Water in the Coconino Sandstone for the Snowflake-Hay Hollow Area Navajo County, Arizona

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-S

Prepared in cooperation with the Arizona State Land Department

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By PHILLIP W. JOHNSON

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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WATER IN THE COCONINO SANDSTONE FOR THE SNOWFLAKE-HAY HOLLOW AREA, NAVAJO COUNTY, ARIZONA

By Phillip W. Johnson

ABSTRACT

The Snowflake-Hay Hollow area includes about 800 square miles in Navajo County, Ariz., in the Colorado Plateaus province. Two perennial streams drain the area: Silver Creek, which trends northward through the central part of the area, and the Little Colorado River, which flows northwestward across the northern edge of the area. Many ephemeral streams and washes draining into the Little Colorado River and Silver Creek flow during periods of heavy precipitation. Precipitation in the area ranges from about 9 inches in the northern part to more than 13 inches in the southern part. In the mountainous Mogollon Rim country south and southwest of the area, the mean annual precipitation ranges from 20 to 30 inches.

The Coconino sandstone of Permian age is the principal aquifer. It is present everywhere in the area and yields ground water under artesian pressure to most wells. The Moenkopi formation of Triassic age yields water to some shallow domestic and stock wells. Other minor aquifers are the Quaternary alluvium and lava beds.

The discharge of ground water from the principal aquifer is estimated to be 15,000 acre-feet per year, of which about 10,500 acre-feet is used for irrigation of 4,000 acres of land and for stock, domestic, and industrial needs. The remaining 4,500 acre-feet is lost by evapotranspiration and surface flow from the area. Much water could be conserved by closing flowing wells during the nonirrigation season. Recharge occurs directly where the Coconino sandstone is exposed along the Mogollon Rim south of the area and indirectly where it is overlain by porous rocks. No progressive declines and only minor seasonal fluctuations occurred in water levels in wells from 1950 to 1958, indicating that the water withdrawn was replaced by recharge. Contours of the water surface indicate that ground water moves northward and northwestward.

It is estimated that about 16,000 acre-feet of ground water is in storage per square mile of aquifer in the area of the tests. Only a part of the stored water can be recovered economically from wells. Chemical analyses of the ground water show that concentrations of dissolved solids average less than 500 ppm (parts per million), which classifies the water as good to excellent for both irrigation and domestic use.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

The Soil Conservation District of Navajo County and the people of the Snowflake-Hay Hollow area requested, through the Arizona State Land Department, that the U. S. Geological Survey undertake a cooperative investigation of ground water for the Snowflake-Hay Hollow area. The need for an investigation arose because of the reduced flow of Silver Creek due to upstream diversion, and an increase in the demand for additional water for irrigating new land. The purpose of the investigation was to ascertain the possibility of obtaining sufficient ground water from one or more wells to replace the amount of surface water lost by diversion and to meet the need for additional water. A satisfactory solution of this problem depends upon a thorough knowledge of the subsurface geology and hydrology including: The location and extent of the water-bearing beds (aquifers), the direction of movement of the ground water, the extent of the recharge area that serves to replenish the ground-water supply, the location and amount of both natural and artificial discharge from the aquifers, and the amount of water in ground-water storage. Sufficient information was obtained about these basic factors of ground-water supply to give a positive answer to the basic question, but additional work will have to be done in the area before close estimates can be made of the total amount of ground water available for development.

The paucity of data on the water-bearing characteristics of the aquifers, and the lack of long-term basic records for the area, limit the answers to all these questions. A prerequisite to determine the water-bearing characteristics and potential of an aquifer is to have accurate data from wells that penetrate the full thickness of the saturated zone of the aquifer. At the time the major part of the fieldwork was completed, no wells in the area penetrated the aquifer completely. Since that time, several test wells have been drilled, but only a small amount of information concerning them has been released.

The collecting and filing of information for each additional well drilled in the area will provide data for more complete answers to geohydrologic questions.

LOCATION AND EXTENT OF THE AREA

The area investigated includes about 800 square miles within a rectangle consisting of Tps. 11–16 N., Rs. 20–23 E., Navajo County, Ariz. (fig. 1). The greatest part of the land is used for grazing. However, about 4,000 acres of land is under irrigation along Silver Creek and its tributary washes south of the town of Snowflake and in the northeastern part of the area along Hay Hollow Wash.

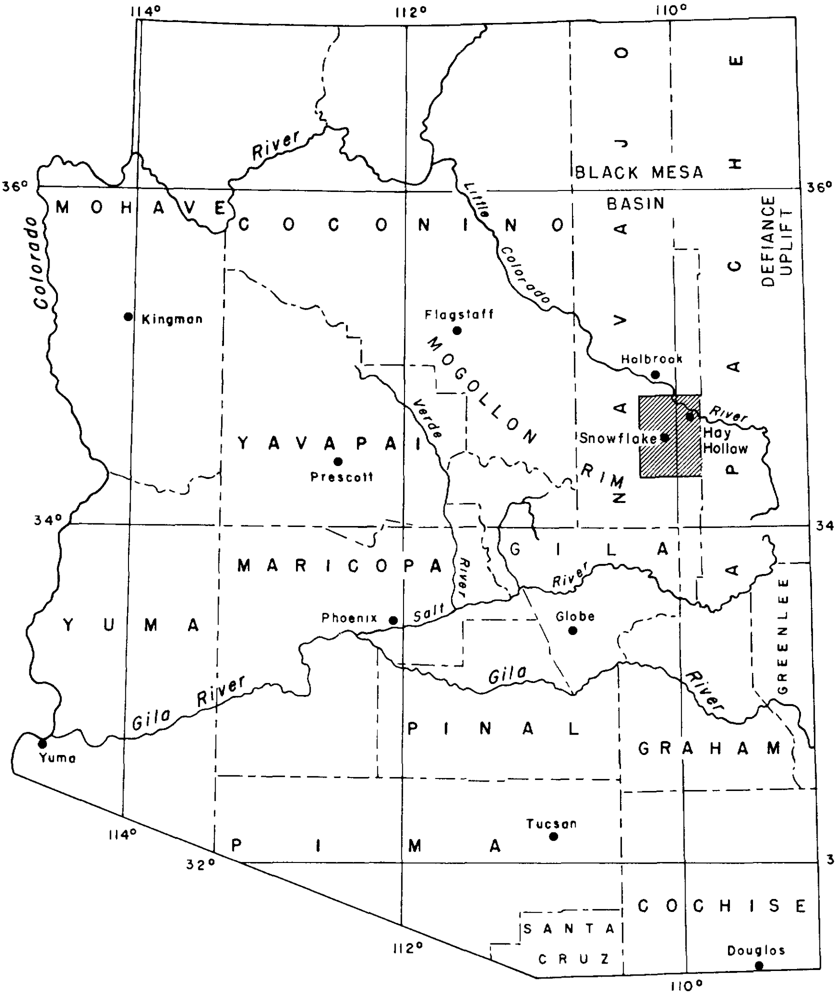

FIGURE 1.—Map of Arizona showing location of Snowflake-Hay Hollow area.

PREVIOUS INVESTIGATIONS

The area has been included in general geologic studies by Gregory (1917), Darton (1910, 1925), McKee (1934, 1938, 1954), and Huddle and Dobrovolny (1945, 1952). These investigations have supplied valuable information concerning the geology and stratigraphy. The area also was included in the water-resources investigations of Harrell and Eckel (1939), and the report by Babcock and Snyder (1947) applies to parts of the area.

ACKNOWLEDGMENTS

The fieldwork for this report was started in December 1950 by J. H. Feth, and was continued during the summer of 1951 and inter-

mittently thereafter by P. W. Johnson. Most of the mapping was done in the field seasons of 1951 and 1958, and most of the hydrologic data were collected in 1951 and 1953.

The cooperation of the farmers, ranchers, and other citizens of the area in providing information and help and the aid given by the drillers and crews who provided samples from new wells is gratefully acknowledged. Special recognition and thanks are given to Mr. Lee Greiner and other members of the Snowflake Work Unit No. 4 of the Soil Conservation Service, who gave access to their files, provided office space, and helped the author in the field.

METHODS OF INVESTIGATION

A base map was prepared from aerial mosaic quadrangle sheets at a scale of 1:63,360. The grid was taken from the General Highway Map of Navajo County. Mapping was done on contact prints of aerial photographs made by the Soil Conservation Service in 1950. An inventory of wells was made, well logs were obtained when available, and water samples were collected for chemical analysis. Samples of drill cuttings were collected from the new wells drilled in the area during the time of the investigation. The Geological Survey made two aquifer tests before this investigation started—one by using well (A–13–21)34dcc near Taylor and the other by using well (A–15–23)34aa in Hay Hollow.

WELL-NUMBERING SYSTEM

The well numbers used by the Ground Water Branch of the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River base line and meridian which divide the State into four quadrants (fig. 2). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d, after the section number, indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract (fig. 2). These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (A–4–5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 N., R. 5 E. Where there

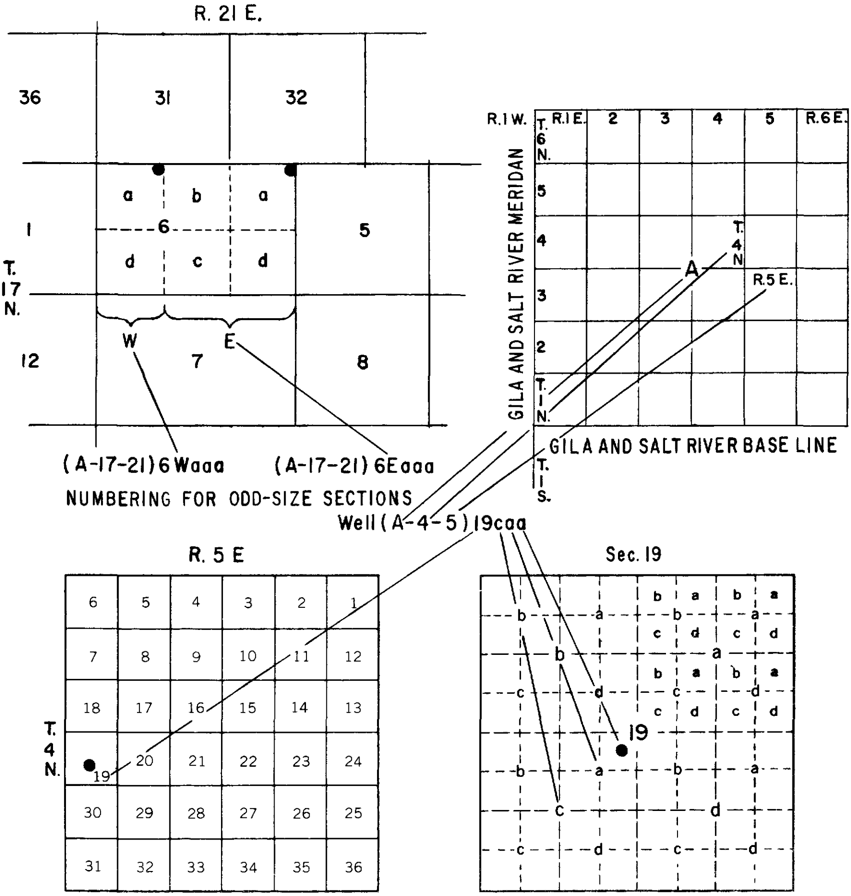

FIGURE 2.—Well-numbering system in Arizona.

is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Where a section is more than a mile in any dimension the section number applies as usual. The oversized section is divided so that a full square-mile unit of it is adjacent to a normal section within the same township; the remainder is considered to be a separate unit of land. Appropriate N., S., E., or W. letters are assigned to the units, depending upon where they lie in relation to the full square-mile unit. A well in an oversized section would be designated as shown in figure 2 with the additional appropriate N., S., E., or W. letter in the well number.

GEOGRAPHIC AND CULTURAL FEATURES

Snowflake, the largest town in the area, is in parts of secs. 23 and 24, T. 13 N., R. 21 E., about 29 miles south of the city of Holbrook and 20 miles north of the city of Show Low, on State Route 77. Its altitude is 5,644 feet. The towns of Taylor and Shumway are about 2 and 5 miles south of Snowflake, respectively. Taylor is smaller than Snowflake and also is along the highway. Shumway, east of the highway, is a community settlement that supports no local stores or businesses. All three towns were settled by early Mormon pioneers who took advantage of the fertile ground and the abundant water in Silver Creek Valley.

The Apache Railway extends south from Holbrook through the area and serves largely as a means of freight transportation for the lumber and livestock industries. These two industries, a small amount of agriculture, and minor businesses serving the public needs compose the chief sources of income for the area.

Hay Hollow is a small rural agricultural settlement comprising about 10 square miles in Tps. 14 and 15 N., R. 23 E. Its chief product is alfalfa hay that is grown with water from irrigation wells and is used for stock feed.

DRAINAGE FEATURES

The Snowflake-Hay Hollow area is part of the Little Colorado River drainage basin. Hay Hollow Wash, a northward-trending ephemeral stream, drains the east side of the area and flows through Hay Hollow. Silver Creek, which drains the greater part of the area, is a perennial stream that receives most of its water from Silver Spring near its headwaters, about 10 miles southeast of Shumway, and flows northwestward to within 1 mile of Shumway, where it turns northward. About 1½ miles north of Snowflake, Silver Creek enters a narrow canyon and continues northward for about 15 miles to the junction with the Little Colorado River, about 4 miles south of Woodruff.

Show Low Creek, several miles west, roughly parallels Silver Creek in the southern part of the area until it turns abruptly eastward and joins Silver Creek about a mile north of Shumway. The flow in Show Low Creek is controlled by diversion near the town of Show Low, about 5 miles south of the area. The main tributaries of Silver Creek are ephemeral washes. The largest of these are Mortensen and Cottonwood Washes, which enter on the west side near Snowflake. In a few places Cottonwood Wash has effluent seepage caused by ground-water barriers of probable structural origin. The large run-off from precipitation in the mountainous areas to the south has caused erosion in these tributaries. Silver Creek, north of Snow-flake, has cut a narrow canyon in the Coconino sandstone to a depth of more than 100 feet in places. North of the point where Silver

Creek enters the canyon and to the west the drainage pattern is mature except where these tributaries approach the Silver Creek canyon and downcutting has been rapid. Comparatively few tributaries enter Silver Creek from the east side. Most tributaries drain either northward into the Little Colorado River or eastward into Hay Hollow Wash. During periods of heavy runoff, the drainage system carries most of the water out of the area so that recharge to the ground-water reservoir is small. In the reaches where the streams flow over the Coconino sandstone more water is absorbed and recharge is greater.

PRECIPITATION AND TEMPERATURE

Four weather stations in or near the Snowflake-Hay Hollow area provide representative climatological data. These are: Show Low station about 5 miles south of the area; Silver Creek Ranch station in sec. 19, T. 11 N., R. 23 E.; Snowflake station in the central part of the area; and Holbrook station about 8 miles north of the area.

The mean annual temperature and total annual precipitation for each of the four stations are given in the following table. These figures are given instead of the Weather Bureau normal because the records from the Show Low and Silver Creek Ranch stations do not meet the standards used by the Bureau in establishing the normal. The arithmetical averages of these figures are given at the end of the table. No temperature records are available for the Silver Creek Ranch station.

Climatic data from the establishment of the stations to 1930, inclusive, were taken from the Climatic Summary of the United States, section 25, Northern Arizona, published by the United States Department of Agriculture, Weather Bureau. Data for the years 1931–57, inclusive, were obtained from annual and monthly summaries of Climatological Data—Arizona and from the Climatic Summary of the United States—Supplement for 1931 through 1952, Arizona, section 2, published by the U.S. Department of Commerce, Weather Bureau.

The precipitation and temperatures at the Show Low and Silver Creek Ranch stations probably are representative of the southern one-third of the Snowflake-Hay Hollow area; those at the Snowflake station are representative of the middle one-third, and those at the Holbrook station are representative of the northern one-third. The records indicate that, from the southern to the northern part of the area, the average annual precipitation decreases at least 5 inches and the average mean annual temperature increases about 5°F.

Mean annual temperature, in °F, and total annual precipitation, in inches, at Show Low, Silver Creek Ranch, Snowflake, and Holbrook weather stations

Year	Show Low		Silver Creek Ranch	Snowflake		Holbrook	
	Temperature	Precipitation	Precipitation	Temperature	Precipitation	Temperature	Precipitation
1887							9.56
1888							10.82
1889							7.63
1890							12.51
1891							6.76
1892							6.31
1893							7.76
1894		21.25					6.23
1895		19.54					10.39
1896		14.59					7.01
1897							7.20
1898					9.39		8.21
1899					6.48		4.58
1900							
1901		15.78					
1902					7.86		
1903					9.72		
1904					7.35		5.20
1905							17.63
1906							8.72
1907							15.16
1908							12.54
1909							
1910							8.14
1911				51.3	15.11		11.82
1912				49.4	8.71		9.02
1913				49.0	7.01		
1914				53.9	15.59		
1915				51.6	23.28		10.37
1916		18.98		51.4	12.53		14.16
1917		11.68		50.6	10.16		6.74
1918		17.51		51.6	10.10		7.41
1919				50.6	18.35		
1920		17.84			13.85		
1921				52.3	14.95	56.3	8.69
1922				51.4	12.54		3.40
1923		24.11		50.4	18.07		13.05
1924		14.91		53.8	9.41	54.5	6.87
1925				51.9	15.36	56.6	12.07
1926				52.1	18.16	56.5	9.23
1927				52.8	13.97	56.0	12.13
1928				51.5	8.16	55.2	6.90
1929				51.3	15.52	53.7	8.60
1930				51.4	17.46	53.4	7.30
1931				50.3	15.41	53.8	10.75
1932				49.4	11.08	53.2	5.71
1933				51.4	14.40	53.0	11.33
1934				52.8	8.46	56.6	7.04
1935				49.6	14.07	54.9	9.94
1936				50.5	13.23	56.2	9.00
1937				51.3	13.14	54.6	6.60
1938				51.7	10.52	55.1	5.83
1939			9.48			55.2	5.27
1940			16.82	54.7	15.32	55.4	11.77
1941			22.17	51.9	16.36	54.3	13.07
1942			13.21	53.0	8.40	56.3	3.07
1943			13.93			57.3	5.63
1944			15.74			54.7	6.50
1945				50.6	8.61		4.89
1946				51.4	14.01	55.7	7.93
1947			16.29			55.1	9.72
1948			11.68	51.9	10.15	54.9	6.87
1949			14.97	51.0	10.86	54.5	8.75
1950			7.80	53.3	3.80	57.3	3.46
1951			15.91	51.5	11.28	55.4	7.10
1952	49.3		18.33	51.4	16.89	54.5	9.81
1953	50.2	9.81	10.75	51.4	9.52	55.6	6.48
1954	51.8	17.14	13.58	53.5	11.98		11.27
1955	49.9	12.18	11.31	51.5	10.29		6.14
1956	50.2	10.34	9.67	51.4	10.17		4.79
1957	50.7	14.76	14.90	52.3	12.52	56.6	10.96
Average	50.4	16.03	13.91	52.1	12.28	55.2	8.54

GEOLOGY

The Snowflake-Hay Hollow area is part of the Colorado Plateaus province (Fenneman, 1931). The geologic strata exposed in the area consist mostly of unconsolidated alluvial material and consolidated sedimentary and igneous rocks. The unconsolidated material is sand, gravel, silt, and clay of Tertiary to Recent age. The sedimentary rocks are sandstone, shale, mudstone, gypsum, conglomerate, and limestone of Paleozoic and Mesozoic age. The igneous rocks are the results of basic volcanic flows. The age of the igneous rocks is not certain, but they probably are Quaternary. Some places have more than one volcanic flow, and it is possible that the older flows may be Tertiary. No rocks older than the Coconino sandstone of Permian age are exposed in the area.

The ground-water resources of the area are related closely not only to the lithologic characteristics of the rocks but also to the geologic structure. The major structural feature in the area is the Holbrook anticline. Minor folds, faults, and fractures are locally important hydrogeologically.

SEDIMENTARY ROCKS AND THEIR WATER-BEARING PROPERTIES

The lithologic characteristics of sedimentary rocks commonly govern their hydrologic properties. Grain size, degree of sorting, composition, type and degree of cementation, compaction, and stratigraphic position are important characteristics of the sediments that control the movement of water. Unconsolidated sand and gravel constitute the best aquifers, whereas clay, silt, and mud usually make poorer aquifers. Likewise, these materials in their consolidated form in general can be classified similarly.

PERMIAN ROCKS

The Coconino sandstone and the Kaibab limestone are the only Permian rocks exposed in the area. Three exploratory oil-test wells, (A–14–20)4dc, (A–14–20)33db, and (A–13–20)3dd were drilled into the Supai formation of Permian age immediately underlying the Coconino sandstone. They penetrated salt beds and salty water. Salt beds also have been penetrated in the Supai formation in other deep test holes within a 50-mile radius of Snowflake. Therefore, the Supai formation in the area is not considered to be a potential fresh-water aquifer. No rocks older than the Coconino sandstone are likely to yield potable water, and, therefore, rocks older than the Coconino will not be described.

TABLE 1.—*Drillers' logs of wells in the Snowflake-Hay Hollow area, Navajo County, Ariz.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
(A-11-22)13cad					
Surface soil	10	10	Hard sandstone, water rose to 76 feet of top	5	285
Malpais	40	50	Broken sandstone, water settled to 118 feet	65	350
Alternate shale, sandstone, and clay	230	280	No information	301	651
(A-11-23)3bba					
Soil	7	7	Red and brown sandstone	21	347
Brown clay	146	153	Red and blue shale	43	390
Red shale and brown sandstone	123	276	Soft white shale, sandstone streaks	21	411
Red and blue shale	11	287	Buff and white sandstone (water)	34	445
Brown sandstone (2 gpm water)	25	312	Buff sandstone	19	464
Red and blue shale	14	326			
(A-11-23)6abb					
Malpais	125	125	Red sand rock (water)	10	270
White clay and soapstone	65	190	Red shale	10	280
Red shale	40	230	Red shale (bad land)	5	285
Sand rock	1	231	Red shale	10	295
Red shale and lime	29	260	Red clay, little shale	62	357
(A-11-23)32ba					
Soil and malpais boulders	6	6	Malpais-seep of water at 176 feet, 1 gpm-level 153 feet	57	176
Malpais	84	90	XT hard malpais	20	196
Red clay	6	96	Soft malpais-water, pumps 21 gpm-level 165 feet	7	203
Malpais	19	115	Malpais	15	218
Red clay	4	119			
(A-12-21)2bd					
Soil	4	4	Brown clay	14	128
Sand and gravel	14	18	Gravel (10 gpm water)	2	130
Red clay	70	88	Red shale	26	156
Gray sandstone (some water)	2	90	Red sandstone (some water)	8	164
Red and blue clay	20	110	Red shale	21	185
Hard red shale	4	114	Coconino sand	15	200
(A-12-21)6ba					
Gray bed, sandstone	14	14	Coconino	29	174
Red shale	131	145	Water strata	66	240
(A-12-21)24ddd					
Top soil	5	5	Moenkopi formation	45	95
Broken rock ledges (thin), conglomeration of red clay and boulders	45	50	Kaibab(?) limestone	7	102
			Coconino sand	133	235
(A-12-23)10ab					
Soil	6	6	Unknown	310	342
Gravel and silt	6	12	White sandstone (Coconino), water strata, level raised to 323 feet	11	353
Silt	6	18	Blue-white sandstone	22	375
Yellow clay	8	26			
Blue-white clay	6	32			

TABLE 1.—*Drillers' logs of wells in the Snowflake-Hay Hollow area, Navajo County, Ariz.*—Continued

(A-13-20)13ddd

	Thickness (feet)	Depth (feet)
Soil	3	3
Hard sandstone and clay streaks	59	62
Red and blue shale and sandstone streaks	84	146
Yellow and blue shale and sandstone streaks	30	176
Hard white sand	53	229
Soft white sand	11	240
Hard sand and soft streaks	18	258
Soft sand and hard streaks	24	282
Hard sand and soft streaks	68	350
Soft sand and hard streaks	25	375
Hard sand and soft streaks	18	393
Soft sand and hard streaks	29	422
Hard sand	11	433
Hard sand and soft streaks	27	460
Soft sand and hard streaks	14	474
Hard sand and soft streaks	46	520
Soft sand and hard streaks	9	529
Hard sand and soft streaks	11	540
Soft sand and hard streaks	17	557
Hard sand and soft streaks	8	565
Soft sand	8	573
Streaks of hard and soft sand	26	599
Hard blue and ıed shale	10	609

(A-13-21)14cbc

	Thickness (feet)	Depth (feet)
Fill	82	82
Sandstone, red (some water)	13	95
Shale, red	40	135
Clay, yellow and blue	7	142
Sand, Coconino	18	160

(A-13-21)23cb

	Thickness (feet)	Depth (feet)
Red sandstone	32	32
Red shale	28	60
White sandstone (some water)	6	66
Red shale with blue streaks	54	120
Red shale	26	146
Hard sandy shale	44	190
Yellow clay	26	216
Kaibab limestone	8	224
Coconino sandstone, water	28	252

(A-13-21)24cc

	Thickness (feet)	Depth (feet)
Sand, gravel, and clay	60	60
Clay(?)	5	65
Brown clay (some boulders)	33	98
Brown sandstone	12	110
Chinle	102	212
Moenkopi sandstone	13	225
Lime	20	245
Coconino	83	328

(A-13-21)29bdb

	Thickness (feet)	Depth (feet)
Soil	2	2
Caliche and sand	13	15
Sandy shale	17	32
Hard sand and streaks shale	96	128
Hard sandstone (red)	10	138
Hard sand and streaks of shale	53	191
Red and blue shale	14	205
Sandy shale, hard	14	219
Red and blue shale	23	242
Sand	4	246
Sandy lime	20	266
White sand (cut good)	33	299
Hard white sand and streaks of soft	28	307
White sand (cut good)	21	328
Hard white sand and streaks of soft sand	25	353
White sand (cut good)	5	358
Hard sand	7	365
White sand (cut good)	19	384
Hard white sand and streaks soft sand	6	390
White sand	11	401
White sand soft and hard streaks	28	429
Hard white sand and streaks soft	27	456
White sand soft with hard streaks	17	473
Hard sand	9	482
White sand and hard streaks	27	509
Hard sand and streaks soft and lime	25	534
Fine white sand and streaks hard	43	577
Hard white sand	11	588
Fine white sand	23	611
Hard and soft sand streaks	28	639
Hard sand	13	652
Hard and soft sand	44	696
Hard sand	18	714
Hard red shale	11	725

(A-13-21)29ddd

	Thickness (feet)	Depth (feet)
Soil and clay	13	13
Sand	3	16
Hard shale and sandstone	14	30
Hard shale	19	49
Hard shale and sandstone	32	81
Sandstone	14	95
Red and blue shale and sandstone	93	188
Sandstone	12	200
Shale	10	210
Sandy lime and sand	7	217
Lime	8	225
Hard sand	11	236

TABLE 1.—*Drillers' logs of wells in the Snowflake-Hay Hollow area, Navajo County, Ariz.*—Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
(A-13-21)29ddd—Continued					
Soft sand	12	248	Soft sand	14	439
Hard sand	17	265	Hard sand	22	461
Soft sand	10	275	Soft sand	8	469
Hard sand	27	302	Hard sand	12	481
Hard sand	18	320	Soft sand and hard streaks; some yellow sand	59	540
Soft sand and streaks of hard	40	360	Hard sand	5	545
Hard sand and shale	10	370	Soft sand and hard streaks	98	643
Hard sand	30	400	Hard sand	21	664
Soft sand	7	407	Green sandy shale	7	671
Hard sand	18	425			
(A-13-21)31dda					
Soil	20	20	Clay	110	154
River bed gravel	10	30	Coconino sandstone	58	212
Sandstone	14	44			
(A-13-21)34cc					
Red clay and shale	48	48	Gray lime	16	148
Red sandstone	62	110	White sandstone	14	162
Blue shale	22	132			
(A-13-21)34dcc					
Clay, red—first water	80	80	Some clay and plenty of rock	98	228
Clay and gravel	10	90	Rock	20	248
Clay gravel (some caving)	40	130			
(A-13-23)11db					
Soil	4	4	Moenkopi clays, red and blue with brown sandstone	236	283
Red clay	2	6	Coconino sandstone	35	318
Red clay with gravel	9	15	White water strata	9	327
Brown conglomerate	29	44	Yellow sandstone	23	350
Brown sandstone	3	47			
(A-14-20)4dc					
Red shale	60	60	Brown sand; shale	43	2260
Hard crossbedded sandstone	274	334	Oil sand, dark brown	40	2300
Yellow limestone	60	394	Brown shale	5	2305
White shale	45	439	Buff water sand, salt water	15	2320
Buff sandstone	42	481	Rotten red lime or shale	15	2335
Buff and red sandstone—base Coconino	68	549	Soft brown shale	40	2375
Red sandstone	62	611	Sandy lime rock, 4-inch casing	5	2380
Red sandstone and shale	69	680	Hard brown lime	5	2385
Hard lime	12	692	Soft brown shale with thin strips of hard brown lime	40	2425
Red shale and gypsum	108	800	Dark brown water sand	13	2438
Shale, salt and gypsum	55	855	Dark brown lime	42	2480
Dark brown shale and salt	10	865	Oil sand	12	2492
Reddish-brown shale	140	1005	Dark brown shale	73	2565
Brown shale	35	1040	Brown shale	45	2610
Blue lime	10	1050	Brown lime	8	2618
Brown shale and salt	40	1090	Brown shale	50	2668
Blue shale and brown sandstone	110	1200	Dark brown shale	57	2725
Blue shale and salt	540	1740	Fossil	5	2730
Blue shale; show oil	10	1750	Dark brown shale and fossil	118	2848
Lime	190	1940	Medium dark, soft gray lime	17	2865
Shale; show oil and gas	10	1950	Black, hard shale and lime	5	2870
Blue lime	78	2028	Dark hard gray lime	9	2879
Water sand, white	12	2040	Dark gray shale	3	2882
Brown shale, soft	110	2150	Brownish water sand	4	2886
Blue-gray lime; thin shale	67	2217	Black lime	4	2890

TABLE 1.—*Drillers' logs of wells in the Snowflake-Hay Hollow area, Navajo County, Ariz.*—Continued

(A-14-20)dc—Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Brownish water sand	6	2896	Thin gray lime and gray shale	90	3275
Gray lime	2	2898	Brown dry sand	20	3295
Gray lime	4	2902	Thin gray lime and shale	65	3360
Water sand	4	2906	Shale	11	3371
Gray black shale	68	2974	Lime	3	3374
Gray lime	16	2990	Shale	2	3376
Dark shale, thin gray limes	95	3085	Lime	2	3378
Dolomite, very dark brown with gray	100	3185	Sandy lime	9	3387
			Dry hole.		

(A-14-20)33db

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sandstone, white, quartzitic, fine-grained	550	550	Shale, brown, calcareous	5	3132
Shale, red-brown, silty, calcareous, in sandstone	70	620	Limestone, dark-gray, silty	6	3138
Anhydrite and gypsum in shale	200	820	Shale, brown-gray, calcareous	3	3141
Sandstone, alternating with gypsum, anhydrite, halite	250	1070	Limestone, gray, very silty, nodular	6	3147
Shale, gray and brown, silty, dolomitic, massive	40	1110	Limestone, aphanitic, gray, cherty, fractured	9	3156
Anhydrite, mottled to white, hard, dense	30	1140	Shale, dark-brownish-gray, calcareous	10	3166
Halite, grading down into anhydrite and shale	110	1250	Limestone, gray, silty, cherty	9	3175
Shale, gray-brown, calcareous	20	1270	Shale, dark-gray to black, fossiliferous, clacareous; minor fractures	9	3184
Shale, red-brown; halite inclusions; grades down to anhydrite, halite, sandstone, red shale	270	1540	Limestone, gray, massive, coarse grained, fossiliferous	32	3216
Dolomite, dark-gray to black, silty; some black organic matter	30	1570	Shale, micaceous, silty, calcareous; minor fractures	57	3273
Shale, gray; alternating with dolomite	108	1678	Shale, gray, silty, bentonitic, calcareous; with lime pebbles	23	3296
Dolomite, brownish-gray	72	1750	Limestone, gray; alternating with gray shale	89	3385
Shale, red-brown, dolomitic	20	1770	Shale, mottled, red-brown, calcareous, nodular; and limestone, thin, granular shaly	39	3424
Halite, with beds of sandstone and anhydrite	390	2160	Limestone, gray, granular, silty, fossiliferous; some chert, minor fractures	47	3471
Anhydrite, gray, massive with halite	15	2175	Sandstone, very fine grained, fractured, calcareous	8	3479
Shale, red to chocolate-brown, sandy; includes gypsum and minor beds of sandstone	445	2620	Limestone, gray, cherty, granular; minor fractures; grades down into shaly limestone	26	3505
Shale, gray, highly micaceous, dolomitic	135	2755	Shale, red-brown, calcareous, micaceous; beds of fossil limestone	34	3539
Dolomite, brown to gray-brown, silty	25	2780	Sandstone, dark-gray, hard, fine-grained; with purple shale partings	5	3544
Shale, gray, dolomitic; and some dolomite	80	2860	Limestone, light-gray, coarse-grained, silty; shaly partings and gray-brown nodular shale	31	3575
Limestone, gray-brown, shaly, dolomitic, with minor streaks of brown, calcareous shale	44	2904	Shale, red-brown, calcareous, fossiliferous	35	3610
Shale, brown, calcareous, hard, dense; some gypsum	26	2930	Shale, red, silty, mottled; with subangular granite fragments	31	3641
Shale, brown, calcareous; streaks of brown limestone	8	2938	Sandstone, very shaly, fine to medium-grained, calcareous; some limestone inclusions	9	3650
Limestone, chert, hard, silty; interbedded with calcareous, mottled green shale	57	2995	Limestone, dolomitic, silty, massive; minor fractures	7	3657
Shale, brown, calcareous, fractured; with anhydrite inclusions	20	3015	Limestone, dolomitic, granular, sandy; vugs of white crystalline limestone, major fractures	28	3685
Limestone conglomerate; smooth brown limestone pebbles in lime matrix	5	3020	Limestone, dolomitic, gray-green; with thin gnarly beds of sandy shale	23	3708
Shale, blue-gray, calcareous, silty	20	3040	Sandstone, fine-grained, calcareous	15	3723
Shale, brown, calcareous, small lime pebbles	50	3090	Granite, biotite, weathered	1	3724
Limestone, brown, silty, some fractures	17	3107			
Shale, brown, calcareous	14	3121			
Limestone, gray, very shaly	6	3127			

TABLE 1.—*Drillers' logs of wells in the Snowflake-Hay Hollow area, Navajo County, Ariz.*—Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
(A-14-22)7ca					
Clay and sandstone	15	15	Coconino (hard)	205	245
Boulders	15	30	Broken Coconino (water)	25	270
Running sand	10	40			
(A-14-23)19aa					
Moenkopi	260	260	Coconino	80	360
Kaibab	20	280			
(A-14-23)31cd					
Soil	2	2	Red and blue shale	11	150
Fine sand	1	3	Red sandstone	2	152
Red sand shale	11	14	Red shale	45	197
Brown sandstone	6	20	Brown sandstone	2	199
Gray sandstone	6	26	Red shale	31	230
Yellow sandy lime	15	41	Brown sandy shale	11	241
Brown sandstone	5	46	White sandy lime	5	246
Red shale	47	93	White sandstone	16	262
Brown sandstone	4	97	Light brown sandstone	43	305
Red and blue shale	16	113	White water sandstone	6	311
Brown sandstone—seep water	26	139	Blue-gray sandstone	29	340
(A-15-23)26cc					
Surface silt, red clay and gravel	107	107	Hard white sandstone	19	273
Brown sandstone	10	117	Soft sandstone	135	408
Shale	35	152	Sandstone, large water flow	7	415
Brown sandstone and shale alternating	102	254	Sandstone, yellow	67	482
(A-15-23)27ddc					
Top soil	12	12	Moenkopi sand	7	310
Shale, red	268	280	Kaibab lime	6	316
Sandstone, red	23	303	Coconino sand	316	600
(A-15-23)28dc					
Moenkopi formation	262	262	Coconino formation	163	425
(A-15-23)28ddd					
Surface soil, gravel and red shale	42	42	Red and blue shale	14	202
Red and blue shale	25	67	Red sandstone	11	213
Red sandstone	9	76	Red and blue shale	32	245
Red and blue shale	32	108	Red sandstone	17	262
Brown sandstone	3	111	White sandstone	23	285
Blue and red shale	7	118	White sandstone, hard, temp. 54°	7	292
Brown sandstone	5	123	White sandstone, water strata, flows 20 gpm	5	297
Red and blue shale	58	181			
Brown sandstone	7	188			

TABLE 1.—*Drillers' logs of wells in the Snowflake-Hay Hollow area, Navajo County, Ariz.*—Continued

(A-15-23)34aa

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface silt	55	55	Red and blue shale	64	300
Gravel, water level 40 feet, poor quality	13	68	Brown sandstone	10	310
Red clay	28	96	Red and blue shale	6	316
Brown sandstone	22	118	Light blue-gray shale	4	320
Blue shale	2	120	Hard light gray sandstone	4	324
Brown sandstone	14	134	Soft white sandstone	12	336
Red and blue shale	14	148	Hard white sandstone	6	342
Brown sandstone	21	169	White sandstone—flowing	8	350
Red and blue shale	61	230	Hard white sandstone	28	378
Brown sandstone	6	236	Soft blue-white sandstone	10	388
			Buff sandstone—flows 175 gpm	42	430

(A-15-23)34dd

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	18	18	Red and blue shale	11	193
Red shale	11	29	Red sandstone	16	209
Red sandstone	4	33	Red and blue shale	36	245
Red and blue shale	8	41	Red sandstone	6	251
Red sandstone	5	46	Brown sandstone	14	265
Blue shale	9	55	Gray sandstone	8	273
Brown sandstone—seep salt water	7	62	White sandstone, water strata—level 9 feet from surface	9	282
Red and blue shale	116	178	Buff sandstone—bail 30 gpm, 10 feet pull down	103	385
Brown sandstone	4	182			

COCONINO SANDSTONE

The Coconino sandstone is in the subsurface throughout the area and crops out in the west-central part, where it has been uplifted near the axis of an anticline, and along Silver Creek, where erosion has removed the overlying rocks. The sandstone is a uniformly fine grained, massive, crossbedded quartz sandstone. The quartz grains are rounded to subrounded, well-sorted, and frosted. Extensive barchan-type crossbedding indicates eolian deposition. In places the sandstone is tightly cemented with silica, but the degree of cementation varies considerably from place to place as well as vertically in any given section. Pyrite cubes occur in the unweathered material, and pseudomorphs of limonite after pyrite occur in the weathered zones. Feldspar crystals have been noticed in some of the samples examined. Weathered exposures of Coconino sandstone form knobby dark-stained slabs, typical of the formation throughout the region. The color of the fresh surface, according to the rock-color chart by the National Research Council (Goddard, 1948), ranges from a very pale orange (10*YR* 8/2) to pale yellowish orange (10*YR* 8/6). Regionally the formation ranges in thickness from about 200 to 900 feet, and in the Snowflake area it is at least 550 feet thick, according to the log of the oil-test well (A-14-20)33db (table 1). The greatest thicknesses occur along the Mogollon Rim southwest of the area and in the Defiance Plateau along the New Mexico State line.

The Coconino sandstone is the principal aquifer, yielding water to all irrigation wells in the Snowflake-Hay Hollow area and to some stock and domestic wells. The difference in the degree of cementation and the fact that the Coconino sandstone is not completely saturated with water in all parts of the area account for the wide range in the productivity of the aquifer. The water is good to excellent in quality. In many places, the formation is confined, and the water is under sufficient hydrostatic pressure to cause it to rise above the formation in some wells and to flow at the surface in several wells.

KAIBAB LIMESTONE

The Kaibab limestone, uppermost of the Permian rocks, is exposed in the southwestern part of the mapped area (pl. 1), and more extensively southward beyond the limits of the map along the Mogollon Rim. In the Snowflake-Hay Hollow area, the Kaibab is a thick-bedded hard sandy limestone. It ranges in thickness from several feet to more than 50 feet. One hundred to 300 feet have been reported in measured sections along the Mogollon Rim (McKee, 1938). The weathered surface is rough, pitted, and dark gray. On the fresh surface, the Kaibab limestone ranges from a yellowish gray (5*Y* 7/2) to a grayish yellow (5*Y* 8/4). Fractures and joints are common and account for the blocky appearance in a typical exposure. Chert nodules or inclusions also are common.

A crossbedded sandstone of varying thickness, overlying the Kaibab limestone in many places in the southwestern part of the area, is so similar in lithologic character and structure to the Coconino sandstone that positive field identification is possible only where underlying or overlying rocks are exposed. Where the crossbedded sandstone only is exposed the possibility that the sandstone-limestone sequence is present should always be considered.

The crossbedded sandstone can be accounted for best in either of the following ways: It is a tongue of Coconino sandstone, and the sequence represents a large-scale transgression and regression of Kaibab seas or the crossbedded sandstone is a sandstone in the Kaibab limestone deposited under conditions very similar to those of the Coconino sandstone. Which of these postulations is correct can be ascertained only after further study. In this report the crossbedded sandstone has been included with the Kaibab limestone.

A silty sandstone in the Snowflake area, formerly accepted as Kaibab limestone (Darton, 1924), now is included as a bed in the Moenkopi formation of Early Triassic age (Shride, McKee, and Harshbarger, 1952).

Although the Kaibab limestone is not a water-bearing formation in the area, it is important as a recharge area for the underlying Coconino sandstone. Precipitation on the many square miles of Kaibab limestone exposed along the Mogollon Rim to the south and west of the area (Harrell and Eckel, 1939) penetrates the limestone through joints, fractures, and fissures, which in many places have developed into solution channels, to recharge the ground water in the Coconino sandstone.

TRIASSIC ROCKS

The Moenkopi and Chinle formations represent the Triassic rocks in the area, and an unconformity marks the division between the Permian and Triassic rocks. This unconformity is well documented by many geologists (Howell, 1875; Gilbert, 1877; Dutton, 1880; and Gregory, 1917). Dake (1920) probably was the first to report the widespread extent and characteristics of the unconformity. During the long period of erosion, represented by the unconformity, the Kaibab limestone was completely removed from much of this area, and the Moenkopi formation rests directly upon the Coconino sandstone.

MOENKOPI FORMATION

Rocks of the Moenkopi formation, of Early and Middle(?) Triassic age, occupy the largest part of the land surface in the Snowflake-Hay Hollow area. The formation has a wide areal extent throughout northern Arizona and southern Utah and extends northeast into Colorado and west into Nevada. It consists of sandstone, siltstone, claystone, mudstone, limestone, and gypsum. It ranges in thickness from more than 2,000 feet in southwestern Utah (Reeside and Bassler, 1922) to less than 100 feet at St. Johns, Ariz., and locally wedges out approximately along the Arizona-New Mexico State line (McKee, 1954). Its average thickness in the Snowflake-Hay Hollow area is about 125 feet.

The formation lies unconformably upon the Kaibab limestone in the southwestern part of the area and upon the Coconino sandstone elsewhere. Exposures of the basal bed of the Moenkopi formation show it to be a yellowish-orange, thin-bedded silty sandstone cemented weakly by calcite, where it overlies the Coconino sandstone. North of Snowflake the basal bed is well exposed in several road cuts along State Route 77, where it is 1 to 6 feet thick. It is well exposed also at "The Sinks" about 9 miles northwest of Snowflake (pl. 1), where it is about 15 to 20 feet thick (fig. 3). The basal sandstone bed continues to thicken to the northwest, and about 30 miles northwest of Snowflake along Clear Creek south of Winslow it is 20 to 35 feet thick.

Six subdivisions of the formation are recognized in northwestern Arizona and southwestern Utah. McKee (1954) suggested three

FIGURE 3.—One of the large sinks on the flank of the Holbrook anticline. The crossbedded Coconino sandstone, Pc, underlies the silty sandstone bed of the Moenkopi(?) formation Ꞧm.

members for the valley of the Little Colorado River: upper, Holbrook member; middle, Moqui member; and lower, Wupatki member. These members do not represent epochs, nor do they grade laterally into the thick sequence to the northwest, but, as pointed out by McKee, they are equivalent only to the upper part of the Moenkopi formation in southwestern Utah.

In the Snowflake-Hay Hollow area, erosion of the Moenkopi formation forms many mesas and buttes commonly capped by relatively massive sandstone beds. Each butte or mesa has a layer-cake appearance, the layers consisting of alternating beds of relatively hard sandstone and relatively weak siltstone and claystone. The margins of many of the buttes and mesas have a steplike appearance caused by the difference in erosional resistance of the sandstone and claystone beds.

One prominent cap rock in the Snowflake-Hay Hollow area is a massive medium-grained crossbedded calcareous cemented bed of sandstone composed of rounded to subangular grains. It is grayish white but contains some red or brown-stained quartz grains. Soft shaly red beds underlying the grayish-white sandstone are being eroded away, resulting in the development of overhanging ledges. In many places parts of the ledges have broken off and rest on the slope beneath the bed, forming a complete or almost complete ring of smooth, flat, slablike boulders around the crest of the butte. Four Mile Knoll, sometimes called First Knoll, north-northwest of Snowflake is a good example of the feature (fig. 4). Although the grayish-white sandstone is prominent, it cannot be used as a marker

FIGURE 4.—Four Mile Knoll north-northwest of Snowflake. Red beds of the Moenkopi formation with flat, slablike boulders of grayish-white sandstone around the slope.

bed because more than one such bed has been observed in a section elsewhere in the area.

In general, the Moenkopi formation ranges from a moderate red (5*R* 4/6) to a pale reddish brown (10*R* 5/4). However, a variety of colors may be found, ranging through very pale orange, grayish orange, light brown, grayish yellow, pale green, and grayish purple in successive thin beds of siltstone, sandstone, clay, or mudstone. Stringers of greenish-gray gypsum, 1 to 3 inches thick, are interbedded with some of these varicolored beds, for example, in a unit about 30 or 35 feet above the base of Four Mile Knoll.

Current ripple marks, rain pits, and salt casts and cusps are common in the beds of the Moenkopi formation in the Snowflake-Hay Hollow area, and these, together with other features, indicate a continental origin for the sediments. The presence of gypsum, mudstone, claystone, and siltstone point strongly to a lagoonal or mudflat type of depositional environment.

The Moenkopi formation is water bearing in parts of the area and yields small quantities of water to shallow wells. The water is found mostly in the more porous sandstone beds rather than the impermeable mudstone, siltstone, or claystone beds. However, the more impermeable beds are important because they act as confining layers, restricting the movement of water. Water in the principal aquifer is under artesian pressure in those areas where the confining beds of the Moenkopi formation overlie permeable beds of the Coconino sandstone. Seeps and springs issue where the confining layers underlie permeable material, such as some beds of lava.

CHINLE FORMATION

The Chinle formation of Late Triassic age consists of the Shinarump member, Mesa Redondo member (Cooley, 1958), and the lower and upper Petrified Forest member, divided by the Sonsela sandstone bed. The Shinarump is the main member of the Chinle in the area and for clarity is presented separately in this report; all other members or beds of the Chinle, if present, have not been differentiated. The Chinle formation does not yield water to wells or springs in the Snowflake-Hay Hollow area.

SHINARUMP MEMBER

In the southern part of the area, the Shinarump member of the Chinle formation is a poorly sorted, heterogeneous conglomerate. Medium- to well-rounded fragments of sandstone, chert, jasper, quartz, limestone, and, in places, metamorphic and basic igneous rocks have been observed. The fragments range in size from granules to cobbles, according to Wentworth's classification (1922). An abundance of white or black petrified wood is common, ranging in size from chips to logs. The matrix is a well-sorted quartz sand and the degree of siliceous cementation ranges from weak to firm.

The Shinarump in the vicinity of Hay Hollow becomes less conglomeratic. In places the beds appear to be coarse sandy lenses that grade into or, in part, intertongue with the more conglomeratic beds. Where the conglomerate is not present, sandy grayish-red banded siltstone occurs. The siltstone consists of fine, well-sorted, rounded to subrounded, stained quartz grains in a calcareous cement. M. E. Cooley (1958) assigned the name Mesa Redondo to this member and correlated it as equivalent to the lower red member of the Chinle formation, which overlies the Shinarump in the Fort Defiance area.

The Shinarump member extends across Arizona and into Utah. It crops out chiefly in the eastern part of the Snowflake-Hay Hollow area (pl. 1), unconformably overlying the Moenkopi formation. In places a well-defined drainage pattern was established before the deposition of the Shinarump. The channels were filled by streams carrying a heterogeneous detrital load. The channel pattern has been largely destroyed by erosion, but in the Snowflake-Hay Hollow area remnants of the pattern can be traced in Shinarump outliers capping the Moenkopi on some mesas and buttes.

The extent of the Shinarump member and its position above the water table prevents it from being water bearing in the area. However, Harshbarger (1954) stated that in the Defiance Plateau, the Shinarump conglomerate yields water to wells.

OTHER MEMBERS OF THE CHINLE FORMATION UNDIFFERENTIATED

The other members of the Chinle formation have not been differentiated in this report, although in the small area in which they crop out the Sonsela sandstone bed and Petrified Forest member have been recognized. They consist largely of varicolored shale and marl and some thin-bedded sandstone and limestone. The extensive and picturesque badlands in the Painted Desert and Petrified Forest northeast of the area are formed mostly by the undifferentiated members of the Chinle formation.

The members or beds in the area are not water bearing because they are above the water table, they are relatively impermeable, and they are thin. Therefore, they have little or no bearing on the groundwater supply in the area.

JURASSIC AND CRETACEOUS UNCONFORMITY

Rocks of the Jurassic system are absent in this part of northern Arizona. Cretaceous rocks crop out just south of the area near Show Low and Pinedale and southeast of the area along U.S. Highway 61. These Upper Cretaceous rocks rest on the Triassic Chinle formation, and the contact is marked by an erosional unconformity of minor relief. The unconformity cuts across progressively younger rocks as it is traced northeastward into the Navajo country.

TERTIARY AND QUATERNARY DEPOSITS

The Tertiary and Quaternary deposits of the area consist of older alluvium that occurs as extensive terraces in the southwestern part of the area and as small isolated hills elsewhere in the area that probably are remnants of terraces. They are referred to in this report as terrace sediments. The rocks consist of interbedded and intertongued unconsolidated to loosely consolidated sand and gravel. The sand is well- to fair-sorted, very fine to medium-grained, rounded to subrounded, clear and stained quartz. The gravel is medium to well rounded, ranging in size from granule to boulder, and consists of chert, jasper, quartzite, sandstone, limestone, and igneous volcanic rocks. Petrified wood is abundant, pieces ranging in size from small fragments to logs and in a variety of colors—red, white, yellow, black, and brown.

The terrace sediments range in thickness from a thin mantle to more than 50 feet. The relation of these deposits to the high-level gravel mapped by Harrell and Eckel (1939) is not known.

Sediments probably of approximately the same age as the terrace sediments occur at two localities, one between Shumway and Taylor along Silver Creek and the second north of Snowflake near the confluence of Cottonwood Wash and Silver Creek. These sediments

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chiefly are sandy and pebbly silt interbedded with thin beds of sand (fig. 3).

A rodent jaw was found by C. A. Repenning in the beds near Taylor. It was tentatively identified by J. F. Lance and confirmed by C. W. Hibbard as belonging to the genus *Sigmodon* and assigned the age "no older than late Pliocene and possibly as young as Pleistocene" (J. F. Lance, oral communication, 1959). Poorly preserved fossil remains of fish and horses were collected at the same site by Lance and the author, but certain identification of these fragments was not possible. Charophyte oogonia also were found here. These are fossils of plant fruitlets that grew on plants that flourished in quiet clear fresh-water ponds or lakes. These fossils are widely distributed stratigraphically and therefore are not diagnostic of age. Other fossil remains from this locality were not preserved sufficiently to permit classification.

The terrace sediments are being used as a source of sand and gravel in the Snowflake-Hay Hollow area. No water wells are known to have been drilled in these sediments.

QUATERNARY (RECENT) ALLUVIUM

Alluvial deposits of sand, gravel, and silt, ranging in thickness from a few inches to several tens of feet, partly fill washes cut by Silver Creek and ephemeral streams. Other Quaternary deposits consist of lacustrine silt and clay deposited in small depressions. The lakes that occupied the depressions, such as White Lake, probably always have been temporary lakes (playas).

In places downcutting by modern streams has left terraces of Quaternary alluvium in which shallow wells have been dug. The wells yield some water but are subject to seasonal fluctuations and are dry during extended drought. Therefore, the alluvial sediments here are considered to be only a minor source of ground water. In places along Silver Creek shallow wells drilled in the alluvial sediments are recharged by water from the creek. A dependable supply of water for domestic and stock use is furnished by such wells.

IGNEOUS ROCKS AND THEIR WATER-BEARING PROPERTIES

The igneous rocks that crop out in the area are from one or more volcanic flows. However, Precambrian intrusive rocks constitute the bedrock in well (A-14-20)33db, which was drilled as an oil test on the Holbrook anticline. Biotite granite reportedly was reached at an altitude of less than 3,700 feet, or about 2,300 feet below the land surface in the well. The depth to bedrock in the area probably is in this order of magnitude.

A sequence of scoriaceous basaltic lava flows, which probably originated in the White Mountain volcanic field to the southeast, covers most of the southeastern part of the area. The flows were deposited on a gentle north-sloping surface at an altitude of about 6,000 feet and have protected the underlying sediments from erosion. At the northern edge of the flow just south of Shumway, an abrupt descent of about 100 feet from the lava-covered area to the valley of Silver Creek indicates the amount of erosion.

For the most part, the lavas are highly fractured and in places are interbedded with cinders. This sequence includes zones of high permeability and transmissibility. The extrusive rocks occur on the highest elevations, which have the greatest amount of percipitation. Consequently they absorb a large amount of percipitation. Some springs and seeps issue at the contact between the lava and the underlying relatively impermeable sediments, and some issue from fissures or fractures in the lava. Silver Spring, near the head of Silver Creek, is one of the largest in the region, flowing approximately 2,000 gpm (gallons per minute) from a fracture zone.

Shallow dug wells in the lavas in places yield water for domestic and stock use. The contact zone between the lavas and the underlying Moenkopi shale beds is water bearing in some parts of the area; however, wells have been drilled through the lava into the underlying formations before obtaining enough water for stock supplies. The extrusive igneous rocks probably are most important as absorbers and transmitters of rainfall to underlying aquifers.

STRUCTURE

The regional dip of the sedimentary beds in the area from the Mogollon Rim north and northeast toward the center of Black Mesa basin, about 100 miles north of Snowflake, is about 30 to 35 feet per mile. The major structural feature that interrupts the regional slope is an asymmetrical fold referred to as the Holbrook anticline. The trace of the anticline plotted on the top of the Coconino sandstone is shown on plate 1, and two sections across it are shown in plate 2. The fold trends approximately N. 45° W., and is expressed topographically as a prominent ridge that begins near the southeast corner of the mapped area and extends to a point about 30 miles west of the area. About 2 miles north of Snowflake, Silver Creek breaches the ridge, cutting a canyon, mostly in the Coconino sandstone, more than 100 feet deep. Farther east the ridge flattens. To the west, at about the middle of T. 14 N., R. 20 E., the axis turns abruptly and trends almost north (fig. 5). The trend continues northward for several miles before the northwest course is resumed. The asymmetry of the fold is expressed in dips of 25° to 35° on the southwest flank and dips of 3° to 4° on the northeast flank. A syncline, commonly called the Dry Lake syncline, parallels the anticline on the south side of the ridge. In places small compressional ridges or buckles are present on the limb that is common to the anticline and syncline. Dips as great as 56° S. and 35° N. have been measured on these compressional ridges.

Superimposed on the main arch of the Holbrook anticline are several small domes, such as the Snowflake structure. Two wildcat oil tests have been drilled on the Snowflake structure, and beds containing some combustible gas were penetrated in the first well drilled, (A–14–20)33db. East of Taylor the Coconino sandstone is exposed in a small dome, which lies en echelon to the trend of the Holbrook anticline.

About 200 sinks (fig. 3) are included in an area of 4 to 5 square miles in Tps. 13–14 N., R. 20 E., on the steep south and west flanks of the Holbrook anticline. The sinks range in diameter from a few tens of

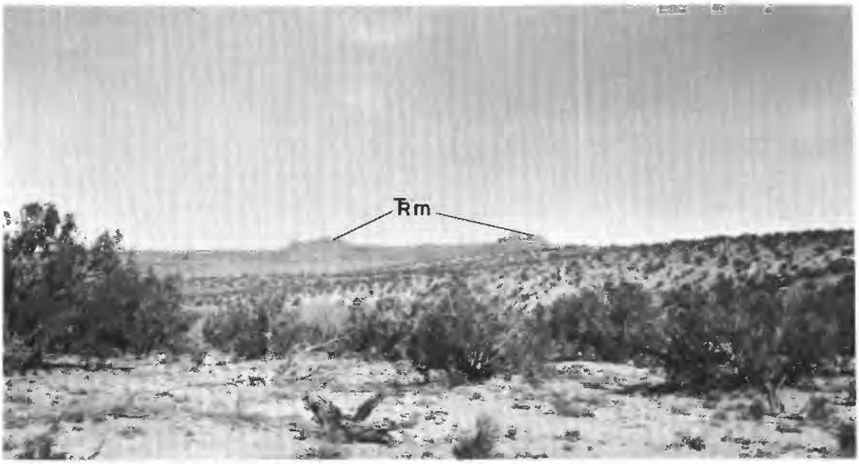

FIGURE 5.—View northward along the axis of the northward-trending part of the Holbrook anticline. The mesa on the left shows beds of the Moenkopi formation (Ꞧm) dipping west.

feet to more than 600 feet and in depth from about 10 to more than 200 feet. The walls of the sinks consist of the crossbedded Coconino sandstone overlain by the yellow sandy siltstone bed assigned to the Moenkopi formation. The surface between the sinks is irregular. Some sinks are enclosed completely by very steep or vertical walls; others have only one steep side. The sinks occur only on the steep limb of the anticline and therefore seem to be related to the fold. No lineation or regular pattern of distribution of the sinks was detected.

Aside from some local cross faulting and jointing, the overall strike of the joints, fractures, or fissures is about N. 45° W., or about parallel to the trend of the Holbrook anticline. The relation between the location of the sinks and the joint pattern is not evident. The area has no large faults; the largest observed is near Shumway (pl. 1).

Therefore, faulting does not seem to have played any part in the formation of the sinks.

The sinks occur stratigraphically below any limestone beds in the Moenkopi formation and the Coconino sandstone has no limestone or other soluble beds. Therefore, if solution of underlying rocks has formed the sinkholes, that solution probably was in the salt beds or possibly in the limestone beds of the Supai formation. In oil-test well (A–14–20)33db, the top of the anhydrite and gypsum beds of the Supai were reached at a depth of 620 feet and the top of the limestone beds of the same formation at a depth of 1,540 feet.

GROUND WATER

SOURCE, OCCURRENCE, AND MOVEMENT

Water from rain and snow may be accounted for in three ways: A part returns to the atmosphere by evapotranspiration from wetted surfaces and from vegetation; a part seeps into the ground and supplies water for soil moisture, and, under favorable conditions, some may percolate beyond this zone to the ground-water reservoir; and a part flows over the land surface in streams and rivers on its way to the ocean. In most areas the part that seeps into the ground is a small percentage of the total, but over long periods of time (centuries) the aquifers have been filled by this process and a hydrologic balance established. That is, the amount of water leaving the underground reservoir by natural discharge (springs, seeps, evaporation, and transpiration) equals the amount that enters. The balance is maintained until it is disturbed by pumping water from wells. Continual pumping of quantities in excess of recharge will result in the drying up of the springs and seeps and the lowering of the water table.

The principal aquifer in the Snowflake-Hay Hollow area is the Coconino sandstone. This formation is at least 550 feet thick (table 1) and of wide areal extent; but it is not uniform in the amount of ground water it contains. The amount of water that the formation will yield to wells varies from bed to bed and from place to place in the same bed, chiefly because of differences in the degree of cementation. The thickness of the saturated zone is variable because of the folding of the formation (pl. 2). Thus, only a fraction of the total thickness of the formation is saturated beneath the Holbrook anticline; whereas the entire thickness is saturated in some other parts of the area, and the water is under artesian pressure. Where faulted and fractured, the Coconino sandstone yields large quantities of water to wells.

Artesian conditions are widespread throughout the area where the Coconino sandstone is confined beneath layers of less permeable material. The amount of pressure varies between wells, causing the water levels to rise a few or many feet above the water surface of the aquifer or to flow at the land surface.

The Moenkopi formation is a secondary aquifer in the area, yielding small amounts of water to shallow domestic and stock wells. Several shallow domestic wells, especially in the towns of Snowflake and Taylor, and a few stock wells in the area supply water of good quality from the Moenkopi formation. The wells drilled in the Moenkopi usually are less than 100 feet deep and have water levels ranging from about 10 to more than 60 feet below the land surface. In places wells drilled through the Moenkopi into the Coconino sandstone tap aquifers in both formations.

Quaternary alluvium along the stream beds and Quaternary lava flows locally contain sufficient water to support small stock or domestic wells.

The following discussion of ground water relates to the principal aquifer only unless otherwise indicated.

Water levels in wells in the Snowflake-Hay Hollow area range from a few feet above to about 530 feet below the land surface (table 2). Measurements of the depth to water were made wherever possible, and the altitude of the land surface above mean sea level was established at the wells by means of an aneroid barometric altimeter. Most of these altitudes have an accuracy of about ± 5 feet. From these data the altitude of the water surface above mean sea level was established at each well where a measurement was taken. In the southwestern part of the area, altitudes of the ground-water surface represent points on the water table of the principal aquifer, but elsewhere, and especially northeast of the Holbrook anticline, the altitudes represent points on the pressure surface of the principal aquifer, where it is confined beneath shale beds of the Moenkopi formation. However, because the ground water in the principal aquifer probably is interconnected throughout the area, a single contour map (pl. 3) has been constructed. For convenience, the water surface will be referred to as a water table, although it is recognized that in much of the area it is a pressure surface of a confined body of water. The direction of ground-water movement can be ascertained at any point in the area from the water-table map. In any given ground-water basin, water moves in the direction of the hydraulic gradient from areas of higher heads toward areas of lower heads. The water-table contour lines on the map show the gradient of the water surface as well as the direction of ground-water movement, which is at right angles to the contour lines. In places where well data are ample, the control is better and the contours more accurately depict the slope and shape of the water table; whereas in areas where wells are scarce more interpolation is needed to establish the contours, and the slope and shape of the water

TABLE 2.—*Records of selected wells and springs in the Snowflake-Hay Hollow area, Navajo County, Ariz.*

Location: Figure 2 shows numbering system for wells and springs.
Pump: C, cylinder; J, jack; T, turbine; N, none.
Power: W, wind; E, electric; Bu, butane; G, gasoline.
Use: I, irrigation; D, domestic; S, stock; PS, public supply; N, none.

Location No.	Depth of well (feet)	Elevation of land surface above msl (feet)	Water level: Depth below land surface (feet)	Water level: Date of measurement	Pump and power	Use	Chemical analysis in report	Well log in report	Remarks
Wells									
(A-11-22) 6dc						I			New well, no data.
13cad	651	6,040	105.55	Nov. 21, 1953	N	N		×	Partial log.
33aaa	485	6,400	438.5	Nov. 22, 1953	C, W	S			
(A-11-23) 3bba	464		[1] 340		C,W	S	×	×	
6abb	357	6,080	231.6	Nov. 20, 1953	C,W	S		×	
14cdd	240	6,360			C,W	S			
19bd	100		[1] 10		E	D,S			
32ba	218		[1] 168		C,W	S		×	
(A-12-21) 2aa	162	5,632	19.70	Jan. 7, 1951	J,E	D			
2ad	205	5,648	41.70	do		D			
2ba	137	5,627			C,E	D			
2bd	200		87.76	Apr. 23, 1952	T,E	PS		×	
2dc	[1] 230		[1] 65		C,W	D	×		
3bb	210		[1] 125		T,E	I			
6ba	240	5,760	161.04	Oct. 24, 1953	T,E	I	×	×	
8cc		5,790	153.47	Nov. 23, 1953	C,W	S			
12dc	123	5,660	35.04	Oct. 24, 1953	T,E	I			
22bbb	210	5,815	142.34	Nov. 22, 1953	C,W	S	×		Depth to water, 146.06 feet, June 10, 1958.
24ad			(2)		N	I			New well.
24ddd	235	5,645	(2)		T,E	I	×	×	
(A-12-22) 4cd	180				C,W	D,S			
30Ebc	427	5,765	98.73	July 31, 1953	T,Bu	I			
30Wdc	82		49.28	Sept. 6, 1951	C,W	D			
(A-12-23) 10ab	375	5,925	319.6	Nov. 21, 1953	C,W	S		×	
20cb	240	5,930	220.1	do	C,W	S			
(A-13-20) 3dd	3,140	5,956			N	N			Oil test.
4ca	485				C,W	S			New well.
13ddd	609	5,780	259.6	Sept. 10, 1956				×	Observation test well No. 5, depth to water 262.88 feet, June 10, 1958.

See footnotes at end of table.

TABLE 2.—*Records of selected wells and springs in the Snowflake-Hay Hollow area, Navajo County, Ariz.*—Continued

Location No.	Depth of well (feet)	Elevation of land surface above msl (feet)	Water level		Pump and power	Use	Chemical analysis in report	Well log in report	Remarks
			Depth below land surface (feet)	Date of measurement					
Wells—Continued									
(A-13-21) 10cda	416	5,632			N	N			Observation test well No. 6.
10ddc	120	5,600	86.36	June 10, 1958	C, W	S			
13ddc	285	5,590	65.80	Apr. 23, 1952	T, E	I			Depth to Coconino sandstone 210 feet.[1]
14cbc	160	5,590	67.08	Oct. 24, 1953	T, E	I		×	
16dc			94.2	June 10, 1958	C, W	S			
23cb	252	5,610	[1]72		T, E	I		×	
23da	82	5,600	57.05	July 11, 1951	T, E	D	×		
23dc	297	5,650	103.90	Oct. 24, 1953	T, E	I	×		Depth to Coconino sandstone 276 feet.[1]
24cc	328	5,608	60.41	do	T, E	I	×	×	
26aa	300	5,670	114.40	do	T, E	PS	×		
26da	65				E	D	×		
29bbb	700	5,724	177.0	June 10, 1958					Main test well No. 2.
29bdb	725	5,727	172.7	June 18, 1956	N	N		×	Observation test well No. 1; depth to water 174.57 feet, June 10, 1958.
29ddd	671	5,740	176.1	Aug. 9, 1956	N	N		×	Observation test well No. 3; depth to water 183.09 feet, June 10, 1958.
31dda	212	5,730	134.00	Nov. 4, 1953	T, E	I	×	×	
34cc	162	5,660	88.07	Oct. 24, 1953	T, E	I	×	×	
34dcc	248	5,660	74.77	do	C, E	D, S	×	×	
36bbb					T, E	I			New well.
(A-13-22) 10cc	280				C, W	D, S			
(A-13-23) 8ad	[1]35		18.2	Mar. 12, 1951	C, W	D, S	×		
11db	350	5,795	[1]303		C, W	S		×	
23db	405	5,865	294	Nov. 4, 1953	C, W	S			Depth to Coconino sandstone 190 feet.[1]
(A-14-20) 4dc	3,387	5,820			N	N		×	Oil test.
33da		6,000	533	Nov. 4, 1953	C, W	S	×		
33db	3,724	6,000			N	N		×	Do.
(A-14-21) 19ba		5,780	[1]357		C, W	S			Depth to Coconino sandstone 173 feet.[1]
24aa	195	5,535	184.59	Oct. 27, 1953	C, W	S			Depth to water, 196.53 feet, June 12, 1958.
(A-14-22) 6ca					J, G	S			New well.
7ca	270		234.27	June 12, 1958	C, W	S		×	
34cc	440	5,795	375.0	Oct. 23, 1953	C, W	S			Depth to Coconino sandstone 100 feet.[1]
(A-14-23) 2bd	525	5,395	54.64	Oct. 25, 1953	T, E	I	×		Depth to Coconino sandstone 312 feet.[1]
19aa	360	5,615	273	do	C, W	S	×	×	
31cd	340	5,710	283	do	C, W	S		×	

(A-15-21) 8da	400	5,510	345.25	Mar. 4, 1953	C, W	S	×		Depth to Coconino sandstone 370 feet.[1]
32ac	[1] 430		372.58	June 11, 1958	C, W	S			
35aa	340	5,540	259.33	Oct. 21, 1953	C, W	S			
(A-15-22) 21ccc									Drilling June 12, 1958.
32dd		5,400	130.67	Oct. 27, 1953	C, W	S			
34ba		5,390				D, S			
36ac		5,460	172.10	Oct. 27, 1953	C, W	S			
(A-15-23) 17da		5,335	37.46	do		S	×		
26bda	530		(2)	Apr. 28, 1952	T, E	I			Not measurable. Estimated level 8 feet above land surface.
26cc	482		13.95	Sept. 14, 1950	T, E	I		×	
27da	500				C, E	I			
27ddc	600	5,335	20.35	July 31, 1953	T, E	I		×	
28dc	425	5,340	24.55	do	T, E	I		×	Depth to water, 10.25 feet, May 13, 1957.
28ddd	297	5,329			C, W	S		×	
34aa	430	5,345	24.8	June 12, 1952	T, E	I	×	×	
34dd	385		14.88	Mar. 8, 1951	T, E	S, I		×	
(A-16-21) 30dd			304.19	June 11, 1958	C, W	S			
35dd		5,340	187.10	Oct. 26, 1953	C, W	S			Depth to water, 199.45 feet, June 11, 1958. Depth to Coconino sandstone 300 feet.[1]
Springs									
(A-11-23) 20d				Oct. 11, 1954		I	×		Discharge 2,260 gpm.
(A-12-21) 25da		5,689				I	×		
(A-12-22) 31Wac		5,690				I	×		
33ac1		5,825				S, I	×		
33ac2		5,825				S, I			
33ac3		5,825				S, I			
33ac4		5,825				S, I			

[1] Reported. [2] Flowing.

table are only approximate. The contour map for the Snowflake-Hay Hollow area (pl. 3) was drawn using 1953 data and indicates that the movement of ground water generally is northward, changing to northwestward near the Little Colorado River. The gradient is about 28 feet per mile.

RECHARGE

Large amounts of rain and snow (20–30 inches) fall in the Mogollon Rim and the mountainous country south of the area, where the Coconino sandstone crops out over an area of several hundreds of square miles. Consequently, a small percentage of the precipitation directly recharges this aquifer. The Coconino sandstone also is recharged by percolation of water through the sandy Kaibab limestone in places where it overlies the Coconino sandstone and through the fractured basaltic lavas that overlie the Kaibab limestone.

Seepage from flow in streams constitutes another means of recharge to the ground-water reservoir. That part of the precipitation that runs off finds its way into the upper reaches of some of the intermittent streams in the southern part of the area, such as Show Low Creek, Cottonwood Wash, and Mortensen Wash. A part of this runoff usually seeps into the coarse sand and gravel of the stream channels, where it may recharge the ground-water reservoir.

Lone Pine Dam and Reservoir on Show Low Creek, although unsuccessful as a water-storage reservoir, allows water to percolate slowly through the thin highly fractured section of the Kaibab limestone into the underlying Coconino sandstone. Runoff in washes farther north and to the east does not usually constitute recharge to the aquifer because many of the washes are cut into the relatively impermeable red silt beds of the Moenkopi formation. Flow in the washes usually reaches the main drainage of Silver Creek, Hay Hollow Wash, or the Little Colorado River.

North of Snowflake, Silver Creek has breached the Holbrook anticline downcutting into the Coconino sandstone, forming a narrow canyon through which the perennial waters of Silver Creek flow for more than 15 miles. In the canyon the channel of the creek is filled to an unknown depth with Recent alluvium, and grasses, trees, and shrubs grow in abundance along the floor. The water-table contours suggest that in places the stream intercepts the water table and is fed by water from the ground-water reservoir. In other places the water table is well below the surface in areas of outcrop of the Coconino sandstone, and the stream probably loses water to the ground-water reservoir.

There has been little residual drawdown of water levels in wells in the Snowflake-Hay Hollow area during the last 10 years. Theoretical computations, using coefficients of transmissibility and storage obtained from the Hay Hollow aquifer test, show substantial drawdowns are possible in 10 years if the ground water is pumped only from storage. Therefore, it is believed that recharge adequate to replace present withdrawals is entering the area.

DISCHARGE

Ground water is discharged from the aquifer by natural means through evaporation, transpiration, and springs and seeps and by artificial means through wells.

NATURAL DISCHARGE

In the Snowflake-Hay Hollow area, ground-water evaporation probably is negligible because throughout most of the area the water table lies several tens to several hundreds of feet below the surface (table 2). Even in places of effluent seepage along the washes, the total amount of wetted area is so small that evaporation losses are small.

The ephemeral streams and washes support the growth of abundant grasses, shrubs, and trees in their channels and along their banks in the southern part of the area. The soil-moisture zone probably supports most of the growth, but the water table in some areas along Cottonwood Wash and elsewhere is close enough to the surface to be reached by the roots of cottonwood trees and other phreatophytes. Data are insufficient to give a quantitative estimate of the amount of water transpired by phreatophytes in the area.

The greatest natural discharge of ground water is by springs and seeps. Silver Spring (A-11-23)20d (pl. 1), the largest in the area, discharges more than 2,000 gpm and is the main source of water for Silver Creek, but numerous seeps in the upper part of Silver Creek contribute to its perennial flow. Four springs are the source of the water for Love Lake. Their total discharge is estimated to range from 500 to 2,000 gpm. Much of the water from the springs is used by diverting it from Silver Creek for irrigation of lands near Shumway, Taylor, and Snowflake.

ARTIFICIAL DISCHARGE

Ground water is discharged from pumped and flowing wells. Wells are pumped only when the water is for irrigation, industrial, and domestic purposes, or for stock watering. On the other hand, the flowing wells are uncontrolled, and, during the nongrowing season, the water flows to waste.

Two areas have flowing wells, one in Hay Hollow and the other south of Snowflake. The number of wells that flow and the amount of discharge from the flowing wells has decreased in the Hay Hollow area with the drilling of more wells and the decline of artesian head caused by pumping. Thus, the amount of water flowing to waste in that area now is small. The flowing wells in the Snowflake area discharge into Silver Creek, and their natural flow is uncontrolled.

As stated in the section on utilization, the amount of ground water discharged in the area is about 15,000 acre-feet per year.

UTILIZATION

Ground water in the Snowflake-Hay Hollow area is utilized directly from pumped wells and indirectly from Silver Creek by diversion of the flow of springs and flowing wells.

Most of the water in Silver Creek is diverted for irrigation during the growing season, which averages about 132 days per year at Snowflake (Smith, 1945). The amount of water used varies with the amount of precipitation during the season, but a large percentage of the streamflow is used in most growing seasons. However, during the nongrowing season, or almost two-thirds of the year, most of the streamflow is not used. Much of it is evaporated and transpired, and the remainder becomes increasingly poor in quality as it flows northward. About 3,000 acre-feet of water is stored in Daggs Reservoir, about 4 miles downstream from Silver Spring in parts of secs. 10, 11, and 15, T. 11 N., R. 22 E., but many springs and seeps, notably in the Shumway area, issue downstream from the reservoir. Thus, the amount of water that might be used from Silver Creek is considerably greater than the amount now used.

More than 100 wells are in use in the area (table 2), of which about 25 are irrigation wells. The irrigation wells range in depth from about 125 feet to more than 400 feet. They yield from about 150 to 2,000 gpm, and water levels range from several feet above to about 160 feet below the land surface. About 1,800 acres of land, or about 35 percent of the total irrigated acreage, is irrigated directly from pumped wells. About 2½ acre-feet of water per acre per year is used to raise the alfalfa, wheat, corn, and other products grown in the area. The annual pumpage for irrigation is about 4,500 acre-feet. The remaining 65 percent of the cultivated land is irrigated by water diverted from the flow in Silver Creek, which consists mostly of ground-water discharge from springs and flowing wells, amounting to about 5,500 acre-feet per year.

Most of the stock wells in the area have been drilled deep enough to tap the Coconino sandstone. Usually, the wells are located on the higher range lands and range in depth from about 200 to more than 600 feet. Most wells are equipped with windmills and have storage tanks. Water levels in the stock wells range in depth from about 65 to more than 500 feet. Domestic, stock, and industrial use is estimated to be about 500 acre-feet a year, bringing the estimate of total use of ground water to 10,500 acre-feet per year.

The difference between the total estimate of ground-water discharge in the area (15,000 acre-feet) and the estimate of total ground water used (10,500 acre-feet) is 4,500 acre-feet, which is attributed to evapotranspiration and surface flow out of the area.

TEST WELLS

In the hope of determining if ground water could be obtained from wells to replace surface water lost to the area by divergence, a test well was drilled by the irrigation district on Silver Creek, half a mile north of Shumway in the SE¼SE¼SE¼ sec. 24, T. 12 N., R. 21 E. The 16-inch well penetrated the top of the Coconino sandstone at 102 feet (table 1). It was reported that water first appeared in the bore hole at 8 feet below the land surface and that additional water was gained as drilling continued. Water in the Coconino sandstone below 102 feet was under sufficient artesian pressure to cause it to flow at the surface. Drilling was difficult because of the caving of the loosely consolidated sandstone, and the driller "lost hole" because he was not able to carry the casing down as he drilled. The well was completed at a depth of 235 feet and equipped with an electric turbine pump. It has no control valve and continues to flow into Silver Creek when not being pumped. The flow is estimated to be about 700 gpm and the pumping rate is about 1,900 gpm.

Another well was drilled half a mile farther north. It also flows into Silver Creek and is not equipped with either pump or shut-in controls. The capacity of these wells is sufficient to replace the surface water lost to the area by divergence.

FLUCTUATIONS OF THE WATER TABLE

Water levels in several observation wells in the Snowflake-Hay Hollow area have been measured periodically. A graphic record of fluctuations in 6 of the wells is given in figure 6. The period of record is 8 years, 1950–58. The water level in well (A–13–21)14cbc in the Snowflake area and that in well (A–12–21)12dc in the Taylor area was nearly constant during the entire period. The water level in well (A–12–22)30Ebc has fluctuated seasonally. It is in the Shumway area at the edge of the lava flow and reflects the pumpage for irrigation during the summers of 1951, 1953, and 1955 and the recovery after the pumping seasons. In the years when no decline in water level was recorded, rains were sufficient in the area to reduce the pumping for irrigation. Wells (A–15–23)28dc and (A–15–23)27ddc are in the Hay Hallow area, where all the irrigation water comes from wells. The water-level fluctuations are larger than those in other areas, but both wells had almost recovered their former water levels by 1957 and

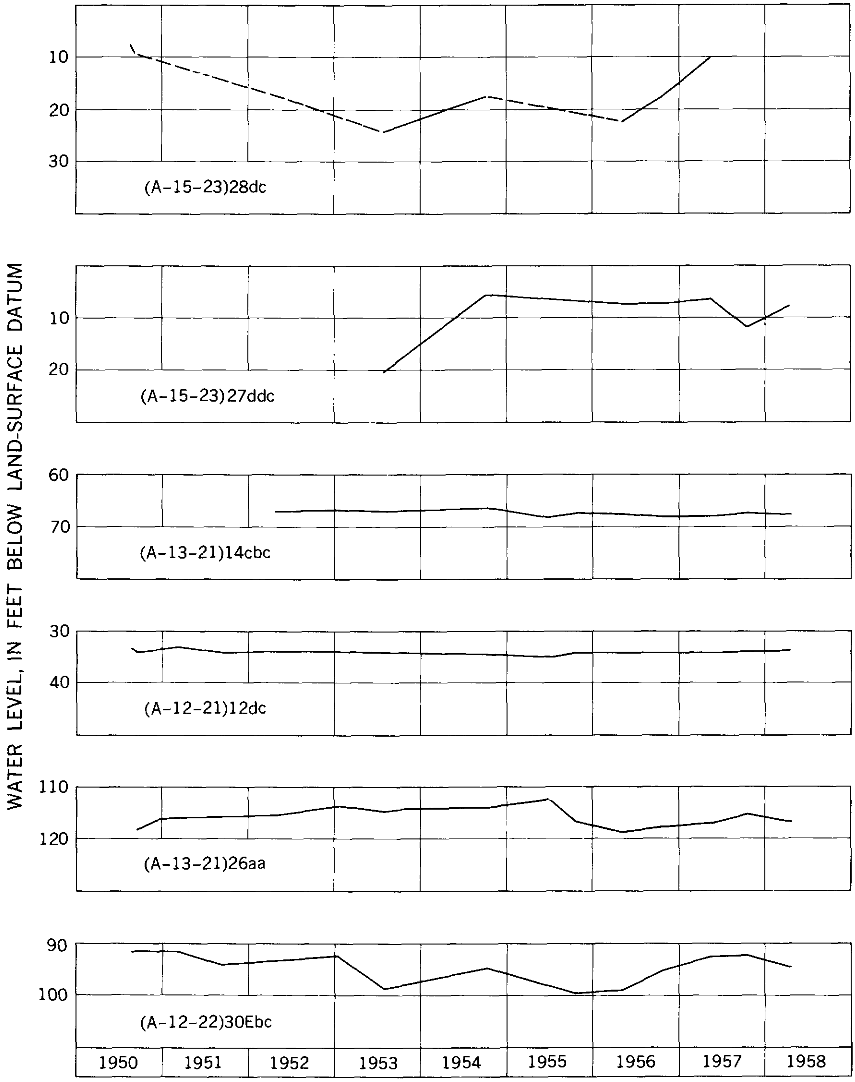

FIGURE 6.—Water levels in selected wells, Snowflake-Hay Hollow area, Navajo County, Ariz.

1958. The absence of any progressive decline in the water table suggests that the ground water in storage is not being depleted by withdrawals and, therefore, that the amount of discharge by the wells and springs is balanced by a like amount of recharge coming into the area.

INTERRELATION OF SURFACE WATER AND GROUND WATER

Ground water and surface water in the Snowflake-Hay Hollow area are related directly. Virtually all the water that flows in the two perennial streams, Silver Creek and the part of the Little Colorado River that traverses the area, comes from ground-water discharge. These streams head in the mountainous country to the south and southeast and depend on the discharge of ground water from springs and seeps for their perennial flow. During periods of drought, some of the springs and seeps that normally supply water to the streams dry up, and the streamflow is reduced.

STORAGE AND TRANSMISSIBILITY

The hydrologic properties of an aquifer are determined by aquifer tests, which consist of pumping a well at a constant rate for a specified time and measuring the decline of the water levels in it and in nearby observation wells. After the pumping well is shut off, measurements are made in all wells to record the recovery of water levels. The field data are analyzed to determine the hydrologic characteristics of the aquifer, which determine the quantity of ground water available to wells in the area. The main hydrologic properties of an aquifer are its ability to transmit and store water. The ability of the aquifer to transmit water is measured by its coefficient of transmissibility, and the ability to store water is measured by its coefficient of storage, or the quantity of water yielded from storage when the head is lowered.

The coefficient of transmissibility, T, is defined as the rate of flow of water, in gallons per day, at the prevailing temperature through a vertical strip of the aquifer 1 foot wide extending the full height of the aquifer under a hydraulic gradient of 100 percent. The coefficient of storage, S, of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

In August 1950, an aquifer test of the Coconino sandstone was made in the Hay Hollow area about 14 miles northeast of Snowflake. A pumping well yielded 700 gpm with about 38 feet of drawdown, indicating a specific capacity of about 18 gpm per foot of drawdown. Water-level declines were observed in a well 1 mile away. Before the test an observation well 3,500 feet from the pumping well was flowing at the rate of 100 gpm and the shut-in head was measured as several feet above the point of discharge. During the test the effect of the pumping well reduced the flow to about 5 gpm with a slight reduction of head. Results of the test indicate a coefficient of transmissibility of 30,000 to 60,000 gpd (gallons per day) per foot and a storage coefficient of 0.001 to 0.003.

The gound water in the Coconino sandstone is under water-table conditions in the southwestern part of the area and grades into artesian conditions northeastward. Results of the aquifer test at Hay Hollow indicate a semiartesian coefficient of storage. In other areas, the coefficient of storage may be much larger and approach water-table conditions. Aquifer tests of short duration (1 day or less) may indicate low values for the coefficient of storage in semiartesian or water-table aquifers because of slow drainage of the sediments. Therefore, the long-term storage coefficient in the Snowflake-Hay Hollow area may be greater than indicated by the aquifer test.

The specific yield is defined as the amount of water that will drain out of saturated material by gravity. No factual data were collected of specific yield from the Coconino sandstone, but, if a reasonable value of 0.05 is assumed with a saturated thickness of 500 feet of sandstone, a square mile of aquifer could yield to wells about 16,000 acre-feet of water from storage.

GROUND WATER FOR FUTURE DEVELOPMENT

The investigation that resulted in this report was made after an extended drought that caused a reduction in the flow of the springs in the Snowflake-Hay Hollow area and, therefore, in the flow of Silver Creek. Because the diversions from Silver Creek were no longer adequate to meet the irrigation requirements, the deficiency was made up in part by increased pumping of wells. The total supply of water, however, still was less than the requirements. When the test wells drilled by the irrigation district proved to be capable of yielding as much as 1,900 gpm per well to the system, the immediate irrigation needs were satisfied. However, the consumption of water for irrigation, industrial, and other uses will increase in the future.

The thickness and regional extent of the principal aquifer, its ability to transmit and to store water, and its exposure to recharge in adjoining areas indicates that considerably more ground water than is presently utilized could be developed. Irrigated acreage in the area is likely to increase, but the increase may be small because the short growing season and other climatic factors limit the crops that can be grown largely to hays and grains. Likewise much of the area has a soil cover of less than 18 inches and is therefore unsuitable for agriculture (Gerald Kester, oral communication, 1952). Industrial development also will be limited by the scarcity of raw materials and the remoteness of markets for finished products. Thus, it appears that the amount of ground water is ample to satisfy the needs of presently anticipated agricultural and industrial growth. Nevertheless, wells should be spaced for enough apart that they do not seriously interfere with one another, careful records should be kept of each well drilled, and further detailed study should be made in the area before undertaking any large-scale development of the ground-water resources.

QUALITY OF WATER

CHEMICAL CHARACTER OF THE WATER

Water in the Snowflake-Hay Hollow area is characterized by uniformity in chemical quality. The water contains moderate amounts of dissolved solids, consisting mostly of calcium and bicarbonate as shown in table 3. The concentration of chemical constituents shows a pattern of increase from south to north. This increase is to be expected, as the water moves away from the area of recharge. From Silver Spring, which has water with the lowest concentration of dissolved solids, north to Snowflake, the dissolved solids range from about 100 to 325 ppm. North of Snowflake, there is a slight increase in sodium, chloride, and sulfate content of the water and a slight decrease in bicarbonate content. The overall effect is an increase in the content of dissolved solids, ranging from about 325 to 625 ppm.

Pattern diagrams of the quality of water in the area (adapted from Stiff, 1951) are shown in plate 4. The diagrams are the results of plotting the chemical constituents of the water on graph paper, in equivalents per million (epm). Equivalents per million is a unit for expressing the concentration of chemical constituents in terms of the reacting values of the electrically charged particles, or ions, in solution. One equivalent per million of a positively charged ion will react with 1 epm of a negatively charged ion. If the water analysis is in parts per million, it can be converted easily to equivalents per million by multiplying each chemical constituent in parts per million units by a factor. A zero vertical line is chosen on a grid and like values are assigned to equally spaced vertical lines on either side. Equally spaced horizontal lines are chosen to represent the various chemical constituents. Cations are plotted to the left and anions to the right of the zero vertical line. Where needed, values for the different ions can be given. The concentration (milliequivalents) of each ion is plotted, and the points are connected by lines, forming a closed pattern. The advantage of this method of presentation is the ease with which various waters can be compared.

The three patterns centered around Snowflake (pl. 4) were plotted from analyses of water from three wells. The two patterns on the right represent water from wells drilled into the Moenkopi formation only, whereas the pattern on the left represents water from a well drilled through the Moenkopi and into the Coconino sandstone. The patterns do not differ markedly. Plate 2 indicates that in places in the Snowflake-Hay Hollow area artesian pressure causes the water to rise above the Coconino sandstone aquifer into the Moenkopi formation. This phenomenon may be the chief reason that the Moenkopi supplies water to some wells in the area. Harrell and

TABLE 3.—*Chemical analyses of ground water from selected wells and springs in the Snowflake-Hay Hollow area, Navajo County, Ariz.*

[Parts per million except as indicated]

Location No.	Date of collection	Depth of well (feet)	Temperature (°F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Specific conductance (micromhos at 25°C)
Wells																
(A-11-23) 3bba	Nov. 21, 1953	464	64	19	21	10	12	124	8.4	6.0	0.2	1.1	139	94	22	222
(A-12-21) 2dc	Mar. 10, 1951	[1] 230	58	29	39	22	19	211	29	17	.4	2.7	262	188	18	461
6ba	Apr. 24, 1952	240	60					240		6.0						451
22bbb	Mar. 10, 1951	210	60	12	59	22	6.2	274	17	5.0	.4	1.2	258	238	5.0	457
24ddd	July 30, 1951	235	62	31	35	21	15	230	9.9	4.0	.2	1.5	231	174	16	369
(A-13-21) 23da	July 11, 1951	82	60	13	66	15	16	238	38	14	.2	8.7	288	226	14	484
23dc	Aug. 24, 1950	297	57	20	51	16	15	224	27	10	.2	.6	250	193	15	413
24cc	June 7, 1951	328	58					413		7.0						686
26aa	July 19, 1946	300	59		66	24	26	305	46	13	.2	2.7	328	263	18	566
26da	June 14, 1951	65	60	27	95	32	34	431	57	15	.6	7.8	480	368	17	777
31dda	Aug. 23, 1950	212	62	15	64	22	9.7	256	45	8.0	.1	2.5	292	250	8.0	485
34cc	Aug. 24, 1950	162	60	25	47	23	17	264	19	7.0	.2	1.2	269	212	15	441
34dcc	July 2, 1946	248	60		52	27	21	278	47	6.0	.0	2.1	292	240		506
(A-13-23) 8ad	Mar. 12, 1951	[1] 35	53	12	76	23	4.1	269	51	3.0	.4	18	320	284	3.0	533
(A-14-20) 33da	July 10, 1951		66	12	107	50	170	221	493	102	.6	4.4	1,050	472	44	1,550
(A-14-23) 2bd	Oct. 16, 1951	525	63					162		31						516
19aa	Oct. 16, 1951	360						143		67						2,680
(A-15-21) 8da	June 11, 1946	400	62		71	28	121	260	110	160	.3	1.1	620	292		1,100
(A-15-23) 17da	Nov. 20, 1953		62	12	65	24	32	168	124	44	.2	.4	385	260	21	644
34aa	Sept. 1, 1950	430	63	12	49	19	27	139	92	34	.6	.3	302	200	23	502
Springs																
(A-11-23) 20d	Feb. 20, 1952		60	28	14	9.0	7.8	100	2.7	2.0	0.1	0.7	113	72	19	162
(A-12-21) 25da	Mar. 12, 1951		65	29	68	32	16	372	20	5.0	.4	1.7	355	301	10	590
(A-12-22) 31Wac	do		63	35	52	30	13	315	14	5.0	.4	1.4	306	253	10	498
33acl	June 25, 1952		58	31	42	20	24	234	21	16	.4	2.6	272	187	22	437

[1] Reported.

Eckel (1937, p. 45) stated that the water from the Moenkopi formation was of very poor quality. Plate 4 shows that in the Snowflake-Hay Hollow area the water from the Moenkopi formation is comparable in quality to that from the Coconino sandstone.

The water from well (A-14-20)33da, 9 miles northwest of Snowflake, has an increase in sodium and chloride and an excessive amount of sulfate as compared to wells near Snowflake. The well taps the lower part of the Coconino sandstone. The total depth of the well or the amount of casing is not known, but it is very likely that it was drilled through the Coconino into the underlying Supai formation. The log of well (A-14-20)33db, an oil test drilled less than a quarter of a mile to the west, shows anhydrite, salt, and gypsum in the interval below 620 feet. Therefore, the quality of water from well (A-14-20)-33da could indicate that highly mineralized water from the underlying Supai formation was entering the well. The sample probably is not representative of water from the Coconino sandstone in this area.

Water from well (A-15-21)8da, about 11 miles north-northeast of the above-mentioned well, has a similar pattern (pl. 4) with the exception of the excessive sulfate content.

RELATION OF QUALITY OF WATER TO USE

The water of the Snowflake-Hay Hollow area can be classified as good to excellent for domestic use, according to the standards set forth by Wilcox (1948, p. 26) and U.S. Public Health Service (1946, p. 371-384). The low fluoride content makes the water safe for consumption by young children. The low percent sodium and the equally low concentrations of other minerals that are harmful to the growth of crops and objectionable for industrial processes also make the water one of the best in the State for these uses.

CONCLUSIONS AND SUGGESTIONS

The purpose of the investigation was accomplished, for the most part, when the drilling of test wells by the irrigation district demonstrated that ground water from the principal aquifer could be obtained in quantities more than sufficient to replace the surface water diverted from the area. Furthermore, the study indicated that ample supplies of ground water probably would be available for the foreseeable irrigation development. The geologic and hydrologic facts upon which these conclusions are based are presented in the report and may be summarized as follows: The principal aquifer (the Coconino sandstone) is present everywhere in the area but varies greatly in its water-bearing characteristics; a map of the water table shows that the ground water moves northward at a rate of less than 1 foot per day under a gradient of about 28 feet per mile; the Cocinono sandstone crops out extensively south and west of the area, where it may be recharged; natural discharge from the principal aquifer is cheifly from springs and seeps, and artificial discharge is from flowing wells and pumped wells; and the amount of ground water in storage that can be pumped by wells for man's use in 500 feet of saturated thickness of the principal aquifer in 1 square mile is less than the assumed specific yield of 16,000 acre-feet.

Rocks older than the Coconino sandstone probably will not yield potable water in the area, and there is little incentive therefore to drill deeper than the principal aquifer. The Coconino sandstone is by far the most important aquifer in the area, but sandstone and conglomerate beds in the Moenkopi formation, Quaternary alluvium along the stream beds, and Quaternary lava flows locally furnish small supplies of water to stock and domestic wells.

Although an ample supply of ground water is available to meet present requirements, a more detailed study of the area would be necessary to make quantitative determinations of the amount of additional ground water available to meet unforeseen future demands. Therefore, it is important that imformation which would facilitate such a detailed study be obtained as new wells are drilled in the area. The information should include the accurate location of each well, the depth to water and total depth drilled, the size and depth of casing, the location of perforation intervals, and a driller's log and samples of the well-bore cuttings. Also, pumping tests should be made and the data preserved. These data should include the altitude of the water table, the quantity of water pumped, the drawdown or pumping lift, and the permeability, transmissibility, and coefficient of storage, if determined.

The growing use of water makes it important to conserve water even in those areas having no water shortage.

Water in the Snowflake-Hay Hollow area can be conserved in several ways. The irrigation ditches that service many of the farms are in need of repair and lining to prevent seepage and leaks. Clearing the heavy growth of weeds, grass, and trees from the ditch areas would save water. However, the most effective conservation measures relate to the springs and uncontrolled flowing wells that discharge into Silver Creek (fig. 7). During the nongrowing season (about 7½ months) this water flows out of the area, and is largely lost to beneficial use (fig. 8). The spring flow could be conserved during the nongrowing season by the construction of one or more storage reservoirs, but the flowing wells could be closed by shutoff valves when not in use.

FIGURE 7.—An irrigation well of the Shumway Irrigation District with pump to augment natural artesian flow.

FIGURE 8.—Silver Creek at Shumway and lava flow (Qv) over Moenkopi formation (T̶Rm) in background.

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