Spring	5M-4	Navajo Sandstone	12–14–89	.1
			12–14–90	.2
			04–15–93	.1
			12–07–94	[2].1

[1]Discharge measured at water-chemistry sampling site only and does not represent the total discharge in the Moenkopi School Spring system.

[2]Estimated.

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 dissolved solids, chloride, and sulfate in the most heavily pumped wells.

In general, water in the N aquifer is a calcium bicarbonate type in the upgradient or recharge part of the study area north and northwest of Black Mesa and a sodium bicarbonate type elsewhere throughout Black Mesa and surrounding areas (Kister and Hatchett, 1963). As water moves from the recharge area under Black Mesa toward discharge areas to the southwest and northeast (fig. 7), ion exchange along the flow path generally converts calcium type water to sodium type water. Locally, however, some wells penetrating the N aquifer may contain large concentrations of sulfate, chloride, and other ions introduced from waters of the D aquifer. Because wells tapping the N aquifer must pass through the D aquifer in the confined area, there is a potential for such wells to pull a mixture of water from both aquifers in places where well seals are either broken or inadequate, or if leakage is induced because of drawdown in the N aquifer. As of 1994, however, chemical data do not substantiate leakage through confining beds because of drawdown in the N aquifer.

All wells sampled in 1994 are completed in the confined area of the N aquifer (tables 7 and 8 and figs. 7 and 8). Ten of the 12 wells sampled, generally in upgradient areas of Black Mesa between the mine, Piñon, and Kykotsmovi, contained a sodium bicarbonate type water. Historically, water from well PM3 at Chilchinbito has been a sodium sulfate type water, and water from Kayenta PM2 has been a calcium bicarbonate type (Littin, 1993).

Dissolved-solids concentrations in water from wells in the N aquifer ranged from 130 mg/L at Peabody well No. 7 to 992 mg/L at the Chilchinbito well PM3 (fig. 8, tables 7 and 8). Long-term comparison of dissolved-solids concentrations in water taken from Keams Canyon 2, Piñon PM6, and Kayenta PM2 wells[3] show no significant change from 1983 to 1994 (fig. 9, table 8). Since 1991, a gradual increase in concentrations of dissolved solids, sulfate, and chloride in water from the Forest Lake well NTUA 1 indicates that, locally, water from the D aquifer may be mixing with water from the N aquifer.[4]

Surface Water

Ten base-flow samples from Laguna Creek and one base-flow sample from Parrish Creek were analyzed in conjunction with the seepage investigation conducted in November 1994 (figs. 7 and 8, table 9). The water generally was a calcium bicarbonate water typical of the N aquifer in the unconfined area north of Black Mesa. Analyses of water downstream from Kayenta, however, showed an increase in dissolved solids that resulted in the water changing from a calcium bicarbonate to a sodium bicarbonate type. Dissolved solids increased from 180 mg/L at LSI-1 near Tsegi to 335 mg/L at LSI-11 above the confluence with Chinle Wash. Water sampled at LSI-5 had the highest concentration of dissolved solids (400 mg/L). This increase in dissolved solids, specifically sodium, chloride, and sulfate ions (table 9), is believed to have been caused by sewage effluent discharging into Laguna Creek at Kayenta and Dennehotso. These data and the chemical analyses of ground water from the confined and unconfined areas of the N aquifer do not indicate that ground water from the confined area under Black Mesa discharges into Laguna Creek.

Three springs were selected for water-chemistry analyses as part of the monitoring program during 1994 (fig. 8, tables 10 and 11). The springs, all of which discharge from the Navajo Sandstone, are Burro Spring near Kykotsmovi, Moenkopi School Spring at Moenkopi, and Whisky Spring near Howell Mesa.

Historically, the chemistry of water from these springs has not changed significantly although there has been some increase in chloride and sulfate ions (table 11). Water from Burro Spring has been a sodium bicarbonate type; water from Moenkopi School Spring has been a calcium bicarbonate type water; and water from Whisky Spring has been a calcium sulfate type. Dissolved-solids concentrations in water from the three springs ranged from

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

[4]Water from Forest Lake NTUA 1 was sampled in August 1995. Specific conductance fluctuated between 410 and 492 μS/cm during the 4 hours preceding sample collection and measured 470 μS/cm at time of sampling.

Table 7. Physical properties and chemical analyses of water from selected industrial and municipal wells completed in the confined part of the N aquifer, 1994

[°C, degrees Celsius; μS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; μg/L, micrograms per liter. Dashes indicate 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)
Chilchinbito PM3	363137110044702	12-01-94	19	1,440	8.9	143	0.14	0.01	9.4	3.3
Forest Lake NTUA 1	361737110180301	11-30-94	28	774	9.4	166	.40	.01	1.5	.15
Hotevilla PM1	355518110400301	11-28-94	18	307	10	140	1.1	.02	.67	.03
Kayenta PM2	364344110151201	12-01-94	16	379	8.1	103	.90	.01	40	6.3
Keams Canyon 2	355023110182701	11-29-94	19	991	9.4	346	.05	.01	.74	.14
Kykotsmovi PM2	355215110375001	11-28-94	22	372	10	164	1.1	.03	.51	.02
Peabody 5	362901110234101	12-01-94	28	281	9.4	110	.92	.01	2.9	.04
Peabody 7	362456110242301	12-01-94	32.5	225	9.4	89	.80	.01	3.5	.03
Piñon PM6	360614110130801	11-29-94	20	488	10.1	227	1.3	.01	.54	.02
Rocky Ridge PM3	360422110353501	11-29-94	21	247	9.6	112	1.2	.02	.51	.03
Rough Rock PM5	362418109514601	11-30-94	21	1,080	9.0	220	1.0	.01	1.9	.25
Second Mesa PM2	354749110300101	11-29-94	19.5	614	10	284	.05	.01	.51	.04

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)
Chilchinbito PM3	280	3.3	21	490	0.4	9.9	--	20	8	922
Forest Lake NTUA 1	150	1	56	100	1.1	17	--	350	100	430
Hotevilla PM1	64	.5	1.4	4.8	.1	20	--	20	6	166
Kayenta PM2	23	1.3	4.2	77	.1	16	--	30	9	236
Keams Canyon 2	210	.8	88	32	1.3	12	--	610	4	562
Kykotsmovi PM2	76	.6	3.6	8.5	.3	23	--	30	4	212
Peabody 5	56	.7	4.7	20	.2	21	--	40	5	170
Peabody 7	44	.7	3.8	16	.2	21	--	30	3	130
Piñon PM6	100	.4	3.9	4.7	.2	27	--	50	4	262
Rocky Ridge PM3	51	.4	1.4	5.5	.1	20	--	20	8	152
Rough Rock PM5	220	1.5	130	110	1.7	12	--	420	9	626
Second Mesa PM2	130	.4	7.6	15	.3	20	--	100	6	342

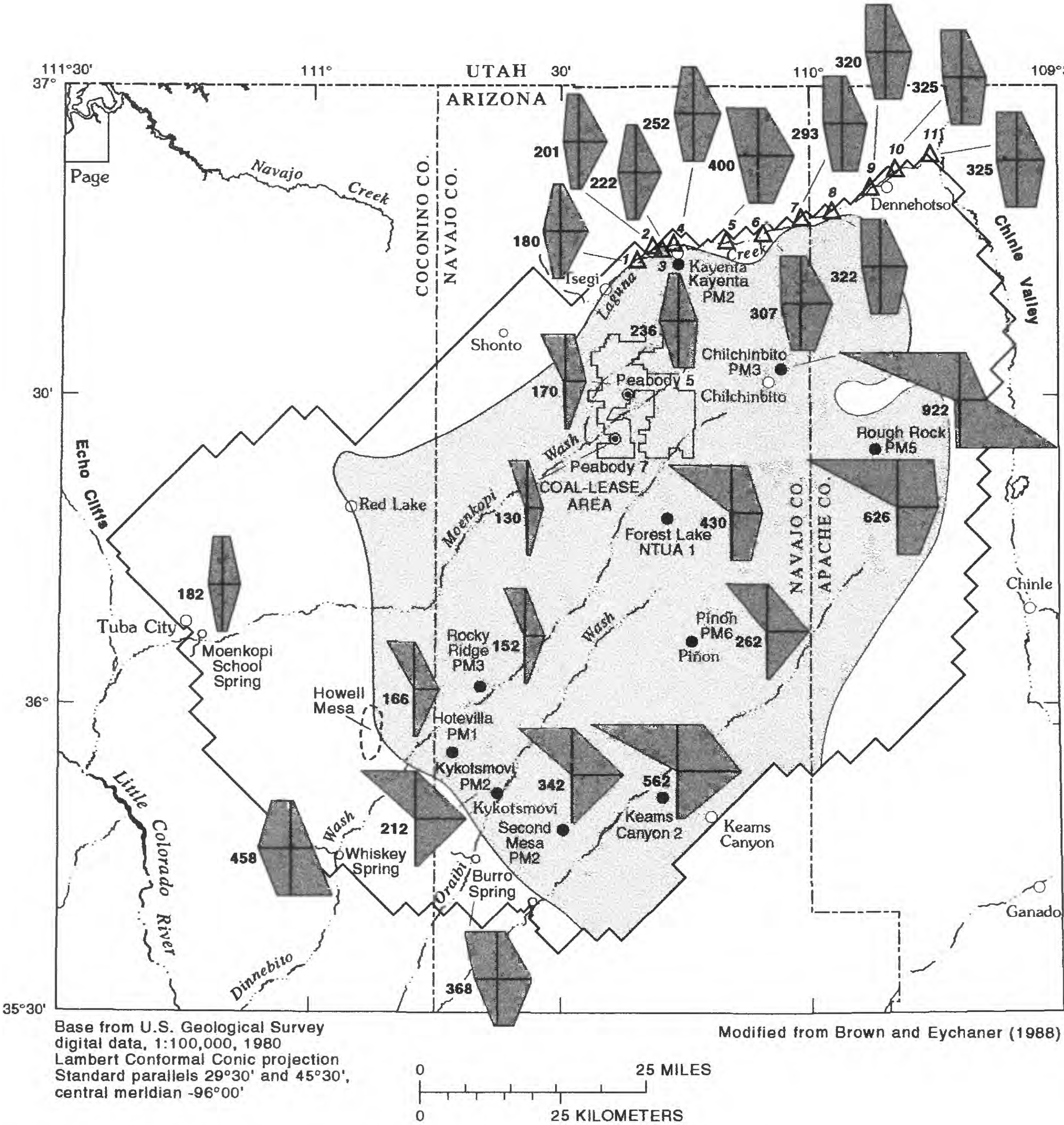


Figure 8. Water chemistry and distribution of dissolved solids in the N aquifer and Laguna Creek, 1994.

182 mg/L at the Moenkopi School Spring to 458 mg/L at Whisky Spring in 1994.

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. In 1994, combined ground-water withdrawals increased from 1993 by 8 percent to about 7,000 acre-ft. Pumpage from the confined part of the aquifer increased by about 9 percent to 5,400 acre-ft, and pumpage from the unconfined part of the aquifer increased by about 2 percent to 1,600 acre-ft.

The median change in water levels in the confined area for 1994 was a decline of about 2.3 ft as opposed to a decline of 3.3 ft for 1993. In the unconfined area, the median change in water levels was a rise of 0.1 ft as opposed to a decline of 0.4 ft for 1993.

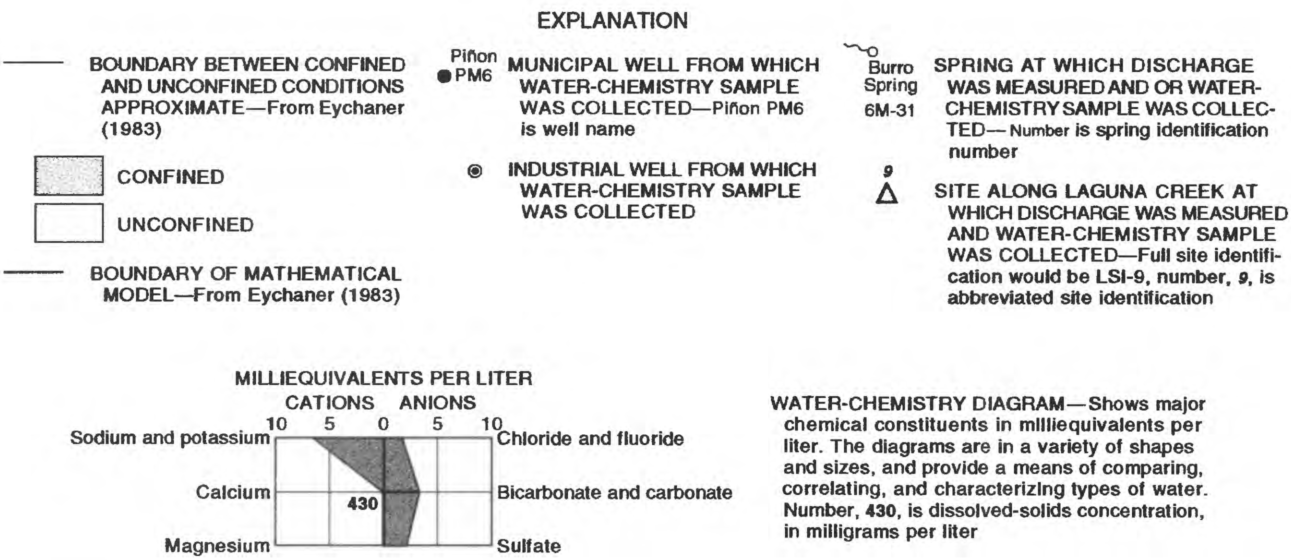


Figure 8. Continued.

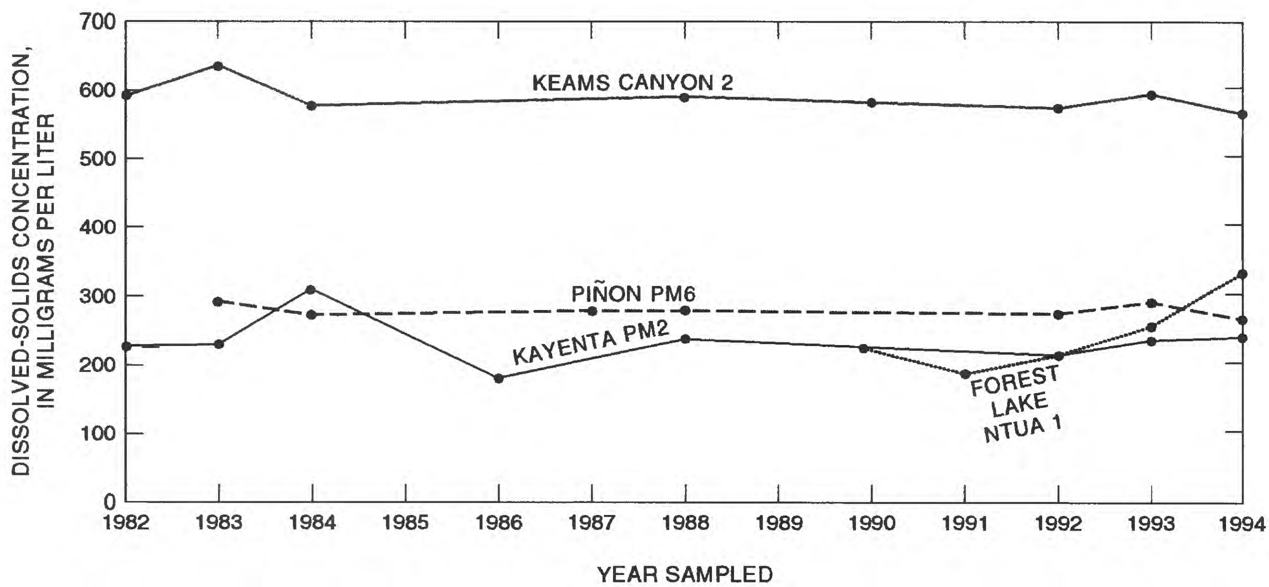


Figure 9. Dissolved-solids concentrations in water from wells Keams Canyon 2, Piñon PM6, Forest Lake NTUA 1, and Kayenta PM2, 1982–94.

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. Measured low flow along Moenkopi Wash was about 2.9 ft^3/s in 1994. Seepage measurements were made along a 40-mile reach of Laguna Creek in November 1994. Discharge was 5.6 ft^3/s near Tsegi and 1.5 ft^3/s above the confluence with Chinle Wash. Maximum discharge was 5.9 ft^3/s about 4 mi upstream from Dennehotso. Discharge at Burro and Whisky Springs was about the same as in 1993. Discharge from Moenkopi School Spring decreased from 14.6 gal/min in 1993 to 12.9 gal/min in 1994.

Calcium bicarbonate water and sodium bicarbonate water are the primary types of water that occur in the N aquifer. Calcium bicarbonate

Table 8. Specific conductance and concentrations of selected chemical constituents in water from industrial and municipal wells completed in the confined part of the N aquifer, 1980–94

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

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)
Chilchinbito PM3				
1986	390	231	2.5	11
1988	414	256	2.7	31
1991	1,500	952	11	620
1992	1,287	812	33	430
1993	1,030	598	7.5	320
1994	1,440	992	21	490
Forest Lake NTUA 1				
1982	470	---	11	67
1990	375	226	8.2	38
1991	350	183	10	24
1993	693	352	35	88
1994	744	430	56	100
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
Kayenta PM2				
1982	360	228	4.5	58
1983	375	230	---	60
1984	365	309	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
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
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
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
Peabody 7				
1980	210	136	3.7	11
1986	217	---	3.6	12
1988	240	151	4.4	18
1993	228	128	3.8	16
1994	225	130	3.8	16
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
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
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
Second Mesa PM2				
1990	590	364	6.5	16
1991	613	292	10	15
1993	630	350	7.5	15
1994	614	342	7.6	15

Table 9. Selected physical properties and chemical analyses of water from Laguna Creek, November 1994

[LSI, Laguna seepage investigation; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter]

Site number	Location description	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)
LSI-1	Laguna Creek near Tsegi, Arizona	363953110245600	11–16–94	0.1	319	8.2	146	0.50	0.01
LSI-2	Parrish Creek above confluence with Laguna Creek	364347110191100	11–16–94	5	357	8.3	166	.15	.01
LSI-3	Laguna Creek above Kayenta, Arizona	364333110183200	11–16–94	1.5	381	8.5	151	.85	.01
LSI-4	Laguna Creek at Kayenta, Arizona	364412110143200	11–16–94	.5	422	8.4	152	.31	.01
LSI-5	Laguna Creek near Lion Rock	364457110111900	11–16–94	3	645	8.6	210	.81	.65
LSI-6	Laguna Creek near Church Rock	364457110080800	11–16–94	2.5	512	8.4	163	.7	.2
LSI-7	Laguna Creek near Baby Rocks	364659110011300	11–16–94	2	483	8.2	161	.74	.01
LSI-8	Laguna Creek near Red Point	364808109560100	11–16–94	4	529	8.2	159	.94	.02
LSI-9	Laguna Creek above Dennehotso, Arizona	365022109515200	11–16–94	5	533	8.2	178	1.0	.02
LSI–10	Laguna Creek below Dennehotso, Arizona	365149109492300	11–16–94	5	546	8.1	172	.9	.01
LSI–11	Laguna Creek above confluence with Chinle Wash	365333109444300	11–16–94	5.5	561	8.3	174	1.1	.02

Site number	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)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, residue at 180°C (mg/L)
LSI–1	37	9.0	16	1.6	6.3	15	0.1	9.0	180
LSI-2	33	10	26	2.2	6.6	15	.1	9.7	201
LSI-3	38	11	21	1.9	8.9	32	.1	7.6	222
LSI-4	41	12	28	2	8.9	53	.1	8.4	252
LSI-5	45	12	76	5.3	28	77	.6	13	400
LSI-6	42	12	49	3.6	16	72	.3	9.3	307
LSI-7	39	12	44	2.7	13	79	.3	7.3	293
LSI-8	41	12	48	2.8	16	87	.3	6.8	322
LSI-9	42	13	48	2.9	17	82	.3	6.4	320
LSI-10	41	13	50	2.9	16	95	.3	5.8	325
LSI-11	44	14	50	3.1	16	94	.3	6.2	335

Table 10. Selected physical properties and chemical analyses of water from selected springs in the Black Mesa area, 1994

[°C, degree Celsius; μS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; μg/L, micrograms per liter. Dashes indicate 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	12–08–94	8.0	601	8.1
Moenkopi School Spring	3GS–77–6	360632111131101	Navajo Sandstone tongue in the Kayenta Formation	12–07–94	17.5	315	7.4
Whisky Spring	5M–4	354446110562001	Navajo Sandstone	12–07–94	11.3	678	8.1

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	184	0.08	0.01	130	--	47	3.3
Moenkopi School Spring	97	2.3	.01	98	--	29	6.3
Whisky Spring	120	.05	.01	250	--	74	17

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	81	3	58	81.5	0.5	26
Moenkopi School Spring	24	1	35	25.3	1.3	17
Whisky Spring	45	1	28	47.9	2.9	8.4

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	80	0.4	13	--	70	13	368
Moenkopi School Spring	23	.1	14	--	40	3	182
Whisky Spring	210	.3	16	--	40	4	458

Table 11. Specific conductance and concentrations of selected chemical constituents in water from springs that discharge from the N aquifer, 1952–94

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

Spring 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)
Burro Spring	1989	485	308	22	59
	1990	546	347	23	65
	1993	595	368	30	85
	1994	601	368	26	80
Moenkopi School Spring	1952	222	---	6	---
	1987	270	161	12	19
	1988	270	155	12	19
	1991	287	157	14	20
	1993	313	204	17	27
	1994	315	182	17	23
Whisky Spring	1954	639	---	10	189
	1989	560	455	7.8	219
	1990	676	451	10	240
	1993	660	464	9.1	220
	1994	678	458	8.4	210

water occurs in the part of the study area north of Black Mesa. The sodium bicarbonate water generally occurs elsewhere throughout the area. All but two of the wells sampled in 1994 contained a sodium bicarbonate type water. Historically, water from Chilchinbito PM3 has been a sodium sulfate type, and water from Kayenta PM2 has been a calcium bicarbonate type. Dissolved-solids concentrations ranged from about 130 to 992 mg/L in 1994.

Ten base-flow samples from Laguna Creek and one base-flow sample from Parrish Creek were analyzed in conjunction with the seepage investigation of November 1994. These analyses of ground water from the confined and unconfined areas of the N aquifer do not indicate that ground water from the confined area under Black Mesa discharges into Laguna Creek.

The potential exists for downward movement of water from the D aquifer to the N aquifer. Recent gradual increases in concentrations of dissolved solids, sulfate, and chloride in water from Forest Lake NTUA 1 indicates some local mixing may be occurring with water from the D aquifer. Regionally, however, long-term water-chemistry data for wells and springs show no discernible change in water quality.

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