Water Resources of Fort Huachuca Military Reservation, Southeastern Arizona

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1819-D

Prepared in cooperation with the U.S. Army Electronic Proving Ground Fort Huachuca, Arizona

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By S. G. BROWN, E. S. DAVIDSON, L. R. KISTER, *and* B. W. THOMSEN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

WATER RESOURCES OF FORT HUACHUCA MILITARY RESERVATION, SOUTHEASTERN ARIZONA

By S. G. Brown, E. S. Davidson, L. R. Kister, and B. W. Thomsen

ABSTRACT

The Fort Huachuca Military Reservation, on the northeast flank of the Huachuca Mountains, is in the southern part of the San Pedro River drainage in the Basin and Range physiographic province in Arizona. The main sources of water available in the reservation area are ground water stored in two unconsolidated sedimentary deposits filling the San Pedro basin, and spring flow in Garden and Huachuca Canyons in the Huachuca Mountains.

The unconsolidated deposits are divided into the upper and lower units of basin fill. These units yield the major part of the fort's water supply, and pumping from them has caused the water level in the Fort Huachuca well field to decline 3 feet per year. All the upper unit and 40 feet of the 220-foot-thick lower unit have been dewatered in post wells 1 and 2. In Garden Canyon, spring flow is derived from solution channels and fractures in carbonate rocks; and in Huachuca Canyon, from fractures in mudstone, sandstone, carbonate rocks, and granite. The flow from springs generally is not used by the fort, but it is sufficient to supply the entire water demand during some periods.

Spring flow, if used to supplement the ground-water supply, will decrease the draft on the ground-water reservoir in the two basin-fill units; or it could be used for artificial recharge to these aquifers. A second well field, if developed in the North Gate-Libby Field area, would partly accomplish the same result by decreasing the heavily concentrated draft on the ground-water reservoir of the Fort Huachuca well field, and by utilizing ground water that now moves unused northeastward to the San Pedro River.

INTRODUCTION

Fort Huachuca, the U.S. Army electronic proving ground, is in Cochise County in southeastern Arizona about 16 miles north of the international boundary. The fort is on the left bank of the San Pedro River, a northward-flowing tributary of the Gila River. The described area, which is in the Basin and Range lowlands, extends eastward from the Huachuca Mountains to the San Pedro River and southward from the Babocomari River to an east-west line through Hereford, about 7 miles north of the international boundary (fig. 1, pl. 1). The San Pedro River, which forms the eastern boundary of the area, flows north-northwest and is joined near Fairbank by its eastward-flowing tributary, the Babocomari River, which forms the northern boundary of the area.

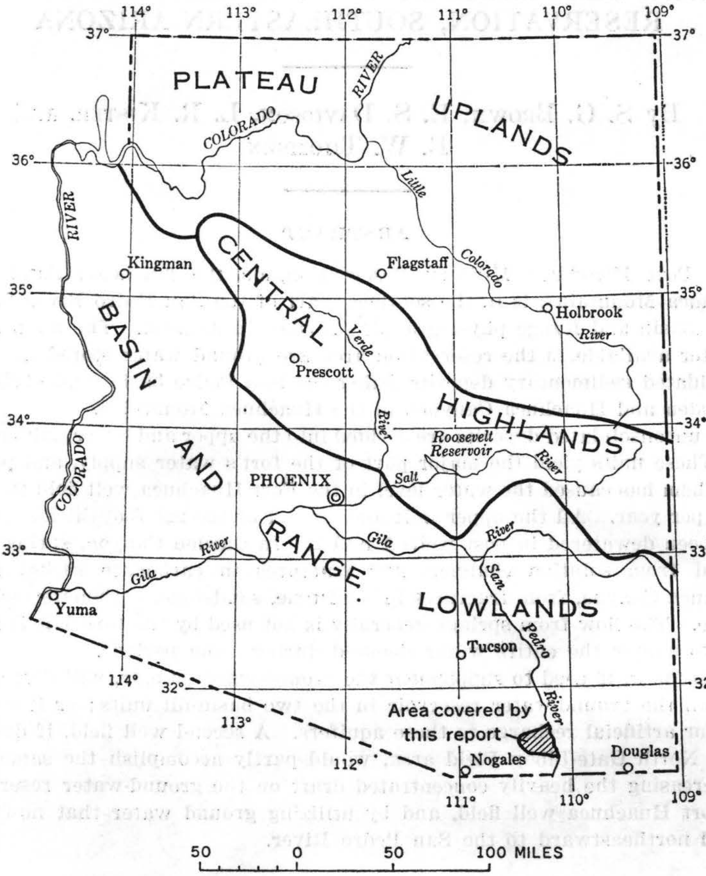


FIGURE 1.—Area investigated and Arizona's water provinces.

The climate of the Fort Huachuca area is mild, sunny, and dry; thundershowers in the summer and light general rains in the winter are common. The average annual precipitation at an altitude of about 5,000 feet is 16.45 inches, and that near the crest of the Huachuca Mountains may be as much as 25 inches (Sellers, 1960).

According to Sellers (1960), summer thundershowers in July and August account for about 50 percent of the fort's annual precipitation; about one-tenth of the winter precipitation is snow. For the period of record, precipitation was at least one-tenth of an inch on an average of 35 days annually.

The mean yearly temperature is 61.7°F. Temperatures are mild most of the year; extremes ranging from 105°F in July 1909 to 1°F in January 1913 are on record. Temperatures of 90°F and above occur on an average of 55 days per year, and temperatures of 32°F and below occur on an average of 49 days per year.

PURPOSE AND SCOPE OF THE INVESTIGATION

This report presents the results of a comprehensive investigation of the water resources of the Fort Huachuca Military Reservation and pertinent adjacent areas. The investigation, started in 1959 and finished in June 1963, was undertaken to locate additional water supplies and to appraise the water sources in use.

The report describes the geology, hydrology, and availability of water. The investigation included the collection and analysis of hydrologic data, including well-field analysis; determination of streamflow and ground-water interrelations; determination of the chemical quality of water; geologic mapping and the concurrent estimation of the rocks' ability to store and yield water; collection and analysis of subsurface information from well logs and borings; determination of geologic control on hydrologic boundaries; and determination of geologic and hydrologic conditions that control the larger springs in the Huachuca Mountains.

METHODS OF INVESTIGATION AND PERSONNEL

All wells in the area were inventoried. Water levels in more than 50 wells were measured at frequent intervals to delineate the water table, define areas of recharge and discharge, and determine the direction of ground-water flow. All springs on or near the reservation were visited; those producing significant quantities of water were investigated thoroughly to determine source, permanence, and quality of the water. Recording gages were installed in three wells to determine the effects of pumping in the area. Pumpage data for analysis were collected from drillers, private well owners, public agencies, and the post engineer. Aquifer tests were conducted to determine the hydraulic properties of the two main ground-water aquifers tapped by the Fort Huachuca well field. The geology was mapped, and the relation of the several geologic formations to the control and availability of water was determined in the San Pedro basin and in the Huachuca Mountains. The flow of surface water from Garden and Huachuca Canyons was measured at the gaging stations, and in October 1961 a conductivity recorder was installed at the Garden Canyon gaging station to make a continuous record of the quality of water passing that point.

The overall supervision of the investigation was by S. G. Brown under the direction of P. E. Dennis, district geologist of the Ground Water Branch, U.S. Geological Survey. The quantitative data were compiled and analyzed by S. G. Brown. The geology was mapped and described by E. S. Davidson, D. W. Layton, and H. G. Page. The stream-discharge data for Garden and Huachuca Canyons were gathered and analyzed by B. W. Thomsen. The quality-of-water data were collected and analyzed by L. R. Kister.

ACKNOWLEDGMENTS

The writers gratefully acknowledge the assistance and cooperation of both military and civilian personnel of Fort Huachuca. Those persons especially helpful and actively interested in the investigation were Maj. Gen. Francis F. Urhane (retired), former commanding general; Col. Charles H. Burch (retired), former deputy post commander; Lt. Col. W. H. Mathes, post engineer; Lt. Col. G. F. Kroehl, former post engineer; and Messrs. H. V. Puzzi and John Sliter, of the post engineers office. Of special help and value was the cooperation of personnel of the 416th Signal Company (Aviation), who provided helicopter support for part of the geologic and hydrologic reconnaissance on the west side of the Huachuca Mountains. The authors also acknowledge the generous assistance of Mr. Philip Hayes, of the Geological Survey, in describing the character and structure of the Mesozoic and Paleozoic rocks; the authors, however, are responsible for the conclusions expressed in this paper.

WELL-NUMBERING SYSTEM

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. (See fig. 2.) The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. 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 is in B quadrant, that south and west is in C quadrant, and that south and east is 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 denotes the 40-acre tract, and the third denotes the 10-acre tract. These letters also are assigned

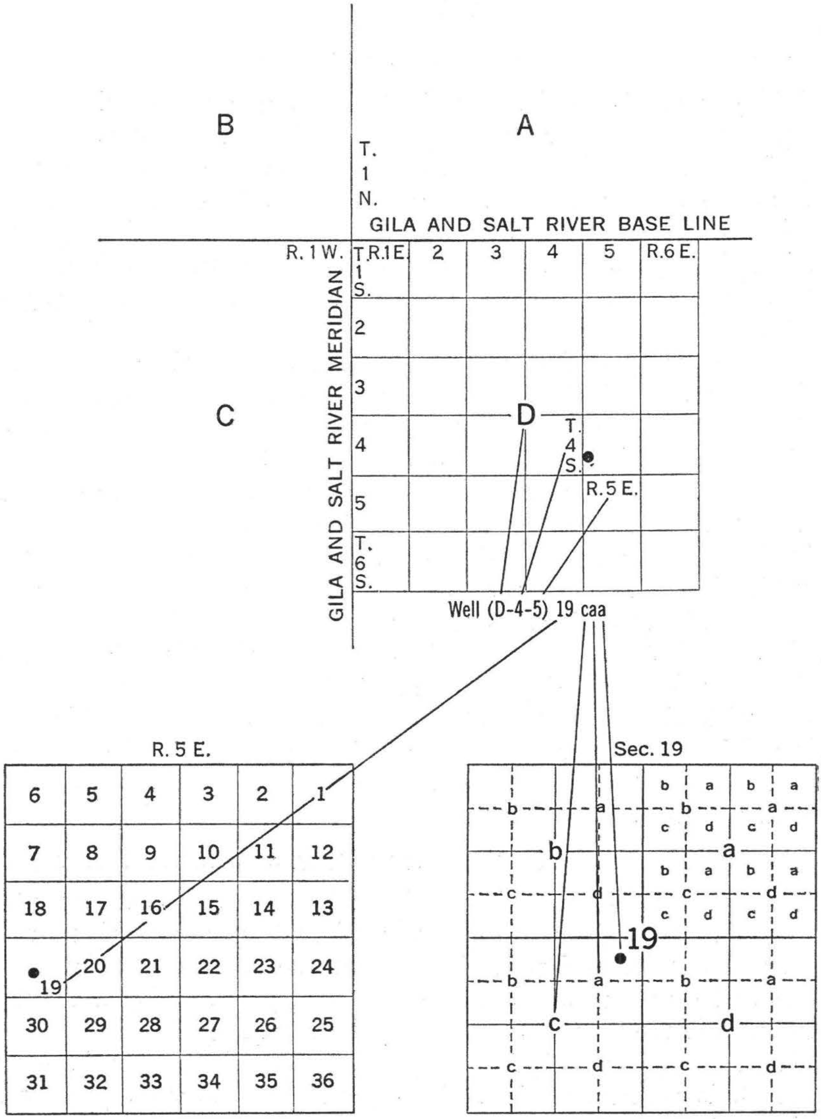


Figure 2.—Well-numbering system in Arizona.

in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown (fig. 2), well number (D–4–5) 19caa designates the well as being in the NE¼NE¼ SW¼ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

GEOLOGY

GEOLOGIC SETTING

The northwest-trending Huachuca Mountains, a faulted complex of granite, carbonate rocks, conglomerate, and claystone ranging in age from Precambrian to Cretaceous, form the southwestern part of the Fort Huachuca area. The southern segment of the San Pedro basin is chiefly underlain by unconsolidated gravel, sand, sandstone, and silt deposits, which are Tertiary to Quaternary in age. This southern segment forms the eastern and northern part of the area (fig. 3, pl. 1).

The lower slopes of the northeastern flank of the Huachuca Mountains are composed of Precambrian granite; higher on the slope and extending almost to the crest are limestone, dolomite, and claystone of Paleozoic age. The northwest-trending Crest Line fault separates these rocks from the mudstone and sandstone of Cretaceous age that form some of the crest and most of the southwestern slope of the Huachuca Mountains. In the general area of Sawmill Canyon and Lyle Peak, the headwater area of Garden Canyon, a northwest-trending block of Paleozoic rocks forms the crestal part of the mountains. This block is elevated west of the steeply dipping Lyle Peak fault.

The San Pedro basin, northeast of the Huachuca Mountains, is filled with about 850 feet of unconsolidated sediments, which are divided into an upper and a lower unit of basin fill. The basin fill unconformably overlies a conglomerate referred to as the Pantano(?) Formation (Miocene) of Brennan (1957, 1962).

CONSOLIDATED ROCKS AND THEIR HYDROLOGIC PROPERTIES

The "consolidated rocks" are principally those rocks that form the Huachuca Mountains and crop out in the Charleston-Fairbank area along the San Pedro River. These rocks are impermeable, but fractures and cracks in them trap water from precipitation and small streams and release the water slowly to the springs.

The lithologic description of the consolidated rocks included in figure 3 is generalized from Hayes (written commun., 1964) and Gilluly (1956, p. 86–105, pl. 5). The granite, Bolsa Quartzite, Canelo Hills Volcanics (Hayes and others, 1965), Bisbee Group, and igneous rocks in the Charleston-Fairbank area have low permeabilities and, except where they are broken by numerous faults or joints, do not yield water to wells. They generally act as impermeable barriers to the passage of ground water.

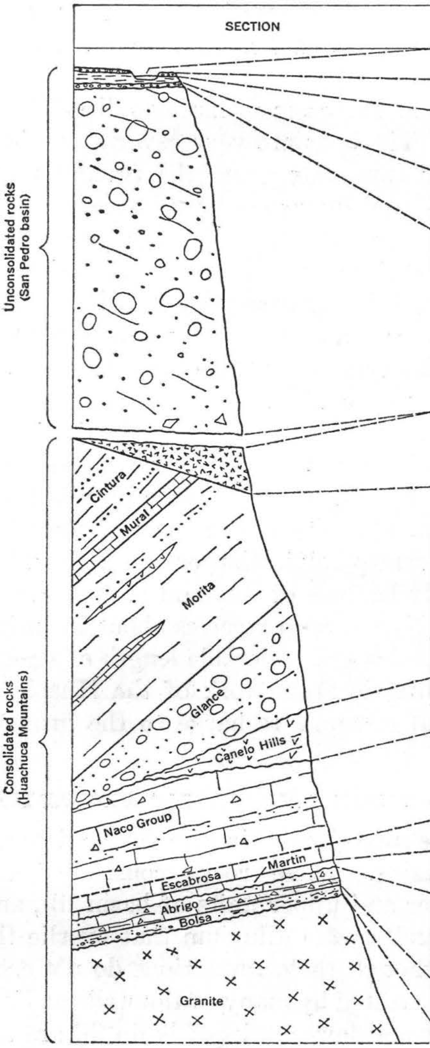
The Canelo Hills Volcanics on the west side of the Huachuca Mountains are host rocks to a few small springs that have extremely variable discharge. The rocks of the Bisbee Group have numerous fractures that may store large amounts of ground water; however, because the fractures are small and poorly connected, only small amounts of water issue from springs.

The thick calcareous beds of the Paleozoic formations dip 30°–40° SW. and are highly fractured. The beds are very cavernous where water has entered and dissolved carbonate along the fractures and bedding planes. Ground water generally moves downgradient or topographically downward through the cavernous openings because of their high degree of interconnection; therefore, the direction of ground-water movement is controlled only locally by the dip. Large springs occur in canyons where the normal downgradient flow of ground water is interrupted by impermeable rocks—such as cemented sandstone, siltstone, granite, or intrusive dikes.

A large slow-draining ground-water reservoir exists in the headwater area of Garden Canyon where upfaulted cavernous limestone of the Naco Group is dammed on the downstream side by relatively impervious Cretaceous rocks (pl. 2). The cavernous rocks quickly accept large amounts of water from precipitation or streamflow, but the water does not escape quickly because of the dam of impervious rocks. The outcrop area of the Naco Group receives about 25 inches of precipitation per year and includes a considerable length of stream bed; this combination, in the climatic framework of the Huachuca Mountains, facilitates substantial constant recharge to the groundwater reservoir.

UNCONSOLIDATED ROCKS AND THEIR HYDROLOGIC PROPERTIES

The unconsolidated rocks are principally in the lowland areas girdling the Huachuca Mountains. These rocks consist of the Pantano(?) Formation, the lower and upper units of basin fill, and thin deposits of terrace gravel and stream alluvium that overlie the other unconsolidated rocks. Although these formations do not crop out extensively, all have been penetrated by many of the wells at Fort Huachuca (table 1). The upper and lower units of basin fill are the chief aquifers tapped by the wells at the fort.



Geologic unit		Thickness, in feet (approximate)
Stream alluvium		0-100
UNCONFORMITY		
Terrace deposits		5-150
UNCONFORMITY		
Upper unit of basin fill		0-650
UNCONFORMITY		
Lower unit of basin fill		0-250
UNCONFORMITY		
Pantano(?) Formation (Miocene) Brennan (1957, 1962)		15,000±
UNCONFORMITY		
Volcanic and intrusive rocks in the Charleston-Fairbank area		-----
UNCONFORMITY		
Bisbee Group	Cintura Formation	2750±
	Mural Limestone	500-675
	Morita Formation	4000-4400
	Glance Conglomerate	0-3000±
UNCONFORMITY		
Canelo Hills Volcanics		6000+
UNCONFORMITY		
Naco Group undivided, probably includes, from top down, Concha Limestone, Epitaph Dolomite, Scherrer Formation, Colina Limestone, Earp Formation, and Horquilla Limestone		3000-4000
Escabrosa Limestone		700±
Martin Limestone		300
UNCONFORMITY		
Abrigo Limestone		750-800
Bolsa Quartzite		350-500
UNCONFORMITY		
Granite		

FIGURE 3.—Columnar section, stratigraphic table, and

PANTANO(?) FORMATION OF BRENNAN

A semiconsolidated brownish-red to brownish-gray conglomerate that crops out on the fringes of the Huachuca Mountains from Lyle Canyon on the north to the Barchas Ranch on the east is called the Pantano(?) Formation of Brennan (1957, 1962) in this report. The conglomerate is well exposed in the canyons north of the mountains but is poorly exposed southeast of Fort Huachuca. The conglomerate

DESCRIPTION	HYDROLOGIC CHARACTERISTICS
Light-brown sand, silt, and gravel	Moderate to very permeable; yields water to wells along Babocomari and San Pedro Rivers
Light-reddish-brown to light-brown sand, gravel, and clay, locally derived	Very permeable but above regional water table; locally may contain small amounts of perched water
Reddish-brown gravel, sand, and silt, some red and green clay, and limy silt	Most productive aquifer in Fort Huachuca well field; permeability moderate to very low; very permeable in some areas; thin on the west side of the mountains yielding little water
Light-gray to light-pinkish-gray gravel and sandstone, strong to weakly cemented, lenticular; locally derived cobbles and pebbles of quartz, granite, limestone, quartzite, and rhyolite tuff	Secondary aquifer in Fort Huachuca well field; permeability moderate to low; yields little water to wells on the west side of the mountains
Dark-reddish-brown to brownish-gray conglomerate, sandstone, and well-cemented gravel; boulders as much as 4 ft in diameter; materials composed of purple to red rhyolitic tuff, gray to pink felsitic tuff, purple to dark-green andesite, red and maroon shale and siltstone, light-yellow granite, dark-gray limestone, and light-gray to white quartzite	Very low to low permeability; generally reported "dry" by well drillers
Gray-green andesite flow breccia, fine-grained light-gray to pinkish- and greenish-gray quartz latite tuff, subordinate pink to dark-gray quartz latite flows; intrusive rocks are gray to pink quartz latite porphyry and light-gray granodiorite	Very low permeability
Dark-red to reddish-brown shale and mudstone, and subordinate gray and brown sandstone, pebble and cobble conglomerate	Contains small springs and seeps; very low permeability; low to moderately permeable where abundantly fractured
Light-gray limestone, fossiliferous; thin interbeds of yellow and olive limy shale and gray to light-brown sandstone; grades into overlying and underlying units	
Dark-red to reddish-brown shale and mudstone, gray and brown sandstone and grit, and minor limestone and greenish-gray shale	
White, light-gray to light-reddish-gray conglomerate, well-rounded cobbles of limestone, rhyolite, andesite, granite, and quartzite; locally interbedded with andesitic lava flows; grades into overlying unit	
Pinkish-gray to yellowish-brown rhyolite to latite flows, volcanic conglomerate, limestone conglomerate, pale-red tuffaceous sandstone, and reddish-brown rhyolitic welded tuff	Very low permeability; low permeability where fractured; small seeps and springs in unit
Dominantly gray to pinkish-gray limestone and dolomite in 6-in.- to 5-ft-thick beds; pale-red calcareous siltstone and mudstone and yellowish-brown sandstone are common in parts of the group	Main ground-water reservoirs and conduits for springs in Garden Canyon; very permeable where carbonate units are fractured and dissolved along fractures; claystone, siltstone, and mudstone units are impermeable and cause ground water to emerge as springs
Light- to medium-gray very thick bedded limestone; contains abundant crinoid stems; forms bold rounded cliffs	
Dark-gray to brownish-gray dolomite; minor beds of gray claystone and sandstone; medium to very thick bedded; forms benches and slopes	
Laminated claystone and gray limestone, claystone weathers yellowish brown; subordinate interbedded limestone in 6-in. to 1-ft- thick beds in lower half; thinly laminated limestone separated by partings and 1-in.-thick beds of edgewise conglomerate and claystone in upper part; forms rounded cliffs	
Light-gray locally banded pale-red-purple quartzitic to feldspathic conglomerate and quartzitic sandstone; grades into overlying shale and limestone	No known springs; very low permeability, slightly more permeable where fractured
Pinkish-gray coarse-grained granite	

hydrologic characteristic of rock units in the Fort Huachuca area.

probably is correlative with the Miocene Pantano Formation of Brennan (1957, 1962), which crops out extensively near the settlement of Pantano, 37 miles northwest of the Huachuca Mountains. The correlation is inferred because of the similarities of the two units in lithology, thickness, structural involvement, and relation to underlying and overlying rocks.

The matrix of the conglomerate ranges from coarse sandstone to grit in which are set many pebbles, cobbles, and boulders as much as 4 feet in diameter. Individual beds range from several inches to a few feet

TABLE 1.—*Drillers' logs of wells near Fort Huachuca, Ariz.*

Stratigraphic unit	Rock description	Thickness (ft)	Depth (ft)
	(D-20-21)3cd [Altitude: 3,855 ft]		
Stream alluvium	Clay	6	6
	Gravel	10	16
Upper unit of basin fill(?)	Clay	89	105
Lower unit of basin fill and older units (undivided)	Hard clay	113	218
	Clay and gravel	32	250
	Gravel and water	12	262
	Sand and gravel	8	270
	Clay	6	276
	Clay and gravel	40	316
	Sandy clay	44	360
	Clay and gravel	114	474
	Cemented gravel	41	515
	Boulders and gravel	15	530
	Sand and gravel	14	544
	Cemented gravel	19	563
	Gravel and clay	10	573
	Cemented gravel	39	612
	Cemented rock	5	617
Bedrock	Solid granite	6	623
	(D-21-20)21aad [Altitude: 4,480 ft]		
Terrace deposit and upper unit of basin fill (undivided)	Red sandy clay and gray sandy clay with occasional boulders. First water, 320–334 ft; second water, 350–375 ft; third water, 380–385 ft; fourth water, 400–435 ft; fifth water, 470–475 ft; sixth water, 515–525 ft	525	525
Lower unit of basin fill	Gray conglomerate (sedimentary)	75	600

TABLE 1.—*Drillers' logs of wells near Fort Huachuca, Ariz.*—Continued

(D–21–20)33aba

[Post well 4. Altitude: 4,619 ft]

Stratigraphic unit	Rock description	Thickness (ft)	Depth (ft)
Terrace deposit and upper unit of basin fill (undivided)	Gravel and adobe	67	67
	Adobe and boulders	230	297
	Sand, gravel, boulders, and adobe	149	446
	Clay	7	453
	Gravel and clay	34	487
	Sand and clay	95	582
	Sand	35	617
?			
Lower unit of basin fill	Cemented sand	100	717
	Sand with thin clay layers	45	762
	Sand and gravel	15	777
	Coarse sand	70	847
?			
Pantano(?) Formation of Brennan (1957, 1962)	Cemented sand and gravel	65	912

(D–21–20)33dbb

[Post well 6. Altitude: 4,645 ft]

Stratigraphic unit	Rock description	Thickness (ft)	Depth (ft)
Terrace deposit	Bouldery loose fill	32	32
	Sand and gravel	8	40
	Caving sand and gravel	5	45
?			
Upper unit of basin fill	Bouldery red clay	30	75
	Gravel	8	83
	Gravelly red clay	267	350
	Caving gravelly red clay	42	392
	Sandy red clay	19	411
	Bouldery red clay	9	420
	Tight sandy red clay, first strong water at 492 ft	72	492
	Tight sandy red clay, grading into conglomerate	78	570
Lower unit of basin fill	Conglomerate	32	602
	Indications of water in break zone	2	604
	Conglomerate	6	610
	Indications of water in break zone	6	616
	Conglomerate	142	758
?			
Pantano(?) Formation of Brennan (1957, 1962) (samples from 815 ft to bottom of hole are characteristic of lower Tertiary unit; no samples were collected above 815 ft)	Very hard conglomerate	13	771
	Conglomerate	114	885
	Very hard conglomerate	35	920
	Conglomerate	105	1, 025
	Little sand in crevices, indications of water	13	1, 038
	Conglomerate	62	1, 100
	Conglomerate, little redder in color	50	1, 150
	Mudstone or reddish shale	13	1, 163
	Conglomerate	27	1, 190
	Hard conglomerate with soft ribs of coarse sandstone cemented with limy material	40	1, 230

TABLE 1.—*Drillers' logs of wells near Fort Huachuca, Ariz.*—Continued

Stratigraphic unit	Rock description	Thickness (ft)	Depth (ft)
	(D-21-21)7bcd [Altitude: 4,265 ft]		
Terrace deposit and upper unit of basin fill (undivided)	Red clay with varying quantities of sand and gravel	300	300
	(D-22-20)3bbb 1 [Unused post well. Altitude: 4, 641 ft]		
Terrace deposit and upper unit of basin fill (undivided)	Adobe with hard boulders	90	90
	Loose gravel, dry	6	96
	Adobe with hard boulders	374	470
Lower unit of basin fill	Hard sandstone, first showing of water at 471 ft	1	471
	Sand and gravel, compacted	18	489
	Loose sand, gravel, and boulders	133	622
	(D-22-20)3bbb 2 [Post well 1. Altitude: 4,641 ft]		
Terrace deposit	Adobe	8	8
?	Boulder bed	19	27
Upper unit of basin fill	Adobe and boulders	61	88
	Sand, gravel, and boulders	24	112
	Adobe and boulders	58	170
	Loose boulders, very hard	86	256
	Adobe, gravel, and boulders	16	272
	Adobe, sand, gravel, and boulders	47	319
	Boulders, very hard, and clay	46	365
	Adobe and gravel	52	417
	Hard sand and gravel, cemented	9	426
	Adobe, sand, and gravel	39	465
Lower unit of basin fill	Hard sand	4	469
	Water, gravel, and sand	1	470
	Sand and gravel	18	488
	Loose sand and gravel, strong showing of water at 488 ft	36	524
	Hard sand, gravel, and boulders	21	545
	Loose sand and gravel	35	580
	Loose boulders	11	591
	Loose water sand and gravel	24	615
	Loose sand, gravel, and boulders	5	620
	Hard boulders	9	629
	Loose sand and boulders	16	645
	Hard sand	10	655
	Loose sand and gravel	25	680
	Adobe (probably weathered zone or soil developed on top of lower Tertiary unit)	12	692
Pantano(?) Formation of Brennan (1957, 1962)	Hard drilling, apparently drilling in rock	9	701

TABLE 1.—*Drillers' logs of wells near Fort Huachuca, Ariz.*—Continued

Stratigraphic unit	Rock description	Thickness (ft)	Depth (ft)
	(D-22-20)4aaa		
	[Post well 2. Altitude: 4,641 ft]		
Terrace deposit and upper unit of basin fill (undivided)	Conglomerate, medium hard	40	40
	Clay and gravel	20	60
	Sandstone and conglomerate, medium hard	70	130
	Conglomerate, medium hard	70	200
	Conglomerate with hard strata	70	270
	Conglomerate, medium	25	295
	Conglomerate with soft strata	15	310
	Conglomerate, medium	30	340
	Sand	30	370
	Large boulders	40	410
	Sand and gravel	30	440
	Water sand conglomerate	37	477
——— ? ———			
Lower unit of basin fill	Conglomerate with lots of water	43	520
	Gravel carrying water	20	540
	Hard conglomerate	30	570
	Sand conglomerate with water	50	620
	Conglomerate, medium, with hard strata	30	650
	Hard conglomerate	40	690
——— ? ———			
Pantano(?) Formation of Brennan (1957, 1962)	Rock	20	710

in thickness. The bedding is tabular to lenticular; crossbedding is uncommon, but many flat pebbles are imbricated. Local unconformities that separate groups of beds in the formation may reflect continual uplift and tectonic unrest coincident with deposition of the conglomerate. Both the local inclusion of landslide material and the large size of the boulders in the Pantano(?) are suggestive of high relief, possibly due to concurrent uplift, in the source area. The formation is firmly cemented; in most exposures individual cobbles can be broken out of the fresh rock, but in many places the cementation is so strong that the rock breaks indiscriminately across cobbles and matrix.

The pebbles and larger fragments are, in approximate order of abundance, pinkish-gray to pale-red rhyolitic welded tuff, gray to pinkish-gray felsitic welded tuff, grayish-purple andesite, reddish-brown to very dark red shale and siltstone, light-yellow granite, greenish-gray epidotized and chloritized andesite, dark-gray limestone, and light-gray to white quartzite. Most of the coarse material is sharply angular, but some pebbles and cobbles show slight rounding, especially in outcrops farthest from the Huachuca Mountains.

The source of the conglomerate is volcanic rocks similar to those cropping out in Lone Mountain and the Canelo Hills. A highland in that general area probably supplied the bulk of the conglomerate fragments. The granite cobbles and some limestone cobbles, neither of which are abundant, may have been derived from the older rocks exposed in canyons that cut through the Bisbee Group and the Canelo Hills Volcanics. Shingling or imbrication of the flat pebbles and cobbles also indicates a southern and western source for the conglomerate. Many flattened pebbles and cobbles dip to the south and southwest, which suggest that the streams depositing the conglomerate flowed to the north and northeast. The very large size of some of the boulders indicates that the highland source was not far away.

The conglomerate beds generally strike northwest and dip 15°–45° SW. On the basis of its attitude and outcrop width, from the Fort Huachuca well field to the northwest edge of the map area, the unit is estimated to be as much as 15,000 feet thick, if no major faults cause repetition of beds in the exposed section.

The entire block of tilted conglomerate is separated from Cretaceous and older rocks by a low-angle fault along the east and north margins of the Huachuca Mountains. From Sycamore Canyon to the Barchas Ranch, the Pantano(?) Formation typically rests on a few tens of feet of Cretaceous(?) contorted maroon shale and mudstone, which in turn rests on a slickensided surface of Precambrian granite or on slickensided quartz veins of pre-Tertiary age. The quartz veins are not more than 20 feet thick and crop out as discontinuous pods along the fault. The contact between the conglomerate and the maroon shale and mudstone is not exposed, but the contact between the shale and the quartz vein or granite is exposed clearly in several places. In every exposed contact, the granite or quartz is intensively sheared and slickensided. The shear planes dip about 25°–40° away from the Huachuca Mountains. West of Sycamore Canyon the Pantano(?) is in fault contact with rocks of the Bisbee Group except in one outcrop north of Pyeatt Ranch, where the conglomerate rests unconformably on a few tens of feet of rocks that may be correlative with the Canelo Hills Volcanics (Hayes and others, 1965, p. M1–M9).

Most exposures of the Pantano(?) have very low to low permeability, mainly owing to the cementation that has lowered markedly the original high permeability of this formation. Ground water in the Pantano(?) occurs primarily in fractures and secondarily in the reduced pore space between grains. Although the Pantano(?) probably will yield small amounts of water to wells, it is generally regarded as "dry" by drillers. Well yields of as much as several hundred gallons per minute may be derived from this formation along fault zones or in other areas where the formation is highly fractured below the regional water table.

LOWER UNIT OF BASIN FILL

The light-gray sedimentary rocks unconformably overlying the Pantano(?) Formation are informally called the lower unit of basin fill. This unit, in contrast to the Pantano(?), was deposited after development of the basin-and-range topography and consists of interbedded gravel and sandstone, the distribution and composition of which are closely associated with the intermontane basin. The Pliocene age of the lower unit is inferred partly by correlation of the lower unit with fossiliferous beds of Pliocene age cropping out about 60 miles north of Fort Huachuca in the Redington area of the San Pedro River valley (Lance, 1960, p. 156, 159) and partly by correlation with fossiliferous beds of Pliocene age (P. A. Wood, oral commun., 1963) exposed a few miles southwest of Lone Mountain. No fossils have been reported from the lower unit in the area adjacent to Fort Huachuca.

The lower unit of basin fill does not crop out extensively; but a few exposures are present in the Sycamore-Lyle Canyon area north of the Huachuca Mountains, and most of the wells at the fort intersect it. The lower unit forms much of the San Pedro River bed between Charleston and Lewis Spring and may underlie the hill (4,876-ft bench mark) half a mile north of the mouth of Garden Canyon (pl. 1). The wells at the fort and Sierra Vista penetrated 235 feet of the unit (pl. 1; table 1), but it may be much thicker in parts of the basin between the fort's well field and the San Pedro River. The lower unit is 250–500 feet thick on the west side of the area, where it underlies the slopes of Sunnyside and Lyle Canyons.

The lower unit of basin fill consists of interbedded lenses and layers of gravel and sandstone, as determined by examination of exposures and drill cuttings and by interpretation of drillers' logs. The bedding ranges from lenticular to tabular; scour-and-fill structures are fairly common, and some units show crossbedding. The cementation is variable; in a few exposures the whole unit is strongly cemented, but in others it is weakly cemented. In only a few places does the rock break across pebbles, cobbles, and matrix when it is hammered. Generally the gravel beds are poorly sorted, and individual beds or layers contain a mixture of silt, sand, pebbles, cobbles, and boulders as much as a foot in diameter. The sandstone beds also are poorly sorted; they range from fine to very coarse grained and contain varying amounts of pebbles.

The pebbles, cobbles, and boulders in the lower unit are subrounded to well rounded and consist mainly of quartz, granite, limestone, and quartzite; however, nearly every rock type exposed in the Huachuca Mountains is present. The matrix of the gravel ranges from silt to coarse sand and contains a high percentage of quartz and lesser amounts of feldspar and rock fragments. The sandstone beds consist of quartz, feldspar, mica, and interstitial clay.

The beds in this unit are gently tilted in most exposures, and dips range from a few degrees to about 20°. The lower unit of basin fill is below the water table in much of the Fort Huachuca well field and is hydraulically connected with the overlying upper unit of basin fill, as discussed more completely in the following sections. The variability in size, sorting, and degree of cementation of the materials in this unit produces an aquifer of fair to good permeability in one area or at one depth and of only poor to fair permeability in another area or at another depth.

UPPER UNIT OF BASIN FILL

The deposits overlying the lower unit of basin fill are called the upper unit of basin fill. The upper unit consists of weakly cemented and compacted soft reddish-brown clay, gravel, sand, and silt. It is poorly exposed and crops out mainly in stream cuts; it forms steep slopes if capped by well-cemented terrace deposits but erodes to a badland topography if not protected by the terrace deposits. The upper unit grades from a very permeable fan gravel near the mouths of major streams issuing from the Huachuca Mountains to relatively impermeable silt and limy clay containing a few sandstone beds in the central part of the basin near Charleston.

Fossils collected from the middle and upper parts of the upper unit of basin fill in the Benson and St. David area, 15 miles north of Fort Huachuca, are early Pleistocene in age (Gazin, 1942; Lance, 1960; Philip Seff, oral commun., 1963). The precise age of the basal beds is not known but is probably Pleistocene or perhaps late Pliocene.

Beds of the upper unit of basin fill dip very gently away from the Huachuca Mountains toward the center of the basin, the axis of which probably lies west of the San Pedro River. The beds dip as much as 5° near the Huachuca Mountains but are horizontal or nearly so near Huachuca City and along the San Pedro River. No faults are known to offset the upper unit in the Fort Huachuca area.

The upper unit of basin fill is about 450–620 feet thick in the Fort Huachuca well field but is only 10 feet thick along the San Pedro River near Charleston. Wells between the fort's well field and the San Pedro River intersect 200–300 feet of the upper unit but do not completely penetrate it; the total thickness is not known. The unit probably is 500–700 feet thick between the well field and the river, but a thickness of 1,000 feet is possible.

A ridge or northeastward-trending nose of low-permeability rock may cause the steep north-dipping configuration of the water table (pl. 1) southeast of the fort and north of the Garden Canyon drainage. The noselike configuration of the water table extends from the Huachuca Mountains to the San Pedro River. The configuration existed prior to extensive pumping of the fort's well field, judging from sparse data collected by S. F. Turner (written commun., 1941) and Kirk Bryan (written commun., 1934). The top of the water table in the ridge area is probably about 50 feet or less above the base of the upper unit, so that a "buildup" effect is caused on the less permeable south side of the ridge and on the steep slope on the more permeable north side. The ridge, if present, probably is formed by the lower unit of basin fill or by the Pantano(?) Formation. The hill (4,876-ft bench mark (pl. 1)) forms the southwest end of the ridge. This hill is covered with float resembling material in the lower unit of basin fill, but no outcrops were found, and drill-hole data are too meager to provide conclusive evidence. The effect of a change in lithology in the upper unit of basin fill, from a less permeable aquifer to the south to a more permeable aquifer to the north, would cause the same water-table configuration; but such a distribution of sediment change in the upper unit is not compatible with the observed facies changes. The authors believe, therefore, that the buried-ridge interpretation is better. The configuration of the water table may also be interpreted to be a nose caused by recharge of ground water to the upper unit from streams issuing from Garden Canyon. This interpretation is not considered as likely as that of a buried ridge because of the long-term existence of the water-table configuration and its definite sharp noselike shape, which extends 8 miles northeastward to the San Pedro River.

The upper unit of basin fill has been divided into three principal facies on the basis of grain size and mode of deposition. The facies are fan gravel near the Huachuca Mountains, clay and silt near the San Pedro River, and sand and silt in the intervening areas. The boundaries between the facies are gradational and are not exposed well enough to permit delineation on the map.

The coarse gravelly material of the fan-gravel facies crops out in a zone several miles wide, banding the Huachuca Mountains from Blacktail Canyon to the southern boundary of the reservation. This coarse material is bedded in 3- to 18-inch-thick layers of silty to sandy gravel and gravelly sand. The fragments in the gravel, which are subrounded to well rounded and as much as 2 feet in diameter, are derived from nearby sources. The fan-gravel facies is light brown to light reddish brown north and northwest of the fort and dark reddish brown south to Garden Canyon. The dark-reddish-brown material contains more red clay than does the light-brown material and is commonly called adobe gravel or sticky clayey gravel in drillers' logs.

The fan-gravel facies grades away from the Huachuca Mountains into the sand and silt facies, which consists of light-brown to reddish-brown evenly bedded pebbly sand, silty sand, and silt. These materials are exposed along the bank of the Babocomari River south of Huachuca City and in small outcrops northeast of the fort.

The clay and silt facies is exposed along the San Pedro River. Judging from float and poorly exposed outcrops along State Route 90 near the Donnet-Fry Ranch, this material probably extends at least 4 miles southwest of the river and there grades into the sand and silt facies. The fine-grained material is dominantly light brown very thin bedded limy silt and clay.

The fan-gravel facies has good to very good permeability. The fan gravel northwest of the fort, where the unit does not contain much red clay, is probably more permeable than that south of the fort, where the clay content is slightly higher. The sand and silt facies has fair to good permeability, and the silt and clay facies has very poor to poor permeability.

TERRACE DEPOSITS AND STREAM ALLUVIUM

The San Pedro basin in the Fort Huachuca area was filled by basin-fill sediments to an altitude of nearly 5,000 feet. At the close of the deposition, regional structural and climatic changes resulted in erosion beginning in middle Pleistocene time and continuing to the present. The San Pedro River became a vigorous throughgoing stream traversing the central part of the upper San Pedro basin. As a result, several hundred feet of soft basin-fill sediment was eroded in the central part of the basin and carried downstream. The remaining part of the upper unit of basin fill is thickest between the mountains and the San Pedro River and thinnest along the San Pedro River and the fringes of the Huachuca Mountains. The first period of downcutting produced the uppermost terrace level, which is now preserved north and west of Huachuca Canyon. An intermediate terrace level, on which most of the fort is located, was subsequently formed. The last major period of downcutting and erosion formed the present surface of the flood plains along the San Pedro River and its tributaries. Prior to 1900, streams incised this surface, producing arroyos, and the streambeds are now 5–25 feet below the flood plain.

The terrace deposits extend from the base of the mountains to the flood plains of the San Pedro and Babocomari Rivers (pl. 1). They are only 5–20 feet thick near the Huachuca Mountains, but, near the center of the basin, they may be as much as 50–100 feet thick in channels roughly parallel to the present course of the San Pedro River. The material in the terrace deposits is a poorly sorted mixture of light-reddish-brown to light-brown gravel, sand, and clay derived from nearby sources. This material is very permeable; but because it is thin, cut by numerous shallow washes, and above the regional water table, it does not provide much ground-water storage in the area.

The youngest terrace deposit, mapped as stream alluvium, is as much as 50 feet thick along the San Pedro River, where it rests locally on the lower unit of basin fill, and along the Babocomari River, where it rests on the upper unit of basin fill. The alluvium is from 5 feet to at least 30 feet thick along the other tributaries extending from the Huachuca Mountains to the San Pedro River, where it rests on the upper unit of basin fill. The alluvium is a very permeable mixture of sand and gravel and forms a productive aquifer along the Babocomari River and parts of the San Pedro River. The stream alluvium of the Babocomari and San Pedro Rivers occupies the lowest topographic position in the San Pedro basin and receives ground water from the basin-fill units and accepts water from and releases it to the two rivers. The alluvium in the small tributaries issuing from the Huachuca Mountains near the fort is generally too thin to be a highly productive aquifer, although some discharge from the tributaries passes downward through this alluvium and recharges the underlying upper and lower units of basin fill.

HYDROLOGY

The ultimate source of ground water and surface water is precipitation on the land surface. Surface water is water in streams, ponds, and lakes; and ground water is water, other than soil moisture, beneath the land surface. Flow from a spring is ground water before it leaves the spring orifice and surface water after it leaves the orifice.

Precipitation on the land surface is absorbed by the soil, unless the rate of precipitation exceeds the rate at which the soil will accept it. The precipitation rejected by the soil becomes runoff and flows overland to stream channels. Water that infiltrates the soil in excess of the ability of the soil to hold it as soil moisture continues to move downward to the zone of saturation and becomes ground water. Any rock formation that is in the zone of saturation and yields water in a sufficient quantity to be used as a water supply is called an aquifer. Water moves downgradient through the aquifer and is discharged naturally

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to streams and springs, artificially to wells, or is lost to the atmosphere by evapotranspiration.

Water supplies on and near the Fort Huachuca Military Reservation can be obtained from two principal sources on the east side of the Huachuca Mountains: (1) ground water from the two basin-fill units, and (2) water from the fracture- and fault-controlled springs issuing from the carbonate rocks of the mountains. On the west side of the Huachuca Mountains, only small amounts of ground water can be obtained from wells in the lower unit of basin fill and from the small ephemeral springs in the mountains. Supplies from these sources are sufficient only for domestic or stock uses during part of the year.

The basin-fill units are recharged along the mountain fronts and in the upper reaches of washes where water debouches from the mountain canyons onto the valley slopes. Flow in washes and creeks from the mountain fronts seldom reaches the San Pedro River, except during the brief torrential summer storms or after prolonged precipitation in the winter. Some of the flow enters the permeable material that underlies the stream channels and moves downward to the ground-water reservoir, but most of the surface flow that emerges from the canyons is lost to evapotranspiration—that is, either evaporation from surface water, soil moisture, and shallow ground water or transpiration by plants. Only small amounts of water enter the soil and continue downward as recharge to the ground-water reservoir. Ground water moves downgradient through the basin-fill units and, except for that withdrawn by pumping or lost to evapotranspiration, emerges in the San Pedro River and to a minor extent in the Babocomari River (pl. 1), where it is again subject to evapotranspiration. Ground water in the alluvium along the San Pedro River is forced to the surface by a ground-water barrier formed by consolidated volcanic and sedimentary rocks cropping out near the Charleston gaging station (pl. 1). As a result, ground water enters the channel of the San Pedro River and maintains a short reach of perennial flow at the gaging station. Ground water is also forced to the surface by consolidated rocks cropping out in the valley of the Babocomari River about 4 miles southwest of Fairbank.

Springs in the Huachuca Mountains are recharged from overland runoff resulting from precipitation and snowmelt. The runoff is intercepted by the more cavernous fractured and jointed carbonate rocks in the mountains. These rocks transmit water rapidly to springs, the largest of which are in places where the interconnections of the cavernous openings are interrupted by impermeable barriers. Only springs in Garden and Huachuca Canyons yield the quantity, quality, and continuity of discharge required for a water supply at the fort.

OCCURRENCE OF WATER IN THE SAN PEDRO BASIN

WATER-TABLE FLUCTUATIONS

Long-term hydrographs of depth to water in six widely separated wells (fig. 4) on the broad slope of the San Pedro River valley show that water levels in five wells declined 0.3–0.5 foot per year; the average decline was 0.4 foot per year. The hydrograph of the sixth well, (D–23–21)6ccc (fig. 4), near the mountain front in an area where recharge occurs, shows abrupt water-level rises and slow declines, which are typical for wells in a recharge area. Runoff from Carr Canyon and a smaller canyon to the south is carried down the wash, and some of it recharges the aquifer and, thus, causes the water level in the well to rise. In the periods between recharge from runoff, the water level in the well slowly declines as the water in the aquifer moves to the discharge area along the San Pedro River.

The regional water-level decline of 0.3–0.5 foot indicates that not all the water-level decline in the Fort Huachuca wells is caused by heavy pumping depleting an aquifer. Some of the water-level decline in the fort's wells probably is caused by the following factors. The San Pedro River channel in the reach from Palominas to Charleston acts as a ground-water drain. Except in the Sierra Vista and Fort Huachuca well fields, pumpage is minimal—mainly for stock and domestic use—and it is not enough to account for the water-table decline. Thus, it can be assumed that either recharge to the aquifers was insufficient to maintain the higher water table or the water table is still adjusting to the lowering of the streambed of the San Pedro River, which occurred in the late 1800's. Regional lowering of the water table will eventually come into long-term balance with recharge and discharge, as determined by the aquifer-transmission characteristics. However, the regional decline is now superimposed on the declines caused by heavy pumping in the Fort Huachuca well field.

From October 1958 to March 1961, water levels in post well 6 declined as much as 7 feet under the influence of the cyclic pumping of post wells 1, 2, 3, 4, and 5 (fig. 5). The rate of decline in well 6, about 2.9 feet per year, is about seven times greater than the average regional decline of 0.4 foot per year in wells outside the influence of pumping of the wells supplying Fort Huachuca and Sierra Vista. The difference between a regional decline of 0.3–0.5 foot per year and a local decline of 2.9 feet per year at well 6 in the Fort Huachuca well field is caused by pumping from the Fort Huachuca and Sierra Vista wells.

The hydrograph for well 5 (fig. 4) shows a sudden increase in rate of decline after the September 1950 measurement. The authors believe that after September 1950 the water level had declined below the base of the upper unit of basin fill and that well 5 was obtaining

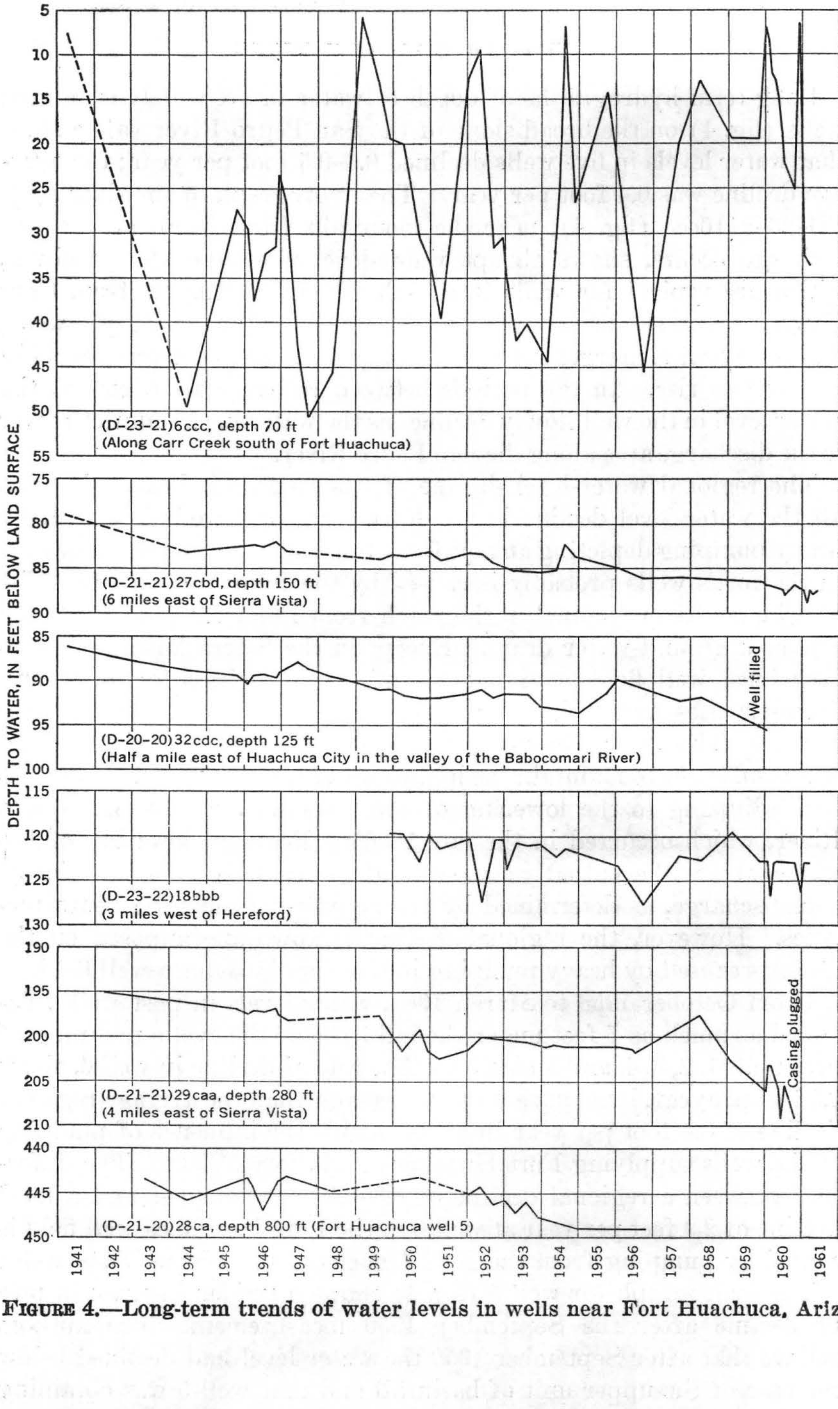

FIGURE 4.—Long-term trends of water levels in wells near Fort Huachuca, Ariz.

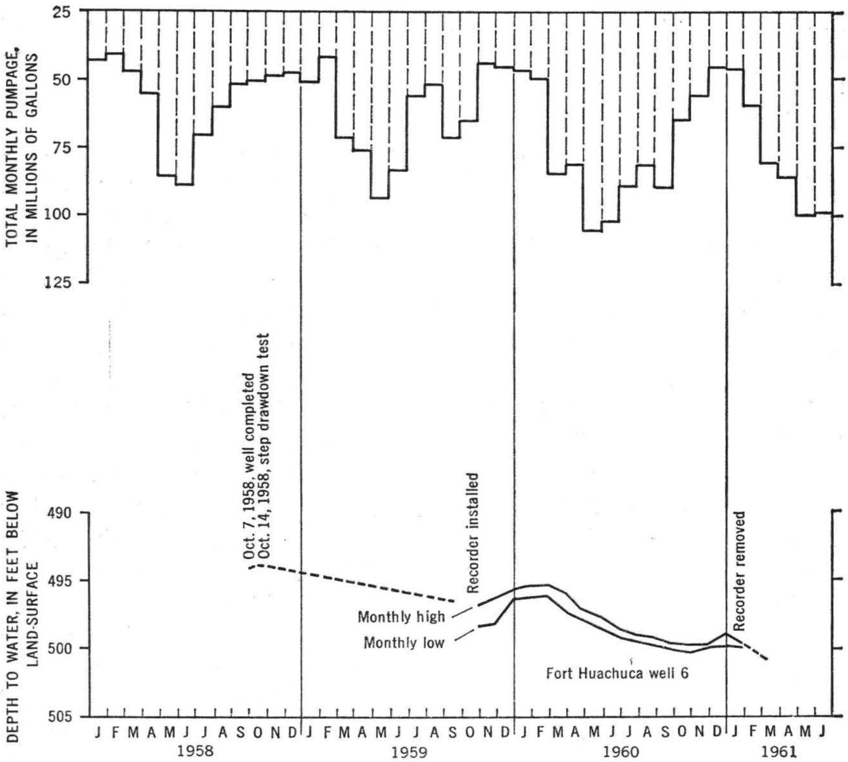

FIGURE 5.—Hydrograph of well 6 compared with the total monthly pumpage from the Fort Huachuca well field.

water entirely from the lower unit of basin fill. The average decline from September 1950 to October 1956 was about 1 foot per year, or a total measured decline of about 6 feet. Well 5 is nine-tenths of a mile north of well 6 and on the northern limits of the Fort Huachuca well field. The hydrographs for wells 5 and 6 show that pumpage from the Fort Huachuca-Sierra Vista well-field complex is exceeding the recharge to the area and that the water pumped is mostly from storage.

RECHARGE AND MOVEMENT OF GROUND WATER

The configuration of the water table near Fort Huachuca in March 1961 is shown on plate 1. The arrows show the direction of ground-water movement from the recharge area near the mountain front both to the discharge area along the San Pedro River and to the cone of depression around the Fort Huachuca-Sierra Vista well-field complex. The water-table contours (pl. 1) show that the basin-fill units are recharged along the east face of the Huachuca Mountains and that the water moves downgradient toward the San Pedro River. Some ground water may be discharged by evapotranspiration from plants or by wells along the way; the rest eventually is discharged into the San Pedro River. In the East Gate-Fort Huachuca-Sierra Vista area, the cone of depression caused by pumping is readily apparent.

On March 7, 1962, measurements were made to determine the possible water losses from Garden Canyon Creek by infiltration to ground water. The weather was cool with intermittent rain and snow showers, and evapotranspiration losses were negligible. The discharge of Garden Canyon Creek, measured at the gaging station, was about 3.5 cfs (cubic feet per second), and discharge was steady during the measurements. The discharge at the point where the creek leaves the reservation was 1.2 cfs. The straight-line distance between these two points is 4.0 miles, and the distance along the bed of Garden Canyon Creek is 4.4 miles. The loss between these two points was 2.3 cfs, or slightly more than 0.5 cfs per mile of channel. Because evapotranspiration was negligible during the measurements, the data probably show accurately the recharge to ground water from the creek for the prevailing creek stage and weather conditions.

The water-table map (pl. 1) indicates that if the aquifer between Garden Canyon and the Fort Huachuca well field is continuous, the underflow from Garden Canyon Creek contributes to the recharge of the Fort Huachuca–Sierra Vista area. Probably not more than half the measured loss could contribute recharge to the well field. At the measured rate of infiltration, recharge from Garden Canyon Creek could be on the order of 1 mgd (million gallons per day), but only for that part of the time when the creek flows out of the canyon under the conditions that prevailed during the time the measurements were made. Estimating the amount of recharge received annually from Garden Canyon Creek is at best a hazardous guess, because evaporation and transpiration can consume the complete discharge of the creek during most of the year. Weather Bureau pan-evaporation at Nogales, Ariz., about 37 miles southwest of the fort, averages 99.92 inches per year. Applying a pan coefficient of 75 percent, evaporation in the area is about 75 inches per year, and it claims much of the surface water and shallow ground water. The amount of recharge estimated from the seepage run of March 1962 probably represents a maximum value. Much of the runoff resulting from the heavy summer rains probably is transpired almost immediately.

WELL-FIELD CHARACTERISTICS

The Fort Huachuca well field obtains ground water from the two basin-fill aquifers. The uppermost aquifer is the upper unit of basin fill, which, from inspection of surface exposures in the fort's well-field area, is estimated to range in permeability from moderate to good. The lower aquifer is the lower unit of basin fill, which is less permeable than the upper aquifer. Qualitative estimates of permeability of surface exposures of the lower unit range from fair to moderate, and the unit can be expected to produce and store a considerable amount of water.

The Fort Huachuca well field consists of six wells referred to at the fort as post wells 1 to 6, numbered in the order in which they were drilled. Logs of four of these wells and of other wells near the fort (table 1) are divided to show what geologic units were penetrated. Section *A–A′* and *B–B′* on plate 1 give visual portrayal of the following discussion.

About 200 feet of the upper unit of basin fill is saturated in the area of well (D–21–20)21aad, more than 170 feet is saturated in well (D–21–21)7bcd, 150 feet is saturated in post well 4, 70 feet is saturated in post well 6, and the upper unit is completely dewatered in the vicinity of post wells 1 and 2. The upper unit of basin fill also may be dewatered between post wells 1 and 2 and the mouth of Garden Canyon because of thinning of the upper unit on the flank of a possible bedrock ridge, which is discussed in the section on geology. If the postulated ridge is present, the Fort Huachuca well field would receive no recharge from Garden Canyon Creek through the upper unit of basin fill.

The less permeable, lower unit of basin fill is completely saturated near all wells intercepting it except post wells 1 and 2, where about the upper 40 feet is dewatered. The lower unit of basin fill was not penetrated by well (D–21–21)7bcd, nor was it completely penetrated by well (D–21–20)21aad. Post well 4 penetrated at least 230 feet of the lower unit and may be bottomed in the relatively impermeable Pantano(?) Formation. Post well 6 penetrated at least 190 feet of the lower aquifer before bottoming out in the Pantano(?) Formation. About 180 feet of the lower unit of basin fill is saturated in post wells 1 and 2, which also bottomed in the Pantano(?) Formation.

PRODUCTION CHARACTERISTICS

The production characteristics of nine wells have been determined (table 2). Depths of these wells range from a reported 280 feet for well (D–20–20)32cdd, now abandoned but which once supplied water for irrigation, to 1,230 feet for well (D–21–20)33dbb, which is well 6 in the Fort Huachuca well field. Well diameters range from 6 to 18 inches. Well yields range from 900 gpm (gallons per minute) with 46 feet of drawdown in Fort Huachuca well 2 (S. F. Turner and E. M. Cushing, unpub. data, 1941) to 80 gpm with 11 feet of drawdown in well (D–21–21)7bcd, known as the East Range Bunker well.

From October 1959 to June 1961, the total recorded production from the Fort Huachuca well field was 1,514.65 million gallons. Average daily production during this period was about 2.4 mgd. During the period of record, the maximum total monthly production was 104.2 million gallons in May 1960—an average for the month of 3.36 mgd. Minimum total monthly production was 43.69 million gallons in November 1959—an average for the month of 1.45 mgd.

Average discharge from each of the wells in the Fort Huachuca well field was calculated from the fort's records of quantity pumped and the length of time each well was pumped. The average calculated discharges from January through March 1961 are as follows.

Well	*Average discharge (gpm)*	*Computed 24-hour production (gal)*
1	610	878,400
2	600	864,000
3	520	720,000
4	600	864,000
5	495	712,800
6	(1)	------
Total	------	4,039,200

[1] (Not in use during this period.)

Drawdowns and the discharges for the six wells are shown in table 3.

STEP-DRAWDOWN TEST

Well 6 was drilled in February 1958 to a depth of 1,230 feet. Sixteen-inch-diameter casing was reported to extend from the land surface to a depth of 803 feet, 16-inch-diameter open hole from 803 to 815 feet, and an 8-inch-diameter open hole from 815 to 1,230 feet. On October 13, 1958, soon after completion of the well, a step-drawdown test was made by L. A. Heindl (unpub. data, 1959; table 2). During this type of test the well is pumped at different rates—in the test cited, at 310, 545, 708, and 780 gpm. Drawdown of the water level is determined at regular intervals for each pumping rate (tables 2, 3). Data obtained are analyzed to determine the specific capacity (gallons per minute per foot of drawdown) of the well and to calculate that part of the drawdown in the well caused by turbulent-flow losses, and thus to estimate the efficiency of the well. The result of this analysis is presented graphically in figure 6. For example, if a well pumped at 800 gpm had a total drawdown of 29 feet at the end of 1 hour, the sum of the head losses due to entrance losses and turbulent flow in the well casing would be 14.8 feet, and the well would be 49 percent efficient. As discharge increases, well losses increase approximately as the square of the discharge. Calculated by this method, the losses due to turbulent flow in a well pumped at 1,000 gpm would

TABLE 2.—*Representative wells near Fort Huachuca, Ariz.*

Water level, depth: R, reported.
Use of water: D, domestic; I, irrigation; In, industrial; N, none; PS, public supply.
Discharge, rate: R, reported.

Other data available: A, chemical analysis; C, capacity test of well made; H, hydrograph included in report; L, log; S, drill-cutting samples on file; T, aquifer test made.

Well location No.	Altitude of land-surface datum (ft)	Depth of well (ft)	Casing		Perforation record			Water level		Use of water	Discharge				Other data available	Remarks
			Diameter (in.)	Depth (ft)	Depth below land surface (ft)	Size (in.)	Spacing interval (ft)	Depth below land surface (ft)	Date measured		Rate (gpm)	Drawdown (ft)	Specific capacity (gpm per foot of drawdown)	Year measured		
(D-20-20)32cdd	4,235	280	16					90 R	9-49	I	1,000 R	30	33			Drawdown reported after 10 hours pumping.
(D-20-21)3cd	3,855	623													L	
(D-21-20)21aad	4,480	600	12	600				317.7	1-26-61	In	350	22	16		C, L	
28cac	4,610.0	800	18-16	800				443.4	5-12-43	PS	700	50	14	1958		Post well 5.
								446.9	6-22-44							
33aba	4,619.3	912	18	807				462	-42	PS	700	18	39	1942	L	Post well 4.
33adc	4,618.4	802	18-16	802				453.2	5-11-48	PS	700	33	21	1958	L	Post well 3.
								471	-58							
33dbb	4,645	1,230	16	803	500-515	6½×3	1	492	-58	PS	310	8.2	38	1959	A, C, H, L, S, T	Post well 6; 8-inch open hole below 815 ft.
					515-525	6½×3	5				545	18.9	29			
					525-535	6½×3	1				708	27.7	25			
					535-600	6½×3	5				780	30.0	26			
					600-620	6½×3	1									
					620-700	6½×3	5									
					700-740	6½×3	1									
					740-760	6½×3	5									
34dad										PS						Sierra Vista, supply well.
34dcc										PS						Do.
35ccd										PS						Do.
(D-21-21)7bcd	4,270	300	6	300				121.2	4-6-61	PS	80	11	7		C, L	Supplies test facilities.
31cdb	4,440	501	12	501				269.8	5-26-60	PS	250				S	
(D-22-20)3bbb$_1$	4,640	622	6					470.75	5-21-42	N					L, T	
3bbb$_2$	4,639.5	701	14					483		PS	500	31	16		A, L, T	Post well 1.
4aaa	4,640.1	710	14							PS	900	46	20		L	Post well 2.
(D-23-21)7cdd	4,800	275	10					60	9-5-56	D					L, S	

TABLE 3.—*Discharge and drawdown in six wells in the Fort Huachuca well field, Arizona*

Well	Discharge (gpm)	Drawdown (feet below static water level)	Specific capacity (gpm per foot of drawdown)	Source of data
1	700	43	16	Turner and Cushing.[1]
	500	31	16	Blanton and Cole.[2]
	550	34	16	Post engineers office.[3]
2	900	46	20	Turner and Cushing.[1]
	750	30	25	Blanton and Cole.[2]
	620	29	21	Post engineers office.[3]
3	700	33	21	Blanton and Cole.[2]
	500	20	25	Post engineers office.[3]
4	700	18	39	Blanton and Cole.[2]
	550	17	32	Post engineers office.[3]
5	700	50	14	Blanton and Cole.[2]
	650	64	10	Post engineers office.[3]
6	310	8.2	38	U.S. Geological Survey.[4]
	545	18.9	29	Do.
	708	27.7	25	Do.
	780	30.0	26	Do.

[1] Turner, S. F., and Cushing, E. M., 1941, unpub. data.
[2] Blanton and Cole (architects-engineers), 1958, unpub. data.
[3] Post engineers office, written commun., 1963.
[4] U.S. Geological Survey, 1959, unpub. data.

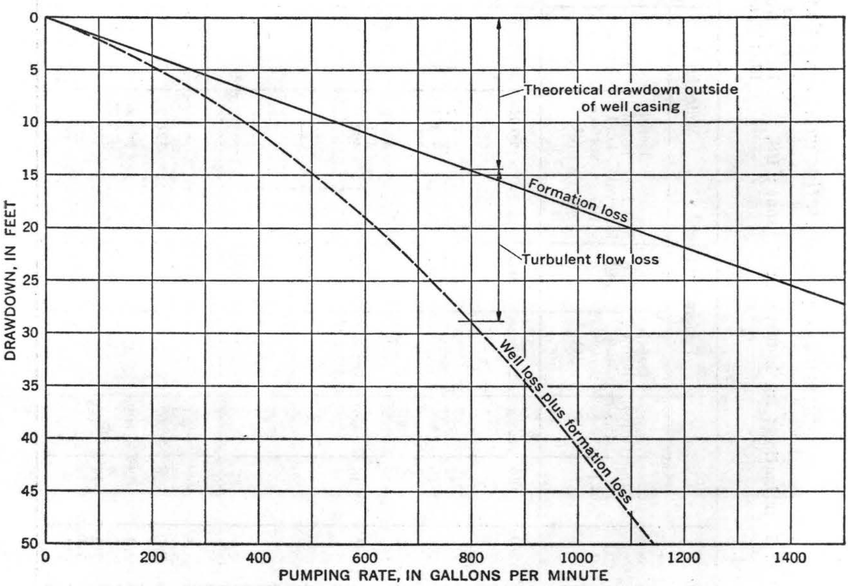

FIGURE 6.—Drawdown-yield curves calculated from step-drawdown test of well 6, Fort Huachuca.

be 22.6 feet of the total drawdown of about 41 feet; the well efficiency would be 45 percent, and head losses in the aquifer due to laminar flow would be about 18.4 feet. If the well is fully developed and discharge is constant, drawdown in the aquifer increases with the logarithm of time; but turbulent-flow losses in the well are constant with time, so the specific capacity decreases as the logarithm of time increases. The specific capacity at the end of 10 days of steady pumping would be less than that after only 1 day of steady pumping.

AQUIFER TESTS

Two aquifer tests to determine the coefficients of transmissibility and storage, *T* and *S*, were made in the Fort Huachuca well field. The first test, using well 6, was made in October 1958 by L. A. Heindl (unpub. data, 1959). The coefficient of transmissibility estimated from this test was about 150,000 gpd (gallons per day) per foot. Well 6 draws water from 70 feet of the upper unit of basin fill and from 156 feet of the lower unit of basin fill.

On November 1, 1960, an aquifer test was made using post wells 1 and 2 as pumping wells and the abandoned well in the Vehicle and Weapons Registration Building as an observation well. The observation well is 90 feet east of well 1 and 534 feet east of well 2. All three wells are in a straight line. The wells obtain water only from the lower unit of basin fill. Values for transmissibility ($T=230{,}000$ gpd per ft) and coefficient of storage ($S=1.6\times10^{-5}$) were determined from the data obtained during this test. The coefficient of transmissibility is the number of gallons of water that will move in 1 day through a vertical strip of the aquifer 1 foot wide having a height equal to the thickness of the aquifer and a hydraulic gradient of unity. The coefficient of storage can be defined as the ratio of the volume of water released from storage or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Knowing these coefficients, it is possible to calculate the drawdown caused by a well pumping at any given rate in an infinite aquifer defined by that *T* and *S*.

POSSIBLE MAGNITUDE OF DRAWDOWN EFFECTS

Figures 7 and 8 show graphically the relations of drawdown, discharge, time, and distance from the pumping well. Water levels decline proportionally with the logarithm of time in a well pumping at a constant rate (fig. 7). Figure 8 shows that for a given discharge at a given time the drawdown in the aquifer varies as the logarithm of the distance from the pumping well to the point of observation. For example, if well 1 is pumped at 500 gpm for 1 day, the drawdown 454 feet away in well 2, by calculation, is about 2.5 feet. The drawdown 2,960 feet away in well 3 is about 1.5 feet. These illustrations show that the rate at which the cone of depression expands is independent of the discharge of the well and is dependent only upon the aquifer constants. the coefficient of transmissibility, and the coefficient

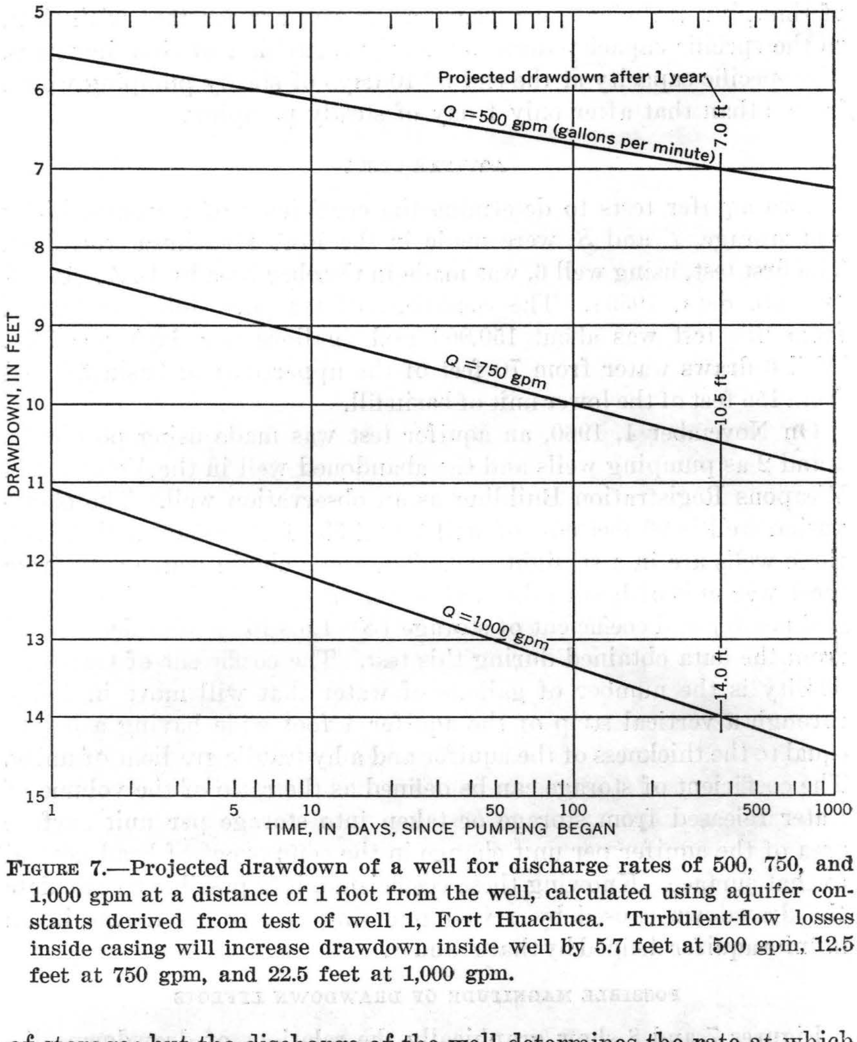

Figure 7.—Projected drawdown of a well for discharge rates of 500, 750, and 1,000 gpm at a distance of 1 foot from the well, calculated using aquifer constants derived from test of well 1, Fort Huachuca. Turbulent-flow losses inside casing will increase drawdown inside well by 5.7 feet at 500 gpm, 12.5 feet at 750 gpm, and 22.5 feet at 1,000 gpm.

of storage; but the discharge of the well determines the rate at which the cone of depression deepens.

Drawdown in a well at the end of a year of cyclic pumping, the type of pumping usually done in municipal and domestic wells, can be predicted using T and S derived from the aquifer tests. The assumed conditions are:

1. No regional change of water levels occurred.
2. The well pumped 500 gpm three-quarters of the day and was shut down the remaining quarter and so on for 365 cycles.
3. The well penetrated material having transmissibility and storage coefficients equal to those derived from the aquifer tests.

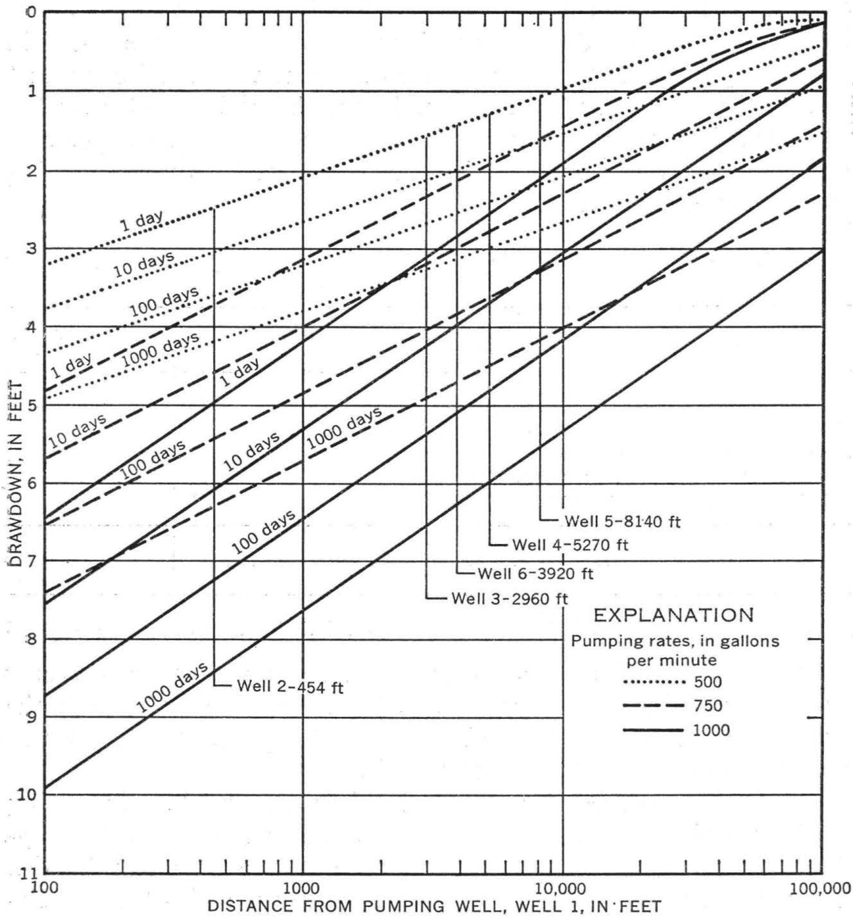

Figure 8.—Relation of calculated drawdown to distance from well 1 pumping at rates of 500, 750, and 1,000 gpm for 1, 10, 100, and 1,000 days, using aquifer constants derived from test of well 1, Fort Huachuca.

At the end of the 365 days, just before the beginning of the 366th period of pumping, the water level in the pumped well was calculated to be 1.4 feet below the original static water level. If it is assumed that the well was pumped only half a day at a time for 365 days, the residual drawdown in a well discharging 500 gpm at the end of the 365th day would be slightly less than 0.9 foot.

As an example of the possible magnitude of drawdown at a distance from a group of pumping wells, it will be assumed that the fort's wells 1 through 5 are pumped continuously for 1 year at the rates shown in table 4; the cumulative drawdown effect at well 6 under these conditions will be 15.8 feet (table 4). If the wells are pumped on daily cycles of 18 hours on and 6 hours off, residual drawdown at well 6 will be less than 3 feet after a year. The hydraulic coefficients used in these computations are for the lower unit of the basin fill at wells 1 and 2; the values for the upper unit may be higher. If so, other conditions being the same, wells drawing water from the upper unit would have less drawdown at the same discharge than wells drawing water from the lower unit.

TABLE 4.—*Calculated drawdown in well 6 when wells 1–5 are pumped continuously at the indicated rates for 1 year*

Well	Discharge (gpm)	Distance from well 6 (ft)	Drawdown at well 6 after a year (ft)
1	600	4, 040	3. 4
2	600	3, 920	3. 4
3	500	2, 080	3. 2
4	600	2, 240	3. 8
5	500	4, 320	2. 0
Cumulative drawdown			15. 8

OCCURRENCE OF WATER IN GARDEN AND HUACHUCA CANYONS

Surface water on the Fort Huachuca Military Reservation occurs as storm runoff, snowmelt runoff, and discharge from springs into the stream channels of Garden and Huachuca Canyons. Other canyons yield little water except for short periods.

The discharge of Garden Canyon has been measured at the gaging station near its mouth since October 1959. Measurements of discharge from springs have been made monthly at three places in Garden Canyon and at three places in Huachuca Canyon (table 5). In November 1961 a recording gage was installed at Huachuca Canyon weir, one of the three measuring sites in that canyon, for the purpose of obtaining a continuous record of the discharge.

DESCRIPTION OF SPRINGS IN GARDEN AND HUACHUCA CANYONS

The springs in Garden and Huachuca Canyons are fed by ground water moving downward toward the San Pedro basin through fractures, faults, and solution channels in the consolidated rocks of the mountain. The formations composed of carbonate rocks are the most permeable, because small fractures and openings are enlarged by dissolution of the rock on either side of the opening, and cavernous rock with many interconnected passageways results. Most larger springs exist where the flow of ground water is impeded by a barrier of rocks of lower permeability, as shown in a geologic cross section of the Garden Canyon drainage (pl. 2).

TABLE 5.—*Discharge measurements, in gallons per minute, In Huachuca and Garden Canyons*

[Measurements are rounded to three significant figures except those less than 10 gpm, which are rounded to the nearest one-tenth gallon per minute. Totals are similarly rounded]

Date	Huachuca Canyon				Garden Canyon				
	Measured discharge (gpm)				Measured discharge (gpm)				
	Pipe 2	Pipe 3	Weir	Total	At gaging station	Spring 1	Spring 2	Upper pipe	Spring total
1959									
Oct. 21–22	18.4	13.5	2.2	34.1	269		108		
Nov. 3–4	18.4	13.9	0	32.3	287	102	96.0	57.0	255
Dec. 1–2	17.5	22.9	0	40.4	431	139	164	52.1	355
Dec. 15–16	19.3	21.5	0	40.8	377	173	171	58.8	403
1960									
Jan. 4–5	21.1	25.6	17.1	63.8	1,240	489	[1] 289	92.0	870
Jan. 20	28.3	72.3	435	536	4,670	534	[1] 1,180	95.6	1,810
Feb. 2	30.5	79.0	395	504	3,760	557	[1] 1,130	95.6	1,780
Feb. 16	31.4	76.3	242	350	2,170	476	186	98.7	761
Mar. 1–2	31.4	67.3	148	247	1,520	426	[1] 220	98.7	744
Mar. 16–17	30.1	49.4	89.8	169	2,110	467	[1] 618	99.6	1,185
Mar. 31	28.3	44.4	71.8	144	1,160	395	[1] 449	89.8	934
Apr. 19–20	26.9	35.9	45.0	108	794	224	[1] 225	67.3	516
Apr. 28	25.6	31.4	36.8	93.8	368	130	180	61.0	371
May 5			31.4		449				
May 18–19	23.8	23.8	19.7	67.3	350	176	118	48.0	342
June 1	22.4	20.2	10.3	52.9	189	126	98.7	36.8	262
June 15–16	20.2	17.5	.7	38.4	112	117	80.8	30.1	228
June 30	18.4	14.8	0	33.2	79.4	97.4	71.4	22.4	191
July 21	20.8	14.2	.1	35.1	93.7	100	62.5	12.3	175
Aug. 2	19.7	13.9	0	33.6	85.3	85.3	53.9	10.8	150
Aug. 31	18.8	18.0	30.1	66.9					
Sept. 1					269	112	80.8	2.9	196
Oct. 4	19.8	15.3	47.6	82.7	166	105	79.4	2.7	187
Oct. 31	19.3	12.1	13.9	45.3	76.3	74.9	59.7	1.4	136
Dec. 2	18.0	10.8	2.7	31.5	89.3	73.6	45.3	2.7	122
1961									
Jan. 10	23.3	12.1	7.2	42.6	121	69.6	43.5	33.2	146
Feb. 1	17.5	10.8	8.5	36.8	110	84.4	56.6	39.9	181
Mar. 2	29.6	13.0	9.0	51.6	67.3	69.1	42.2	29.2	140
Apr. 3–4	29.3	12.1	4.2	44.6	43.5	64.2	39.0	23.8	127
May 2	15.3	10.8	1.9	28.0	17.5	54.2	34.9	18.4	108
June 5	14.8	8.5	0	23.3	1.9	40.4	29.6	13.5	83.5
July 5	13.8	8.0	0	21.8	0	42.1	28.9	11.9	82.9
Aug. 10	12.5	8.2	0	20.7	0	67.8	28.9	9.3	106
Oct. 3	7.7	33.8	80.0	122	108	87.1	65.1	14.4	168
Oct. 31	3.0	18.4	22.4	43.8	197	148	130	19.3	297
Dec. 8	.4	27.4	43.1	70.9	117				
Dec. 14						458	[1] 246	4.5	686
1962									
Jan. 12	1.4	73.2	165	240	408	359	[1] 245	0	604
Jan. 29	1.1	79.4	548	628	3,180	642	186	2.3	830
Mar. 6					1,280	370	[1] 400	5.5	776
Mar. 8	.1	67.3	184	251					
Apr. 27	0	56.1	109	165	875	361	[1] 383	5.8	750
June 13	0	21.5	29.6	51.1	224	130	101	2.2	233
July 25	0	16.6	9.9	26.5	54.7	87.1	68.2	26.5	182
Aug. 23			10.8		188				
Sept. 26	0	18.4	10.0	28.4	94.2	89.3	65.8	0	155
Nov. 9	16.5	18.2	5.6	40.3	37.1	55.6	43.7	0	99.3
1963									
Jan. 8	14.4	18.8	10.8	44.0	130	94.2	76.3	3.1	174
Feb. 11	13.9	22.2	20.2	56.3	83.9	134	75.4		
Mar. 29	11.7	24.2	14.4	50.3	59.7	112	67.3		
May 10	11.7	20.6	5.4	37.7	23.3	65.5	47.1	8.5	121
June 11	10.8	15.3	.4	26.5	0	39.5	35.5	7.2	82.2

The springs in Garden Canyon are recharged from precipitation on the drainage area outlined on plate 1. In the headwater area of the canyon, limestone of the Naco Group forms a slow-draining ground-water reservoir. This reservoir exists because the Naco (1) has abundant fractures and solution channels along the fractures, (2) crops out in an area of high precipitation and is there crossed by a considerable length of streambed so that it frequently receives recharge from the streambed, and (3) is dammed on the downstream side of its outcrop by relatively impermeable siltstone beds (pl. 2).

Cabin Spring (pls. 1, 2) issues from shallow stream alluvium overlying the nearly impermeable Glance Conglomerate. The spring is ephemeral and has low yield; its source is mainly from underflow moving through the thin alluvium of Sawmill Canyon.

Springs 2, 3, and 4 in Garden Canyon (pl. 2) issue from fractures in the limestone beds of the Naco Group. Springs 3 and 4, and the many seeps between them, probably are due to drainage of the Naco by Garden Canyon, in contrast to other springs, which are caused by the presence of rock barriers. Spring 2 (pl. 2) is forced out of the Naco by the relatively impermeable Morita Formation, which crops out downstream, and by beds of red siltstone, which are intercalated with limestone of the Naco.

Spring 1a flows only after storms or extended periods of rain and issues from cavernous carbonate rocks along the Crest Line fault. Spring 1b, on the south bank of the canyon near spring 1a, is similarly a wet weather, nonpermanent spring issuing from cavernous carbonate rocks.

Spring 1 is a permanent spring, and it and spring 2 are probably the major exit points for ground water in the Garden Canyon drainage. The flow of spring 1 is steadier than that of spring 2, probably because the block of the Morita Formation between the springs acts as a leaky barrier controlling ground water moving east. The difference in ranges of discharge (fig. 9; table 5) of springs 1 and 2 is due to the regulating effect of the intervening mudstone of the Morita Formation. Spring 1 discharges from the Martin Limestone on the upstream side of a rhyolite dike, which is presumably the reason for its location.

Chain Spring (pl. 2) probably results from excess underflow moving downstream in the shallow alluvium and in fractured carbonate rocks along McClure Canyon. The alluvium below the streambed in Garden Canyon is saturated at the intersection of McClure and Garden Canyons, and the inflow from McClure Canyon is rejected recharge at that point.

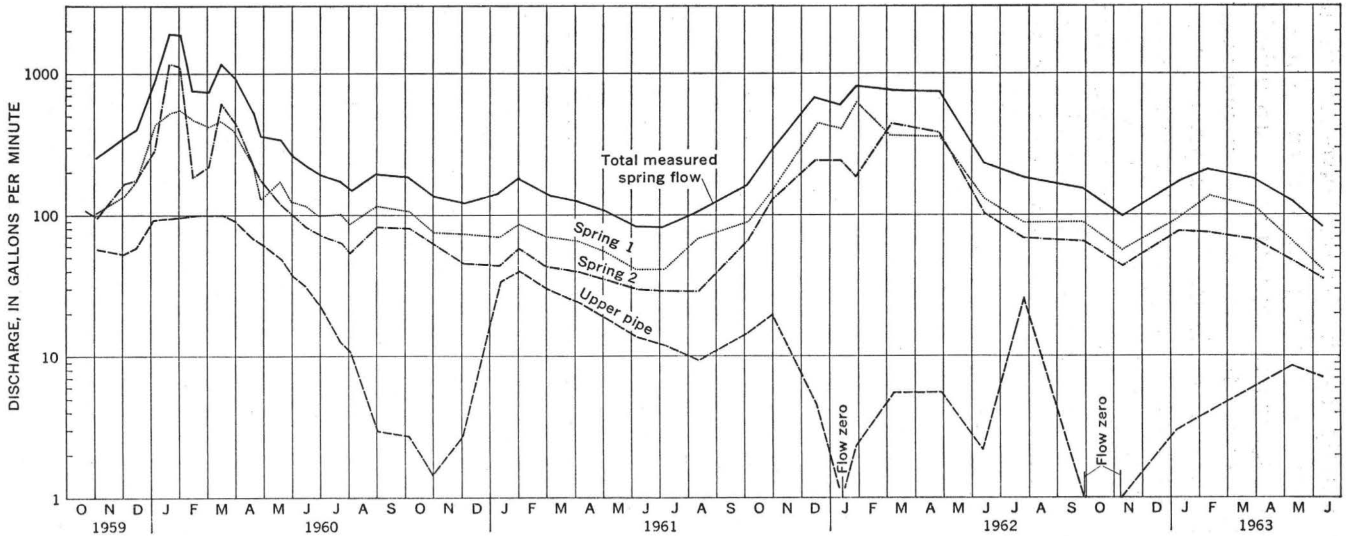

FIGURE 9.—Individual and total measured spring flow in Garden Canyon near Fort Huachuca.

Picnic and Chain Springs, in Garden Canyon, are the lowest points of discharge for ground water in the canyon. The comparatively impermeable Bolsa Quartzite crops out in the streambed at the lower end of the picnic area and forces most of the ground water to the surface, where it is measured at the Garden Canyon gaging station.

The springs in Huachuca Canyon yield smaller amounts of water than do those in Garden Canyon because the Morita Formation and very small exposures of carbonate rocks are the main reservoir in the drainage area. The Morita accepts recharge and yields ground water at low rates because the fractures that store the water are small and not as open as those in the carbonate rocks, along which solution channels have formed. Thus, much of the precipitation in the Huachuca Canyon drainage area is converted to runoff, and only small amounts are stored and released through springs.

Springs 3, 3a, and 4 (pl. 1) issue from the base of the Abrigo Limestone on or near the Crest Line fault. They probably are maintained by ground water moving along fractures and forced to the surface by the relatively impermeable Bolsa Quartzite.

Springs 1 and 2, in Huachuca Canyon (pl. 1), are at the base of the Bolsa Quartzite along a fault offsetting the Bolsa against Precambrian granite. The fault zone, which lies along the canyon, is probably less permeable downstream, so that ground water moving along the fractures of the zone is forced to the surface.

SURFACE-WATER FLOW IN GARDEN CANYON

The Garden Canyon gaging station is near the mouth of Garden Canyon at a point downstream from Picnic Spring (pls. 1, 2). The drainage area upstream from the gaging station includes 8.38 square miles and ranges in altitude from about 5,300 feet at the gaging station to 8,406 feet at Huachuca Peak.

The total runoff from Garden Canyon from October 1, 1959, to June 30, 1963, was 3,040 acre-feet or 994 million gallons. The average discharge was 1.12 cfs or 503 gpm (fig. 10). The maximum daily discharge was 47 cfs (21,100 gpm) on January 12, 1960; from May 29 to September 7, 1961, all discharge at the gaging station stopped except for intermittent flow resulting from thunderstorm runoff. Also no flow was recorded from May 28 to June 30, 1963. (See table 6 for yearly summaries of data.)

SPRING FLOW IN GARDEN CANYON

The total spring flow measured in Garden Canyon from October 1959 to June 1963 ranged from 1,810 gpm on January 20, 1960, to 82.2 gpm on June 11, 1963. The average of 44 discharge measurements for the period of record was 413 gpm or about 0.59 mgd (fig. 9; table 5).

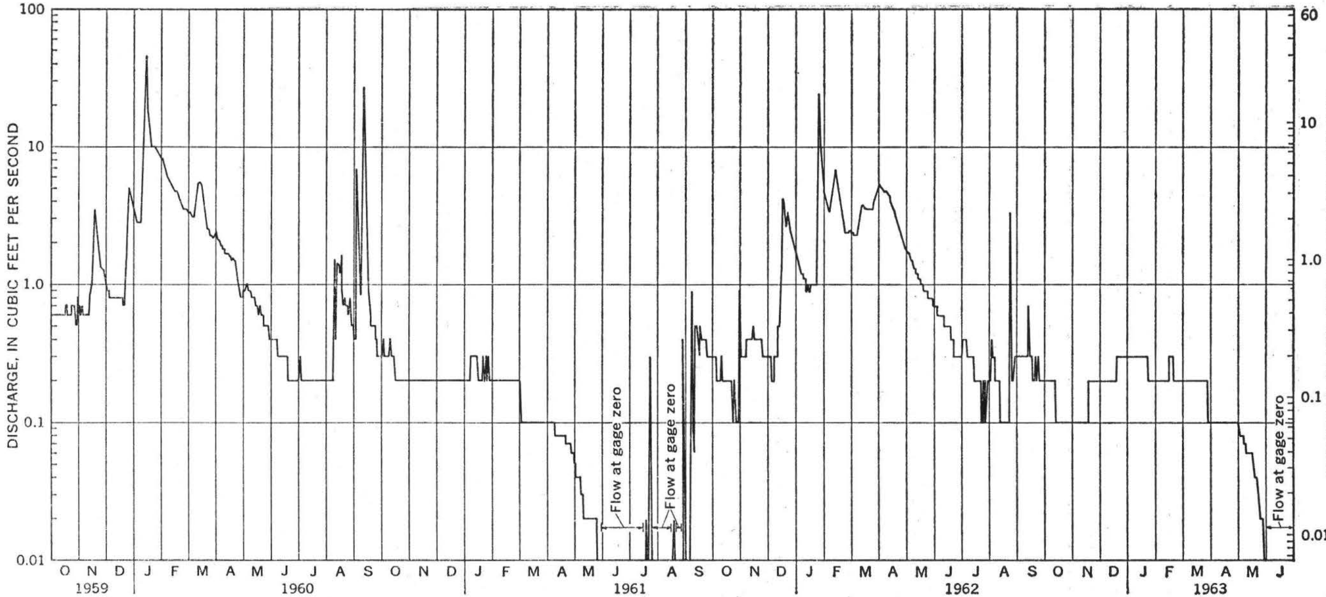

FIGURE 10.—Daily discharge in Garden Canyon Creek near Fort Huachuca.

TABLE 6.—*Discharge of Garden Canyon measured at the gaging station*

Period	Total discharge		Mean discharge		Maximum daily discharge		Minimum daily discharge	
	Acre-ft	Millions of gallons	cfs	gpm	cfs	gpm	cfs	gpm
Oct. 1, 1959–Sept. 30, 1960	1,720	562	2.36	1,060	47	21,100	0.2	90
Oct. 1, 1960–Sept. 30, 1961	95	31	.134	60	.9	400	[1] 0	0
Oct. 1, 1961–Sept. 30, 1962	1,150	375	1.59	714	24	10,800	.1	45
Oct. 1, 1962–June 30, 1963	80	26	.146	66	.3	135	[2] 0	0

[1] No flow from May 29 to Sept. 7, 1961, except for intermittent flow resulting from thunderstorm runoff.
[2] No flow during most of June 1963.

SPRING 1

The maximum discharge measured at spring 1 was 642 gpm on January 29, 1962, and the minimum measured was 39.5 gpm on June 11, 1963. The average of 46 discharge measurements at spring 1 made during the period of record was 194 gpm.

SPRING 2

The discharge of spring 2 generally is measured at a cut pipe a short distance downstream from a spring box. When the carrying capacity of the pipe (about 195 gpm) is exceeded, the spring box overflows, and the overflow is measured separately from the pipe flow. Maximum total flow measured from spring 2 was 1,180 gpm on January 20, 1960, when pipe flow was 195 gpm. Minimum flow of 28.9 gpm was measured on July 5 and August 10, 1961. The average of 47 measurements was 176 gpm. Overflow from the spring was observed and measured on seven occasions from January 5 to April 20, 1960, and on four occasions from December 14, 1961, to April 27, 1962 (table 5).

UPPER GARDEN CANYON PIPE

Upstream from spring 2 the flow from springs 3 and 4, which have relatively low output, is partly collected and carried by an old pipeline. This pipeline was cut at the beginning of the project to measure the discharge of the springs. This measuring point is called Upper Garden Canyon pipe. The maximum flow measured at this point was 99.6 gpm on March 16, 1960. No flow was observed on January 12, September 26, and November 9, 1962. The observation of no flow on January 12, 1962, probably was caused by ice conditions, which resulted from the low temperature of the previous day when a high of 35°F and a low of 9°F were recorded at the Weather Bureau station at Fort Huachuca. The average of 43 flow measurements, including the three observations of no flow, was 32.9 gpm.

MISCELLANEOUS SPRING FLOW

Other springs (pl. 1) in the Garden Canyon drainage area flow mainly in wet weather and were measured less frequently than springs

1 and 2 and the Upper Garden Canyon pipe. Cabin Spring flows 15–25 gpm in wet weather and either is a seep or is dry most of the year. Garden Canyon spring 4, downstream from Cabin Spring, was slightly improved and used in the past. Spring 1a is about 20 feet above the streambed and flowed as much as 400 gpm during the winter of 1960–61.

Chain Spring discharges about 150–250 gpm during wet weather but does not flow during the remainder of the year. Picnic Spring has contributed as much as 540 gpm to the flow of Garden Canyon Creek.

In March 1962, discharge measurements were made in Garden Canyon to determine the magnitude of the gains and losses of streamflow. As a part of these measurements, the discharge of the stream was measured both above Picnic Spring and at the gaging station a short distance below the spring. The increase in streamflow downstream between these two stations was 1.2 cfs, or slightly more than 776,000 gpd. As far as the authors know, there has always been flow in the creek in this area, even in the driest periods. The increase in streamflow measured in this area is an indication of the amount of underflow forced to the surface by shallow bedrock.

McClure Canyon joins Garden Canyon about one-fifth of a mile upstream from the upper picnic area and trends west-northwest. Five springs have been reported in McClure Canyon, but only three were found during this investigation. A pipeline, the full course of which could not be followed with certainty, formerly carried water from at least three of these springs and apparently joined the old pipeline to the fort near the Garden Canyon picnic area. The exact discharge of the pipeline could not be measured, but from indirect evidence it was estimated to be at least 30 gpm.

SURFACE RUNOFF AND SPRING FLOW IN HUACHUCA CANYON

The Huachuca Canyon weir and gaging station are about 2½ miles upstream from the mouth of the canyon at an altitude of about 5,800 feet (pl. 1). The drainage area above the gaging station is 3.24 square miles and extends to an altitude of as much as 8,406 feet at the top of Huachuca Peak. Spring area 3 is just upstream from the weir, and spring area 2 is about half a mile downstream from the weir (pl. 1). Old pipelines from these two spring areas carry water down the canyon to the fort.

Surface flow in Huachuca Canyon is derived from storm and snowmelt runoff and discharge from many small springs. Flow has been measured periodically since 1959 at pipe 2, pipe 3, and the Huachuca Canyon weir (fig. 11).

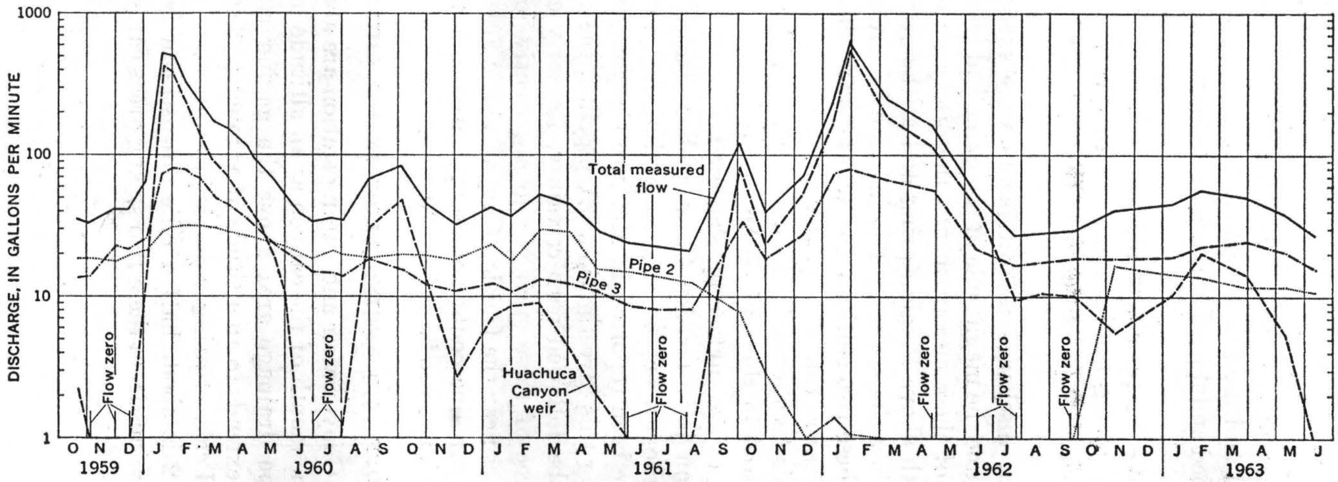

FIGURE 11.—Individual and total measured flow in Huachuca Canyon near Fort Huachuca.

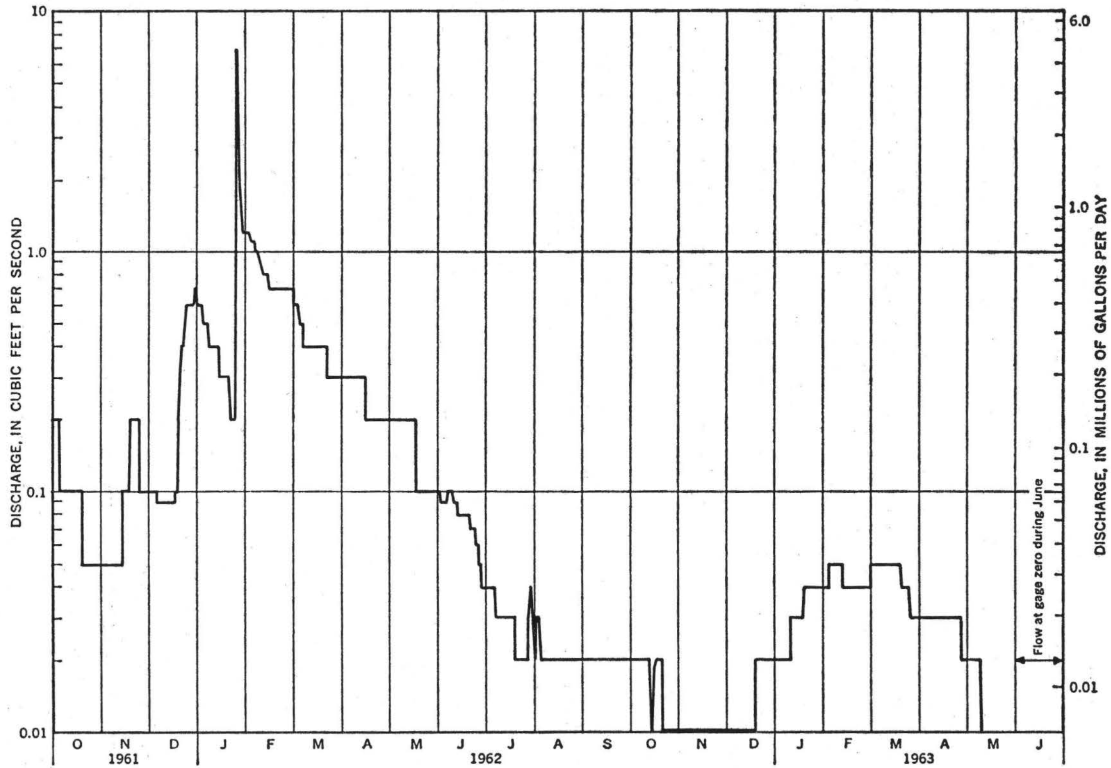

FIGURE 12.—Daily discharge in Huachuca Canyon near Fort Huachuca.

Pipe 2 collects some of the flow from spring area 2 and carries it to the lake at the officers' club. This pipeline was cut and a sleeve splice inserted so that measurements of flow could be made periodically without materially reducing the flow to the lake. The maximum measured flow at pipe 2 was 31.4 gpm on February 16 and March 1, 1960. Four observations of no flow were made from April 27 to September 26, 1962 (fig. 11; table 5). The average of 47 discharge measurements, including the four observations of no flow, was 16.5 gpm.

Pipe 3 collects discharge from several small springs in and above spring area 3. This pipeline was cut at a point just downstream from the Huachuca Canyon weir to facilitate periodic measurements of flow. The maximum measured flow at pipe 3 was 79.4 gpm on January 29, 1962, and the minimum measured flow was 8.0 gpm on July 5, 1961 (fig. 11; table 5). The average of 47 discharge measurements was 28.3 gpm.

The Huachuca Canyon weir was installed in 1959 as a means of periodically measuring the discharge from numerous small springs upstream from the weir. In 1961 a recording gage was installed at the weir to provide a continuous record of all surface flow (fig. 12). The maximum measured flow at the weir was 548 gpm on January 29, 1962. No flow was observed on 8 occasions (fig. 11; table 5), and the average of 49 discharge measurements, including the eight observations of no flow, was 60.0 gpm. Between November 22, 1961, and June 30, 1963, when the recording gage was in operation, the maximum recorded flow was 4,500 gpm on January 24, 1962. The average recorded flow in that period was 71.8 gpm.

The maximum measured total discharge at pipe 2, pipe 3, and the weir in Huachuca Canyon was 628 gpm on January 29, 1962, and the minimum was 20.7 gpm on August 10, 1961 (table 5). The average of 47 measurements was 106 gpm.

UNDERFLOW IN HUACHUCA CANYON

An estimate of the underflow down Huachuca Canyon was made in October–November 1959, when a large excavation was made across the bottom of Huachuca Canyon just upstream from spring area 2. At a depth of about 30 feet, water flooded the hole, and pumps discharging 200–300 gpm could not lower the water level more than a few feet. Where the stream channel comes out of Huachuca Canyon on bedrock near the post engineers office, most of the underflow is consumed by evapotranspiration, and flow has been noted only a few times—usually after prolonged precipitation in the winter or exceptionally heavy summer storms. The excavation was never completely dewatered; so the rate at which water was pumped is equivalent to the underflow through the alluvium of Huachuca Canyon.

SPRING FLOW AND PRECIPITATION

The total precipitation recorded in the Fort Huachuca area in 1962 was the lowest in more than 60 years; even so, four springs continued to flow throughout the year, and continuous flow was recorded at the Garden Canyon gaging station. The first half of 1963 also was extremely dry, and by the end of May all flow had ceased at the Garden Canyon gaging station. The discharge of the springs in Garden and Huachuca Canyons increased slightly during January and February 1963, as it had in the three previous winters, and then began a gradual decline. All six springs were flowing when the last measurement was made on June 11, 1963. At the Huachuca Canyon gaging station, the average daily discharge dropped to less than 0.005 cfs from May 28 to June 30, 1963, but some flow was recorded at the gaging station in a part of each day during this time.

WELL-FIELD PRODUCTION COMPARED WITH RUNOFF IN GARDEN CANYON

A comparison of runoff from Garden Canyon Creek with production from the Fort Huachuca well field (fig. 13) shows that runoff from Garden Canyon Creek would have supplied the fort's water needs twice since October 1959: from January through June 1960 and from December 1961 through May 1962. From October 1959 through June 1963 runoff past the gaging station on Garden Canyon Creek would have supplied slightly more than three-tenths of the fort's needs. Figure 14 graphically compares the runoff of Garden Canyon Creek and the fort's needs. From January through March 1960 and January through March 1962, runoff of Garden Canyon Creek exceeded the fort's needs. For protracted periods, however, the flow of Garden Canyon Creek was less than 10 million gallons per month, notably through most of 1961, the later half of 1962, and the first 6 months of 1963. For the period of record, the runoff from Huachuca Canyon has been about one-tenth of the runoff of Garden Canyon.

QUALITY OF WATER

Water samples have been collected intermittently since 1941 from the Fort Huachuca well field and springs in Garden and Huachuca Canyons (table 7). In general, the water from all the sources sampled is of excellent quality and would be satisfactory for most uses without extensive treatment. The concentration of dissolved solids is low, ranging from 180 to 420 ppm (parts per million). The hardness,

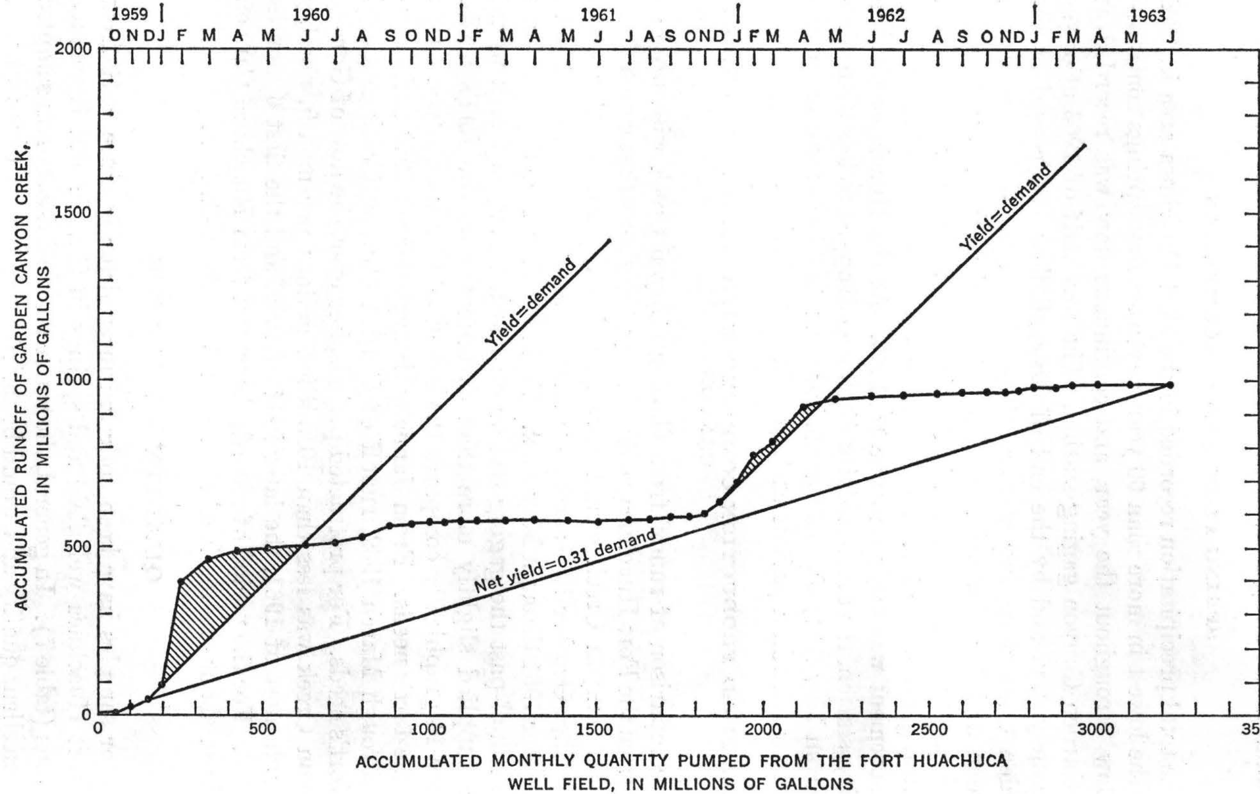

FIGURE 13.—Double mass curve of runoff from Garden Canyon Creek and the production from the Fort Huachuca well field. Shaded pattern indicates yield of Garden Canyon Creek exceeds post's water needs.

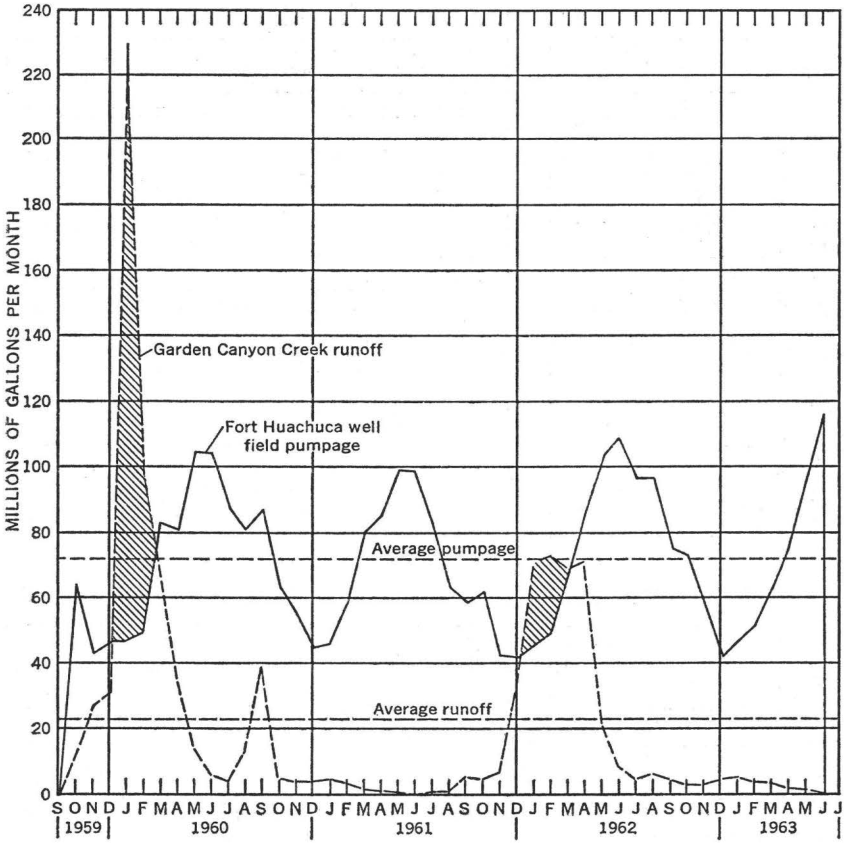

FIGURE 14.—Comparison of monthly total runoff of Garden Canyon Creek with monthly total pumpage from the Fort Huachuca well field. Average pumpage is 71.6 million gallons per month (1,670 gpm), and average runoff is 22.4 million gallons per month (520 gpm). Shaded pattern indicates Garden Canyon Creek runoff exceeds post's water needs.

as calcium carbonate, ranges from 124 to 390 ppm. The range of several chemical constituents in the water from the Fort Huachuca well field and from Huachuca and Garden Canyons is shown in table 8.

To compare the chemical quality of the water from the three sources, the median dissolved-solids value for each water was selected as being representative or typical of that water. Table 9 shows a typical analysis for water from each of the three sources of water available to the fort.

TABLE 7.—*Chemical analyses of water from wells, springs, and streams near Fort Huachuca, Ariz.*

[Constituents in parts per million except as indicated. Source: S, stream; Sp, spring; W, well. Color: Determined by platinum-cobalt method]

Location	Name	Date of collection	Source	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Color	Dissolved solids: Parts per million	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
Fort Huachuca Well Field																									
(D-21-20) 28cac	Post 5	8-31-53	W	----	25	0.02	38	7.2	14		172	0	5.1	5.8	0.1	0.9	2	180	0.25	124	0	20	0.5	295	7.6
		11- 2-55	W	----	30	.03	39	7.4	20		183	0	8.9	5.8	.3	3.5	3	204	.28	128	0	25	.8	317	7.6
33aba	Post 4	9-17-51	W	58	33	.01	43	11	17		214	0	5.6	4.8	0	2.6	----	221	.30	152	0	20	.6	349	7.5
		8-31-53	W	----	25	.02	44	10	13		201	0	6.0	4.8	.1	1.2	3	203	.28	151	0	16	.5	333	7.5
		9-14-54	W	----	29	.01	44	10	17		210	0	6.7	5.5	.2	1.0	3	213	.29	151	0	20	.6	342	7.9
		11- 2-55	W	----	31	0	42	9.0	17		198	0	7.6	5.0	.3	.9	2	209	.29	142	0	21	.6	331	7.7
33adc	Post 3	4-16-52	W	60	31	0	44	11	17		213	0	6.6	5.2	.1	2.1	----	225	.30	155	0	19	.6	350	8.0
		8-11-52	W	----	32	.02	44	11	15		208	0	7.2	5.2	.3	2.2	----	218	.30	155	0	18	.5	345	7.8
		8-31-53	W	----	31	.02	45	11	13		208	0	6.3	5.2	.1	1.5	3	214	.29	158	0	15	.4	343	7.5
		9-14-54	W	----	25	0	59	12	14		248	0	14.0	5.2	.2	2.2	3	249	.35	196	0	14	.4	413	7.9
		11- 2-55	W	----	33	0	39	11	17		197	0	7.6	5.5	.3	2.0	2	211	.29	142	0	21	.6	331	7.6
33dbb	Post 6	10-13-58	W	78	----	----	----	----	----		192	0	----	6.0	----	----	----	----	----	130	0	----	----	324	7.7
		10-14-58	W	78	----	----	----	----	----		192	0	----	7.0	----	----	----	----	----	128	0	----	----	331	7.2
(D-22-20) $3bbb_2$	Post 1	2- 4-46	W	----	----	----	----	----	----		221	0	7	5.0	----	----	----	----	----	----	----	----	----	350	----
		10-18-51	W	60	29	0	45	12	13		213	0	6.7	4.8	.1	1.9	----	217	.30	162	0	15	.4	347	7.8
		6-24-52	W	----	31	.02	46	12	14		214	0	8.8	5.2	.1	2.0	----	223	.30	164	0	15	.5	351	7.9
		9-16-52	W	75	----	----	----	----	----		210	0	----	6.0	----	----	----	----	----	----	----	----	----	360	----
		7-10-53	W	76	----	----	----	----	----		218	0	----	5.0	----	----	----	----	----	----	----	----	----	353	----
		8-31-53	W	----	31	.02	45	11	14		213	0	6.0	4.5	.1	1.3	2	221	.30	158	0	16	.5	348	7.4
		8-26-54	W	----	35	----	46	11	16		212	0	5.8	9.0	.4	1.1	----	228	.31	160	0	18	.5	371	----
		9-14-54	W	----	32	0	45	11	16		214	0	6.4	6.0	.1	1.2	3	222	.30	158	0	18	.5	361	7.6
		9- 8-55	W	75	----	----	----	----	----		216	0	----	7.0	----	----	----	----	----	----	----	----	----	354	7.3
4aaa	Post 2	4-18-41	W	----	----	----	49	11	12		214	0	12.0	4.0	----	----	----	193	.26	168	0	13	.4	347	----
		2-11-46	W	----	32	.02	43	12	14		212	0	5.8	4.9	0	2.1	----	213	.30	157	0	16	.5	343	7.9
		1-18-52	W	60	32	.01	43	12	15		211	0	7.2	4.8	.2	2.3	----	223	.30	157	0	17	.5	342	7.4
		12- 4-52	W	----	33	.01	44	12	16		218	0	7.6	4.0	.1	1.6	3	220	.31	160	0	18	.6	354	7.7
		8-31-53	W	----	31	.02	43	12	14		210	0	5.9	4.5	.1	1.9	2	213	.29	157	0	16	.5	344	7.5
		9-14-54	W	----	32	0	41	11	18		209	0	6.0	5.2	.2	1.8	3	213	.30	148	0	21	.7	344	7.7
		11- 2-55	W	----	34	.01	40	11	20		206	0	8.7	5.5	.3	1.8	2	222	.30	145	0	23	.7	339	7.5

Huachuca Canyon Springs and Stream

(D-22-19)1cca	Contaminated Spring.[1]	4- 3-41	Sp	55			67	16		221	0	34	5				231	0.31	233	52			408	
11aad	Huachuca Canyon Creek.	4- 5-41	S	58			78	15		281	0	17	6				254	.35	256	26			440	
		11- 2-55	S		15	0	81	17	2.5	309	0	16	5	0.1	0.4	3	298	.39	272	19	2	0.1	499	7.5
		1-26-60	S	54						233	0		4.8						210	19			421	7.7
14cba	Spring 1	4- 4-41	Sp	65			88	19		326	0	20	5				293	.40	298	31			541	
	Spring 2	4- 4-41	Sp	68			78	15		277	0	20	5				254	.35	256	29			440	
	Springs 1 and 2.	2-11-46	Sp		14	.04	79	14	4.6	301	0	13	3.2	0	.1		272	.38	254	8	4	.1	471	
	Spring 1	4-16-46	Sp		12	.01	82	15	3.9	311	0	13	3.8	.1	.1		286	.38	266	11	4	.1	498	7.4
		8-11-52	Sp		14	.01	86	16	3.0	325	0	15	3.2	.1	.2		298	.41	280	14	2	.1	510	7.7
		12- 4-52	Sp	48	13	.01	81	15	3.9	307	0	14	4	.1	.1	3	277	.38	264	12	3	.1	484	7.7
		8-31-53	Sp		13	.02	88	16	.7	330		11	3.2	.1	.2	2	292	.40	286	15	1	0	519	7.4
		9-14-54	Sp		13	0	83	14	7.4	308	0	19	5.0	.2	.4	3	296	.40	264	12	6	.2	503	7.4
	Springs 1 and 2.	1-26-60	Sp	60						317	0		4.6						274	14			516	7.3
22aad	Spring 3	1-26-60	Sp	58						292	0		4.6						254	14			482	7.1
	Huachuca Canyon Creek.	1-26-60	S	58						173	0		4.2						151	9			313	7.9
22adb1	Spring 3*a*	4-19-60	Sp	59						288	0		5.2						256	20			478	7.0
22adb2	Spring 4	4- 4-41	Sp	57			77	14	5.9	278	0	28	4				266	.36	250	22	5	.2	434	
		4-19-60	Sp	59						273	0		5.0						239	16			460	7.0
23bbb	Pipe 3	1-26-60	Sp	58						249	0		5.0						220	16			429	7.1

Garden Canyon Springs and Stream

(D-22-19)36ddd	Spring 1	4- 4-41	Sp	57			94	9.2	3.9	296	0	32	3	0.3			288	0.39	272	29	3	0.1	475	
		6-24-52	Sp	60	14	0.01	86	16	3.2	322	0	17	4	.1	0.2		302	.41	280	16	2	.1	509	7.7
		9-14-54	Sp		9.0	0	99	18	2.8	349	0	32	2.8	.1	3.8	3	347	.46	321	35	2	.1	581	7.4
		9-16-59	Sp	58	13		116	9.4	2.8	367	0	25	3.5	.2	2.1		352	.48	328	27	2	.1	595	7.5
		1-26-60	Sp	58						349	0		3.6						316	30			573	7.5
(D-22-20)31cac	Picnic Spring.[2]	4- 4-41	Sp, S	57			88	19	6.0	286	0	68	4				326	.44	298	64	4	.2	474	
		9-16-59	Sp, S	61	18		111	24	2.1	404	0	40	5.2	.2	.2		400	.54	376	45	1	0	678	7.1
		2- 3-60	Sp, S	47						393	0		5.2						364	42			654	7.3
31cdb	Chain Spring.	4- 4-41	Sp	59			92	16	19	317	0	68	5				356	.48	295	35	13	.5	506	
		9-19-59	Sp	62	21		106	32	2.8	428	0	38	9	.3	.6		420	.57	398	48	1	.1	694	7.4
		1-26-60	Sp	63						418	0		5.6						386	44			688	7.4
31dbb		4- 4-41	S				69	13		214	12	20	5				224	.30	226	51			391	
		4- 5-41	S	57			89	8.7	2.5	287	0	23	3				268	.36	258	23	2	.1	455	
		2- 3-60	S	50						284	0		4.2						264	32			489	7.6
		4-20-60	S	59						316	0		5.6						288	29			539	7.6

TABLE 7.—*Chemical analyses of water from wells, springs, and streams near Fort Huachuca, Ariz.*—Continued

Location	Name	Date of collection	Source	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Color	Dissolved solids: Parts per million	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
(D-23-19) 1aaa	Spring 1a	2-3-60	Sp	58	----	----	----	----	----		364	0	----	3.6	----	----	----	----	----	328	30	----	----	590	7.5
1cad	Spring 3	4-4-41	Sp	52	----	----	106	23	3.6		385	0	44	4	----	----	----	370	.50	359	43	2	.1	640	----
	Upper pipe[3]	1-26-60	Sp	48	----	----	----	----	----		370	0	----	5.2	----	----	----	----	----	336	33	----	----	610	7.6
1dbc	Spring 2	4-4-41	Sp	58	----	----	68	9.2	13		229	0	40	4	----	----	----	247	.34	208	20	12	.4	382	----
		4-12-52	Sp	47	11	0	94	19	2.8		338	0	35	3	.1	.9	3	335	.45	312	36	2	.1	565	7.7
		9-9-52	Sp	----	13	.02	80	15	2.1		292	0	18	5	.2	0	2	278	.38	261	22	2	.1	474	7.4
		1-26-60	Sp	59	----	----	----	----	----		326	0	----	3.8	----	----	----	----	----	290	23	----	----	530	7.2
2ddd	Cabin Spring.	4-4-41	Sp	51	----	----	116	20	2.3		419	0	28	3	----	----	----	376	.51	372	28	1	.1	634	----
		9-16-59	Sp	62	19	----	120	18	4.4		430	0	25	2.8	.2	.7	----	401	.55	374	22	2	.1	670	7.3
		1-26-60	Sp	50	----	----	----	----	----		385	0	----	3.2	----	----	----	----	----	334	18	----	----	605	7.7
McClure Canyon, Tributary to Garden Canyon																									
(D-22-19) 35	Jetmore Spring.	4-4-41	Sp	68	----	----	99	24	5		385	0	32	5	----	----	----	355	0.48	346	30	3	0.1	582	----
		4-20-60	Sp	69	----	----	----	----	----		376	0	----	5.2	----	----	----	----	----	328	20	----	----	591	7.3
	Cave Spring	4-4-41	Sp	----	----	----	93	34	----		332	31	34	8	----	----	----	364	.50	372	100	----	----	593	----
	Upper McClure Spring.	4-4-41	Sp	56	----	----	107	27	2.5		417	0	32	5	----	----	----	380	.52	378	36	1	.1	632	----
36cb	Lower McClure Spring.	4-4-41	Sp	56	----	----	110	28	4.0		413	0	48	7	----	----	----	400	.54	390	51	2	.1	658	----
		4-20-60	Sp	61	----	----	----	----	----		416	0	----	5.6	----	----	----	----	----	386	45	----	----	691	7.1

[1] Spring not found during this investigation.
[2] In streambed.
[3] Collects from several springs.

TABLE 8.—*Range of several chemical constituents in the water from the Fort Huachuca Military Reservation*

[Results in parts per million]

Source	Number of samples	Silica (SiO_2)	Bicarbonate (HCO_3)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$
Fort Huachuca well field	29	11–35	172–248	0.1–0.4	180–249	124–196
Huachuca Canyon	19	12–14	173–330	0–0.4	231–298	151–298
Garden Canyon	30	9–21	214–430	.1–0.3	224–420	208–390

The water from the three sources is similar in chemical composition, the chief ionic constituents being calcium and bicarbonate. Water from the Fort Huachuca well field has the least amount of dissolved solids, but it contains more silica than does the water from Garden and Huachuca Canyons. Silica constitutes as much as 15 percent of the total dissolved solids in the water from the well field, whereas the water from the other two sources contains only 3–5 percent silica. Weathering products in the two basin-fill units, derived in part from rocks containing feldspar, probably are responsible for the relatively high percentage of silica in the ground water as compared with the percentage of silica in the water from Huachuca and Garden Canyons springs and streams. Large amounts of silica in water for domestic use cause very hard scale to be deposited on porcelain fixtures. The water from the well field also contains more sodium than does water from Huachuca and Garden Canyons and, consequently, is not as hard. The water undoubtedly has entered into ion-exchange reactions with the clay in the basin-fill units and has been "softened." The probable source of the sodium is the weathering products of feldspar.

TABLE 9.—*Median dissolved constituents in water from the Fort Huachuca Military Reservation*

Constituent (parts per million except as indicated)	Fort Huachuca well field	Huachuca Canyon	Garden Canyon
Silica (SiO_2)	32	14	9.0
Calcium (Ca)	44	79	99
Magnesium (Mg)	11	14	18
Sodium and potassium (Na+K)	15	4.6	2.8
Bicarbonate (HCO_3)	208	301	349
Sulfate (SO_4)	7.2	13	32
Chloride (Cl)	5.2	3.2	2.8
Fluoride (F)	.3		.1
Nitrate (NO_3)	2.2	.1	3.8
Dissolved solids	218	272	347
Hardness as $CaCO_3$	155	254	321
Percent sodium	18	4	2
Specific conductance (micromhos at 25°C)	345	471	581
pH	7.8		7.4

Sulfate content of the water from the three sources is generally low; however, water from Huachuca and Garden Canyons contains 3–5 times as much sulfate as does the water from the well field. Oxidation of sulfide minerals leached from some of the rocks cropping out in Huachuca and Garden Canyons may explain the presence of sulfate in the water.

Low concentrations of chloride and sulfate in the water from the fort's well field seem to preclude the possibility of the presence of evaporites in the aquifers there. This is further substantiated by the fact that no such material is listed in the lithologic logs of the wells in the area.

Because of the variation of chemical quality and sediment concentration in the water from both canyons and the possibility of differences in chemical quality of the ground water with depth, comprehensive water sampling was begun in 1963. This sampling is now being carried on as part of a program to evaluate the feasibility of injecting water from Garden Canyon into recharge wells in the Fort Huachuca well field.

Collection of water samples for chemical analysis was begun in October 1961 on a weekly basis at the gaging station in Garden Canyon. Continuous specific-conductance measurements of the water also were made by means of a conductivity recorder installed at the gaging station.

Figure 15 shows the relation between the average daily discharge and the average daily specific conductance. During periods of low flow, when the flow is supplied by ground-water discharge to the stream, the specific conductance varies between about 500 and 580 micromhos. The specific conductance of a solution is proportional to the total solids dissolved in it. The amount of dissolved material in the water can be estimated by multiplying the specific conductance, in micromhos, by 0.6. Thus, the dissolved-solids content at low flow probably ranges from 300 to 350 ppm. The specific conductance varies inversely with the discharge of the stream; that is, the specific conductance of the water decreases as the stream discharge increases. Water, released to the stream from the stream alluvium and the other rocks of the Huachuca Mountains, dissolves various substances and maintains a rather constant mineral content. Surface runoff to the stream from thunderstorms or snowmelt dilutes the base flow and causes the specific conductance of the stream water to decrease. A typical example of the stream stage-specific conductance relation during a runoff event for a 3-day period in November and December 1961 is shown in figure 16. Fluctuations of gage height before, during, and after the peak discharge are reflected in changes in the specific conductance of the water during this 3-day period. The graph for the specific conductance was plotted in descending order to show its similarity to the gage-height graph.

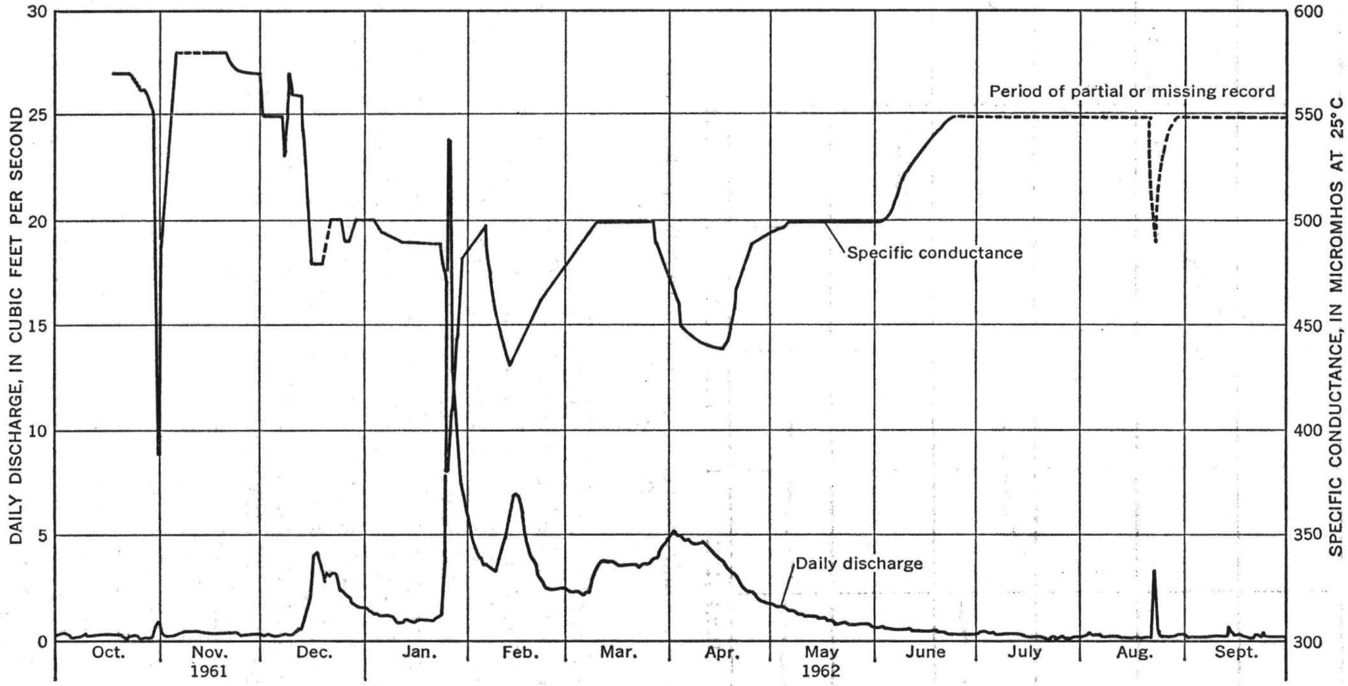

FIGURE 15.—Average daily discharge and average daily specific conductance, Garden Canyon Creek near Fort Huachuca.

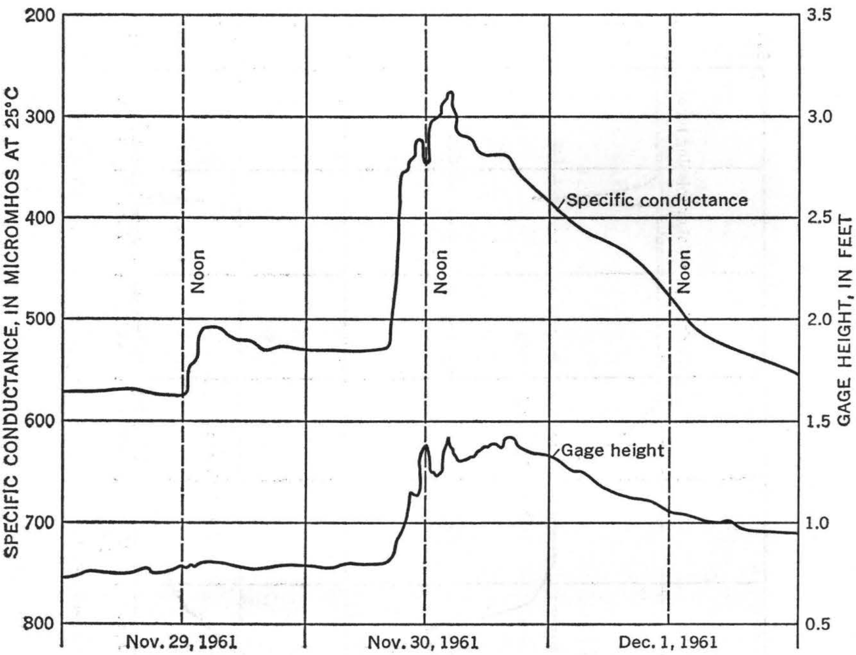

FIGURE 16.—Instantaneous specific conductance and gage height, Garden Canyon Creek near Fort Huachuca.

Collection of suspended-sedimented samples was begun in October 1961 on a weekly basis at the gaging station in Garden Canyon. In periods of low flow the sediment concentration of Garden Canyon Creek generally is less than 10 ppm. The sediment is made up of very fine sand and clay composed of mica, quartz, and some feldspar. The heavier concentrations of sediment occur in runoff from thunderstorms. The peak concentration generally occurs at about the same time as the peak stage and decreases rapidly with recession in stage.

The monthly load of suspended sediment, in tons, and the runoff, in acre-feet, are shown in figure 17. The graph for January–May 1962 shows the effect of heavy rainfall and snowmelt on the sediment burden of the stream. The runoff during this period was sustained by springs fed by infiltration from rainfall and snowmelt. The maximum discharge for the year occurred in January, and the succeeding lower peaks occurred in February–April. The sediment loads decreased from January through April, although the runoff remained nearly constant. The sustained spring flow was relatively free from sediment. The greater loads of sediment during January, February, and March probably occurred in a few days during the peak runoff periods. The abnormally large load of sediment during August and September is not representative of the sediment discharge of Garden Canyon. Road repairs above the station caused excessive erosion, which resulted in transport of sediment past the gaging station. Two runoff events occurred while the road repairs were being made.

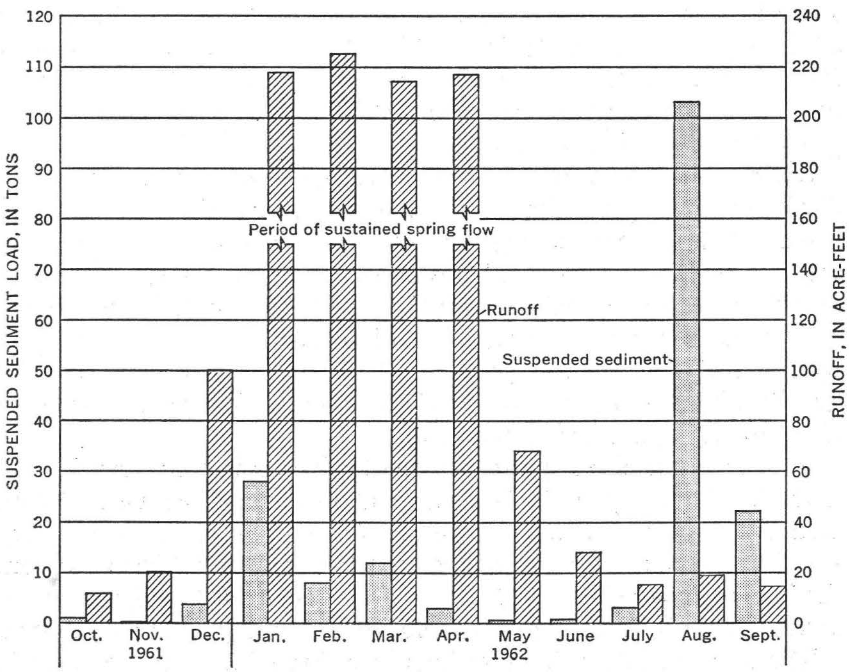

FIGURE 17.—Monthly sediment load and runoff of Garden Canyon Creek near Fort Huachuca, 1962 water year.

SOURCES OF ADDITIONAL WATER SUPPLY

From October 1959 to June 1963, the water from Garden Canyon Creek would have supplied 1,508 million gallons, about three-tenths of the fort's water supply; but only 122 million gallons could have been obtained from Huachuca Canyon runoff in the same period. Most of the runoff in Garden Canyon Creek and Huachuca Canyon is lost to evapotranspiration, but some recharges the ground-water reservoir. The present large evapotranspiration losses in Garden Canyon could be avoided by (1) collecting and diverting the water for use by the fort and (2) possibly using any excess water for artificial recharge. Because of the favorable topographic location of Garden Canyon, water could flow by gravity to the fort for immediate use or to the Fort Huachuca well field for artificial recharge.

If artificial recharge through wells is considered a means of augmenting the available supply, the effects of injecting water into a well under heads of 450–500 feet should be investigated and the major problems of air entrainment and chemical compatibility studied. These and other problems associated with artificial recharge are being studied elsewhere, and satisfactory solutions are being found for some of them (Sniegocki, 1963; Sniegocki and others, 1963; Sniegocki and Reed, 1963). Each artificial-recharge project must still be considered as experimental for any particular geohydrologic situation, and it will present its own unique problems.

Springs associated with faults in the Huachuca Canyon picnic area discharge small quantities of water. In October and November 1959, ground water entered a large excavation at the upstream end of the area. The water was pumped at a rate of more than 200 gpm without lowering the water surface more than a few feet in this excavation. This underflow could be caught in an infiltration gallery and stopped by a cutoff wall built to bedrock. The water could than flow by gravity pipeline to one of the fort's reservoirs. At least 200 gpm, or about 300,000 gpd, could be obtained.

Ground water also is present at shallow depth in a narrow channel in the Garden Canyon picnic area, about a quarter of a mile upstream from the gaging station. Here, a cutoff wall or an infiltration gallery could be constructed, as was suggested for use in Huachuca Canyon. An increase in streamflow of 1.2 cfs, or almost 775,000 gpd, was measured on March 7, 1962, in this short reach through the picnic area.

The measured flow from springs in either of the canyon areas is not all the spring discharge of the canyons. In both canyons from 200 to 300 gpm of water is unmeasured. Proper development probably could increase the reliable yield of water from the canyons.

North of the fort, on the west artillery range, the prospects of obtaining additional water are poor. Here the valley slope from the Babocomari River south to the mountains is underlain at shallow depths by the poorly permeable Pantano(?) Formation. Unless fractures and occasional zones of greater permeability are found, prospects of obtaining additional water in this area are poorer than those indicated for the other areas. Some water might be obtained from the more permeable alluvium of the Babocomari River. Well logs are not available, but the areas of low water-table gradient in the valley of the Babocomari River east of Huachuca City indicate that transmissibility is fair to good; however, production from wells in Huachuca City, north of the fort, is estimated to be not more than 100 gpm. A now abandoned irrigation well in sec. 32, T. 20 S., R. 20 E., reportedly pumped about 1,000 gpm, with 30 feet of drawdown below static water level after pumping for 10 hours, sometime in 1949.

The relations expressed in Darcy's law can, with the aid of a water-table map (pl. 1), be used to determine the best place to explore for ground water. Ground-water flow is proportional to the hydraulic gradient and the permeability of the aquifer. It is expressed by Darcy's law as $Q = PiA$. If Q is expressed in gallons per day, i is the hydraulic gradient in feet per foot, and A is the cross-sectional area in square feet; then P, the coefficient of permeability, is expressed in gallons per day per square foot. For many ground-water problems, it is more convenient to write Darcy's law in the form: $Q=TiL$, where T, the coefficient of transmissibility, is equal to P multiplied by the thickness of the aquifer, and L is the width, in feet, of the section through which discharge occurs. For areas having uniform ground-water flow, those with lower water-table gradients (wider contour spacing) will be underlain either by more permeable materials or by thicker materials of about the same permeability as those areas with steeper gradients (close contour spacing). Plate 1 shows an area of low water-table gradient in T. 21 S., R. 20 E., which includes most of the east artillery range and extends northward almost to the valley of the Babocomari River. If the basin-fill units are as thick in this area as they are farther south at the well field, then, on the basis of the relations expressed in Darcy's law, it can be said that this is an area of higher permeability. If the aquifer is thicker, as suggested by the cross section (pl. 1), it has a higher transmissibility than in the area farther south and would be a good place to prospect for additional water from wells.

SUMMARY AND CONCLUSIONS

Two substantial sources of water are available to Fort Huachuca: spring flow in Garden and Huachuca Canyons and ground water pumped from wells in the San Pedro River basin. The springs are replenished seasonably by precipitation, but the discharge is lost mostly to evaporation and transpiration. The wells produce ground water from two hydraulically connected aquifers that provide a large ground-water storage reservoir. Recharge to the aquifers is small, and most water pumped by the wells comes from storage.

Rocks on the west side of the Huachuca Mountains yield only small amounts of ground water to wells and springs and therefore cannot provide reliable sources of water for the fort.

From October 1959 to June 1963, more than 1 billion gallons of spring flow and runoff was measured at the gaging stations in Garden Canyon, and more than 3.2 billion gallons was pumped from the Fort Huachuca well field. Therefore, the spring flow can significantly add to the fort's water supply. Unfortunately, spring flow and streamflow are variable, and large flows do not always occur at times of greatest need. Conservation of all the runoff would require storage in a surface reservoir or in the ground-water reservoir by recharge through wells.

Recharge to the ground-water reservoir occurs where the streams, such as Garden Canyon Creek, carrying storm runoff are above the water table and cross underlying material permeable enough to allow downward percolation of water. The ground-water reservoir is recharged along the east face of the Huachuca Mountains. Ground water from the mountain front moves northeastward downgradient and contributes part of the perennial flow of the San Pedro River at Charleston.

More than 1,500 million gallons of water was pumped from five of the six wells in the Fort Huachuca well field from October 1959 through June 1961. In this period well 6 was used as an observation well, and the water level in it declined more than 7 feet, which indicates that the cone of depression formed by pumping the wells at Fort Huachuca and Sierra Vista is deepening and expanding.

The aquifers tapped by the Fort Huachuca well field, Sierra Vista, and the housing developments around Sierra Vista are hydraulically continuous. Because of this hydraulic continuity, any pumping of wells in the Sierra Vista area will in time cause drawdown in the Fort Huachuca well field. Mutual interference from the pumping of wells has been deduced by short-term aquifer tests and confirmed by long-term water-level measurements. The interference at the end of a day from the operation of well 1 can cause an increase in drawdown of about 2.5 feet in well 2, 1.5 feet in well 3, 1.4 feet in well 6, 1.3 feet in well 4, and about 1 foot in well 5. The residual drawdown measured in well 6 from November 1959 through May 1961, caused by pumping of the fort well field and interference from the Sierra Vista well field, averaged 3 feet per year.

The amount of suspended sediment carried by Garden Canyon Creek under natural conditions is small. The maximum sediment load occurring under natural conditions in 1962 was only 28 tons in January, when the runoff past the gaging station was 217 acre-feet. The amount of total dissolved solids in Garden Canyon Creek has an inverse relation to the gage height and discharge. Measurements of conductivity made during low flow, when the dissolved-solids content is highest, indicate that the total dissolved-solids content in Garden Canyon Creek is 300–350 ppm. The sediment load and conductivity indicate that the spring flow may be suitable, with little or no processing for use as a potable water supply.

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