HYDROLOGY OF THE

ARAVAIPA WATERSHED

Final Report to

The Defenders of Wildlife

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by

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attn: Molton

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SUMMARY AND RECOMMENDATIONS

The Aravaipa Creek watershed comprises some 541 square miles of land in the Basin and Range province of 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 6,000 to 4,000 feet of Tertiary volcanics and later basin-fill deposits. The basin is separated from Sulphur Springs Valley to the south by a very shallow, crystalline rock high, which impedes interbasin ground-water flow.

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, in places more than 100 feet thick. 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.

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. A single specific capacity test comprises the entire quantitative information into the aquifer parameters; analysis of these data suggests an aquifer transmissivity between 90,000 and 144,000 gpd/ft.

The yield of wells in Aravaipa Valley is directly related to the saturated thickness of the younger alluvium penetrated. Wells not placed in this younger alluvium yield small amounts of water as do wells penetrating the younger alluvium where the water table lies beneath it.

Precipitation over the watershed averages nearly 16 inches per year for a total precipitation volume of 480,000 acre-feet per year. It is estimated that 94.6 percent of this precipitation is evaporated or transpired soon after falling, 3.2 percent runs off down the canyon without infiltration, and 2.2 percent infiltrates into the alluvial aquifer of Aravaipa Valley. This infiltration volume is equal to 10,500 acre-feet per year and is distributed between pumpage (3,100 acre-feet) and base flow in Aravaipa Creek (7,400 acre-feet). Of the base flow in Aravaipa Creek, 2,400 acre-feet are expected to be lost to evapotranspiration within Aravaipa Canyon.

The lack of data concerning the basic aquifer properties precludes a flow net-type analysis of the expected impacts on stream flow due to possible increases in ground-water withdrawals in Aravaipa Valley. A means of attaining more aquifer parameter information is to conduct "aquifer pump tests." These are tests where ground-water levels in and around the production well are measured before, during, and after the pumping period. The discharge rate of the pump is also measured. For an aquifer as transmissive as the one in Aravaipa Valley, the discharge rate of the pump needs to be larger than that attainable from any well presently owned by the Defenders of Wildlife. To avoid expensive investments in drilling and pump purchases, present wells owned by ranchers in Aravaipa Valley might be used. This would entail agreement between all parties and should be conducted in early sumner at the beginning of the irrigation season. One or more days of continual pumping would be required for a good test. If more specific information on this matter is requested, please write.

What is available for this estimation is the hydrologic budget discussed above. This would suggest that an increase in pumpage would be felt as a decrease of equal magnitude in stream flow and evapotanspiration, probably the former. In stating this, it is necessary to treat annual aquifer recharge as a constant under all pumping conditions, which may not be valid. Threats to the base flow of Aravaipa Creek include increases in agricultural irrigation and the reintroduction of mining into Aravaipa Valley, which would require new development of ground water.

At present the ground-water quality of the Aravaipa Valley area is suitable for irrigation and domestic and stock-watering purposes. All samples indicate a similar hydrochemical facies. No mercury was detectable in any of the analyzed samples.

Protection of the perennial nature of Aravaipa Creek must involve monitoring stream flow and ground-water developments in Aravaipa Valley. Stream-flow measurements give an unbiased, albeit naturally variable, measure of the quantity concerned, especially during periods of low flow. Statistical methods of interpretation such as those suggested in the section on surface water may be most effective for the recognition of long-term gradual changes, while visual observations of stream flow are irreplaceable in identifying sudden changes of a magnitude that deserves immediate investigation.

The advent of new, potentially large, ground-water withdrawals would have to be preceded by the construction of wells and the accompanying fields or structures and possibly by public hearing if the use is to be of an industrial nature. Visual identification of these changes should be possible and should be followed by an investigation. If such an investigation indicates a potential conflict with the established values of the Aravaipa Canyon Primitive Area, a legal solution to the problem must be sought.

A guaranteed minimum base flow, based on the historical streamflow record and adjudicated by the proper legal authority would be the strongest insurance available. In the event that such legal action becomes necessary, cooperation with the Bureau of Land Management and the establishment of a federal "reserve" water right for Aravaipa Canyon might be possible (Cappaert v. U.S., 426 U.S. 128, 48 L. Ed. 2d 523). Any such case will have to be based in part on either actual evidence of base-flow depletion or evidence of its inevitability.

The purchase of lands to the east and southeast of the beginning of Aravaipa Canyon for conservation purposes would prevent ground water from being withdrawn from those lands. However, in view of the ground-water flow system, it would be necessary to purchase much of the bottom-land in the valley to ensure that no one pumped the water out before it got to the conservatory land. The price of such a solution and the resolve of the ranchers in the area render this possibility unlikely in the near term.

The proposed establishment of a gaging point in the east end of Aravaipa Canyon is a good one. Such data and their comparison with data from the downstream station will offer unique insights into changes occurring in stream flow within Aravaipa Canyon and also the irrigation diversions between the two sites.

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 report was supported 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.

From May through September, 1979, field work and data analysis were carred out toward fullment of these objectives.

The research area comprised the entire Aravaipa watershed but 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 east 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. To the north some 35 miles the watershed ends in a hilly region adjacent to an area drained by tributaries of the Gila River. The total area of the watershed is 541 square miles (1,900 km^2) (U.S. Geological Survey gaging station data).

The topography of the Aravaipa watershed varies greatly due to a wide variety of physiographic featues represented within it. The central valley floor is generally narrow, low, and flat. This "ribbon" is surrounded by hills of semi-consolidated 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 which has been cut within the last 20 million years through the Galiuro Mountains (Scarborough, pers. comm., 1979). 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 2,160 feet above mean sea level.

Previous investigations in the Aravaipa watershed relating to hydrology include geologic reports, ground-water measurements, surface water quality, and flow. Ross (1925) published a report dealing with the geology of the Aravaipa area as it relates 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 (1968) published geologic maps of the HolyJoe 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 has been collecting streamflow measurements on and off since 1919. A few statistics are kept on these data, and Minchkley (1977) conducted some further analyses on stream discharge. Surface-water quality is well documented due to work by Sommerfeld (1977) and De Cook and others (1977).

D. Moliter of the Safford Bureau of Land Management office has taken flow measurements in Aravaipa Creek in preparation for the installation of a stream gage on Defenders of Wildlife land at the east end of Aravaipa Canyon. He has graciously supplied me with these data, some of which appear in Table 4.

Ground-water level measurements have been taken by personnel of the U.S. Geological Survey Water-Resources district. 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.

GEOLOGY

Geologic history concerned directly with the formation of Aravaipa Creek and Basin must begin in Tertiary times with the outpouring of the Galiuro Volcanics. 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 by previous eruptions called the Horse Mountain Volcanics. The origin of the Horse Mountain Volcanics is near the present 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 the uplift of the Galiuro Mountains around it.

Petrology

From a gross hydrologic viewpoint, the rocks contained within the drainage area of Aravaipa Creek can be 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.

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 Aravaipa drainage is underlain by this rock (Fig. 1).

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, including quarzite and limestone with lesser amounts

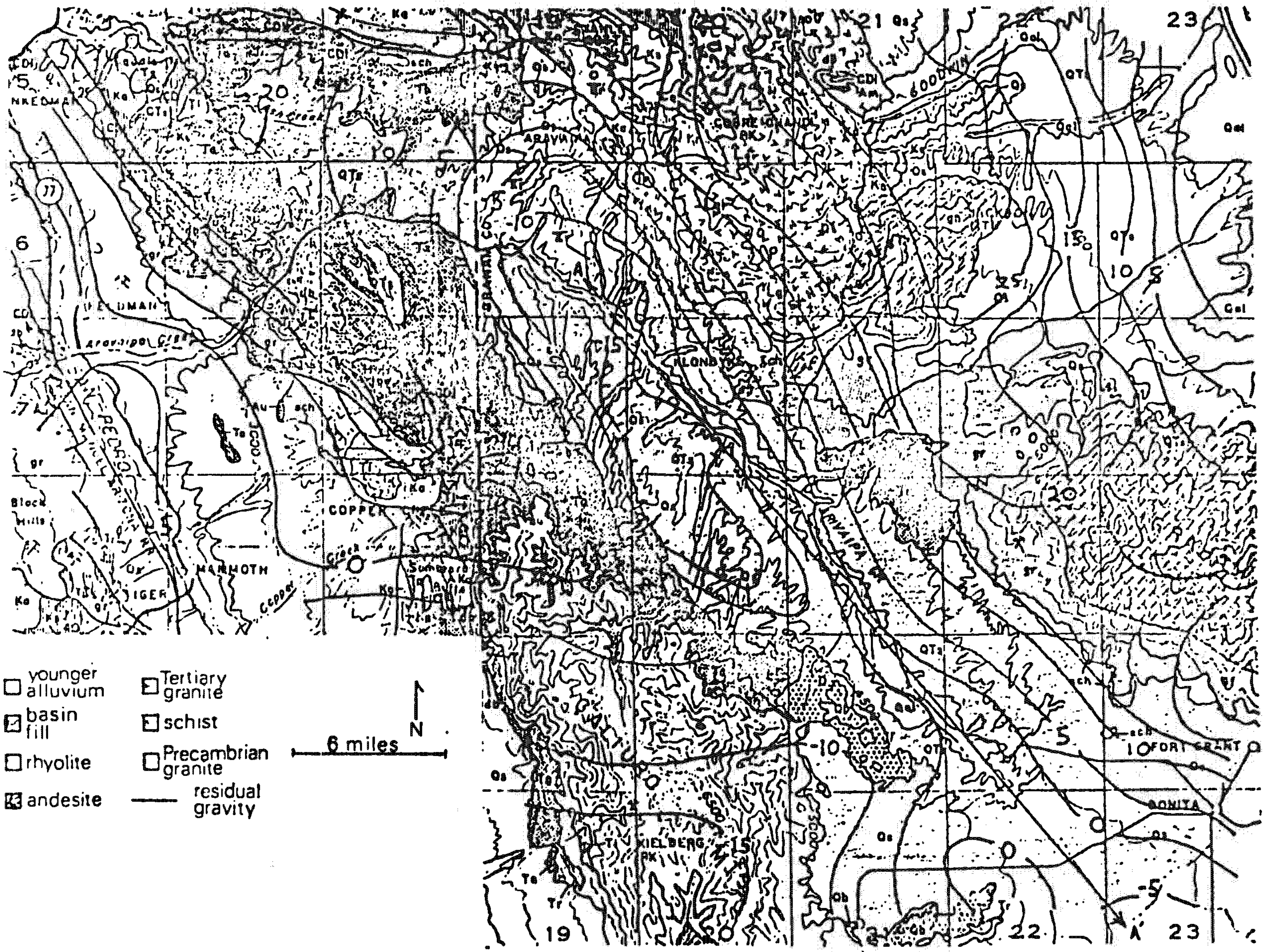


Fig.1. Aravaipa regional geology and residual gravity

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 called the Horse Mountain Volcanics and two extensive plutons, one consisting of Santa Tereas 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 far the largest of the group called 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), followed by 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 233 square miles, or 43 percent, of the area drained by Aravaipa Creek.

Fluvial sediments, deposited during and after the creation of the Aravaipa Basin in the Tertiary period are now mappable as two units. These are the well-indurated, 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, pers. comm., 1979). Where it appears the contact between the two is conformably; it is very gradual and even "obscure" (Simons, 1964). Indeed, the degree of induration 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 Conglomrate 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 Coral Draw and Maroga Canyon, while 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, pers. comm., 1979). 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 resistant volcanic knobs separates the Hell Hole Conglomerate from older and younger alluvium (Fig. 2, in pocket). The volcanics are thought to be Horse Mountain Volcanics. Simons (1964) has interpreted this lineament to be 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 in part be responsible for the extensive exposure of Hell Hole Conglomerate on its upthrown side. It is also thought that the shallowing 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 has been named "older alluvium" by Simons (1964). It is poorly bedded, unconsolidated to moderately indurated clay, silt, sand, and gravel. Its fragments are rocks of both volcanic and intrusive origin, from both 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 depositional 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 Four-mile Creeks, and Buford and Rattlesnake Canyons have narrow floors consisting of these deposits.

From Eureka Ranch to its confluence with Stowe Gulch, the flood plain is usually 0.5 to 1 mile wide. The stream enters Aravaipa Canyon at this point, and the flood-plain width narrows to 400 to 1,500 feet. At Aravaipa's confluence with Turkey Creek the canyon narrows 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. 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 this study suggest thicknesses of at least 130 and 100 feet in particular locations, respectively.

The younger alluvium of the flood plain just described is composed of unconsolidated, poorly sorted sand and gravel, all of Holocene age deposition. These sediments rest unconformably on older sedimentary and volcanic rocks of Tertiary age. Approximately 25 square miles, or 4.6 percent, of the area drained by Aravaipa Creek is underlain by younger alluvium.

Water-bearing Properties of the Geologic Units

In view of the rock types and the relief of the area involved, it is likely that little rainwater infiltrates into the ground-water system on the eastern margin of the Aravaipa drainage. There is evidence, however, that water is both stored and transported in this intrusive complex, these properties probably strongly controlled by faults and fractures.

Stowe Spring 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 portion of the Aravaipa drainage underlain by the granite of the Graham Mountains was not studied during this project, but hydrologic properties are expected to be similar along the entire eastern margin.

The water-bearing and transmitting properties of volcanic rocks are known to vary widely (Harshbarger, pers. comm., 1979). Within the Aravaipa drainage, only indirect and qualitative estimations of these properties are possible because of the absence of any attempt 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. These 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.

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.

Tributary base flow into Aravaipa Creek from streams heading in the Galiuro Mountains is likely due more to the storage of water in the narrow belts of stream-channel alluvium than to storage and discharge of water held in the volcanic rocks. However, the only good example of this to be observed was in a stream underlain by the well-indurated Hell Hole Conglomerate, not the Galiuro Volcanics.

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.

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 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 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.

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 drainag 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 aquifer are used for stock watering. They are powered either by the wind or in a few instances, electricity. Yields to wells tend to be 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 rock 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 flood-plain sediments. 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, usually in the N½ sec. 35, T. 6 S., R. 19 E., Aravaipa Creek emerges from these younger sediments and flows perennially through the Galiuro Mountains.

Geologic Structure

Aravaipa Valley is the present surface expression of a well-defined, sediment-filled graben created during the Basin-and-Range disturbance initiated in late Miocene time. It is bounded to 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 lays 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 stractural features of Aravaipa Basin and surrounding mountains fit in well with the general trend of many other Basin-and-Range features of southern Arizona. As yet unpublished residual gravity data of Arizona show clearly Aravaipa Basin and the structural province of which it is a part (Lysonski and others, n.d.) (see Fig. 1).

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 and that in its deepest region, about 7 miles south-southwest of Klondyke, basement crystalline rock may be 12,000 feet below the land surface. An average axis depth to basement crystalline rock is shown to be 6,000 to 8,000 feet below the land surface (Robinson, 1976).

An east-west geologic profile through Aravaipa Valley near Klondyke was developed by Moore (1961) without the aid of subsequent gravity data. Robinson (1976) has modified this profile on indications of his gravity survey. Both of these profiles are presented for comparison (Figs. 3 and 4).

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, unpublished residual gravity map, mentioned earlier, clearly shows Aravaipa Basin being separated to the south from the northern Willcox Basin by a basement high in the general vicinity of the topographic divide separating the two valleys.

Geophysics

Magnetic Survey

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

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

A magnetic survey was conducted at the entrance of Aravaipa Canyon to help in interpreting (1) the relative depths of younger alluvium on either side of the fault proposed by Simons (1964) in secs. 35 and 36, T. 6 W., R. 19 E. and (2) the exact positiong 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, the data from which appear on Figure 5. Plotting of the data in map view and then contouring have produced the map of Figure 6. All data were adjusted for total field diurnal changes.

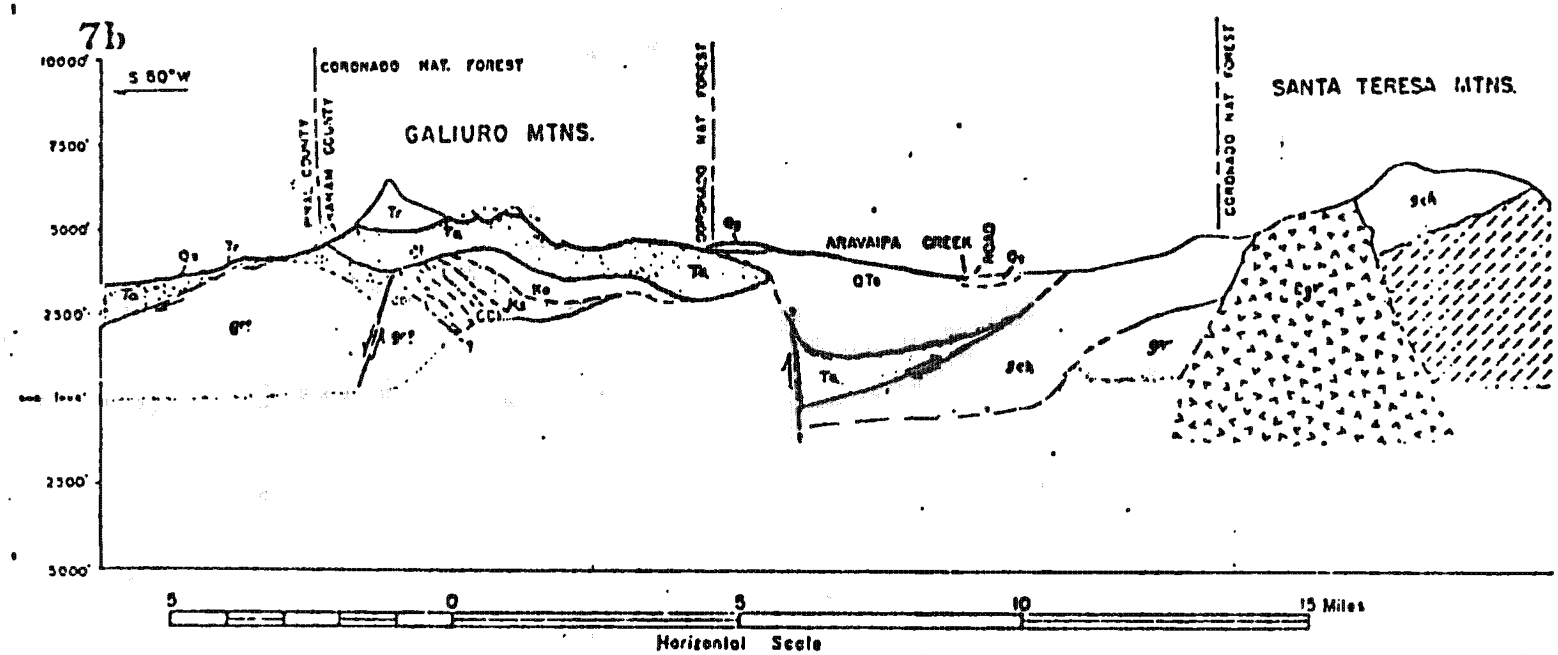


Fig. 3. Geologic cross section of Aravaipa Valley near Klondyke, Arizona--From Moore (1962)

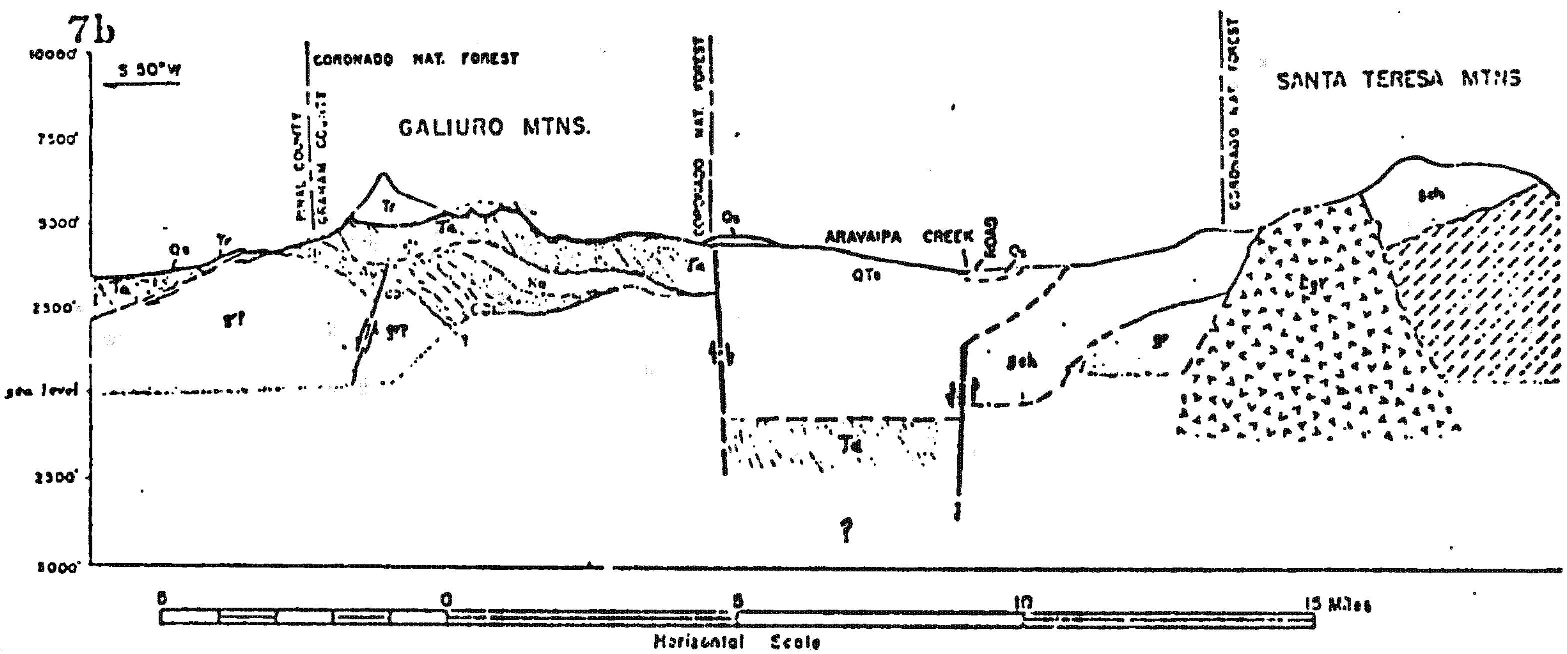


Fig. 4 . Modified geologic cross section of Aravaipa Valley near Klondyke, Arizona
--From Robinson (1976)

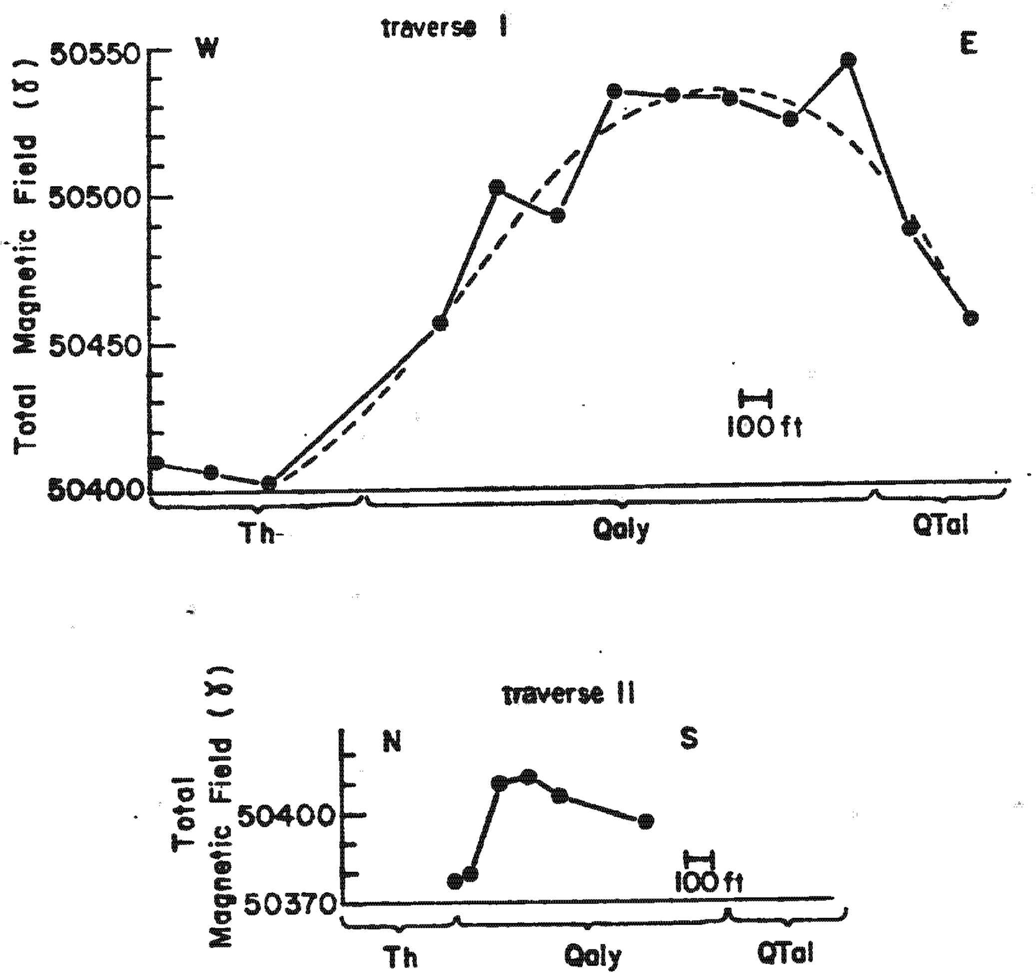
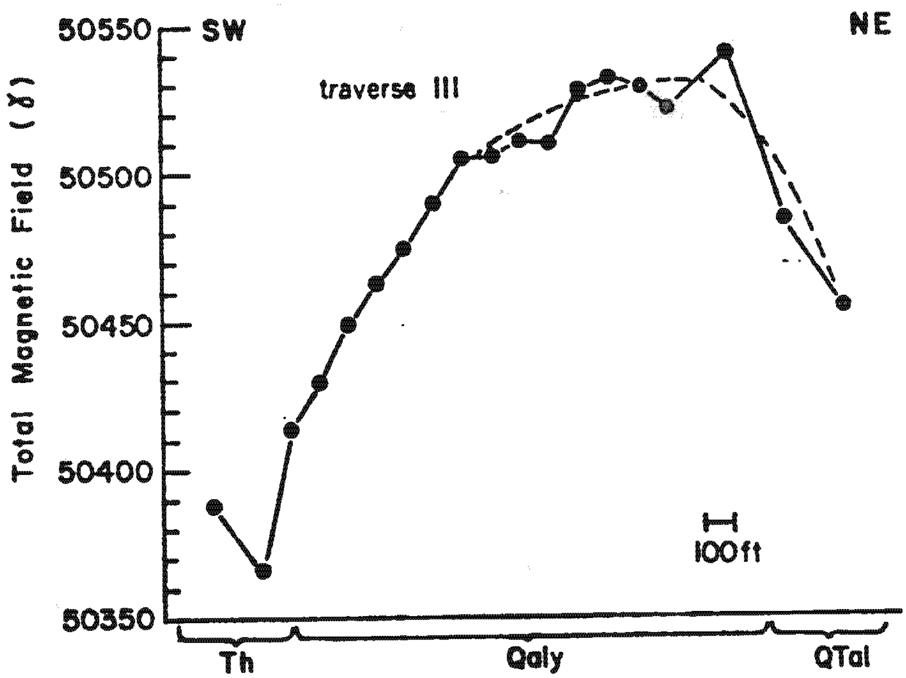


Fig. 5. Total field magnetic profiles



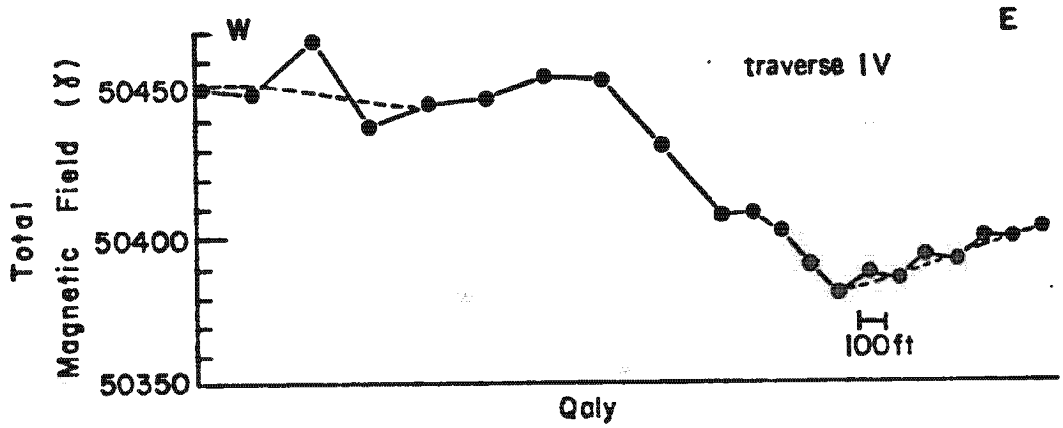


Fig. 5. Total field magnetic profiles--Continued

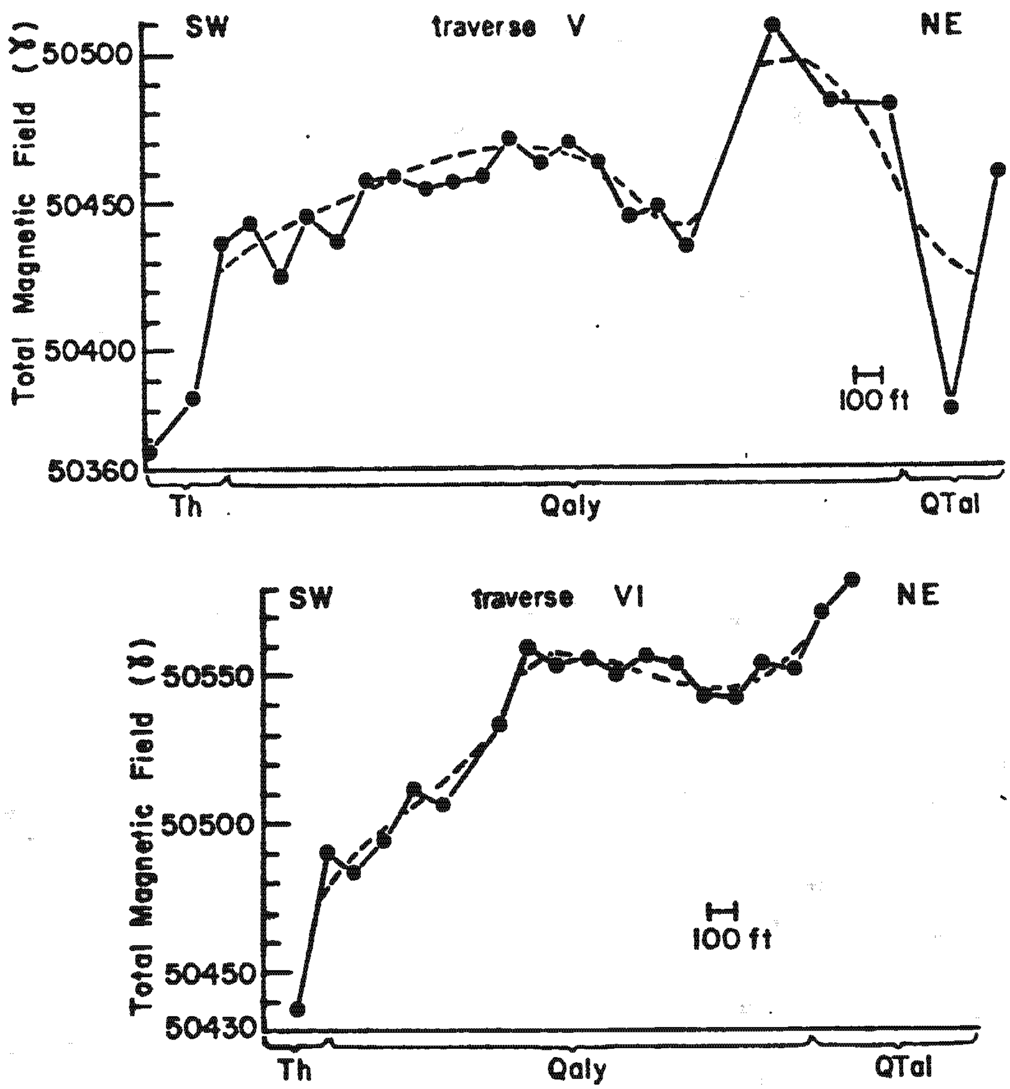


Fig. 5. Total field magnetic profiles--Continued

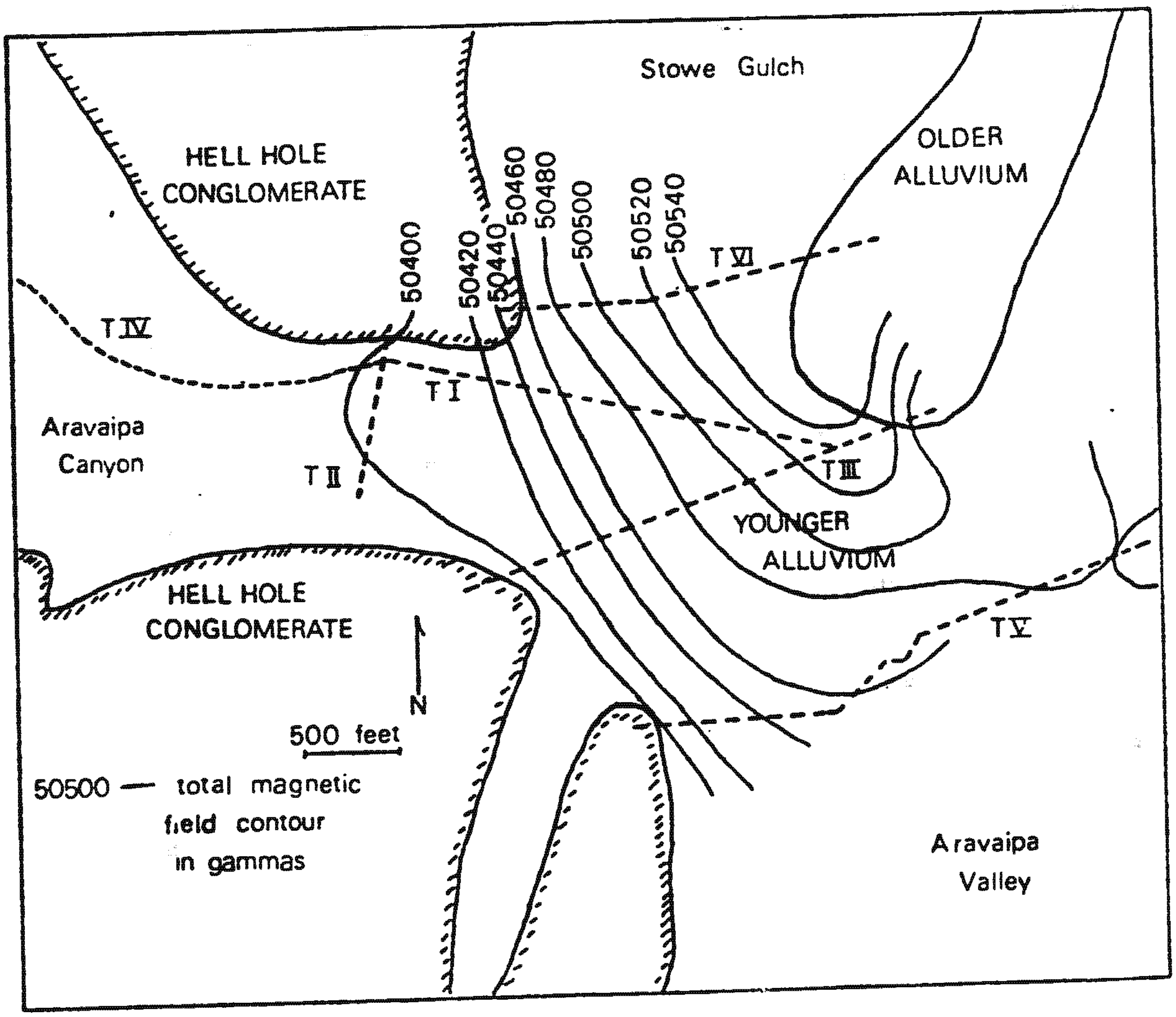


Fig. 6. Total magnetic field at the entrance to Aravaipa Canyon, east end

The 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 6. For procedure see Breiner (1973). An indication of these data, which are presented in Table 1, is 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.

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 shape of profile II (Fig. 5) suggests that the magnetic readings are rather sensitive to the presence and thickness of the more highly magnetic younger alluvium. This traverse begain 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 assume geologically simple profile to the information obtained near the mouth of the canyon suggests that the depth of the younger alluvium (plus older 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 proposed 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. 2).

It may be significant that the lowest recording occurred only 1,500 feet west of the canyon entrance, followed to the west by higher readings. This may be an indication that the canyon sediments do not continuously become shallower as one proceeds farther into the canyon.

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 used was a Bison Instruments signal enhancement seismograph, model 1570C. Three successful profiles were obtained: these are marked SP1, SP2, and SP3 on Figure 7 (in pocket). Figures 8, 9, and 10 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 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

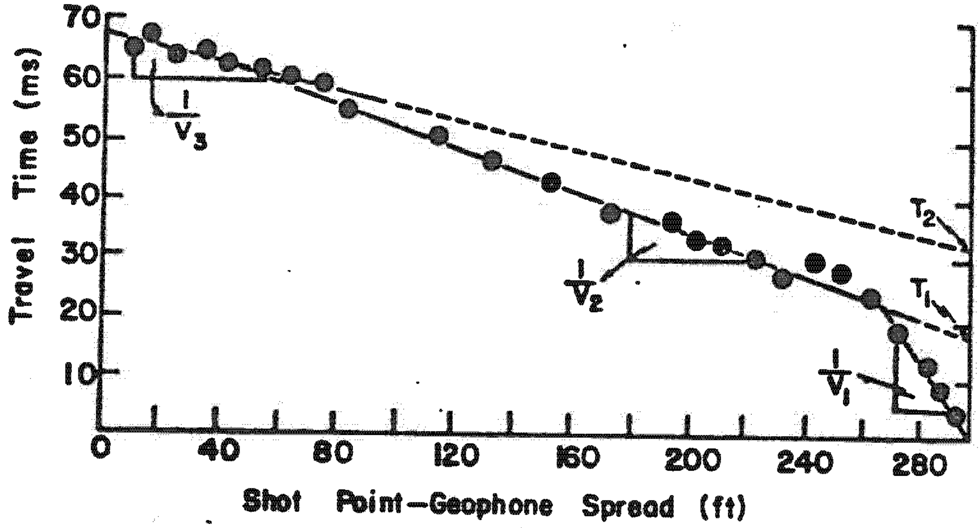


Fig. 8. Distance-travel time plot for seismic profile SP1

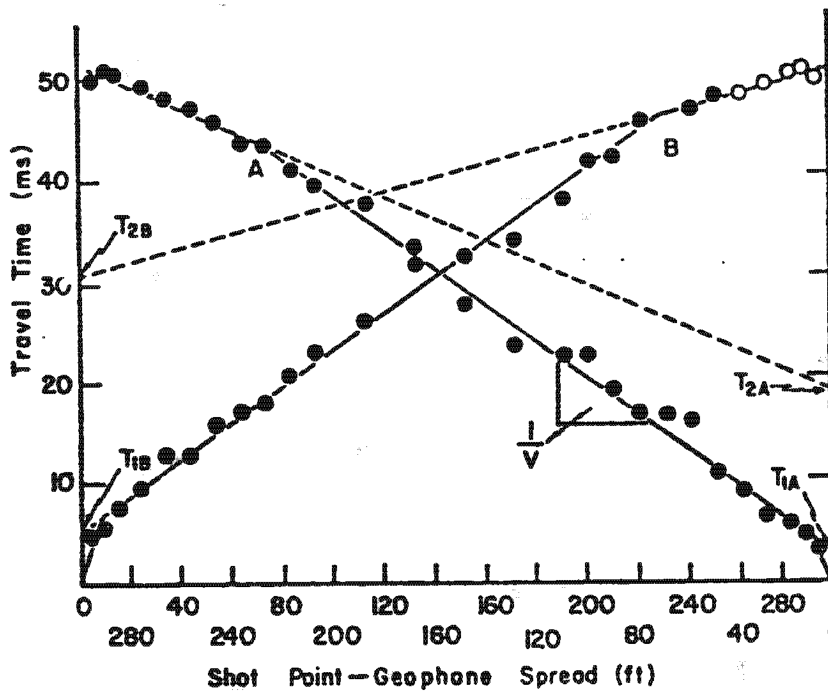


Fig. 9. Distance-travel time plot for seismic profile SP2

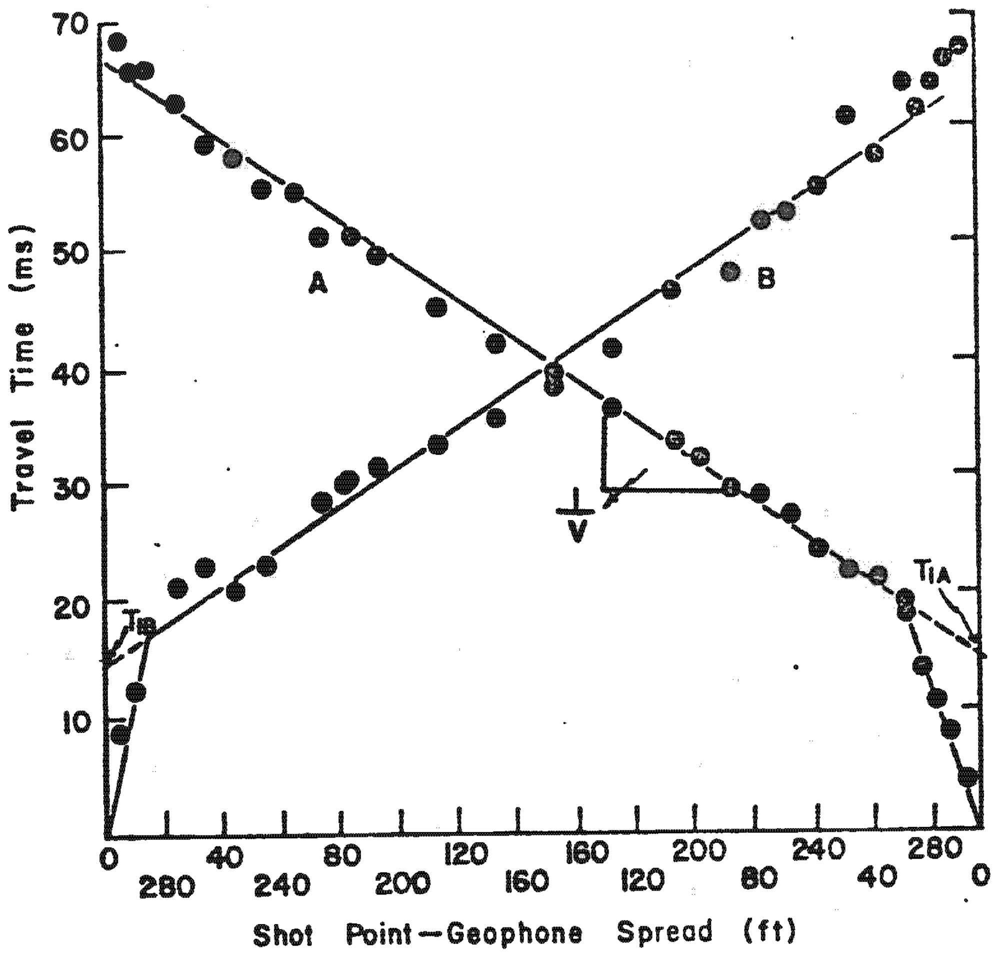


Fig. 10. Distance-travel time plot for seismic profile SP3

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 reponsible for the refraction.

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 -	older alluvium (?)
		>100.0	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 -	saturated young alluvium
		>100	Hell Hole Conglomerate

Seismic profile 1 (SP1) is located just 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. The highest seismic velocity recorded during the survey was 11,600 ft/s; this layer occurred 68.4 feet below the land surface in seismic profile 2 and is interpreted to be Hell Hole Conglomerate. This is very near the location that historically Aravaipa Creek emerges from the sediments during times of little precipitation (Tapia, pers. comm., 1979; Schnell, pers. comm., 1979). Slopes on the distance-travel time plots corresponding to a velocity near 11,600 ft/s were looked for in identifying the Hell Hole Conglomerate once this layer had been observed on SP2. In seismic profile 3, placed near the Defender's guest house, no layer of sufficient velocity was observed to be called the Hell Hole Conglomerate; therefore, it is placed at a minimum depth of 100 feet below the land surface.

In summary, the position of the thinnest unconsolidated sediment layer (68.4 ft) of the three locations tested is at SP2, 3,000 feet west of the entrance to the canyon. At SP1 near the position of the buried fault at the entrance to the canyon, the Hell Hole Conglomerate is more than 100 feet below land surface as it is nearly 2 miles into the canyon at SP3. In consideration of the variability in the canyon's width and the apparent variability in its depth, the cross-sectional area of the unconsolidated material in a vertical plane normal to the direction of the ground-water flow is also highly variable. This is important due to this parameter's influence on underflow through Aravaipa Canyon and the emergence of Aravaipa Creek.

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. 2). The Grand Reef mine and the mines to the 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 x 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 having 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 relinquished 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 relinquished.

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 interpreted by the authors to indicate leakage along the fault from a possible mineralized body at unknown, but great depth.

WATER RESOURCES

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

The Aquifer

The aquifer system of Aravaipa Valley consists mainly of the younger and older alluviums. These two deposits are continually fed by springs and, very likely, subsurface flow from the mountain fronts on either side of the valley. The discussion here will concern the production properties of the alluvial aquifer, water movement within it, and its relationship to perennial Aravaipa Creek.

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 various units. The younger alluvium is the formation on which most of the water wells begin; this formation is likely the most permeable, and water is usually found shallower than in other places. Nine well logs have been collected from wells beginning in this material, from Eureka Ranch to the south downstream to within Aravaipa Canyon.

Inspection of the logs reveals three that 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 "conglomerate," at 96 feet. The example far to the south, near Eureka Ranch, shows much clay beginning at 27 feet and sand and gravel above that point. It is likely that the changes noted represent the upper surface of the older alluvium.

The possibility of the younger alluvium being more than 100 feet thick is also supported by the seismic data. Simons (1964) suggested that the thickness of this deposit "may be several tends of feet." The terms "top soil," "gravel," "sand," and "clay" are all used in describing various horizons within the younger alluvium.

At least five wells in this formation 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. The following equation relates a well's specific capacity to the aquifer's important parameters, transmissivity and storativity. Transmissivity is a measure of an aquifer's ability to transmit water. From Walton (1970,

$$Q/s = \frac{T}{264 \log\left(\frac{Tt}{2693 r_w^2 S}\right) - 65.5}$$

where:

		This Case
Q/s	= specific capacity, in gpm/ft	61.25 and 93.75
Q	= discharge, in gpm	1,225
s	= drawdown in well, in feet	20 and 13
T	= transmissivity, in gpd/ft	90,000 and 144,000
S	= storativity, a fraction	0.15 (assumed)
r_w	= nominal radius of well, in feet	1.3
t	= time after pumping started, in minutes	3,600 (assumed)

The range in computed drawdown, specific capcity, and transmissivity values stems from the low value being calculated, assuming 100 percent well efficiency and full penetration, and the high value being calculated by correcting the observed drawdown for 30 percent well loss and partial penetration (see Hantush, 1964). Due to this circumstance not meeting some assumptions used in deriving the above equation, e.g., artesian aquifer, etc., and the inherent unknowns in specific capacity data, e.g., percent well loss, etc., the range 90,000 to 144,000 gpd/ft for the transmissivity range is to be viewed with some uncertainty. Also, this is a point value in an inhomogeneous, anisotropic aquifer of considerable areal extent. Therefore, calculations based on this value range should be viewed with even more uncertainty if the transmissivity is taken to represent the aquifer as a whole.

Five well logs have been collected that definitely penetrate the older alluvium. They described 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 is at least 350 feet thick (Gould and Wilson, 1976). Probably an absolute thickness of 825 feet of older alluvium is penetrated in well (D-9-21)14caa before the first cemented rock is reached.

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

Well (D-9-21)14aaa begins in the younger alluvium below Eureka Ranch headquarters. It penetrates 27 feet of younger alluvium, 825 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 feet. 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. 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.

While 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, possibly on the order of a few tens of feet. One well in the basin at Eureka Ranch is reported to flow, but the depth from which the water is being produced is not know (Valenzuela, pers. comm., 1979). 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 in the northern reaches of Aravaipa Valley where the water table nears land surface.

The productivity of wells not placed in the younger alluvium is generally small.

Ground-water Flow

It is assumed that water enters the ground-water system of Aravaipa Basin from (a) spring and subsurface flow near the mountain fronts, (b) streambed infiltration of runoff water from the highlands, and (c) direct infiltration of precipitation. The relative quantitites of these contributions are not known, but observations of spring discharges and the ground-water contours of Figure 11 (in pocket) suggest that mountain-front recharge may be the largest contributor. As will be shown later, an estimated 2.2 percent of the watershed's total annual rainfall is expected to find its way into the ground-water reservoir.

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 11 (in pocket).

Figure 11 ahows that 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 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 Figures 1 and 7. From the contouring of the ground-water levels 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, while 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 and others, 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.

Possibly 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 basement high is supported both by gravity data represented in Figure 1 and the longitudinal ground-water and topographic cross section of Figure 12.

The gravity data show a residual gravity anomaly of zero coinciding with the topographic and ground-water divide; theoretically, this would mean that granitic basement rock should be at land surface. Observations in this area do not confirm this prediction, suggesting that basement rock should be very shallow.

The topographic and ground-water cross sections of Figure 12 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 would not be possible for the water levels shown in Figure 12 to 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 shown in the figure drained into Aravaipa Creek to the left of that figure. The impeding structure is 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 1.

The Emergence of Aravaipa Creek

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, pers. comm., 1979). 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

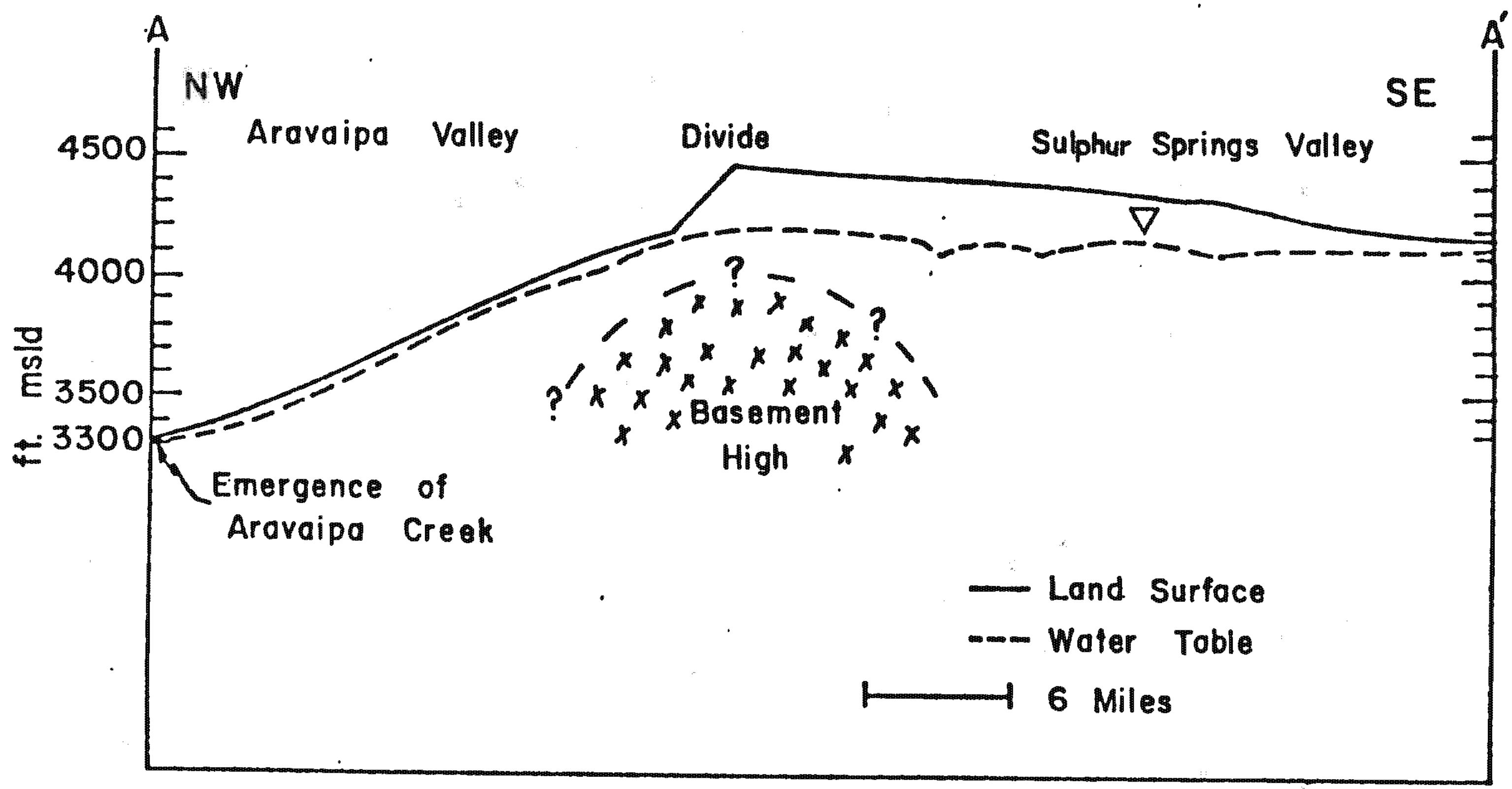


Fig. 12. Topographic and ground-water profile along section A-A' of Figure 1

this water due to the restricted flow path. The 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. 11). 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. 2 and the section on geophysics).

During times of above-average rainfall, Aravaipa Creek may emerge from the alluvium well upstream from the beinning 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 1978 precipitation's being twice the annual average in this area, Aravaipa Creek was flowing at least 0.5 mile upstream from the canyon during the entire summer of 1979 when this study was conducted.

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

$$Q = KAI$$

where Q = ground-water discharge (L^3/T)
K = hydraulic conductivity (L/T)
A = cross-sectional 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 11.

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 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 dramatically, 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.)

Because the point of emergence is historically not immediately at the entrance to the canyon and this point wanders considerably (Schnell, pers. comm., 1979) even while within the canyon, the alluvium is not thought to reach its final thickness immediately on the upthrown side of the fault marking the canyon entrance (see sections on geology and geophysics). More, the sedimentary cover within Aravaipa Canyon probably becomes shallower gradually possibly to its confluence with Turkey Creek where its width is also considerably reduced.

The 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:

$$\text{Rainfall} = \text{Evapotranspiration} + \text{Stream Discharge} + \text{Pumpage}$$

Ground-water levels are 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 (NOAA). Information on the distribution of this rainfall over the area of interest is presented in Figure 13 and was obtained from a map by the Department of Geosciences, The University of Arizona, and others in 1965. From calculations based on this map the estimated total volume of precipitation on the watershed is 480,000 acre-feet/year. Calculations and data used in these analyses are presented in Appendix B. The monthly distribution of precipitation for Klondyke and temperature for Aravaipa Canyon are presented in Figure 14.

Evapotranspiration

Evapotranspiration was broken into two factors: evapotranspiration by surface water and phreatophytes in Aravaipa Canyon and evapotranspiration of water over the entire watershed that never reaches the water table. This latter component was not dealt with directly and is assumed to account for the rainfall not accounted for by the other components.

A method of estimating the potential evapotranspiration (P.E.T.) was developed by Thornthwaite (1948), which requires only mean monthly temperatures and the area's latitude. This method has shown high results when 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 3.

The P.E.T. by month, in inches of water, is for the area of growth, in this case, the floor of Aravaipa Canyon. An estimation of the area of phreatophyte growth in Aravaipa Canyon was measured 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 1.41 square miles. By multiplying this area by the monthly

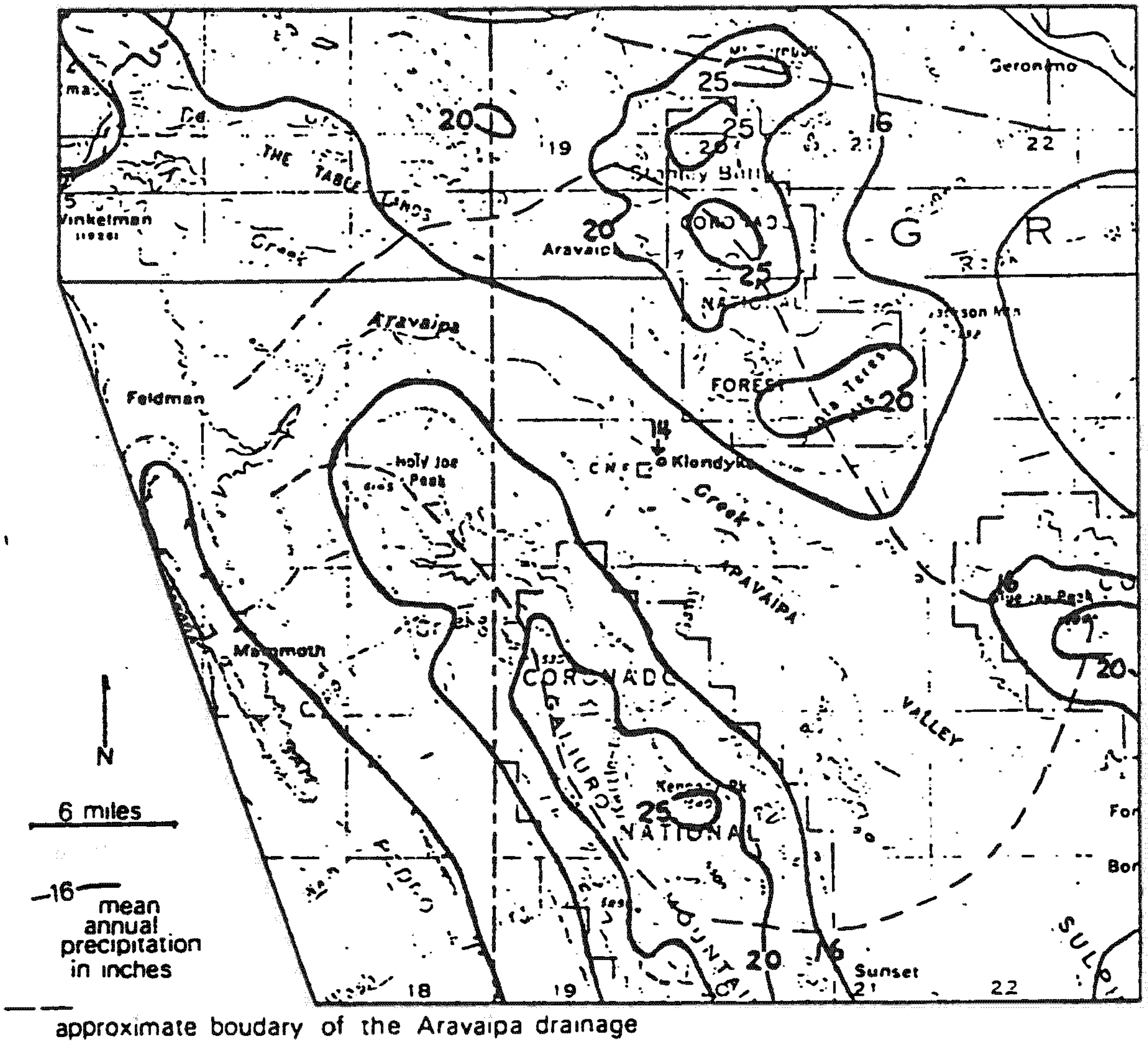


Fig. 13. Mean annual rainfall, Aravaipa area

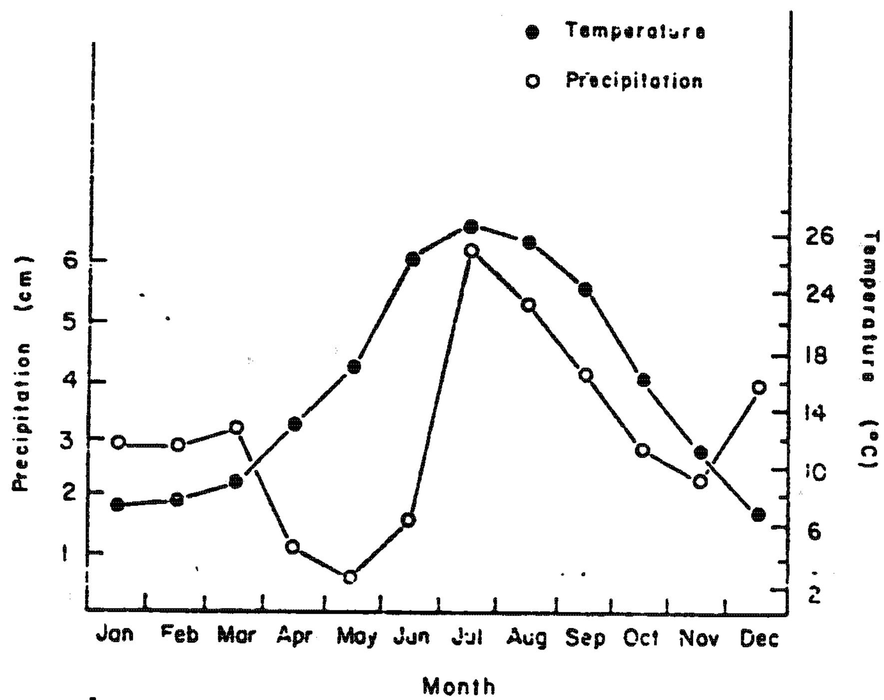


Fig. 14. Monthly distributions of precipitation at Klondyke, Arizona, and temperature in Aravaipa Canyon, Arizona

Table 3. Potential Evapotranspiration

Month	Potential Evapotranspiration	
	inches	acre-feet
Jan	1.44	107
Feb	1.45	109
Mar	2.05	152
Apr	3.34	198
May	4.87	365
Jun	7.42	556
Jul	8.38	628
Aug	7.67	575
Sep	5.81	437
Oct	3.78	283
Nov	2.26	169
Dec	1.20	98

use in inches, a volume is calculated and presented in the third column of Table 3. The addition of these monthly P.E.T. volumes equals 3,654 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). Results of these data indicated for August a mean relative humidity of 62 percent. Based on his method the P.E.T. for August is 7.96 inches, which agrees well with Thornthwaite's (see Appendix B). Further work by Eagleman indicates that actual evapotranspiration may 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 create 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 inches.

The average of Eagleman's estimated ET and White's ET 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 has been shown 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 2,448 acre-feet.

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 S., R. 17 E.). For the 22-year record available, its mean flow is equal to 28.0 cubic feet per second (cfs), or 20,271 acre-feet per year (U.S. Geological Survey gaging station data). Further discussion of stream flow is included under the discussion of surface water.

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 percentage of water that returns to the ground-water system after application.

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 this equation is

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

Total rainfall		480,000 acre-ft
$ET_{indirect}$	2,400 acre-ft	
Stream discharge	20,300	
Pumpage	3,100	
Total volume accounted for		25,800
Total volume unaccounted for		454,200 acre-ft
	or	94.6%

This unaccounted-for 94.6 percent of the rainfall is evaporated soon after it falls or is transpired after infiltration into the root zone; 5.4 percent of the watershed's total rainfall has been accounted for by the above analysis. As will be shown, 3.2 percent of this water runs off the land and downstream without infiltration and the other 2.2 percent infiltrates into the ground-water system.

Total surface runoff values of 2.0 and 2.7 percent have been measured by Renard (1970) and Resnick (pers. comm., 1979), 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 annual basis is highly correlated negatively with drainage area." This is attributed to stream-channel infiltration between the precipitation local and the runoff measuring point. This correlation, along with Aravaipa's tenfold greater drainage area suggests that 3.2 percent surface runoff may be 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.

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 American 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. 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.

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 July 10, 1979 flow data are also available from the U.S. Geological Survey Aravaipa Creek gaging station. These data, along with the differences between the recordings, are given in Table 4. The differences between the recordings are due to changes in streamflow along the more than 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 4. Correlation between simultaneous measurements of creek discharge in the summer of 1978, Aravaipa Creek, Arizona

Monthly Precipitation in Aravaipa Canyon [a]		Date of Measurement	Discharge Measured at East End (Site S2)	Discharge Measured at West End by U.S.G.S Gage (09473000)	Difference in discharge
Mar	2.06 in.	3/20/79	30 cfs	38 cfs	- 8 cfs
Apr	0.34	4/2	31	40	- 9
		4/23	29	51	-22
May	1.96	5/10	28	42	-14
Jun	0.54	6/8	27	21	+ 6
		6/13	26	29	- 3
		6/27	28	24	+ 4
		6/30	27	23	+ 4

a. Data from Schnell (unpublished)

Surface-water contributions to Aravaipa Creek within the canyon 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. The significant canyons and springs have been located on Figure 7. It can be inferred from the data in Table 4 that surface-water contributions were most significant during the early portion of the study when rainfall and therefore surface runoff were at their highest. These are the months for which the gaging station down stream had consistently higher flows than did the measuring point on the east end, S2. For the 4 days during the month of June (when rainfall was 0.54 inches) the S2 measuring point averaged 3 cfs higher 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 surface-water contributions, the increase in the evapotranspiration rate, and possible irrigation diversions.

With the tributary streams not contributing to Aravaipa Creek flow the gaging station data should represent the portion of Aravaipa Creek flow that can be attributed to ground-water runoff from the Aravaipa Basin aquifer; this quantity is base flow.

The difference between the actual base flow and the base flow recorded at the gaging station is the +3 cfs difference measured during June 1979.

To estimate base flow, data collected over more than one summer are necessary. By using the +3 cfs difference obtained above to adjust the base flow measured over the years at the downstream gaging station, the necessary information can be obtained. Unadjusted base flow was measured for 4 full years from a hydrograph consisting of daily mean flows. The process used was to count only that portion under the hydrograph curve that did not represent runoff, draw a line between these points, and then determine the average position of this line in cfs (see Appendix B). This process was conducted for flow data from years October 1971 to October 1974 and October 1975 to September 1976. These included years of above-, below-, and near-normal precipitation. From this the calculated mean unadjusted base flow is 7.22 cfs. To this value is added the 3 cfs taken to be the error in the gaging station's base flow for a "best value" mean base flow of 10.22 cfs (~7,400 acre-ft/yr).

Aquifer recharge is equal to base flow plus pumpage and is therefore 7,400 + 3,100 = 10,500 acre-ft/yr. This is 2.2 percent of the watershed's total rainfall, not all of which even drains toward the aquifer.

There is evidence from analysis of the hydrographs that aquifer recharge occurs mainly during the winter and spring months when evapotranspiration requirements are at their lowest. Only during years of heavy summer rains is there an observable increase in the base flow of Aravaipa Creek.

Water Use

At the present time, surface-water is diverted from Aravaipa Creek for the 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's gaging station data show several months in 1920-1921 in which no flow reached the station site. This is attributed to larger irrigation diversions during those years (U.S. Geological sruvey stream gage data), 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-feet per year for irrigation, 13 acre-feet per year for domestic purposes, and 45 acre-feet per year for stock water (see section on hydrologic cycle). The history of the development of ground water in Aravaipa Valley is sketchy but 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 electricity costs (Lackner, pers. comm., 1979, and Claridge, pers. comm., 1979). The actual population of Aravaipa Valley has decreased also (Tapia, pers. comm., 1979). 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.

In my opinion, it seems unlikely that a serious threat to this perennial flow exists under the present economic status of Aravaipa Valley. Irrigated acres and therefore ground-water withdrawals could conceivably increase by 50 percent if all the presently installed wells were in use, but even the effect of an increase on this level is questionable.

A more serious threat to stream flow would be encountered if modern mining activities began in the area along with large-scale refinery water requirements.

Surface Water

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, and 1967 to the present 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 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 15 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 plot is

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

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

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

$\bar{Q}_i$ = 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

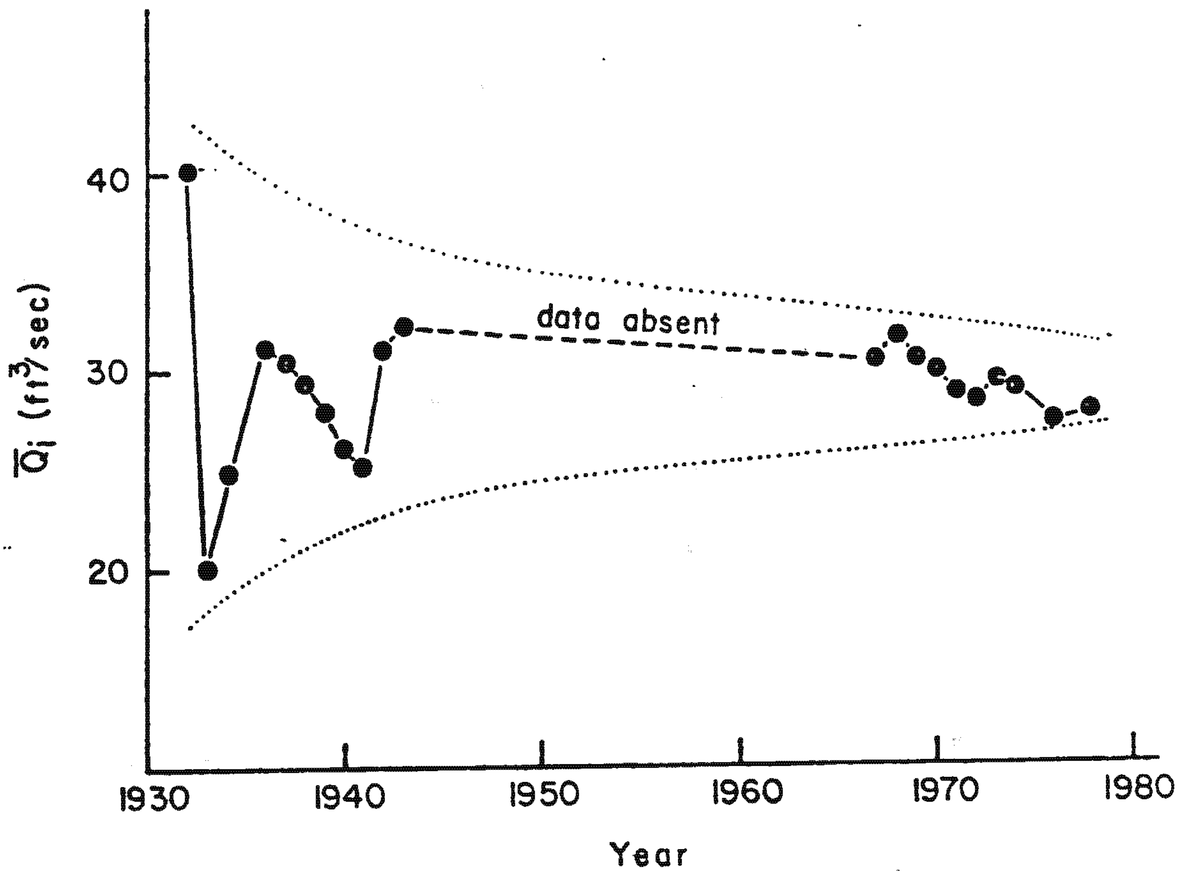


Fig. 15. Cumulative mean annual discharge for Aravaipa Creek from 1932 to 1978

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.

The dashed lines in Figure 15 represent the limits within which $\bar{Q}_i$ should fall given the stream's natural variation. The cone defined by the upper and lower dashed lines should be symmetrical about this "true mean" if discharge is normally distributed. It is clear from the plot that n is not large enough to exactly define this "true mean" and that at present, $\bar{Q}_i$ (i = 1978) falls in the lower region of the expected cone of variation about the apparent "true mean."

Figure 15 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 $\bar{Q}_i$s for i = > 1980 will not fall in the cone of variation established during the time i < 1980.

Cumulative means such as the quantity $\bar{Q}_i$ are more useful in recognizing changes than simply a plot of Q_i because natural variability is somewhat damped out and a smoother, more easily interpretable curve prevails.

For Aravaipa Creek it must be noted that only 22 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 $\bar{Q}_i$ must signal one of the following: (1) increasing human use of the ground or surface water or (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 1967-1978, these data groups were analyzed separately to make possible a statistical "test" to determine the probability of the observed changes being due to external influences. Table 5 contains the statistical information necessary for the analyses.

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

Table 5. Data for discharge for Aravaipa Creek

Data Grouping	Mean Discharge	Variance
1. Pooled data	28.00 cfs	276.07
2. 1932–1942	32.07	372.6
3. 1967–1978	23.93	179.54
4. 1932–1942[a]	27.33	174.92

a. For this group, a Q_i value with an exceedence probabilty of 1.5×10^{-3} (= 750-year event) was thrown out.

is: What is the probability that the observed difference in the means between data groups 2 and 3 is due to natural variation? The answer for data groups 2 and 3, assuming a normal distribution, is 26 percent. This says that given the observed variance of the data, there is a 26 percent chance that a difference of ± 8.14 cfs would show up between the two means. This is equal to a 13 percent chance that a difference of - 8.14 cfs would show up. The value - 8.14 cfs is the observed difference.

An extreme value of 78.5 cfs appears in the 1932-1942 data group. It was determined to have an exceedence probability of 1.5×10^{-3}, this corresponds to a recurrence interval of approximately 750 years. Based on the unlikeliness of this event occurring, it was thrown out and the hypothesis test run again. This time there turned out to be a 33 percent chance that the observed difference in the mans (- 8.41 cfs) was due to natural variation.

In most situations a statistician would not rule out a hypothesis unless it had a 5 percent or less chance of explaining the observed data. Both tests run on the Aravaipa data yielded a greater than 5 percent chance of natural variation explaining the observed data; therefore, this possibility, by convention, is not ruled out.

The second test run, without the extreme value of 78.5 cfs included, is probably the more accurate in representing what can be expected of Aravaipa Creek. The indication of this test suggests a large probability (33%) that no external influence has played a role in determining Aravaipa Creek's mean annual flow over the years for which data are available.

Figure 16 is a plot of the mean monthly discharges for the two data groupings 1932-1942 and 1967-1978. 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, pers. comm., 1979). Seeing that it is also a month of low rainfall (0.60 inches), the data may suggest that irrigation practices have not changed significantly over the period for which data exist. It would be during these low-flow months that the stream would be most sensitive to such changes.

Streamflow-Geology Relationships

Flow measurements of Aravaipa Creek were taken throughout the perennial flow stretch to try to identify the relationship 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 meter stations were selected at each measurement location, and one reading depth per station was used. Figure 17 presents these measurements as a function of time and position, plus an indication of the canyon floor width at the particular locations.

It was recognized early on that 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" (see Figure 7), the flow measured 14.6 cfs on the first pass through the canyon. The second measuring point, S2, measured 27.41 cfs, which was 81 percent of the maximum recorded for that pass. Downstream, only about one mile, after no consumed diversions, the flow as 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.

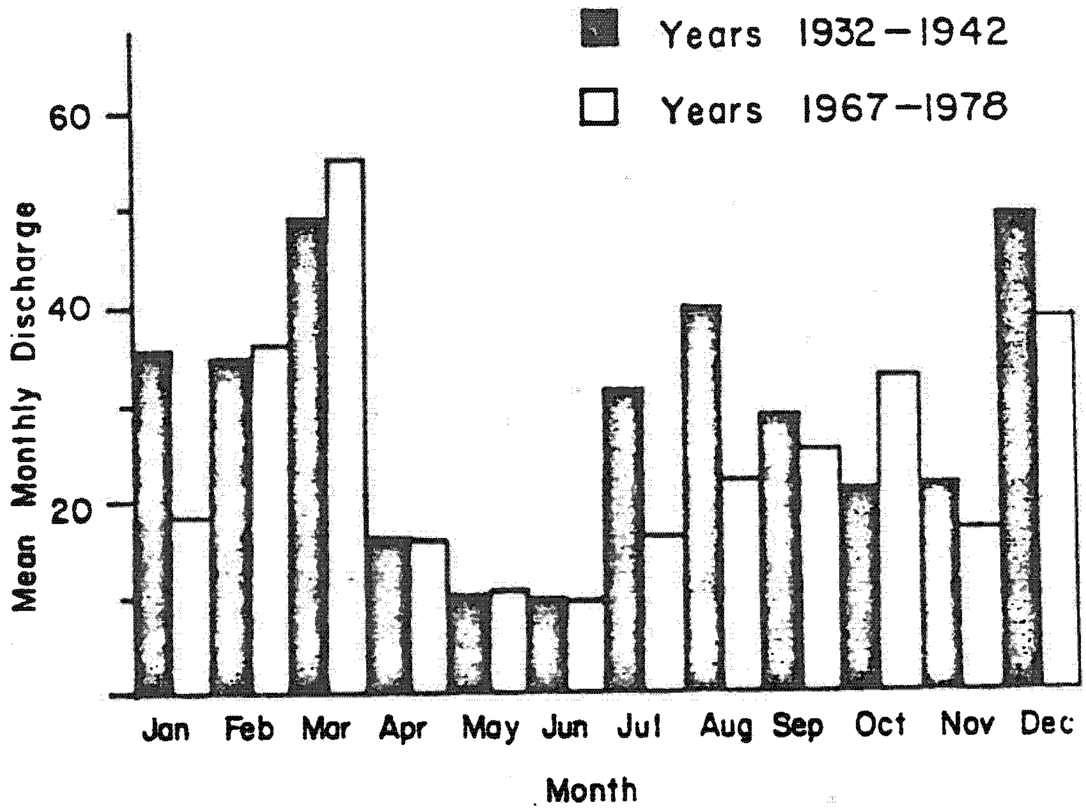


Fig. 16. Comparison of mean monthly discharges from years 1932-1942 and 1967-1978

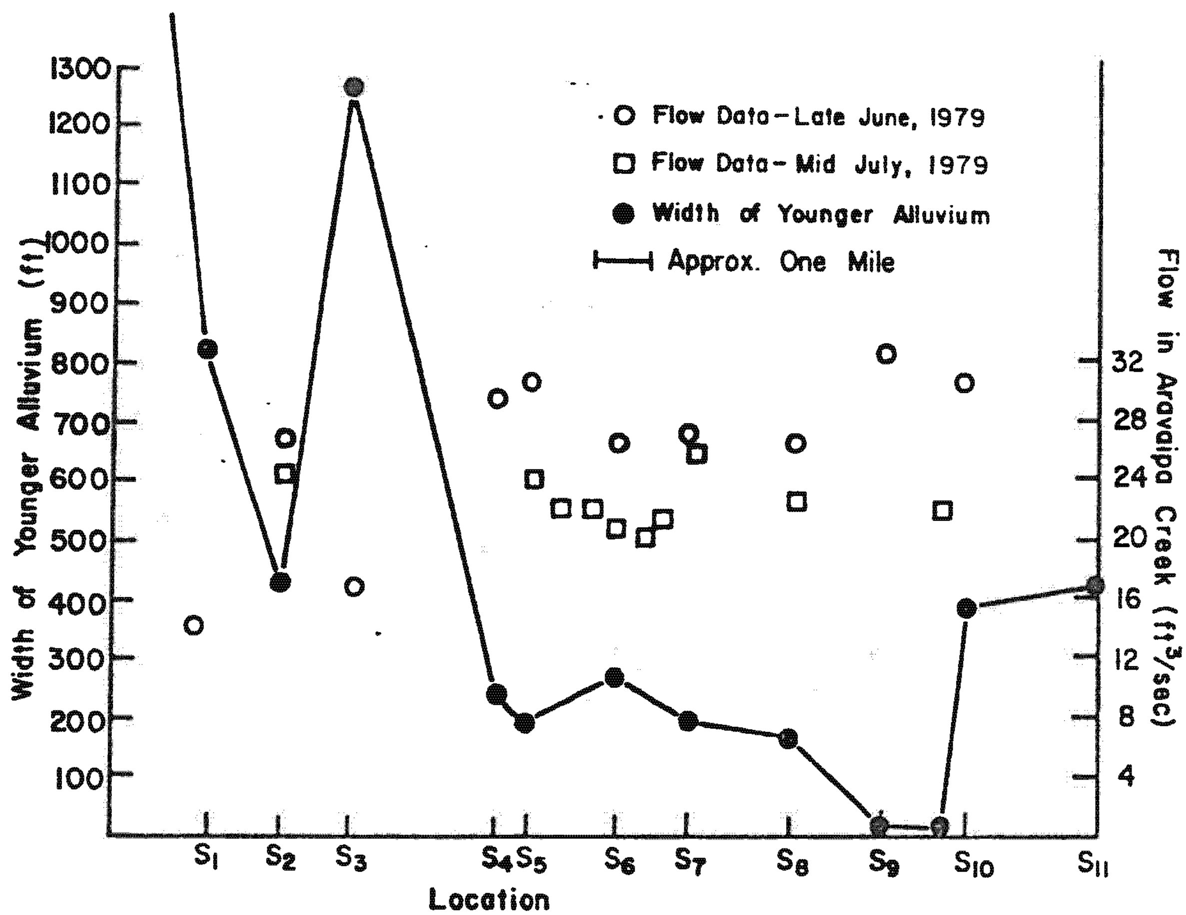


Fig. 17. Flow data for Aravaipa Creek shown as a function of position and canyon floor (younger alluvium) width

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 17.

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 (at S9). Due to possible underflow at S2, 81 percent is a minimum ground-water percentage contribution, thus suggesting that contributions from springs and tributaries in the Hell Hole Conglomerate and Galiuro Mountains are at most 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.

Water Quality

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 7.

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 render comparison of total chemicals less informative in regards to tracing the source of Aravaipa Creek water. The analyses presented in Table 6 were conducted by the Soils, Water and Plant Tissue Testing Laboratory, Department of Soils, Water and Engineering, College of Agriculture, The University of Arizona. The data are grouped according to source and are presented Diagrammatically in Figures 18-20.

Following the recommendations of Sommerfeld (1977), who found up to 75 ppb Hg in Aravaipa Creek water, samples from the 12 sites were

Table 6. 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	Mg	Na	Cl	SO_4	HCO_3	CO_3	F	N[a]	Pb	SiO_4	SAR[b]	Hardness	% Error in Analysis[c]
SW¼SE¼ sec. 7, T7S, R20E	Haby	7/21	windmill	0.24	257	7.2 (7.5)	22	31	6	24	16.8	11	166	0	0.41	2.14	0.022	28.8	0.99	6.5	3.42
SE¼SW¼ sec. 25, T6S, R19E	Proctor house	7/21	domestic well	0.22	264	8.0 (8.4)	23	6	1	69	17	11	151	7.2	1.72	0.09	0.022	19.6	6.12	1.41	0.29
	Peyote Church of God	7/21	irrigation well	0.27	343	7.3 (7.7)	22.5	38	11	44	16.8	11	225	0	0.55	2.43	0.036	39.2	1.62	8.2	4.08
SE¼SW¼ sec. 36, T6S, R19E	Proctor	7/21	irrigation well	0.28	259	7.1 (7.8)	18	46	8	18	16	30	107	0	0.42	3.02	0.033	31.6	0.64	8.64	12.65
SW¼ sec. 14, T9S, R19E	Eureka Ranch	7/23	domestic well	0.18	211	7.9 (8.0)		19	7	28	12	2	142	1.2	0.5	0.95	0.022	34.4	1.4	4.5	0.90
SE¼NE¼ sec. 35, T6S, R19E	Cobra Ranch	7/21	domestic well	0.41	485	7.0 (7.6)	21	88	14	22	16	42	278	0	1.05	1.18	0.033	25.0	0.57	16.22	4.95
W¼ sec. 27, T8S, R21E	Claridge	7/21	stock well	0.25	297	7.1 (7.7)	23 23	40 40	9 9	28 28	15 15	5 5	200 200	0 0	0.45 0.45	1.45 1.45	0.033 0.033	30.8 30.8	1.04 1.04	8.09 8.01	0.64 0.64
SW¼ sec 27, T7S, R19E	Lackner	7/21	mountain-front spring	0.33	416	7.1 (7.7)	24	56	17	27	14.4	2	300	0	0.3	0.47	0.036	50.4	0.81	12.3	0.19
E¼ sec 1, T6S, R19E	Stowe Spring	7/22	mountain-front spring	0.37	415	6.9 (7.7)	21	69	16	20	16	42	225	0	1.6	0.04	0.036	27.2	0.56	14.0	4.94
W¼NE¼ sec. 19, T6S, R19E	Turkey Creek seep	7/22	conglomerate bedding-plane seep	0.28	341	>8.0 (8.8)	22	5	0.6	98	22	3	200	12.0	1.17	1.87	0.022	44.0	11.0	0.87	1.22
E¼SE¼ sec. 35, T6S, R19E	Aravaipa Creek, first crossing	7/22	surface stream	0.30	304	7.8 (7.6)	22	54	11	19	16.4	33	171	0	0.42	2.95	0.033	32.8	0.62	10.5	4.85
E¼SW¼, sec. 27, T6S, R19E	Aravaipa Creek, near guest house	7/23	surface stream	0.32	366	7.8	22	59	11	22	16	53	205	0	0.58	3.92	0.033	34.0	0.69	11.3	2.04

Analyses by Soils, Water and Plant Tissue Testing Laboratory, Department of Soils, Water and Engineering, College of Agriculture, The University of Arizona

a. Analyzed as nitrate. b. Soidum absorption ratio = (meq Na)/((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.

Table 6. 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	Mg	Na	Cl	SO_4	HCO_3	CO_3	F^-	N[a]	Pb	SiO_2	SAR[b]	Hardness	% Error[c] in Analysis
SW¼SE¼ sec. 7, T7S, R20E	Haby	7/21	windmill	0.24	257	7.2 (7.5)	22	31	6	24	16.8	11	166	0	0.41	2.14	0.022	28.8	0.99	6.5	3.42
NE¼SW¼ sec. 25, T6S, R19E	Proctor house	7/21	domestic well	0.22	264	8.0 (8.4)	23	6	1	69	17	11	151	7.2	1.72	0.09	0.022	19.6	6.12	1.41	0.29
	Peyote Church of God	7/21	irrigation well	0.27	343	7.3 (7.7)	22.5	38	11	44	16.8	11	225	0	0.55	2.43	0.036	39.2	1.62	8.2	4.08
SE¼SW¼ sec. 36, T6S, R19E	Proctor	7/21	irrigation well	0.28	259	7.1 (7.8)	18	46	8	18	16	30	107	0	0.42	3.02	0.033	31.6	0.64	8.64	12.65
SW¼ sec. 14, T9S, R19E	Eureka Ranch	7/23	domestic well	0.18	211	7.9 (8.0)		19	7	28	12	2	142	1.2	0.5	0.95	0.022	34.4	1.4	4.5	0.90
SE¼NE¼ sec. 35, T6S, R19E	Cobra Ranch	7/21	domestic well	0.41	485	7.0 (7.6)	21	88	14	22	16	42	278	0	1.05	1.18	0.033	25.0	0.57	16.22	4.95
SW¼ sec. 27, T8S, R21E	Claridge	7/21	stock well	0.25	297	7.1 (7.7)	23 23	40 40	9 9	28 28	15 15	5 5	200 200	0 0	0.45 0.45	1.45 1.45	0.033 0.033	30.8 30.6	1.04 1.04	8.09 8.01	0.64 0.64
SW¼ sec 27, T7S, R19E	Lackner	7/21	mountain-front spring	0.33	416	7.1 (7.7)	24	56	17	27	14.4	2	300	0	0.3	0.47	0.036	50.4	0.81	12.3	0.19
SE¼ sec 1, T6S, R19E	Stowe Spring	7/22	mountain-front spring	0.37	415	6.9 (7.7)	21	69	16	20	16	42	225	0	1.6	0.04	0.036	27.2	0.56	14.0	4.94
SW¼NE¼ sec. 19, T6S, R19E	Turkey Creek seep	7/22	conglomerate bedding-plane seep	0.28	341	>8.0 (8.8)	22	5	0.6	98	22	3	200	12.0	1.17	1.87	0.022	44.0	11.0	0.87	1.22
NE¼SE¼ sec. 35, T6S, R19E	Aravaipa Creek, first crossing	7/22	surface stream	0.30	304	7.8 (7.6)	22	54	11	19	16.4	33	171	0	0.42	2.95	0.033	32.8	0.62	10.5	4.85
SE¼SW¼, sec. 27, T6S, R19E	Aravaipa Creek, near guest house	7/23	surface stream	0.32	366	7.8	22	59	11	22	16	53	205	0	0.58	3.92	0.033	34.0	0.69	11.3	2.04

Analyses by Soils, Water and Plant Tissue Testing Laboratory, Department of Soils, Water and Engineering, College of Agriculture, The University of Arizona

a. Analyzed as nitrate. b. Soidum absorption ratio = (meq Na)/((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.

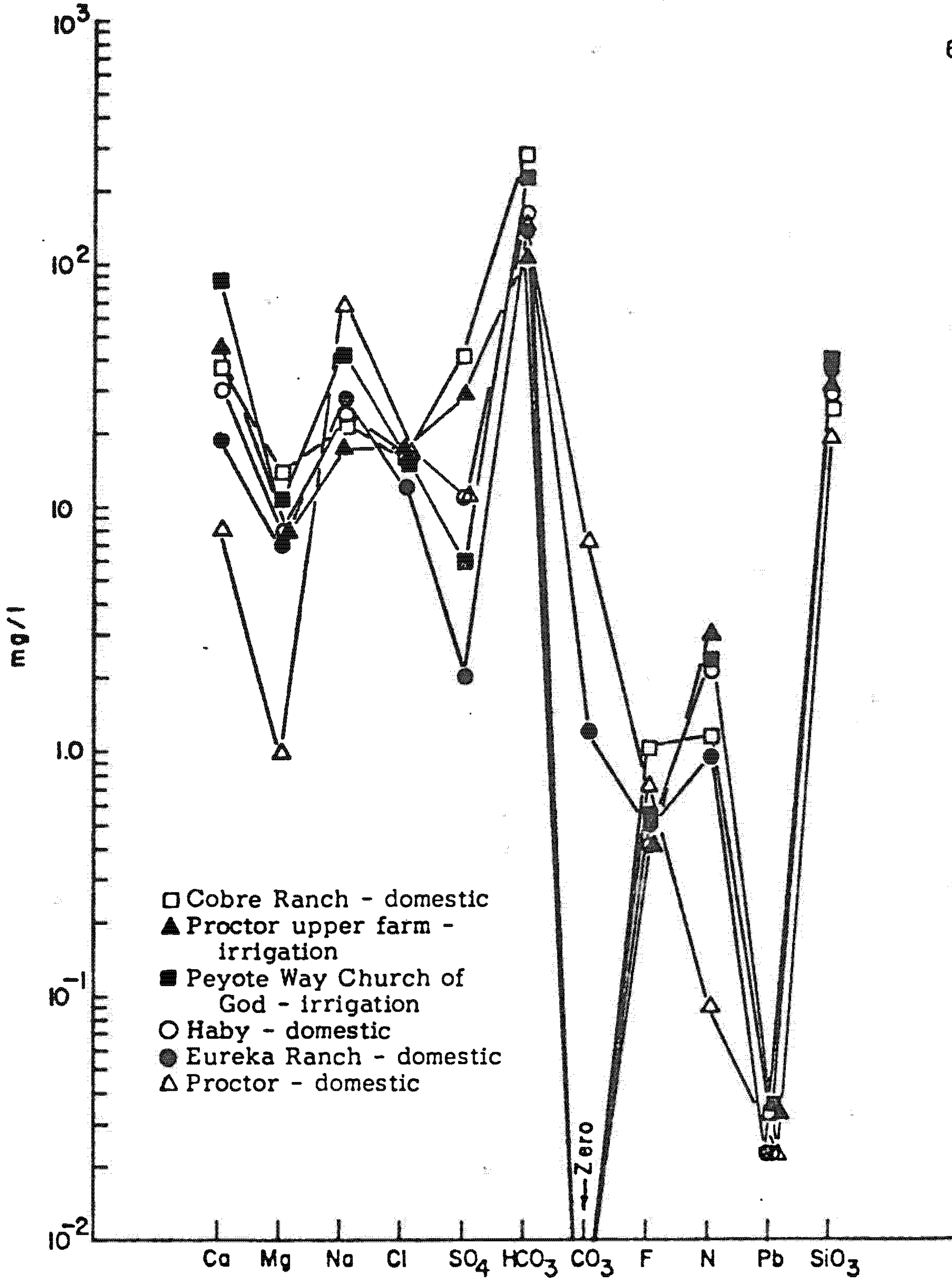


Fig. 18. Ground-water chemical data

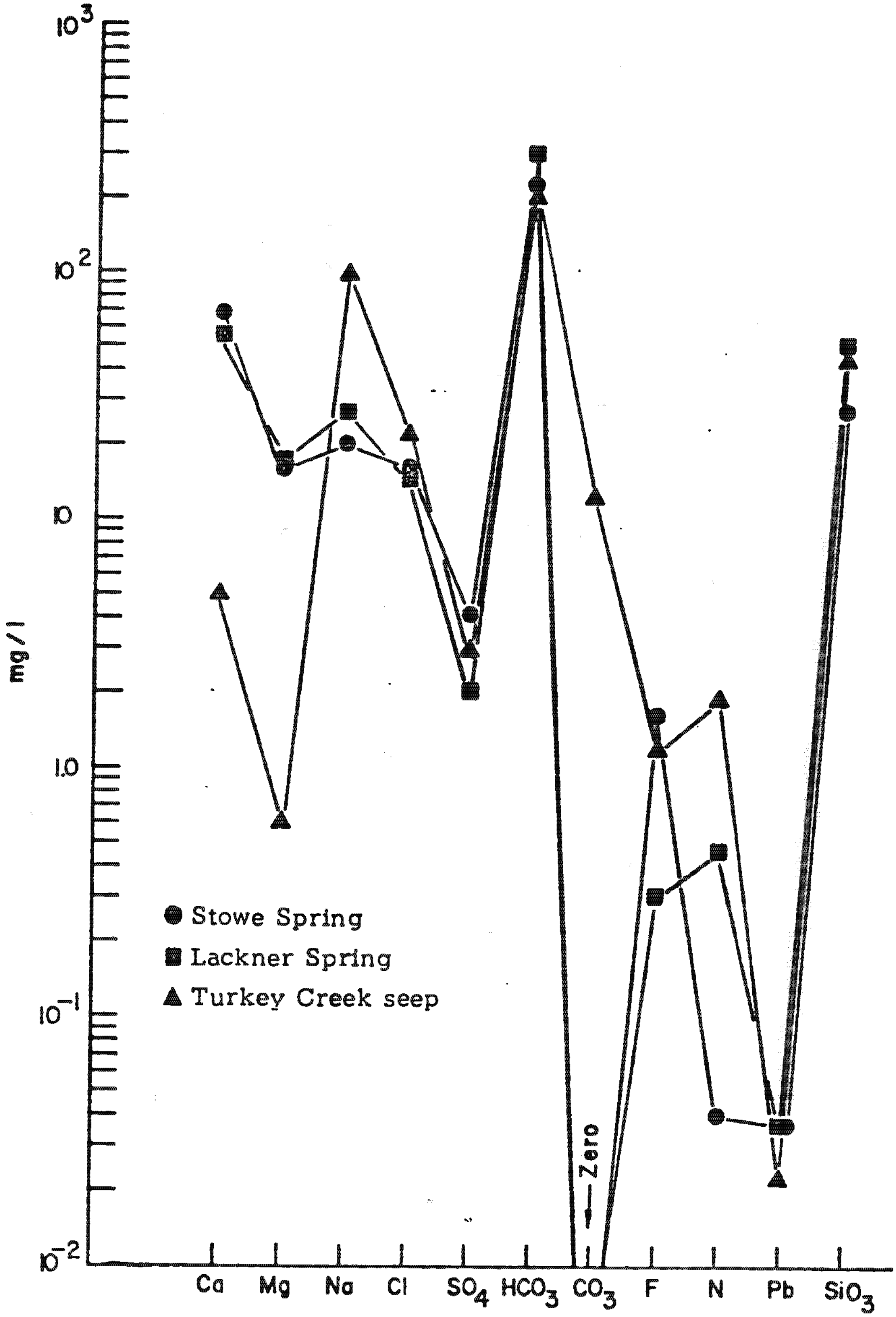


Fig 19. Spring-water chemical data

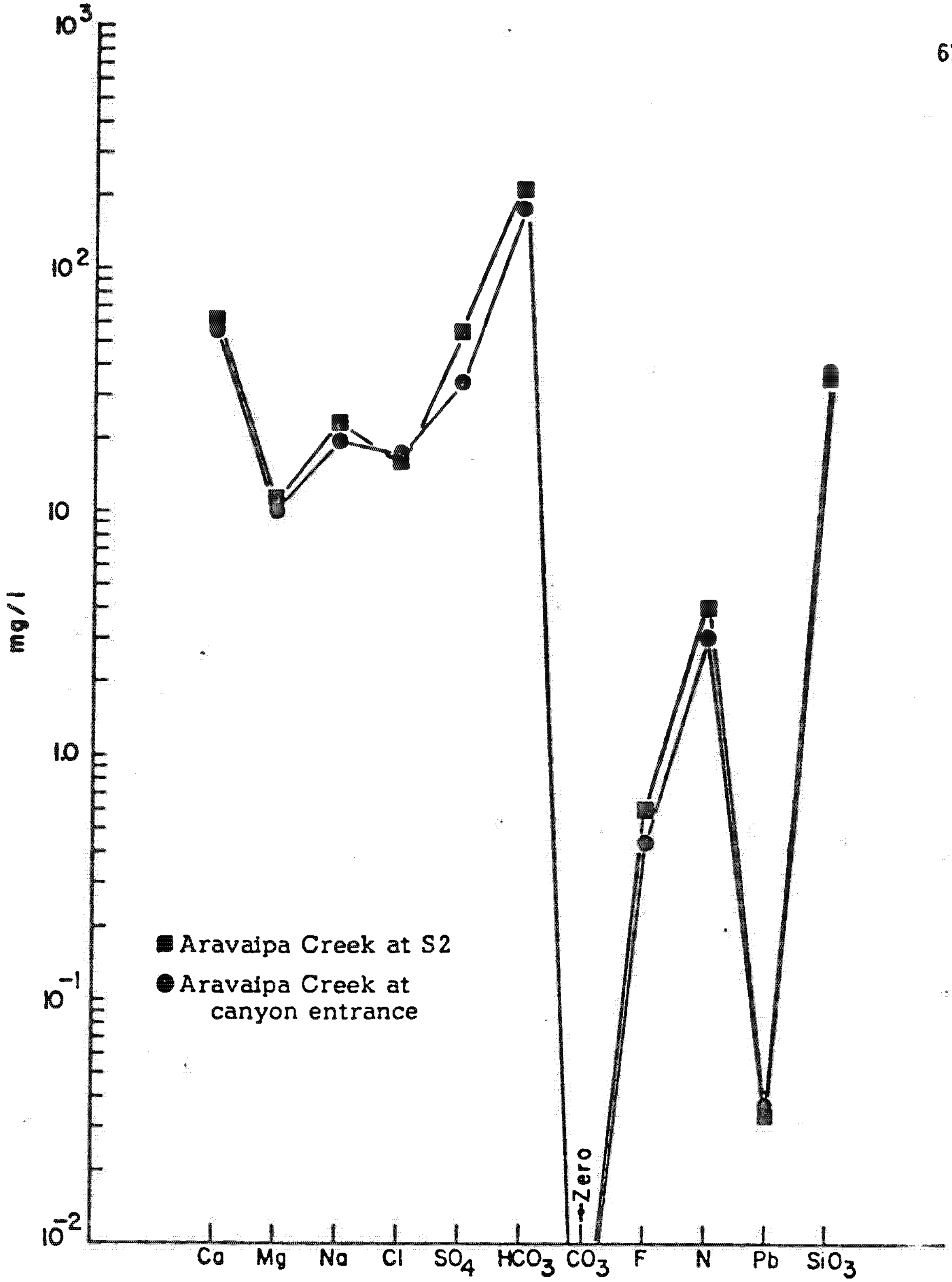


Fig. 20. Surface-water chemical data

were collected for mercury analysis. Approximately 200 ml of water were collected and filtered, then to each sample was added 1 ml $K_2Cr_2O_7$ and 10 ml HNO_3 for preservation of the dissolved mercury. Analyses were conducted by the atomic absorption technique at the University Analytical Center, Department of Chemistry, The University of Arizona. These analyses indicated that all samples contained less than 2 ppb Hg. This level is the lower limit of the technique's reliability (Auble, pers. comm., 1979).

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 permisslbe levels for these types of water supplies (Enrivonmental Protection Agency, 1975).

In general, the dissolved ion data indicate that all of the sources sampled belong to relatively similar hydrochemical facies (Bentley, pers. comm., 1979). 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. In all of these cases the data are well explained by the local lithology, being a lake-bed deposit, older alluvium, and well-indurated conglomerate, respectively.

Most of the samples analyzed 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 of the ground-water samples 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 National Academy of Sciences and National Academy of Engineering (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 is the mottling of children's teeth (Smith, Cammack, and Foster, 1936).

No other ion concentration is high enough to pose a serious health threat for domestic users (McKee and Wolf, 1963).

Prediction of Effects of Increased Ground-water Development on Flow in Aravaipa Creek

Analytical techniques capable of determining the drop in the water table due to pumpage from one or more wells require information regarding the quantity and distribution of aquifer transmissivity and storativity plus the geometry of the aquifer. Research on the Aravaipa Basin has uncovered one specific capacity test to yield a dubious point transmissivity and information on the surface distribution of the water-bearing rocks. More complete information is not available due to the valley's being relatively undeveloped. What is totally lacking is quantitative information on the distribution of transmissivity and storativity. This lack of data precludes reliable quantitative estimates of impact based on a flow-net-type analysis.

Another method is available that may yield semi-quantitative answers, but no specific information on the effect of well placement and the like. This method employs the hydrologic budget.

Under the present set of conditions, it is estimated that approximately 3,100 acre-feet are pumped from the Aravaipa aquifer every year out of a total of 10,500 acre-feet of annual aquifer recharge. Pumpage then equals about 30 percent of recharge. The remaining 7,400 acre-feet (70%) of recharge presently makes its way into Aravaipa Canyon as base flow where 2,400 acre-feet per year (23% of total) are expected to be lost to evapotranspiration. These losses leave an estimated 5,000 acre-feet (47% of total) of base flow to be registered at the U.S. Geological Survey gaging station.

If the mean annual aquifer recharge were a constant under all conditions, an increase in the amount pumped would have to show up as a decrease in the base flow and the evapotranspiration. Considering that the evapotranspiration occurs in the canyon where the water table would be high even if there were no stream flow, the base flow of Aravaipa Creek should suffer the major loss in the event of increased ground-water withdrawals. The evapotranspiration requirements of the plants will remain and will be satisfied after the stream is gone as long as the water table is not too deep.

Given these assumptions, any increase in pumpage from the Aravaipa Valley aquifer will result in a decrease of the same magnitude in Aravaipa Creek's base flow.

As indicated earlier, 98 percent of the ground water now pumped from the aquifer is used for irrigation; no upward trend in the amount of irrigated land is evident in the information gathered. If irrigation uses do increase they could occur at any point along the creek in the flat younger alluvium and would be expected to affect base flow in the creek by the rule above.

Water requirements for mining and concentrating purposes can far exceed the annual aquifer recharge of the Aravaipa Valley aquifer. Furthermore, recharge water from these operations can be high in metals after use and is generally unsuitable for terrestrial or aquatic life (Doudoroff, 1952; Follett and Wilson, 1969). The return of mining to the Klondyke area on the scale of the past would probably have negligible effect, but on the scale most common in today's practices, the industry's water requirements could not be met without serious alteration of the flow pattern present today and probably a deterioration of water quality.

In reality, the annual aquifer recharge is not constant under all conditions. As the water table may be lowered by pumpage, an increase in available storage in the aquifer is created by dewatering of the pores nearest the land surface. Also, the hydraulic gradient may be increased along the edges of the aquifer, thus increasing the rate at which water flows into it. By these changes, pumpage could actually increase aquifer recharge, but in no way could it ever increase the flow of ground water into Aravaipa Creek. The increase in recharge would be equal to or less than the increase in pumpage.

In consideration of the constant ground-water withdrawals necessary for industrial processes as opposed to the seasonal variation in the recharge rate, it is most likely that a critical season for Aravaipa Creek flow would develop if such industry were to exist. This season would most likely be summer when recharge rates are low and evapotranspiration requirements high. The fish in Aravaipa Creek cannot survive even one "critical summer," so the fact that the aquifer may recharge to full storage in the winter is really not pertinent.

Since there is no sure method of determining if or by how much the aquifer recharge might change given an increase in ground-water withdrawals, the recharge may be considered constant. By doing this the estimates of impacts become the most conservative possible; that is, they predict the most impact for a given change.

Aravaipa Creek would respond to any reduction in its base flow by emerging from the sediments farther and farther within Aravaipa Canyon. In this respect it is fortunate that the sediments of the canyon floor have considerable thickness and do not become immediately shallow on entrance to the canyon, because in that case flow could be totally cut off to the canyon if ground-water levels dropped below the younger alluvium at the canyon entrance. This condition could still happen but is seen as unlikely in view of the probably more than 100-foot thickness of the younger alluvium. At the time the emergence point of the creek reached the same elevation as the highest elevation of rock of low permeability beneath the canyon alluvium, ground-water flow would cease from the valley into the canyon and Aravaipa stream would essentially dry up.

The highest elevation of rock of low permeability beneath the canyon alluvium is 68 feet below SP2 (Fig. 7), which has a surface elevation of 3,290 feet above mean sea level. Therefore, the stream would not be expected to emerge below a surface elevation of 3,222 feet above mean sea level because at this point ground-water flow from the valley would be impeded by the high point in the Hell Hole Conglomerate. A stream surface elevation of 3,222 feet is reached in SE¼SE¼NE¼ sec. 28, T. 6 S., R. 19 E., approximately two miles downstream from the entrance to the canyon.

Acknowledgments

For the opportunity to conduct this research, I owe James Posedly the Defenders of Wildlife much thanks.

Field work was made bearable by the friends I made in Aravaipa, among the most helpful, Charles Proctor, John Luepke, the Tapia Family, John Allison, and Jay and Ginny Schnell. The assistance of Helle B. Andersen and Kathleen Maddock is also greatly appreciated.

Investigation design and data analysis were guided by many helpful professionals, among them, Drs. Daniel Evans, John Sumner, Robert Scarborough, Harold Bentley, John Harshbarger, and Teko Van Kyklama. I thank these most considerate people.

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).

> 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.

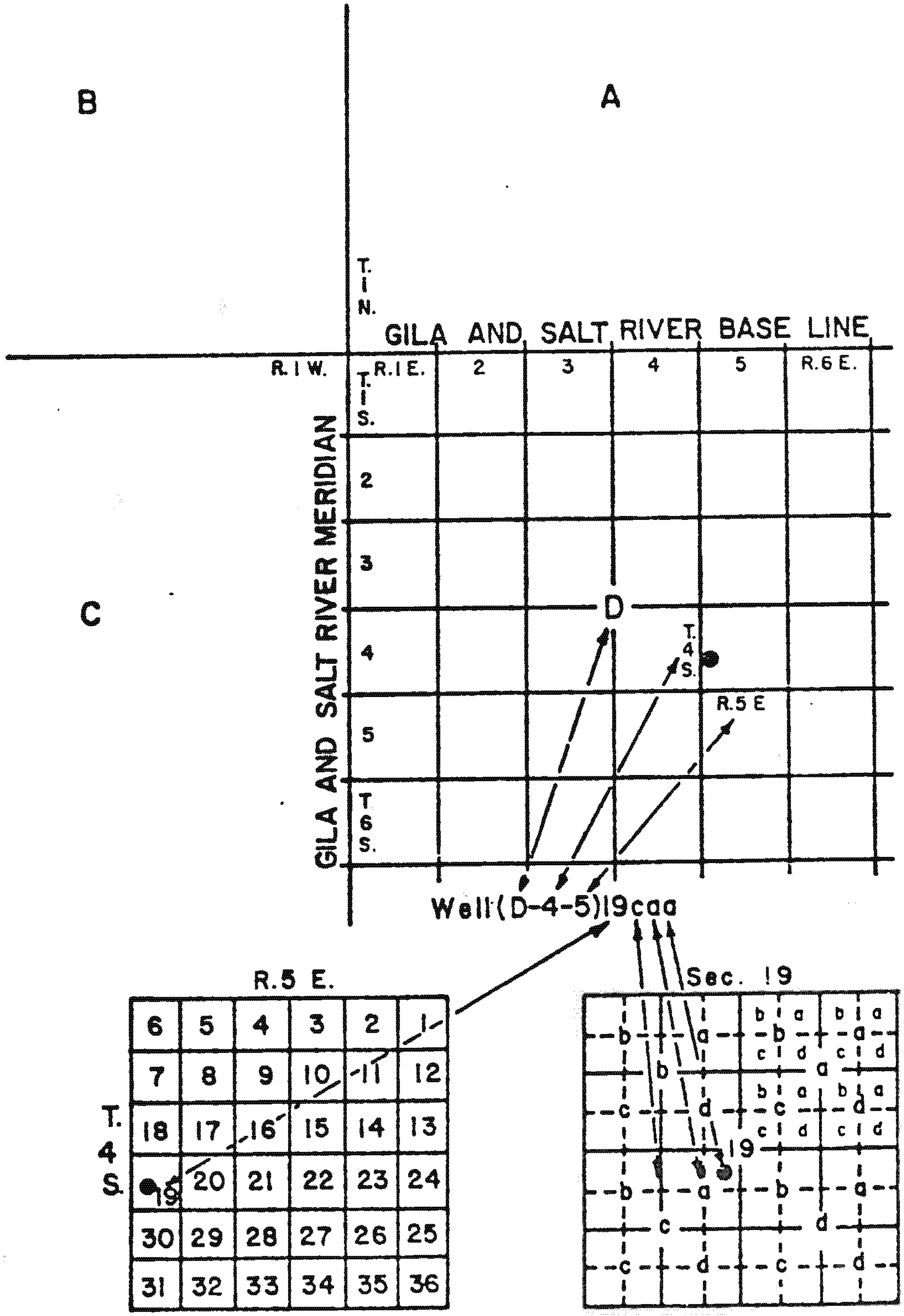


Fig. A-1. U.S. Geological Survey well-numbering system

Table A-1. Wells beginning in younger alluvium

Well	Interval (ft)	Interval Description	Depth to Water (ft)	Yield (gpm)
(D-6-19) 35ada	0-15	sand	20.4	
	15-35	red clay		
	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)	Interval 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 sail	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, gravel		
	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	grave (>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 13, 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

$J = \sum_{i=1}^{12} (t_i/5)^{1.514}$; i = 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	I	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)	=	3,654

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

2. Eagleman's (1966) formula

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

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:

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

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

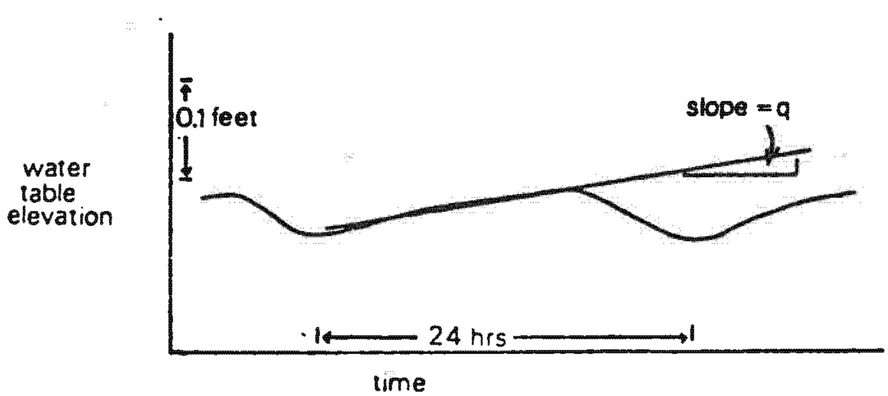
q = seepage velocity (= slope of graph of well level from 6 pm to 4 am)

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:



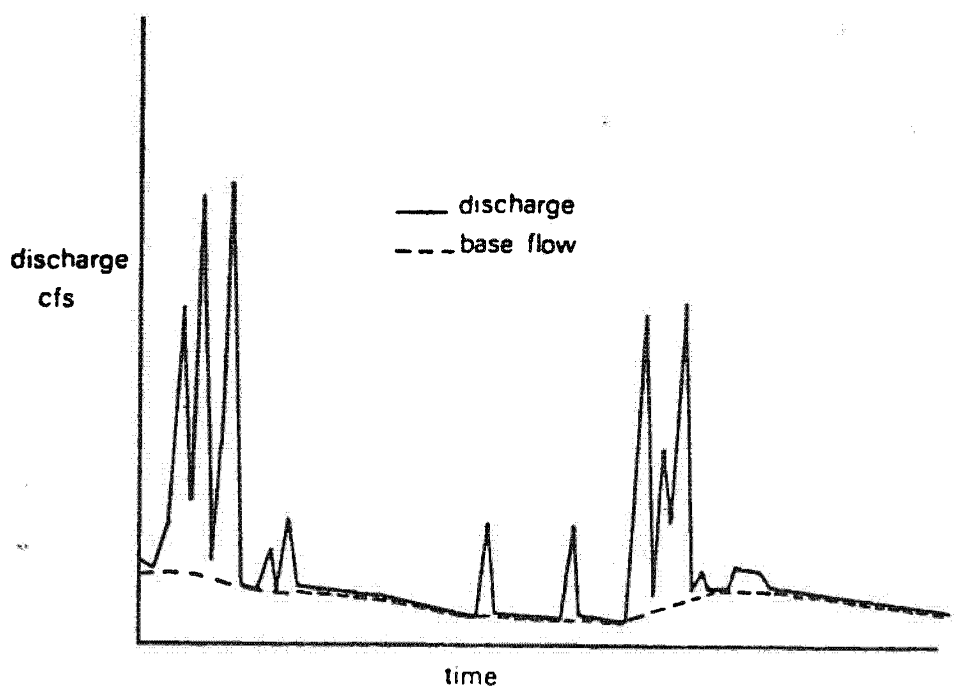
Example

Base Flow and Aquifer Recharge

From plots of daily mean discharge vs. time for a total of 4 years of records, the following mean base flows were determined:

Time Span	Precipitation (inches)	Precipitation/ Mean Precipitation	Mean Base Flows (cfs)
Nov 1971-Oct 1972	19.2	1.36	7.62
Nov 1972-Oct 1974	15.9	1.12	8.51
Oct 1975-Sep 1976	10.91	0.77	5.22
		Overall mean base flow	7.22

This value is then adjusted for errors due to the location of the measurements (U.S. Geological Survey stream gage at west end of Aravaipa Canyon). This adjustment is +3 cfs (see aquifer recharge).



Base flow determination

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