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GEOLOGICAL SURVEY

PROGRESS REPORT ON BLACK MESA MONITORING PROGRAM—1984

By George W. Hill

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and the U.S. BUREAU OF INDIAN AFFAIRS

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CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain SI unit
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

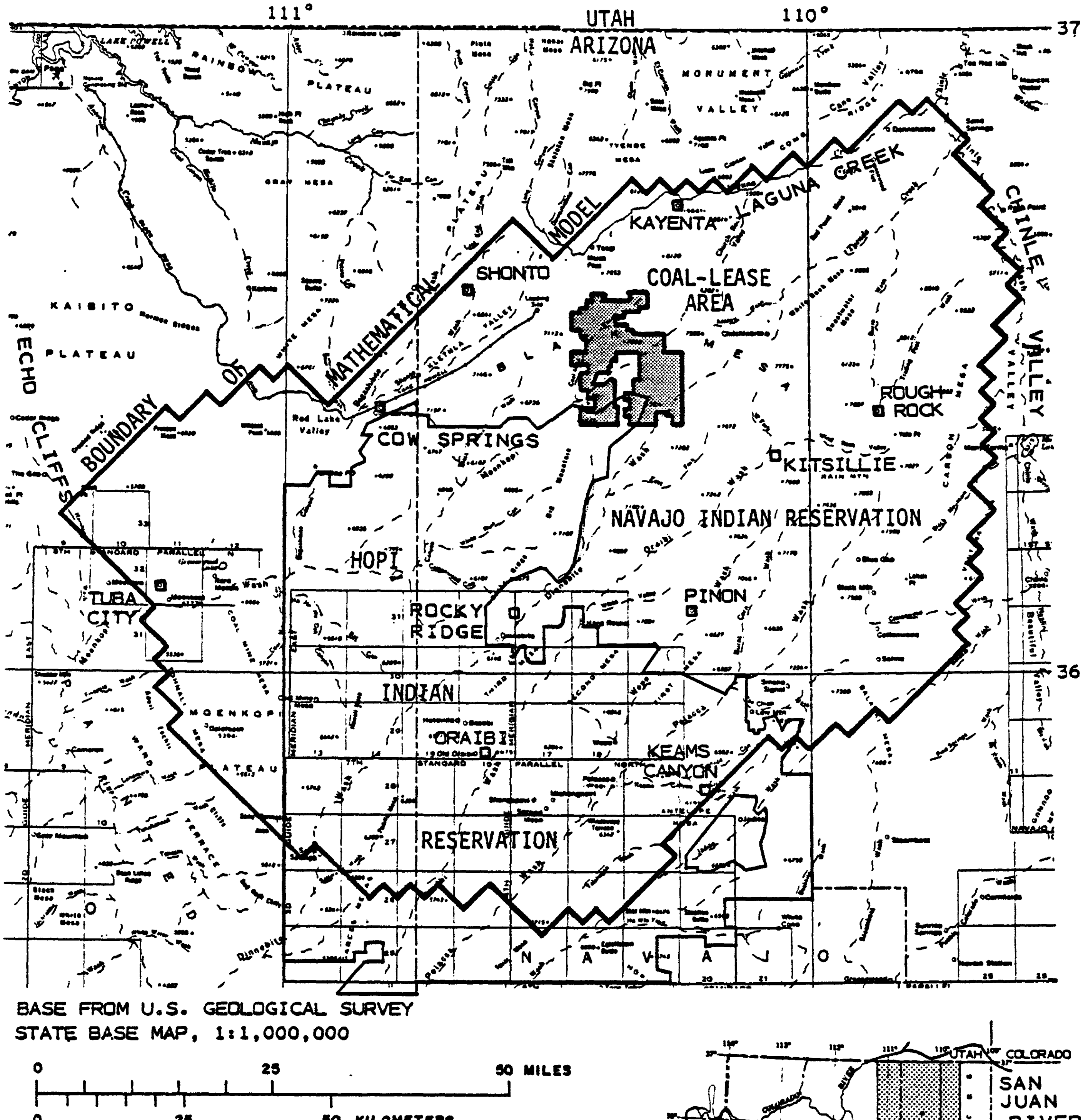
The N aquifer is an important source of water in the 5,400 square-mile Black Mesa area on the Navajo and Hopi Indian Reservations. The project is designed to monitor long-term effects on the ground-water resources of the mesa as a result of withdrawals from the aquifer by the strip-mining operation of Peabody Coal Co. Withdrawals from the N aquifer by the mine have increased from 95 acre-ft in 1968 to more than 4,000 acre-ft in 1984.

Water levels in the confined area of the aquifer have declined as much as 75 feet 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 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. Withdrawals from the N aquifer for municipal use increased from an estimated 70 acre-ft in 1965 to about 2,500 acre-ft in 1984. 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.

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.



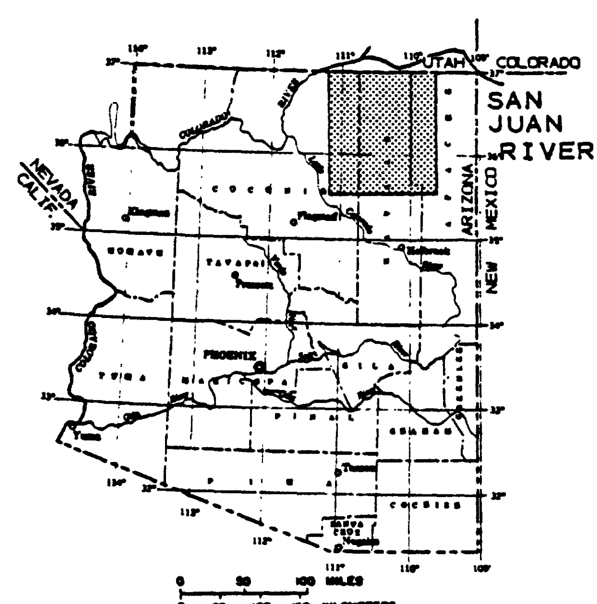


Figure 1.--Area of report.

Purpose and Scope of the Report

The report covers the progress of the Black Mesa Monitoring Program from October 1, 1983, to September 30, 1984, 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 Project

Three 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, U.S. Geological Survey, written commun., 1982, 1983). 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, 1976-84). 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, 1984

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.

Ground-Water Levels

Ground-water levels continue to decline in wells that penetrate the confined area of the N aquifer. Observation wells in the unconfined area of the N aquifer indicate no decline in water levels. The net change of water levels in selected wells in the N aquifer within the Black Mesa area since prestress times, which is prior to 1965, is shown in figure 3.

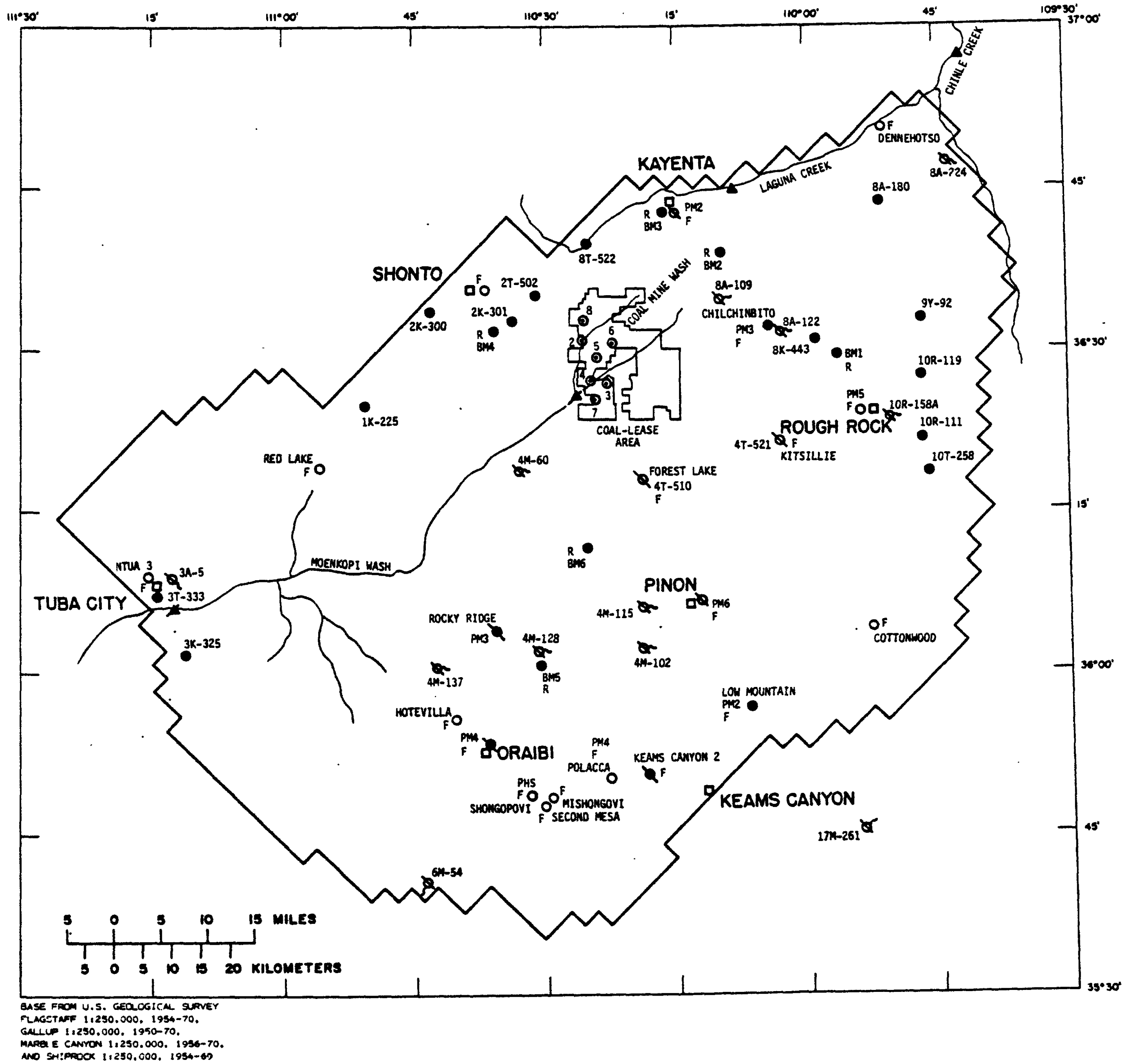


Figure 2.--Data-collection sites, 1984.

E X P L A N A T I O N

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

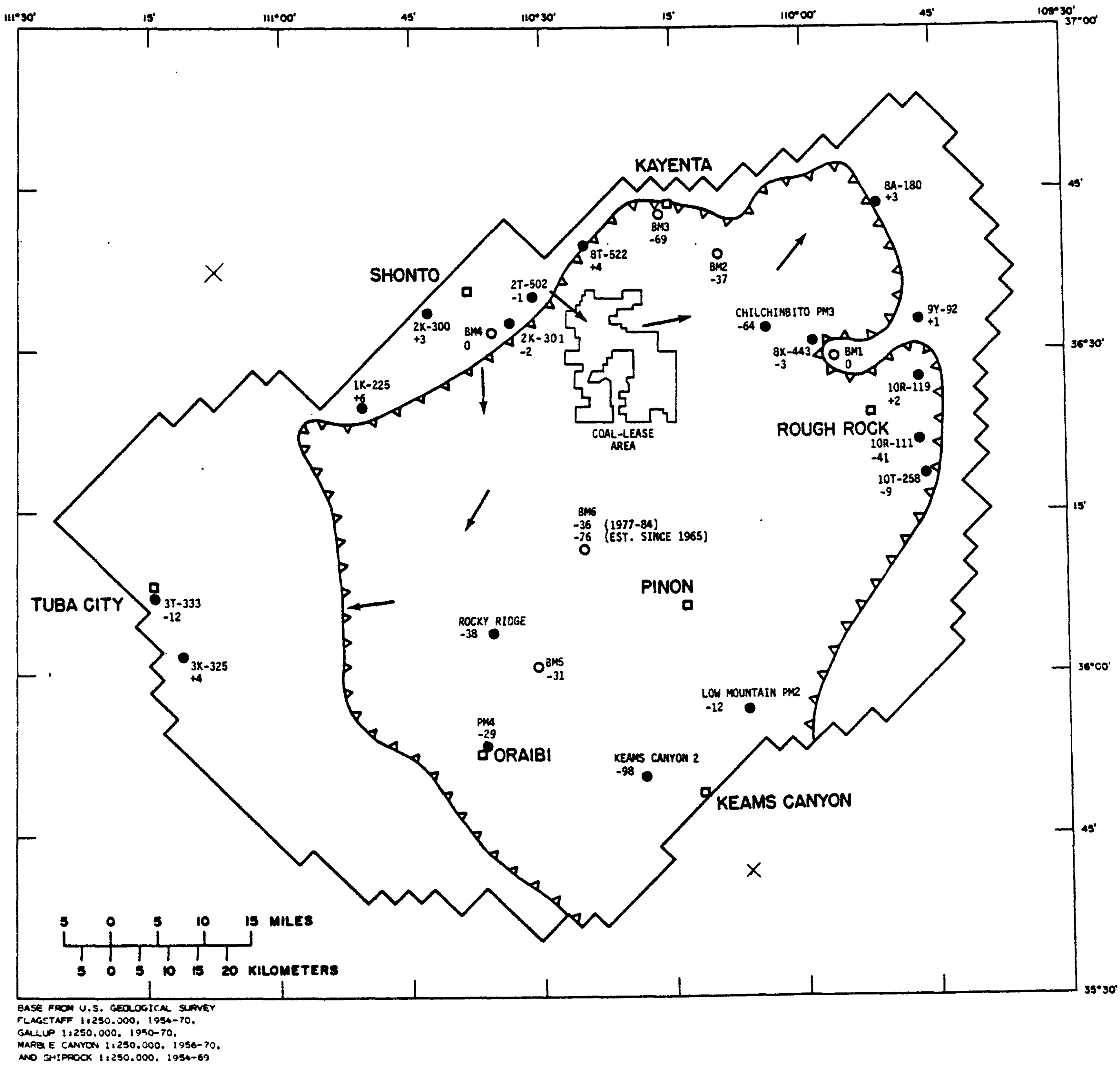


Figure 3.--Water-level changes in wells that tap the N aquifer, 1953-84.

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

The three largest measured water-level declines in municipal wells outside the coal-lease area are at Kayenta, Keams Canyon, and Chilchinbito (fig. 3). Wells in or near these communities are pumped for public supply, and the water levels may be affected by local pumping as well as by industrial withdrawals.

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 1959-84 is shown in figure 4.

Withdrawals from the N Aquifer

The three categories of 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.

A concerted effort has been continued by the U.S. Geological Survey to inventory withdrawals from nonindustrial supply wells that penetrate the N aquifer and to determine where additional flowmeters are needed. Thirty distribution systems, which included about 55 nonindustrial wells, serve the Hopi and Navajo Tribes in the project area. Most of the wells have meters, but function and accuracy of meters have not been checked. Communities that have metered wells are identified by a representative well in figure 2. Annual pumpage for the three categories of withdrawals from the N aquifer for 1965-84 is given in table 1. Withdrawals for the 1984 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 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).

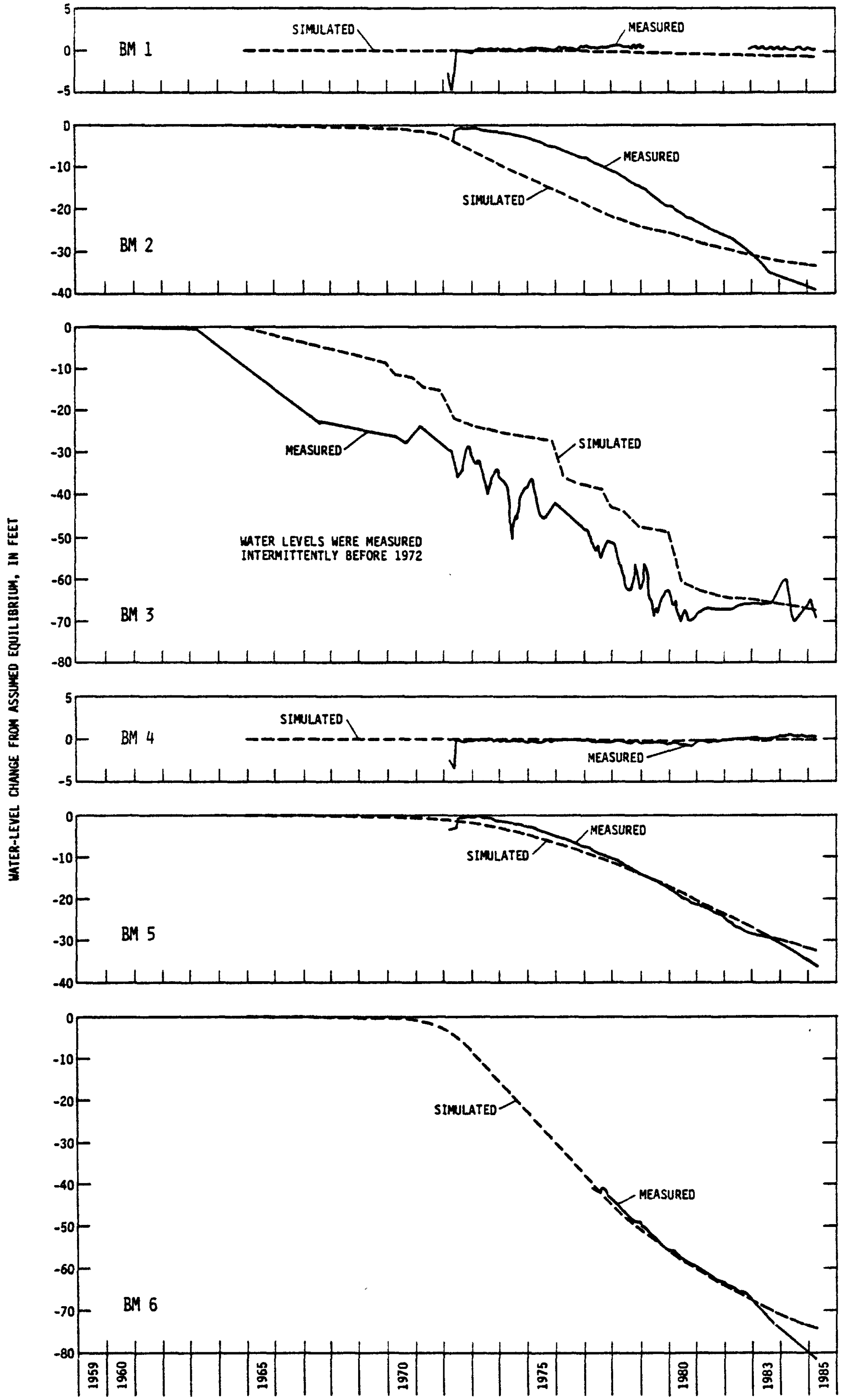


Figure 4.--Measured and simulated water-level changes for observation wells, 1959-84

Table 1.--Withdrawals from the N aquifer, 1965-84
[Measurements are in acre-feet. Data for 1965-79 from Eychaner, 1983]

Year	Industrial[1]	Nonindustrial[2] year	
		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

[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, 1980-84.

[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, 1980-84.

Table 2.--Withdrawals from the N aquifer, Black Mesa area, in acre-feet, 1984

Locations	Confined	Unconfined
Bureau of Indian Affairs[1]		
Tuba City[2]		316
Chilchinbeto[2]	13.2	
Dinnehotso[2]		38.6
Kayenta[2]	75.8	
Red Lake[2]		27.7
Rocky Ridge[2]	19.7	
Shonto		140
Cottonwood		13.2
Low Mountain	11.6	
Pinon	123	
Rough Rock	40.5	
Hotevilla	25.6	
Second Mesa	8.9	
Navajo Tribal Utility Authority[1]		
Kayenta	451	
Chilchinbeto	27.9	
Dinnehotso		29.7
Shonto		16.1
Forest Lake	2.3	
Shonto Junction		3.2
Tuba City		780
Red Lake		20.4
Rough Rock	9.1	
Cottonwood		11.0
Pinon	68.1	
Kitsillie	3.3	
Peabody Coal Company[1]		
Mine well field	4,174	
U.S. Geological Survey[1]		
Keams Canyon	45.1	
Polacca[3]	85	
Oraibi	48.7	
Shungopovi[3]	12.0	
Shipaulovi-Mishongovi	2.1	

[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.

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). Concentrations of dissolved solids, sulfate ions, or chloride ions did not increase in Peabody Wells 2 through 7 from 1967 to 1980 or in Peabody Well 8 for 1980-84 (table 3). Chemical analyses of water from all Peabody wells will be done in 1986.

The same wells sampled in 1983 were sampled in 1984 for major ions and fluoride. The wells were Peabody Well 8, Keams Canyon 2, New Oraibi PM 3, Kayenta PM 2, Kitsillie, Pinon PM 6, and Rough Rock PM 5 (fig. 2, table 4). Wells sampled in 1982 were Peabody Well 8, Keams Canyon 2, Rocky Ridge PM 3, New Oraibi PM 4, Kayenta PM 2, Forest Lake, Kitsillie, and Pinon PM 6 (G. W. Hill, written commun., 1982). Selected parameters from chemical analyses of water from all nonindustrial wells sampled in 1982-84 are shown in table 5. Of the nonindustrial wells sampled since 1983, Kayenta PM 2 is nearest the Peabody Coal Co. well field and no significant changes have occurred in specific conductance, dissolved solids, dissolved chloride ions, and dissolved sulfate ions. The same is true of all other nonindustrial wells sampled since 1982.

The marked difference noted between the chemical composition of water from the Rough Rock PM 5 and Keams Canyon 2 wells and that of the other nonindustrial wells sampled in 1982-84 still exists (table 5). Comparison of chemical analyses of samples taken from Rough Rock PM 5 in 1964 and Keams Canyon 2 in 1972 and those taken in 1984 indicate no significant change in chemical composition. In 1964, water from Rough Rock PM 5 had a specific conductance of 1,120 micromhos compared to 1,090 micromhos in 1984, dissolved solids (sum of constituents) of 638 mg/L (milligrams per liter) compared to 613 mg/L in 1984, and dissolved chloride of 100 mg/L compared to 130 mg/L in 1984. Analysis of water from Keams Canyon 2 in 1972 showed specific conductance of 937 micromhos compared to 1,040 micromhos in 1984, dissolved solids of 597 mg/L compared to 578 mg/L in 1984, and dissolved chloride of 91 mg/L compared to 96 mg/L in 1984.

As discussed by G. W. Hill (written commun., 1983), one possibility for the differences in chemical composition between Rough Rock PM5 and Keams Canyon 2 and other nonindustrial wells is that Rough Rock PM 5 and Keams Canyon 2 are finished below the Navajo Sandstone and the other wells are finished in the Navajo Sandstone. Well construction and withdrawal stress also may affect the chemical composition.

Discharge and Chemical Quality of Springs

The effect of withdrawals from the N aquifer on the quality of spring water 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

Table 3.--Selected parameters from chemical analysis of water from wells of the Peabody Coal Co., Black Mesa area, 1967-74 and 1980-84

Well number	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)
2	1967	221	144[1]	5.0	21
	1980	225	144	11	20
3	1968	236	154[1]	4.0	17
	1980	230	151	3.5	14
4	1974	200	140	3.8	13
	1980	230	139	4.3	13
5	1968	224	149[1]	3.5	16
	1980	210	134	2.9	9.5
6	1968	201	333[1]	3.0	13
	1980	260	160	3.5	15
7	1972	222	141[1]	2.5	20
	1980	210	136	3.7	11
8	1980	420	283	4.8	100
	1983	440	278	4.8	100
	1984	436	264	4.7	100

[1]Dissolved-solids data from 1974.

Table 4.--Chemical analyses of selected industrial and nonindustrial wells, Black Mesa area, 1984

Site name	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 8	363130110254501	08-16-84	29.5	445	8.8	104	1.5
Keams Canyon 2	355023110182701	08-13-84	19.0	1,060	9.3	336	<.10
Rough Rock PM 5	362418109514601	08-15-84	21.0	1,100	9.0	210	1.1
New Oraibi PM 3	355236110364501	08-14-84	21.0	385	9.9	174	1.2
Kayenta PM 2	364347110145901	08-16-84	16.0	370	8.0	122	.79
Kitsillie	362035110032201	08-15-84	26.5	460	9.9	204	1.2
Pinon PM 6	360614110130801	08-14-84	27.0	490	10.0	220	1.4

Site name	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 8	363130110254501	08-16-84	<0.01	24	3.2	63
Keams Canyon 2	355023110182701	08-13-84	<.01	.90	.20	240
Rough Rock PM 5	362418109514601	08-15-84	<.01	2.1	.29	230
New Oraibi PM 3	355236110364501	08-14-84	.03	.43	.02	86
Kayenta PM 2	364347110145901	08-16-84	<.01	39	8.0	28
Kitsillie	362035110032201	08-15-84	<.01	1.9	.60	100
Pinon PM 6	360614110130801	08-14-84	<.01	.50	.01	110

Table 4.--Chemical analyses of selected industrial and nonindustrial wells, Black Mesa area, 1984--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 8	363130110254501	08-16-84	2.4	4.7	100	.01
Keams Canyon 2	355023110182701	08-13-84	.70	96	36	1.3
Rough Rock PM 5	362418109514601	08-15-84	1.3	130	99	1.7
New Oraibi PM 4	355236110364501	08-14-84	.40	4.0	9.9	.20
Kayenta PM 2	364347110145901	08-16-84	1.3	4.2	51	.20
Kitsillie	362035110032201	08-15-84	.90	5.2	20	.20
Pinon PM 6	360614110130801	08-14-84	.40	3.7	5.4	.20

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)	Dissolved solids
						Sum of constituents (mg/L)
Peabody Well 8	363130110254501	08-16-84	19	60	11	264
Keams Canyon 2	355023110182701	08-13-84	12	680	8	578
Rough Rock PM 5	362418109514601	08-15-84	12	430	20	613
New Oraibi PM 4	355236110364501	08-14-84	22	50	11	216
Kayenta PM 2	364347110145901	08-16-84	16	50	6	209
Kitsillie	362035110032201	08-15-84	21	70	14	258
Pinon PM 6	360614110130801	08-14-84	26	60	6	273

Table 5.--Selected parameters from chemical analysis of water from nonindustrial wells that tap the N aquifer, Black Mesa area, 1982-84

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 Canyon 2	1982	1,010	592	94	35
	1983	1,120	636	120	42
	1984	1,040	578	96	36
Rough Rock PM 5	1983	1,090	628	130	110
	1984	1,090	613	130	99
Rocky Ridge PM 3	1982	255	---	1.4	6.0
New Oraibi PM 4	1982	385	228	4.0	10
New Oraibi PM 3	1983	400	235	4.1	9.8
	1984	395	216	4.0	9.9
Kayenta PM 2	1982	360	228	4.5	58
	1983	375	230	-----	60
	1984	365	209	4.2	51
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 PM 6	1982	485	---	3.7	5.0
	1983	505	293	3.6	5.3
	1984	495	273	3.7	5.4

units are exposed. Discharge from springs sampled in 1984 are as follows:

Spring	Discharge, in gallons per minute
Near Steamboat	seeping (discharge unobtainable)
Nasjo Toh	1.0 (estimate)
Shonto	.67
Near Dinnehotso	2.0

In 1982-84, water-quality samples were analyzed for 12 springs representing the Navajo Sandstone, Morrison Formation, Dakota Sandstone, Toreva and Wepo Formations, and alluvium[1] (fig. 2). Nine of the springs were sampled from 1948 to 1954 (Kister and Hatchett, 1963). Chemical analyses of four selected springs in the Black Mesa area for 1949, 1952, and 1984 are shown in table 6. Chemical analyses of eight selected springs sampled in 1982 have been presented (G. W. Hill, written commun., 1982, 1983). Selected parameters from chemical analyses from all springs sampled in 1948-54 and 1982-84 are shown in table 7. In general, these data indicate that no significant changes in specific conductance, chloride, and sulfate have occurred since 1948-54. In most cases, the analyses show decreases in these constituents. The changes indicated are not considered major and could be due, in part, to differences between analytical procedures in 1948-54 and 1984.

Surface-Water Data

The continuous-record streamflow stations on Moenkopi Wash at Moenkopi and Chinle Wash near Mexican Water 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 of base-flow discharge measurements made during November-February in the 1984 water year was 3.0 ft^3/s, which is equivalent to about 2,170 acre-ft/yr. The average of all base-flow discharge measurements during November-February from 1976 to 1984 was 3.2 ft^3/s, which is equivalent to about 2,320 acre-ft/yr. Mean daily discharges during the 1983 water year are shown in table 8. Data for previous water years have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1976-84).

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

Table 6.--Chemical analysis of selected springs, Black Mesa area, 1949, 1952, and 1984

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)
Near Steamboat	17M-261	354523109504300	07-10-49	Dakota	18.0	222	---	---	----
Do.	Do.	Do.	06-26-84	Do.	18.0	280	7.6	112	.47
Nasjo Toh	8A-109	363504110093701	08-15-84	Dakota	----	480	8.4	134	.68
Shonto	6M-54	354032110443900	07-09-52	Navajo	22.0	1,080	---	---	----
Do.	Do.	Do.	06-26-84	Do.	20.5	990	7.3	133	3.8
Near Dinnehotso	8A-224	364656109425400	06-27-84	Navajo	18.0	195	8.1	51	1.6

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)
Near Steamboat	17M-261	354523109504300	07-10-49	Dakota	----	112	14	34
Do.	Do.	Do.	06-26-84	Do.	.03	---	--	44
Nasjo Toh	8A-109	363504110093701	08-15-84	Dakota	<.01	---	--	49
Shonto	6M-54	354032110443900	07-09-52	Navajo	----	328	192	105
Do.	Do.	Do.	06-26-84	Do.	.02	---	---	94
Near Dinnehotso	8A-224	364656109425400	06-27-84	Navajo	.03	---	---	27

Table 6.--Chemical analysis of selected springs, Black Mesa area, 1949, 1952, and 1984--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
Near Steamboat	17M-261	354523109504300	07-10-49	Dakota	6.7	----	3	.1
Do.	Do.	Do.	06-26-84	Do.	5.2	5.9	---	--
Nasjo Toh	8A-109	363504110093701	08-15-84	Dakota	24	13	---	--
Shonto	6M-54	354032110443900	07-09-52	Navajo	16	----	2.6	42
Do.	Do.	Do.	06-26-84	Do.	13	100	---	--
Near Dinnehotso	8A-224	364656109425400	06-27-84	Navajo	3.9	4.8	---	--

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)
Near Steamboat	17M-261	354523109504300	07-10-49	Dakota	1.8	---	3.0
Do.	Do.	Do.	06-26-84	Do.	---	1.3	4.0
Nasjo Toh	8A-109	363504110093701	08-15-84	Dakota	---	2.3	10
Shonto	6M-54	354032110443900	07-09-52	Navajo	109	---	82
Do.	Do.	Do.	06-26-84	Do.	---	1.8	64
Near Dinnehotso	8A-224	364656109425400	06-27-84	Navajo	---	1.1	2.8

Table 6.--Chemical analysis of selected springs, Black Mesa area, 1949, 1952, and 1984--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)
Near Steamboat	17M-261	354523109504300	07-10-49	Dakota	11	.4	18
Do.	Do.	Do.	06-26-84	Do.	15	.3	15
Nasjo Toh	8A-109	363504110093701	08-15-84	Dakota	100	.6	11
Shonto	6M-54	354032110443900	07-09-52	Navajo	281	.5	17
Do.	Do.	Do.	06-26-84	Do.	260	.6	15
Near Dinnehotso	8A-224	364656109425400	06-27-84	Navajo	7.1	.3	13

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)	Sum of constituents (mg/L)
Near Steamboat	17M-261	354523109504300	07-10-49	Dakota	---	--	136	---
Do.	Do.	Do.	06-26-84	Do.	20	6	159	161
Nasjo Toh	8A-109	363504110093701	08-15-84	Dakota	60	4	276	280
Shonto	6M-54	354032110443900	07-09-52	Navajo	---	--	716	---
Do.	Do.	Do.	06-26-84	Do.	120	20	643	649
Near Dinnehotso	8A-224	364656109425400	06-27-84	Navajo	20	5	112	112

Table 7.--Selected parameters from chemical analyses of water sampled from springs in the Black Mesa area, 1948-54 and 1982-84

Spring name	Bureau of Indian Affairs number	Date sampled	Formation	Specific conductance (umhos)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Pasture Canyon	3A-5	02-27-48	Navajo SS	199	5.0	13
Do.	Do.	09-18-82	Do.	240	5.1	18
Pigeon	4M-115	10-26-54	Wepo	287	12	11
Do.	Do.	09-02-82	Do.	350	9.7	17
Hard Rocks	4M-128	08-01-52	Toreva	541	32	91
Do.	Do.	06-10-82	Do.	525	37	110
Crooked Finger	4M-102	09-01-82	Wepo	305	9.7	26
Chilchinbito	8A-122	06-12-54	Morrison	2,750	30	1,520
Do.	Do.	07-20-83	Do.	1,980	31	990
Red Willow	4M-60	10-28-54	Toreva	530	21	126
Do.	Do.	08-17-83	Do.	580	19	140
Cottonwood	4M-137	10-28-54	Alluvium	560	10	62
Do.	Do.	08-23-83	Do.	550	7.1	60
Near Rough Rock	10R-158A	07-28-49	Dakota	362	27	39
Do.	Do.	07-20-83	Do.	290	6.0	25
Near Steamboat	17M-261	07-10-49	Dakota	222	3.0	11
Do.	Do.	06-26-84	Do.	280	4.0	15
Nasjo Toh	8A-109	08-15-84	Dakota	470	10	100
Shonto	6M-54	07-09-52	Navajo	1,080	82	281
Do.	Do.	06-26-84	Do.	989	64	260
Near Dinnehotso	8A-224	06-27-84	Navajo	187	2.8	7.1

Table 8.--Discharge data, Moenkopi Wash at Moenkopi, 1983 water year

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1982 TO SEPTEMBER 1983
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	7.0	3.5	4.8	3.0	3.0	3.5	1.1	1.6	.10	.00	70	.00
2	6.0	3.1	4.4	3.0	3.0	3.5	.95	1.6	.10	.00	50	.00
3	6.0	2.3	1.6	3.0	3.0	3.5	.95	1.6	.00	.00	20	.00
4	5.0	2.3	2.3	3.0	3.0	3.5	.80	1.1	.00	.00	250	.00
5	5.0	3.5	1.6	3.0	3.0	6.4	.95	.95	.00	.00	50	.00
6	5.0	4.0	1.6	3.0	3.0	5.6	1.1	.95	.00	.00	80	.00
7	4.0	4.0	2.0	3.0	3.0	3.5	2.0	1.3	.00	.00	100	.00
8	4.0	4.4	2.0	3.0	3.0	3.1	2.0	1.6	.00	.00	160	.00
9	4.0	4.8	1.6	3.0	3.0	1.6	1.3	1.1	.00	.00	100	.00
10	3.0	5.2	3.1	3.0	3.0	1.1	.80	1.3	.00	.00	50	.00
11	3.0	5.2	2.3	3.0	3.0	1.1	.95	1.6	.00	.00	20	.00
12	3.0	4.8	2.0	3.0	3.0	1.1	.95	2.3	.00	.00	400	.00
13	2.0	4.4	2.0	3.0	3.0	1.1	.95	2.0	.00	.00	50	.00
14	2.0	4.0	1.6	3.0	3.0	1.3	2.0	1.3	.00	.00	20	.00
15	2.0	4.0	1.6	3.0	3.0	2.7	2.0	1.1	.00	.00	7.0	.00
16	2.0	4.0	1.6	3.0	3.0	2.3	1.6	1.1	.00	.00	2.0	.00
17	2.0	4.4	2.7	3.0	3.0	1.3	1.3	2.0	.00	.00	.00	.00
18	2.0	4.8	2.7	3.0	3.0	2.3	1.1	1.3	.00	.00	.00	.00
19	2.3	4.4	2.0	3.0	3.0	2.7	1.3	1.1	.00	.00	20	.00
20	2.3	4.4	2.0	3.0	3.0	2.3	1.3	1.3	.00	.00	5.0	.00
21	2.3	4.0	2.0	3.0	3.0	2.3	1.6	1.3	.00	.00	.00	.00
22	2.3	4.0	2.0	3.0	3.0	3.1	2.7	.80	.00	.00	.00	.00
23	2.3	3.1	2.0	3.0	3.5	3.5	2.3	.80	.00	.00	.00	50
24	2.7	2.3	2.0	3.0	3.5	2.7	1.6	.70	.00	46	.00	20
25	2.7	2.0	2.0	3.0	3.5	2.0	1.1	.60	.00	500	.00	5.0
26	2.3	1.6	2.0	3.0	3.5	2.3	1.3	.52	.00	50	.00	2.0
27	2.3	1.6	2.0	3.0	3.5	2.7	1.3	.52	.00	20	.00	20
28	2.3	1.6	2.0	3.0	3.5	1.3	1.3	.10	.00	10	.00	10
29	2.3	2.0	2.0	3.0	---	1.3	1.1	.10	.00	10	.00	400
30	2.3	4.4	2.0	3.0	---	2.0	1.3	.20	.00	10	.00	3500
31	3.1	---	2.0	3.0	---	4.4	---	.20	---	20	.00	---
TOTAL	98.5	108.1	67.5	93.0	87.0	81.1	41.00	34.04	.20	666.00	1454.00	4007.00
MEAN	3.18	3.60	2.18	3.00	3.11	2.62	1.37	1.10	.01	21.5	46.9	134
MAX	7.0	5.2	4.8	3.0	3.5	6.4	2.7	2.3	.10	500	400	3500
MIN	2.0	1.6	1.6	3.0	3.0	1.1	.80	.10	.00	.00	.00	.00
AC-FT	195	214	134	184	173	161	81	68	.4	1320	2880	7950

CAL YR 1982 TOTAL 3036.20 MEAN 8.32 MAX 600 MIN .00 AC-FT 6020
WTR YR 1983 TOTAL 6737.44 MEAN 18.5 MAX 3500 MIN .00 AC-FT 13360

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 Wash about 5 mi above the gaging station near Mexican Water (fig. 2). Low-flow measurements made from November through February in the 1984 water year were 13.0, 7.2, and 7.1 ft^3/s. These measurements are somewhat higher than the average discharge of all low-flow measurements made during the winter months from 1976 to 1983, which was 5.5 ft^3/s (about 3,950 acre-ft/yr). The daily mean discharges for the 1983 water year are shown in table 9. All previous data have been published in Water Resources Data for Arizona (U.S. Geological Survey, 1976-84).

The average discharge of all low-flow measurements made on Laguna Creek from November through February since the station was established in 1981 was 3.3 ft^3/s, which is equivalent to 2,410 acre-ft/yr. Continuous streamflow data are not available for this station.

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Table 9.--Discharge data, Chinle Creek near Mexican Water, 1983 water year

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1982 TO SEPTEMBER 1983
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	100	3.0	8.0	8.0	76	217	367	360	112	.35	20	.00
2	80	3.0	30	4.8	56	236	356	307	46	.30	8.0	.00
3	40	3.0	12	5.3	32	211	257	263	33	.20	4.0	.00
4	20	3.0	8.0	5.7	28	198	254	251	26	.10	2.0	.00
5	10	3.0	4.0	5.7	46	284	185	338	23	.10	1.0	.00
6	8.0	3.0	4.0	4.4	127	254	133	413	21	.10	.40	.00
7	8.0	4.0	4.0	4.4	190	188	121	453	18	.38	.20	.00
8	8.0	4.0	4.0	5.3	198	168	96	397	18	.71	.10	.00
9	8.0	4.0	6.0	2.5	193	190	82	413	15	87	.00	.00
10	6.0	6.0	12	4.1	148	254	76	496	12	150	.00	.00
11	6.0	4.0	30	6.2	77	288	93	492	8.4	200	.00	.00
12	6.0	4.0	25	8.0	52	297	137	462	6.2	180	.00	.00
13	6.0	4.0	20	20	41	317	137	331	4.4	80	.00	.00
14	6.0	4.0	18	17	41	307	137	248	1.4	40	.00	.00
15	6.0	4.0	16	17	55	314	133	231	1.4	30	.00	.00
16	6.0	4.0	14	18	62	324	119	201	1.0	20	.00	.00
17	6.0	4.0	14	4.0	71	245	127	222	.36	10	.00	.00
18	6.0	4.0	12	43	74	173	198	240	.20	9.0	.00	.00
19	6.0	8.0	12	160	69	159	212	200	.10	9.0	.00	.00
20	6.0	16	10	160	60	166	225	220	.10	4.0	.00	.00
21	6.0	12	10	140	65	157	214	280	.00	2.0	.00	1.0
22	5.0	10	11	140	69	173	203	240	.00	1.0	.00	.40
23	4.0	18	26	120	69	173	242	200	.00	60	.00	.20
24	4.0	26	166	120	72	157	195	180	.38	10	.00	.10
25	4.0	20	95	150	138	159	164	180	1.2	3.0	.00	.00
26	3.0	12	25	150	193	157	228	171	.60	1.0	.00	.00
27	3.0	8.0	8.0	124	211	155	304	171	.30	50	.00	.00
28	3.0	6.0	5.7	166	180	139	304	173	.30	1500	.00	.00
29	3.0	4.0	8.8	288	---	142	352	164	1.0	200	.00	.00
30	3.0	4.0	12	171	---	166	352	166	1.5	60	.00	70
31	3.0	---	8.0	125	---	291	---	148	---	30	.00	---
TOTAL	389.0	212.0	638.5	2197.4	2693	6659	6003	8611	352.84	2738.24	35.70	71.70
MEAN	12.5	7.07	20.6	70.9	96.2	215	200	278	11.8	88.3	1.15	2.39
MAX	100	26	166	288	211	324	367	496	112	1500	20	70
MIN	3.0	3.0	4.0	2.5	28	139	76	148	.00	.10	.00	.00
AC-FT	772	421	1270	4360	5340	13210	11910	17080	700	5430	71	142

CAL YR 1982 TOTAL 34139.60 MEAN 93.5 MAX 6000 MIN .00 AC-FT 67720

WTR YR 1983 TOTAL 30601.38 MEAN 83.8 MAX 1500 MIN .00 AC-FT 60700