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PROGRESS REPORT ON BLACK MESA MONITORING PROGRAM—1985-86

By George W. Hill and Marlin I. Whetten

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UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Box FB-44
Federal Building
300 West Congress Street
Tucson, Arizona 85701-1393

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CONVERSION FACTORS

For readers who use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

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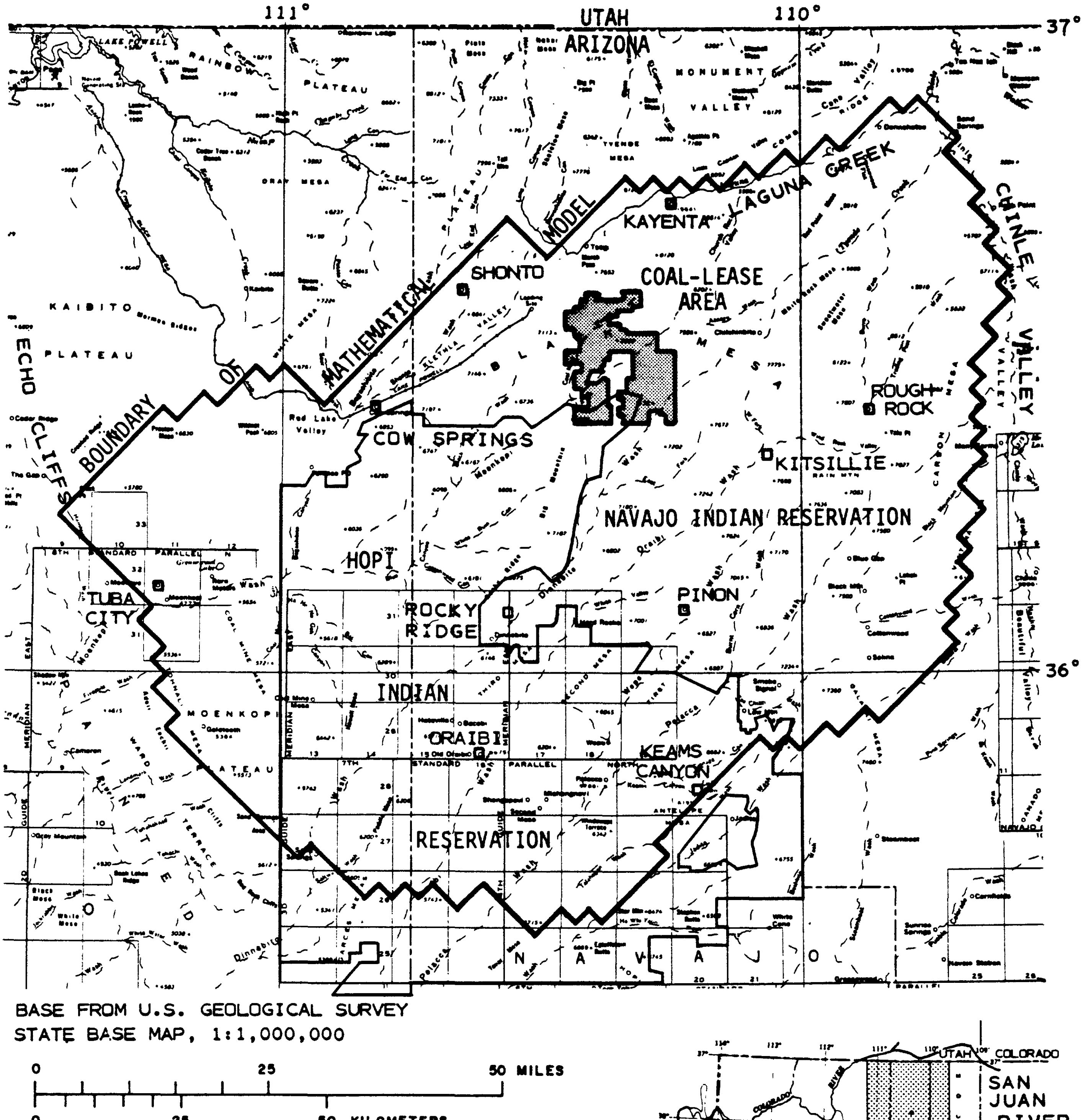
ABSTRACT

The Black Mesa monitoring program is designed to monitor long-term effects on the ground-water resources of the mesa as a result of withdrawals from the N aquifer by the strip-mining operation of Peabody Coal Co. The N aquifer is an important source of water in the 5,400 square-mile Black Mesa area on the Navajo and Hopi Indian Reservations. Withdrawals from the N aquifer by the mine increased from 95 acre-feet in 1968 to more than 4,000 acre-feet in 1984. In 1985, withdrawals from the mine wells were temporarily reduced to about 2,500 acre-feet.

Water levels in the confined area of the aquifer declined as much as 87 feet from 1965 to 1985 in some municipal and observation wells within about a 15-mile radius of the mine well field. In 1986, measurements indicated some recovery in water levels in most of these wells because of an approximate 90-percent reduction in pumpage from Peabody Coal Co. wells during the last half of 1985. Part of the drawdown in municipal wells is due to local pumpage. Water levels have not declined in wells tapping the unconfined area of the aquifer. Chemical analyses indicate no significant changes in the quality of water from wells that tap the N aquifer or from springs that discharge from several stratigraphic units, including the N aquifer, since pumping began at the mine.

INTRODUCTION

The N aquifer is an important source of water in the 5,400 mi^2 Black Mesa area on the Navajo and Hopi Indian Reservations in northeastern Arizona (fig. 1). On the northern part of the mesa, Peabody Coal Co. operates a strip mine in a lease area of about 100 mi^2. When operation of the mine began in 1968, the company pumped about 95 acre-ft of ground water from the N aquifer; in 1984 more than 4,000 acre-ft was pumped, but in 1985 withdrawals were reduced temporarily to about 2,500 acre-ft because the slurry pipeline was not used for about 6 months. Withdrawals from the N aquifer for municipal use increased from an estimated 70 acre-ft in 1965 to about 2,200 acre-ft in 1985. The Navajo and Hopi Tribes became concerned about the long-term effects of withdrawals from the N aquifer on supplies for domestic and municipal purposes. These and other concerns about the effects of strip mining led to the Black Mesa water-resources investigation by the U.S. Geological Survey in cooperation with the Arizona Department of Water Resources. In 1983, the U.S. Bureau of Indian Affairs joined the cooperative effort.



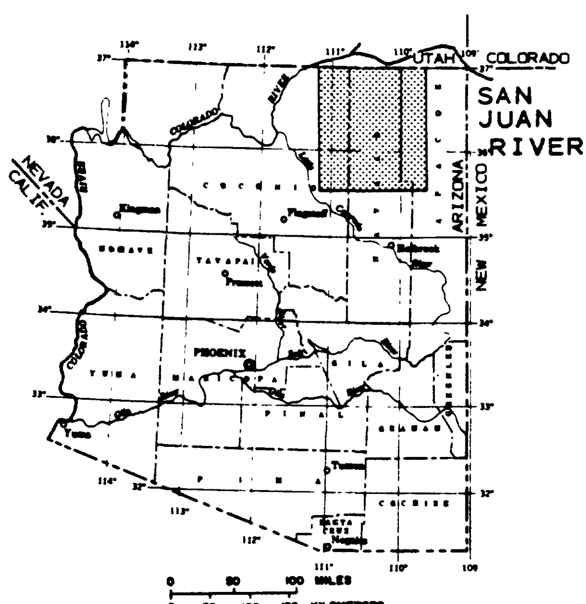


Figure 1.--Area of report.

The cooperation and assistance of the Navajo and Hopi Tribes and Peabody Coal Co. are gratefully acknowledged. The assistance in the collection of pumpage data by the Western Navajo Agency, Chinle Agency, and Hopi Agency of the U.S. Bureau of Indian Affairs and by the Navajo Tribal Utility Authority is also gratefully acknowledged.

Purpose and Scope of the Report

The report covers the progress of the Black Mesa monitoring program from October 1, 1984, to June 30, 1986, and discusses data collected throughout the monitoring program from its beginning in 1972. Except for some earlier data that are used for comparison, only new data will appear in this report.

Previous Reports on the Program

Four progress reports by the U.S. Geological Survey on the monitoring phase of the program have been done (U.S. Geological Survey, 1978; G. W. Hill, Hydrologist, U.S. Geological Survey, written commun., 1982, 1983; Hill, 1985). Most of the basic data are contained in these reports except for stream-discharge and sediment-discharge data from Moenkopi Wash, which have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1976-86). 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 is used to predict the effects of withdrawals through the year 2014, which is 13 years after the existing coal lease expires. The present monitoring program is essential for checking the model simulations and water quality of the N aquifer as water levels decline.

HYDROLOGIC-DATA COLLECTION, 1985-86

In accordance with the objectives of the program, monitoring activities have been continued by continuous or periodic measurements of (1) ground-water levels in the confined and unconfined areas of the N aquifer; (2) major withdrawals from the N aquifer by industrial and nonindustrial pumping from the confined and unconfined areas; (3) ground-water quality of the N aquifer in the coal-lease area and other areas of the mesa; (4) discharge and chemical quality of selected springs that discharge from the various formations, including the N aquifer; and (5) surface-water discharge, which reflects the conditions of the N aquifer. The data-collection network is shown in figure 2.

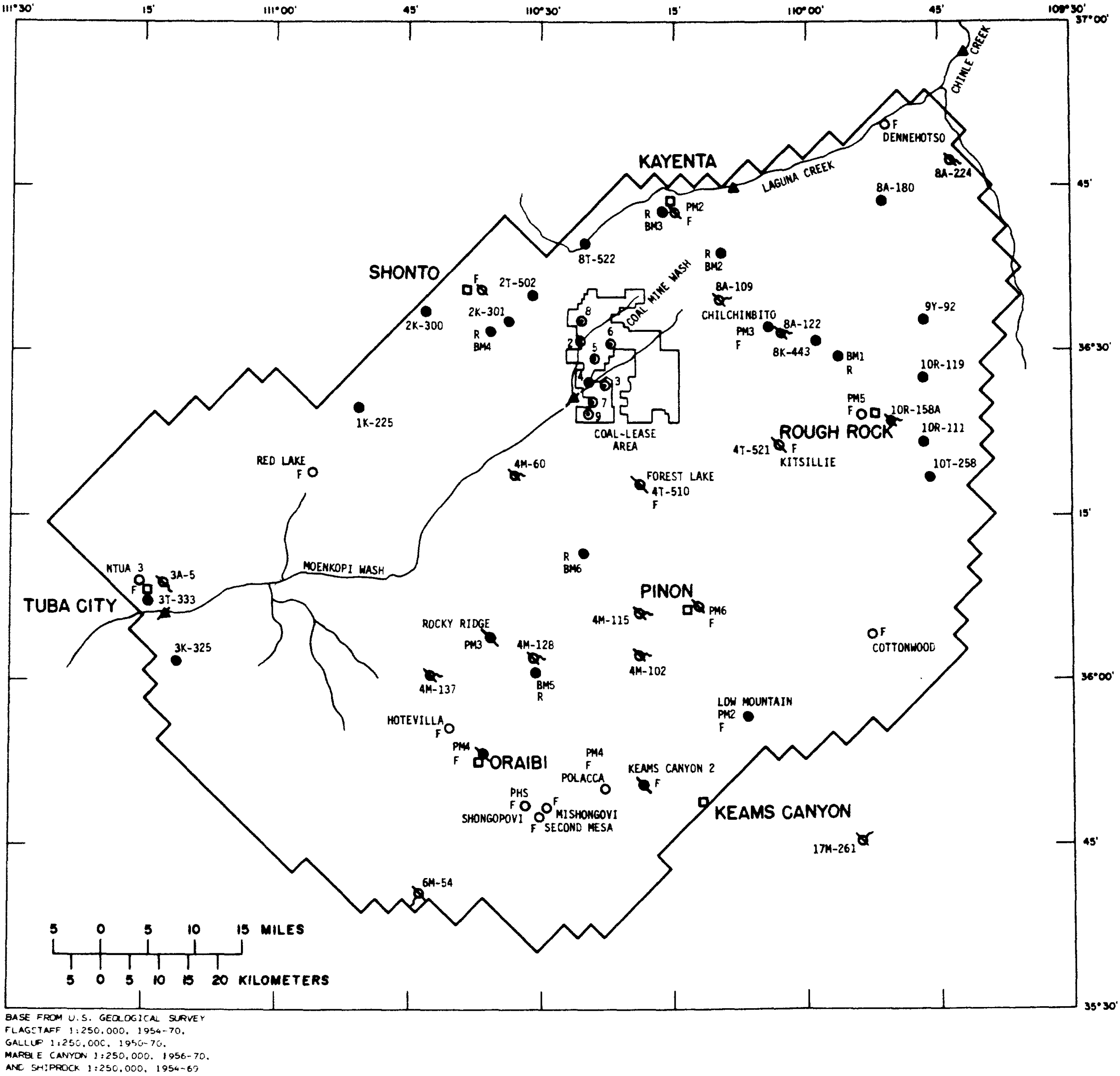


Figure 2.--Data-collection sites, 1982-86.

EXPLANATION

R F
BM2

WELL THAT TAPS THE N AQUIFER IN WHICH WATER LEVEL WAS MEASURED—BM2, is well identifier. R, indicates well equipped with a recorder; \ , indicates water-quality sample was collected; F, indicates one or more wells in the area equipped with a flowmeter

F
PM6

WELL THAT TAPS THE N AQUIFER—PM6, is well identifier. \ , indicates water-quality sample was collected; F, indicates one or more wells in the area equipped with a flowmeter

8

PEABODY COAL CO. PRODUCTION WELL— Water-quality sample was collected. 8, is well number

SPRING AT WHICH DISCHARGE WAS MEASURED AND WATER-QUALITY SAMPLE WAS COLLECTED

GAGING STATION OPERATED BY THE U.S. GEOLOGICAL SURVEY— /, indicates water-quality and sediment samples were collected

BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Figure 2

Ground-Water Levels

Ground-water levels in nonindustrial wells in the N aquifer have continued a steady decline since 1968 when withdrawals from wells in the Peabody Coal Co. mine area began. Water-level data collected in May 1986, however, showed that water levels in several nonindustrial wells in the confined area of the N aquifer had risen during the past year. These wells are BM3, Chilchinbito PM3, 10R-111, 10T-258, Keams Canyon PM2, and Oraibi PM3 (fig. 3). Recovery in water levels in wells in the northern part of the study area nearest the mine well field may be attributed to large reductions in withdrawals from the mine wells between June 1985 and January 1986 when the wells except one Peabody well were pumping little or no water. Withdrawals by Peabody Coal Co. in 1985 were about half of those in 1984 because the slurry pipeline to the Nevada powerplant was not operated during the last half of 1985. Observation well BM3, near Kayenta, showed a 9-ft recovery since the summer of 1985; however, the water level in this well shows large fluctuations even when all or most of the mine wells are continuously pumping. Chilchinbito PM3 showed a recovery of 17 ft, and well 10R-111, near Chilchinbito, showed a recovery of 22 ft; well 10T-258, which is a short distance to the south of 10R-111, showed a 6-ft recovery. Observation well BM2, which is about halfway between BM3 and Chilchinbito PM3 and about the same distance from the mine area, showed a 7-ft decline in water level (fig. 3).

Water levels declined in the observation wells to the south of the mine area except in Oraibi PM3 and Keams Canyon PM2. The recovery in these two wells is probably due to local conditions rather than to the influence from water-level recovery in the mine area. The well at Oraibi, which showed an 18-ft recovery since 1985, had not been pumped for several months. The recovery of 17 ft measured in Keams Canyon PM 2 could be the result of nonuse for a considerable period of time. In most observation wells in the unconfined area of the N aquifer, water levels increased since the summer of 1985. The net change in water levels in selected wells that tap the N aquifer in the Black Mesa area since prestress times (prior to 1965) is shown in figure 3.

In the construction of the mathematical model of the N-aquifer system, water-level changes were simulated for several continuous-record observation and nonindustrial wells that penetrate the N aquifer (Eychaner, 1983). A comparison between measured and simulated water levels in the six continuous-record observation wells—BM1 through BM6—for 1959-85 is shown in figure 4.

In 1985, the simulation model was rerun for 1980-84 to include pumpage measured during those 5 years. Measured water-level changes were beginning to diverge from the earlier simulated changes, which had used projected pumpage amounts. The simulated water-level changes in BM2, BM5, and BM6 are now very close to the measured water-level changes and the simulated trends follow the measured trends (fig. 4). The curves showing the updated simulated water-level changes for wells

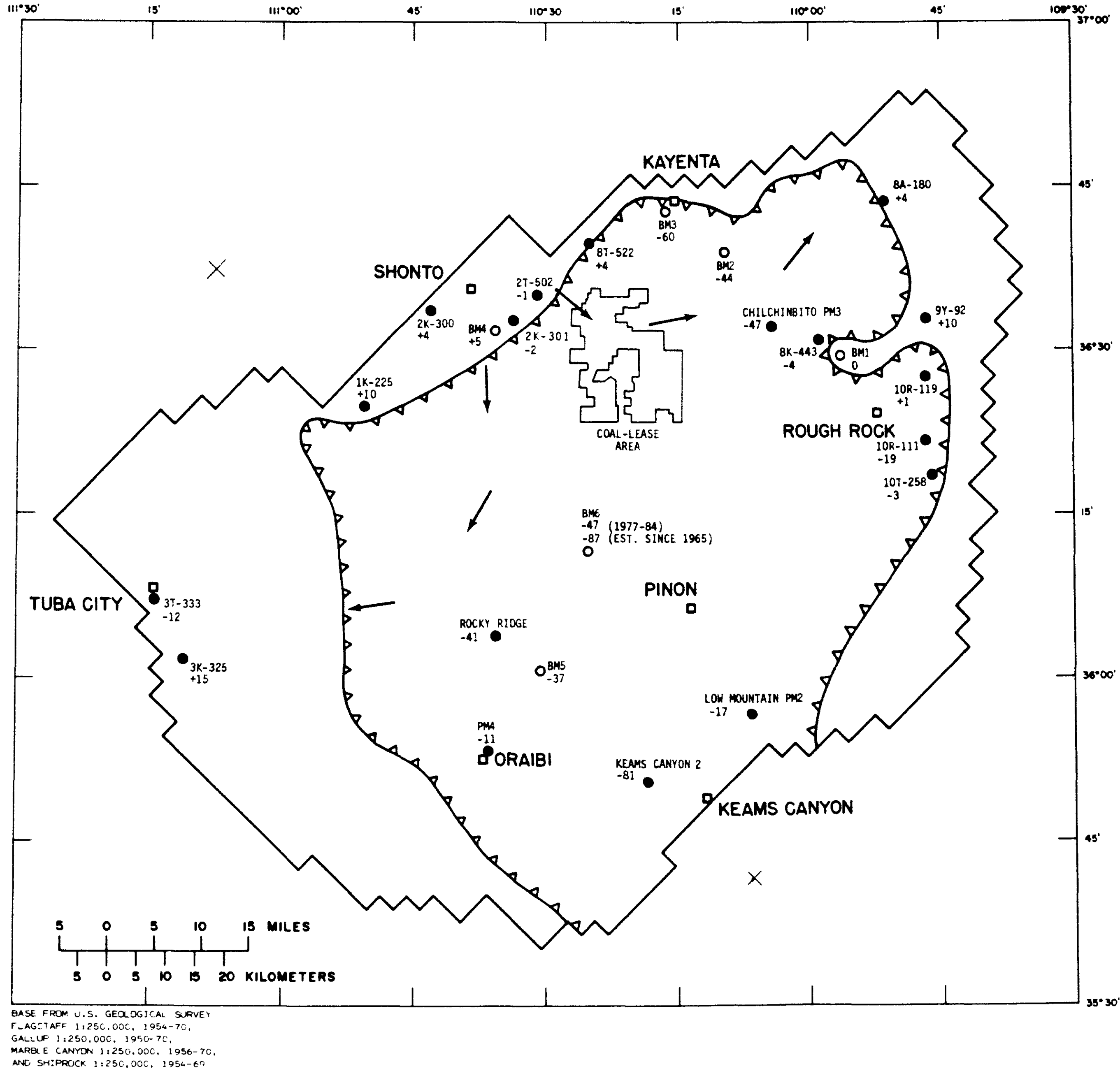


Figure 3.--Water-level changes in wells that tap the N aquifer, 1953-86.

EXPLANATION

● 3T-333 -5	WELL IN WHICH DEPTH TO WATER WAS MEASURED INTERMITTENTLY—First entry, 3T-333, is Bureau of Indian Affairs site identification; second entry, -5, is difference, in feet, between water-level measurements during assumed local equilibrium 1953-72 and 1983
○ BM2 -34	CONTINUOUS-RECORD OBSERVATION WELL—First entry, BM2, is well identifier. Second entry, -34, is difference, in feet, between water-level measurements during assumed local equilibrium 1965-72 and 1983
CONFINED △△△△△△△△△ UNCONFINED	APPROXIMATE BOUNDARY BETWEEN CONFINED AND UNCONFINED CONDITIONS—From Eychaner (1983)
→	GENERALIZED DIRECTION OF GROUND-WATER MOVEMENT
———	BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Figure 3

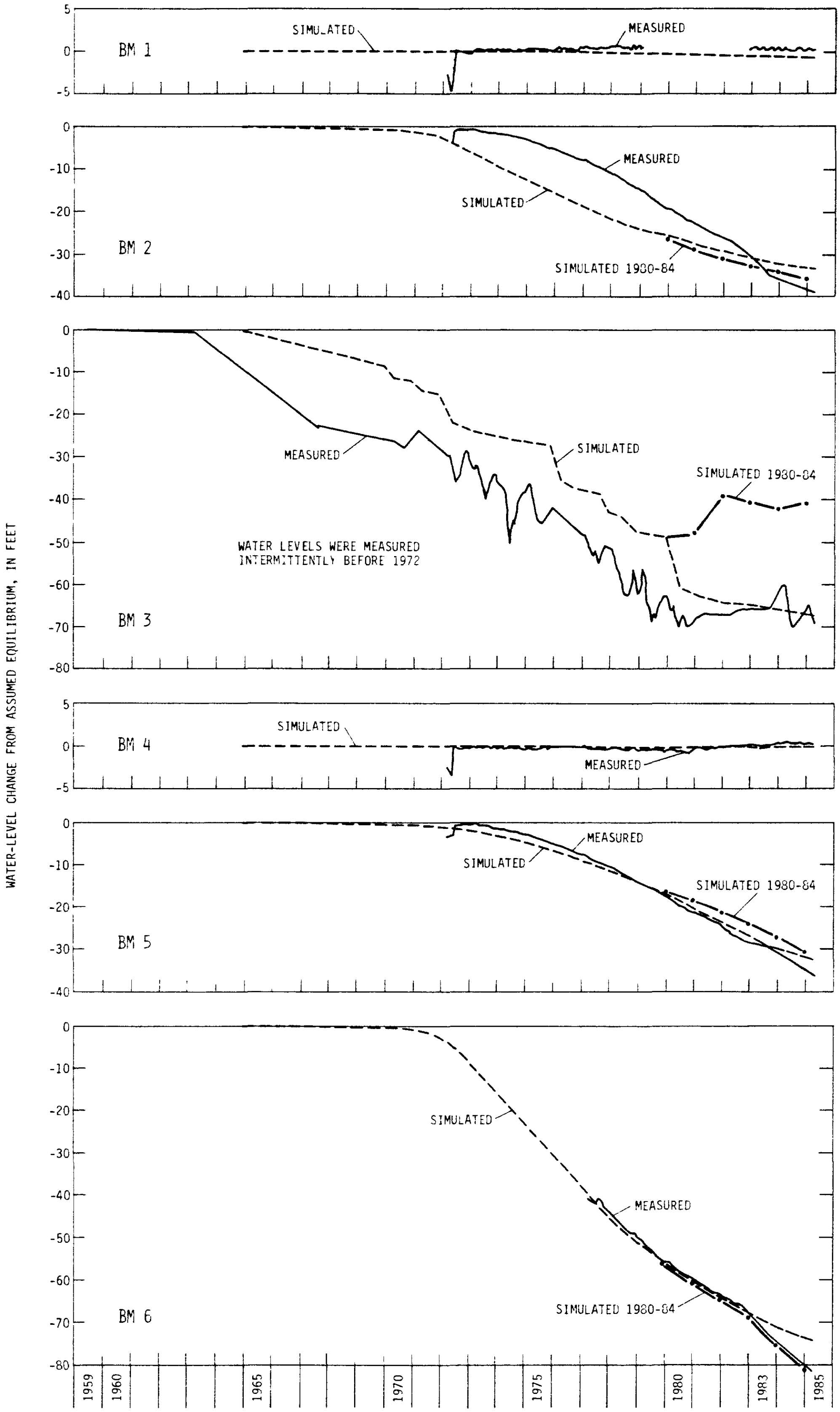


Figure 4.--Measured and simulated water-level changes for observations wells, 1959-85.

BM1 and BM4, which are in the unconfined area of the N aquifer, are not significantly different from the earlier simulation curves and are not shown.

Water-level changes measured and simulated for observation well BM3 are not simple to compare. Changes in the amount and location of pumpage for the village of Kayenta have strongly influenced the water levels in BM3 while not as dramatically affecting water levels in the area represented by the model block. However, the fact that measured and simulated water levels have parallel trends for the periods 1970-79 and 1982-84 indicates that the model reasonably represents the real world (fig. 4).

Withdrawals from the N Aquifer

The three categories of ground-water withdrawals from the N aquifer are industrial (Peabody Coal Co.) from the confined area, nonindustrial from the confined area, and nonindustrial from the unconfined area. The primary interest is in withdrawals related to the mining operation and nonindustrial pumpage of significant amounts. Pumpage data have not been collected from wells equipped with windmills.

The Geological Survey has continued its efforts to improve and insure accuracy of withdrawal data from both industrial and nonindustrial wells that penetrate the N aquifer in the study area. Thirty nonindustrial distribution systems, which include about 58 wells, serve the Hopi and Navajo Tribes in the Black Mesa area. Only one industrial system, which includes eight wells—Peabody Coal Co. mine well field—withdraws water from the N aquifer within the study area. In 1985 and 1986, the Survey made an inventory of the wells and conducted accuracy tests on the flowmeters.

Two methods were used to test the accuracy of flowmeters. Most meters were tested using a simple volumetric method in which the volume of water pumped through the flowmeter was measured over a period of time and compared with the meter reading for the same period. Flow rates for a few wells were determined with a Cox flowmeter. The results are shown as a percent difference of the metered pumpage from the measured pumpage (table 1). For the purpose of this study, the allowable limit between metered and measured pumpage should be no greater than ±10 percent.

In 1986, ten flowmeters were purchased by the Geological Survey and installed on Bureau of Indian Affairs and Hopi Tribal wells by their Facilities Management personnel. These meters either replaced faulty meters or were installed on the wells without meters. The meters were tested for accuracy after installation. Installation sites are given on table 2. Communities that now have metered wells are identified by a representative well in figure 2.

Table 1.--Flowmeter test results for industrial and nonindustrial wells in the N aquifer, Black Mesa area, 1985-86

Well system	Well[1] number	Date tested	Test method	Measured pumpage (gal/min)	Metered pumpage (gal/min)	Percent difference
			Peabody Coal Co.			
Peabody	2	05-14-86	Cox meter	484	465	+4.1
Do.	3	02-21-86	do.	613	600	+2.1
Do.	4	05-14-86	do.	577	570	+1.2
Do.	5	01-23-86	do.	608	615	-1.1
Do.	6	01-23-86	do.	460	475	-3.3
Do.	7	02-21-86	do.	540	540	0.0
Do.	8	01-23-86	do.	611	600	+1.8
Do.	9	02-21-86	do.	568	585	-3.0
			Bureau of Indian Affairs			
Tuba City	4	05-19-86	Volumetric	143	140	+2.1
Do.	5	06-26-85	do.	92.8	95	-2.4
Do.	6	05-19-86	do.	123	120	+2.4
Do.	Day Spring	06-26-85	do.	61.4	60.8	+1.0
Red Lake	1	06-27-85	do.	34.1	30.2	+11.4
Do.	2	07-09-85	do.	74.5		
Shonto	1	05-15-86	do.	178	170	+4.5
Do.	2	05-15-86	do.	96	91	+5.2
Do.	3	05-15-86	do.	78	75	+3.8
Kayenta	2	05-20-86	do.	139	133	+4.3
Do.	3	05-15-86	do.	164	156	+4.9
Dennehotso	1	05-13-86	do.	62	61	+1.6
Do.	2	05-13-86	do.	51	48	+5.9
Chilchinbeto	2	07-02-85	do.	25.5	25.5	0.0
Rough Rock	1	05-14-86	do.	44	42	+4.5
Do.	2	07-03-85	do.	25.2	27.0	-7.1
Do.	3	07-03-85	do.	52.2	52.7	-1.0
Do.	4	07-03-85	do.	51.6	49.0	+5.0
Rocky Ridge	1	07-11-85	do.	47.7	46.3	+2.9
Do.	2	07-11-85	do.	50.3	51.5	-2.4
Cottonwood	3	07-10-85	do.	61.0	62.8	-3.0
Piñon	3	05-20-86	do.	67	67	0.0
Do.	6	07-10-85	do.	104.0	107.1	-3.0
Low Mountain	1	07-10-85	do.	16.4	15.5	+5.5
Keams Canyon	PM1	07-11-85	do.	75.0	73.6	+1.9
Do.	PM2	05-29-86	do.	93	75	+19.4
Hotevilla	PM1	05-30-86	do.	52	49	+5.8
Do.	PM2	07-11-85	do.	22.0	22.8	-3.6
Second Mesa	PM1	07-11-85	do.	104.8	76.3	+27.2
Do.	PM2	05-29-86	do.	44	40	+9.1

See footnote at end of table.

Table 1.--Flowmeter test results for industrial and nonindustrial wells in the N aquifer, Black Mesa area, 1985-86—Continued

Well system	Well[1] number	Date tested	Test method	Measured pumpage (gal/min)	Metered pumpage (gal/min)	Percent difference
Navajo Tribal Utility Authority						
Tuba City	1	05-12-86	Volumetric	115	122	-6.1
Do.	2	05-12-86	do.	95	74	+22.1
Do.	3	05-12-86	do.	114	104	+8.8
Do.	4	(meter inoperable at time of test)				
Do.	5	05-12-86	Volumetric	162	140	+13.6
Do.	6	(meter operable but inaccessible for test)				
Red Lake	1	07-09-85	Volumetric	64.3	66	-2.6
Shonto	1	06-27-85	Cox meter	65.1	50.8	+22.0
Shonto Junction	1	06-27-85	do.	69.1	68.3	+1.2
Kayenta	1	(meter inoperable at time of test)				
Do.	2	07-02-85	Volumetric	91.3	88.2	+3.4
Do.	3	(meter inoperable at time of test)				
Do	4	07-02-85	Cox meter	72.0	60-90	([2])
Do.	5	05-15-85	do.	201	205	-2.0
Do.	6	05-15-86	Volumetric	122	123	-0.8
Do.	7	05-15-86	do.	83	74	+10.8
Dinnehotso	1	07-03-85	do.	34.4	33.9	+1.4
Chilchinbeto	1	07-02-85	do.	49.8	42.4	+14.9
Rough Rock	1	07-03-85	do.	32.5	30.7	+5.5
Cottonwood	1	(well not in operation at time of test)				
Do.	2	07-10-85	Volumetric	50.0	50.0	0.0
Pinon	1	07-10-85	do.	86.8	84.7	+2.4
Kitsillie	1	07-10-85	do.	44.4	42.5	+4.3
Forest Lake	1	07-09-85	do.	44.1	42.8	+2.9
Hopi Tribe						
Oraibi	PM1	07-12-85	Volumetric	55.5	55.5	0.0
Do.	PM2	06-20-85	do.	92.7	90	+2.9
Do.	PM3	(well not in operation at time of test)				
Shungopovi	1	07-12-85	Volumetric	46.9	46.2	+1.5
Mishongovi	1	05-21-86	do.	13	13	0.0
Shipaulovi	1	06-11-86	do.	108	98.9	+8.4

[1]Well numbers do not necessarily coincide with Agency well numbers.

[2]Test results inconclusive.

Table 2.--Flowmeters installed on nonindustrial wells that tap the N aquifer, Black Mesa area, 1986

Location	Agency	Well number[1]	Meter size (inches)	Date installed
Shonto	BIA	1	1½	05-14-86
Shonto	BIA	2	1½	05-14-86
Shonto	BIA	3	1½	05-14-86
Red Lake	BIA	2	1½	06- -86
Oraibi	HOPI	PM1	1½	04-15-86
Dennehotso	BIA	2	1½	03-27-86
Tuba City	BIA	4	2	05-15-86
Tuba City	BIA	6	2	05-15-86
Kayenta	BIA	2	2	05-15-86
Kayenta	BIA	3	2	04-16-86

[1]Well numbers do not necessarily coincide with Agency well numbers.

Annual pumpage for the three categories of withdrawals from the N aquifer for 1965-85 is given on table 3. Withdrawals during the 1985 calendar year from nonindustrial and industrial well systems that pump from the N aquifer are given on table 4.

Chemical Quality of Water from Wells that Tap the N Aquifer

One major concern on the part of some residents of the Black Mesa area has been the effect of withdrawals on the chemical quality of water from the N aquifer. Eychaner (1983) stated that some water may enter the N aquifer from the upper confining beds. He also stated that the driving force for such flow is present because the head in the overlying D aquifer in 1964 averaged about 300 ft higher than that in the N aquifer. Differences in the chemical composition of the waters of the two aquifers, D and N, indicate that the amount of downward leakage must be small (Eychaner, 1983). On the average, the concentration of dissolved solids in water from the D aquifer is about 7 times greater than that from the N aquifer, the concentration of chloride ions is 11 times greater, and the concentration of sulfate ions is 30 times greater (Eychaner, 1983).

Any increase in the leakage rate due to pumping from the N aquifer should appear first as an increase in the dissolved-solids concentrations in the water from Peabody wells (Eychaner, 1983). Other indicators of leakage caused by stress on the N aquifer are increases in specific conductance, concentrations of dissolved chloride, and concentrations of dissolved sulfate.

In 1986, all Peabody Coal Co. industrial wells and one nonindustrial well at Shonto (fig. 2) were sampled for major ions and fluoride. Chemical analyses are shown on table 5. The concentrations of dissolved sulfate and dissolved chloride in Peabody Wells 2-4 and 6-7 have not increased since 1967, the year before withdrawals began at the mine. Peabody Well 5 analysis indicates increases in specific conductance, dissolved sulfate, and dissolved chloride since last sampled in 1980. Specific conductance increased from 210 μmhos (micromhos) to 398 μmhos; dissolved sulfate increased from 9.5 mg/L (milligrams per liter) to 28 mg/L, and dissolved chloride increased from 2.9 mg/L to 8.0 mg/L (table 6). Peabody Well 8 showed slight increases in specific conductance, dissolved sulfate, and dissolved chloride since last sampled in 1984 (table 6). Peabody Well 9 was sampled for the first time by the Geological Survey in 1986. Chemical analysis shows the constituents of specific conductance, dissolved sulfate, and dissolved chloride to be in the same magnitude range as those for wells 2-4 and 6-7 (table 6).

The municipal well at Shonto was sampled for quality by the Geological Survey for the first time in 1986 (table 5). Complete chemical analyses of selected industrial and nonindustrial wells tapping the N aquifer in the Black Mesa area sampled since 1976 have been reported (G. W. Hill, written commun., 1982, 1983; Hill, 1985).

Table 3.--Withdrawals from the N aquifer, 1965-85

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

Year	Industrial[1]	Nonindustrial[2]	
		Confined[3]	Unconfined[4]
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

[1]Metered pumpage by Peabody Coal Co. at their mine on Black Mesa.

[2]Does not include withdrawals from wells equipped with windmills.

[3]Includes metered pumpage at Kayenta and estimated pumpage at Chilchinbito, Rough Rock, Pinon, Keams Canyon, and Oraibi 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.

[4]Includes estimated pumpage, 1965-73, and metered pumpage, 1974-79, at Tuba City; metered and estimated data furnished by the Navajo Tribal Utility Authority and the U.S. Bureau of Indian Affairs, 1980-85.

Table 4.--Withdrawals from the N aquifer by well systems, Black Mesa area, 1985

[Measurements are in acre-feet]

Location	Confined	Unconfined
Bureau of Indian Affairs[1]		
Tuba City[2]		129
Chilchinbeto[2]	17.6	
Dinnehotso[2]		17.6
Kayenta[2]	71.3	
Red Lake[2]		40.9
Rocky Ridge[2]	55.4	
Shonto		128
Cottonwood		12.2
Low Mountain	13.9	
Pinon	35.3	
Rough Rock	41.2	
Hotevilla	28.9	
Second Mesa	19.6	
Navajo Tribal Utility Authority[1]		
Kayenta	470	
Chilchinbeto	31.5	
Dinnehotso		29.6
Shonto		16.8
Forest Lake	5.7	
Shonto Junction		16.8
Tuba City		734
Red Lake		20.7
Rough Rock	12.5	
Cottonwood		12.2
Pinon	33.9	
Kitsillie	6.6	
Peabody Coal Company[1]		
Mine well field	2,520	
U.S. Geological Survey[1]		
Keams Canyon	15.5	
Polacca[3]	100	
Oraibi	56.3	
Shungopovi[3]	11.1	
Shipaulovi	8.0	
Shipaulovi-Mishongovi	1.7	

[1]Reporting agency.

[2]Pumpage computed on the basis of the U.S. Bureau of Indian Affairs' compound population figures allowing an average consumption of 110 gallons per day per person.

[3]Estimated.

Table 5.--Chemical analyses of selected industrial and nonindustrial wells that tap the N aquifer, Black Mesa area, 1986

Well number	Identification number	Date of sample	Temperature (°C)	Specific conductance (μmhos)	pH (units)	Alkalinity (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)
Peabody Well 2	363005110250901	02-21-86	31	172	8.7	--	0.97
Peabody Well 3	362625110223701	01-23-86	32	175	9.2	64	<.85
Peabody Well 4	362647110243501	03-25-86	32	205	9.3	80	1.0
Peabody Well 5	362901110234101	01-23-86	31	398	9.6	134	<1.1
Peabody Well 6	363007110221201	01-23-86	33.5	182	9.1	76	.72
Peabody Well 7	362456110242301	01-23-86	31	217	9.2	64	.86
Peabody Well 8	363130110254501	02-21-86	29	445	8.3	--	<1.6
Peabody Well 9	362333110250001	02-21-86	31.5	181	9.2	96	.73
Shonto	363558110392501	05-20-86	14	290	8.0	101	3.3

Well number	Identification number	Date of sample	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)
Peabody Well 2	363005110250901	02-21-86	<0.01	9.4	0.21	26
Peabody Well 3	362625110223701	01-23-86	<.01	4	.03	36
Peabody Well 4	362647110243501	03-25-86	.02	4.9	.04	41
Peabody Well 5	362901110234101	01-23-86	<.01	.94	.01	89
Peabody Well 6	363007110221201	01-23-86	<.01	4.7	.04	38
Peabody Well 7	362456110242301	01-23-86	<.01	4.1	.04	45
Peabody Well 8	363130110254501	01-23-86	<.01	24	3.4	66
Peabody Well 9	362333112500001	02-21-86	<.01	4	.08	34
Shonto	363558110392501	05-20-86	.01	41	5.4	5.7

Table 5.--Chemical analyses of selected industrial and nonindustrial wells that tap the N aquifer, Black Mesa area, 1986--Continued

Site name	Identification number	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)
Peabody Well 2	363005110250901	02-21-86	0.9	2.6	8.1	0.1
Peabody Well 3	362625110223701	01-23-86	.7	2.4	9.7	.2
Peabody Well 4	362647110243501	03-25-86	.7	4.2	12	.2
Peabody Well 5	362901110234101	01-23-86	.7	8.0	28	.2
Peabody Well 6	363007110221201	01-23-86	.8	2.3	9.6	.2
Peabody Well 7	362456110242301	01-23-86	.7	3.6	12	.2
Peabody Well 8	363130110254501	01-23-86	2.8	4.9	110	.1
Peabody Well 9	362333112500001	02-21-86	.8	3.1	4.9	.2
Shonto	363558110392501	05-20-86	1.6	10	14	<.1

Site name	Identification number	Date of sample	Silica, dissolved (mg/L as SiO_2)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)
Peabody Well 2	363005110250901	02-21-86	22	20	4	<1
Peabody Well 3	362625110223701	01-23-86	20	20	14	1
Peabody Well 4	362647110243501	03-25-86	20	20	27	3
Peabody Well 5	362901110234101	01-23-86	20	50	10	<1
Peabody Well 6	363007110221201	01-23-86	22	20	10	<1
Peabody Well 7	362456110242301	01-23-86	20	30	5	<1
Peabody Well 8	363130110254501	01-23-86	19	40	26	2
Peabody Well 9	362333112500001	02-21-86	19	30	11	1
Shonto	363558110392501	05-20-86	14	20	71	1

Table 6.--Selected parameters from chemical analyses of water from Peabody Coal Co. wells that tap the N aquifer, Black Mesa area, 1967-74 and 1980-86

Well number	Year	Specific conductance (µmhos)	Dissolved solids Residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
2	1967	221	[1]144	5.0	21
	1980	225	144	11	20
	1986	172	--	2.6	8.1
3	1968	236	[1]154	4.0	17
	1980	230	151	3.5	14
	1986	175	--	2.4	9.7
4	1974	200	140	3.8	13
	1980	230	139	4.3	13
	1986	205	--	4.2	12
5	1968	224	[1]149	3.5	16
	1980	210	134	2.9	9.5
	1986	398	--	8.0	28
6	1968	201	[1]333	3.0	13
	1980	260	160	3.5	15
	1986	182	--	2.3	9.6
7	1972	222	[1]141	2.5	20
	1980	210	136	3.7	11
	1986	217	--	3.6	12
8	1980	420	283	4.8	100
	1983	440	278	4.8	100
	1984	436	264	4.7	100
	1986	445	--	4.9	110
9	1986	181	--	3.1	4.9

[1]Dissolved-solids data from 1974.

Discharge and Chemical Quality of Springs

The effect of withdrawals from the N aquifer on the quality of springs used for domestic purposes is a major concern of some residents of the reservations. Many springs on Black Mesa discharge from several stratigraphic units including the Navajo Sandstone where the units are exposed. Between 1982 and 1984, discharge measurement were made and water-quality samples were analyzed for 12 springs (fig. 2) representing the Navajo Sandstone, Morrison Formation, Dakota Sandstone, Toreva Formation, Wepo Formation, and alluvium[1] (fig. 2). Nine of the springs were sampled from 1948 to 1954 (Kister and Hatchett, 1963). Discharge and chemical analyses of these springs have been reported (G. W. Hill, written commun., 1982, 1983; Hill, 1985).

In 1985-86, three springs sampled previously in 1948-54 and 1982-83 were selected for discharge measurements and water-quality analyses. The springs were Pasture Canyon Springs (3A-5, Navajo Sandstone), Pigeon Springs (4M-115, Wepo Formation) and near Rough Rock (10R-158A, Dakota Sandstone) (fig. 2). Discharge from springs sampled in 1985-86 was as follows:

Spring	BIA Number	Discharge, in gallons per minute
Pasture Canyon	3A-5	160
Pigeon	4M-115	seeping (discharge unobtainable)
Near Rough Rock	10R-158A	0.21

Chemical analyses of water samples taken from these springs in 1985-86 are not available at this time owing to laboratory delay.

Surface-Water Data

The continuous-record streamflow stations on Moenkopi Wash at Moenkopi (09401260) and Chinle Creek near Mexican Water (09379200) and the partial-record streamflow station on Laguna Creek near Church Rock were continued (fig. 2). The base flow of Moenkopi Wash during winter months when evapotranspiration is at a minimum is maintained by discharge from the N aquifer. The average discharge of low-flow measurements made during November through February in the 1985 and 1986 water years was 3.2 ft^3/s, which is equivalent to about 2,320 acre-ft/yr. The average of all measurements made during the same period from 1976 to 1984 was 3.2 ft^3/s. Base flow in Moenkopi Wash does not appear to have diminished as a result of withdrawal of water from the N aquifer. Mean daily discharges during the 1984 water year are shown on table 7. Data for previous water years have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1976-86).

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[1]This report has not been reviewed for conformity with U.S. Geological Survey nomenclature.

Table 7.--Discharge data, Moenkopi Wash at Moenkopi, 1984 water year

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1983 TO SEPTEMBER 1984
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	150	3.5	5.2	3.0	5.6	4.4	2.0	.00	.00	.00	10	824
2	40	3.5	5.2	3.0	5.6	4.8	2.0	.00	.00	.00	2.0	128
3	20	3.5	5.6	3.0	6.0	4.8	2.0	.00	.00	.00	1.0	16
4	15	3.5	5.2	3.0	5.6	4.0	2.3	.00	.00	.00	5.0	6.4
5	8.7	3.5	5.0	3.0	6.0	3.1	2.0	.00	.00	.00	10	4.0
6	6.9	3.5	5.0	3.0	5.6	3.1	2.3	.00	.00	.00	10	3.1
7	7.4	3.5	5.0	3.0	6.0	3.5	2.7	.00	.00	.00	5.0	2.3
8	6.9	4.4	5.0	3.0	5.2	3.1	4.4	.00	.00	.00	2.0	1.6
9	5.6	6.4	5.0	3.0	4.8	3.1	2.3	.00	.00	.00	1.0	1.6
10	5.2	4.4	5.0	3.0	5.2	3.1	3.1	.00	.00	.00	1.0	2.3
11	4.8	4.4	5.0	3.0	4.8	2.7	4.0	.00	.00	.00	1.0	2.7
12	4.0	4.4	5.0	2.7	4.4	2.7	3.5	.00	.00	.00	50	3.1
13	3.5	4.4	5.0	2.0	5.2	2.7	4.4	.00	.00	.00	20	3.1
14	2.7	4.4	5.0	2.7	6.0	3.1	3.5	.00	.00	.00	10	3.1
15	2.3	4.4	4.0	3.5	5.2	4.0	3.1	.00	.00	58	5.0	3.1
16	2.7	4.0	4.0	3.5	5.2	4.0	3.1	.00	.00	13	100	3.5
17	2.7	4.8	4.0	4.0	6.0	4.0	3.5	.00	.00	8.7	37	3.1
18	2.7	11	4.0	3.1	5.2	4.0	3.1	.50	.00	7.4	1880	8.0
19	2.7	8.7	4.0	2.7	5.6	4.0	2.7	1.0	.00	.52	112	20
20	2.7	6.9	4.0	2.3	5.6	3.1	4.4	1.0	.00	.16	647	15
21	2.7	4.8	4.0	4.4	4.8	4.0	4.8	1.0	.00	.40	83	10
22	2.7	3.5	4.0	5.2	4.8	4.4	3.5	1.0	.00	.10	82	5.0
23	2.7	4.0	4.0	5.6	4.0	4.8	3.0	1.0	.00	10	14	2.0
24	3.1	4.0	4.0	6.0	4.0	4.4	3.0	1.0	.00	100	144	2.0
25	3.1	4.8	6.0	6.4	4.4	4.0	2.0	1.0	.00	20	618	1.0
26	3.1	5.2	10	6.4	3.5	3.5	2.0	1.0	.00	40	82	15
27	3.1	4.8	20	6.9	3.5	4.8	1.0	.50	.00	150	11	12
28	3.1	4.8	15	7.4	4.4	4.4	.50	.50	.00	100	13	10
29	3.1	5.2	5.0	6.9	4.0	2.7	.30	.00	.00	10	19	5.0
30	3.5	5.2	4.0	6.4	---	2.3	.20	.00	.00	50	5.6	4.0
31	3.5	---	4.0	6.0	---	2.0	---	.00	---	20	5.0	---
TOTAL	330.2	143.4	175.2	127.1	146.2	112.6	80.70	9.50	.00	588.28	3985.6	1120.0
MEAN	10.7	4.78	5.65	4.10	5.04	3.63	2.69	.31	.00	19.0	129	37.3
MAX	150	11	20	7.4	6.0	4.8	4.8	1.0	.00	150	1880	824
MIN	2.3	3.5	4.0	2.0	3.5	2.0	.20	.00	.00	.00	1.0	1.0
AC-FT	655	284	348	252	290	223	160	19	.00	1170	7910	2220

CAL YR 1983 TOTAL 7112.14 MEAN 19.5 MAX 3500 MIN .00 AC-FT 14110
WTR YR 1984 TOTAL 6818.78 MEAN 18.6 MAX 1880 MIN .00 AC-FT 13530

Chinle Creek, which is along the northeast perimeter of the study area, receives water from the N aquifer principally from Laguna Creek. Laguna Creek flows along the north boundary of the study area and empties into Chinle Creek about 5 mi above the gaging station near Mexican Water (fig. 2). The average discharge of low-flow measurements made on Chinle Creek for November through February in the 1985 and 1986 water years is 5.7 ft^3/s (about 4,130 acre-ft/yr). The average discharge of low-flow measurements for the same months from 1976 to 1983 was 5.5 ft^3/s. Low-flow measurements during winter months of the 1984 water year were not averaged because the measurements, which were made intermittently, did not represent discharge in the approximate base-flow range. The daily mean discharges for the 1984 water year are shown on table 8. All previous data have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1976-86).

The average discharge of low-flow measurements made on Laguna Creek from November through February in the 1985 and 1986 water years was 5.2 ft^3/s. These measurements probably do not represent base-flow discharge because the average of the low-flow measurements made on Laguna Creek from November through February since the station was established in 1981 is 3.4 ft^3/s or about 2,460 acre-ft/yr. Continuous streamflow data are not collected at this station.

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Table 8.--Discharge data, Chinle Creek near Mexican Water, 1984 water year

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1983 TO SEPTEMBER 1984
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	40	4.8	8.4	15	20	3.4	77	123	.00	.00	59	.00
2	20	4.8	15	15	15	8.0	82	123	.00	.00	24	1000
3	10	4.8	59	15	15	19	95	161	.00	.00	14	1640
4	8.0	4.8	93	15	15	44	86	222	.00	.00	6.2	100
5	8.0	5.3	68	10	15	37	92	360	.00	.00	1.8	20
6	8.0	5.3	42	10	15	16	108	433	.00	.00	22	5.0
7	8.0	10	11	10	15	13	256	367	.00	.00	17	3.0
8	8.0	70	9.2	10	10	21	291	275	.00	.00	8.8	2.0
9	6.0	40	8.8	8.0	10	24	288	228	.00	.00	12	2.0
10	6.0	20	11	8.0	10	25	178	201	.00	.00	6.2	2.0
11	6.0	10	25	8.0	10	48	161	201	.00	.00	4.5	6.0
12	6.0	8.0	26	8.0	10	67	106	195	.00	.00	17	5.0
13	5.0	8.0	15	12	10	72	121	183	.00	.00	1.8	3.0
14	5.0	6.0	11	8.8	15	44	102	159	.00	3.5	2.5	2.0
15	5.0	6.0	10	10	15	38	139	137	.00	20	6.2	2.0
16	4.0	6.0	6.9	16	15	34	190	139	.00	32	59	5.0
17	4.0	5.0	10	15	15	33	307	141	.00	16	59	129
18	4.0	150	12	14	15	21	371	125	.00	10	87	10
19	4.0	80	13	14	15	23	466	82	.00	7.2	865	8.0
20	4.0	20	16	8.8	15	25	458	74	.00	.80	450	8.0
21	3.7	15	17	6.2	15	151	328	71	.00	.40	200	8.0
22	3.7	19	12	3.1	15	24	198	42	.00	.20	75	6.0
23	3.4	33	8.0	3.1	12	24	173	31	.00	17	50	6.0
24	3.4	29	14	4.1	6.5	74	171	21	.00	1080	20	5.0
25	3.4	18	38	12	4.4	51	206	16	.00	40	10	5.0
26	3.1	15	38	12	5.8	36	291	6.2	.00	25	5.0	5.0
27	3.1	12	40	21	6.2	86	201	1.4	.00	20	.00	5.0
28	1.8	9.6	40	16	4.1	178	152	.00	.00	10	.00	5.0
29	2.8	9.2	30	26	4.1	84	168	.00	.00	5.0	.00	5.0
30	3.4	6.2	20	20	---	50	131	.00	.00	915	.00	5.0
31	5.7	---	20	20	---	60	---	.00	---	763	.00	---
TOTAL	206.5	634.8	747.3	374.1	348.1	1433.4	5993	4117.60	.00	2965.10	2083.00	3007.00
MEAN	6.66	21.2	24.1	12.1	12.0	46.2	200	133	.00	95.6	67.2	100
MAX	40	150	93	26	20	178	466	433	.00	1080	865	1640
MIN	1.8	4.8	6.9	3.1	4.1	3.4	77	.00	.00	.00	.00	.00
AC-FT	410	1260	1480	742	690	2840	11890	8170	.00	5880	4130	5960

CAL YR 1983 TOTAL 30950.48 MEAN 84.8 MAX 1500 MIN .00 AC-FT 61390

WTR YR 1984 TOTAL 21909.90 MEAN 59.9 MAX 1640 MIN .00 AC-FT 43460