PROGRESS REPORT ON THE GROUND-WATER, SURFACE-WATER, AND QUALITY-OF-WATER MONITORING PROGRAM, BLACK MESA AREA, NORTHEASTERN ARIZONA--1987

By George W. Hill and John P. Sottilare

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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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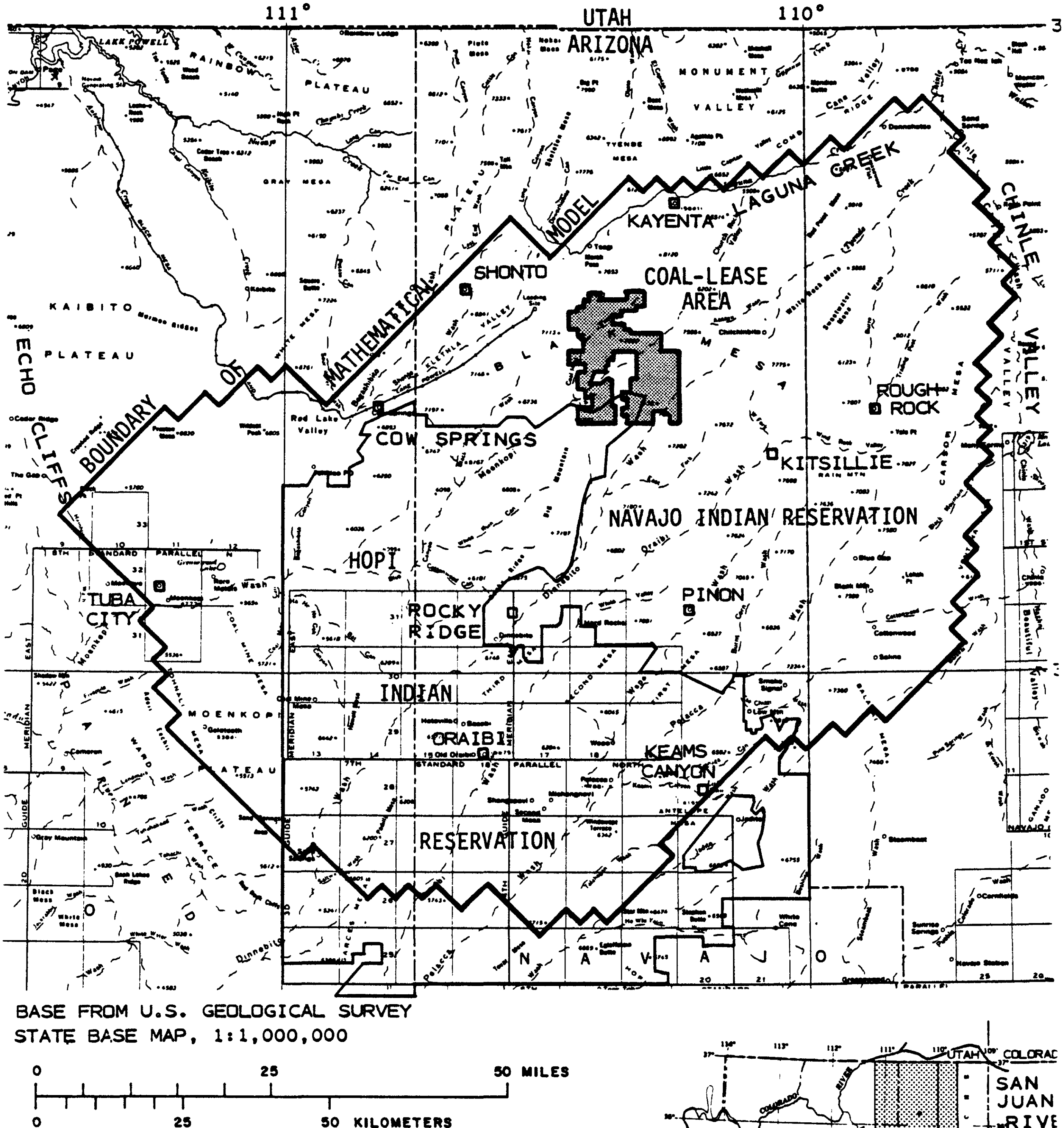
ABSTRACT

The Black Mesa monitoring program is designed to determine 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 Company. 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 1986.

Water levels in the confined area of the aquifer declined as much as 90 feet from 1965 to 1987 in some municipal and observation wells within about a 15-mile radius of the mine well field. Part of the drawdown in municipal wells is due to local pumpage. Water levels have not declined in wells that tap 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 (Eychaner, 1983) 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 Company 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 1986 more than 4,000 acre-ft was pumped. Withdrawals from the N aquifer for municipal use increased from an estimated 70 acre-ft in 1965 to about 2,200 acre-ft in 1986. 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 water-resources investigation of the Black Mesa area 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.



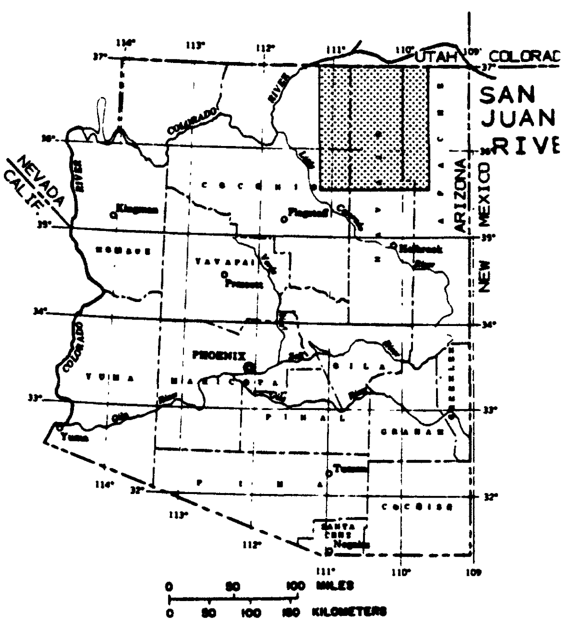


Figure 1.--Area of report.

The cooperation and assistance of the Navajo and Hopi Tribes and Peabody Coal Company 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

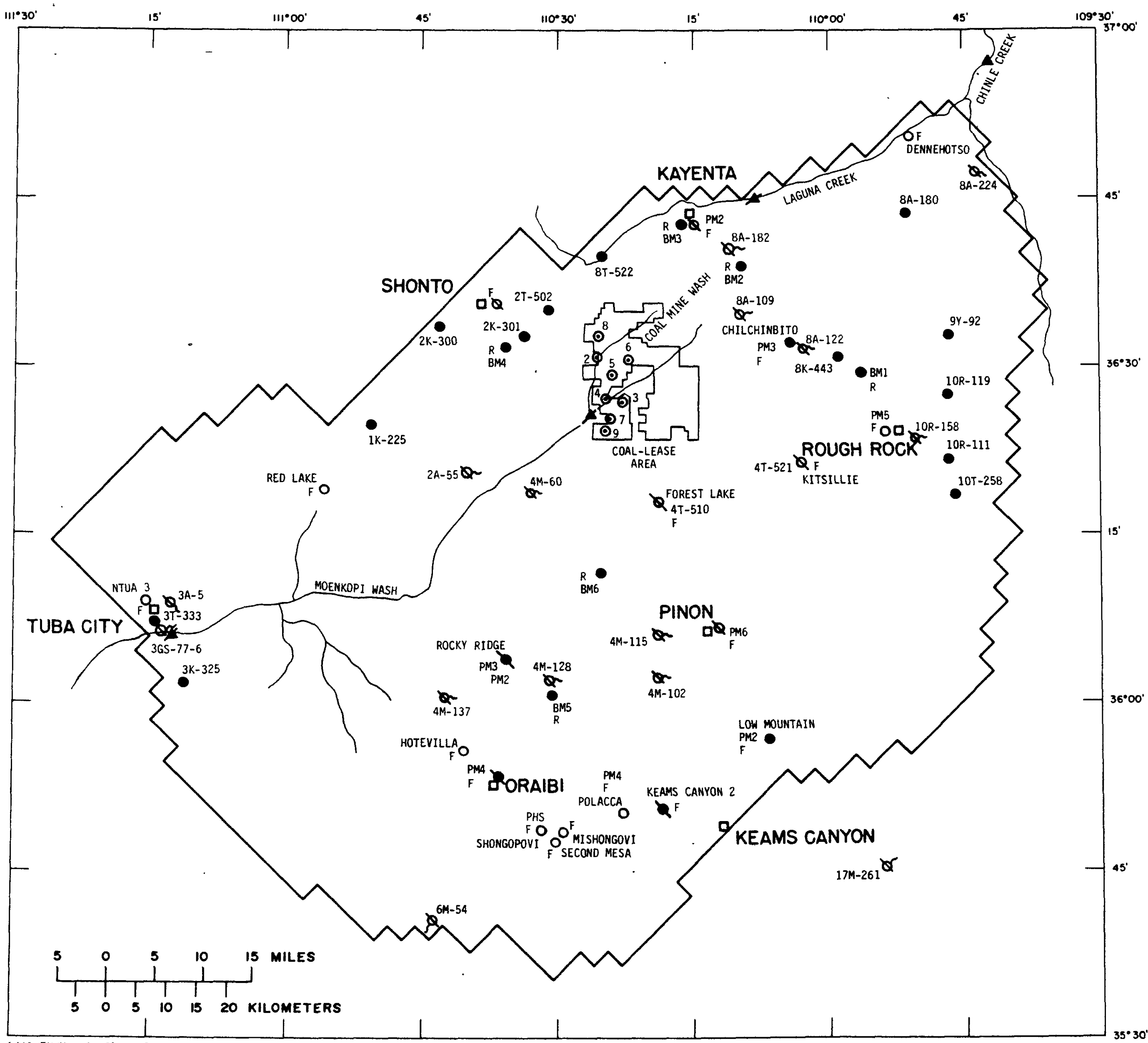
This report covers the progress of the ground-water, surface-water and quality-of-water monitoring program, Black Mesa area, northeastern Arizona, from July 1, 1986, to June 30, 1987, and discusses data collected throughout the monitoring program from its beginning in 1972. Except for some earlier data that are used for comparison, only new data will appear in this report.

Previous Reports on the Program

Five 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; Hill and Whetten, 1986). 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, 1976-87). 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 expiration of the existing coal lease. 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, 1986-87

In accordance with the objectives of the program, monitoring activities include continuous or periodic measurements of (1) ground-water levels in the confined and unconfined areas of the N aquifer; (2) major withdrawals 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 flow from the various formations, including the N aquifer; and (5) surface-water discharge and quality, which reflects the conditions of the N aquifer. The data-collection network is shown in figure 2.



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

Figure 2.--Data-collection sites, 1982-87.

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
o8	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 (or) sediment samples were collected
———	BOUNDARY OF MATHEMATICAL MODEL—From Eychaner (1983)

Figure 2

Ground-Water Levels

Ground-water levels in nonindustrial wells in the confined area of the N aquifer have continued a steady decline since 1968 when withdrawals from wells in the Peabody Coal Company mine area began. Water-level data collected in May 1986, however, showed a temporary reversal of this trend in a number of wells owing to a shutdown of production in the mine well field for the last 6 months of 1985 (Hill and Whetten, 1986). By the spring of 1987, water-level data showed that nonindustrial wells in the confined area of the aquifer, except 8K-443 and 10R-119, had resumed the declining trend and had reached the lowest levels since 1968 (fig. 3). Observation well BM6, about 15 mi south of the mine well field had declined about 90 ft. Observation well BM3, north of the mine well field near Kayenta, showed a decline of 76 ft. Most of the observation and nonindustrial wells in the northeastern section of the confined area of the N aquifer showed record declines. The municipal well near Keams Canyon in the extreme southern section of the confined area showed a record decline of 114 ft since pumping began at the mine.

Part of the drawdown in municipal wells probably is caused by local pumping. Pumping from the Kayenta municipal well field also may affect water levels in observation well BM3. Withdrawals are not made from any observation wells.

Significant water-level changes have not occurred in wells in the unconfined area of the N aquifer since pumping began at the mine. Well 3T-333 at Tuba City shows a drawdown of -12 ft, but this is the result of local pumpage (fig. 3). 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). In 1985, the simulation model was rerun for the period 1980-84 to include pumpage measured during the 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 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.

Measured and simulated water-level changes for observation well BM3 are not simple to compare. Changes in the location and amount 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. The parallel trends of the measured and simulated water levels for 1970-79 and 1982-84 however do indicate that the model reasonably represents the real world (fig. 4).

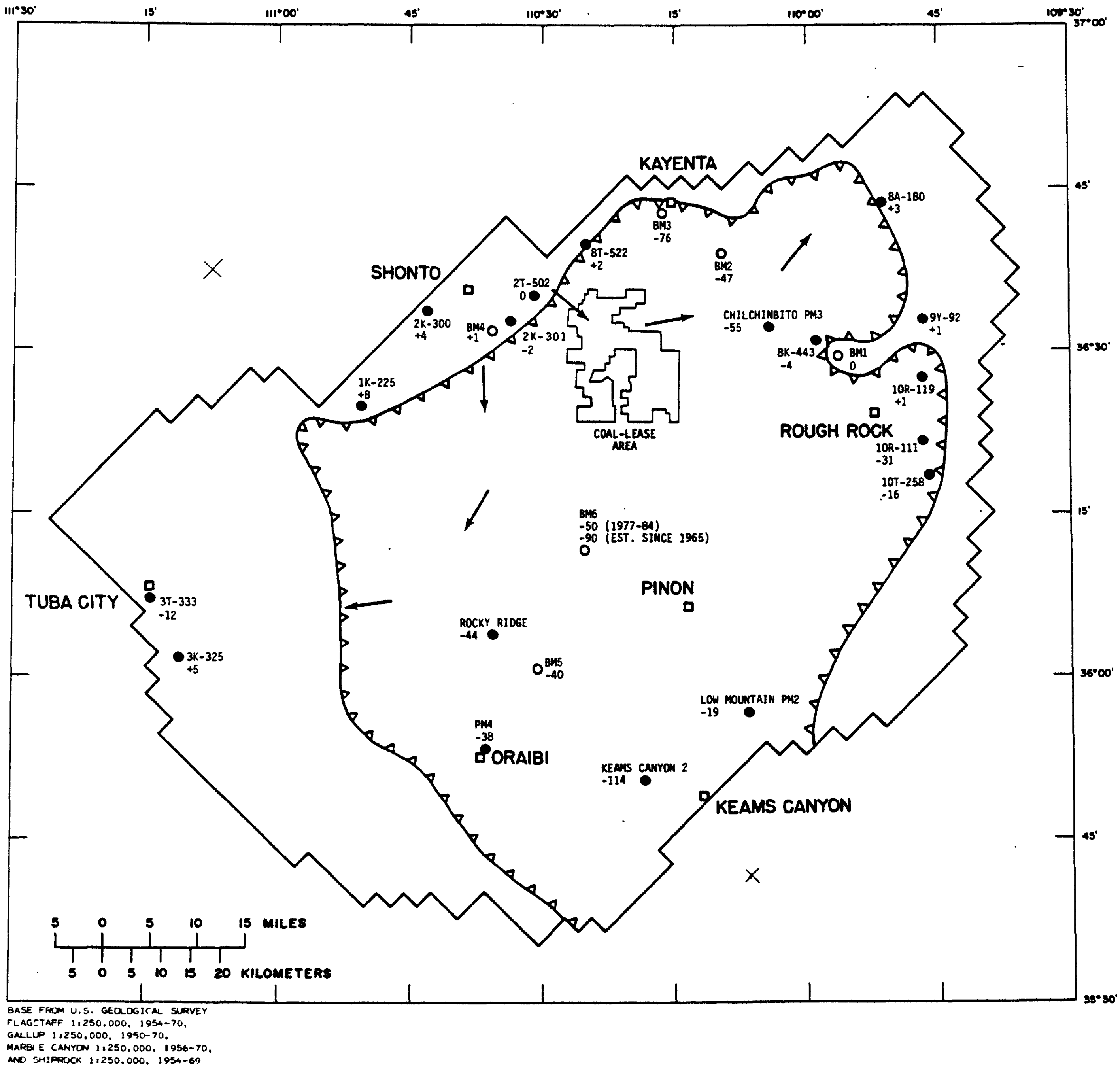


Figure 3.--Water-level changes in wells that tap the N aquifer, 1953-87.

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

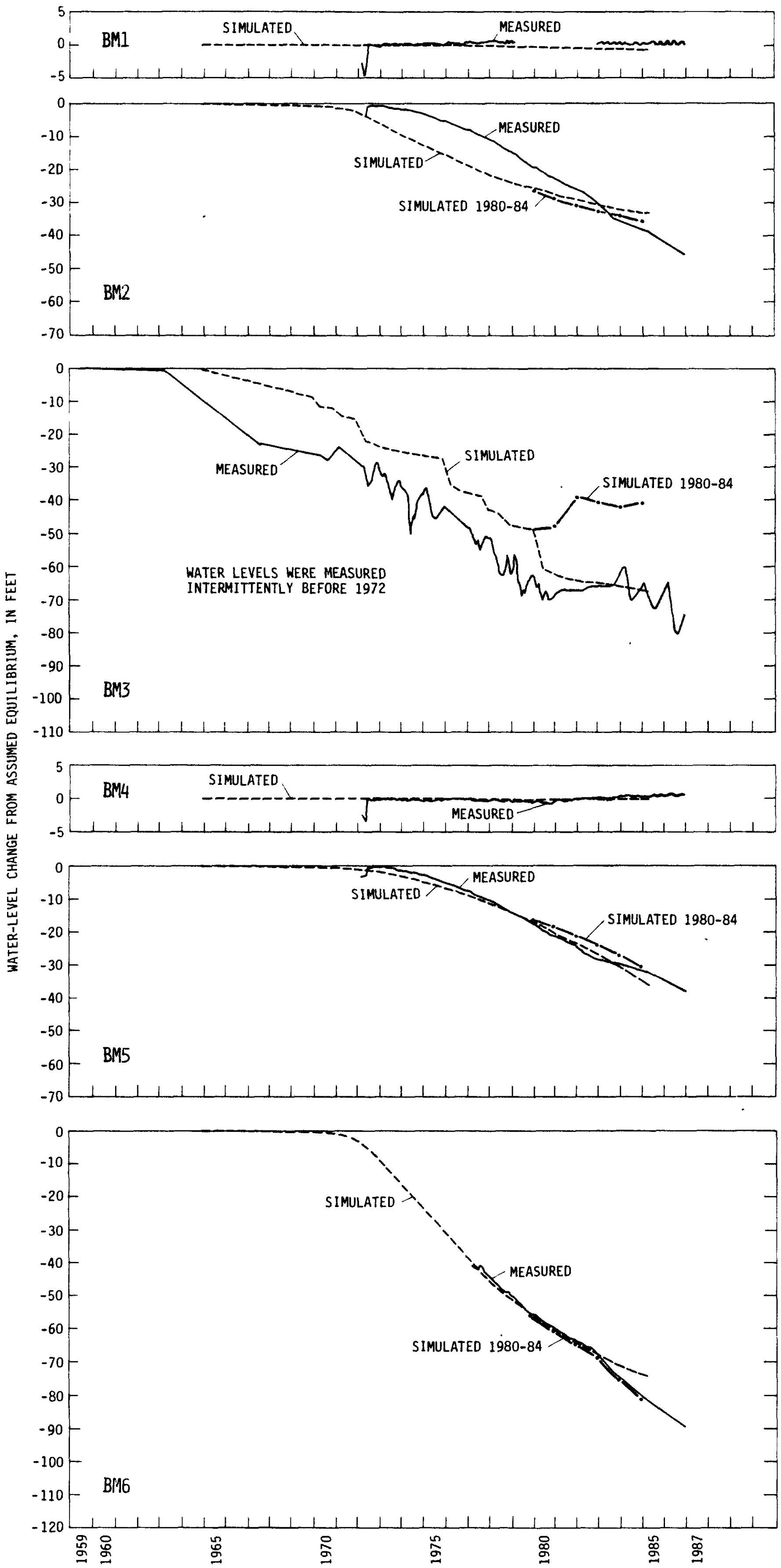


Figure 4.--Measured and simulated water-level changes for observation wells, 1959-86.

Withdrawals from the N Aquifer

The three categories of ground-water withdrawal from the N aquifer are industrial (Peabody Coal Company) 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 ensure accuracy of withdrawal data from industrial and nonindustrial wells that penetrate the N aquifer in the study area. Thirty nonindustrial distribution systems, which include about 60 wells, serve the Hopi and Navajo Tribes in the Black Mesa area. The industrial system, which includes eight wells—the Peabody Coal Company 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 (Hill and Whetten, 1986). A pumpage quality-assurance program was initiated that will be ongoing and will consist of flowmeter-accuracy tests every third year on all wells that penetrate the N aquifer except those with windmills.

Annual pumpage for the three categories of withdrawals from the N aquifer for 1965-86 is given in table 1. Withdrawals during the 1986 calendar year from nonindustrial and industrial well systems that pump from the N aquifer are given in table 2.

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 in 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 as a result of 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.

Table 1.--Withdrawals from the N aquifer, 1965-86

[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
1986	4,480	970	1,260

[1]Metered pumpage by Peabody Coal Company 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; and metered pumpage furnished by the Navajo Tribal Utility Authority, the U.S. Bureau of Indian Affairs, and the U.S. Geological Survey, 1986.

[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; and metered pumpage furnished by the Navajo Tribal Utility Authority, the U.S. Bureau of Indian Affairs, and the U.S. Geological Survey, 1986.

Table 2.--Withdrawals from the N aquifer by well systems, Black Mesa area, 1986

[Measurements, in acre-feet, are flowmeter data]

Location	Confined	Unconfined
Bureau of Indian Affairs[1]		
Tuba City		266
Chilchinbeto	4.9	
Dinnehotso		24.2
Kayenta	112.6	
Red Lake		9.2
Rocky Ridge	12.2	
Shonto		150
Low Mountain	11.9	
Pinon	37.3	
Rough Rock	43.9	
Hotevilla	15.2	
Second Mesa	10.7	
Navajo Tribal Utility Authority[1]		
Kayenta	436	
Chilchinbeto	31.3	
Dinnehotso		28.1
Shonto		18.9
Forest Lake	9.2	
Shonto Junction		14.5
Tuba City		728
Red Lake		21.7
Rough Rock	9.6	
Pinon	25.3	
Kitsillie	8.6	
Peabody Coal Company[1]		
Mine well field	4,480	
U.S. Geological Survey[1]		
Keams Canyon	80.3	
Polacca	34.6	
Oraibi	55.7	
Shungopovi	12.3	
Shipaulovi	18.1	
Mishongovi	1.2	

[1]Reporting agency.

In 1986-87, six industrial and nonindustrial wells that penetrate the N aquifer were sampled. The wells were Peabody Well 5, Rough Rock PM5, Kayenta PM2, Pinon PM6, Chilchinbito PM3, and Rocky Ridge PM2. Two other wells in the study area, but not in the N aquifer, were also sampled—Hopi Jr.-Sr. High School Well 1 and municipal well 3 at Cottonwood. Chemical analyses of wells that tap the N aquifer are shown in table 3.

In 1986, chemical analysis of water from Peabody Well 5 indicated increases in specific conductance, dissolved sulfate, and dissolved chloride since the previous sample in 1980 (Hill and Whetten, 1986). The well was sampled again in the fall of 1986, and the increasing trend in the quantities of the above indicators was again present. An investigation of sampling techniques was conducted. The conclusion was that in both cases the well had not been pumped for a sufficent length of time for standing water in the well bore to be replaced by water being pumped directly from the aquifer. In January 1987, Peabody Well 5 was resampled after allowing pumping to continue over a much longer period of time (24 hours) than the two previous samplings. Chemical analysis of this sample showed large decreases in specific conductance, dissolved solids, dissolved chloride, and dissolved sulfate as compared to the previous two samples in 1986 (table 4). The values for the above constituents however are still slightly higher than they were in 1968 and 1980 (table 4). On the basis of chemical analyses of water from 1967 to 1987 by the U.S. Geological Survey, no significant changes have occurred in the quality of water in the Peabody Coal Company mine wells (table 4).

Chemical analyses made during 1986-87 when compared to analyses made during 1982-83 show no significant changes in the chemical quality of nonindustrial wells at Rough Rock, Rocky Ridge, Kayenta, and Pinon (fig. 2; table 5). Nonindustrial well PM3 at Chilchinibito (fig. 2) was sampled for quality the first time by the Geological Survey in 1986. This chemical analysis indicates a quality that is typical of water from the N aquifer (table 5).

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 these units crop out. Between 1982 and 1984, discharge measurements 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 (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 previously (G. W. Hill, written commun., 1982, 1983; Hill, 1985; Hill and Whetten, 1986).

Table 3.--Chemical analyses of selected industrial and nonindustrial wells that tap the N aquifer, Black Mesa area, 1986-87

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 5	362901110234101	10-31-86	30.0	602	9.6	176	1.40
Do.	do.	01-29-87	31.5	270	9.4	111	.770
Rocky Ridge PM2	360418110352701	12-10-86	13.0	246	9.6	117	1.20
Chilchinbito PM3	363137110044702	12-11-86	17.9	390	9.9	168	1.20
Rough Rock PM5	362418109514601	12-11-86	21.0	1,010	9.1	194	1.00
Kayenta PM2	364347110145901	12-12-86	15.0	300	8.0	108	.640
Pinon PM6	360614110130801	04-16-87	27.0	500	9.9	227	1.30

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 5	362901110234101	10-31-86	0.250	0.90	0.60	120
Do.	do.	01-29-87	.010	3.2	.01	55
Rocky Ridge PM2	360418110352701	12-10-86	.021	.70	.10	57
Chilchinbito PM3	363137110044702	12-11-86	.010	.80	.05	90
Rough Rock PM5	362418109514601	12-11-86	.010	2.1	.30	230
Kayenta PM2	364347110145901	12-12-86	.010	23.0	9.1	29
Pinon PM6	360614110130801	04-16-87	.010	.53	.07	100

Table 3.--Chemical analyses of selected industrial and nonindustrial wells that tap the N aquifer, Black Mesa area, 1986-87--Continued

Well number	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 5	362901110234101	10-31-86	0.90	12	62	0.20
Do.	do.	01-29-87	.80	4.6	21	.20
Rocky Ridge PM2	360418110352701	12-10-86	.50	2.4	6.4	.10
Chilchinbito PM3	363137110044702	12-11-86	.60	2.4	2.4	.20
Rough Rock PM5	362418109514601	12-11-86	1.4	140	120	1.7
Kayenta PM2	364347110145901	12-12-86	1.5	8.2	30	.30
Pinon PM6	360614110130801	04-16-87	.50	3.7	3.8	.20

Well number	Identification number	Date of sample	Silica, dissolved (mg/L as SiO_2)	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids Residue at 180°C (mg/L)
Peabody Well 5	362901110234101	10-31-86	21	50	83	338
Do.	do.	01-29-87	20	40	3	168
Rocky Ridge PM2	360418110352701	12-10-86	20	20	88	164
Chilchinbito PM3	363137110044702	12-11-86	17	40	8	231
Rough Rock PM5	362418109514601	12-11-86	12	400	24	633
Kayenta PM2	364347110145901	12-12-86	17	50	94	181
Pinon PM6	360614110130801	04-16-87	26	50	5	279

Table 4.--Selected parameters from chemical analyses of water from Peabody Coal Company wells that tap the N aquifer, Black Mesa area, 1967-74 and 1980-87

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
	[2]1986	602	338	12.0	62
	1987	270	168	4.6	21
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.

[2]Volume of well bore not completely displaced prior to sampling.

Table 5.--Selected parameters from chemical analyses of water from nonindustrial wells that tap the N aquifer, Black Mesa area, 1982-87

Site name	Year	Specific conductance (umhos)	Dissolved solids, Residue at 180°C (mg/L)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Keams	1982	1,010	592	94	35
Canyon 2	1983	1,120	636	120	42
	1984	1,040	578	96	36
Rough Rock	1983	1,090	628	130	110
PM5	1984	1,090	613	130	99
	1986	1,010	633	140	120
Rocky Ridge PM3	1982	255	---	1.4	6.0
Rocky Ridge PM2	1986	245	164	2.4	6.4
New Oraibi PM4	1982	385	228	4.0	10
New Oraibi	1983	400	235	4.1	9.8
PM3	1984	395	216	4.0	9.9
Kayenta	1982	360	228	4.5	58
PM2	1983	375	230	-----	60
	1984	365	209	4.2	51
	1986	300	181	8.2	30
Forest Lake	1982	470	281	11	67
Kitsillie	1982	580	365	5.4	84
	1983	505	291	4.4	37
	1984	460	258	5.2	20
Pinon PM6	1982	485	---	3.7	5.0
	1983	505	293	3.6	5.3
	1984	495	273	3.7	5.4
	1987	500	279	3.7	3.8
Chinchinbito	1986	390	231	2.4	11

Three springs sampled during 1948-54 and 1982-83 were selected for discharge measurements and water-quality analyses again during 1985-86. The springs were Pasture Canyon Springs (3A-5, Navajo Sandstone), Pigeon Springs (4M-115, Wepo Formation), and near Rough Rock (10R-158, Dakota Sandstone) (fig. 2). In 1987, three additional springs were selected for discharge measurements and water-quality analyses. These were an unnamed spring near Kayenta (8A-182, Morrison Formation), Kydestea Spring near Shonto (2A-55, alluvium) and Moenkopi School Spring (3GS-77-6, Navajo Sandstone) (fig. 2). Of the latter three, only Moenkopi School Spring had been sampled previously (1952). Discharge for springs sampled in 1985-87 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-158	0.21
Unnamed near Kayenta	8A-182	Collection well (unmeasurable)
Moenkopi School	3GS-77-6	21.5
Kydestea near Shonto	2A-55	4.5

Chemical analyses of selected springs sampled in 1948-54 and 1982-87 are shown in table 6.

Surface-Water Data

Data were collected from the continuous-record streamflow stations on Moenkopi Wash at Moenkopi (09401260) and Chinle Creek near Mexican Water (09379200) and from the partial-record streamflow station on Laguna Creek near Church Rock (fig. 2). The base flow of Moenkopi Wash during winter months when evapotranspiration is at a minimum is discharge from the N aquifer. The average discharge of low-flow measurements made during November through February in the 1986 and 1987 water years was 3.3 ft^3/s, which is equivalent to about 2,390 acre-ft/yr. The average of all measurements made during the same period from 1976 to 1987 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 1985 water year are shown on table 7. Mean daily discharges for previous water years have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1977-87).

Table 6.--Chemical analyses of selected springs, Black Mesa area, 1948-54 and 1982-87

Site name	Bureau of Indian Affairs field number	Identification number	Date of sample	Formation	Temperature (°C)	Specific conductance (µmhos)	pH (units)	Alkalinity (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)
Unnamed spring	8A-182	364026110105901	04-16-87	Morrison (Salt Wash)	9.0	605	8.1	143	2.50
Kydestea Spring	2A-55	361947110401801	04-21-87	Alluvium	10.0	2,400	7.8	226	.100
Moenkopi School Spring	3GS-77-6	360632111131101	05-16-52	Tongue of Navajo in Kayenta	----	222	---	92	-----
Do.	do.	do.	04-22-87	do.	16.0	270	7.4	101	1.70
Pasture Canyon	3A-5	361021111115901	02-27-48	Navajo	15.5	199	---	77	----
Do.	do.	do.	09-18-82	do.	19.0	240	7.6	98	5.2
Do.	do.	do.	05-19-86	do.	17.0	257	8.0	76	4.7
Pigeon Spring	4M-115	360559110190201	10-26-54	Wepo	16.0	287	---	121	-----
Do.	do.	do.	09-02-82	do.	20.0	350	7.2	---	.10
Do.	do.	do.	05-20-86	do.	13.0	320	7.6	130	<.100
Near Rough Rock	10R-158	362410109521201	07-28-49	Dakota	14.0	294	---	113	------
Do.	do.	do.	05-20-86	do.	8.5	266	7.9	93	.980

Table 6.--Chemical analyses of selected springs, Black Mesa area, 1948-54 and 1982-87--Continued

Site name	Bureau of Indian Affairs field number	Identification number	Date of sample	Formation	Phosphorus, otho, dissolved (mg/L as P)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
Unnamed spring	8A-182	364026110105901	04-16-87	Morrison (Salt Wash)	0.010	219	--	64
Kydestea Spring	2A-55	361947110401801	04-21-87	Alluvium	.010	1,200	--	250
Moenkopi School Spring	3GS-77-6	360632111131101	05-16-52	Tongue of Navajo in Kayenta	------	78	0	21
Do.	do.	do.	04-22-87	do.	.010	85	--	25
Pasture Canyon Spring	3A-5	361021111115901	02-27-48	Najavo	------	85	8	26
Do.	do.	do.	09-18-82	do.	.01	95	12	30
Do.	do.	do.	05-19-86	do.	.01	94	--	30
Pigeon Spring	4M-115	360559110190201	10-26-54	Wepo	------	109	0	28
Do.	do.	do.	09-02-82	do.	.01	130	0	38
Do.	do.	do.	05-20-86	do.	<.010	120	--	35
Near Rough Rock	10R-158	362410109521201	07-28-49	Dakota	------	136	23	40
Do.	do.	do.	05-20-86	do.	<.010	109	--	34

Table 6.--Chemical analyses of selected springs, Black Mesa area, 1948-52 and 1982-87--Continued

Site name	Bureau of Indian Affairs field number	Identification number	Date of sample	Formation	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium absorption ratio	Percent sodium
Unnamed spring	8A-182	364026110105901	04-16-87	Morrison (Salt Wash)	15	42	1	--
Kydestea Spring	2A-55	361947110401801	04-21-87	Alluvium	130	210	3	--
Moenkopi School Spring	3GS-77-6	360632111131101	05-16-52	Tongue of Navajo in Kayenta	6.1	-----	0.9	33
Do.	do.	do.	04-22-87	do.	5.5	22	1	--
Pasture Canyon Spring	3A-5	361021111115901	02-27-48	Navajo	4.9	-----	.6	23
Do.	do.	do.	09-18-82	do.	4.8	11	.5	20
Do.	do.	do.	05-19-86	do.	4.6	11	.5	--
Pigeon Spring	4M-115	360559110190201	10-26-54	Wepo	9.5	-----	.8	28
Do.	do.	do.	09-02-82	do.	9.7	17	.7	21
Do.	do.	do.	05-20-86	do.	7.9	15	.6	--
Near Rough Rock	10R-158	362410109521201	07-28-49	Dakota	8.8	-----	.4	13
Do.	do.	do.	05-20-86	do.	7.0	5.7	.2	--

Table 6.--Chemical analyses of selected springs, Black Mesa area, 1948-54 and 1982-87--Continued

Site name	Bureau of Indian Affairs field number	Identification number	Date of sample	Formation	Sodium+ Potassium, dissolved (mg/L as Na+K)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)
Unnamed spring	8A-182	364026110105901	04-16-87	Morrison (Salt Wash)	----	3.1	43
Kydestea Spring	2A-55	361947110401801	04-21-87	Alluvium	----	5.0	12
Moenkopi School Spring	3GS-77-6	360632111131101	05-16-52	Tongue of Navajo in Kayenta	17	---	6.0
Do.	do.	do.	04-22-87	do.	----	1.3	12
Pasture Canyon Spring	3A-5	361021111115901	02-27-48	Navajo	12	---	5.0
Do.	do.	do.	09-18-82	do.	----	1.2	5.1
Do.	do.	do.	05-19-86	do.	----	1.3	5.4
Pigeon Spring	4M-115	360559110190201	10-26-54	Wepo	20	---	12
Do.	do.	do.	09-02-82	do.	----	2.4	9.7
Do.	do.	do.	05-20-86	do.	----	1.8	9.3
Near Rough Rock	10R-158	362410109521201	07-28-49	Dakota	9.4	---	7.0
Do.	do.	do.	05-20-86	do.	----	1.8	5.8

Table 6.--Chemical analyses of selected springs, Black Mesa area, 1948-54 and 1982-87--Continued

Site name	Bureau of Indian Affairs field number	Identification number	Date of sample	Formation	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
Unnamed spring	8A-182	364026110105901	04-16-87	Morrison (Salt Wash)	109	0.60	7.2
Kydestea Spring	2A-55	361947110401801	04-21-87	Alluvium	1,400	.50	11
Moenkopi School Spring	3GS-77-6	360632111131101	05-16-52	Tongue of Navajo in Kayenta	-----	----	----
Do.	do.	do.	04-22-87	do.	19	.20	13
Pasture Canyon Spring	3A-5	361021111115901	02-27-48	Navajo	13	.2	----
Do.	do.	do.	09-18-82	do.	18	.2	9.7
Do.	do.	do.	05-19-86	do.	19	.2	9.8
Pigeon Spring	4M-115	360559110190201	10-26-54	Wepo	11	.4	23
Do.	do.	do.	09-02-82	do.	17	.4	15
Do.	do.	do.	05-20-86	do.	14	.30	14
Near Rough Rock	10R-158	362410109521201	07-28-49	Dakota	28	.6	----
Do.	do.	do.	05-20-86	do.	28	.30	7.8

Table 6.--Chemical analyses of selected springs, Black Mesa area, 1948-54 and 1982-87--Continued

Site name	Bureau of Indian Affairs field number	Identification number	Date of sample	Formation	Boron, dissolved (µg/L as B)	Iron, dissolved (µg/L as Fe)	Dissolved solids: Residue at 180°C mg/L)	Dissolved solids: Sum of Constituents (mg/L)
Unnamed spring	8A-182	364026110105901	04-16-87	Morrison (Salt Wash)	60	17	383	---
Kydestea Spring	2A-55	361947110401801	04-21-87	Alluvium	80	20	2,280	---
Moenkopi School Spring	3GS-77-6	360632111131101	05-16-52	Tongue of Navajo in Kayenta	---	--	-----	---
Do.	do.	do.	04-22-87	do.	40	5	161	---
Pasture Canyon Spring	3A-5	361021111115901	02-27-48	Navajo	---	--	123	---
Do.	do.	do.	09-18-83	do.	30	3	-----	153
Do.	do.	do.	05-19-86	do.	30	5	-----	---
Pigeon Spring	4M-115	360559110190201	10-26-54	Wepo	---	--	279	---
Do.	do.	do.	09-02-82	do.	140	3	-----	200
Do.	do.	do.	05-20-86	do.	20	16	-----	---
Near Rough Rock	10R-158	362410109521201	07-28-49	Dakota	---	--	165	---
Do.	do.	do.	05-20-86	do.	30	12	-----	---

Table 7.--Discharge data, Moenkopi Wash at Moenkopi, 1985 water year

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.0	3.5	2.7	2.0	4.0	3.0	1.5	2.0	.24	.00	.00	.00
2	2.0	3.1	2.7	2.0	4.0	3.0	1.5	1.5	.14	.00	95	.00
3	2.0	2.7	2.3	2.0	7.4	3.0	1.8	1.5	.00	.00	5.2	.00
4	14	2.3	2.7	1.5	6.4	3.0	2.0	1.5	.20	.00	.45	.00
5	6.4	1.3	2.0	1.5	7.4	2.7	2.3	1.5	.28	.00	.10	.00
6	4.0	1.1	2.7	1.5	6.0	3.0	2.3	1.5	.28	.00	.00	.00
7	4.0	2.0	2.7	1.5	6.0	2.0	2.3	2.0	.20	.00	.00	.00
8	2.0	1.6	2.5	1.5	6.0	2.0	1.3	2.0	.10	.00	.00	.00
9	2.0	1.6	2.5	1.5	6.0	2.0	2.0	2.0	.00	.00	.00	.00
10	6.0	2.3	2.5	1.5	6.0	2.0	1.6	2.0	.00	.00	.00	.00
11	6.4	3.1	2.5	2.5	6.0	4.0	1.6	2.0	.00	.00	.00	41
12	8.0	2.0	2.5	2.5	6.0	4.0	1.6	2.0	.00	.00	.00	143
13	61	2.0	2.5	2.5	6.0	4.0	1.6	2.0	.00	.00	.00	50
14	12	2.3	2.5	2.5	5.0	3.0	1.1	1.5	.00	.00	.00	10
15	6.4	2.0	2.5	2.5	5.0	62	1.0	1.0	.00	.00	.00	2.0
16	4.8	2.0	2.5	2.5	6.0	68	1.0	.40	.00	.00	.00	2.0
17	4.8	2.0	2.5	2.5	6.0	41	1.3	.36	.00	.00	.00	2.0
18	4.0	2.0	2.5	2.5	5.0	14	4.0	.40	.00	.00	.00	2.0
19	4.0	3.5	2.5	3.0	5.0	16	6.4	.45	.00	.00	.00	15
20	4.0	3.1	2.5	4.4	4.0	16	4.0	.45	.00	.00	.00	4.0
21	3.0	2.7	2.5	4.0	4.0	14	8.0	.45	.00	.00	.00	2.0
22	3.0	2.7	2.5	3.1	3.0	14	7.4	.52	.00	.00	.00	2.0
23	3.0	2.7	2.5	5.2	3.0	9.6	4.8	.60	.00	2.2	.00	2.0
24	2.0	2.7	2.5	5.2	3.0	2.0	3.5	.60	.00	7.4	.00	1.5
25	2.0	3.1	2.5	4.4	3.0	2.0	2.3	.60	.00	.40	.00	1.5
26	2.0	4.0	2.5	4.4	3.0	1.5	2.7	.52	.00	.12	.00	1.5
27	2.0	2.7	2.5	4.4	3.0	1.5	2.5	.40	.00	.12	.00	1.5
28	2.0	3.5	2.5	5.2	3.0	1.5	2.0	.32	.00	.10	.00	1.5
29	2.0	4.0	2.5	4.4	---	1.5	2.0	.20	.00	.10	.00	1.5
30	2.7	3.1	2.5	6.0	---	1.5	2.0	.00	.00	.10	.00	1.5
31	3.1	---	2.5	12	---	1.5	---	.00	---	.00	.00	---
TOTAL	187.6	76.7	77.8	102.2	138.2	308.3	79.4	32.27	1.44	10.54	100.75	287.50
MEAN	6.05	2.56	2.51	3.30	4.94	9.95	2.65	1.04	.048	.34	3.25	9.58
MAX	61	4.0	2.7	12	7.4	68	8.0	2.0	.28	7.4	95	143
MIN	2.0	1.1	2.0	1.5	3.0	1.5	1.0	.00	.00	.00	.00	.00
AC-FT	372	152	154	203	274	612	157	64	2.9	21	200	570

CAL YR 1984 TOTAL 6512.06 MEAN 17.8 MAX 1880 MIN .00 AC-FT 12920
WTR YR 1985 TOTAL 1402.70 MEAN 3.84 MAX 143 MIN .00 AC-FT 2780

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 1986 and 1987 water years was 5.8 ft^3/s, which is about 4,200 acre-ft/yr. The average discharge of low-flow measurements for the same months during water years 1977 to 1987, excluding water year 1984, was 6.7 ft^3/s, which is about 4,860 acre-ft/yr. Low-flow measurements made during the winter months of the 1984 water year were not averaged because the measurements, which were made intermittently, did not represent discharge in the base-flow range. The mean daily discharges for the 1985 water year are shown in table 8. All previous mean daily discharges have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1964-87).

The average discharge of 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. Measurements made during the winter months of the 1985 water year were not averaged because low-flow measurements did not represent the base flow of Laguna Creek. Continuous streamflow data are not collected at this station.

Chemical Quality of Surface Water

In 1987, a water sample from Laguna Creek was analyzed for major ions and fluoride. The sample was taken at streamflow-gaging station 09379160 (fig. 2). The chemical analysis is shown in table 9.

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Table 8.--Discharge data, Chinle Creek near Mexican Water, 1985 water year

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5.0	17	10	15	3.0	130	36	536	8.0	.00	14	.00
2	5.0	15	10	10	2.0	160	32	345	6.0	.00	4.8	.00
3	10	14	10	7.0	2.0	135	38	349	5.0	.00	43	.00
4	50	14	10	5.0	1.0	100	147	260	4.0	.00	233	.00
5	900	14	10	5.0	2.0	68	155	222	3.0	.00	36	.00
6	400	13	9.0	5.0	3.0	39	193	188	2.0	.00	12	.00
7	170	13	9.5	5.0	3.0	26	219	164	1.0	.00	6.2	.00
8	50	13	3.1	10	3.0	26	324	127	.40	.00	2.5	.00
9	20	12	3.1	15	3.0	34	417	106	.10	.00	32	.00
10	10	12	12	15	10	30	437	104	.00	.00	54	.00
11	5.0	14	22	10	100	50	546	106	.00	.00	16	5.0
12	5.0	15	6.9	10	85	648	532	87	.00	.00	7.8	150
13	250	16	7.2	10	51	954	546	91	.00	.00	3.4	70
14	100	22	14	7.0	65	1100	470	89	.00	.00	.87	25
15	50	39	15	7.0	58	500	421	74	.00	.00	.46	10
16	40	33	15	5.0	60	150	363	56	.00	.00	.38	2.0
17	30	33	15	5.0	60	70	304	28	.00	.00	.30	1.0
18	20	25	12	5.0	52	30	294	30	.00	.00	.10	5.0
19	20	28	12	5.0	80	10	335	28	.00	.00	.00	85
20	60	25	20	5.0	206	10	275	32	.00	.00	.00	60
21	100	25	20	5.0	239	10	217	41	.00	51	.00	20
22	130	20	15	5.0	217	7.0	276	45	.00	159	.00	8.0
23	115	20	10	20	146	7.0	502	26	.00	39	.00	4.0
24	95	20	10	150	95	7.0	317	20	.00	20	.30	3.0
25	60	15	10	60	74	5.0	309	15	.00	11	.40	2.2
26	50	15	10	80	51	4.0	382	41	.00	9.0	.10	2.2
27	30	15	30	100	55	2.2	390	35	.00	5.0	.00	1.5
28	25	15	100	50	89	2.2	278	20	.00	1.1	.00	1.1
29	20	10	150	20	---	5.3	1030	15	.00	1.0	.00	1.1
30	14	10	80	10	---	6.2	2280	12	.00	21	.00	.90
31	17	---	30	5.0	---	76	---	10	---	19	.00	---
TOTAL	2856.0	552	690.8	666.0	1815.0	4401.9	12065	3302	29.50	336.10	467.61	457.00
MEAN	92.1	18.4	22.3	21.5	64.8	142	402	107	.98	10.8	15.1	15.2
MAX	900	39	150	150	239	1100	2280	536	8.0	159	233	150
MIN	5.0	10	3.1	5.0	1.0	2.2	32	10	.00	.00	.00	.00
AC-FT	5660	1090	1370	1320	3600	8730	23930	6550	59	667	928	906

CAL YR 1984 TOTAL 24420.08 MEAN 66.7 MAX 1640 MIN .00 AC-FT 48440
WTR YR 1985 TOTAL 27638.86 MEAN 75.7 MAX 2280 MIN .00 AC-FT 54820

Table 9.--Chemical analysis of water from Laguna Creek near Church Rock (09379160), April 17, 1987

[Values are in milligrams per liter except as indicated]

Constituent	Value
Temperature (degrees Celsius)	23.5
Specific conductance (microsiemens)	720
pH (units)	9.4
Alkalinity (as $CaCO_3$)	95
Bicarbonate (HCO_3)	66
Carbonate (CO_3)	26
Nitrogen (NO_2+NO_3 as N)	.101
Phosphorus (orthophosphate as P)	.571
Calcium (Ca)	48
Magnesium (Mg)	22
Sodium (Na)	72
Potassium (K)	3.7
Chloride (Cl)	22
Sulfate (SO_4)	250
Fluoride (F)	.30
Silica (SiO_2)	5.3
Boron (B) (micrograms per liter)	120
Iron (Fe) (micrograms per liter)	14
Dissolved solids	
Residue at 180 degrees Celsius	485
Sum of constituents	510

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