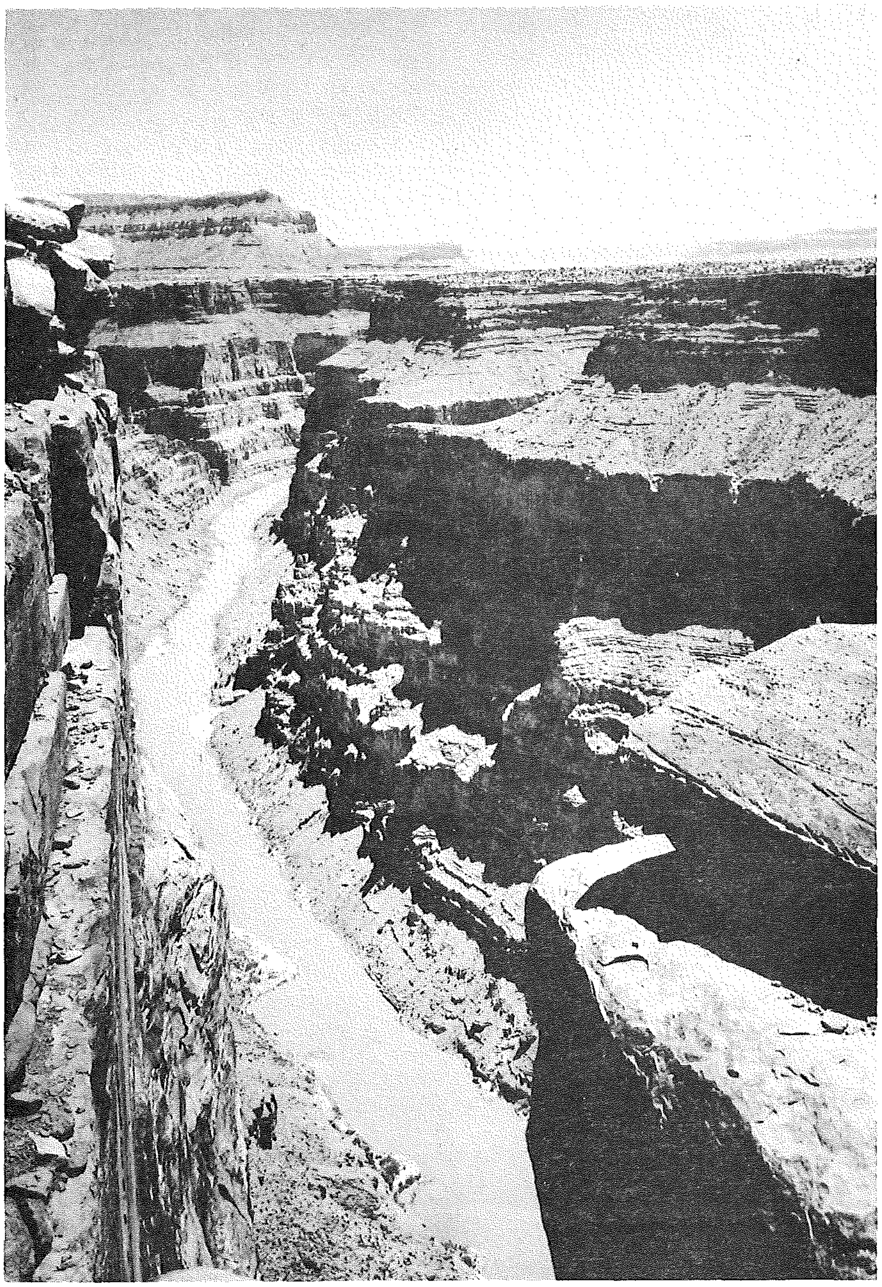

Photograph by Ray Manley

FRONTISPIECE

The Grand Canyon near Toroweap Valley, looking upstream.

WATER-RESOURCES REPORT NUMBER THIRTY-FOUR

ARIZONA STATE LAND DEPARTMENT

OBED M. LASSEN, COMMISSIONER

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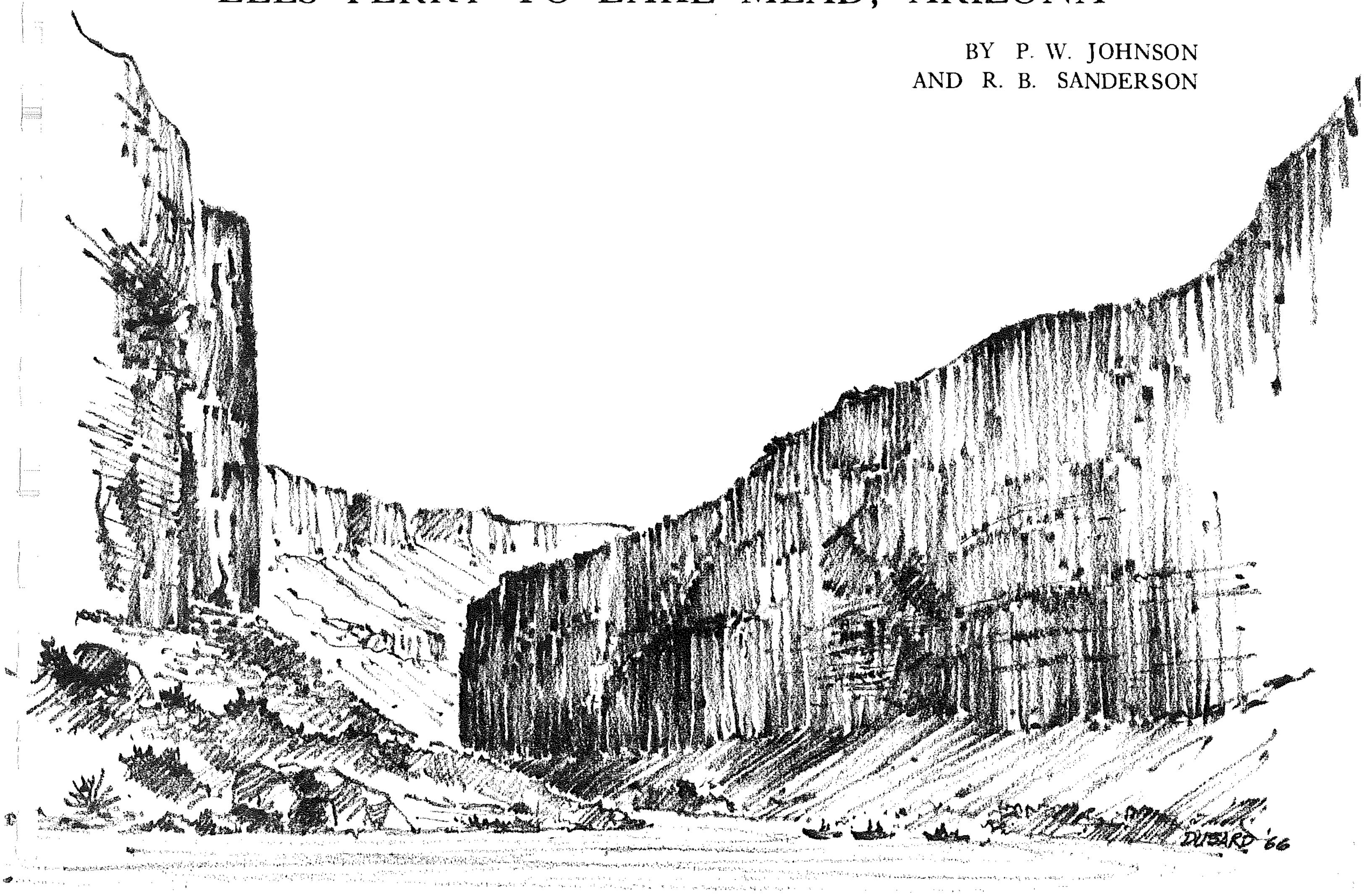
SPRING FLOW INTO THE COLORADO RIVER LEES FERRY TO LAKE MEAD, ARIZONA

BY P. W. JOHNSON
AND R. B. SANDERSON



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UNITED STATES DEPARTMENT OF THE INTERIOR

PHOENIX, ARIZONA
APRIL 1968

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SPRING FLOW INTO THE COLORADO RIVER—LEES FERRY TO LAKE MEAD, ARIZONA

By

P. W. Johnson and R. B. Sanderson

INTRODUCTION

The Grand Canyon of the Colorado River is a monumental example of the cutting and carrying power of water, which are the chief agents in the erosional process. The Grand Canyon is a mile deep, from 8 to 10 miles wide, and divides the Colorado Plateaus into the Kaibab, Kanab, Uinkaret, and Shivwits Plateaus (north rim) and the Coconino Plateau (south rim). (See fig. 1.) As the river cut a canyon through the thick section of sedimentary rocks, the ground water in them drained into the gorge, and today the water issues from these rocks as springs near the bottom of the canyon.

Because of the inaccessibility of the Colorado River in the canyon country, no systematic program has been undertaken for the measurement of spring discharge or for the collection of water samples from the springs for chemical analysis. During the last half a century, however, miscellaneous discharge measurements and chemical analyses of water from the different springs have been made.

Some of the earliest hydrologic information available for the canyons of the Colorado River was collected by LaRue (1925) in 1923 during a boat trip down the Colorado River from Lees Ferry, Ariz., to Needles, Calif. In 1950, S. F. Turner, J. H. Gardiner, and J. A. Baumgartner of the U. S. Geological Survey initiated a plan for the investigation of spring flow in some of the canyons of the Colorado River; spearheaded by the late John Baumgartner, several trips were made from the canyon rims down the precipitous cliffs to the sources of some of the principal springs. In addition, inflow data were collected during three boat trips from Lees Ferry to Lake Mead—by John Baumgartner in 1953, R. B. Sanderson and P. W. Johnson in 1960, and R. M. Myrick, F. M. Bell, L. B. Leopold, and others in 1965. A trip to Havasu Creek, Tapeats Creek, and Blue Spring by J. D. Hem and J. L. Hatchett in June 1951 provided data on the chemical quality of the water at these places.

During the 10-day boat trip made by the authors in June 1960, all the major inflow spots to the Colorado River were visited from Lees Ferry at the upstream end of Marble Canyon to Pierce Ferry (abandoned) at the downstream end of Grand Canyon—a distance of about 300 river miles (fig. 1). The inflow was measured at 14 points and estimated at several others; most of the measurements were made at places where the inflow had been measured previously within the last 50 years. Field measurements were made of the specific conductance of the water, and water samples were collected from springs or from the tributary inflow to the Colorado River for chemical analysis.

The purpose of this report is to describe briefly all the springs visited during the 1960 trip and to compile all known additional discharge data for the springs. The study was conducted under the immediate supervision of H. M. Babcock, district chief of the Water Resources Division in Arizona.

The Director of the U.S. Geological Survey has approved the change in reporting of Survey water-quality data from the English system to metric system. Therefore, the water-quality data in this report are given in milligrams per liter (mg/l), degrees Celsius (°C), and micromhos at 25°C. The terms ''parts per million'' and ''milligrams per liter'' are practically synonymous for water containing as much as 5,000 to 10,000 mg/l of dissolved solids. The exact amount is dependent on the nature of the dissolved material. The Survey has set 7,000 mg/l dissolved solids as the point above which the difference in parts per million and milligrams per liter becomes significant. In order to convert data from one system to the other, a density factor must be applied to the analytical results of all water containing more than 7,000 mg/l of dissolved solids.

Temperature data given in table 2 can be converted to degrees Fahrenheit (°F) by using the tabulation on page 5.

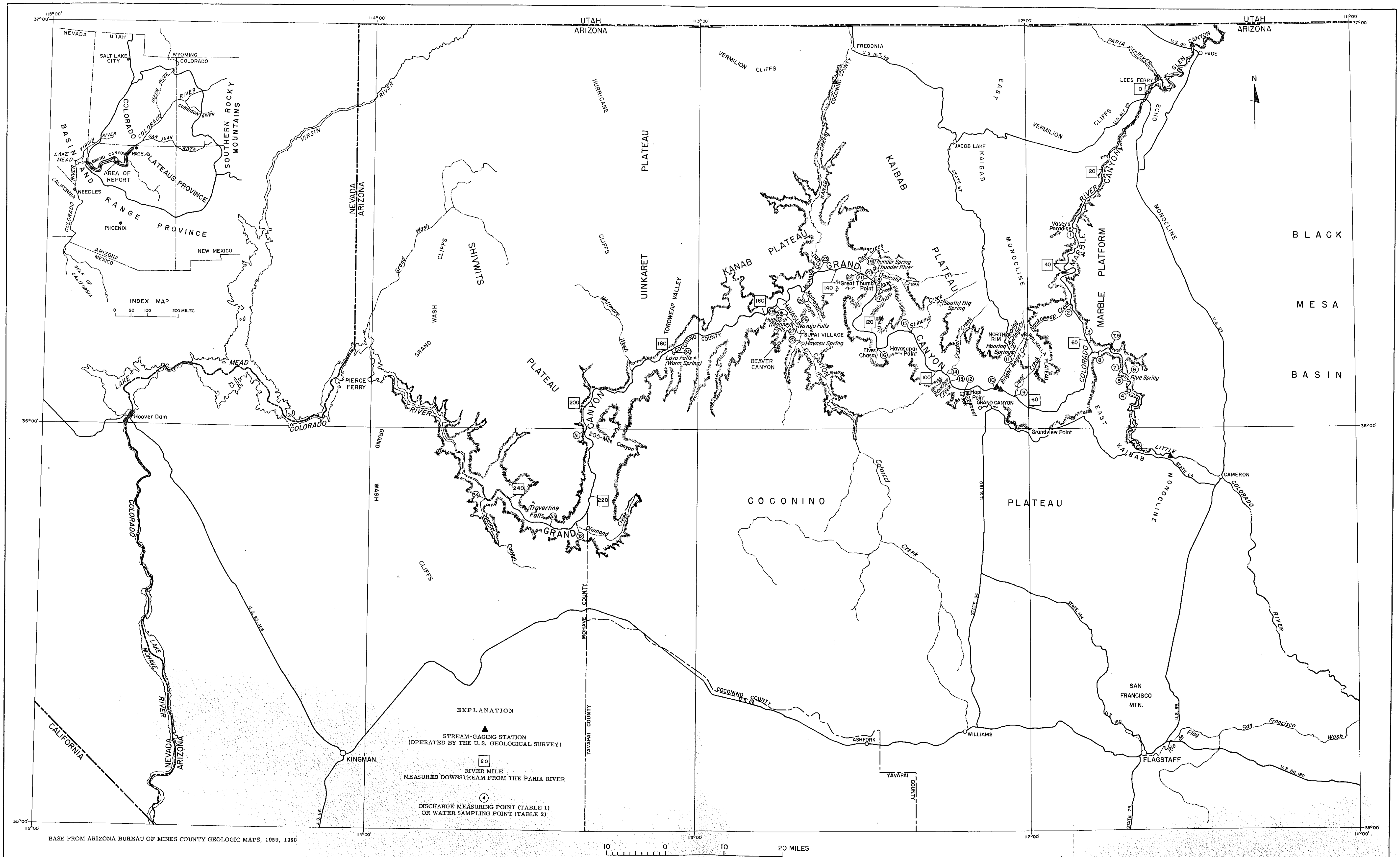


FIGURE 1.--COLORADO RIVER AREA, LEES FERRY TO LAKE MEAD, ARIZONA.

°F	°C	°F	°C	°F	°C	°F	°C
32 ...	0	55 ...	13	78 ...	26	101 ...	38
33 ...	1	56 ...	13	79 ...	26	102 ...	39
34 ...	1	57 ...	14	80 ...	27	103 ...	39
35 ...	2	58 ...	14	81 ...	27	104 ...	40
36 ...	2	59 ...	15	82 ...	28	105 ...	41
37 ...	3	60 ...	16	83 ...	28	106 ...	41
38 ...	3	61 ...	16	84 ...	29	107 ...	42
39 ...	4	62 ...	17	85 ...	29	108 ...	42
40 ...	4	63 ...	17	86 ...	30	109 ...	43
41 ...	5	64 ...	18	87 ...	31	110 ...	43
42 ...	6	65 ...	18	88 ...	31	111 ...	44
43 ...	6	66 ...	19	89 ...	32	112 ...	44
44 ...	7	67 ...	19	90 ...	32	113 ...	45
45 ...	7	68 ...	20	91 ...	33	114 ...	46
46 ...	8	69 ...	21	92 ...	33	115 ...	46
47 ...	8	70 ...	21	93 ...	34	116 ...	47
48 ...	9	71 ...	22	94 ...	34	117 ...	47
49 ...	9	72 ...	22	95 ...	35	118 ...	48
50 ...	10	73 ...	23	96 ...	36	119 ...	48
51 ...	11	74 ...	23	97 ...	36	120 ...	49
52 ...	11	75 ...	24	98 ...	37	121 ...	49
53 ...	12	76 ...	24	99 ...	37	122 ...	50
54 ...	12	77 ...	25	100 ...	38		

PHYSIOGRAPHIC SETTING

The Colorado River heads in the Rocky Mountains of Colorado and traverses the Colorado Plateaus and Basin and Range physiographic provinces before it empties into the Gulf of California in northwestern Mexico. The river is in the Basin and Range province from the mouth upstream to the Grand Wash Cliffs at the downstream end of the Grand Canyon. This area generally consists of wide alluvial valleys and narrow steeply rising mountains, which have a semiarid climate and, in general, sparse vegetation. Upstream from the Grand Wash Cliffs in Arizona, Utah, and western Colorado, the Colorado River is in the Colorado Plateaus province. In this area the Colorado River and its tributaries flow through a labyrinth of deep narrow canyons, of which the Grand Canyon is the largest and most well known. The Grand Canyon extends from the Grand Wash Cliffs upstream to the mouth of the Little Colorado River. The Colorado River flows in Marble Canyon between the Little Colorado and the mouth of the Paria River at Lees Ferry and flows in Glen Canyon upstream from this point (fig. 1).

The walls of the canyons, which are more than 5,000 feet high in the Grand Canyon, are a series of sheer cliffs, cut from moderately cemented sandstone and limestone, and steep irregular slopes, eroded from shale and weakly cemented sandstone and limestone (fig. 2). In the bottom of the Grand Canyon, the Colorado River generally is less than 300 feet wide. In the Grand Canyon the cliffs and slopes recede from both sides of the river in stairstep fashion to the canyon rims, which are separated by a maximum distance of about 10 miles.

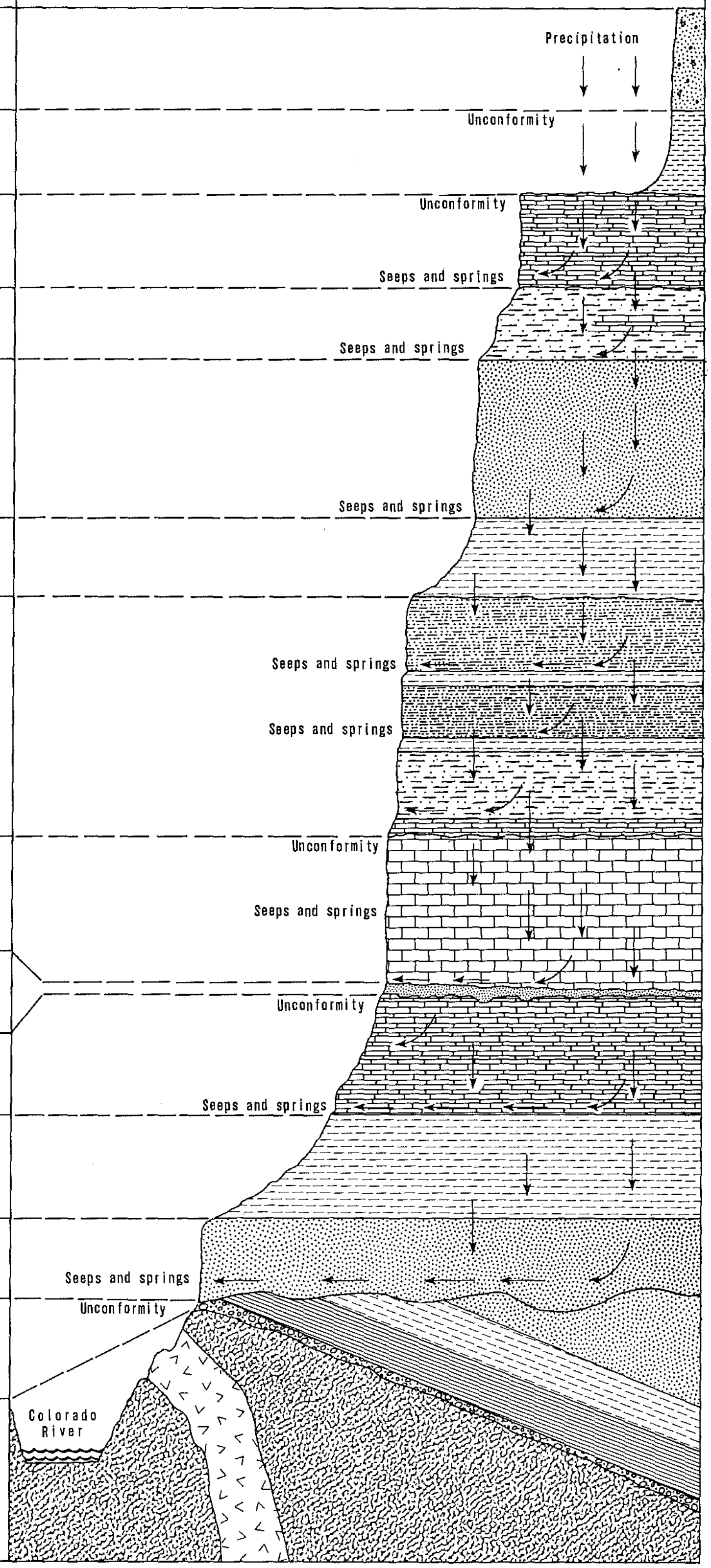
Most small side tributary washes—except the Little Colorado River and Bright Angel, Cataract, and Kanab Creeks—flow only in direct response to precipitation within the canyon area. Some tributaries flow to the Colorado River in narrow, steep-sided, slotlike canyons. The tributaries excavated the canyons in an effort to keep up with the fast downcutting action of the Colorado River. Other tributaries, lacking the erosive power of the Colorado, flow over rapids and waterfalls in their lower reaches.

OCCURRENCE AND MOVEMENT OF GROUND WATER

In the canyon areas of the Colorado River that are discussed in this report, the occurrence and movement of ground water are a function of the geologic structure, the geohydrologic characteristics of the rock sequence in the canyon walls, the character of the surface materials in the recharge areas, the amount of precipitation on these areas, and other factors. The flow in the Colorado River is perennial, but the flow in most of the tributary streams is intermittent; where perennial flow occurs in the tributary streams, it is supplied by ground-water discharge. Perched ground water occurs in some of the rock units along the canyon walls. Where a permeable unit is underlain by impervious or semipervious strata, ground water may move through the permeable unit and issue above the contact with the underlying impervious strata (fig. 2). Recharge to the aquifers takes place where highly permeable units, such as the Kaibab Limestone and Coconino Sandstone, crop out in the Coconino and Kaibab Plateaus and in other areas adjacent to the canyons that receive large amounts of precipitation.

ERA	PERIOD		FORMATION AND THICKNESS (FEET)	DESCRIPTION AND WATER-BEARING CHARACTERISTICS
CENOZOIC	TERTIARY AND QUATERNARY		Basalt	Flows and cinders; transmits water readily
MESOZOIC	TRIASSIC		Moenkopi Formation	Reddish-brown shale; generally nonwater bearing
PALEOZOIC	PERMIAN	Aubrey Group	Kaibab Limestone 300-600	Yellowish- to light-gray dolomitic limestone; transmits water readily
PALEOZOIC	PERMIAN	Aubrey Group	Toroweap Formation 0-300	Light-gray crossbedded sandstone and alternating red sandstone and buff limestone beds; water bearing
PALEOZOIC	PERMIAN	Aubrey Group	Coconino Sandstone 300-900	Very pale orange to pale-yellowish-orange, massive crossbedded sandstone; regional aquifer
PALEOZOIC	PERMIAN	Aubrey Group	Hermit Shale 0-500	Weakly cemented, red, fine-grained sandstone and interbedded thin red shale
PALEOZOIC	PERMIAN / PENNSYLVANIAN	Aubrey Group	Supai Formation 900-1000	Fine-grained yellow-red-brown crossbedded sandstone, interbedded red shale, siltstone, and bluish-gray limestone at base; generally dry; small seeps and springs occur at top of permeable beds
PALEOZOIC	MISSISSIPPIAN		Redwall Limestone 450-800	Thick-bedded, bluish-gray, cherty, crystalline limestone
PALEOZOIC	DEVONIAN		Temple Butte Limestone 0-150	Purplish-gray and light-colored limy sandstone and limestone
PALEOZOIC	CAMBRIAN	Tonto Group	Muav Limestone 400-500	Gray to buff limestone, dolomite, calcareous sandstone, and shale partings
PALEOZOIC	CAMBRIAN	Tonto Group	Bright Angel Shale 200-600	Green and buff micaceous shale and thin beds of sandstone, limestone, and dolomite
PALEOZOIC	CAMBRIAN	Tonto Group	Tapeats Sandstone 50-350	Brown and white crossbedded sandstone, shale partings, and conglomerate lenses
PRECAMBRIAN	YOUNGER		Grand Canyon Series 10,000	Sandstone, shale, basalt, limestone, and conglomerate at base
PRECAMBRIAN	OLDER		Vishnu Schist and granite	Gneiss, mica schist, and intrusive igneous rocks

SECTION



Modified from Metzger (1961, pl. 14)

Figure 2.--Generalized geologic section, Grand Canyon, showing the relation of springs to water-bearing rocks.

The Colorado River and its tributaries are the lowest discharge points for ground water in the aquifers in the canyons. North and south of the river, ground water moves generally toward the river; in some places it emerges as springs in the tributary canyons, and in other places it emerges as springs along or very close to the Colorado River. Along the Colorado River, ground water in the formations above the Muav and Redwall Limestones has, for the most part, drained downward to these formations, where it moves laterally along joints and solution channels (Cooley, 1963, p. 36). The major springs in the canyons issue from these formations, but a few small springs issue from the underlying Tapeats Sandstone. Most of the springs in the Grand Canyon are on the north or west side, although the two largest—Blue Spring and Havasu Spring—are on the east and south sides.

SOURCE, QUANTITY, AND QUALITY OF INFLOW INTO THE COLORADO RIVER

Perennial springs are the source of base flow in the major tributaries that contribute water to the Colorado River between Lees Ferry and Lake Mead. During this investigation, the authors attempted to measure the flow in each tributary and, if possible, to determine the source of the water. The source of the base flow in the tributaries is the accumulated flow of many small springs and seeps that issue from the sides or bottoms of the streambeds. This flow may augment that of a main spring at the head of the stream, or it may be the sole source. In these instances, the accumulated flow was measured near the mouth of the tributary stream above its confluence with the Colorado. In places where it was not possible to make a measurement, estimates of the flow were made. Table 1 gives the discharge measurements made through March 1967. Water samples for chemical analysis also were collected at many of the points of discharge (table 2). The dissolved solids for samples collected in 1965 are expressed as residue on evaporation; the others are expressed as the sum of determined constituents, using the carbonate equivalent of the reported bicarbonate.

Four main tributaries and their associated springs and many small springs and seeps in the 300-mile reach from Lees Ferry to Lake Mead contribute inflow to the Colorado River. Two large spring systems are on the east and south sides of the canyon—Blue Spring on the Little Colorado River and Havasu Spring on Havasu Creek—and two are on the north side of the canyon—Thunder Spring on Tapeats Creek and Roaring Springs on Bright Angel Creek.

Table 1.--Discharge measurements of sources of inflow to the Colorado River, Lees Ferry to Lake Mead

Source	Measuring point (fig. 1)	Distance downstream from Paria River (miles)	Discharge (cfs)	Date measured	Party
Vaseys Paradise	1	32	a/10	Aug. 8, 1923	LaRue
			a/5.5	May 17, 1950	Baumgartner
			a/.3	June 6, 1953	Baumgartner
			a/.15	June 14, 1960	Sanderson
			a/4.0	June 20, 1965	Bell-Myrick
Nankoweap Creek	2	52.3	3.13	Aug. 12, 1923	LaRue
			.77	June 7, 1953	Baumgartner
			.61	June 14, 1960	Sanderson
			Dry	June 21, 1965	Bell-Myrick
Blue Spring area (1 mile above mouth of Little Colorado River)	8	61.5	220	June 7, 1952	Baumgartner-Macias
			226	May 15, 1953	Heckler-Sanderson
			218	June 7, 1953	Baumgartner
			226	May 5, 1954	McDonald-Oeltjen
			226	June 19, 1956	McDonald-Hely
			221	June 19, 1957	Heckler-Rickher
			218	June 14, 1960	Sanderson
			220	June 21, 1965	Bell-Myrick
			232	May 17, 1966	Ligner-J. B. Gillespie
			230	July 12, 1966	Babcock-J. B. Gillespie
			223	Nov. 2, 1966	Buell-Neff
			217	Jan. 10, 1967	Blee-Edmonds
			223	Mar. 15, 1967	E. L. Gillespie-Cooley
Clear Creek	9	84.1	a/3.0	Aug. 22, 1923	LaRue
			a/1.0	June 7, 1953	Baumgartner
			2.23	June 7, 1958	Aelson
			1.95	June 15, 1960	Sanderson
			Dry	June 23, 1965	Bell-Myrick

Table 1.--Discharge measurements of sources of inflow to the Colorado River, Lees Ferry to Lake Mead—Continued

Source	Measuring point (fig. 1)	Distance downstream from Paria River (miles)	Discharge (cfs)	Date measured	Party
Bright Angel Creek	10	88	32.8	Aug. 25, 1923	LaRue
			b/21		
			c/35.4		
Crystal Creek	14	98	2.0	Aug. 30, 1923	LaRue
			a/1.5	June 16, 1960	Sanderson
			a/1.1	June 24, 1965	Bell-Myrick
Shinumo Creek	15	108.5	15.5	Sept. 3, 1923	LaRue
			a/5	June 8, 1953	Baumgartner
			6.74	June 16, 1960	Sanderson
Elves Chasm	16	116.5	a/.5	Sept. 5, 1923	LaRue
			.19	June 9, 1953	Baumgartner
			.12	June 17, 1960	Sanderson
			a/.25	June 25, 1965	Bell-Myrick
Stone Creek	17	131.8	a/1.2	Sept. 8, 1923	LaRue
			a/.6	June 9, 1953	Baumgartner
			.27	June 17, 1960	Sanderson
			Dry	June 25, 1965	Bell-Myrick
Tapeats Creek	21	133.6	93.9	Sept. 9, 1923	LaRue
			59.7	June 27, 1951	Baumgartner
			283	May 28, 1952	Baumgartner
			61.8	May 19, 1953	Heckler-Sanderson
			55.6	June 9, 1953	Baumgartner
			157	Apr. 26, 1954	Baumgartner-McDonald
			58.8	May 29, 1955	Yoder-Hoff
			51.4	June 18, 1960	Sanderson
			79.8	June 25, 1965	Bell-Myrick
Deer Creek	22	136.2	8.2	Sept. 10, 1923	LaRue
			7.2	June 10, 1953	Baumgartner
			5.44	June 19, 1960	Sanderson
			a/8.0	June 25, 1965	Bell-Myrick

Table 1. --Discharge measurements of sources of inflow to the Colorado River, Lees Ferry to Lake Mead—Continued

Source	Measuring point (fig. 1)	Distance downstream from Paria River (miles)	Discharge (cfs)	Date measured	Party
Kanab Creek	23	143.5	3.8	Sept. 11, 1923	LaRue
			3.83	June 10, 1953	Baumgartner
			4.10	June 19, 1960	Sanderson
			a/ 4.0	June 25, 1965	Bell-Myrick
Havasu Creek	29	156.7	d/ 74.5	Sept. 13, 1923	LaRue
			60.0	May 20, 1950	Baumgartner
			63.8	Oct. 20, 1950	Sanderson
			59.3	June 14, 1951	Baumgartner
			63.3	June 16, 1951	Baumgartner
			62.9	June 12, 1952	Hely
			65.7	June 13, 1952	Hely
			66.5	Apr. 6, 1965	Musgrove
			a/ 60.0	June 25, 1965	Bell-Myrick
			59.5	Aug. 7, 1965	Musgrove
			66.6	Dec. 28, 1966	Babcock-J.B. Gillespie
Lava Falls (Warm Spring)	30	179.3	15	(e/)	
			a/ 15	Sept. 18, 1923	LaRue
			a/ 8	June 11, 1953	Baumgartner
			a/ 6	June 20, 1960	Sanderson
Diamond Creek	32	225.8	2.2	Oct. 4, 1923	LaRue
			2.12	June 11, 1953	Baumgartner
			1.47	June 21, 1960	Sanderson
Spencer Canyon	34	246	4.4	Oct. 11, 1923	LaRue
			1.05	June 22, 1960	Sanderson

a/ Estimate.

b/ Average base flow from gaging-station records.

c/ Average discharge, based on 41 years of record.

d/ Probable canyon inflow upstream from springs.

e/ Discharge reported by Peale (1886, p. 196).

Table 2.--Chemical analyses of water from sources of inflow to the Colorado River, Lees Ferry to Lake Mead

[Analyses in milligrams per liter except as indicated. E, estimated. Dissolved solids: Dissolved-solids values for samples collected in 1965 are residue on evaporation; the others represent sum of the determined constituents in solution]

Source	Sampling point (fig. 1)	Location	Date of collection	Discharge (cfs)	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids		Hardness as $CaCO_3$		Percent sodium	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
																Milligrams per liter	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
Vaseys Paradise	1	Mile 32; spring from Redwall Limestone	6-20-65	4.0 E	14	40	15	1.4	0.8	195	0	4	1.5	0.2	0.4	163	0.22	162	2	2	0.1	308	7.4
Nankoweap Creek	2	Mile 52.3; at mouth	6-14-60	.61	32	32	52	29		256	2	118	14	---	---	373	.51	291	81	18	.7	620	---
Spring issuing from Bright Angel Shale	3	About mile 60, high on left bank	6-15-60	---	--	111	85	1,600		317	0	558	2,320	---	---	4,830	6.57	627	367	85	31	7,900	---
Blue Spring area	4	16 miles above mouth of Little Colorado River; "head of flow"	6-20-51	2 E	22	---	---	---		694	0	---	1,650	---	---	---	---	---	---	---	---	6,220	---
Do.	5	13 miles above mouth of Little Colorado River; "Blue Spring"	6-14-50	220	21	264	79	513	23	964	0	147	815	.2	3.2	2,320	3.16	984	194	---	---	3,940	6.5
			6-21-51	---	20	---	---	---		914	0	---	825	---	---	---	---	---	---	---	---	3,910	---
Do.	6	12.5 miles above mouth of Little Colorado River; small spring	6-20-51	.4	22	215	76	1,200		634	0	243	1,910	.2	1.0	3,960	5.38	849	330	76	18	6,840	---
Do.	7	10 miles above mouth of Little Colorado River	6-21-51	200	--	167	75	707		622	0	165	1,120	.2	1.1	2,540	3.45	725	216	68	---	4,500	---
Do.	7.5	3.1 miles above mouth of Little Colorado River	5-17-66	232	--	112	77	761		464	0	170	1,200	.2	---	a/2,560	3.48	595	215	---	---	4,540	7.3
			7-12-66	230	--	120	79	765		494	0	170	1,210	.2	---	b/2,600	3.54	625	220	---	---	4,580	7.8
Do.	8	Mile 61.5; 1 mile above mouth of Little Colorado River	6-21-65	220	22	91	64	780	35	396	0	163	1,220	.2	0	2,500	3.40	490	166	76	15	4,520	7.3
Clear Creek	9	Mile 84.1; at mouth	6-15-60	1.95	27	29	25	14		204	4	13	14	---	---	199	.27	175	8	15	.7	400	---
Bright Angel Creek	10	Mile 88; at mouth	12-15-55	17	--	41	26	5.8		238	0	15	8.0	---	.1	213	.29	210	14	6	.2	390	7.7
Roaring Springs Creek	11	10 miles above mouth of Bright Angel Creek; "Roaring Springs"	11-11-61	5.67	9	---	---	---		197	0	---	2.0	---	---	---	---	167	5	---	---	309	7.7
Monument Creek	12	Mile 93.4; at mouth	6-15-60	.002 E	34	81	71	340		220	0	225	580	---	---	1,400	1.90	493	313	60	6.5	2,500	---
Boucher Creek	13	Mile 96.5; at mouth	6-16-60	.05 E	31	44	50	153		174	2	141	252	---	---	728	.99	315	172	51	3.7	1,350	---
Crystal Creek	14	Mile 98; at mouth	6-24-65	1.5 E	27	33	32	178	24	262	0	118	219	.3	.2	747	1.02	214	0	61	5.3	1,330	7.8
Shinumo Creek	15	Mile 108.5; at mouth	6-16-60	6.74	28	25	17	6.4		154	2	8.0	6.0	---	---	140	.19	132	6	10	.3	300	---
Elves Chasm	16	Mile 116.5; at mouth	6-25-65	.25 E	17	79	45	25	3.4	186	0	216	45	.4	1.7	559	.76	382	230	12	.6	833	7.3
Stone Creek	17	Mile 131.8; at mouth	6-17-60	.27	28	29	37	12		255	6	15	12	---	---	237	.32	224	15	11	.3	480	---
Tapeats Creek	18	Above mouth of Thunder River, 2 miles above mouth of Tapeats Creek	6-27-51	37.3	14	44	19	---		206	0	4.7	2.0	0	0	---	---	188	19	---	.3	318	---
Thunder River	19	At junction with Tapeats Creek; "Thunder Spring"	6-27-51	16.5	13	44	19	---		205	Trace	3.3	1	0	0	---	---	188	20	---	.3	311	---

[illegible] gpm

7406.5 gpm

Table 2. --Chemical analyses of water from sources of inflow to the Colorado River, Lees Ferry to Lake Mead—Continued

Source	Sampling point (fig. 1)	Location	Date of collection	Discharge (cfs)	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Milligrams per liter	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
Tapeats Creek	20	500 feet below mouth of Thunder River	6-27-51	53.8	13	40	19	---		206	0	---	1.0	---	---	---	---	178	9	---	---	315	---
Do.	21	Mile 133.6; at mouth	6-27-51	59.7	17	40	18	---		202	0	3.9	1	0	0	---	---	174	8	---	---	312	---
			6-25-65	79.8	14	36	11	1.5	0.6	168	0	3.8	1.3	.2	.2	147	0.20	135	0	3	0.1	267	7.1
Deer Creek	22	Mile 136.2; at mouth	6-25-65	8.0 E	16	47	14	2.0	1.0	208	0	10	2.1	.1	.1	179	.24	175	5	2	.1	340	7.1
Kanab Creek	23	Mile 143.5; at mouth	6-25-65	4.0 E	24	180	75	37	7.0	145	0	660	22	.4	1.4	1,160	1.58	758	639	10	.6	1,420	7.0
Matkatamiba Canyon	24	Mile 147.8; at mouth	6-20-60	.005 E	26	168	98		7.4	124	0	675	24	---	---	1,030	1.40	825	723	2	.1	1,450	---
Havasu Creek	25	At trail crossing below head-water springs, 1 mile above Supai, Ariz.	10-20-50	62.1	21	133	48	27		588	0	36	48	.2	1.4	584	.79	530	48	10	---	1,030	---
			6-17-51	59.3	22	---	---	---		574	0	---	46	---	---	---	---	---	---	---	---	1,000	---
			8- 7-65	59.5	--	74	45	36		416	0	36	48	.2	---	444	.60	368	27	---	---	820	7.7
Do.	26	Below Navajo Falls	6-16-51	---	--	---	---	---		384	0	---	47	---	---	---	---	---	---	---	---	752	---
Do.	27	Spring inflow below Mooney Falls	6-16-51	---	22	109	47	36		526	0	44	48	0	0	543	.74	466	34	15	.7	959	---
Do.	28	Below Beaver Wash	6-16-51	---	21	52	47	28		338	Trace	38	48	0	.3	380	.52	323	46	16	.7	704	---
Do.	29	Mile 156.7; 500 feet above mouth	6-16-51	63.3	21	---	---	---		304	Trace	---	48	---	---	---	---	---	---	---	---	661	---
Lava Falls (Warm Spring)	30	Mile 179.3; at mouth	6-20-60	6 E	26	54	80	58		532	0	38	80	---	---	572	.78	462	26	21	1.2	1,100	---
205-Mile Canyon	31	At mouth	6-21-60	---	23	75	61	50		234	0	210	96	---	---	607	.83	438	246	20	1.0	1,140	---
Diamond Creek	32	Mile 225.8; at mouth	6-21-60	1.47	29	12	53	69		298	14	43	60	---	---	398	.54	250	6	37	1.9	800	---
Travertine Falls	33	Mile 230.5; at mouth	6-22-60	.2 E	21	16	40	310		642	12	75	180	---	---	949	1.29	204	0	77	.9	1,680	---
Spencer Canyon	34	Mile 246; at mouth	6-22-60	1.05	28	22	60	22		327	5	28	32	---	---	330	.45	301	33	14	.6	680	---

a/ Silica 17 mg/l.

b/ Silica 15 mg/l.

Blue Spring and the Little Colorado River

The main source of inflow to the Colorado River between Lees Ferry and Lake Mead is the Little Colorado River. Blue Spring, which is about 13 miles upstream from the mouth of the Little Colorado River, is the largest of a group of springs that flow into the river in a 10-mile reach near its mouth. The other springs issue along the Little Colorado River from near Blue Spring to within 3 miles of the mouth of the river; there is no apparent spring inflow in the last 3-mile reach above the mouth of the river. The springs provide a continuous steady flow into the Colorado River. Since 1952, 13 discharge measurements of the total flow from these springs have been made at a point 3 miles above the mouth of the Little Colorado River (table 3). The discharge measurements range from 217 to 232 cfs (cubic feet per second) and average 223 cfs.

The close agreement between the 13 discharge measurements indicates that there is very little variation in the rate of flow of the springs. The difference in the discharge measurements is attributed to inherent error in the discharge measurements rather than to variation in flow. All measurements are within the acceptable limits of accuracy for measurements of streamflow.

Blue Spring issues from the upper part of the Redwall Limestone. The continuous flow of the spring indicates that the Redwall is an extensive aquifer, and it supplies ground water under a constant head at the spring outlet. Blue Spring is the natural ground-water discharge point for most of the Black Mesa hydrologic basin—an area of about 28,000 square miles (Cooley, 1963, p. 34). About two-thirds of the ground water moving through the aquifers of Black Mesa basin discharges through Blue Spring and the other springs that issue along the Little Colorado downstream from Blue Spring; yield from Blue Spring measured at the mouth of the Little Colorado River is about 161,000 acre-feet per year (Cooley, 1963, p. 35). The surface materials in the recharge area are very pervious volcanic cinders or the Kaibab Limestone, which are underlain by the permeable Toroweap Formation, Coconino Sandstone, and Supai Formation. Precipitation on the recharge area is as much as 30 inches per year in places, and some percolates rapidly into the permeable rocks. The amount of ground water that discharges from the basin along the Little Colorado River, however, is only a small part of the total annual precipitation that falls on the area (Cooley, 1963, p. 35).

Table 3. --Flow of the Little Colorado River at designated points upstream from the mouth
[Note: no apparent spring inflow to river below mile 3. 0]

Date	Discharge, in cfs							
	Mile 3. 0	Mile 6. 7	Mile 10	Mile 12. 5	Mile 12. 8	Mile 13. 0	Mile 13. 3	Mile 45. 5[a]
June 14, 1950	---	---	196	---	---	98. 1	[b]5. 0	0
Oct. 21, 1950	---	---	---	162	---	---	---	0
June 20, 1951	---	---	---	---	98. 5	---	7. 0	0
June 21, 1951	---	---	200	155	---	---	---	0
June 7, 1952	220	199	---	---	---	---	---	0
May 15, 1953	226	---	---	---	---	---	---	0
May 16, 1953	---	212	---	---	---	---	---	0
June 7, 1953	218	---	---	---	---	---	---	0
May 5, 1954	226	---	---	---	---	---	---	0
June 19, 1956	226	---	---	---	---	---	---	0
June 18, 1957	221	---	---	---	---	---	---	0
June 14, 1960	218	---	---	---	---	---	---	0
June 21, 1965	220	---	---	---	---	---	---	0
May 17, 1966	232	---	---	---	---	104	---	0
July 12, 1966	230	---	---	---	---	---	---	---
Nov. 2, 1966	223	---	---	---	---	---	---	---
Jan. 10, 1967	217	---	---	---	---	---	---	---
Mar. 15, 1967	223	---	---	---	---	---	---	---

a/ Gaging station near Cameron, Arizona.

b/ Estimate.

After his trip to Blue Spring in 1951, Hem (written commun., 1951) stated:

> The various inflows in the Blue Spring area differ considerably in concentration of dissolved solids. The most highly mineralized sample, collected from a spring at mile 12.5, had a total solids content of 3,960 ppm (parts per million) of which 1,910 was chloride. The best water, that from the main openings at Blue Spring, had a dissolved solids content of 2,320 ppm and a chloride concentration of 815 ppm. At mile 10 the dissolved solids in the river water was 2,540 ppm and the chloride 1,120 ppm. The chloride content of the sample from the springs at mile 16 was 1,650 ppm. Although differing in concentration, the waters of this area are similar to each other in that the principal constituents in all samples are sodium, calcium, chloride and bicarbonate.

Although the salt content of the water from Blue Spring is high, Heckler and Sanderson reported many fish in the spring water during their investigation in May 1953. The fish were as much as 9 or 10 inches long, but the species could not be identified; in June 1960 the fish again were noted by Sanderson and were identified as Blue-Channel catfish. Sanderson found many carcasses along the bank, which were completely devoured except for the head, backbone, and spikes. The shallow-water fisherman probably was a mountain lion, judging from large cat tracks at the site.

In discussing mineral deposits resulting from spring flow, Hem (written commun., 1951) stated:

> Mineral deposits on the sides of the canyon, apparently resulting from past and present spring activity, are common above Blue Spring, and there are large deposits on the north side of the canyon at mile 12.5. Little or no evidence of deposition is visible at Blue Spring, however. The small flow in the river channel above Blue Spring is rather cloudy in appearance and deposits of what appears to be travertine occur on the rocks in the stream bed. From Blue Spring to mile 12.5 the water is clear with little evidence of deposition. The springs in this area all discharge water containing considerable amounts of dissolved carbon dioxide. This CO_2 is gradually lost as the river flows downstream, causing deposition of carbonates at mile 10 and

below. The decrease in bicarbonate from 914 ppm at Blue Spring to 622 ppm at mile 10 probably is indicative of deposition of carbonates. Part of the decrease, however, may be the result of inflow of water lower in bicarbonate than that from Blue Spring.

The temperature of the water in the springs generally is about 20°C. The temperature of total spring flow at the mouth of the Little Colorado River varies with air temperature but usually is about 24°C in June.

Havasu Spring and Havasu Creek

Havasu Creek flows into the Colorado River through a narrow slotted canyon. Navigation up Havasu Creek through the canyon opening depends on the water level in the river. During the trip in June 1960, the flow of the river was about 40,000 cfs, and it was not possible to navigate the creek; therefore, no discharge measurements were made. Havasu Creek, however, is accessible by horse trail from roads along the south rim, and, as a result, it is one of the better known spring-fed tributaries entering the Colorado from the south side of the canyon. The area has been visited many times by personnel of the U.S. Geological Survey, and many discharge measurements and water samples have been taken.

Havasu Spring occurs as a series of seeps that emerge from the bottom of Havasu Canyon along several branches of Havasu Creek; the seeps are within a quarter of a mile of each other about 10 miles upstream from the mouth of Havasu Creek. The water collects in the main creekbed as it flows downstream. Discharge measurements made at several places downstream from Havasu Spring indicate a base flow of about 64 cfs or 46,300 acre-feet per year.

Havasu Spring issues from the Redwall Limestone—a part of an extensive ground-water system that is not readily affected by seasonal or yearly differences in precipitation. The spring is a major discharge point for ground water moving toward the Colorado River from the south (Cooley, 1963, fig. 7 and p. 35). West of Havasu Canyon a series of faults has upthrown the formations, creating an effective barrier to the movement of ground water away from Havasu Spring. Therefore, the spring is a natural discharge point for ground water.

In a discussion of the quality-of-water studies for Havasu Creek, Hem (written commun., 1951) stated:

> Six water samples were collected as follows: (1) From the creek just below the headwater springs, (2) from the creek below Navajo Falls, (3) from inflow below Hualapai (Mooney) Falls, (4) from the creek below Beaver Canyon, (5) from the creek 500 feet above the mouth, and (6) from the well at Supai Village (tap in guest house). Dissolved solids concentrations ranged from 704 to about 380 ppm. The highest concentration was found in water from the well. The highest dissolved solids in the creek and spring samples was about 600 ppm at the headwaters. The lowest concentration was at the mouth of the creek. Calcium, magnesium and bicarbonate are the principal components of the dissolved matter. Use of the field conductance apparatus indicated that the many small springs making up the flow of Havasu Creek above Supai have a common source.
>
> The water tends to precipitate calcium carbonate and the difference in dissolved solids among the creek and spring samples apparently is the result of calcium carbonate deposition. The tendency to precipitate calcium carbonate is further evident in the travertine deposits in the creek bed. The extent to which deposition of travertine in the channel occurs may be indicated by a reduction in bicarbonate in solution from 574 ppm at the headwaters of the creek to 304 ppm at the mouth, as shown by the analyses of samples collected during this study. It is possible that growth of algae in the water may have some influence on the deposition of calcium carbonate.

The temperature of the water from Havasu Creek ranged from 19° to 22°C at the time of the discharge measurements in June 1951. The temperature of Havasu Spring at its sources probably varies only slightly, if at all. Hem (written commun., 1951) reported a water temperature of 22°C at the source; other workers have reported temperatures of 19°C at the source.

Roaring Springs and Bright Angel Creek

Major John Wesley Powell, on his trip down the Colorado River in 1869, referred to Bright Angel as a sparkling creek, cool, swift, and clear as crystal—with trout. Powell named the stream Silver Creek but later changed it to Bright Angel to compensate for having applied the name Dirty Devil to one of the Colorado River tributaries far upstream.

The U.S. Geological Survey has operated a gaging station on Bright Angel Creek near its mouth on the Colorado River (mile 88) since 1923 (U. S. Geological Survey, issued annually). Little information has been collected, however, on the flow of Roaring Springs, which contribute most of the base flow to Roaring Springs Creek, a major source of inflow to Bright Angel Creek (fig. 3). The springs are about 10 miles upstream from the gaging station (fig. 1) just above the confluence of Roaring Springs Creek and Bright Angel Creek. The many small springs at the headwaters of Bright Angel Creek probably are a part of the same spring system that feeds Roaring Springs Creek. The base flow of Bright Angel Creek is about 21 cfs, and the average discharge is about 35 cfs (based on 41 years of record); miscellaneous measurements indicate that Roaring Springs Creek may furnish about one-third of this flow.

Roaring Springs issue from solution channels high on a steep slope near the base of the Muav Limestone. Most of the water flows into three main tributaries that cascade several hundred feet down the slope into Roaring Springs Creek. Although the flow of the springs varies seasonally, a high base flow is maintained even in times of drought. The flow of Roaring Springs is derived from ground water in the Kaibab Plateau on the north side of the canyon; the area receives large amounts of precipitation, and the surface and subsurface materials allow rapid infiltration to the limestone formations that store and transmit the ground water.

Water is pumped from Roaring Springs to supply the National Park facilities on the north rim of the Grand Canyon. The pumping lift is about 3,800 feet, and the water is piped several miles. Electric power generated from the fall of the water is used to pump the water to the rim. The water is of excellent chemical quality and contains less than 200 mg/l dissolved solids—mostly calcium, magnesium, and bicarbonate.

Thunder Spring and Tapeats Creek

Thunder Spring, which supplies the base flow to Thunder River, gushes from a vertical cliff of Muav Limestone and near the base of this limestone (G. L. Beck, geologist, oral commun., 1968). The water drops 300 to 400 feet in a series of falls to form Thunder River—a half a mile reach of churning, violent white water. Thunder River joins Tapeats Creek

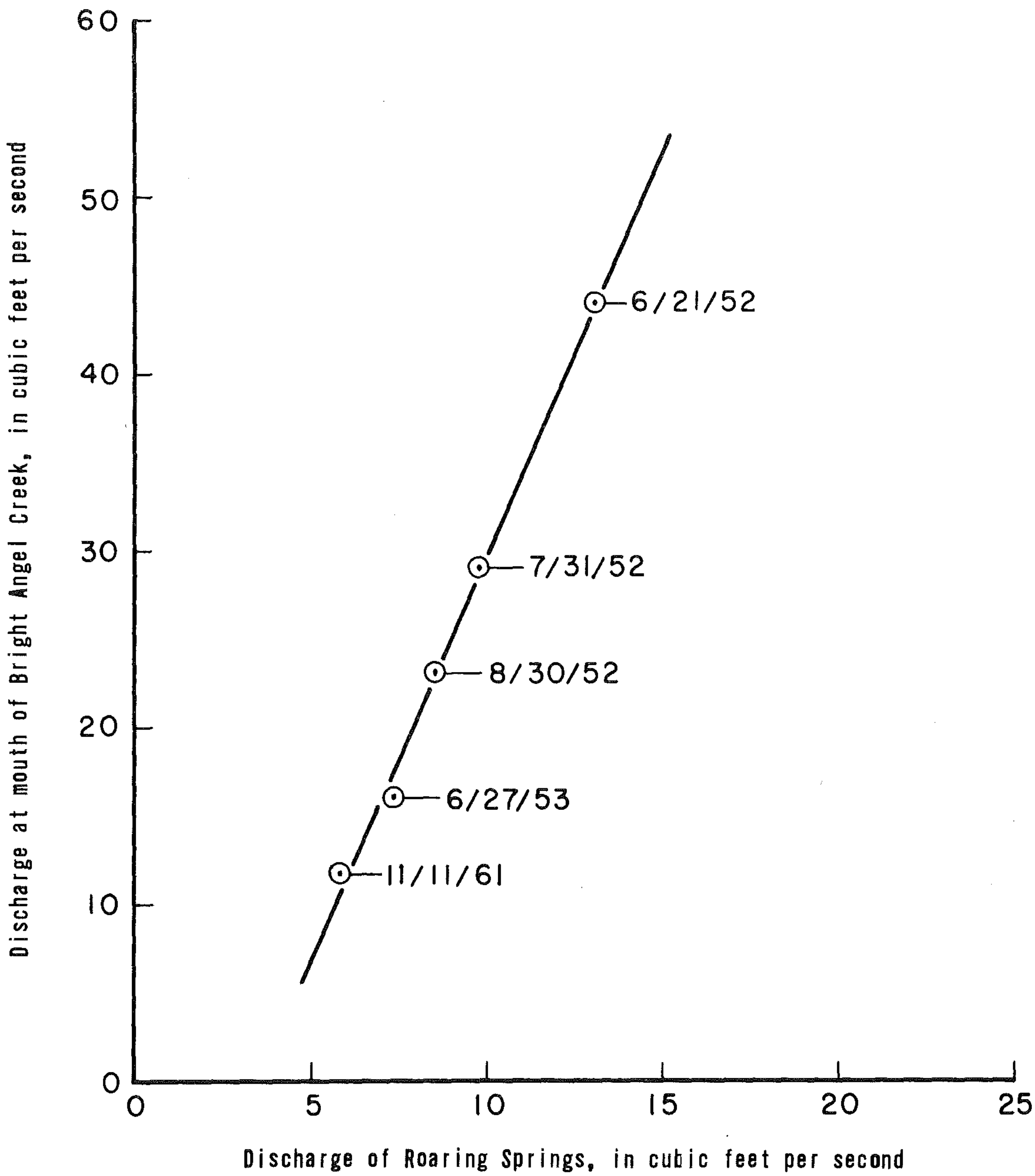


Figure 3.--Comparison of flow of Bright Angel Creek and Roaring Springs.

about 2 miles above its confluence with the Colorado River. In addition to the flow from Thunder River (fig. 4), Tapeats Creek is fed by springs near its headwaters; the creek constitutes the largest inflow to the Colorado River from the north side of the canyon.

The flow of Thunder Spring and the springs near the headwaters, like the flow of the springs that supply Bright Angel Creek and its tributaries, is derived from ground water that has percolated downward from its recharge area in the Kaibab Plateau. The springs are subject to some seasonal variations, but they maintain a high constant base flow even in periods of drought. The correlation between Tapeats and Bright Angel Creeks is shown by a comparison of the simultaneous discharge of the creeks (fig. 5).

Hem (written commun., 1951) described the quality-of-water studies of Tapeats Creek as follows:

> Tapeats Creek: Four samples of water were collected on this trip. One was obtained from Tapeats Creek just above Thunder River, another from Tapeats Creek just below Thunder River, one from Thunder River at its mouth, and one three-fourths of a mile above the mouth of Tapeats Creek. Three of these were points where measurements were made. All four samples were nearly identical in chemical quality with a range in dissolved solids from 170 to 178 ppm. The dissolved constituents were almost exclusively calcium, magnesium and bicarbonate. The temperature of the water ranged from 56° to 63°F.

In 1965 a water sample was collected at the mouth of Tapeats Creek that contained 147 mg/l dissolved solids (table 2).

Miscellaneous Springs and Streams

In addition to the major sources of inflow to the Colorado River previously discussed, several lesser sources of inflow have been measured during trips through the canyons. Although data for these sources are incomplete, sufficient measurements of the amount of inflow have been made to warrant brief discussion. The inflow to the river from these sources (table 1) and the chemical quality of the water (table 2) are described in downstream order, bypassing those sources previously discussed.

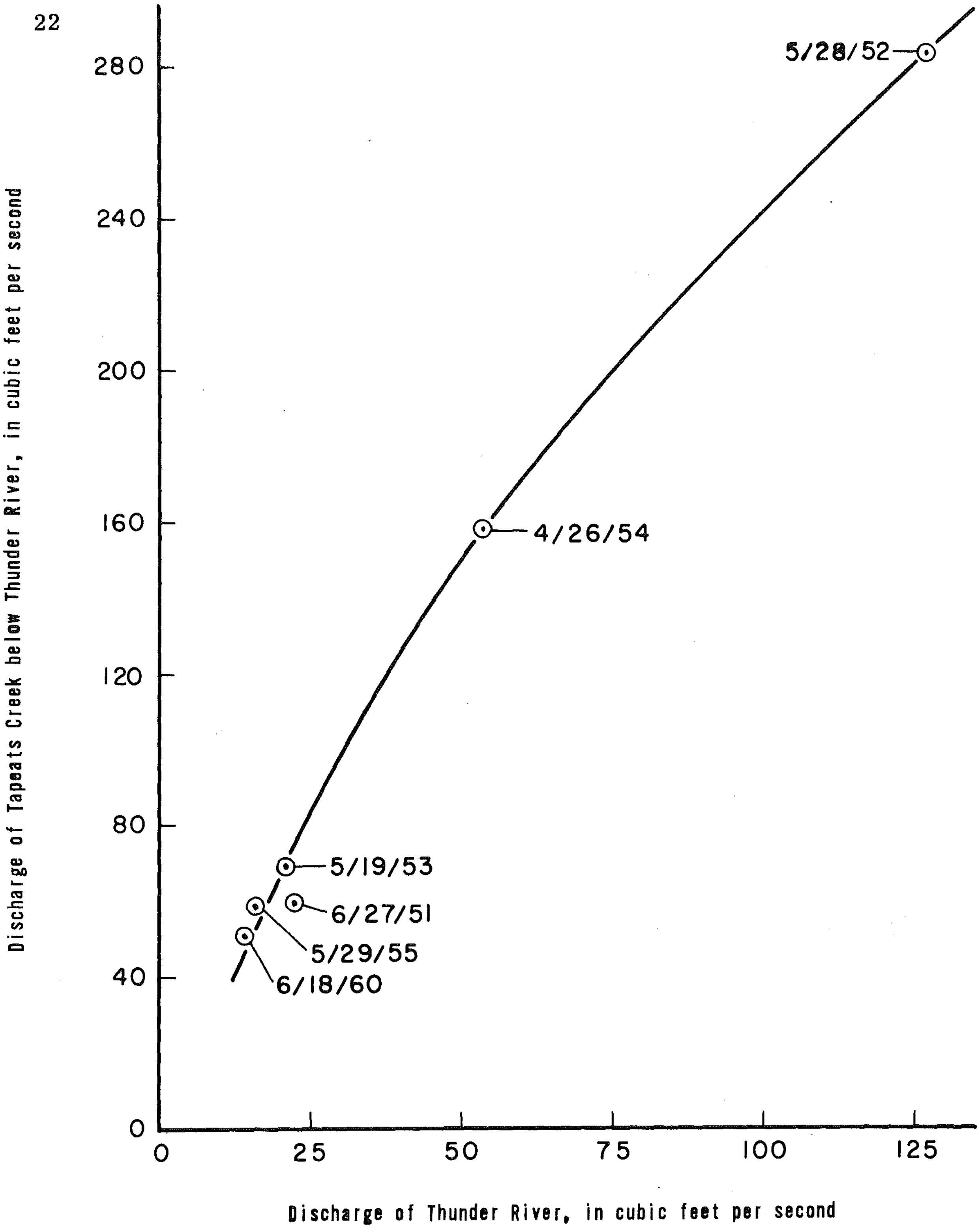


Figure 4.--Comparison of flow of Thunder River and Tapeats Creek.

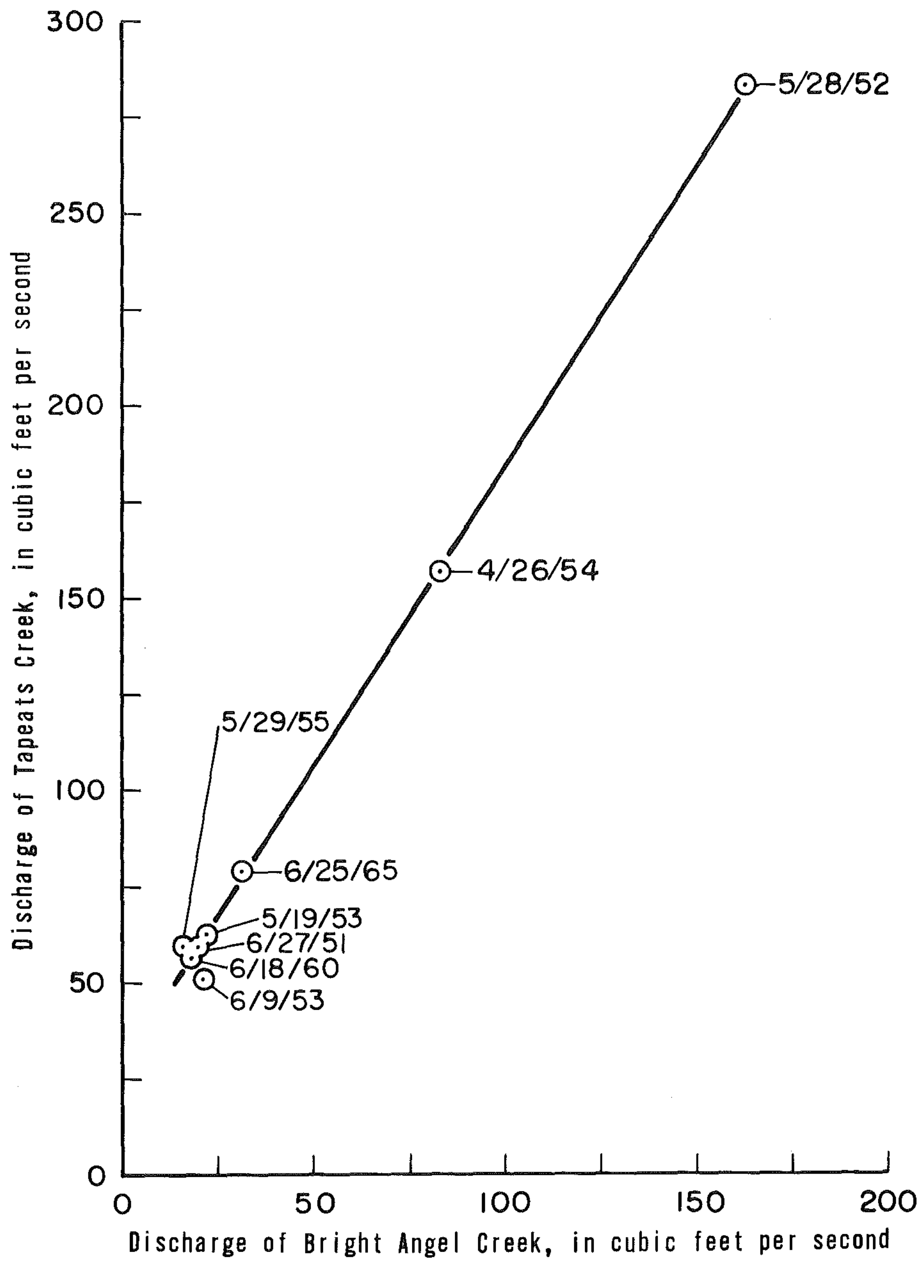


Figure 5.--Comparison of discharge of Bright Angel and Tapeats Creeks.

Spring flow issues from the Redwall Limestone at Vaseys Paradise (river mile 32). Five estimates indicate a wide range in the flow from the spring. The water from the spring is of good chemical quality; analysis of a water sample collected in 1965 showed a dissolved-solids content of only 163 mg/l (table 2).

Nankoweap Creek is an intermittent stream that flows into the Colorado River at mile 52.3. Three discharge measurements and one observation of no flow have been made. The June 1960 measurement was made on an alluvial-fan deposit that extended upstream for a considerable distance; therefore, it is possible that, in addition to the measured inflow, some water enters the river as underflow through the fan deposits. The chemical analysis of a water sample collected in June 1960 showed a dissolved-solids content of 373 mg/l and a bicarbonate content of 256 mg/l.

Clear Creek is an intermittent stream that flows into the Colorado River at mile 84.1; its drainage area includes part of the Walhalla Plateau at an altitude of about 8,400 feet. Discharge data include two estimates, two measurements, and one observation of no flow. The dissolved-solids content of the water is 199 mg/l.

Crystal Creek, at mile 98, is shown on topographic maps as a perennial stream at the mouth and is perennial for about 4 miles upstream. The base flow, however, is small, as shown by two estimates and one measurement. The water in the creek contains nearly 750 mg/l dissolved solids.

Shinumo Creek is a perennial stream that flows into the Colorado River at mile 108.5. It is joined by White Creek, also a perennial stream, about 3 miles upstream from the mouth. Shinumo Creek is about 12 miles long from its source at Big South Spring on the rim of the Kaibab Plateau to its confluence with the Colorado River, and in this distance it falls about 5,400 feet (Noble, 1914). The water in Shinumo Creek is extremely clear and in striking contrast to the muddy torrent of the Colorado River. It is similar in appearance to Bright Angel Creek, except that the base flow is about one-third of the base flow of Bright Angel. The dissolved-solids content of the water is low—only about 140 mg/l.

The inflow to the Colorado River from springs at Elves Chasm, mile 116.5, is small and intermittent, as shown by two estimates and two measurements of the discharge. Elves Chasm is characterized by high waterfalls and crystal-clear pools and is one of the most beautiful spots in the canyon. The chemical analysis of a water sample collected in 1965 showed a dissolved-solids content of 559 mg/l.

Stone Creek is an intermittent stream that flows into the Colorado River at mile 131.8. Stone Creek drains only a small area and the amount of discharge is small. Discharge data include two estimates, one measurement, and one observation of no flow.

Deer Creek flows into the Colorado River over a waterfall that is about 150 feet high. The creek is fed by several springs along its course. The chemical analysis of a water sample collected in 1965 showed a dissolved-solids content of 179 mg/l; the temperature of the water was 16°C.

Although the total drainage area of Kanab Creek is more than 2,000 square miles, its contribution to the Colorado River is small. South of the Arizona-Utah State line, Kanab Creek is an intermittent stream that flows into the Colorado River at mile 143.5. A water sample taken in 1965 contained 1,160 mg/l dissolved solids.

Warm Spring contributes inflow to the Colorado River at mile 179.3, just downstream from Lava Falls—one of the largest rapids along the river. The spring does not issue from the canyon walls but appears from a densely overgrown marsh on a bar adjacent to Lava Falls. Water from Warm Spring contained 572 mg/l dissolved solids, and the temperature was 26°C when the sample was taken in June 1960.

Diamond Creek flows into the Colorado River at mile 225.8. Three discharge measurements have been made of the flow in the creek; some subsurface flow may enter the Colorado River through the alluvial fan at the mouth of the creek. The chemical analysis of a water sample collected in 1960 showed a dissolved-solids content of 398 mg/l; the temperature of the water was 29°C.

The flow from Spencer Canyon, which enters the Colorado River at mile 246, has been measured only twice. The chemical analysis of a water sample collected in 1960 showed a dissolved-solids content of 330 mg/l, and the temperature of the water was 28°C.

Many other small seeps issue from the canyon walls and contribute inflow to the Colorado River. For the most part, these are "wet weather" seeps, and the flow is too small or issues from the canyon walls in such a way that it cannot be measured. The total quantity probably is not significant.

REFERENCES CITED

Cooley, M. E., 1963, Hydrology of the Plateau uplands province, in Annual report on ground water in Arizona, spring 1962 to spring 1963, by Natalie D. White, R. S. Stulik, E. K. Morse, and others: Arizona State Land Dept. Water-Resources Rept. 15, p. 27-38.

LaRue, E. C., 1925, Water power and flood control of Colorado River below Green River, Utah: U. S. Geol. Survey Water-Supply Paper 556, 176 p.

Metzger, D. G., 1961, Geology in relation to availability of water along the south rim, Grand Canyon National Park, Arizona: U. S. Geol. Survey Water-Supply Paper 1475-C, p. 105-138.

Noble, L. F., 1914, The Shinumo quadrangle, Grand Canyon district, Arizona: U. S. Geol. Survey Bull. 549, 100 p.

Peale, A. C., 1886, Lists and analyses of the mineral springs of the United States (a preliminary study): U. S. Geol. Survey Bull. 32, 285 p.

U. S. Geological Survey, issued annually, Surface water records of Arizona: U. S. Geol. Survey open-file reports.

________ issued annually, Surface water supply of the United States, pt. 9, Colorado River basin: U. S. Geol. Survey water-supply papers.