THE HYDROLOGY OF ARAVAIPA CREEK, SOUTHEASTERN ARIZONA

by

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TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS	vi
LIST OF TABLES	viii
ABSTRACT	ix
INTRODUCTION	1
GEOLOGY	6
Petrology	7
Geologic Structure	15
Geophysical Surveys	21
Magnetic Survey	21
Seismic Survey	24
Mining	28
HYDROLOGY AND WATER RESOURCES	31
Water-bearing and Transmitting Properties of Geologic Units	31
Basin-margin Formations	31
The Alluvial Aquifer	34
Ground-water Flow	40
Regional Flow Pattern	40
Emergence of Aravaipa Creek and Stream Flow-Geology Relationships	45
Hydrologic Cycle in the Aravaipa Watershed	55
Rainfall	55
Evapotranspiration	57
Stream Discharge	61
Pumpage	61
Base Flow and Aquifer Recharge	63
Water Use	68
Streamflow Statistics	69
Water Quality	75
CONCLUSIONS	82
RECOMMENDATIONS	86
Base-flow Protection Schemes	86
Artificial Recharge	86

TABLE OF CONTENTS--Continued

Page

Low-flow Augmentation 87
Adjudication 87
Additional Research 88
Distribution of Aquifer Recharge 88
Distribution of Aquifer Parameters 89
Evapotranspiration from the Water Table in Aravaipa Valley . 90
Improvement of Base-flow Estimation 91

APPENDIX A: ARAVAIPA WELL LOGS 92

APPENDIX B: HYDROLOGIC CALCULATIONS 97

REFERENCES 100

LIST OF ILLUSTRATIONS

Figure		Page
1.	Location of Aravaipa watershed	3
2.	Aravaipa regional geology	9
3.	Geology of the Klondyke quadrangle	in pocket
4.	Expression of Aravaipa Basin in residual Bouguer gravity data	17
5.	Geologic cross section of Aravaipa Valley near Klondyke, Arizona	19
6.	Modified geologic cross section of Aravaipa Valley near Klondyke, Arizona	20
7.	Total magnetic field at the entrance to Aravaipa Canyon, east end	22
8.	Map showing the Aravaipa watershed and investigation sites	in pocket
9.	Distance-travel time plot for seismic profile SP1	25
10.	Distance-travel time plot for seismic profile SP2	25
11.	Distance-travel time plot for seismic profile SP3	26
12.	Map showing ground-water conditions in the Aravaipa Valley area, Graham and Pinal Counties, Arizona	in pocket
13.	Correlation of ground-water elevation and base flow	42
14.	Topographic and ground-water profile along section A-A' of Figure 2	44
15.	Flow data for Aravaipa Creek shown as a function of position and width of canyon floor (younger alluvium)	47
16.	Emergence of Aravaipa Creek, July 1980	48
17.	Mean annual rainfall, Aravaipa area	56

LIST OF ILLUSTRATIONS--Continued

Figure		Page
18.	Monthly distributions of precipitation at Klondyke, Arizona, and temperature in Aravaipa Canyon, Arizona	58
19.	Base flow of Aravaipa Creek at west end of Aravaipa Canyon and expected evapotranspiration within the canyon	62
20.	Mean discharge for Aravaipa Creek from 1932 to 1979	71
21.	Comparison of mean monthly discharges from years 1932-1942 and 1967-1979	74
22.	Ground-water chemical data	77
23.	Spring-water chemical data	78
24.	Surface-water chemical data	79

LIST OF TABLES

Table		Page
1.	Remanent magnetizations and permanent dipole moments of the Hell Hole Conglomerate and younger alluvium	23
2.	Seismic profile data and interpretation	28
3.	Transmissivity of Aravaipa Canyon sediments	53
4.	Calculated evapotranspiration	59
5.	Correlation between simultaneous measurements of creek discharge in the summer of 1979, Aravaipa Creek, Arizona	65
6.	Discharge statistics for Aravaipa Creek	72
7.	Chemical analyses	76

ABSTRACT

The hydrologic system responsible for the perennial flow of Aravaipa Creek in southeastern Arizona consists of a basin filled with sediments and ground water. Ground-water flow through the basin sediments converges at the entrance of Aravaipa Canyon where much of it is forced to the surface due to a restriction in the cross-sectional area of the unindurated sediments. By applying Darcy's law, these sediments are found to have a hydraulic conductivity of up to 1,300 feet/day. The data used in the analysis show that Aravaipa Creek attains its full discharge within 2 miles of the canyon entrance due to a gradual reduction in the transmissivity of the sediments.

Precipitation over the watershed is divided quantitatively into evapotranspiration, stream discharge, and pumpage. Ten years of streamflow data divided into base flow and storm runoff show that 8,500 acre-feet/year become base flow due to ground-water runoff from the valley aquifer. Recharge in the Aravaipa aquifer equals discharge. The discharge, Aravaipa Creek base flow plus pumpage, is 11,600 acre-feet/year, or 2.4 percent of total precipitation. Streamflow statistics, water quality, and current water use are documented, and suggestions for further research are made.

INTRODUCTION

Aravaipa Canyon Primitive Area and adjacent lands occupy a narrow stream-cut canyon in the Galiuro Mountains in Pinal and Graham Counties, Arizona. The stream responsible for the erosion of the canyon is perennial, and to it can be attributed the abundant life, both floral and faunal, of the canyon floor.

Concern for the ecological status of Aravaipa Canyon has prompted the Defenders of Wildlife to support research into many facets of the canyon's unique existence. The research behind this thesis was partially funded by the Defenders and concerns the origin and status of Aravaipa Creek and information, both original and otherwise, on the ground-water reservoir to which it owes its perennial nature. The stated objectives of the inquiry were:

1. To establish a data base that describes stream-flow patterns, historical to the present, in Aravaipa Creek.

2. To investigate the relationship between the various rock units of Aravaipa Canyon and the flow of water in Aravaipa Creek.

3. To determine the depth of alluvial sediments in Aravaipa Valley and the nature of the underlying consolidated rocks.

4. To identify water-use patterns in Aravaipa Valley for the purpose of monitoring surface- and ground-water withdrawal.

5. To predict the effects of increased water development activities on Aravaipa Canyon.

The research area comprised the entire Aravaipa watershed, but field work was concentrated in the lowlands of Aravaipa Valley and Aravaipa Canyon. The watershed begins at the summit of the Galiuro Mountains, about 50 miles northeast of Tucson, and extends 10 to 15 miles to the central ridge of the Santa Teresa Mountains. The southern limit of the Aravaipa drainage is on a low divide about 27 miles north of Willcox, Arizona, on the northern end of Sulphur Springs Valley. The watershed ends some 35 miles to the north in a hilly region adjacent to an area drained by tributaries of the Gila River. The total area of the watershed (Fig. 1) is 541 square miles (1,900 km^2) (U.S. Geological Survey, 1954).

The topography of the Aravaipa watershed varies greatly due to a wide variety of physiographic features represented within it. The central valley floor is generally narrow, low, and flat. This "ribbon" is surrounded by hills of semiconsolidated alluvium, which lead up to the mountain blocks on both sides of the valley. As the stream flows to the low point in the valley, it enters Aravaipa Canyon, an incised valley cut within the last 20 million years through the Galiuro Mountains. The relief in the canyon area and its tributaries is considerable: the walls of the canyon can be vertical and 700 feet high. It is this rare situation where a stream flows *from* a valley *into* mountains that makes it possible for surface water to flow in the creek all year round.

The highest point in the watershed is 8,441 feet above mean sea level in the northwest corner of the Pinaleño Mountains, and the lowest point is at Aravaipa Creek's confluence with the San Pedro River at about 2,180 feet above mean sea level.

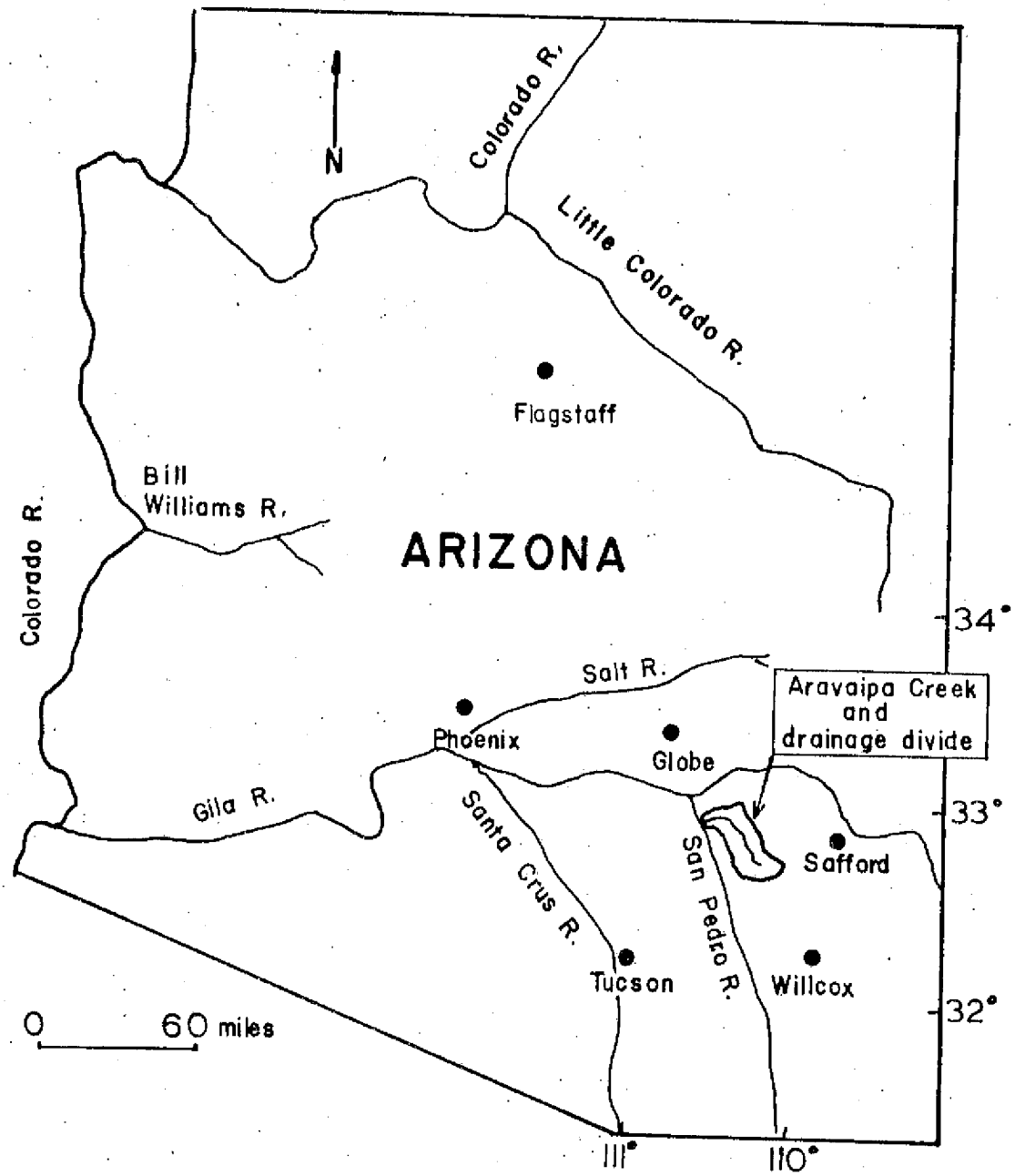


Fig. 1. Location of Aravaipa watershed

Previous work in the Aravaipa watershed relating to hydrology includes geologic reports, ground-water and stream-flow measurements, and surface-water quality. Ross (1925) published a report dealing with the geology of the Aravaipa area as it related to the minerals found there. This was followed by a report on the geology of the Klondyke quadrangle by Simons (1964). This is the most complete work done to date on the geology of the Aravaipa Valley area. Krieger (1968a, 1968b) published geologic maps of the Holy Joe Peak and Lookout Mountain quadrangles in the Galiuro Mountains. Rather detailed gravity data were collected in Aravaipa Valley and interpreted by Robinson (1976).

A U.S. Geological Survey stream gage located in the NW¼NW¼ sec. 9, T. 7 S., R. 17 E., has been used to measure stream flow on and off since 1919. A few statistics are kept on these data, and Minckley (1977) conducted some further analyses on stream discharge. Surface-water quality is well documented due to work by Sommerfeld (1977) and DeCook and others (1977).

Del Moliter of the Safford Bureau of Land Managment office has taken flow measurements in Aravaipa Creek in preparation for the installation of a stream gage on the east end of Aravaipa Canyon. He has graciously supplied me with these data, some of which appear in Table 5.

Ground-water level measurements have been taken by personnel of the U.S. Geological Survey, Water Resources Division. Most of these are unpublished, but some appear on the ground-water map of Gould and Wilson (1976). The unpublished data are available at the U.S. Geological Survey office in Tucson, Arizona.

Throughout this thesis reference will be made to the "valley," the "east end," and the "west end." "Valley" refers to Aravaipa Valley, which contains the ephemeral portion of Aravaipa Creek. "East end" refers to the eastern portion of Aravaipa Canyon, which is the area where the perennial reach begins. From the east end, Aravaipa Creek flows through the Galiuro Mountains to the "west end" where Aravaipa Canyon opens up into the valley of the San Pedro River.

GEOLOGY

The geologic history that is important and recognizable in the present geomorphology of the Aravaipa Creek area and Aravaipa Basin began in Tertiary time. At this time, the site of the present Galiuro Mountains consisted of an erosional surface of considerable relief on a granodiorite pluton. To the east lay the ancestral Santa Teresa and Turnbull Mountains.

Upon this terrain was extruded the sequence of andesitic to rhyolitic tuffs and lavas known as the Galiuro Volcanics, both at their present position and possibly extending east for some distance. There is some evidence that the present site of Aravaipa Valley was covered by volcanics, either the Galiuro sequence or the older Horse Mountain Volcanics. The origin of the Horse Mountain Volcanics is near the presest Santa Teresa Mountains (Simons, 1964). These central volcanics are now mostly buried beneath sediments deposited in a basin created by relative uplift of the adjacent mountain blocks. This movement took place along faults defining the boundaries of Aravaipa Basin. At this time, the apparent graben structure recognized today in Aravaipa Basin was beginning to develop (Simons, 1964; Robinson, 1976). This development was part of a regional tectonic event known as the Basin and Range disturbance, which is responsible for the block-fault structure of most of Nevada, southern California, southern Arizona, and parts of Mexico (Scarborough and Peirce, 1978). The position of this relatively small basin coincided

approximately with the present course of Aravaipa Valley to Stowe Gulch from where it extended north-northwestward for some distance.

Beginning at this time, sediments washing down from the mountains on both sides of Aravaipa Basin began accumulating as basin-fill deposits. In Aravaipa these include what Simons (1964) has termed the "Hell Hole conglomerate" and "older alluvium." Continued movement along the graben-forming faults was likely during this period of aggradation.

At the end of this period of deposition, Aravaipa Valley may have been a broad alluvium-filled valley of low relief. The position of Aravaipa Creek, if it existed at this time, is not obvious from the information that remains. Subsequent uplift of the Galiuro Volcanics and Aravaipa Valley was accompanied by broad warping of the volcanics. This warping created a synclinal trough, the axis of which approximately coincides with Aravaipa Canyon. The structural and topographic low coinciding with this trough created a preferred route west for Aravaipa Creek. Aravaipa Creek was able to maintain its westward course during further uplift of the Galiuro Mountains by eroding the canyon in which it presently flows. In this way, the elevation of Aravaipa Creek may have been quite constant throughout its history, Aravaipa Canyon being formed by uplift of the Galiuro Mountains around it.

Petrology

For the purposes of this investigation, the rocks contained within the drainage area of Aravaipa Creek were divided into four broad groups. These are the Santa Teresa-Turnbull Mountains complex plus the granite of the Graham Mountains to the south, the Galiuro Volcanics, the basin-fill

deposits, and the Pleistocene-to-Holocene alluvium presently occupying the flood plain of Aravaipa Creek. For more complete descriptions of all except the Mount Graham pluton the reader is referred to the works of Simons (1964) and Krieger (1968a, 1968b). The groups mentioned will be discussed in order of decreasing age and are located on Figure 2.

The entire eastern margin of the Aravaipa drainage is occupied by a series of plutons and their associated disrupted country rocks. The southern and easternmost of this series is the Precambrian granite pluton of the Graham Mountains. Only the southeasternmost corner of the Aravaipa drainage is underlain by this rock.

The Santa Teresa and Turnbull mountain ranges include rocks of sedimentary, volcanic, and intrusive origin. Precambrian rocks include the Pinal Schist, hornfels, and moderately metamorphosed sedimentary and volcanic rocks (Simons, 1964). The Paleozoic sequence is entirely of sedimentary origin and includes quartzite and limestone with lesser amounts of conglomerate and shale. Lower to middle Mesozoic rocks are also sedimentary, being sandstone and shale. The Tertiary system of the Santa Teresa-Turnbull mountain ranges is dominated by a thick sequence of silicic-to-intermediate volcanic rocks, the Horse Mountain Volcanics, and two extensive plutons, one consisting of Santa Teresa granite and the other Goodwin Canyon quartz monzonite. The largely intrusive rocks on the eastern margin cover approximately 21 percent of the area drained by Aravaipa Creek.

The western and part of the northern margins of the Aravaipa drainage are underlain by a thick sequence of silicic-to-intermediate volcanic tuffs and flows of Tertiary age. Along the western margin lies by

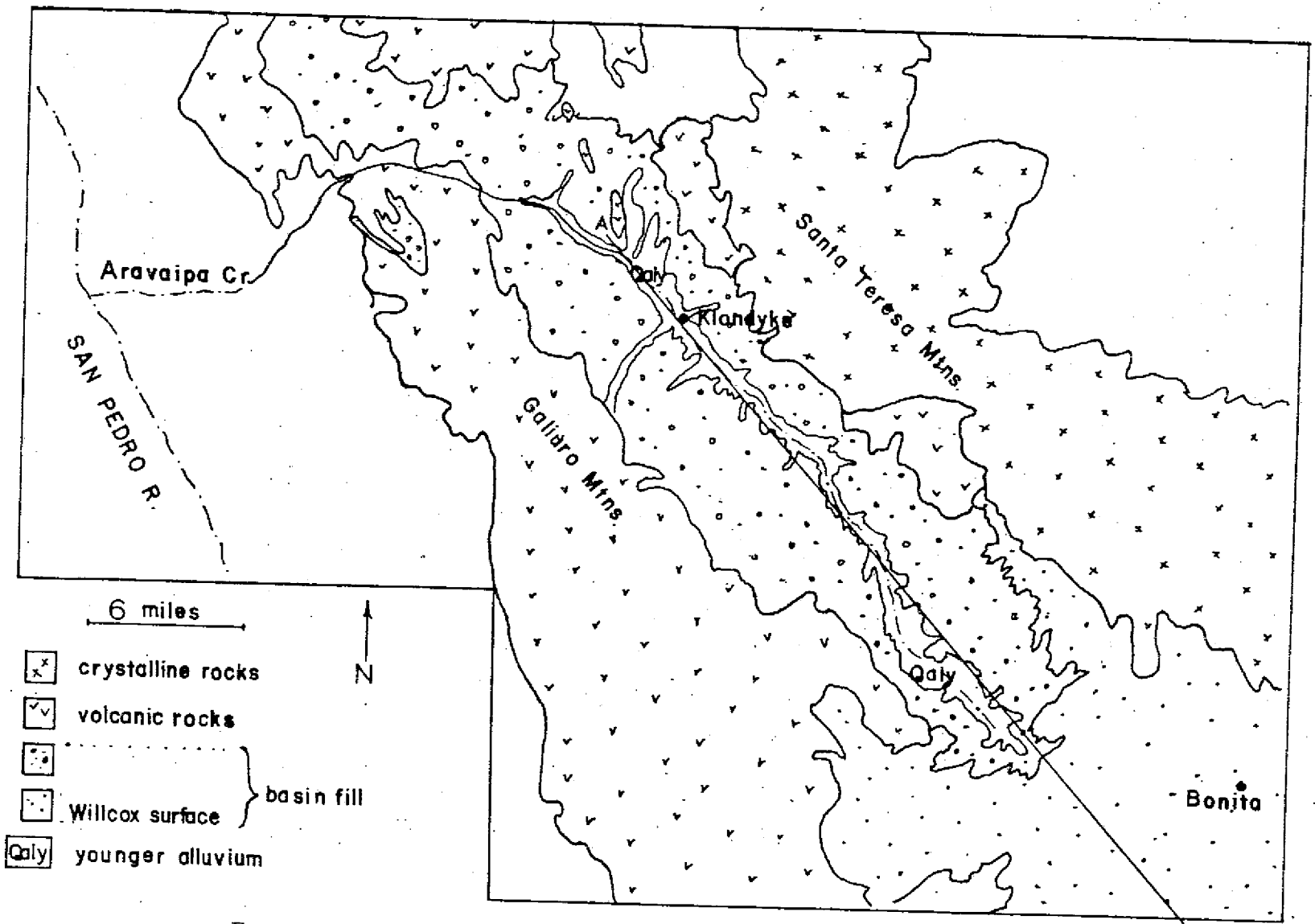


Fig. 2. Aravaipa regional geology. -- See Figure 14 for cross section A-A'

far the largest of the group, the Galiuro Volcanics. This formation is made up of lavas and tuffs, ranging in composition from rhyolite to olivine andesite or basaltic andesite (Simons, 1964). A total aggregate thickness of 6,500 feet was measured by Simons, of which 48 percent is attributed to andesite, 37 percent to silicic lava, tuff, and welded tuff, 10.5 percent to rhyolite flows and obsidian, and 4.5 percent to coarse silicic tuff. A deep exploration drill hole was drilled in the NE¼ sec. 26, T. 7 S., R. 19 E., by Bear Creek Mining Company (a subsidiary of Kennecott Copper Company) in 1970-1971. At this location 600 feet of upper (silicic) Galiuro Volcanics were penetrated, followed by 1,190 feet of lower (andesitic) Galiuro Volcanics and 677 feet of Precambrian Pinal Schist with sills of diabase from 20 to 177 feet thick. If the schist-volcanic contact dips parallel to the surface volcanics, these data would imply that the Pinal Schist lies 1,800 feet below Aravaipa Creek as it passes through the Galiuro Mountains (Krieger and others, 1979). In other areas of the Klondyke quadrangle the Galiuro Volcanics are known to overlie Glory Hole Volcanics, Escabrosa Limestone, and clastic sedimentary rocks of Cretaceous age (Simons, 1964).

In the eastern part of the Galiuro Mountains, faults are largely restricted to the vicinity of the contact of the volcanics with the Hell Hole Conglomerate. Most of these are normal faults downthrown to the east and are of small displacement. The similar placement of these faults expressed at the surface and the large basin-forming fault suggested by Robinson's (1976) gravity data have been noted and may indicate movement along the basin-range fault subsequent to deposition of the

volcanic pile. The Galiuro Volcanics occupy approximately 232 square miles, or 43 percent of the area drained by Aravaipa Creek.

Fluvial sediments deposited during and after the creation of Aravaipa Basin in the Tertiary period are now mappable as two units. These are the well-consolidated, slightly deformed Hell Hole Conglomerate and the well to poorly consolidated, undeformed older alluvium (Simons, 1964). These two units constitute the basin fill of Aravaipa, defined as "the sedimentary group that was deposited in basins created by the Basin and Range disturbance" initiated 10 to 15 m.y. ago (Scarborough and Peirce, 1978, p. 253). Simons (1964) seems to have differentiated the older alluvium from the Hell Hole Conglomerate based largely on the degree of deformation along with induration (Scarborough, 1979, personal commun.). Where it appears conformable, the contact between the two is very gradual and even "obscure" (Simons, 1964). Indeed, the degree of consolidation may generally increase from the surface down to a contact between deformed and undeformed basin fill. The Hell Hole Conglomerate is exposed where Aravaipa Creek cuts through the Galiuro Mountains because of downcutting by Aravaipa Creek and high-angle normal faulting at the canyon's mouth. It is expected that the entire sequence of basin fill is present in most of Aravaipa Basin except possibly above pediment surfaces and north of the confluence of Stowe Gulch and Aravaipa Creek. In this respect it is unfortunate that well log data are lacking in both quality and quantity.

The Hell Hole Conglomerate is in general a light-colored, cream, buff, or brown, moderately to well-indurated rock composed of angular to rounded pebbles, cobbles, and occasional boulders of volcanic rock in a

sand matrix (Simons, 1964). The formation is generally massive with the larger fragments concentrated in lenses. The clastic particles composing the rock are types exposed in the Galiuro Volcanics. Sorting ranges from good to poor but in general is more characteristic of fluviatile deposits than mudflows. The cementing agent is calcite. Where cut by Aravaipa Creek and its tributaries, the Hell Hole Conglomerate stands in near-vertical cliffs up to 700 feet high and is often cavernous due to differential erosion along certain bedding planes. Simons measured a maximum thickness of 2,000 feet between Wire Corral Draw and Maroga Canyon, whereas common single exposures are from 400 to 600 feet thick.

The Hell Hole Conglomerate rests unconformably upon Galiuro Volcanics. The contact is sometimes an angular unconformity, with the conglomerate bedding horizontal, and sometimes a discontinuity where the bedding of the volcanics and conglomerate is parallel. The original upper surface of the Hell Hole Conglomerate may be only exposed southeast of Fourmile Creek where the contact with the older alluvium appears conformable (Simons, 1964; Scarborough, 1979, personal commun.) (see Fig. 3, in pocket). Elsewhere the upper surface is an erosional surface occupying the present land surface or is buried by younger alluvium. Approximately 50 square miles, or 19 percent, of the Aravaipa watershed is underlain by Hell Hole Conglomerate.

Along the western edge of Stowe Gulch, north of its confluence with Aravaipa Creek, a linear series of resistance volcanic knobs separates the Hell Hole Conglomerate from older and younger alluvium (Fig. 3). The volcanics are thought to be Horse Mountain Volcanics. Simons (1964) has interpreted this lineament as a fault line scarp, upthrown to the west,

although no actual evidence of movement was verified. The proposed strike, position, and displacement of this fault would suggest that it fits well with other surface expressions of late Basin-and-Range adjustments. This fault may be responsible in part for the extensive exposure of Hell Hole Conglomerate on its upthrown side. It is also thought that the shallowing or disappearance of older alluvium created by this displacement is a controlling factor of perennial Aravaipa Creek. The character of the sediments on either side of this fault in the Aravaipa stream channel was a subject of this investigation and will be discussed in further detail.

A later basin-fill sequence named "older alluvium" by Simons (1964) is poorly bedded, unconsolidated to moderately consolidated clay, silt, sand, and gravel. Its fragments are rocks of both volcanic and intrusive origin from the Galiuro and Santa Teresa mountain ranges. The combined Hell Hole Conglomerate and older alluvium form continuous exposures of basin fill separating the younger alluvium of the Aravaipa flood plain from the Santa Teresa, Graham, and Galiuro mountain ranges except within Aravaipa Canyon. At the drainage divide between Aravaipa and the northern Willcox Basin, the flat depostional plain of the Willcox drainage is giving way to the headward erosion of Aravaipa Creek. This downcutting is occurring in older alluvium, a sequence of which is exposed in the Aravaipa drainage and whose original surface is still exposed in the Willcox drainage. The Willcox surface is in places mantled by loess and underlain by a caliche horizon, which forms small cliffs where cut by Aravaipa Creek. Measured thicknesses of the older alluvium range up to 700 feet with the lower contact not exposed and the upper surface one of erosion (Simons, 1964).

The older alluvium is expected to overlie Hell Hole Conglomerate in the deepest part of the basin, and it overlies the Horse Mountain Volcanics, Pinal Schist, and Galiuro Volcanics along the basin margins and pediments. It is overlain by younger flood-plain deposits along Aravaipa Creek but elsewhere occupies the present land surface. Along the southern part of Aravaipa Creek, the older alluvium has been dissected and stands in steep bluffs up to 280 feet high (Simons, 1964). The older alluvium underlies approximately 120 square miles, or 27 percent, of the area of the Aravaipa watershed.

The older alluvium extends without interruption south into Sulphur Springs Valley and around the southeast end of the Pinaleño Mountains into the valley of the Gila River. It was in this area, east of Safford, that Gilbert (1875) coined the term "Gila Conglomerate" for alluvial, basin-fill deposits along the Gila River. Neither of the basin-fill units of Aravaipa Valley are positively correlated to this original Gila Conglomerate because of the unresearched areas separating the two basins. Indeed, the widespread use of the term "Gila Conglomerate" may be more of a detriment to understanding basin-fill geology than its popularity would suggest (Heindl, 1952).

The major stream courses of the Aravaipa watershed are floored with alluvium deposited by the present streams. These deposits have been named "younger alluvium" by Simons (1964). Aravaipa Creek flows entirely upon these sediments from its headwaters southeast of Eureka Ranch (sec. 33, T. 9 S., R. 22 E.) to its confluence with the San Pedro River more than 50 river miles distant. Many of the major tributaries such as Stowe Gulch, Old Deer Creek, Bear Canyon, Turkey and

Fourmile Creeks, and Buford and Rattlesnake Canyons have narrow floors consisting of these deposits.

From Eureka Ranch to the confluence of Aravaipa Creek with Stowe Gulch, the younger alluvium deposit is usually 0.5 to 1 mile wide. The stream enters Aravaipa Canyon at this point, and the width of the deposit narrows to between 300 and 1,500 feet (Fig. 3). The canyon narrows further at the confluence of Aravaipa and Turkey Creeks, and the walls become nearly vertical. Here the floor of the canyon, generally totally sedimented, ranges from 25 to 400 feet in width until it opens up again on the western flank of the Galiuro Mountains. Although not so mapped by Simons, at no point in its length does Aravaipa Creek flow completely over consolidated rock.

The minimum depth of these younger sediments is on the order of several tens of feet (Simons, 1964). Well log data and geophysical measurements conducted during the present study suggest a thickness of as much as 130 feet.

The younger alluvium is composed of unconsolidated, poorly sorted sand and gravel deposited during Holocene time. These sediments rest unconformably on older sedimentary and volcanic rocks of Tertiary age. Approximately 25 square miles, or 4.5 percent, of the area drained by Aravaipa Creek is underlain by younger alluvium.

Geologic Structure

Aravaipa Valley is the present surface expression of a well-defined, sediment-filled basin created during the Basin and Range disturbance initiated in late Miocene time. It is bounded on the east by a

complex of carbonate, clastic sedimentary, and volcanic rocks that were intruded by two plutons prior to the Laramide orogeny, which displaced the blocks from the basin. The uplifted block containing this complex comprises the Santa Teresa and Turnbull mountain ranges. To the west of Aravaipa Valley lies another uplifted block consisting of the Galiuro Mountains, which are a thick sequence of mostly andesitic-to-rhyolitic tuffs and lava flows also of Tertiary age (Simons, 1964).

The north-northwest-trending axes of the major structural features of Aravaipa Basin and surrounding mountains fit in well with the general trend of many other Basin-and-Range features of southern Arizona. An as yet unpublished residual Bouguer gravity map of Arizona clearly shows Aravaipa Basin and the structural province of which it is a part (Lysonski and others, 1980) (see Fig. 4).

Rather detailed gravity information on Aravaipa Basin was collected and interpreted by Robinson (1976). It is his data that most clearly indicate the basement graben structure underlying Aravaipa Valley. The major normal fault bounding the downthrown block to the west is shown to coincide approximately with the contact between the Galiuro Volcanics and the basin-fill deposits (Hell Hole Conglomerate and older alluvium). The eastern margin of the basin may be marked by a similar large normal fault or faults striking north-northwest and passing about a mile east of Klondyke. The same data indicate that the central axis of the basin is displaced 2 to 3 miles west of the present topographic axis. An average axis depth to basement crystalline rock is report by Robinson to be 6,000 to 8,000 feet below the land surface.

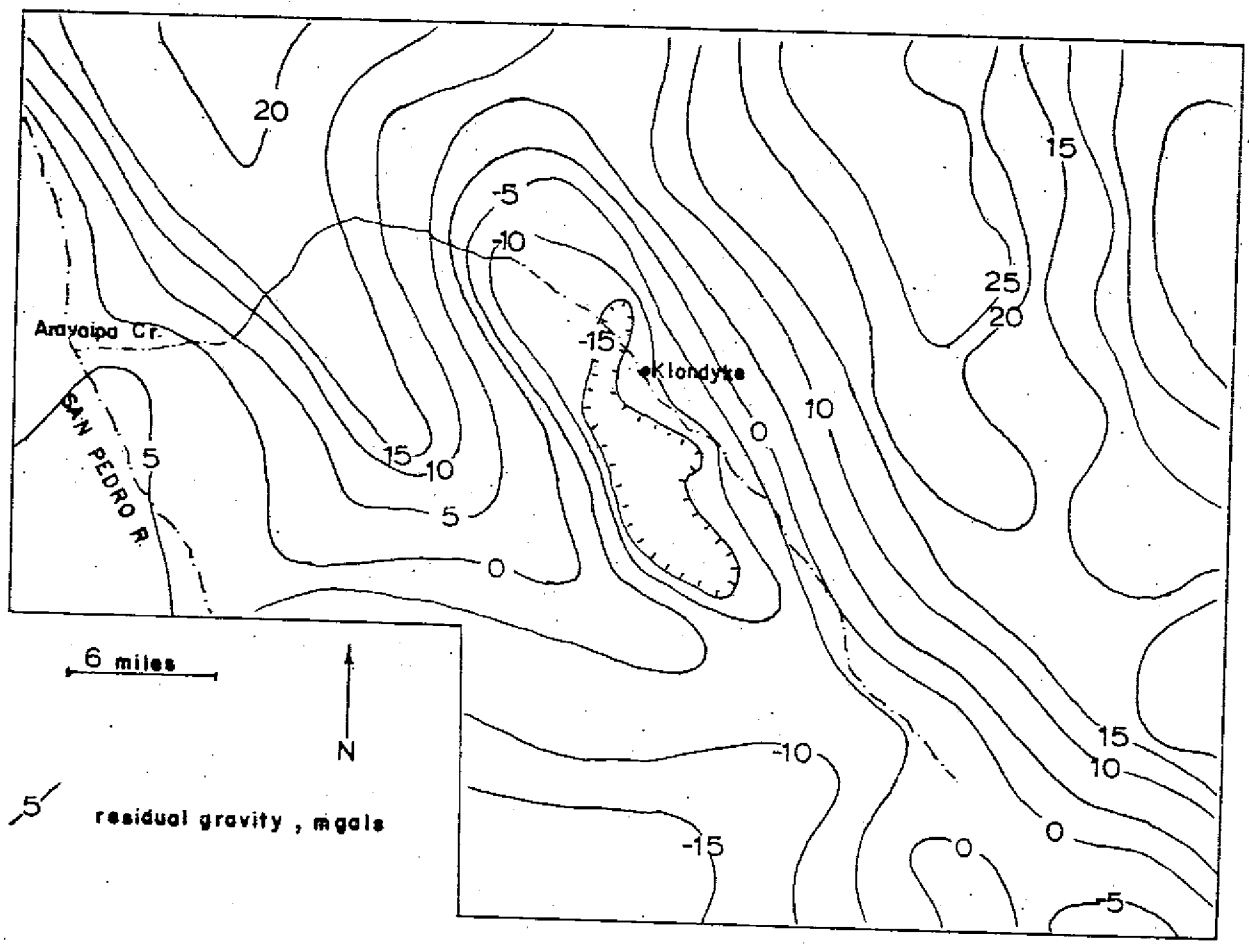


Fig. 4. Expression of Aravaipa Basin in residual Bouguer gravity data. --After Lysonski and others (1980)

Recent work by Oppenheimer (1980) using the same gravity data and computer model that Robinson used but assuming a lower density for the basin fill and volcanic formations indicates that basement rock should be expected somewhat deeper than 1,800 feet below the land surface. The large discrepancy between these results is due strictly to the differing assumptions of basin-fill and volcanic densities. Robinson's work dealt solely with the Aravaipa Basin, and his density values were derived mainly from samples taken within the basin. Oppenheimer's study included all of Arizona, and the density values she used were averages from samples taken from all over the state. For this reason, it is expected that Robinson's values may be the more accurate.

An east-west geologic profile through Aravaipa Valley near Klondyke was developed by Moore (1962) without the aid of subsequent gravity data. Robinson (1976) modified this profile on indications of his gravity survey. Both of these profiles are presented for comparison in Figures 5 and 6.

The bounds of Aravaipa Basin to the northwest and southeast are less clearly defined. Robinson's data indicate that the graben structure does not extend farther north than T. 6 S., R. 19 E., nor farther south than T. 9 S., R. 21 E. The smaller scale, residual Bouguer gravity anomaly map of Lysonski and others (1980), mentioned earlier, clearly shows Aravaipa Basin as being separated in the south from the northern Willcox Basin by a basement high in the general vicinity of the topographic divide that separates the two valleys.

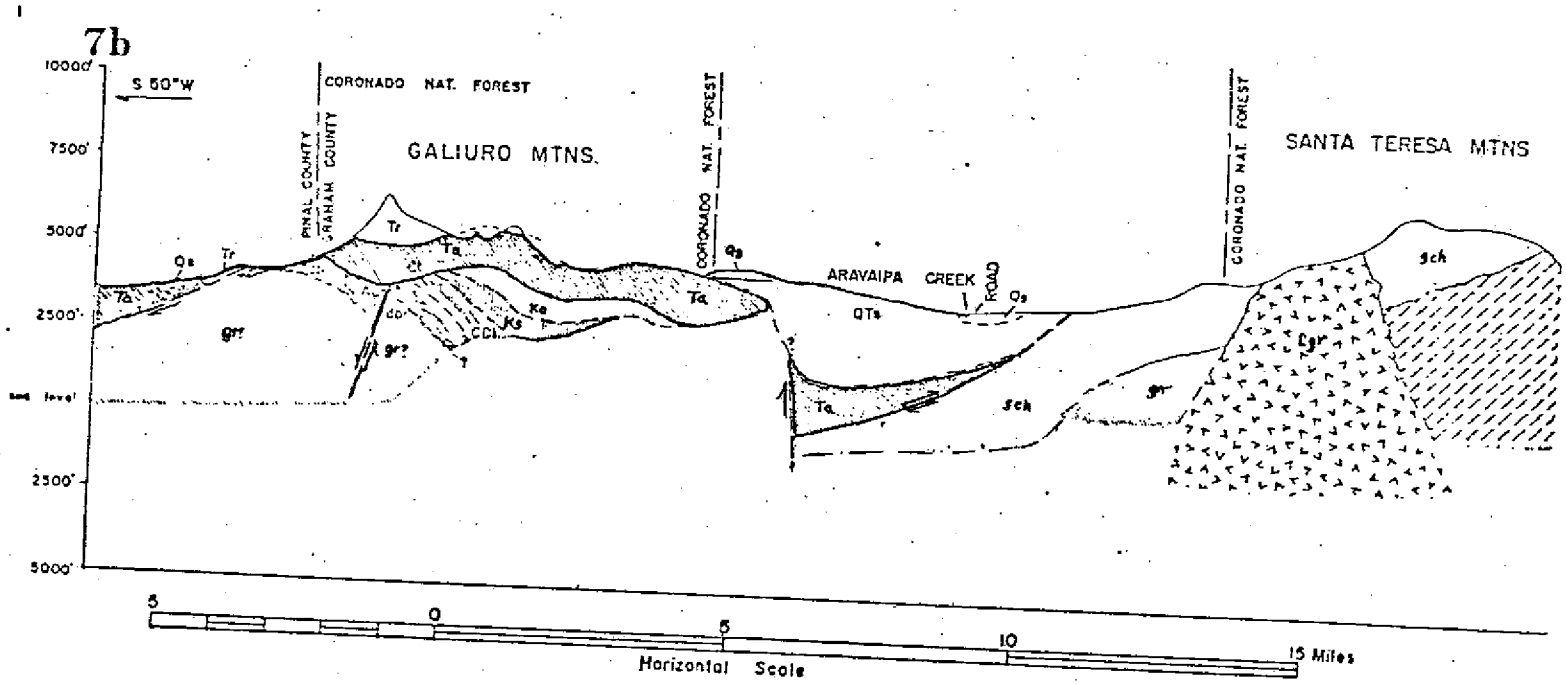


Fig. 5. Geologic cross section of Aravaipa Valley near Klondyke, Arizona. -- From Moore (1962)

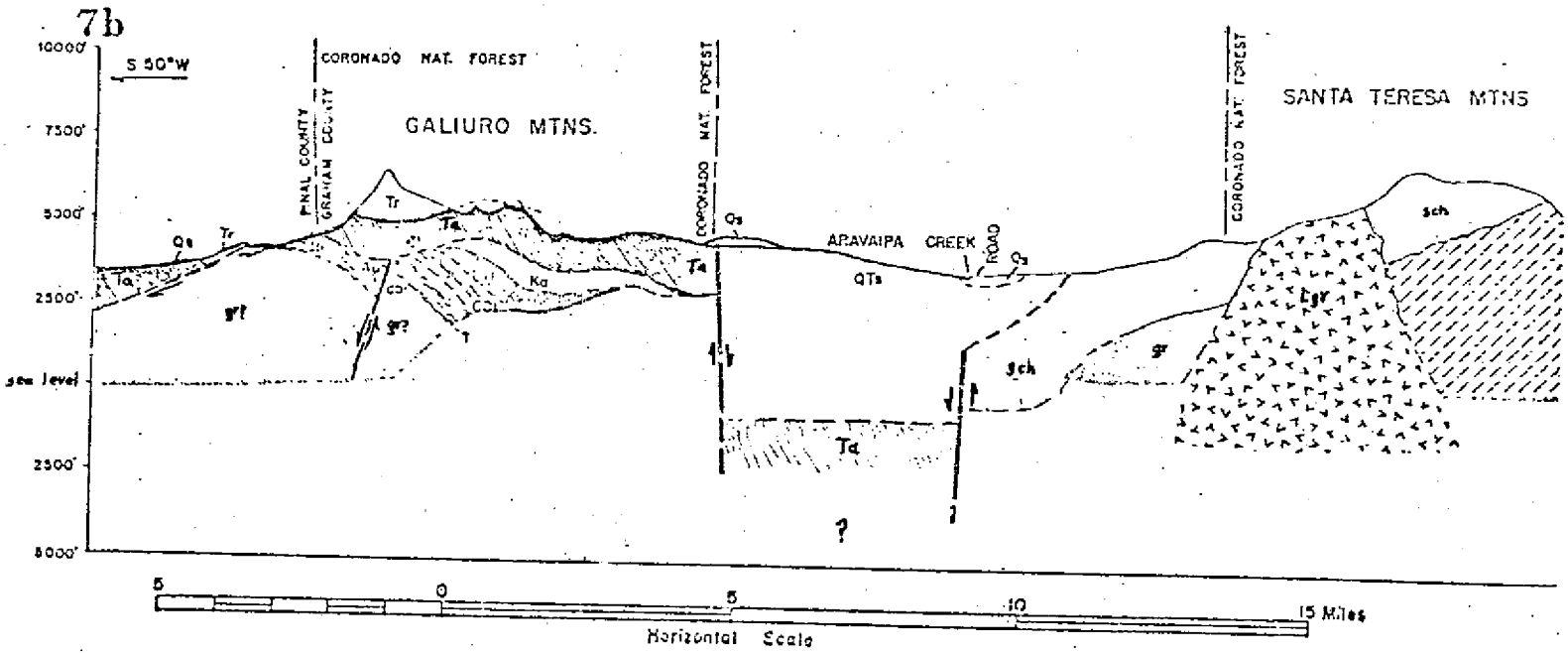


Fig. 6. Modified geologic cross section of Aravaipa Valley near Klondyke, Arizona. --From Robinson (1976).

Geophysical Surveys

Prior to this study the large-scale geologic structure of Aravaipa Basin had been interpreted with the aid of Robinson's (1976) residual gravity data. These data are presently being incorporated with other data to form a statewide residual gravity map (Lysonski and others, 1980). These data, along with the statewide aeromagnetic map of Sauck and Sumner (1971) contain valuable information on the general structure and lithology of the Aravaipa Basin.

Geophysical measurements taken during the present study were designed to provide information on structure and lithology of sites important in the flow of ground water in Aravaipa Basin and Aravaipa Canyon.

Magnetic Survey

A magnetic survey was conducted at the entrance of Aravaipa Canyon to help in interpreting (1) the relative depths of alluvium on either side of the fault postulated by Simons (1964) in secs. 35 and 36, T. 6 S., R. 19 E., and (2) the position of the (buried) fault.

The survey was conducted with a Geometrics Model G816 portable proton magnetometer on loan from the Geophysics Laboratory, Department of Geosciences, The University of Arizona. Grid points were distributed 100 to 200 feet apart along six traverses. Plotting of the data in map view and then contouring have produced the map of Figure 7. All data were adjusted for total field diurnal changes.

Remanent magnetization and permanent dipole moments of the Hell Hole Conglomerate and the younger alluvium were measured in the field to aid in the interpretation of Figure 7. For procedure see Breiner (1973).

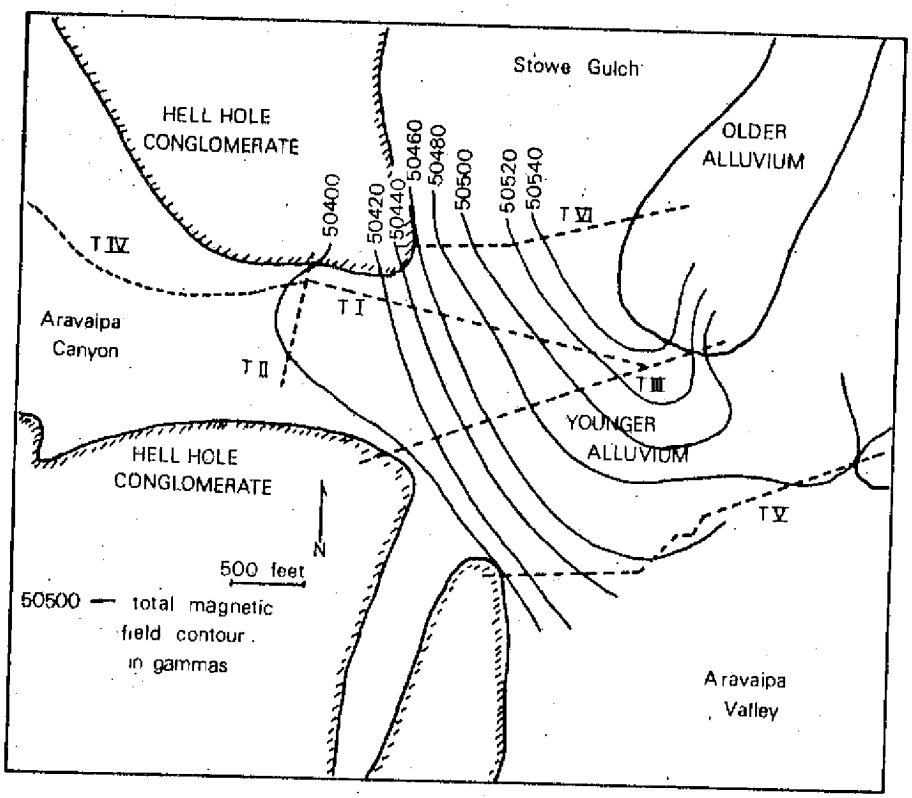


Fig. 7. Total magnetic field at the entrance to Aravaipa Canyon, east end

These data, presented in Table 1, indicate that the younger alluvium is more magnetic than the Hell Hole Conglomerate. This is expected in light of the source of the materials composing the two formations. The older alluvium is composed of materials similar to those in the younger alluvium.

Table 1. Remanent magnetizations and permanent dipole moments of the Hell Hole Conglomerate and younger alluvium. -- all units cgs

	Remanent Magnetism		Permanent Dipole Moment	
	I_r	Mean	I_r	Mean
Hell Hole Conglomerate	1.974×10^{-4}	1.66×10^{-4}	0.0754	0.066
	1.037		.0186	
	1.980		.1037	
Younger alluvium	3.200×10^{-4}	5.40×10^{-4}	0.1676	1.31
	2.28		.4147	
	1.36		3.341	

The data of profile II (Fig. 7) suggest that the magnetic readings are rather sensitive to the presence and thickness of the more highly magnetic younger alluvium. This traverse began in Hell Hole Conglomerate with relatively low magnetic readings, and as it traversed the canyon sediments, attains its highest magnetic value. Upon approaching the contact with the Hell Hole Conglomerate on the other side of the canyon, the magnetic readings again decreased. Applying the indications of this assumed geologically simple profile to the information obtained near the mouth of the canyon suggests that the depth of the alluvium increases to the east as

one leaves the canyon (secs. 35 and 36, T. 6 S., R. 19 E.) or, conversely, that the depth to the Hell Hole Conglomerate is greater east of the canyon than it is beneath the sediments of the canyon. The reason for this displacement is the hidden fault marked by Simons (1964). The data indicate that the fault scarp may lie nearly at the present contact between the Hell Hole Conglomerate and younger alluvium; this is west of the position proposed by Simons (Fig. 3).

No quantitative analysis was conducted on the magnetic data. Magnetic data, as is common with other forms of geophysical information, can be explained by an infinite number of geologic settings. The interpretations of the magnetic data given above have been arrived at in light of other information that helped define what may be a geologically reasonable interpretation.

Seismic Survey

The depth to the contact between the Hell Hole Conglomerate and the overlying younger alluvium inside Aravaipa Canyon was further studied using seismic refraction. The instrument was a Bison Instruments signal enhancement seismograph, model 1570C. Three successful profiles were obtained: these are marked SP1, SP2, and SP3 on Figure 8 (in pocket). Figures 9, 10, and 11 are the distance-travel time plots for these profiles.

Seismic refraction profiling operates by transmitting acoustic waves from an energy source at one point and recording the arrival times of the compressional waves moving through the ground at another point. The quantity, (distance)/(travel time), is the compressional velocity of

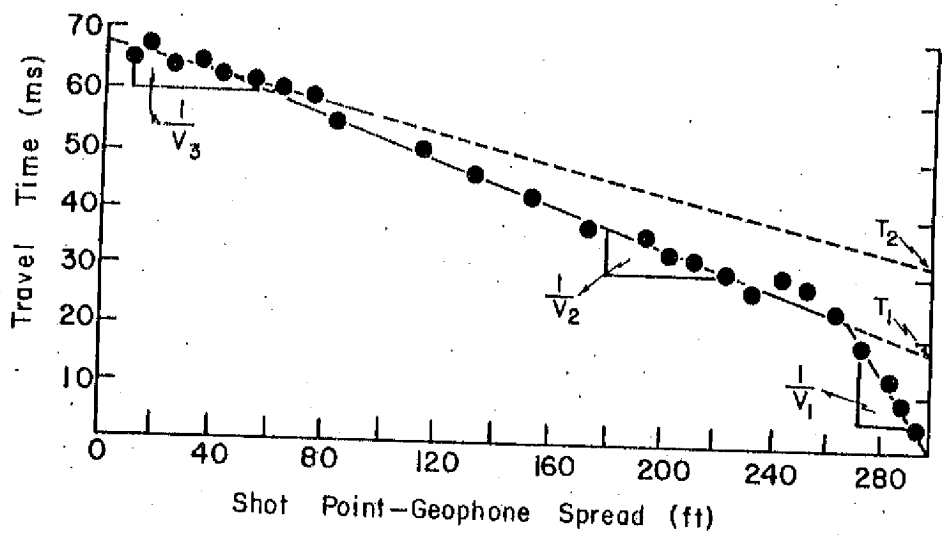


Fig. 9. Distance-travel time plot for seismic profile SP1

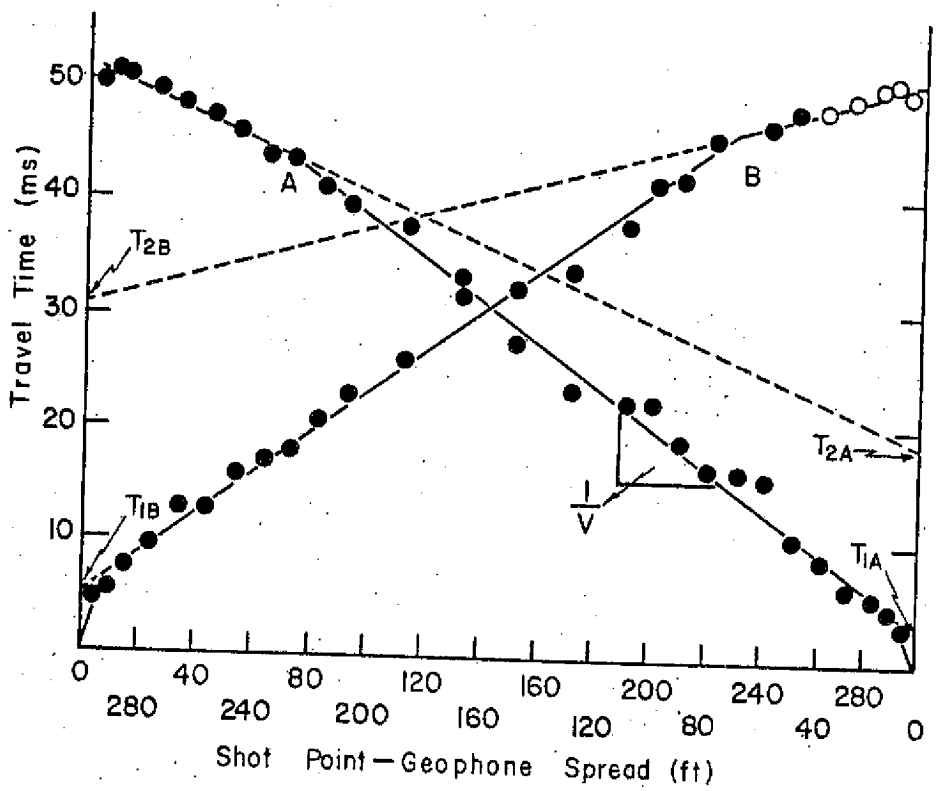


Fig. 10. Distance-travel time plot for seismic profile SP2

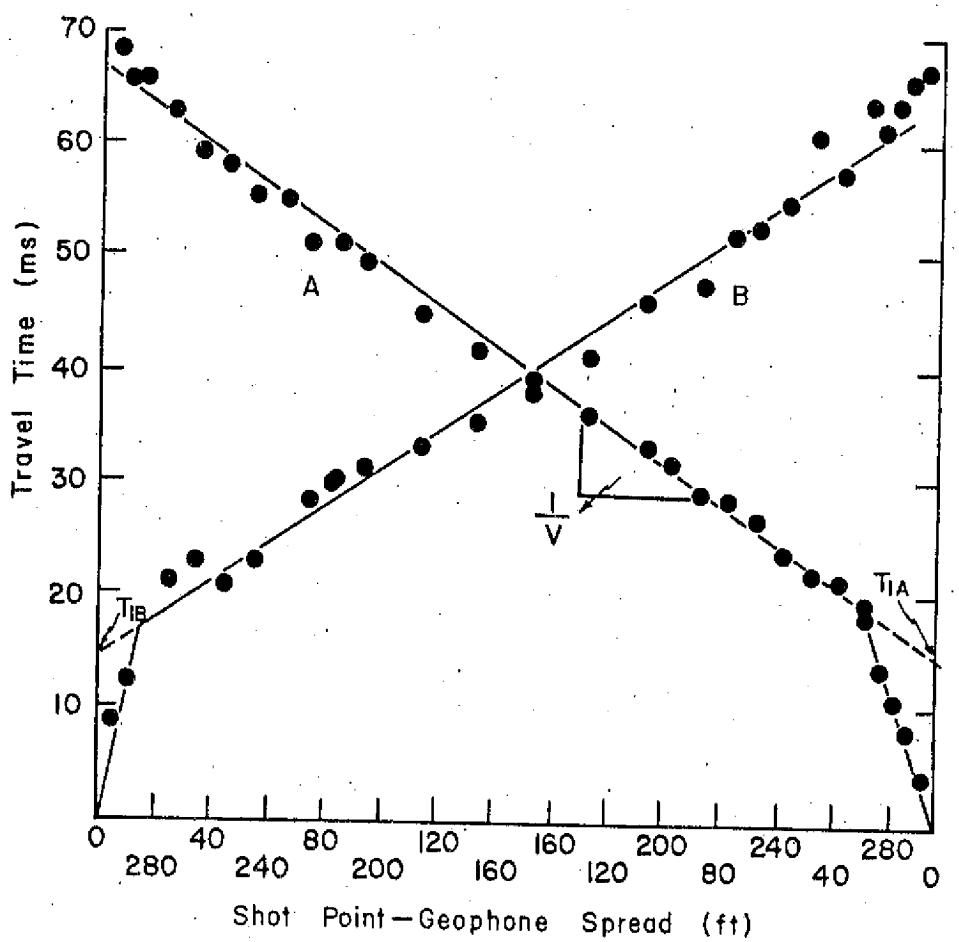


Fig. 11. Distance-travel time plot for seismic profile SP3

the formation involved. If a high-velocity layer underlies a low-velocity layer, then at some separation distance the waves traveling down from the source to the high-velocity layer and then along the top of the high-velocity layer will arrive before the waves traveling a straight path through the upper, low-velocity layer. This event is recorded on a plot of time vs. separation distance as a change of slope in the line connecting the data points. Development of the equation used and further discussion can be found in Dobrin (1976).

The particular instrument used in this study has a sledge-hammer energy source and a maximum geophone-energy source separation of 300 feet. Both of these choices tend to limit the depth to which the instrument can "feel" a high-velocity layer to about 100 feet below the land surface. If the high-velocity layer is known to exist but is not recorded in the profile, only a minimum depth of 100 feet can be assigned to the interface.

Table 2 contains the seismic velocities measured at the different profiles, their locations, the calculated depths to the various interfaces, and the geologic formation thought to be responsible for the refraction.

Seismic profile 1 (SP1) is located outside of Aravaipa Canyon in the stream channel of Aravaipa Creek (far west-central sec. 36, T. 6 S., R. 19 E.). The information obtained from this profile suggests that the Hell Hole Conglomerate lies more than 100 feet below the land surface at this point.

At SP2, within the canyon, a velocity of 11,600 ft/s was observed at 68.4 feet below the land surface. This layer may be the Hell Hole Conglomerate, but more profiles in this area would be required to say for certain.

Table 2. Seismic profile data and interpretation

Location	Velocities (ft/s)	Depth (ft)	Formation
SP1 (far west-central sec. 36, T. 6 S., R. 18 E.)	1,273	0.0 - 11.5	unsaturated young alluvium
	5,349	11.5 - 78.0	saturated young alluvium
	8,364	78.0 - >100.0	older alluvium (?)
			Hell Hole Conglomerate (?)
SP2 (NE¼NW¼ sec. 35, T. 6 S., R. 19 E.)	1,281	0.0 - 2.6	unsaturated young alluvium
	5,534	2.6 - 68.4	saturated young alluvium
	11,621	68.4	Hell Hole Conglomerate (?)
SP3 (SW¼SW¼ sec. 27 T. 6 S., R. 19 E.)	1,181	0.0 - 9.0	unsaturated young alluvium
	5,868	9.0 - >100	saturated young alluvium
			Hell Hole Conglomerate

At SP3, in a large bend of the canyon below the Defenders guest house, interpretations suggest that the Hell Hole Conglomerate lies more than 100 feet below the land surface.

In summary, the thickness of younger alluvium near the east entrance of Aravaipa Canyon is generally greater than 100 feet. An isolated bedrock high or a complete shallowing of the younger alluvium may occur near SP2. The data are not dense enough to characterize the observed high-velocity layer.

Mining

The watershed of Aravaipa Creek encompasses the Aravaipa mining district and the Table Mountain mine group. The Aravaipa mining district includes over 15 mines and prospects spread between the

settlements of Aravaipa and Klondyke (Fig. 3). The Grand Reef mine and the mines east and west of Aravaipa were the main producers of this district and were active from the 1870s to the 1950s (Simons, 1964). Production during this period included 60 × 10^6 lb of totaled lead, zinc, and copper and 14,240 lb gold and silver. The Athletic Mining Company built a flotation concentrator in 1948 with a capacity of 100 tons per day (Simons, 1964). The tailings from the operation are visible from the road between Klondyke and Aravaipa Canyon, a mile northwest of Klondyke.

The Table Mountain mine group consists of one small copper mine and several prospects spreading southeast from Little Table Mountain and Table Mountain mine (SE¼ sec. 15, T. 7 S., R. 18 E.) to Fourmile Creek. The only recorded production of this group was 400-600 tons of ore assaying more than 14% copper.

In Aravaipa Canyon, between Horse Camp and Booger Canyons, a mining claim was established in 1927 and 1928 in what was thought to be a minable potassium nitrate deposit. The claim was relinguished when the nature of the deposit was ascertained: potassium from the volcanic rocks combined with nitrogen from bat guano to form a coating of the observed mineral (Krieger and others, 1979).

In describing the Galiuro volcanic pile, the deep drill holes made by Bear Creek Mining Company on the lands above and south of Aravaipa Canyon were mentioned. The location of these holes and the accompanying mining claims was determined by the position of a local magnetic anomaly found in an aeromagnetic survey (Sauck and Sumner, 1971). After drilling the holes it was decided that the anomaly could be explained

by magnetite contained in flows and sills associated with the Galiuro Volcanics, and in 1971 the mining claims were relinguished.

Mining activity has been very low in recent years, and at the present time is restricted to mineral specimen mining in the Grand Reef mine (E½ sec. 29, T. 6 S., R. 20 E.). Recent mineral exploration in the Aravaipa Canyon Primitive Area and adjacent lands has been conducted by personnel of the U.S. Geological Survey. Discoveries include an estimated 1.25×10^6 tons of zeolite in the form of clinoptilolite found in the west wall of Cave Creek and west Aravaipa Canyon (Krieger and others, 1979). Zeolites can be used in a molecular sieving process, in catalysts, and as dessicants. The economic feasibility of mining this deposit is questionable due to its position high on the walls of the mentioned canyons.

Geochemical analyses conducted for the same study showed sporadic high metal contents both in stream sediments and in situ rock samples. A small high anomaly is shown to occur near the faulted contact between the Galiuro Volcanics and the Hell Hole Conglomerate in sec. 26, T. 6 S., R. 18 E. This anomaly was interpeted by Krieger and others (1979) to indicate leakage along the fault from a possible mineralized body at unknown, but great depth.

HYDROLOGY AND WATER RESOURCES

Although the water resources within the Aravaipa watershed are not completely developed, the usual variety of water-supply systems exist. These sources include ground-water withdrawal, surface-water diversions, and catchment of surface runoff.

Water-bearing and Transmitting Properties of Geologic Units

Those formations that constitute the basin margins to the east and west are here differentiated from the older and younger alluvium, which makes up the water-table aquifer of Aravaipa Valley. The basin-margin formations are thought to be much less permeable than either the basin fill or younger alluvium, except possibly where well fractured. This categorization is based on field observations of spring discharge and geology and not on quantitative hydrologic measurements. Such measurements exist only within the alluvial deposits.

Basin-margin Formations

Little information on ground-water occurrence exists along the eastern margin of the Aravaipa drainage in the Turnbull and Santa Teresa mountain ranges. Information is available only in the form of spring discharge, and these are not common. One example is Stowe Spring, which emerges at the contact of the Horse Mountain Volcanics with the basin fill in the SE¼ sec. 1, T. 6 S., R. 19 E. It is a perennial spring and during the course of this study was estimated to flow at 150 gpm late in a summer

of almost no rainfall. Few other springs are reported or mapped, and no well is known to have been drilled in the Santa Teresa or Turnbull mountain ranges. The largely abandoned mining town of Aravaipa in what would be sec. 36, T. 5 S., R. 19 E., is placed in a highly faulted area of limestone, sandstone, and shale. No perennial ground- or surface-water supply was ever developed for the town or the mining operation.

The water-bearing and transmitting properties of volcanic rocks are known to vary widely. Within the Galiuro Volcanics, only indirect and qualitative estimations of these properties are possible because of the few attempts to develop whatever water might be in them. Evidence for the existence of ground water in these rocks consists of a number of springs that drain the sequence. Springs in Aravaipa Canyon are noted to emerge both near stream level and high on the canyon walls. This suggests that these different springs do not drain a regional water table but rather local perched water lenses in pervious strata. The exact lithology of the rocks surrounding most springs was not observable due to relief and soil cover. The largest spring observed emerging from the volcanics was located 0.3 miles downstream from Virgus Canyon on the north side of Aravaipa Creek nearly at stream level. It was estimated to flow at 100 gpm. The flow rate of this spring was measured at 16 gpm on 5 Dec 2010

Two major influences on water movement in rocks of low permeability are fractures and faults. Good examples of this are the springs feeding Right Prong Fourmile Creek in sec. 27, T 7 S., R. 19 E. These springs can be attributed to the water storage and transmissability along the adjacent fault on the contact between the volcanics and the Hell Hole Conglomerate. The Lackner family of a nearby residence has been quite

successful in developing these springs for irrigation and domestic uses. Horizontal drilling into the volcanic rocks of the western block is the method in use. Elsewhere in the Galiuro Volcanics, fractures are not particularly abundant. One vertical set was observed striking north-northeast in sec. 24, T. 6 S., R. 18 E.

The only water well known to be drilled into the Galiuro Volcanics within the Aravaipa watershed is 500 feet deep and supplies water for stock in sec. 32, T. 6 S., R. 18 E. (Gould and Wilson, 1976). The altitude of the water being pumped is greater than 3,600 feet, putting it approximately a thousand feet higher than the level of Aravaipa Creek 0.5 mile to the northwest. This also suggests that the ground water being developed is perched on a bed of low permeability.

Water was observed in the bedding planes of the Hell Hole Conglomerate inside Aravaipa Canyon. Accelerated erosion has created indentations from which the water drips. By far the majority of springs within both the conglomerate and the Galiuro Volcanics occur on the north wall of Aravaipa Canyon. This may be due to the smaller size of the tributary streams draining the Galiuro Mountains north of the canyon.

Only one seep in the Hell Hole Conglomerate is known to be developed for human use. At Dry Camp at the confluence of Arizona Gulch and Old Deer Creek, horizontal drilling into the seep has resulted in a continuous supply of water through a ½-inch garden hose. It is not expected that ground-water development in this conglomerate on a scale substantially larger than this example would be successful unless zones of fracturing are taken advantage of.

One such fracture zone in the Hell Hole Conglomerate exists in Oak Grove Canyon. A series of large (100 gpm) springs emerges from the north wall of this narrow canyon near the contact of the Hell Hole Conglomerate with the Galiuro Volcanics in sec. 6, T. 7 S., R. 19 E. The contact cannot be observed from the springs but is shown to be very near on the map by Simons (1964). Neither is the contact shown to be a fault, but well-defined fractures in the walls of the canyon are prevalent.

Old Deer Creek and Turkey Creek, of which Oak Grove Canyon is a tributary, are two major tributaries of Aravaipa Creek that head in Hell Hole Conglomerate. Both of their canyons have considerable amounts of younger alluvium, affording storage for rainfall and in the case of Oak Grove Canyon, headwater spring discharge. The effect of this alluvium storage is to prolong discharge into Aravaipa Creek long after rains have ceased.

The Alluvial Aquifer

The aquifer system of Aravaipa Valley consists mainly of the younger and older alluvial deposits. These two deposits are continually fed by springs and, very likely, by subsurface flow from the mountain fronts on either side of the valley.

Ground water occurs in the older alluvium starting from 26 feet below the land surface near the contact with the younger flood-plain sediments to probably over 500 feet below land surface in the uplands near the southern drainage divide (Gould and Wilson, 1976). Because of the relief of the older alluvium's surface, the land is used exclusively as cattle range, and the wells placed in this formation are used for stock

watering. They are powered either by the wind or, in a few instances, electricity. Yields to wells are small to moderate, and this does not seem to be due simply to casing sizes and pump capacities as will be discussed later.

The younger alluvium is undoubtedly the most permeable formation in Aravaipa Valley, and most of the wells in the drainage have been placed in this formation. These wells yield up to 1,200 gpm, and although most of them penetrate the underlying older alluvium, most of the water is thought to be derived from the younger alluvium. Both within Aravaipa Canyon and upstream in the valley, the younger alluvium is the main source of water for irrigation, stock, and domestic uses. Depths to water range from less than 10 feet within the canyon to near 100 feet near the headwaters southeast of Eureka Ranch. In the Aravaipa stream channel proper, near the entrance to Aravaipa Canyon, Aravaipa Creek emerges from these younger sediments and flows perennially through the Galiuro Mountains. During all of 1979 and through August 1980, Aravaipa Creek emerged well upstream from the mouth of the canyon due to the exceptionally heavy rainfall of the winter of 1978-1979. This is an indication of the long-term storage available in the Aravaipa Basin aquifer, which remains unsaturated during years of average recharge.

A longitudinal geologic profile of Aravaipa Valley along the present stream course should show, in sequence from the land surface, younger alluvium, older alluvium, Hell Hole Conglomerate, Galiuro Volcanics, then Pinal Schist or some other pre-Tertiary formation. In the northern portion of Aravaipa Valley, the older alluvium may lie directly on Horse Mountain Volcanics. Except in a few particular locations very little

is known about the thicknesses of these units. The younger alluvium is the formation in which most of the water wells are drilled, and the water is usually found shallower than in other places. Nine well logs have been collected from wells beginning in this material, from Eureka Ranch downstream to within Aravaipa Canyon. The terms "top soil," "gravel," "sand," and "clay" are all used in describing various horizons within the younger alluvium.

Three of the well logs indicate a significant change of lithology with depth. Two of these wells are placed near Aravaipa Creek in the vicinity of Klondyke; one shows a change of lithology to "clay" (20 ft thick) at a depth of 136 feet, the other shows "congomerate" at 96 feet. The third well, far to the south near Eureka Ranch, shows much clay beginning at 27 feet and sand and gravel above that depth. It is likely that the changes noted represent the upper surface of the older alluvium.

The possibility of the younger alluvium's being more than 100 feet thick is also supported by the seismic data presented earlier. Simons (1964) suggested that the thickness of this deposit "may be several tens of feet." At least five wells in the younger alluvium are known to produce over 1,000 gpm, and none of these is over 160 feet deep. Logs for three of these wells are included in Appendix A.

The only quantitative aquifer response data were collected during the pumping of well (D-7-20)21bbb (U.S. Geological Survey notation; see Appendix A) in the younger alluvium. The well is 150 feet deep, and the static water level was near 84 feet. It is reported to have produced 1,225 gpm with 20 feet of drawdown in the well casing (Appendix A). This corresponds to a specific capacity of 61.25 gpm/ft if the well efficiency is

100 percent. If the well efficiency is 50 percent, the drawdown that should be used is 10 ft, yielding a specific capacity of 122.5 gpm/ft. Many new wells fail between 50 and 80 percent well efficiency.

The following equation is a "rule of thumb" relating the specific capacity of a well to the aquifer transmissivity:

$$T = 2000\ C_s$$

where T = transmissivity in gpd/ft and C_s = specific capacity in gpm/ft. For the range $61 < C_s < 123$, the transmissivity is estimated to be between 122,000 gpd/ft (16,500 ft^2/day) and 246,000 gpd/ft (33,100 ft^2/day).

Probably a more reliable estimate of the transmissivity of the younger alluvium was established as a result of measurements conducted for this study employing Darcy's law. (See the section on the emergence of Aravaipa Creek and streamflow-geology relationships.) These measurements indicate transmissivity values up to 1,200,000 gpd/ft (165,000 ft^2/day) and corresponding hydraulic conductivity values of up to 1,300 ft/day. The discrepancy between the specific capacity test results and results from Darcy's law analysis may be due to the fact that only 40 ft of saturated younger alluvium were penetrated by the well, whereas probably over 100 ft of saturated thickness exist where the Darcy's law analysis was conducted. Furthermore, the accuracy of the specific capacity test results cannot be verified.

Logs of five wells that definitely penetrate the older alluvium have been collected. They describe the older alluvium as a mixture of "clay," "sand," "gravel," and "conglomerate." The clay facies greatly predominates in most wells, and increasing induration with depth is noted

in four of the five logs. Signs of cementation begin at burial depths of between 10 and 852 feet.

Little is known about the thickness of the older alluvium. Exposed thicknesses measured by Simons (1964) range up to 700 feet, with neither the lower contact exposed nor the upper surface noneroded. In the SW¼ sec. 4, T. 7 S., R.20 E., the older alluvium is at least 715 feet thick, and near Aravaipa stream channel it is at least 350 feet thick (Gould and Wilson, 1976).

At some depth beneath most of Aravaipa Valley the older alluvium either gradually grades into or is unconformably in contact with the older basin-fill deposit, the well-indurated Hell Hole Conglomerate. Below this level no highly productive aquifer has been found. Two water wells in the area penetrate these basin-fill deposits and volcanics. These will be used later in comparison to the wells placed in and producing water from the younger alluvium.

Well (D-9-21)14caa begins in the younger alluvium below Eureka Ranch headquarters. It penetrates 27 feet of younger alluvium, 852 feet of older alluvium (mostly clay), then 233 feet of cemented alluvium, probably the Hell Hole Conglomerate. At 1,079 feet below land surface the well penetrates a horizon of "burned gravel," then 41 feet of intermixed volcanics and various clays. The well ends in 318 feet of nearly pure clay for a total depth of 1,501. The static water level in this well stands near 81 feet below land surface; note that this is below the younger alluvium. The driller's comment on the productivity of this well was: "Hole would bail dry easy."

Another deep well only about 2½ miles away from the one above is placed 300 feet higher in elevation in the older alluvium to the west of the creek. Eighty feet of unconsolidated silt, clay, and sand are underlain by 540 feet of "Hard blue malpais" (volcanics?). The only water was encountered in fractures at 235 feet. The sequence of rocks was underlain by 600 feet of volcanic rocks of the types exposed in the Galiuro Mountains. At 1,205 feet, the well ends in this volcanic rock. The water level in this well was reported to be at 219 feet below land surface. During an 8-hour well test the maximum sustained yield was 50 gpm.

No deep wells have been drilled and pump tested north of Eureka Ranch where the thickness of the basin fill can be expected to be greatest. Inferences drawn on the data at hand should be viewed with this lack of information in mind.

Whereas water within the younger alluvium is unconfined in all known cases, confined conditions prevail in the deeper zones of the older alluvium. The artesian heads of these confined aquifers are not known to be large. One well in the basin at Eureka Ranch is reported to flow, but the depth from which the water is being produced is not known (Valenzuela, 1979, personal commun.). The water from this well was also reported to be impalatable due to its taste "of gasoline."

From the discussion above it should be clear that well productivity depends mostly on position. The wells with the highest yields are those placed in areas where the younger alluvium has a maximum saturated thickness. This favors wells placed near Aravaipa stream and generally near the mouth of Aravaipa Canyon where the water table approaches the land surface.

Ground-water Flow

Regional Flow Pattern

It is assumed that water enters the ground-water system of Aravaipa Basin from (1) spring and subsurface flow near the mountain fronts, (2) streambed infiltration of runoff water from the highlands, and (3) direct infiltration of precipitation. The relative quantities of these contributions are not known, but observations of spring discharges and the ground-water contours of Figure 12 (in pocket) suggest that mountain-front recharge may be the largest contributor. As will be shown later, an esimated 2.4 percent (11,600 acre-ft) of the watershed's total annual rainfall is expected to find its way into the ground-water reservoir.

It's more likely that #2 is dominant

Springs observed to be contributing water to the valley sediments include ones from both eastern and western mountain fronts. They generally occur very near the faulted contacts of either the mountain-block rocks and the basin fill or along fault zones in rocks totally of the mountain blocks. They are assumed to be discharging water stored in the faults and their associated fracture zones.

Two of the principal spring-fed streams are Stowe Gulch fed by Stowe Spring (SE¼ sec. 1, T. 6 S., R. 19 E.) and Right Prong Fourmile Creek fed by a series of large springs (secs. 28 and 33, T. 7 S., R. 19 E.). Several other unvisited springs are shown on maps available for the area. Oak Grove Canyon Spring (S½ sec. 6, T. 7 S., R. 19 E.) contributes to the ground-water supply of Turkey Creek and therefore Aravaipa Creek surface flow but not to the ground-water reservoir of Aravaipa Valley.

Stream-channel infiltration probably occurs mostly in the main channel of Aravaipa Creek during floods. The mean stream-channel gradient of Aravaipa Creek in the valley is approximately 0.8 percent. This is quite a reduction from the gradients of the tributaries and slopes and allows a reduction in flow velocity and subsequent stream-channel infiltration as flood waters are transmitted downstream.

Ground-water level measurements taken by personnel of the U.S. Geological Survey in 1975 are the most complete set of data of this type available (Gould and Wilson, 1976). The data have been used to construct the water-table map of Figure 12 (in pocket).

U.S. Geological Survey ground-water level measurements taken over several years in the same wells in Aravaipa Valley have been plotted against the mean base flow in Aravaipa Creek for the day on which the measurements were taken. The resulting plots in Figure 13 indicate the imprecision with which these two variables are related and therefore the importance of other factors such as pumpage, diversion, response lag, and evapotranspiration. All the measurements were taken in January or February. Data from the well placed farthest from the canyon show no correlation, whereas data from the two wells nearer the canyon show positive but not strong correlations. In general, it can be concluded that the higher the ground-water levels in the valley close to the canyon entrance the higher the base flow in the stream and that the systems are therefore hydrologically connected.

Figure 12 shows that the ground water in Aravaipa Basin moves generally from southeast to northwest along Aravaipa Creek and from north to south in the Stowe Gulch area. The common convergence point

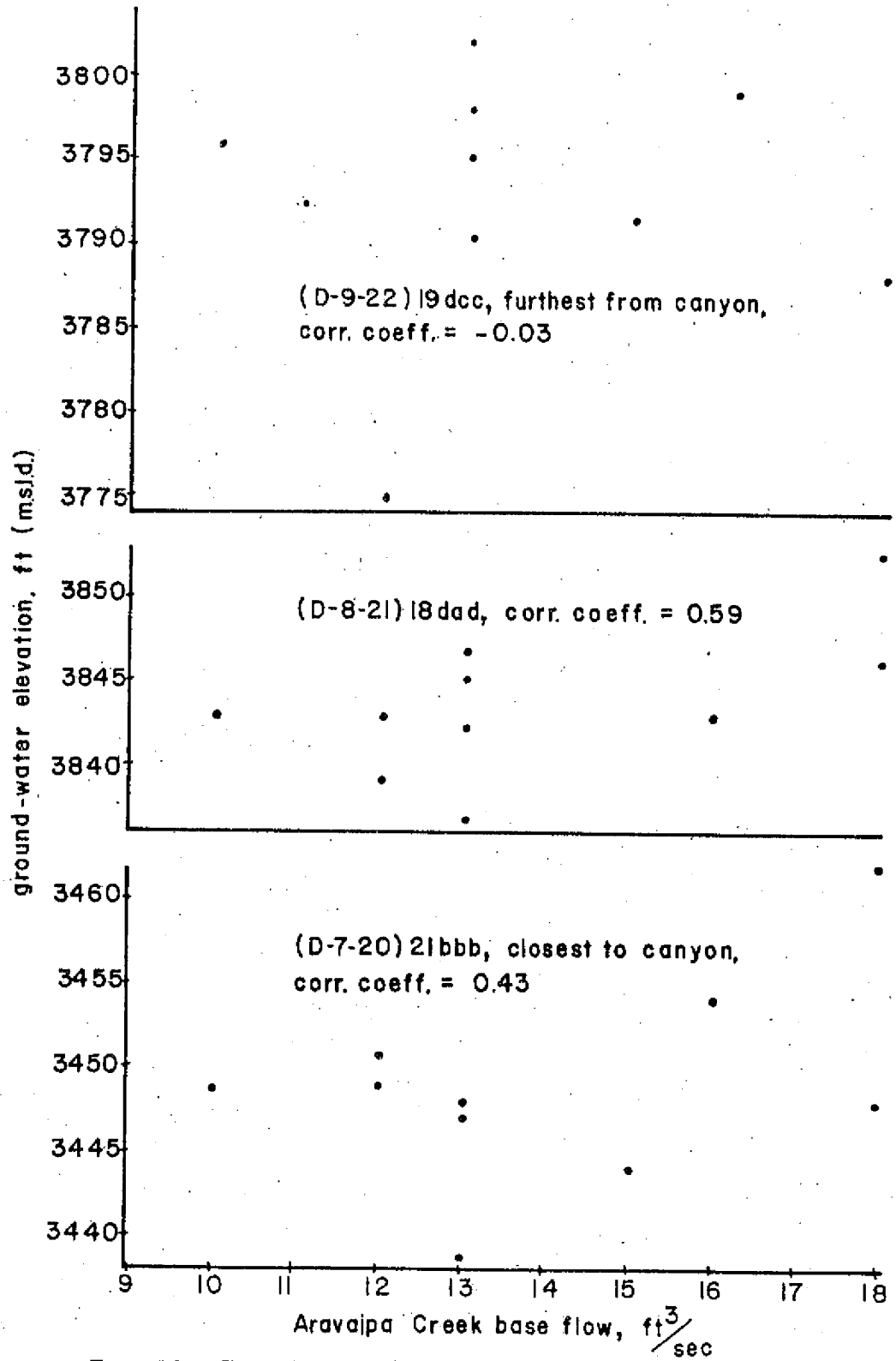


Fig. 13. Correlation of ground-water elevation and base flow

for all the ground water flowing naturally in the basin is the beginning of Aravaipa Canyon, the lowest point in the valley at 3,320 feet above mean sea level (far west-central sec. 36, T. 6 S., R. 19 E.). From the scant data available on ground-water levels away from the center of the valley, it appears that the ground-water contours bend sharply north as they leave the younger alluvium. This may suggest that recharge occurring along the mountain fronts moves almost straight toward the Aravaipa stream channel, then turns and moves northwest in the highly permeable younger alluvium of the valley center.

The position of the surface-water divide between northern Sulphur Springs Valley and the Aravaipa drainage is shown in Figure 14. It can be seen that the ground-water divide between the two basins is approximately at the same location as the topographic divide.

Aravaipa Valley ground water is discharged mainly through Aravaipa Canyon, whereas that of Sulphur Springs Valley to the south, with internal drainage, is discharged mainly by pumpage and evaporation. Pumpage for irrigation in northern Sulphur Springs Valley averaged near 300,000 acre-feet per year for years 1963 through 1975. The effect of this pumpage on ground-water flow patterns and water levels has been dramatic (Mann, White, and Wilson (1978). Nearly all flow now occurs toward the several irrigation centers in the valley, and in some areas ground-water levels dropped over 100 feet between 1957 and 1975.

An important factor in the response of ground-water levels near the southern Aravaipa drainage divide to pumpage in Sulphur Springs Valley is whether there exists a basement high separating the two basins and, if so, at what depth is its top surface. The existence of such a

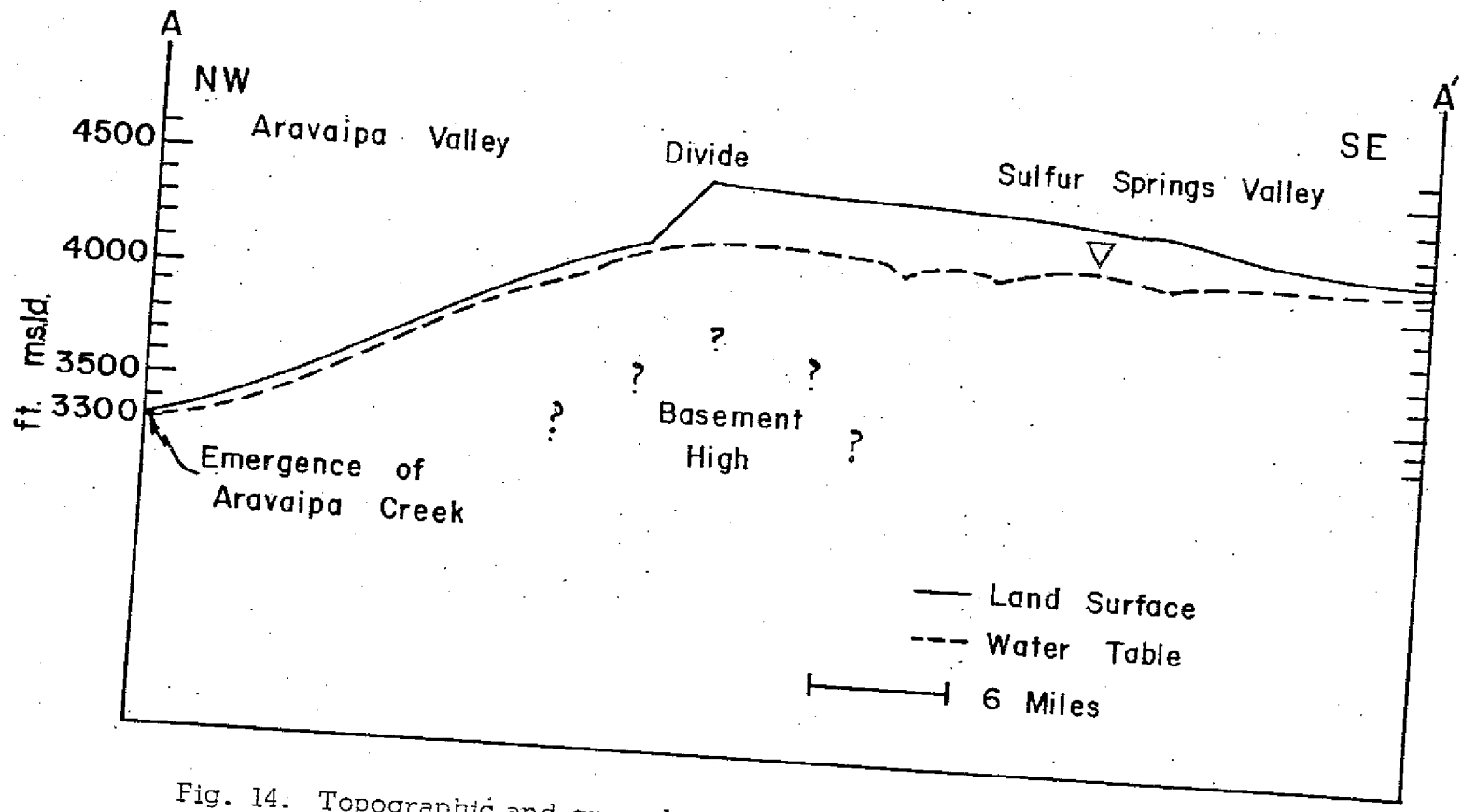


Fig. 14. Topographic and ground-water profile along section A-A' of Figure 2

basement high is supported both by gravity data represented in Figure 4 and the longitudinal ground-water and topographic cross section of Figure 14. The gravity data show a residual gravity anomaly of zero coinciding with the topographic and ground-water divide. This indicates a reduction in the depth to basement rock.

The topographic and ground-water cross sections of Figure 14 show, in general, a relatively high and level water table in Sulphur Springs Valley separated from the generally lower and naturally draining Aravaipa water table by the coincident topographic and ground-water divides. It is unlikely that the water levels shown in Figure 14 would maintain themselves if it were not for some structure impeding flow between the two basins. Without such a structure, the ground-water divide would shift continually southeast until all the ground water drained into Aravaipa Creek to the left of that figure. The impeding structure is associated with the basement high indicated by the residual gravity data and is positioned just south of the topographic divide at the ridge of high gravity values trending northeast-southwest in Figure 4.

Emergence of Aravaipa Creek and Stream Flow-Geology Relationships

Historically, for the years in which verbal information is available, Aravaipa Creek has maintained its perennial nature from about the NW¼ sec. 35, T. 6 S., R. 19 E., to the western margin of the Galiuro Mountains through which it flows (Tapia and Tapia, 1979, personal commun.). The source of the creek's water in times of no rainfall is the ground water moving north through the Aravaipa Valley aquifer from as far south as Eureka Ranch and from ground water moving south through the alluvium

of the Stowe Gulch area. Other sources may add water to Aravaipa Creek farther downstream.

As ground water from all parts of the valley moves toward the discharge point at the beginning of Aravaipa Canyon the cross-sectional area of the alluvial rocks is greatly reduced and there is a "ponding" of this water due to the restricted flow path. From historical data, ponding shows up as a reduced ground-water gradient from near 0.85 percent over most of the valley length to near 0.40 percent within about 3 miles of the beginning of the canyon (Fig. 12). The restricted cross-sectional area of flow is obvious, knowing the direction of flow and the measured reductions in both alluvium width and depth in moving from Aravaipa Valley into Aravaipa Canyon (see Fig. 3 and the section on geophysics).

During times of above-average rainfall, Aravaipa Creek may emerge from the alluvium well upstream from the beginning of the canyon, but generally the emergence point, as mentioned above is 0.5 mile or so downstream from the canyon entrance. Due to the exceptionally heavy precipitation of the winter of 1978-1979, Aravaipa Creek emerged at least 0.5 miles upstream from the canyon during the time of this study. The ground-water gradient also increased to an average of nearly 1 percent at the canyon entrance (Figs. 15 and 16).

An examination of Darcy's law can be applied to the above discussion in explaining the emergence of Aravaipa Creek. Darcy's law reads:

$$Q = KAI \qquad (1)$$

where Q = ground-water discharge $[L^3/t]$

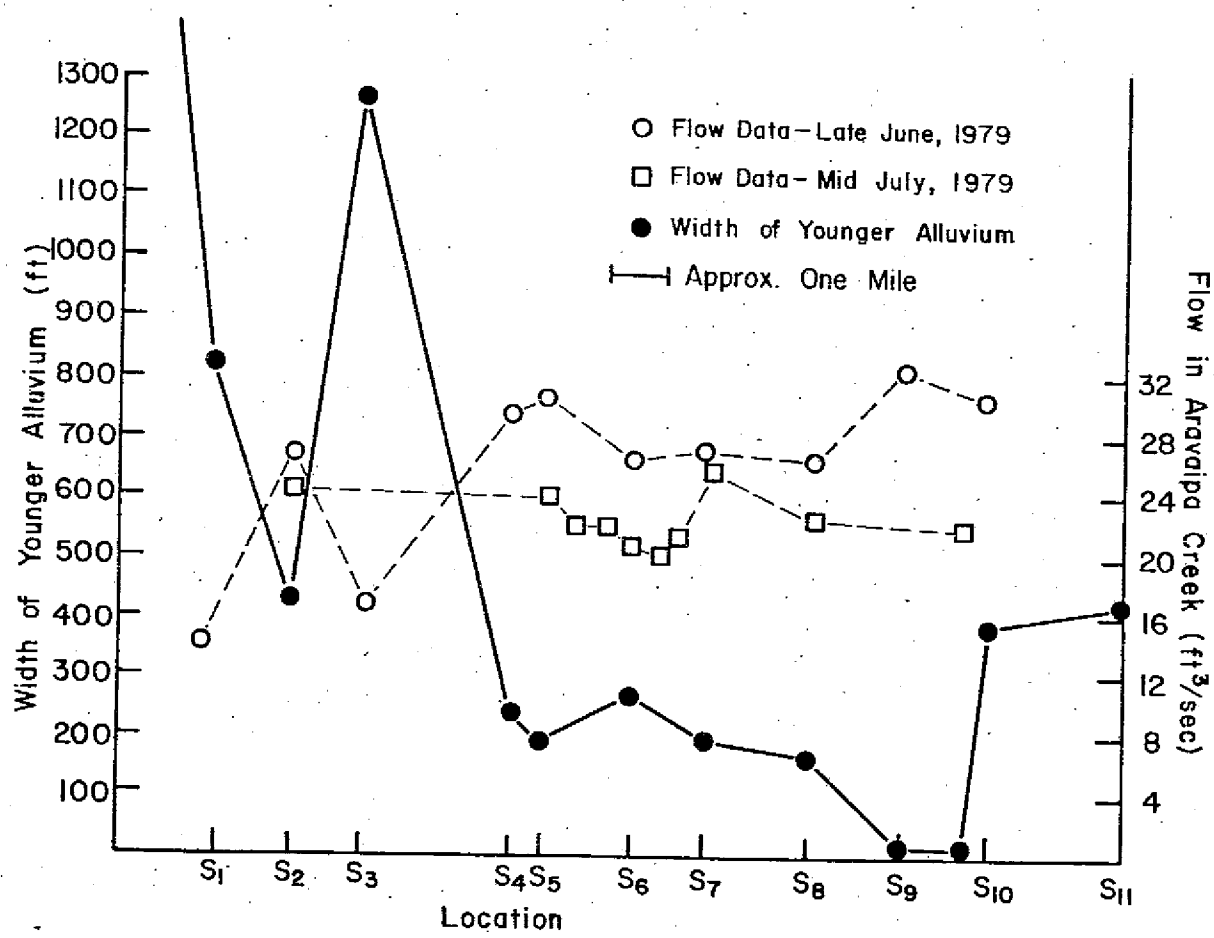


Fig. 15. Flow data for Aravaipa Creek shown as a function of position and width of canyon floor (younger alluvium)

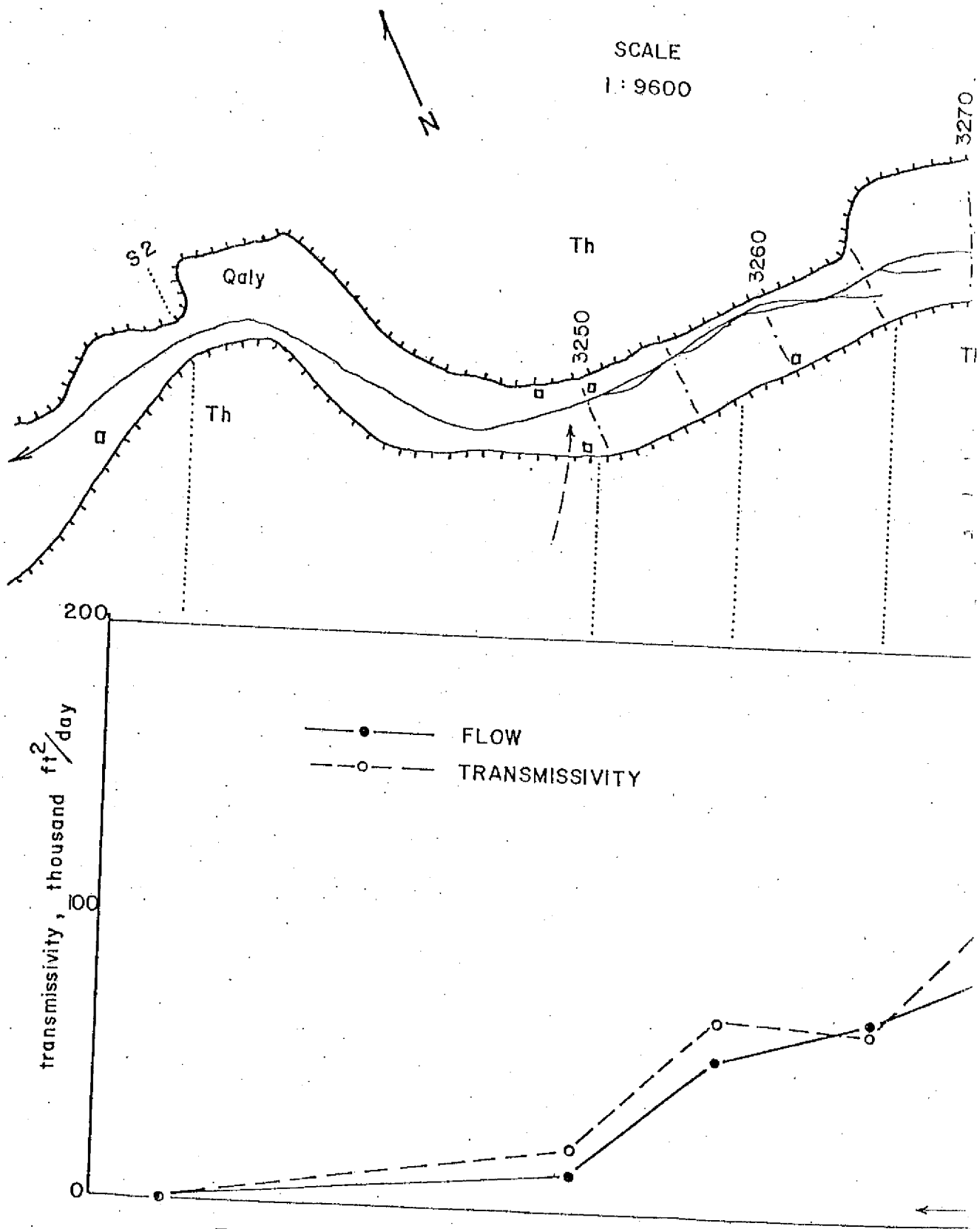
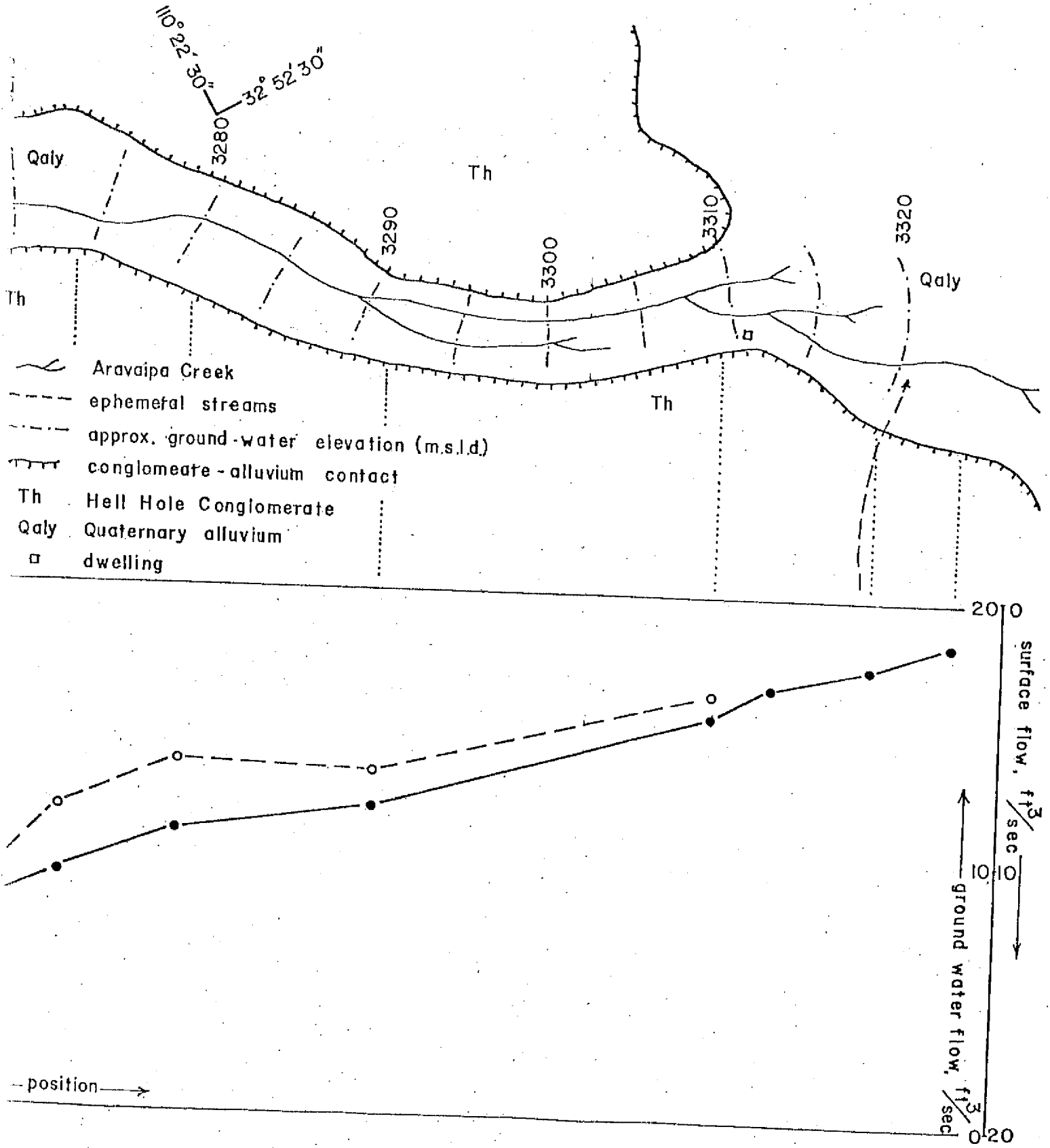


Fig. 16. Emergence of Aravaipa Creek, July 1980


110° 22' 30"
32° 52' 30"
3280
3290
3300
3310
3320
Qaly
Th
Qaly
Th
Th
Aravaipa Creek
ephemeral streams
approx. ground-water elevation (m.s.l.d.)
conglomerate - alluvium contact
Th Hell Hole Conglomerate
Qaly Quaternary alluvium
dwelling
position
surface flow, ft³/sec
ground water flow, ft³/sec
20
10
0
10
20
0

K = hydraulic conductivity [L/t]

A = cross-section area through which ground water flows [L^2]

I = hydraulic gradient [fraction]

Let us assume that all ground water flows toward the canyon entrance in the younger alluvium and assign to this aquifer a constant K and also that flow from the mountain fronts adds water to this conducting layer all the way from the southern extent of the drainage to the canyon, as is suggested by the water-table map of Figure 12.

Far upgradient from the canyon to the south near Eureka Ranch, ground-water flow is least due to the small catchment area upgradient from this point. In this area it was seen that water levels stood below the younger alluvium (conducting layer) and therefore A in our example would equal zero. As our observation proceeds down the valley, water is added to the flow from the mountains and the saturated thickness of the younger alluvium increases from zero, meaning a positive A and a positive Q. More and more water is added to the conducting layer until near the canyon entrance the saturated thickness of the conducting layer is equal to its total thickness. Now, given constant K and I values, the ground-water discharge Q is at a maximum. This situation is approached between the town of Klondyke and the entrance to Aravaipa Canyon. Quite abruptly in our example the cross-sectional area of flow, A, is decreased markedly and Q must also then decrease if K and I are constant. The difference between the maximum Q attained when A was maximum and the new lower Q must emerge onto the surface as stream flow. (If I increased

at the point where A decreased, it would be possible to avoid surface flow, but in the Aravaipa case the Galiuro Mountains make this impossible.

Flow measurements of Aravaipa Creek were taken throughout the perennial flow stretch to try to identify the relationships between streamflow and the different rock units with which the stream comes in contact. Flow measurements were taken with a Price-type pygmy current meter on loan from the Water Resources Research Center, The University of Arizona. A minimum of 15 velocity measurements were taken at each discharge measurement location. Figure 15 presents these measurements as a function of time and position and also shows an indication of the canyon floor width at the particular locations.

It was recognized early on that surface flow was negatively correlated with the width of the relatively flat, younger alluvium between the canyon walls. For example, at the first measuring point, S1, just upstream from the historical "headwaters" (Fig 8), the flow measured 14.6 cfs on the first pass through the canyon. At the second measuring point, S2, the flow measured 27.41 cfs, which was 81 percent of the maximum recorded discharge for that pass down the canyon Downstrea, only about one mile, after no consumed diversion, the flow was only 17.6 cfs. The reason for the observed fluctuations is the interaction between ground- and surface-water flows. At the narrowest point in the canyon, the stream occupies nearly the entire width of the canyon of approximately 25 feet. It was at this location that the greatest flow measurement of the first pass was made.

Because of the magnitude of the observed fluctuations, it is difficult to distinguish inputs into the stream that are on a smaller scale.

Two important characterizations can be stated from the general trend of the data presented in Figure 15:

1. Measurements at S2 represent ground-water contributions only. This component was measured to be 81 percent of the maximum flow observed for the earliest data set. This suggests that contributions from springs and tributaries in the Hell Hole Conglomerate and Galiuro Mountains are about 20 percent of the total flow for periods of similar runoff and ground-water stage.

2. The maximum flow of Aravaipa Creek, except possibly during times of heavy runoff, occurs near the center of the canyon between the Hell Hole to just downstream from Cave Canyon.

The transmissivity, T, of an aquifer is defined by the following equation:

$$T = Kb \tag{2}$$

where T = transmissivity $[L^2/t)$

b = aquifer thickness $[L]$

By substituting this relationship into equation (1) (Darcy's law), the latter becomes:

$$Q = TwI \tag{3}$$

where w = aquifer width.

A series of measurements that defined three of the four variables in equation (3) were obtained during the summer of 1980. The remaining unknown was transmissivity.

All measurements taken during the course of this study suggest that the discharge of Aravaipa Creek increases continuously from its emergence to the vicinity of S2 (Figs. 15 and 16). Beginning in this area stream discharge begins to fluctuate inversely as a function of canyon width. This suggests that ground-water flow through the sediments at S2 is less than at any point upstream and probably is as small here as anywhere in the canyon. Based on these data, and for the purposes of this investigation, it was assumed that the surface flow at S2 equaled the total ground-water runoff from Aravaipa Valley. In other words, there is no ground-water flow at this point and no contributions or losses between the canyon entrance and S2. Therefore, upstream from S2 the surface flow plus ground-water flow must equal the stream flow at S2 (Fig. 16). By measuring stream flow at S2 and various locations upstream, the ground-water flow, Q, was derived as a function of position.

The ground-water gradient, I, was measured by surveying with a transit and a stadia rod attached to a driven well point in which depth to water was measured.

The width of the flow path, w (equal to canyon width), was measured by surveying in several locations and by measurements on aerial photographs where transects were not run. Agreement between the two methods was good where checked.

Figure 16 is a map and summary of the quantities measured and listed in Table 3 plus the resulting transmissivity values calculated from Darcy's law. It is apparent from these data that Aravaipa Creek's emergence to its maximum flow during July 1980 occurred gradually due to a gradual reduction in the transmissivity of the canyon alluvium. The most

Table 3. Transmissivity of Aravaipa Canyon sediments

Location	w (ft)	I	Q, cfs Surface Water	Q, cfs Ground Water	T (ft^2/day)
S2	300	0.01	19.88	0[a]	0[a]
A	560	0.01	18.7	1.18	18,205
B	680	0.01	14.61	5.27	66,960
C	960	0.01	13	6.88	61,920
D	670	0.01	11.32	8.56	110,386
E	679	0.01	9.48	10.40	134,113
F	800	0.01	8.14	11.74	126,846
G	800	0.01	4.5	15.38	166.104
- - - - - - - - - - - - - - Entrance of Canyon - - - - - - - - - - - - - -					
H		0.01	3.5		
I		0.01	2.86		
J		0.01	1.17		

a. Assumed

likely explanation of this reduction is the shallowing of the younger alluvium. There is no surface evidence of a change in alluvial makeup that might account for a lowering of the hydraulic conductivity of the alluvium.

If the thickness of the younger alluvium is assumed initially to be that found in Aravaipa Valley (100-130 ft), the average conductivity of these sediments may be as high as 1,300 ft/day. This conductivity is not unreasonable in light of the particle size distribution of the younger alluvium and its lack of induration. (For examples, see Davis and DeWiest, 1966, p. 164).

The assumption of no underflow at the narrowing of the canyon near S2 renders the calculated transmissivities minimum values. The sensitivity of calculated transmissivity values to the amount of unrecorded underflow at S2 varies with position. Obviously, the transmissivity at S2 will increase from zero to some positive value; however, near the mouth of the canyon where transmissivity values are on the order of 150,000 ft^2/day the percentage change is not as great. The calculated hydraulic conductivity of 1,300 ft/day is therefore expected to be reasonable regardless of the accuracy of this simplification.

If Aravaipa Creek derives its base flow from discharge from the Hell Hole Conglomerate near the entrance of the canyon and not from Aravaipa Valley ground-water runoff, the results of the above analysis are wrong. The flow data just presented do not support such an explanation for the bulk of Aravaipa Creek's base flow. However, contributions probably do occur, and ignoring these leads to overestimating the ground-water flow and transmissivity near the canyon entrance.

Evapostranspiration loss upstream from S2 may be as high as 1 cfs based on repeated flow measurements at different times of the day. This loss would tend to counteract contributions from the Hell Hole Conglomerate. Its effect alone would lead to an underestimation of transmissivity for the aquifer near the canyon mouth.

The cross-sectional shape of Aravaipa Canyon beneath the alluvial cover is probably highly variable. The above analysis assumes a rectangular aquifer as wide as the canyon at the present land surface. In most places this would be a maximum possible width. Use of these values leads to minimizing the calculated aquifer transmissivity.

The importance of the above conclusions lies in the significance of this particular boundary in any attempt at impact prediction. The limits of analysis should extend to S2 and not stop at the entrance of Aravaipa Canyon. If a numerical scheme is used, the mesh should extend into the canyon to S2 with appropriately decreasing transmissivity values. The boundary condition at S2 might be a dependent variable flux-type boundary, the flux in this case being the quantity of major interest, i.e., the base flow of Aravaipa Creek.

Hydrologic Cycle in the Aravaipa Watershed

An attempt to quantify components of the hydrologic cycle in the Aravaipa watershed has been conducted with previously published data supplemented by measurements and interviews conducted during the course of this study. The simplified equation that is used is:

Rainfall = Evapotranspiration + Stream Discharge + Pumpage

Ground-water levels were assumed to be constant on an annual basis.

Rainfall

Rainfall in the Aravaipa watershed ranges from near 20 inches per year in the Galiuro and Santa Teresa Mountains to 14.1 inches per year at the Klondyke rain gage (National Oceanic and Atmospheric Administration, 1952-1977). Information on the distribution of this rainfall over the area of interest is presented in Figure 17 and was obtained from a map by the University of Arizona, Department of Geology, Arizona Agriculture Experiment Stations, and Institute of Atmospheric Physics, 1965). From calculations based on this map the estimated average total volume of precipitation on the watershed is 480,000 acre-feet/year. Calculations and

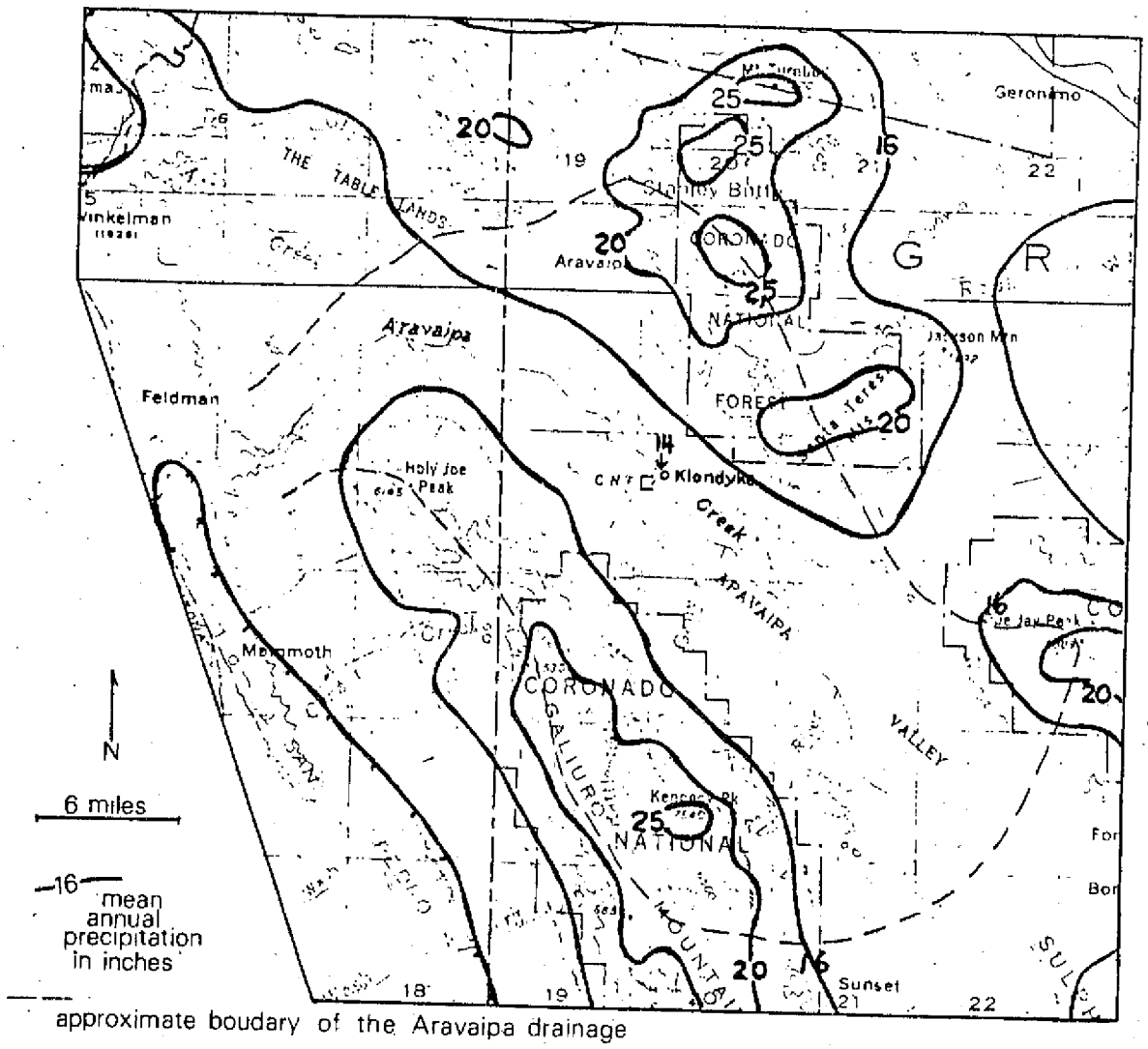


Fig. 17. Mean annual rainfall, Aravaipa area. -- Adapted from University of Arizona, Department of Geology, and others (1965)

and data are presented in Appendix B. Monthly distribution of precipitation for Klondyke and temperature for Aravaipa Canyon appear in Figure 18.

Evapotranspiration

For the purposes of this study, water losses by evapotranspiration were divided into several distinguishable factors. The largest component is the loss of water that never reaches the water table but is evaporated or transpired soon after a rain. This component was not dealt with directly and is assumed to account for the rainfall not accounted for by the other components. Another evaportanspiration mechanism that is not dealt with explicity is that of losses due to phreatophyte growth in the lowlands of Aravaipa Valley where no surface water exists but where the water table may be shallow. Inclusion of this component would have the effect of increasing the recharge volume estimated by the process outlined over the following pages. The component calculated explicitly is evapotranspiration by surface water and dense phreatophyte growth within Aravaipa Canyon.

A method of estimating the potential evapotranspiration (P.E.T.) that requires only mean monthly temperatures and the area's latitude was developed by Thornthwaite (1948). This method has shown high results as compared to other methods but was considered appropriate due to Aravaipa Canyon's very shallow water table and near complete vegetative cover (Eagleman, 1966). Monthly potential evapotranspiration values calculated by this method are shown in Table 4.

The P.E.T. by month, in inches of water, is for the area of phreatophyte growth, in this case, the floor of Aravaipa Canyon. An

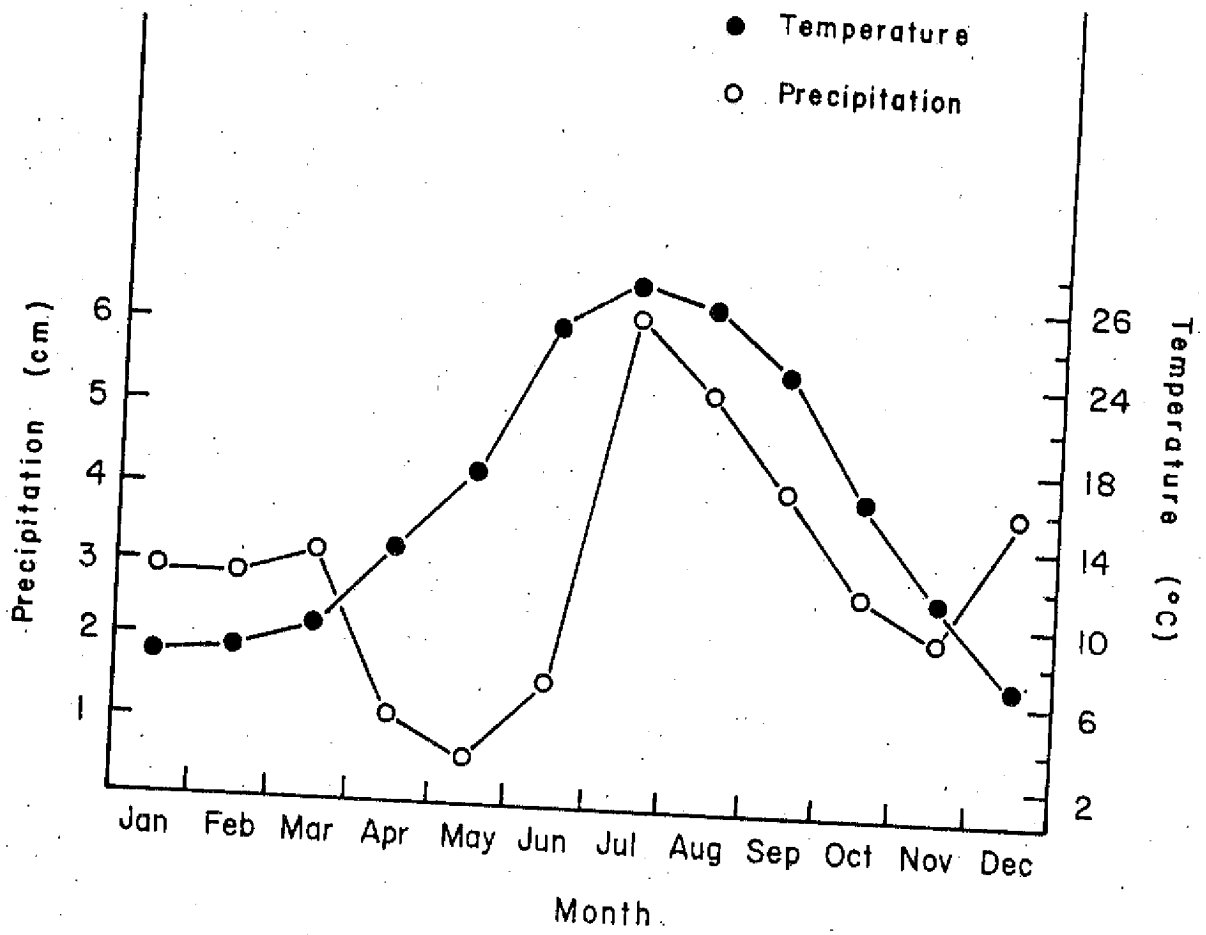


Fig. 18. Monthly distributions of precipitation at Klondyke, Arizona, and temperature in Aravaipa Canyon, Arizona

Table 4. Calculated evapotranspiration

Month	Potential[a] inches	Potential[a] Use in Canyon, acre-feet	Actual (67% Potential)[b] inches	Actual (67% Potential)[b] Use in Canyon, acre-feet
Jan	1.44	107	0.96	72
Feb	1.45	109	0.97	73
Mar	2.05	152	1.37	102
Apr	3.34	109	2.24	133
May	4.87	365	3.26	245
Jun	7.42	556	4.97	373
Jul	8.38	628	5.61	421 = 6.85 cfs
Aug	7.67	575	[c]5.14	385
Sep	5.81	437	3.89	293
Oct	3.78	283	2.53	190
Nov	2.26	169	1.51	113
Dec	1.20	98	0.80	66
Total		3,677		2,466

JE Fuller (1980) estimates 2200 in the canyon (p. 4-6) and 3800 overall

a. Calculated by the Thornthwaite (1948) method.
b. Calculated by Eagleman's (1966) and White's (1932) methods.
c. Calculated from measurements made in August 1979.

estimation of the area of phreatophyte growth in Aravaipa Canyon was obtained by transferring the areas of growth indicated on infrared aerial photographs (available at the Arizona Bureau of Geology and Mineral Technology, Tucson) to topographic maps and then measuring these areas by counting squares on an overlay. The area of phreatophyte growth measured by this method is 1.4 square miles. By multiplying this area by the monthly use in inches, a volume is calculated and

presented in the third column of Table 4. The addition of these monthly P.E.T. volumes equals 3,677 acre-feet of annual P.E.T. in the canyon.

For the month of August 1979, relative humidity data were collected to enable the potential evapotranspiration to be calculated for this month by a method developed by Eagleman (1966). Indications were that the average relative humidity for August 1979 was 62 percent. Based on his method the P.E.T. for August is 7.96 inches, which agrees well with the value of 7.67 inches calculated by Thornthwaite's method (Table 4). Further work by Eagleman indicates that actual evapotranspiration may often be estimated by using 76 percent of P.E.T. This would suggest an actual water use of 6.05 inches for August.

The third method used to estimate evapotranspiration is based on work by White (1932) and uses ground-water level fluctuation data. Two wells in the water-table aquifer of Aravaipa Canyon were monitored at different times during the month of August by a continuously recording float-operated device. Diurnal fluctuations corresponding to times of withdrawal and recovery of water in the sediments created by a wavelike pattern with a period of one day. The slope of this wave for times between 6 p.m. and 4 a.m. is used in the present method to calculate the evapotranspiration (see Appendix B). Calculations based on this method in which a storativity value (0.15) is assumed indicate an evapotranspiration value for August of 4.29.

The average of Eagleman's estimated ET of 6.05 inches and White's estimated ET of 4.29 inches is 67 percent of the P.E.T. calculated by Thornthwaite's formula for August. Considering that most of the evapotranspiration occurs during the hot summer months and actual ET is

expected to be approximately 67 percent of P.E.T. for August, the best estimate available for annual ET is 67 percent of the calculated annual P.E.T., or 2,466 acre-feet. Columns 4 and 5 of Table 4 give the expected monthly ET based on the combined methods as described above. The time distribution of this estimated ET is presented in Figure 19.

Stream Discharge

The U.S. Geological Survey maintains a gaging station on Aravaipa Creek in the west end of Aravaipa Canyon (NW¼NW¼ sec. 9, T. 7 9., R. 17 E.). For the 24-year record available, the mean flow of the creek is equal to 30.1 cfs, or 21,800 acre-feet per year (U.S. Geological Survey, 1954, 1968-1980). Further discussion of stream flow is included under the discussion of stream-flow statistics.

Pumpage

A count of the number of dwellings in the Aravaipa watershed and interviews with some of the residents have enabled an estimation of the total amount of ground water used for human and animal purposes to be made. Volumes based on this work are as follows:

Irrigation	3,000 acre-ft/yr
Domestic	13
Stock	45
Total	3,058 acre-ft/yr

By far the largest use of water in the Aravaipa watershed is for irrigation. The estimation above is for total water pumped and does not include a reduction based on an estimate of the water that returns to the ground-water system after application.

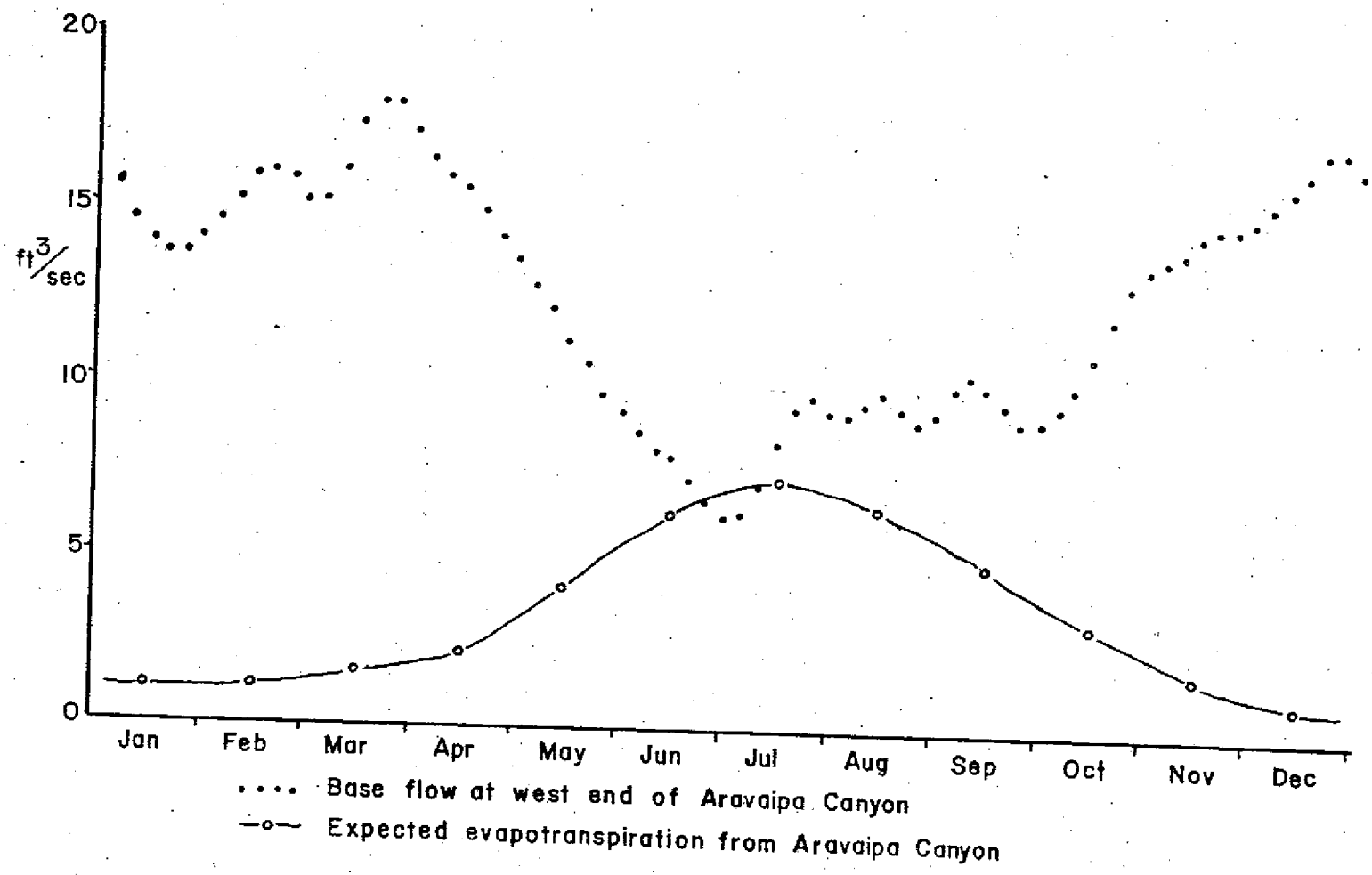


Fig. 19. Base flow of Aravaipa Creek at west end of Aravaipa Canyon and expected evapotranspiration within the canyon

With all of the terms in the hydrologic cycle equation defined, the relative magnitudes of the components can be analyzed. The values have all been rounded to the nearest 100 acre-feet/year. An expanded version of the budget equation is

$$\text{Rainfall} - ET_{direct} = ET_{indirect} + \text{stream discharge} + \text{pumpage}$$

Total rainfall		480,000 acre-ft
$ET_{indirect}$	2,500 acre-ft	
Stream discharge	21,800	
Pumpage	3,100	
Total volume accounted for		27,400
Total volume unaccounted for		452,600 acre-ft
	or	94.3%

The unaccounted-for 94.3 percent of the rainfall is evaporated soon after it falls or is transpired after infiltration into the root zone; 5.7 percent of the watershed's total rainfall has been accounted for by the above analysis. As will be shown, 3.3 percent of this water runs off the land and downstream without infiltration and the other 2.4 percent infiltrates into the ground-water system.

Base Flow and Aquifer Recharge

To estimate the annual aquifer recharge of the alluvium in Aravaipa Valley, an assumption is made that on an annual basis ground-water levels are constant. This assumption is quite acceptable in Aravaipa Valley where water levels in wells show no continual decline as is so common in other parts of the Southwest (Gould and Wilson, 1976). With this

assumption made, what is actually being said is that the aquifer from year to year is in steady state; therefore, recharge must equal discharge.

Discharge from the ground-water reservoir in Aravaipa Valley is equal to the base flow of Aravaipa Creek plus pumpage from the aquifer plus evapotranspiration losses in Aravaipa Canyon and possibly from the shallow water table in Aravaipa Valley. Because the recharge is equal to the discharge, we may determine the recharge by determining Aravaipa Creek's mean base flow and adding to this the pumpage value mentioned earlier. The method of determining the base flow will take into account evapotranspiration in Aravaipa Canyon. Any evapotranspiration occurring from the valley aquifer has not been measured.

On 19 separate days during the course of this study a flow measurement was taken in Aravaipa Creek in the south-central portion of sec. 27, T. 6 S., R. 19 E., near the Defender's guest house (site S2). For the dates occurring before August 3, 1979, flow data are also available from the U.S. Geological Survey's Aravaipa Creek gaging station. These data, along with the differences between the recordings, are given in Table 5. The differences between the recordings are due to changes in streamflow along the 17 miles of canyon separating the two locations; these changes include:

1. Contributions of tributary surface water.
2. Evapotranspiration.
3. Interactions between ground water and surface water.
4. Diversion of surface water for irrigation.
5. Contributions of tributary ground water.

Table 5. Correlation between simultaneous measurements of creek discharge in the summer of 1979, Aravaipa Creek, Arizona

Monthly Precipitation in Canyon [a] (inches)		Discharge			
		Date of Measurement	East End (cfs)	West End [b] (cfs)	Difference (cfs)
Mar	2.06	3/20/79	[c]30	38	- 8
Apr	0.34	4/2	[c]31	40	- 9
		4/23	[c]29	51	-22
May	1.96	5/10	[c]28	42	-14
		6/8	[d]27	21	+ 6
		6/13	[c]26	29	- 3
		6/27	[c]28	24	+ 4
		6/30	[d]27	23	+ 4
July	e	7/16	[d]26	28	- 2
		7/22	[d]25	23	+ 2
		7/23	[d]26	27	- 1
Aug	e	8/3	[d]24	22	+ 2

a. Unpublished data from Schnell and Schnell (1979).

b. Measured by U.S. Geological Survey gage 09473000.

c. Measured by D. Moliter, Bureau of Land Management, Safford, Arizona.

d. Measured by author.

e. Data not available.

The major tributaries between the two measuring locations contribute to Aravaipa Creek flow mostly during runoff events, but small springs sustain this contribution into drier periods. These major tributaries include the large side-canyon creeks such as Turkey Creek, Parsons Canyon, Old Deer Creek, Virgus Canyon, and Horse Camp Canyon plus several springs that emerge along the canyon walls. It can be inferred from the data in Table 5 that tributary contributions were most significant during the early portion of the study when rainfall and therefore surface runoff and tributary spring discharge were at their highest. These are the months for which the gaging station downstream had consistently higher flows than did the measuring point on the east end, S2. As the dry summer progressed the tendency was for the east-end measuring point to have a greater flow than the downstream gaging station. This reversal of the trend seen earlier in the year is assumed to be due to the reduction of tributary surface-water and spring discharge contributions, an increase in the ET rate, and possibly irrigation diversion.

Ground-water runoff from Aravaipa Valley is determined below by neglecting the offsetting factors of tributary contributions and ET losses. In the winter months the side canyons may contribute base flow, whereas in the summer months ET is expected to more than compensate for any contributions. In this way, base flow as measured at the U.S. Geological Survey station at the west end is expected to overestimate ground-water runoff in the winter and underestimate it in the summer.

To estimate base flow, stream gaging data from the U.S. Geological Survey gage were partitioned into runoff and base-flow components. This process was conducted for a total of 10 years of record, including years

of above-, below-, and near-normal precipitation. The mean base flow indicated by this analysis is 11.76 cfs, or 8,500 acre-ft/yr.

Aquifer recharge is equal to base flow plus pumpage and is therefore 8,500 + 3,100 = 11,600 acre-ft/yr. This is 2.4 percent of the watershed's total rainfall, not all of which even drains toward the aquifer.

The time distribution of base flow measured at the U.S. Geological Survey gaging station is represented in Figure 19. Recall that this base flow is expected to overestimate ground-water runoff from Aravaipa Valley in the winter months and underestimate it in the summer months for reasons already mentioned.

8500 ac-ft base flow

The 5.7 percent (27,300 acre-ft/yr) of average annual rainfall that is not immediately lost to evapotranspiration is distributed between runoff and ground-water recharge. Recharge has been calculated to be 2.4 percent (11,600 acre-ft/yr) of the average annual rainfall, indicating that 3.3 percent (15,700 acre-ft/yr) of the average annual rainfall leaves the watershed as storm runoff.

15,700 ac-ft runoff

Totals 21,200 ac-ft of streamflow (cf to p. 61 where GWR = 21,800 ac-ft)

Total surface runoff values of 2.0 and 2.7 percent have been measured by Renard (1970) and Resnick (1979, personal commun.), respectively. The basins they studied were smaller, more densely instrumented watersheds of southern Arizona. No water was thought to have infiltrated to the water table in these basins. Renard (1970, p. 7) also noted that "water yield (runoff) on both a storm and on an annual basis is highly correlated negatively with drainage area." This is attributed to stream-channel infiltration between the precipitation location and the runoff measuring point. This correlation, along with Aravaipa's tenfold greater drainage area, suggests that 3.3 percent surface runoff may be

[Analysis here uses 10 yrs of record. GWR on p. 61 is entire 24 yrs of USGS record.]

quite a high value for a watershed of Aravaipa's size. The relatively impermeable rocks along much of the watershed's margin, the high mean relief afforded by the mountains, and the narrowness of Aravaipa Valley may be factors contributing to enhance runoff.

Water Use

At the present time, surface water is diverted from Aravaipa Creek for irrigation of alfalfa and other cattle feeds on the east end and the same, plus garden crops and orchards, on the west end. At any one time these diversions are estimated to total from zero to 10 cfs, depending on the season, the rainfall, the condition of the diversion works and canals, and the available streamflow. During the course of this study many of these works were in serious need of repair due to the damaging floods of December 1978.

The U.S. Geological Survey gaging station data show several months in 1920-1921 in which no flow reached the stations site (U.S. Geological Survey, 1954). This is attributed to larger irrigation diversions during those years, plus possibly the fact that at that time the station was further downstream.

Ground-water use in the Aravaipa drainage is estimated to be 3,000 acre-ft/yr for irrigation, 13 acre-ft/yr for domestic purposes, and 45 acre-ft/yr for stock water (see section on hydrologic cycle). The history of the development of ground water in Aravaipa Valley is sketchy but development is presumed to have been larger in the past. In 1948 a flotation ore concentrator was constructed in the valley that must have used ground water for its water source, and there is evidence from

discussions that suggest that the economic benefits of irrigating stock feed are decreasing due to electrical costs (Lackner, 1979, personal commun., and Claridge, 1979, personal commun.). The actual population of Aravaipa Valley has also decreased (Tapia and Tapia, 1979, personal commun.). These all indirectly suggest that water consumption in the area has decreased from what it has been in the past. The main threat to perennial flow in Aravaipa Creek is a possible increase in ground-water withdrawals from the aquifer that provides the creek's water in times of no runoff.

Streamflow Statistics

Historical streamflow data for Aravaipa Creek were analyzed in an attempt to recognize patterns that might not be attributable to natural sources. Data for Aravaipa Creek are available for the years 1920-1921, 1932-1942 (U.S. Geological Survey, 1954) and 1967 to the present (U.S. Geological Survey, 1968-1980) from a U.S. Geological Survey continuously recording gaging station 09473000 in the west end of Aravaipa Canyon (NW¼NW¼ sec. 9, T. 7 S., R. 17 E.). For the 1932-1942 data group the gage was downstream 0.3 mile in SE¼NE¼ sec. 8, T. 7 S., R. 17 E.

Human activities that would likely affect streamflow are ground-water withdrawals from the Aravaipa Valley and Aravaipa Canyon aquifer and direct surface-water diversion from the creek. The two major uses of ground water in the past were crop irrigation and from 1948 until possibly 1957 industrial supply for mining activities. Diverted surface-water use is restricted to irrigation of lands adjacent to the perennial stretch of Aravaipa Creek.

Figure 20 is a plot of Aravaipa Creek's mean discharge as it has changed through the years for which data are available. The equation describing the data points is

$$\overline{Q}_i = \frac{1}{n+1} \sum_{i=1}^{n} Q_i$$

where Q_i = mean flow of year i (from U.S.Geological Survey data)

n = number of years before i for which data are available

$\overline{Q}_i$ = mean flow for year i and all preceding years for which data are available.

The variation of the plot in early years is due to the size of n, which is small. As more and more data are collected the magnitude of these variations diminish until at a very large n they should nearly disappear. This is due to the diminishing effect of a single value as the number of values becomes large. Given no external influence and no change in natural stream influencing factors, this plot will, when n becomes large, approach a straight horizontal line defining the "true mean" of the discharge of the creek.

Figure 20 can be used as a tool to recognize variation due to influences that were not present during the years for which the early data were collected. For instance, if ground-water withdrawals, beginning in 1980, are to affect streamflow, then the $\overline{Q}_i$s for i = >1980 will approach a new, lower mean discharge.

Inclusive means such as the quantity $\overline{Q}_i$ are more useful in recognizing changes than simply a plot of Q_i because natural variability

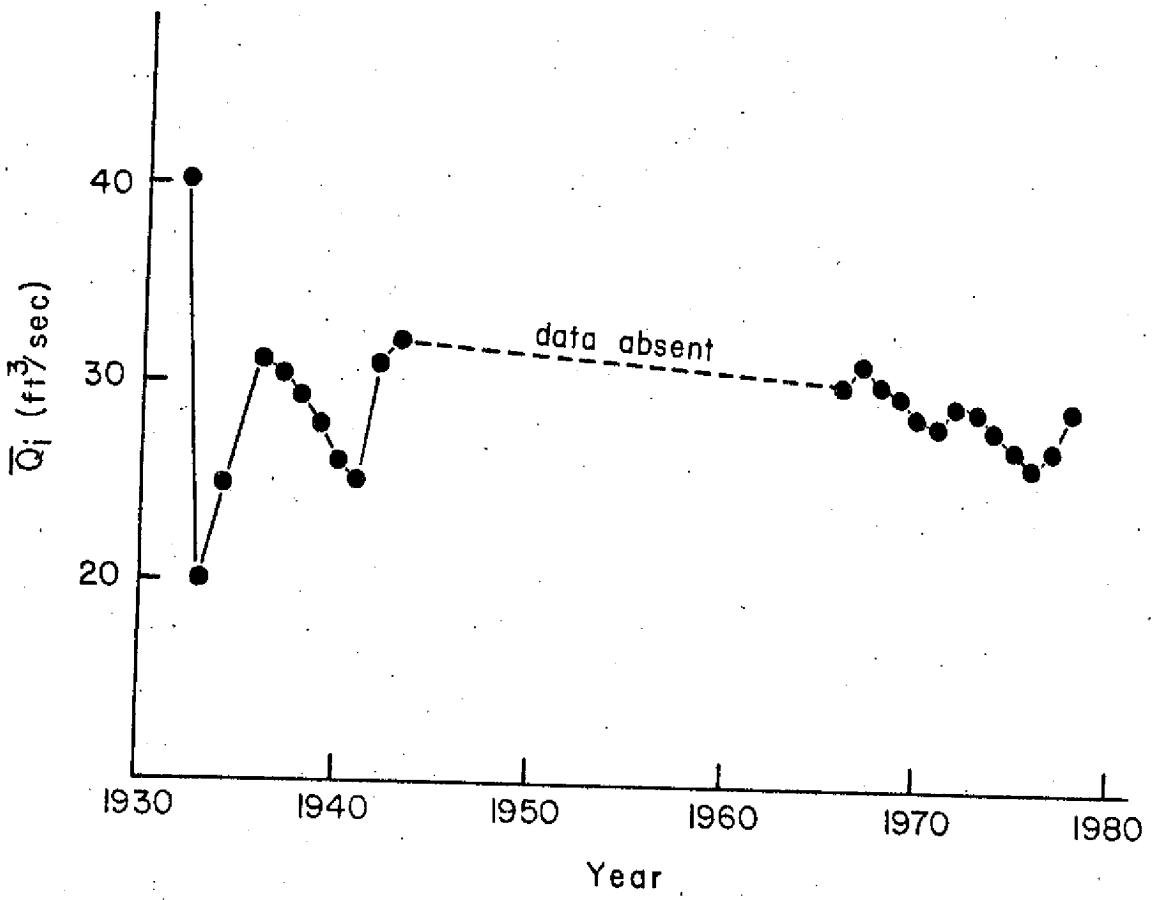


Fig. 20. Mean discharge for Aravaipa Creek from 1932 to 1979. -- Data from U.S. Geological Survey (1954, 1968-1980)

is somewhat damped out and a smoother, more easily interpretable curve prevails.

For Aravaipa Creek it must be noted that only 24 years of data are available for the estimation of all quantities mentioned and that in these years human influences were both present and variable. Nevertheless, a continuing decline in $\overline{Q}_i$ must signal one of the following: (1) increasing human use of the ground or surface water, (2) changes in climate, or (3) natural changes in the ground- or surface-water flow regimens.

Because flow data for Aravaipa Creek are contained mostly in two time spans, 1932-1942 and 1967-1979, these data groups were analyzed separately to make possible a statistical "test" to determine the probability that the observed changes are due to external influences. Table 6 contains the statistical information necessary for the analyses.

Table 6. Discharge statistics for Aravaipa Creek. -- Data from U.S. Geological Survey (1954, 1968-1980)

Data Grouping		Mean Discharge, cfs	Variance
1	Pooled data	30.29	520.15
2	1932-1942	32.07	372.60
3	1967-1979	28.78	650.00
4	1932-1942[a]	27.33	174.92
5	1967-1979[a]	22.77	195.71

a. The single largest value from the data set is not included.

The test conducted is called a "hypothesis test" for which a full explanation can be found in Haan (1977). The question to be answered is:

What is the probability that the observed difference in the means is due to natural variation? Between data groups 2 and 3 the answer is 37 percent. Therefore, given the observed variance of the data, there is a 37 percent chance that a difference of ± 3.29 cfs would occur. This is equal to an 18.5 percent chance that the observed difference of - 3.29 cfs would be observed.

Extreme values of 79.5 cfs and 101 cfs occur in the earlier and recent data groups, respectively. Results of calculating the means and variances of the data groups without including these values are represented in groups 4 and 5 of Table 6. The hypothesis test indicates a probability of 14.5 percent that the observed difference of -4.56 cfs (between groups 4 and 5) would occur.

Although the data of Table 6 indicate a reduction of the mean discharge since the 1930s, there exists considerable probability (18.5 or 14.5 percent) that natural variation and not increasing consumption accounts for the reduction.

Figure 21 is a plot of the mean monthly discharges for the two data groups 1932-1942 and 1967-1979. As can be seen, the greater mean for the earlier set is due mainly to differences in the months of December, January, July, and August. Almost no differences are recorded for the 3 months of lowest flow and lowest rainfall, April, May, and June. June, in particular, is a month of heavy irrigation in Aravaipa Valley (Proctor, 1979, personal commun.). Seeing that it is also a month of low rainfall (0.06 inches), the data may suggest that irrigation practices have not changed significantly over the period for which data exist. It would be

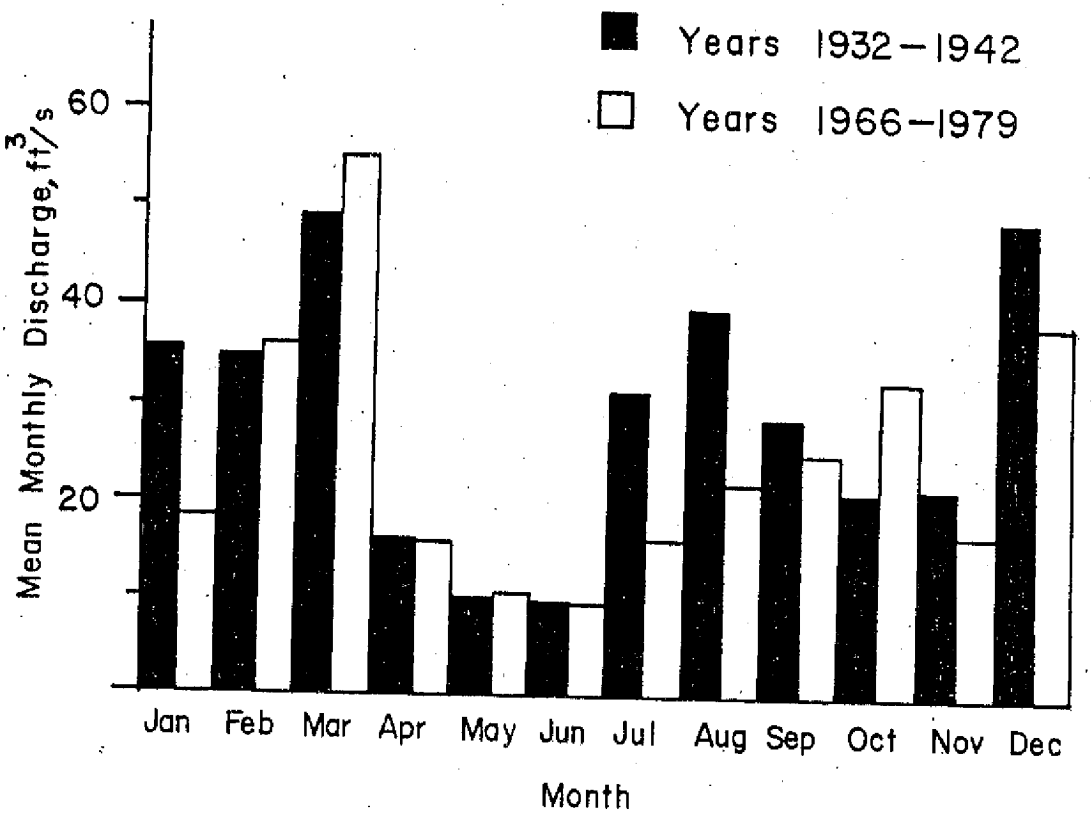


Fig. 21. Comparison of mean monthly discharges from years 1932-1942 and 1967-1979

during these low-flow months that the stream would be most sensitive to such changes. Base flow in Aravaipa Creek may have a lagged response to ground-water withdrawals in Aravaipa Valley. The data in Figure 21 for July and August might be explained in this manner. It would be difficult to identify this affect from the data in Figure 21 because of the highly variable, large runoff component of the late summer rainy season.

Water Quality

Skipped the water quality section

A survey of the ground-water quality of Aravaipa Basin was conducted to establish baseline data on the water upgradient from the perennial reach of Aravaipa Creek. A total of 12 sampling locations were chosen, 7 from wells in Aravaipa Valley, 3 from springs emerging from mountain fronts, and 2 from Aravaipa Creek, as indicated on Figure 8.

Each sample collected for routine analysis consisted of 500 ml of water. All samples were filtered through a 0.4 μm membrane filter to facilitate comparison of the dissolved constituents of the ground and surface waters. The higher suspended loads expected in surface-water samples would make comparison of total chemicals less informative in regards to tracing the source of Aravaipa Creek water. The analyses presented in Table 7 were performed by the Soils, Water, and Plant Tissue Testing Laboratory, Department of Soils, Water, and Engineering, The University of Arizona. The data are grouped according to source and are presented diagrammatically in Figures 22-24.

Samples for mercury analysis as recommended by Sommerfeld (1977) were collected from the 12 sites. Approximately 200 ml of water were collected and filtered; then to each sample was added 1 ml $K_2Cr_2O_7$

Table 7. Chemical analyses. -- in mg/l

Sample Location	Place Name or Owner	Date 1979	Source	mmho/ cm	TDS (ppm)	pH Field (Lab)	Field Temp. °C	Ca
SW¼SE¼ sec. 7, T7S, R20E	Haby	7/21	windmill	0.24	257	7.2 (7.5)	22	31
NE¼SW¼ sec. 25, T6S, R19E	Proctor house	7/21	domestic well	0.22	264	8.0 (8.4)	23	8
	Peyote Church of God	7/21	irrigation well	0.27	343	7.3 (7.7)	22.5	38
SE¼SW¼ sec. 36, T6S, R19E	Proctor	7/21	irrigation well	0.28	259	7.1 (7.8)	18	46
SW¼ sec. 14, T9S, R19E	Eureka Ranch	7/23	domestic well	0.18	211	7.9 (8.0)		19
SE¼NE¼ sec. 35, T6S, R19E	Cobra Ranch	7/21	domestic well	0.41	485	7.0 (7.6)	21	88
SW¼ sec. 27, T8S, R21E	Claridge	7/21	stock well	0.25	297	7.1 (7.7)	23 23	40 40
SW¼ sec. 27, T7S, R19E	Lackner	7/21	mountain-front spring	0.33	416	7.1 (7.7)	24	56
SE¼ sec. 1, T6S, R19E	Stowe Spring	7/22	mountain-front spring	0.37	415	6.9 (7.7)	21	69
SW¼NE¼ sec. 19, T6S, R19E	Turkey Creek seep	7/22	conglomerate bedding-plane seep	0.28	341	>8.0 (8.8)	22	5
NE¼SE¼ sec. 35, T6S, R19E	Aravaipa Creek, first crossing	7/22	surface stream	0.30	304	7.8 (7.6)	22	54
SE¼SW½, sec. 27, T6S, R19E	Aravaipa Creek, near guest house	7/23	surface stream	0.32	366	7.8	22	59

Analyses by Soils, Water and Plant Tissue Testing Laboratory, Department of

a. Analyzed as nitrate. b. Sodium absorption ratio = (meq Na)/((meqCa +

Field Temp. °C	Ca	Mg	Na	Cl	SO_4	HCO_3	CO_3	F^-	N[a]	Pb	SiO_4	SAR[b]	Hardness	% Error[c] in Analysis
22	31	8	24	16.8	11	166	0	0.41	2.14	0.022	28.8	0.99	6.5	3.42
23	8	1	69	17	11	151	7.2	1.72	0.09	0.022	19.6	6.12	1.41	0.29
22.5	38	11	44	16.8	11	225	0	0.55	2.43	0.036	39.2	1.62	8.2	4.08
18	46	8	18	16	30	107	0	0.42	3.02	0.033	31.6	0.64	8.64	12.65
	19	7	28	12	2	142	1.2	0.5	0.95	0.022	34.4	1.4	4.5	0.90
21	88	14	22	16	42	278	0	1.05	1.18	0.033	25.0	0.57	16.22	4.95
23	40	9	28	15	5	200	0	0.45	1.45	0.033	30.8	1.04	8.09	0.64
23	40	9	28	15	5	200	0	0.45	1.45	0.033	30.8	1.04	8.01	0.64
24	56	17	27	14.4	2	300	0	0.3	0.47	0.036	50.4	0.81	12.3	0.19
21	69	16	20	16	42	225	0	1.6	0.04	0.036	27.2	0.56	14.0	4.94
22	5	0.6	98	22	3	200	12.0	1.17	1.87	0.022	44.0	11.0	0.87	1.22
22	54	11	19	16.4	33	171	0	0.42	2.95	0.033	32.8	0.62	10.5	4.85
22	59	11	22	16	53	205	0	0.58	3.92	0.033	34.0	0.69	11.3	2.04

artment of Soils, Water and Engineering, College of Agriculture, The University of Arizona
((meqCa + meq Mg)/2)$^{\frac{1}{2}}$. c. % error in analysis = $\left(\frac{\Sigma cation - \Sigma anion}{\Sigma cation + \Sigma anion}\right)100$; all units meq.

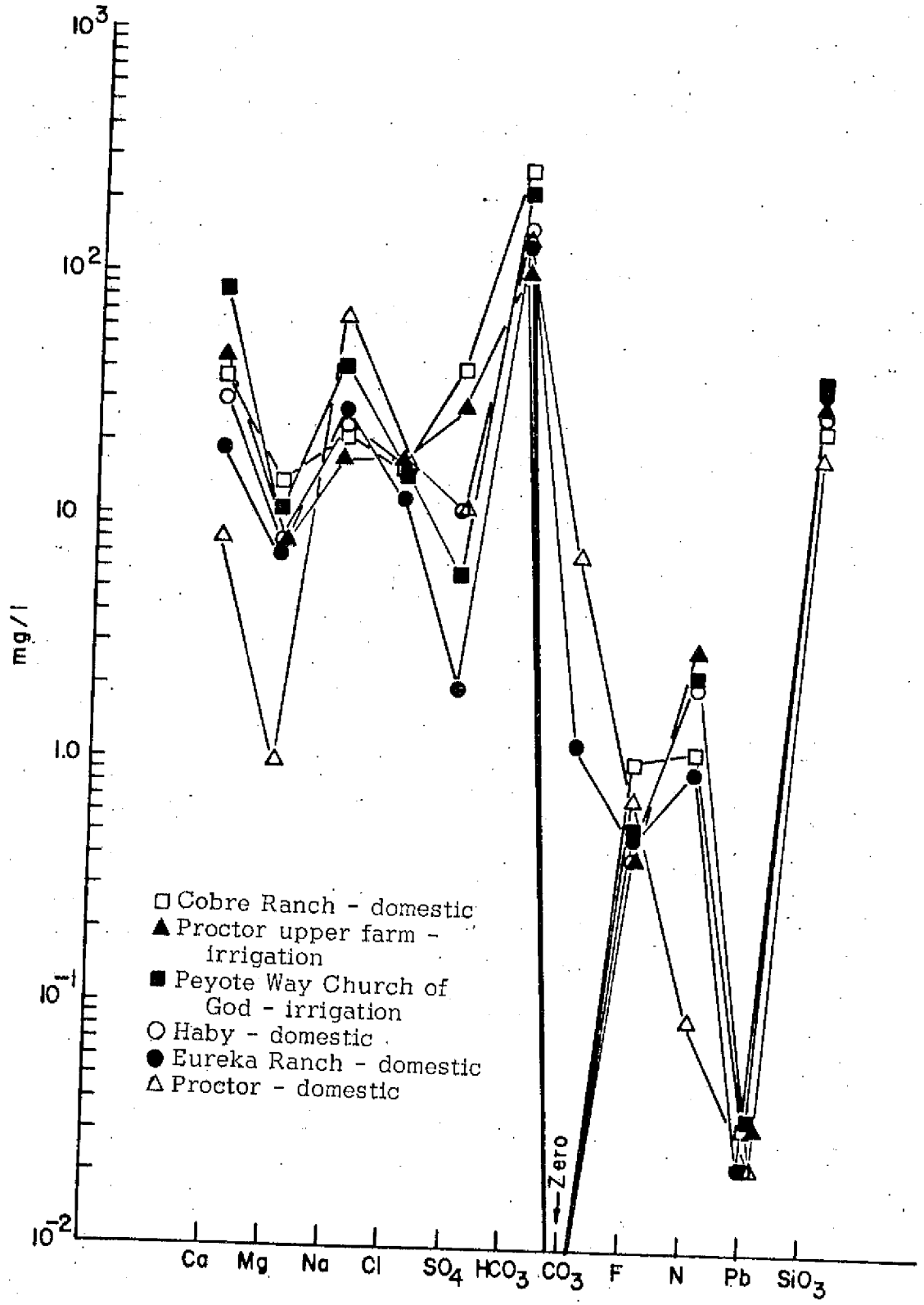


Fig. 22. Ground-water chemical data

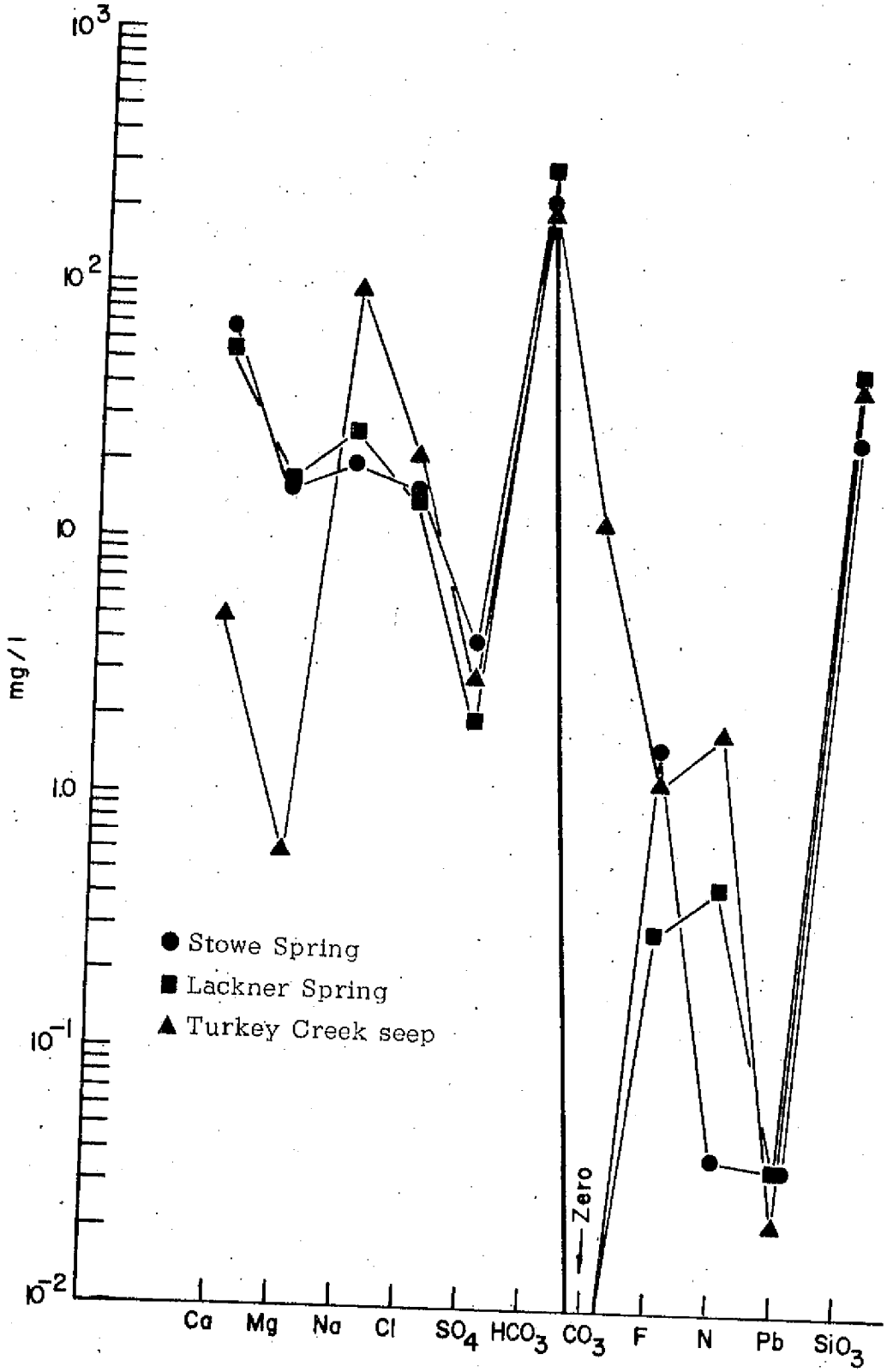


Fig. 23. Spring-water chemical data

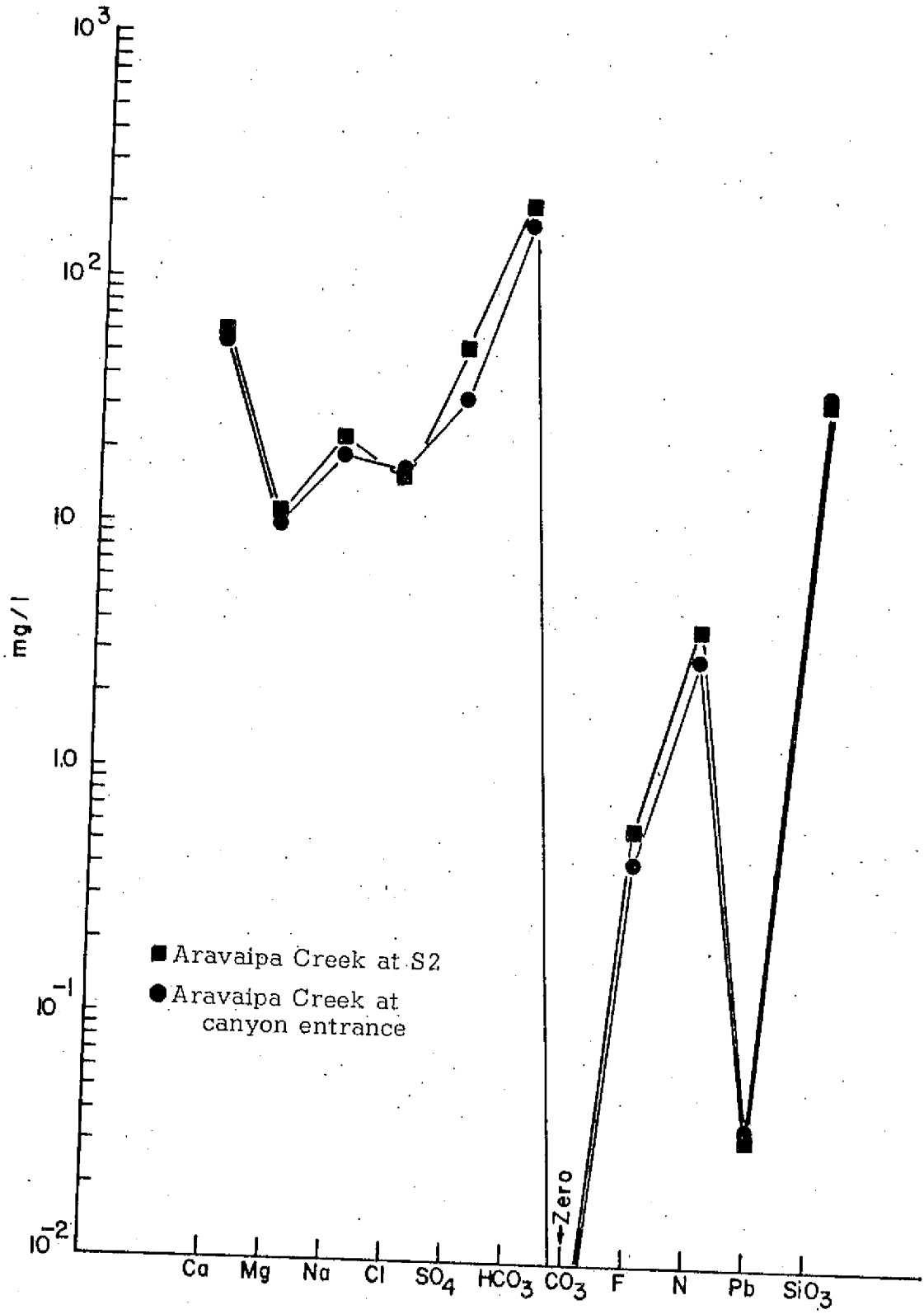


Fig. 24. Surface-water chemical data

and 10 ml HNO_3 for preservation of the dissolved mercury. Analyses were conducted by the atomic absorption technique at The University of Arizona Analytical Center, Department of Chemistry. These analyses indicated that all samples contained less than 2 ppb Hg. This level is the lower limit of the technique's reliability (Auble, 1979, personal commun.).

The results of the mercury analyses completed during this study suggest that the high mean of 5.3 ppb for mercury found by Sommerfeld (1977) is not attributable to a source within the ground-water basin of Aravaipa Valley or in any of the natural springs sampled. Sommerfeld mentioned the possibility of a single, very high value of 75 ppb being an "analytical artifact"; the rest of his mercury analyses showed less than 5 ppb Hg. Furthermore the data suggest that mercury levels in the water used for domestic purposes in Aravaipa Valley do not exceed maximum permissible levels for these types of water supplies (U.S. Environmental Protection Agency, 1975).

In general, the dissolved ion data indicate that all of the sources sampled belong to relatively similar hydrochemical facies (Bentley, 1979, personal commun.). The possible exceptions to this pattern are the samples from the Proctor house well, Eureka Ranch well, and Turkey Creek seep. These samples showed the highest pH values, low Ca and Mg, and high Na and CO_3 concentrations. These differences may suggest a longer travel path in contact with material capable of ion exchange. The findings for these samples are well explained by the local lithology of the sample sites: a lake-bed deposit, older alluvium, and well-indurated conglomerate, respectively.

Most analyzed samples indicate that the ground water is both stored and transmitted in a rock aquifer relatively low in clays and of relatively high permeability. The samples within this group are all from wells placed in the young flood-plain deposits.

It is noted that all ground-water samples from north of the confluence of Stowe Gulch and Aravaipa Creek contain fluoride concentrations greater than 1 mg/l. These sources include Stowe Spring (1.6 mg/l), Proctor house well (1.72 mg/l), Cobra Ranch well (1.05 mg/l), and Turkey Creek seep (1.17 mg/l). The Committee of Water Quality Criteria (1972) set the maximum desired fluoride concentration at 1.5 mg/l for temperatures that can be expected in Aravaipa Valley. A possible detrimental effect of drinking water having the concentrations found in these samples is mottling of children's teeth (Smith, Cammack, and Foster, 1936).

CONCLUSIONS

The Aravaipa Creek watershed comprises some 541 square miles of land in the Basin and Range province in southeastern Arizona about 55 miles northeast of Tucson in Pinal and Graham Counties. It consists of a ground-water-filled basin, surrounded by mountains, that drains to the northwest through Aravaipa Canyon in which lies perennial Aravaipa Creek.

The basin is of a graben structure filled with up to 8,000 feet of Tertiary volcanics and later basin-fill deposits. The basin is separated from Sulphur Springs Valley to the south by a basement rock high, and impediment of the interbasin ground-water flow occurs at this location.

Ground-water flow within the basin is from the mountains to the center of the valley, then downgradient in the younger alluvium of the valley floor and into Aravaipa Canyon. At the canyon entrance much of the ground-water flow is forced to the surface by a restriction in the cross-sectional area of the highly permeable, modern stream channel alluvium. The alluvium of the canyon is, however, more than 100 feet thick in places. It is from this area of restricted flow path that Aravaipa Creek begins its perennial existence; it retains its perennial nature for approximately 17 miles downstream through the canyon, which it has eroded. At least 80 percent of Aravaipa Creek's discharge was contributed by effluent ground-water flow from the Aravaipa Valley aquifer during a time of no runoff during June 1979.

Historical ground-water levels show a positive but not strong correlation to base flow in Aravaipa Creek. This suggests important roles for evapotranspiration, diversion, and pumpage in determining base flow.

The water-table aquifer system of Aravaipa Valley is composed of the highly permeable younger alluvium along the stream's flood plain and the older alluvium underlying and surrounding the edges of the flood-plain deposits. The yield of wells in Aravaipa Valley is directly related to the saturated thickness of the younger alluvium penetrated. Wells placed in areas where this saturated thickness is 100 feet or more yield up to 1,200 gpm of water. Wells not placed in the younger alluvium yield a maximum of 50 gpm.

A reported specific capacity well test indicates an aquifer transmissivity of between 16,500 and 33,100 ft^2/day where 40 feet of saturated younger alluvium was penetrated. Calculations based on Darcy's law indicate that the transmissivity of the younger alluvium is on the order of 150,000 ft^2/day. In this area over 100 feet of saturated thickness is expected. The corresponding hydraulic conductivity of the younger alluvium is expected to be 1,300 ft/day.

Precipitation over the watershed averages nearly 16 inches per year for an average total precipitation volume of 480,000 acre-feet per year. It is estimated that 94.3 percent of this precipitation is evaporated or transpired soon after falling, 3.3 percent runs off down the canyon without infiltration, and 2.4 percent infiltrates into the alluvial aquifer of Aravaipa Valley. This infiltration volume is equal to 11,600 acre-feet per year and is distributed between pumpage (3,100 acre-feet) and base flow in Aravaipa Creek (8,500 acre-feet). Of the base flow in Aravaipa

Creek, 2,500 acre-feet are expected to be lost to evapotranspiration within Aravaipa Canyon. The diversion of surface water for irrigation purposes is restricted to Aravaipa Canyon and is estimated to vary from zero to 10 cfs. However, return flow from the flooded fields to Aravaipa Creek can be quite high. The pumpage volume is divided between irrigation (3,000 acre-feet), stock (45 acre-feet), and domestic (13 acre-feet) uses.

The water in Aravaipa Valley is chemically suitable for the purposes for which it is used. However, fluoride contents slightly above the recommended limit were encountered in the northern part of the valley. In general, all samples indicate a similar hydrochemical facies.

A discontinuous record of stream discharge began in 1919. Analysis shows that the mean discharge of Aravaipa Creek decreased about 3 cfs from the years 1932 through 1942 to years 1967 to the present, and there is an 18.5 percent chance that this reduction is attributable to natural variation in the data. Irrigation pumpage is not a likely cause for the reduction; the driest months, also the months of heaviest irrigation, show very little change in mean stream flow over the years for which data are available. The reduction is due to changes in stream flow during the months of January, July, August, and December, which are often the wettest months of the year.

Not being able to meet the objective of determining the vertical distribution of the Aravaipa basin-fill formations is one of the reasons that the objective of impact prediction has also not been met. A drilling program designed to investigate the lithologic sequence of Aravaipa Basin and establish observation wells for water-level monitoring is recommended. This program, along with aquifer pump testing, aerial photography, and

geologic mapping should provide the data necessary for predicting the effects of increased ground-water withdrawals on the base flow of Aravaipa Creek.

RECOMMENDATIONS

The goal in understanding the hydrology responsible for the perennial flow of Aravaipa Creek is to protect that flow in the advent of increasing ground-water withdrawals. A decision must be made as to the best method of protecting the flow, and this decision should be based on a good understanding of the hydrologic system.

Three base-flow protection schemes are presented below for consideration. These are followed by recommendations for additional research necessary for understanding the hydrology of Aravaipa Creek.

Base-flow Protection Schemes

Three overlapping schemes for protecting the base flow of Aravaipa Creek are recognized. These are (1) artificial recharge to the valley aquifer, (2) low-flow augmentation by runoff impoundment, and (3) a legal solution whereby the existing base flow is ensured by restricting further development. A version of the third scheme would accompany either of the first two.

Artificial Recharge

The potential for long-term ground-water storage in the valley aquifer is demonstrated by the sustained high base flow of Aravaipa Creek 19 months after the exceptional recharge events of the winter of 1978-1979. Considerable storage capacity exists, which remains unused during years of average recharge; this capacity could be used in artificially recharging the aquifer and therefore increasing the "safe yield"

of the system. Impoundment of runoff in a structure built on sediments with a hydraulic conductivity of 1,300 ft/day should work well. A problem with this solution might be verification and monitoring of the recharged water.

Low-flow Augmentation

Impoundment of runoff in a structure designed to retain water for direct additions to Aravaipa Creek during times of low flow has been suggested by Resnick (1979, personal commun.). For this purpose a reservoir built in the Galiuro Mountains would probably be required to avoid engineering problems with the highly permeable valley alluvium. Another problem might be the maintenance of an acceptable physiochemical environment in the reservoir water; the ecosystem is presently supported by ground-water runoff with its moderated temperature and biochemical fluctuations.

Adjudication

Any solution to the water problems in the Aravaipa watershed will have to be accompanied by a legal decision addressing the various water rights. In the event of an engineering solution to maintain base flow, rights to the supplemental water are obviously essential. Restrictions on ground-water development could not be separated from this problem. Possibly the strongest legal solution would be the establishment of a federal "reserve" water right for the Aravaipa Canyon Primitive Area (Cappaert v. U.S., 426 U.S. 128, 48L. Ed. 2nd 523).

Additional Research

Implementation of any of the above schemes should be preceded by research into feasibility as a function of cost, location, effectiveness, impact, and engineering requirements. Some of these studies could be best conducted on calibrated rainfall-runoff or ground-water flow models.

However, at the present time there are large crucial gaps in the knowledge of the system; these gaps preclude the type of analysis necessary. Outlined below are some of the factors that are presently unknown and recommendations as to how they might be investigated.

Distribution of Aquifer Recharge

The distribution of aquifer recharge in Aravaipa Valley will have a major role in determining how the system responds to changes in ground-water withdrawals. Zones of recharge could be identified by flow-net analysis on a good peiziometric surface map of Aravaipa Valley. The data presented in Figure 12 are not sufficient for such an analysis. Observation points away from the valley bottom are necessary to establish the two-dimensional information needed for a flow net. An observation well drilling program and utilization of abandoned mine shafts along the basin margins could supply sufficient data-gathering locations if combined with the wells presently used by the U.S. Geological Survey in their annual monitoring (Fig. 12). A minimum of biyearly measurements are recommended, corresponding to the water-level extremes of winter and summer.

Recharge occurring by channel infiltration during runoff events could be measured by monitoring ground-water level response near the

stream channel. If recharge is occurring by this process, a ground-water mound will develop near the channel soon after the infiltration event. The volume of water in the mound could be measured if a group of wells in a line transverse to the channel were monitored. This would yield the cross-sectional shape of the mound, which could be extrapolated up- and downstream for the length of the recharged area to yield the total recharge volume for the event.

Distribution of Aquifer Parameters

The distribution of aquifer transmissivity and storage is largely unknown. A few well-placed aquifer pump tests and more detailed geologic mapping should supply the necessary information. The geologic mapping units used by Simons (1964) are not such that each could be assigned representative conductivity and storage values. In particular, Simons' "older alluvium" varies from unconsolidated to well consolidated, and it is likely that this change has a strong effect on the hydrologic characteristics of that formation. The hydrologic characteristics of the older alluvium should be studied by aquifer pump testing accompanied by definition of the distribution of cementation.

South of the Klondyke quadrangle no detailed geologic work has been conducted in Aravaipa Valley. Distribution of the various rock formations is very basic to a description of the flow system; therefore, it is recommended that this area be geologically mapped. A fast and accurate method to do this is by aerial photography. At the time of this writing the available photographs of this area were insufficient for mapping.

The vertical distributions of hydrologic parameters are also necessary for a complete understanding of the flow system. No information presently exists on the basin-fill geology in the deeper part of Aravaipa Basin. To remedy this, an exploration well is being designed that will be drilled in Aravaipa Valley within a few miles of the mouth of Aravaipa Canyon. It will begin in the younger alluvium and hopefully will be continued through a complete sequence of the basin-fill and volcanic formations. Pump testing the various formations during, or subsequent to, drilling should yield the hydrologic characteristics necessary to define the vertical boundaries of the flow system.

Evapotranspiration from the Water Table in Aravaipa Valley

Evapotranspiration losses from the shallow water table in Aravaipa Valley may be significant. The distribution of phreatophytes growing in the flood plain should delineate potential sites where losses may be occurring, but aerial photographs adequate for this purpose are not presently available. It is recommended that color (and possibly infrared) aerial photographs be taken for this purpose, plus the geologic mapping mentioned earlier.

Depth-to-water measurements in the phreatophyte growth areas along with established relationships between depth to water, vegetation type, and evapotranspiration losses could yield the desired information (see Robinson, 1958). Ignorance of this evapotranspiration loss is a possible error in the hydrologic budget presented in this thesis.

Improvement of Base-flow Estimation

A gaging station on the east end of Aravaipa Canyon is presently being constructed by personnel of the Bureau of Land Management. Flow data from this station should be collected and analyzed much as was done with the U.S. Geological Survey stream gaging data in the section on base flow and aquifer recharge. Data from this new location should contain less distorted information on ground-water runoff from Aravaipa Valley than is now available. These data, when compared to those of the U.S. Geological Survey stream gage, should be used to identify sinks and sources operating within the canyon

Correlation of the base-flow data with data collected from observation wells should be used to develop the relationships between ground-water stage and base flow. The difference between the relationship in summer and that in winter can be used to estimate relative values of evapotranspiration (see Walton, 1970, p. 394).

APPENDIX A

ARAVAIPA WELL LOGS

Before presenting the Aravaipa well logs, it may be useful to the reader to review the method of locating wells used by the U.S. Geological Survey. The following explanation is from Davis (1967, Fig. 4, p. 13).

> The well numbers used by the U.S. Geological Survey in Arizona accord with the Bureau of Land Management system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divides 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, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown [Fig. A-1], well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, TRS, R5E. Where there is more than one well within a 10-acre tract, consecutive numbers begining with 1 are added as suffixes.

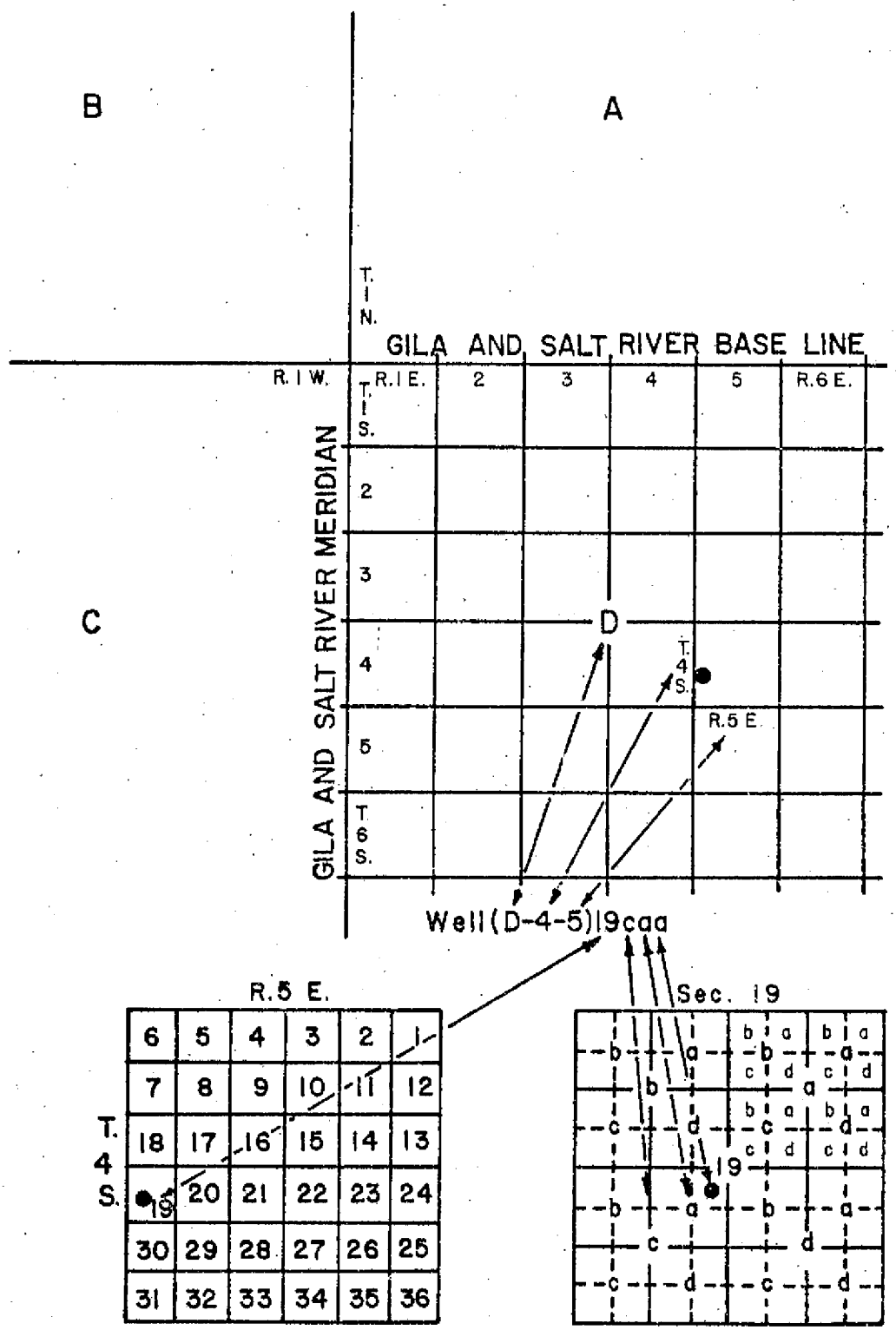


Fig. A-1. U.S. Geological Survey well-numbering system

Table A-1. Wells beginning in younger alluvium

Well	Interval (ft)	Description	Depth to Water (ft)	Yield (gpm)
(D-6-19) 35ada	0-15	sand		
	15-35	red clay	20.4	
	35	conglomerate		
(D-6-19) 35bbb	0-5	top soil	6	
	5-24	sand		
	24-27	sand rocks		
	27-29	boulders		
	29-31	gravel		
	31-33	boulders		
	33-49	gravel rocks		
(D-6-19) 36bcc	0-19	sandy clay	14	
	19-47	sand, gravel, water		
(D-6-18) 36cdd				1,136
(D-7-20) 21bbb	0-64	fill	87.9	1,225 with 20 ft of drawdown in casing
	64-69	dry gravel		
	69-84	water gravel		
	96-122	dirt and rock		
	122-136	water gravel		
	136-150	clay		
(D-7-20) 21bda	0-51	water-bearing gravel		1,073
	51-54	clay and rock		
	54-77	water-bearing sand		
	77-87	clay and rock		
	87-95	water sand		
	95-96	conglomerate		
	96-115	conglomerate		
	115-116	water sand		
	116-152	conglomerate		
(D-7-20) 27ada	0-12	soil		
	12-18	gravel	16	
	18-38	gravel, red clay (water)		
	38-61	rock, red clay (water)		
	61-65	gravel (water)		
	65-68	red clay		
	68-72	gravel (water)		
	72-83	rock (water)		
	83-90	red clay		

Table A-1. Wells beginning in younger alluvium--Continued

Well	Interval (ft)	Description	Depth to Water (ft)	Yield (gpm)
(D-7-20) 27dbd	0-1	top soil	9.5	
	1-15	red clay, rock, sand		
	15-18	gravel, water		
	18-28	red clay, rock, sand		
	28-40	gravel, water		
	40-63	red clay, rock, sand		
	63-73	gravel ,water		
	73-115	red clay, rock		
	115-127	gravel, water		
	127-180	red clay, rock		
(D-8-21) 7dcd	0.16	top soil	43.4	
	16-39	red sand, rock		
	39-53	water, gravel		
	53-58	blue sand, water		
	58-65	red clay, sand, rock		
	65-76	water, gravel		
	76-86	sand, rock		
	86-105	water, gravel		
	105-115	red sand, clay		
	115-125	water, gravel		
	125-132	red clay		
(D-9-21) 14caa	0-27	sand, gravel	83.8	"bailed dry easy"
	27-244	clay, sand, gravel		
	244-488	clay		
	488-852	clay		
	852-1079	cemented clay, sand, gravel		
	1079-1085	burned gravel		
	1085-1175	volcanics, clay		
	1175-1501	clay		
(D-9-22) 19dcc	0-2	clay	90	20
	2-10	clay, sand		
	10-12	boulders		
	12-35	sand (hard)		
	35-40	dry sand		
	40-50	hard sand		
	50-124	clay		
	124-129	white clay (1st water)		
	129-184	clay		
	184-189	gravel (>5 gpm)		
	189-218	clay		
	218-224	red sand		
	224-278	clay with gravel streaks		

Table A-2. Wells beginning in older alluvium

Well	Interval (ft)	Interval Description	Depth to Water (ft)	Yield (gpm)
(D-6-19) 25cac	0-134	Clay (reported)	75	
(D-7-20) 4dd	0-230	clay, sand, gravel		
	230-608	clay, sand, gravel, sandstone, shale		
	608-715	clay, shale, sand, sandstone		
(D-8-21) 22aca	0-10	fill	125	
	10-200	conglomerate.		
(D-9-21) 27daa	0-80	fill, broken rock with silt and clay	219	50
	80-600	hard blue malpais (water at 235 ft)		
	600-605	soft red clay		
	605-1205	volcanic rock; dacite, tuff		

APPENDIX B

HYDROLOGIC CALCULATIONS

Rainfall

From the map of Figure , the following areas were associated with the mean annual rainfalls shown. The mean annual precipitation volume is calculated as the product of the area and the precipitation.

Mean Annual Precipitation (inches)	Areal Distribution ($miles^2$)	Mean Annual Precipitation Volume (acre-feet)
20	145	154,600
16	245	209,000
14	156	116,400
	Total	480,000

Evapotranspiration

Evapotranspiration in the area of phreatophyte growth (Aravaipa Canyon floor) calculated by three methods:

1. Thornthwaite's (1948) formula

$$P.E.T. = f(1.6(10t/J)^a)$$

where P.E.T. = monthly potential evapotranspiration

f = factor relating to daylight (= function of latitude)

t = mean monthly temperatue, °C

$$J = \sum_{i=1}^{12} (t_i/5)^{1.514}; \quad i = \text{month}$$

$$a = 6.75 \times 10^{-7} J^3 - 7.71 \times 10^{-5} J^3 + 1.792 \times 10^{-2} J = 0.49239$$

The formula yields P.E.T. in inches for that month. A conversion to volume per month requires that this P.E.T. be multiplied by the area of phreatophyte growth measured (1.41 mi^2). This volume is presented in

the last column of the table below.

Month	t*	a	J	f	P.E.T. inches	P.E.T. acre-feet
Jan	7.4	1.12	7,269	0.88	1.44	107
Feb	7.7			.85	1.45	109
Mar	8.8			1.03	2.04	152
Apr	13.0			1.09	3.34	198
May	16.7			1.20	4.87	365
Jun	24.3			1.20	7.42	556
Jul	26.7			1.22	8.38	628
Aug	25.8			1.16	7.67	575
Sep	22.4			1.03	5.81	435
Oct	16.1			.97	3.78	283
Nov	11.2			.87	2.26	169
Dec	6.9			.86	1.30	98
				P.E.T. (acre-feet/yr)	=	3,675

*Temperature data courtesy of Mr. and Mrs. Jay Schell, Klondyke, Arizona.

2. Eagleman's (1966) formula

$$P.E.T. = C(0.035es)(100 - RH)^{\frac{1}{2}}$$

where P.E.T. = monthly potential evapotranspiration

C = factor related to vegetative cycle and cover

es = saturation vapor pressure corresponding to mean monthly temperature

RH = mean monthly relative humidity

For the month of August 1979, P.E.T. can be calculated as follows:

$$1.13(0.035 \cdot 32.66)(100 - .62)^{\frac{1}{2}} = 7.96 \text{ inches, or } 597 \text{ acre-feet}$$

RH was measured by a hygrothermograph in the field in August 1979; C was determined by Eagleman (1966). Eagleman suggested that 76 percent of P.E.T. will often be a best estimate of actual ET:

$$(0.76)(7.69) = 6.05 \text{ inches}$$

3. White's (1932) formula

Using well-level fluctuation data, the rate of ground-water flow into the well area during times of no ET is assumed to be equal to the mean rate of flow over a 24-hour period. Also, in this case a storativity value of 0.15 is assumed.

$$ET = SqA$$

where ET = evapotranspiration

S = storativity

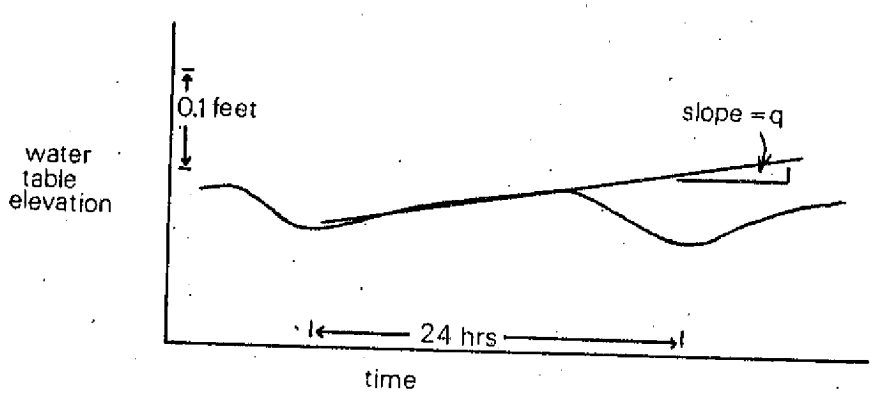
q = seepage velocity (= slope of graph of well level from 6 pm to 4 am)

A = area of phreatophyte growth

For August 1979, ET can be calculated as

$$(0.15)(3.2 \times 10^{-3} \text{ ft/hr})\ (1.41 \text{ mi}^2) = 18{,}734 \text{ ft/hr, or } 320 \text{ acre-feet}$$

In the above calculation, q is the mean of four slopes measured in a 15-day period (sunny) during August 1979 in two Aravaipa Canyon walls:



Example

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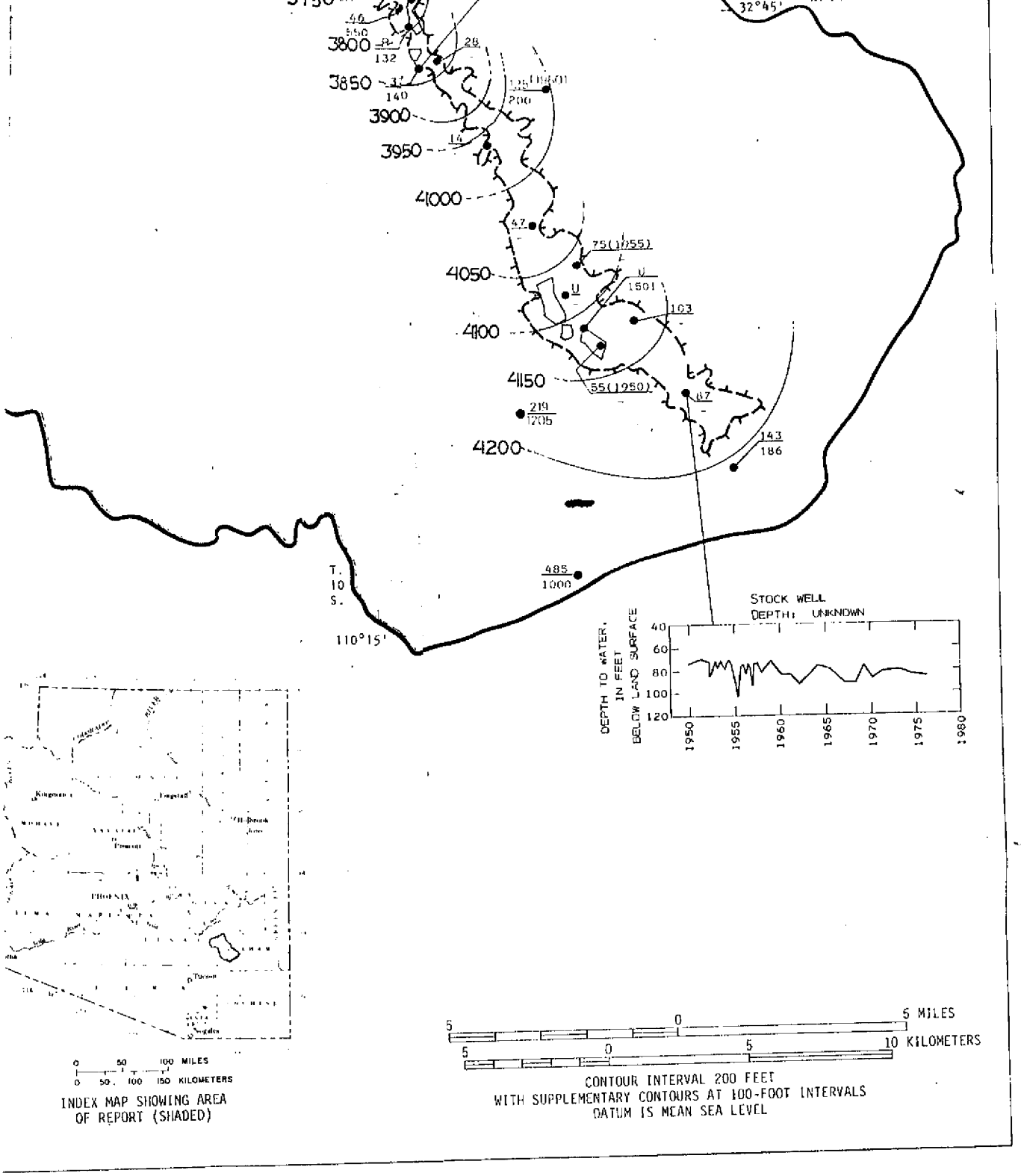

DEPTH TO WATER, WELL DEPTH, AND IRRIGATED AREA

ONS IN THE ARAVAIPA VALLEY AREA, GRAHAM AND PINAL COUNTIES, ARIZONA—1975

By

J. A. Gould and R. P. Wilson

ALTERATIONS BY C.T. ELLINGSON, 1979)

C. T. Ellingston,
M.S. Thesis
Department of Hydrology and
Water Resources, 1980

The hydrologic data on which these maps are based are available, for the most part, in computer-printout form for consultation at the Arizona Water Commission, 222 North Central Avenue, Suite 800, Phoenix, and at U.S. Geological Survey offices in: Federal Building, 301 West Congress Street, Tucson, and Valley Center, Suite 1880, Phoenix. Material from which copies can be made at private expense is available at the Tucson and Phoenix offices of the U.S. Geological Survey.

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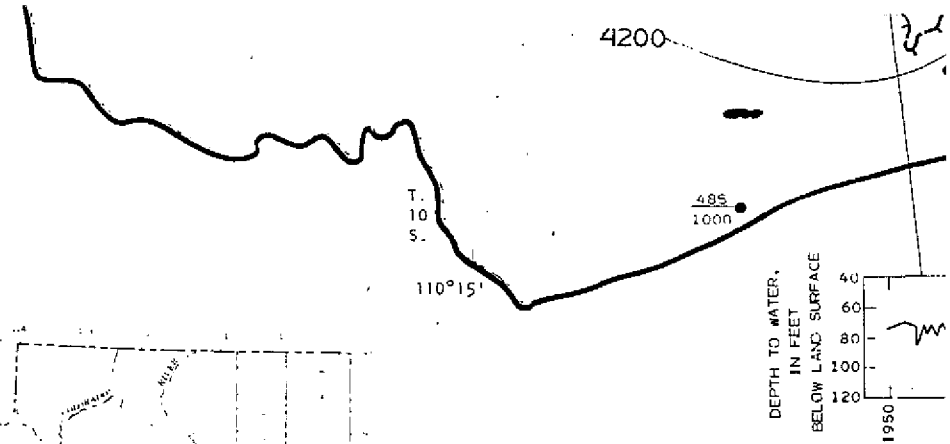
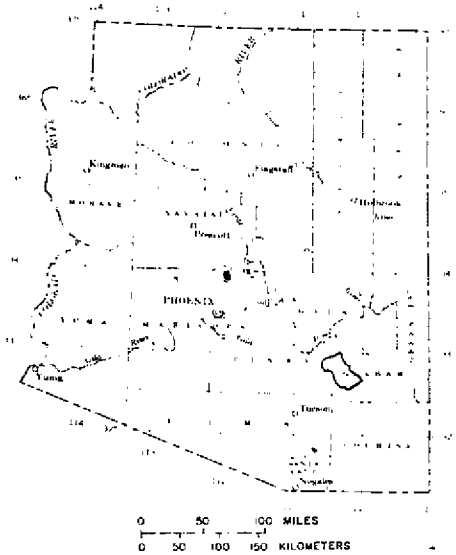
For use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain metric unit
feet (ft)	0.3048	meters (m)
acre-feet (acre-ft)	.001233	cubic hectometers (hm^3)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	.06309	liters per second (l/s)





INDEX MAP SHOWING AREA OF REPORT (SHADED)

CONTOUR INTERVAL 20
WITH SUPPLEMENTARY CONTOURS AT
DATUM IS MEAN SEA

BASE FROM U.S. GEOLOGICAL SURVEY
TUCSON 1:250,000, 1956 AND
MESA 1:250,000, 1954

FIGURE 12 GROUND-WATER ELEVATION, DEPTH TO WATER, WELL DEPTH, AND IRRIGATED AREA

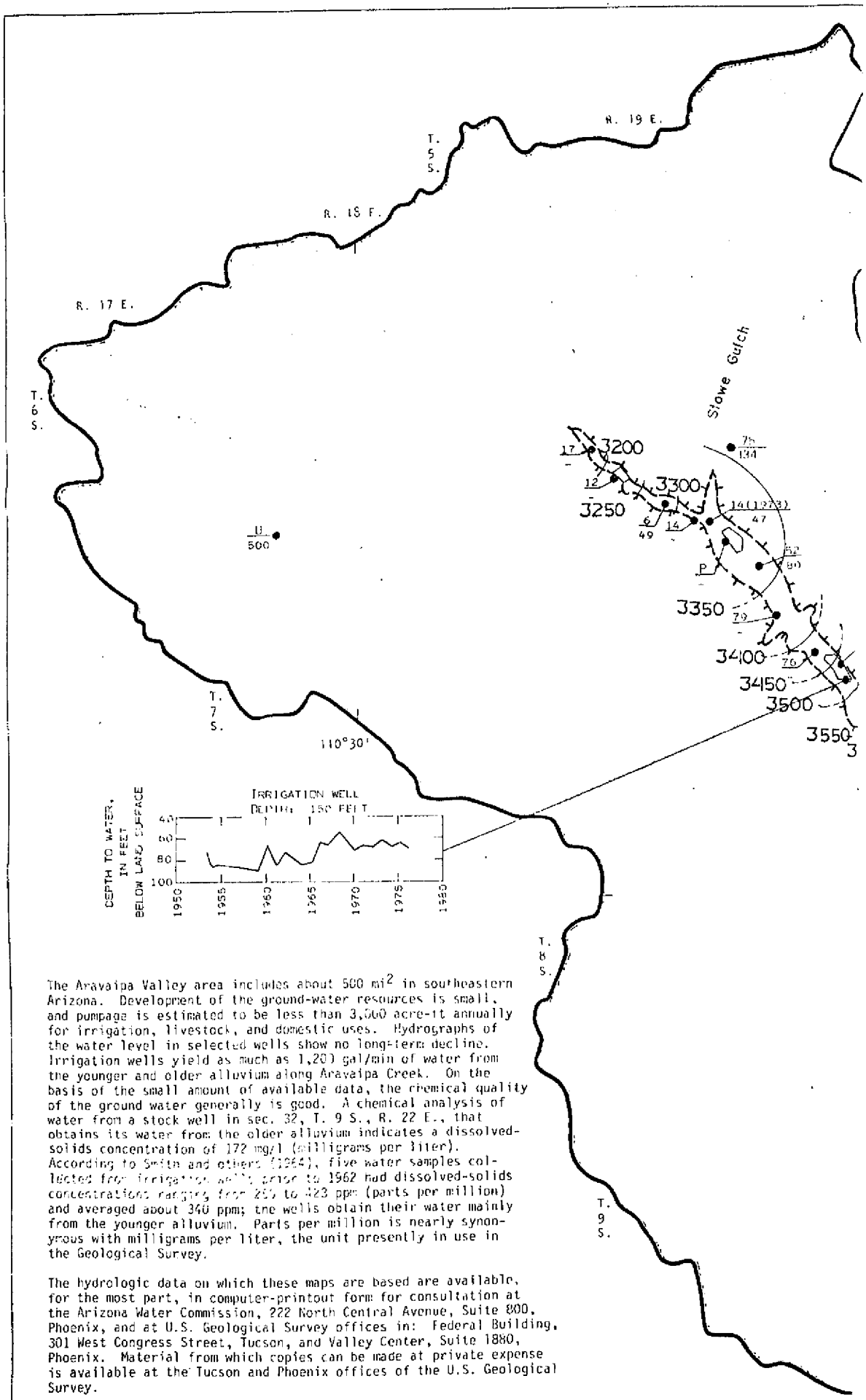
MAP SHOWING GROUND-WATER CONDITIONS IN THE ARAVAIPA VALLEY AREA, GRAHAM AND PINAL COUNTIES, ARIZONA—1975

By

J. A. Gould and R. P. Wilson

(ALTERATIONS BY C.I. ELLINGSON, 1979)

PREPARED IN COOPERATION
ARIZONA WATER COMMI



The Aravaipa Valley area includes about 500 mi^2 in southeastern Arizona. Development of the ground-water resources is small, and pumpage is estimated to be less than 3,000 acre-ft annually for irrigation, livestock, and domestic uses. Hydrographs of the water level in selected wells show no long-term decline. Irrigation wells yield as much as 1,200 gal/min of water from the younger and older alluvium along Aravaipa Creek. On the basis of the small amount of available data, the chemical quality of the ground water generally is good. A chemical analysis of water from a stock well in sec. 32, T. 9 S., R. 22 E., that obtains its water from the older alluvium indicates a dissolved-solids concentration of 172 mg/l (milligrams per liter). According to Smith and others (1964), five water samples collected from irrigation wells prior to 1962 had dissolved-solids concentrations ranging from 255 to 423 ppm (parts per million) and averaged about 340 ppm; the wells obtain their water mainly from the younger alluvium. Parts per million is nearly synonymous with milligrams per liter, the unit presently in use in the Geological Survey.

The hydrologic data on which these maps are based are available, for the most part, in computer-printout form for consultation at the Arizona Water Commission, 222 North Central Avenue, Suite 800, Phoenix, and at U.S. Geological Survey offices in: Federal Building, 301 West Congress Street, Tucson, and Valley Center, Suite 1880, Phoenix. Material from which copies can be made at private expense is available at the Tucson and Phoenix offices of the U.S. Geological Survey.

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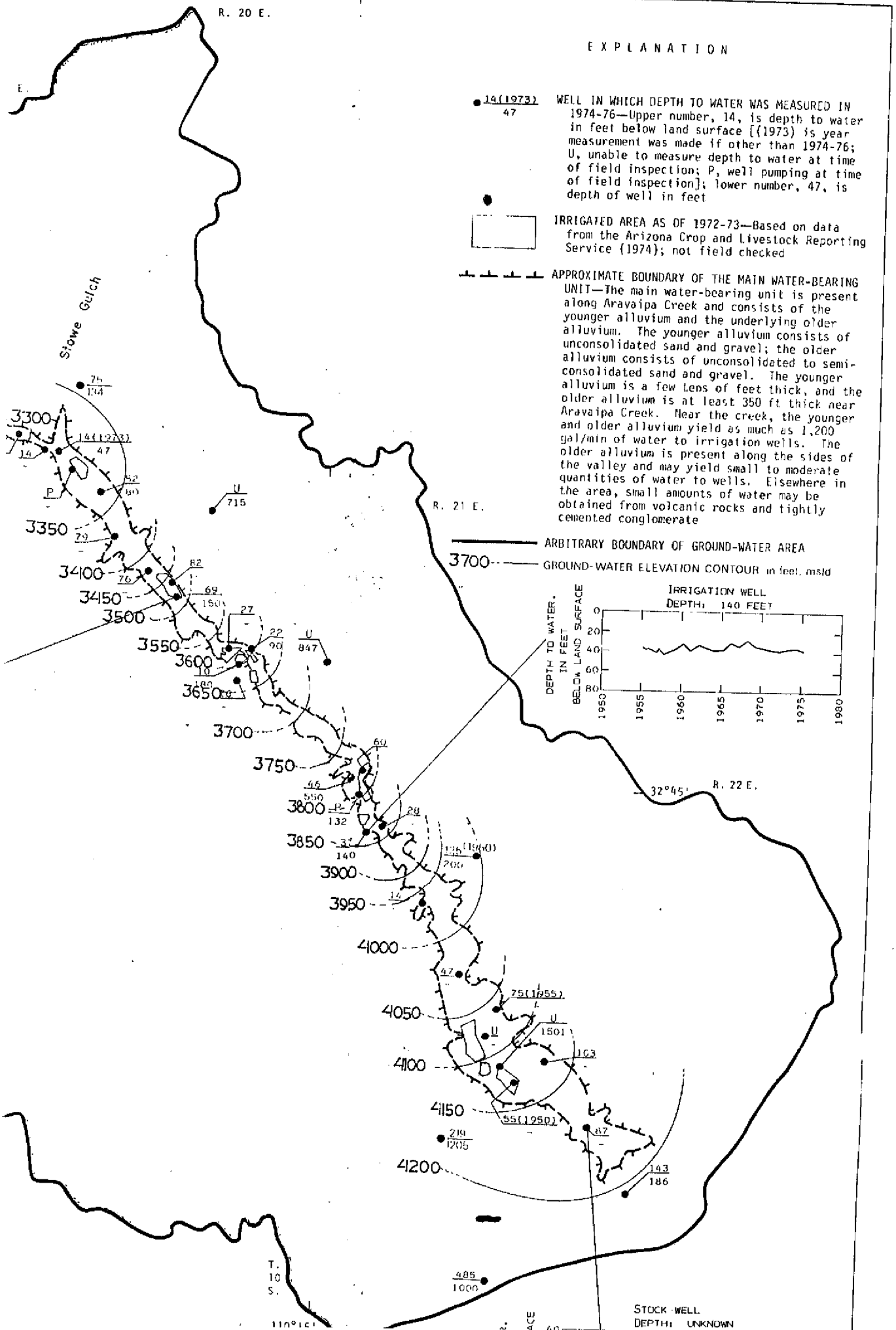

R. 20 E.
R. 21 E.
R. 22 E.
32°45'
T. 10 S.
Stowe Gulch
3300
3350
3400
3450
3500
3550
3600
3650
3700
3750
3800
3850
3900
3950
4000
4050
4100
4150
4200
EXPLANATION
14(1973)
47
WELL IN WHICH DEPTH TO WATER WAS MEASURED IN 1974-76—Upper number, 14, is depth to water in feet below land surface [(1973) is year measurement was made if other than 1974-76; U, unable to measure depth to water at time of field inspection; P, well pumping at time of field inspection]; lower number, 47, is depth of well in feet
IRRIGATED AREA AS OF 1972-73—Based on data from the Arizona Crop and Livestock Reporting Service (1974); not field checked
APPROXIMATE BOUNDARY OF THE MAIN WATER-BEARING UNIT—The main water-bearing unit is present along Aravaipa Creek and consists of the younger alluvium and the underlying older alluvium. The younger alluvium consists of unconsolidated sand and gravel; the older alluvium consists of unconsolidated to semi-consolidated sand and gravel. The younger alluvium is a few tens of feet thick, and the older alluvium is at least 350 ft thick near Aravaipa Creek. Near the creek, the younger and older alluvium yield as much as 1,200 gal/min of water to irrigation wells. The older alluvium is present along the sides of the valley and may yield small to moderate quantities of water to wells. Elsewhere in the area, small amounts of water may be obtained from volcanic rocks and tightly cemented conglomerate
ARBITRARY BOUNDARY OF GROUND-WATER AREA
3700
GROUND-WATER ELEVATION CONTOUR in feet, msld
IRRIGATION WELL
DEPTH: 140 FEET
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
0
20
40
60
80
1950
1955
1960
1965
1970
1975
1980
STOCK WELL
DEPTH: UNKNOWN

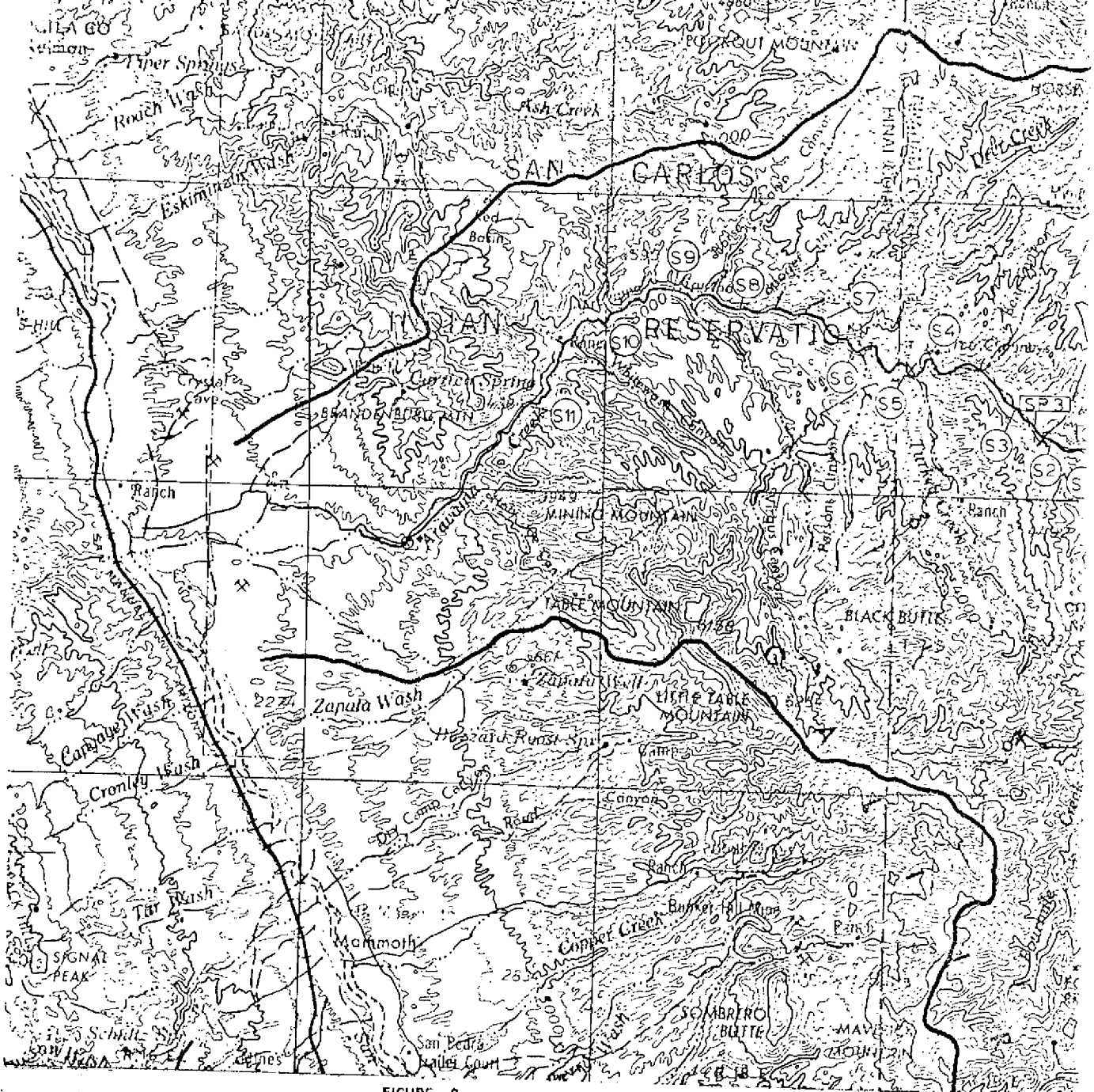


FIGURE 8

MAP SHOWING THE ARAVAIPA WATERSHED AND INVESTIGATION LOCATIONS

By C. T. Ellingson

EXPLANATION

(S5) stream flow measurement location

SP 3 seismic profile location

⊕ U.S.G.S gaging station

X water quality sampling location

perennial Aravaipa Creek

Aravaipa watershed boundary

♂ major springs

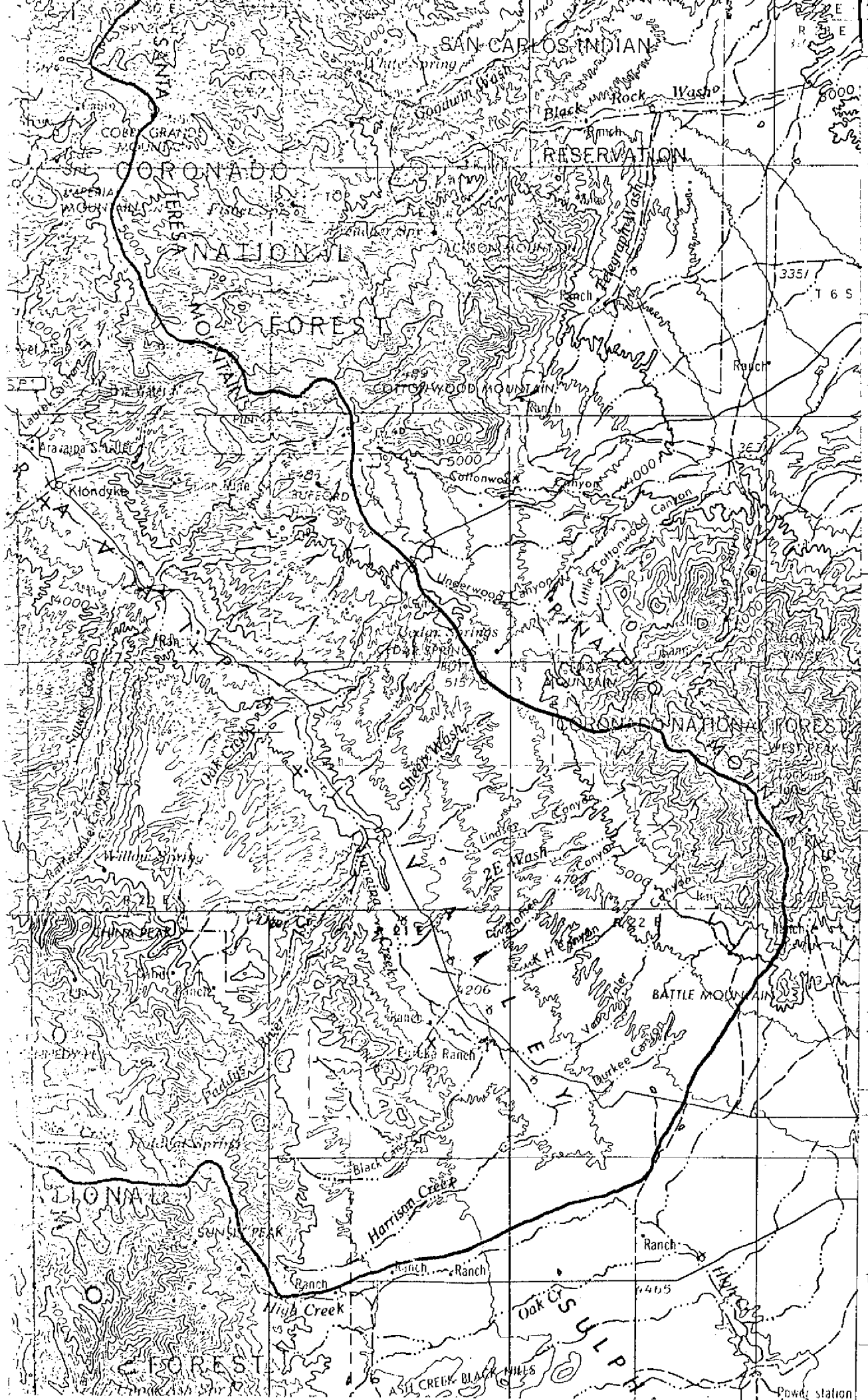
N

Scale

1:250,000

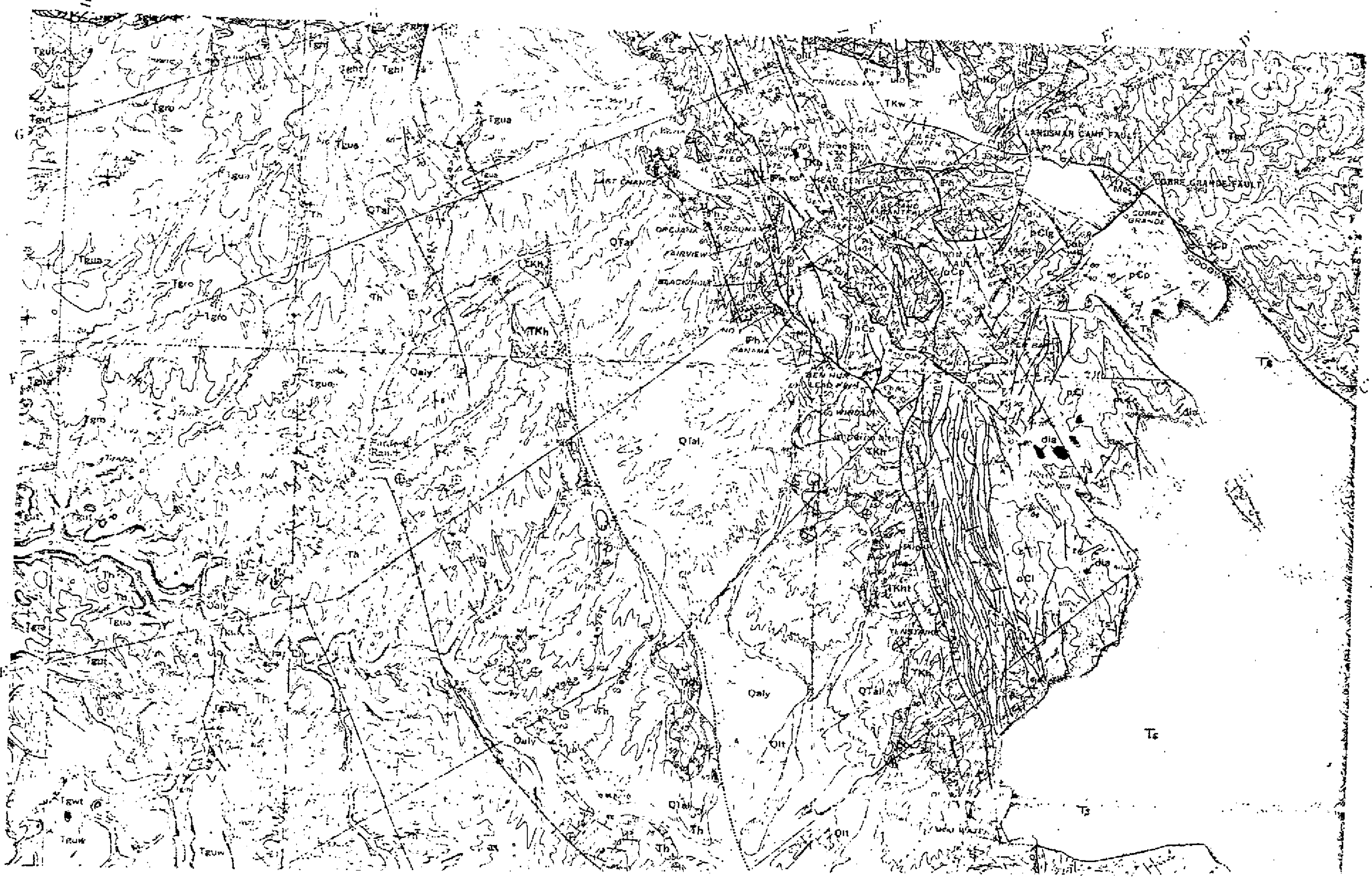
5 miles

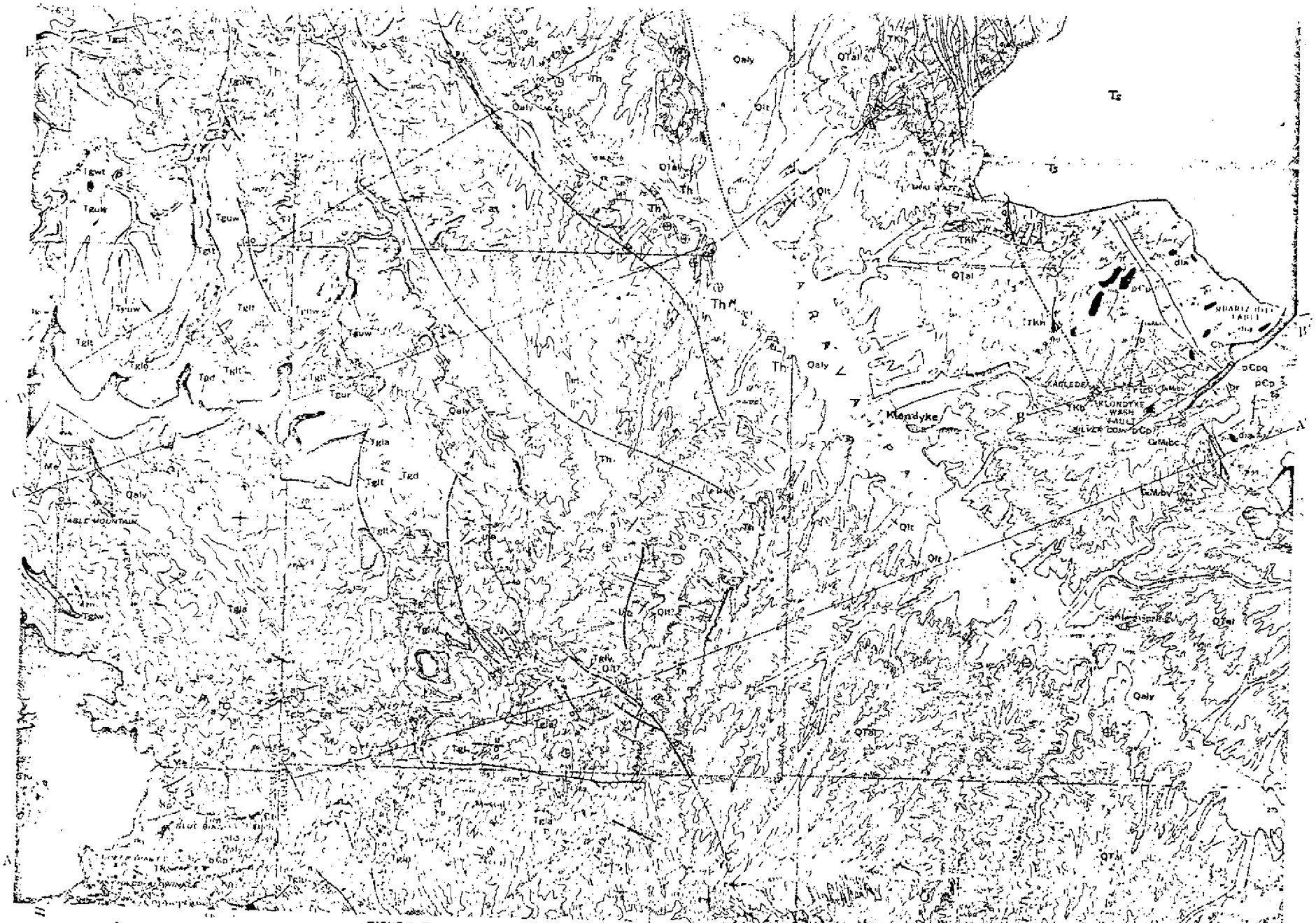
base from U.S. Geological Survey Tucson 1:250,000, 1956 and Mesa 1:250,000, 1954


SAN CARLOS INDIAN
RESERVATION
CORONADO
NATIONAL
FOREST
SANTA
MOUNTAINS
Goodwin Wash
Black Rock Wash
Ranch
Telegraph Wash
JACKSON MOUNTAIN
COTTONWOOD MOUNTAIN
Cottonwood Canyon
Little Cottonwood Canyon
Underwood Canyon
Klondyke
Bravada Spring
Cedar Springs
OAK SPRING
CLOAK MOUNTAIN
CORONADO NATIONAL FOREST
WISH PEAK
Sheep Wash
Oak Creek
Willow Springs
Lindsey Canyon
2E Wash
Canyon
CHIMA PEAK
Creek
BATTLE MOUNTAIN
Van Valer Canyon
Durkee Canyon
Eureka Ranch
Paddle Wash
Black Creek
Harrison Creek
SUNSET PEAK
High Creek
Oak Creek
ASH CREEK BLACK HILLS
Powder station
T 5 S
T 6 S
T 7 S
T 8 S
T 9 S
T 10 S
33 00
45'
BONITA 2 MI

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 2





Scale
1:62,500
1 mile

N

FIGURE 3. GEOLOGY OF THE KLONDYKE QUADRANGLE

from Simons (1964)

C.T. Ellingston, M. S. Thesis, Department of Hydrology and Water Resources, 1980

Explanation

Qaly· younger alluvium
QTal· older alluvium
Th· Hell Hole Congomerate
Tg Galiuro Volcanics
Tkh Horse Mountain Volcanics
Ts· Santa Teresa Granite
pCp Pinal Schist

Geology by F. S. Simons, 1957–59