Geology and the Availability of Water in the Lower Bonita Creek Area Graham County, Arizona

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By L. A. Heindl and R. A. McCullough

ABSTRACT

The lower Bonita Creek area lies in the southeastern part of the valley between the Gila and Turtle Mountains, about 15 miles northeast of Safford, Graham County, Ariz. Most of the area, about 70 square miles, is drained by Bonita Creek, a tributary of the Gila River.

The city of Safford obtains its water supply from an infiltration gallery in the alluvial fill of Bonita Creek about 4 miles above the confluence of Bonita Creek and the Gila River. Discharge from the infiltration gallery during 1939–56 ranged generally from 900 to 2,500 acre-feet per year. There has been a small steady decrease in production since 1953. Virtually no other ground water is pumped in the area except from a standby well which is actually a part of the infiltration-gallery system.

Igneous and sedimentary rocks of possible Cretaceous age, volcanic rocks and alluvium of probable Tertiary age, alluvium of Pliocene and Pleistocene age, and younger alluvium of Quaternary age are not exposed in the area. Only the rocks of the upper part of the Tertiary volcanic sequence and the late Quaternary alluvium that forms the channel fill along Bonita Creek yield water in moderate quantities. The channel fill is the more important producer at the present time.

Bonita Creek is chiefly perennial within the area. Surface flows at times are less than 1 cfs (cubic feet per second) and have reached a short-term peak of 17,000 cfs. The greatest sustained surface flows, averaging about 6 cfs during 1955 and 1956, are encountered in The Box, a constricted portion of the Bonita Creek canyon. The amount of surface flow into the Gila River at the mouth of Bonita Creek, the diversions at the infiltration gallery, the estimated underflow into the Gila River from Bonita Creek, and losses due to evapotranspiration also total about 6 cfs.

The alluvial deposits of the channel fill of Bonita Creek are composed of intertonguing lenses of heterogeneous gravel, sand, and silt whose permeabilities determine the transmission and storage of water in the deposit. The long narrow shallow shape of the deposit limits the amount of water it is capable of transmitting and storing. The limited storage capacity suggests that much of the water required for the sustained level of diversions at the infiltration gallery must come from continuous recharge.

At the infiltration gallery the amount of water within the channel fill may be augmented by infiltration from the adjacent volcanic rocks. Near the mouth of

Bonita Creek the underflow of the channel fill is estimated to be about 0.8 cfs, which is a measure of the probable sustained productivity of the channel fill in this vicinity.

Chemical analyses of surface, underflow, seep, and gallery water indicated that the chemical content and proportions of constituents are similar in water from all sources. The mineral constituents range in concentration from 173 to 462 ppm (parts per million) and are predominantly calcium and magnesium bicarbonate. The silica content generally ranges between 40 and 60 ppm.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The purpose of this investigation was to determine the ground-water resources of the lower Bonita Creek area, Graham County, Ariz., and the possibility of developing additional water supplies in the area for the city of Safford. The investigation was a cooperative project of the city of Safford and the U.S. Geological Survey. The scope of the investigation included a geological reconnaissance and a hydrologic study of the lower Bonita Creek drainage basin. The investigation was made under the direct supervision of J. W. Harshbarger, district geologist in charge of ground-water investigations in Arizona.

The city of Safford and adjoining communities depend almost entirely on the present water supplies obtained from Bonita Creek for their municipal and domestic needs. These supplies have declined steadily, and an adequate understanding of the ground-water conditions is necessary to facilitate the development of needed additional supplies.

LOCATION AND EXTENT OF AREA

Lower Bonita Creek is in the east-central part of Graham County, Ariz., about 15 miles northeast of the city of Safford (fig. 1). The area studied contains about 70 square miles, bounded by the Gila River on the southeast, Turtle Mountain on the northeast, the San Carlos Indian Reservation on the north, and the Gila Mountains on the west and southwest.

PREVIOUS INVESTIGATIONS

No comprehensive report of the geology or ground-water resources of lower Bonita Creek is available. The geology of the area is briefly mentioned by Gilbert (1875) and the regional geology and ground-water resources of the Safford Valley south and west of the area are discussed by Schwennesen (1921), Knechtel (1938), and Turner (1946). Lindgren (1905), Knechtel (1936), and Bromfield and Shride (1956) discuss the geology of adjoining areas.

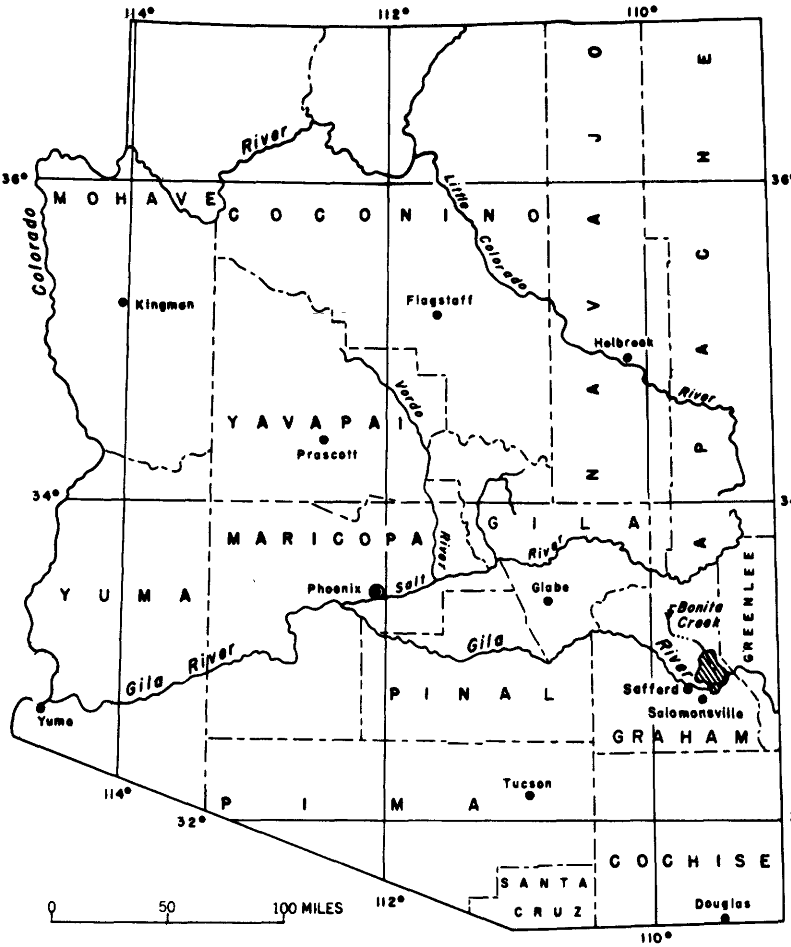

FIGURE 1.—Index map showing location of the lower Bonita Creek area, Graham County, Ariz.

METHODS OF INVESTIGATION

The fieldwork was done intermittently between the fall of 1955 and the spring of 1957. The geologic mapping was started by C. A. Armstrong and completed by the senior author. The hydrologic data obtained during the investigation included an inventory of existing boreholes, wells, and springs in and near the area, a pumping test on the Safford Municipal Utilities' wells near the mouth of Bonita Creek, and the collection of water samples for chemical analysis. Records of Bonita Creek flow, chemical analyses made prior to this investigation, and infiltration-gallery deliveries were obtained from the Safford Municipal Utilities. Graham County court records describe the water conditions along lower Bonita Creek prior to the development of the infiltration gallery, and include additional chemical analyses of water and other supplementary data. These hydrologic data were compiled and analyzed by the junior author.

Samples of water collected during the present study were analyzed by the U.S. Geological Survey at Albuquerque, N. Mex.

The geologic mapping was done on aerial contact prints obtained from the U.S. Soil Conservation Service and on a preliminary contour map prepared by the U.S. Geological Survey. The base map was prepared from this contour map and the township grid was drawn using the location of the infiltration gallery as a base point. Contour altitudes are not consistent with earlier spirit leveling in the area, but the contour altitudes from the preliminary map are used throughout the report for the purpose of uniformity.

ACKNOWLEDGMENTS

The writers acknowledge with appreciation the assistance and co-operation of G. A. Rhoads and G. B. Smith of the Safford Municipal Utilities who supplied basic records, historical data, and many helpful suggestions. Ray Robinson of the Bear Creek Mining Co. provided information from exploratory churn-holes and other geologic data from a mining prospect area about 1 mile northwest of Lone Star Peak. D. H. Orr of the Phelps-Dodge Corp. at Morenci supplied data regarding the company's exploratory wells along Eagle Creek; M. E. Earven and R. S. Claridge, local ranchers, gave generously of their intimate knowledge of the area.

GEOGRAPHY AND CULTURE

LANDFORMS AND DRAINAGE

The lower Bonita Creek area lies within the Mexican Highland physiographic section (Fenneman, 1931). The altitude of the area ranges from about 3,200 feet along the Gila River to about 7,000 feet at Turtle Mountain, a southeast extension of the Natanes Rim. The area includes the southeasternmost part of the Gila Mountains, the west slopes of Turtle Mountain, and the dissected valley between them.

The mountains are tilted fault blocks composed predominantly of volcanic rocks and the valley area is underlain by dissected alluvial conglomerate of Tertiary and Quaternary age. Turtle Mountain stands about 1,000 to 2,000 feet above the upper margins of the valley and the west slopes of Turtle Mountain dip as much as 5,000 feet per mile. The steepest fronts are cut on younger volcanic flows. The upper parts of the back slope of the Gila Mountains are also cut on younger volcanic rocks and are almost as steep as the west front of Turtle Mountain. The slopes cut on rhyolite of the middle volcanic unit (p. 15) are generally more subdued in relief, but they are much more irregular and locally are as steep as those on the younger volcanic flows.

The topography in the central part of the area consists of long irregular fingerlike mesas and ridges which have gently rounded tops in marked contrast to their steep sides. Along lower Bonita Creek, hanging valleys with vertical or nearly vertical walls from a few tens to more than 200 feet high are common. Except along the Gila River, a gentle southeastward-dipping erosional surface is cut on both volcanic rocks and alluvium. This dissected erosional plain can be traced by eye to the broad open slopes of Ash Flat to the northwest. At the San Carlos Reservation boundary, the central part of this surface lies at an altitude of about 4,400 feet. About 10 miles southeast it lies about 800 feet above the Gila River at an altitude of about 4,000 feet. Along the Gila River, lower surfaces, representing terraces successively developed by the river, lie at altitudes of about 3,300 feet. The best developed of these terraces appears to be coextensive with the main surface above the Gila River flood plain in the Safford Valley.

The area is drained by the Gila River and Bonita Creek. Most of the smaller washes drain into Bonita Creek, but in the southwest corner a few drain into the Gila River directly. The Gila River and lower Bonita Creek are perennial but their tributaries are intermittent.

CLIMATE

The climate of the lower Bonita Creek area is semiarid. Details regarding precipitation and temperature are interpolated from nearby U.S. Weather Bureau stations. A precipitation station has been established about 1 mile above the mouth of Bonita Creek but records are available only from March 1956. The nearest weather stations are at Safford, Clifton, and Black River Pumps. Precipitation and temperature records for these stations are summarized in table 1.

Isohyetal contours of the upper Gila River drainage basin for a 71-year precipitation record to 1941 (Peterson, 1945) suggest that an approximate basinwide range in annual precipitation in the lower Bonita Creek area is from about 10 to 16 inches, and averages about 13 inches. The average annual precipitation, computed by the Thiessen method (Thiessen, 1911) from data obtained during 1937–56 for the Black River Pumps, Clifton, Eagle Creek, Safford, and San Carlos Reservoir weather stations, is about 12 inches. A comparison of the average annual precipitation during 1951–56 with that of the long-term averages (table 1) shows the effects of the drought which is considered to have begun in 1942 in Arizona (Searles, 1951, p. 14).

TABLE 1.—*Average precipitation and temperature at weather stations near the lower Bonita Creek area*

Station	Location (referred to lower Bonita Creek area)		Altitude (feet)	Average total annual precipitation (inches)			Average mean annual temperature (°F)		
	Distance (miles)	Direction		1951–56 average	Long-term average	Long-term years of record	1952–56 average	Long-term average	Long-term years of record
Black River Pumps	22±	North	6,040	17.29			52.8		
Clifton	15±	Northeast	3,465	8.30	11.84	59	67.3	67.0	46
Safford	15±	Southwest	2,900	7.31	8.81	47	64.8	63.8	39

Precipitation occurs principally in two seasons, summer and winter, and is appreciably greater during the summer months. The pattern of monthly precipitation in the general area for 1952–56, shown in figure 2, is computed by the Thiessen method from precipitation records of the five weather stations listed.

The earliest killing frosts generally occur during late October or early November.

INFILTRATION GALLERY

The Safford Municipal Utilities' infiltration gallery is on Bonita Creek about 4 miles above the mouth at a site locally known as The Meadows (fig. 12). At The Meadows, the canyon bottom is about 120 feet wide and lies between steep 400-foot walls composed of volcanic flows and overlying alluvial deposits. The gallery (fig. 3) consists of about 1,100 feet of 12- and 15-inch perforated galvanized steel pipe arranged in 4 lateral lines extending the full width of the canyon with a central line connecting the laterals. The gallery is about 17 feet below the surface of the creek and the collection pipes are gravel packed. From the farthest downstream lateral, 2 pipelines lead to sand traps and a 16-inch pipeline carries the water from the lower sand trap to the mouth of Bonita Creek. From there 2 smaller pipelines carry the water to Safford, about 17.5 miles to the southwest. The system operates entirely by gravity flow. During the original testing, the gallery area produced as much as 4.5 mgd (million gallons per day), but in the last few years production has averaged less than 2.5 mgd. The water flows into storage tanks in Safford from which it is distributed to users in Safford and other communities in the Safford Valley such as Solomonsville, Central, Pima, and Thatcher. A short distance above the mouth of Bonita Creek, two shallow wells, one of which contains a pump, provide a small supplementary source for emergency supplies.

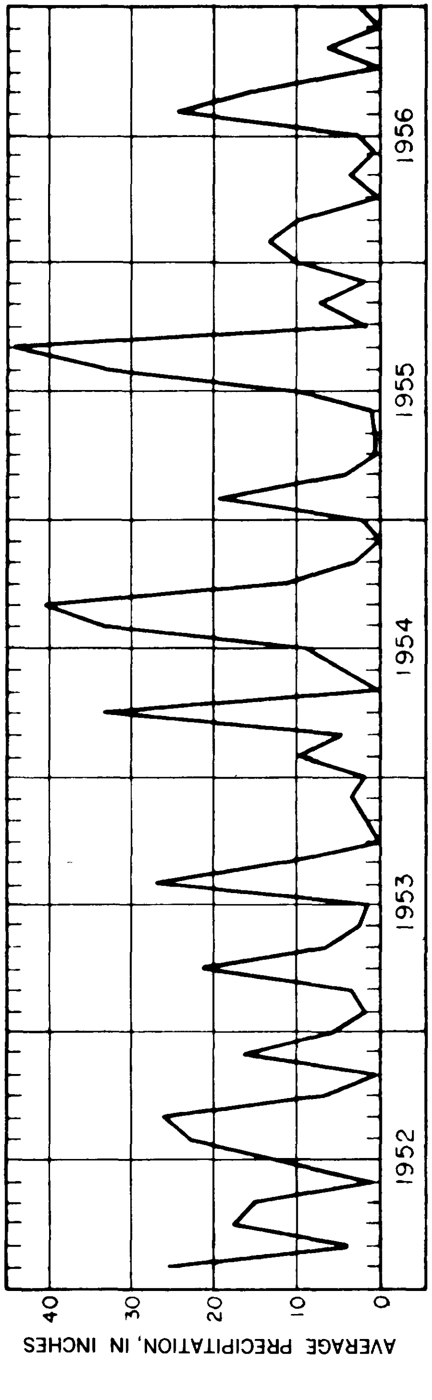

FIGURE 2.—Mean total monthly precipitation at U.S. Weather Bureau stations of Safford, San Carlos, Black River Pumps, and Eagle Creek, Ariz., 1952–56.

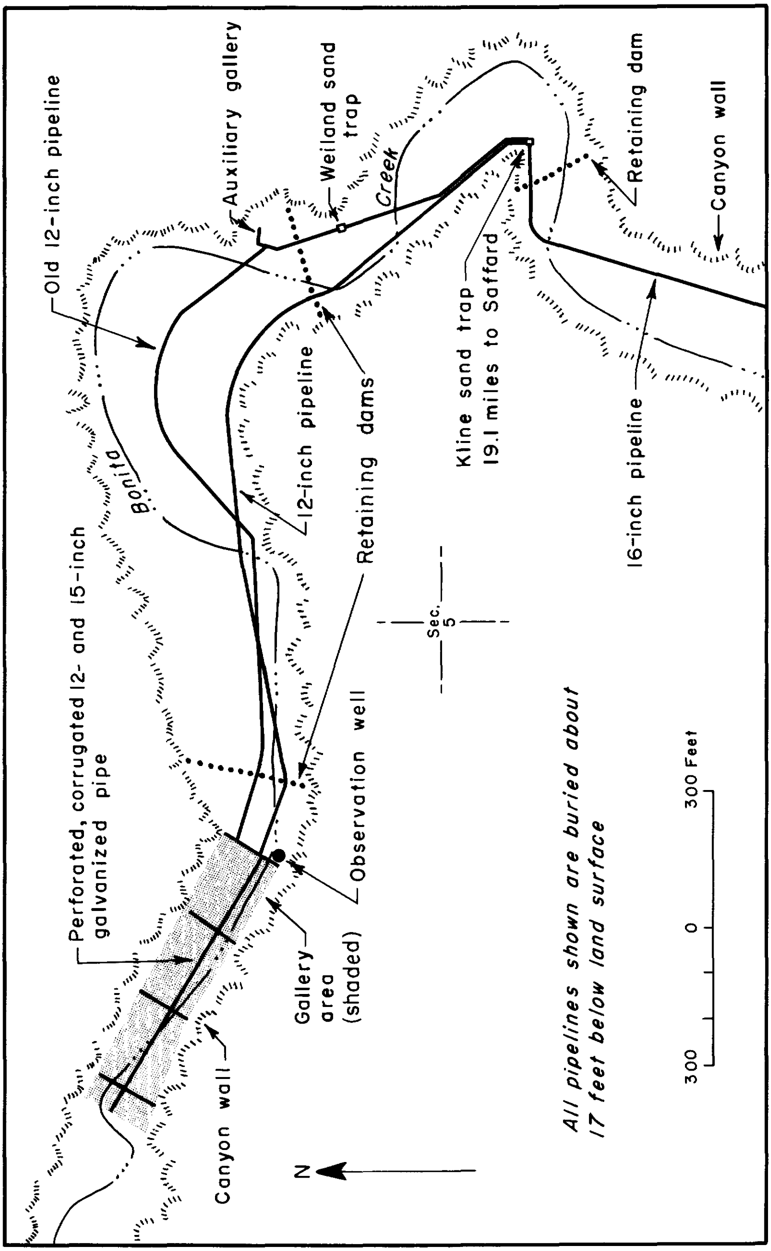

FIGURE 3.—Sketch of Safford Municipal Utilities' infiltration gallery area, Bonita Creek, sec. 5, T. 6 S., R. 28 E., Graham County, Ariz.

A brief historical record of the development of the gallery system was obtained from Graham County Superior Court records[1] and information provided by the Safford Municipal Utilities. The preliminary survey was made in 1933 by A. A. Weiland, consulting engineer, and in December 1935 he and a group of engineers made a reconnaissance up the creek to determine whether or not there was sufficient water to justify the installation of a pipeline to supply the town of Safford. The flow of the creek immediately below The Meadows at that time was determined to be between 2 and 3 cfs (cubic feet per second). A well dug at the gallery site at The Meadows produced 1,000 gpm (gallons per minute), according to weir measurements made by Weiland. When completed the gallery produced about 3,000 gpm in excess of the base flow of Bonita Creek, which was about 3 cfs. Construction of a 10-inch pipeline began in July 1937 and was completed in October 1938; the first water was delivered to the town of Safford in February 1939. The pipeline was approximately 21.6 miles long, including the gallery and its laterals.

In 1949 a flood in Bonita Creek washed out a section of the 10-inch pipe. This was replaced by a section of 16-inch pipe which was attached to the canyon wall several feet above the highest terrace level as an experiment to determine the feasibility of relocating the balance of the line to eliminate the possibilities of future flood damage and interruption of the municipal water supply. Within the next 3 years the 10-inch pipe in Bonita Creek canyon was replaced entirely by a 16-inch pipe, which, except where it crossed the creek, was attached to the canyon wall. Two supplementary 12-inch pipelines were installed to carry the capacity of the 16-inch pipe. The first of these paralleled the old 12-inch line in the gallery area and the second was laid between the mouth of Bonita Creek and Safford.

In 1956, the retention dams, originally installed to lessen the dangers of washing out the gallery, were realined and reinforced. During this operation a short section of the gallery was uncovered and it was discovered that the gravel pack around the collection pipe had been replaced by a mixture of silty sand and gravel. This replacement apparently occurred with the movement of channel material during the summer floods.

GEOLOGY

The rocks exposed in the lower Bonita Creek area are predominantly volcanic and alluvial in origin. The rocks range in age from probable Cretaceous to Quaternary and their outcrop areas are shown on plate 1. Age designations are made on the basis of lithologic sim-

[1] From *Gila Valley Irrigation District, et al.* v. *The Town of Safford, a municipal corporation* (1956) : Graham County Superior Court record on file at Safford, Ariz.

ilarity to, or continuity with, rocks of known or accepted age in southeastern Arizona, as no fossils have been found in this area. The Tertiary volcanic rocks are continuous with rocks designated as Tertiary by Bromfield and Shride (1956) and consist of basaltic, andesitic, and rhyolitic flows, breccias, agglomerates, tuffs, and interbedded sedimentary lenses. Tertiary alluvial conglomerate crops out discontinuously along the central part of the area. Lakebed material and interbedded coarse clastic rocks of Pliocene and Pleistocene age (Van Horn, 1957)[2] are exposed along the Gila River. Younger Quaternary deposits include terrace, flood-plain, talus-scree, channel, and residual gravel deposits.

The Cretaceous(?) rocks were intricately deformed and eroded before the deposition of the younger rocks. Following and in part contemporaneous with the deposition of the Tertiary volcanic rocks and alluvium the area was broken into northeastward-tilted fault blocks along northwestward-trending normal faults. The Tertiary volcanic conglomerate is faulted along its northeastern margin and warped into a shallow syncline having a gentle plunge to the southeast.

The Pliocene and Pleistocene deposits were laid down on a surface eroded on Tertiary and older rocks and are virtually undeformed. A period of degradation by the Gila River was followed by deposition of alluvial deposits.

ROCKS AND THEIR WATER-BEARING PROPERTIES

The water-bearing properties of rocks depend in part on the degree of interconnection between open spaces within them. These open spaces occur between grains and as fractures and they may form during or after deposition. The degree of interconnection may be modified after deposition by fracturing owing to deformation and solution, or decreased by compaction, cementation, or alteration.

In the lower Bonita Creek area, the chief aquifer is the unconsolidated alluvium partly filling the Bonita Creek and Gila River canyons. The Tertiary volcanic rocks seem, at least locally, to be sufficiently porous to yield ground water in moderate quantities, but nowhere in the area have their water-yielding properties been adequately tested. The Cretaceous(?) rocks are non-water-bearing and the Tertiary and Quaternary conglomerates are chiefly above the water table everywhere in the area.

CRETACEOUS(?) UNDIFFERENTIATED ROCKS

Undifferentiated sedimentary, volcanic, and intrustive rocks of probable Cretaceous age crop out in small areas along the upper slopes of

[2] Van Horn, W. L., 1957, Late Cenozoic beds in the upper Safford Valley, Graham County, Arizona: unpublished master's thesis, Arizona Univ., Tucson.

the east side of the Gila Mountains, in a narrow strip north of Johnny Creek, and along Midnight Canyon (pl. 1). Light-colored sandstone, green and red mudstone, and black muddy limestone crop out at the south end of the Cretaceous(?) exposures along Midnight Canyon. The volcanic rocks include tuff, tuffaceous agglomerate, breccia agglomerate, associated lithic graywacke (Pettijohn, 1957) and poorly sorted conglomerate, and some andesitic flows. The volcanic rocks are generally rhyolitic to andesitic in composition and predominantly gray green to gray purple. Along the west front of the Gila Mountains the Cretaceous(?) volcanic rocks are intruded by fine-grained porphyritic rocks, extensively epidotized, and locally mineralized by copper. The relation between the sedimentary and volcanic rocks in the area of scattered exposures is not known.

Nowhere in the mapped area is the base of the Cretaceous(?) rocks exposed. In the Midnight Canyon area they are disconformably overlain by the lower and middle units of Tertiary volcanic rocks and in the Gila Mountains they are overlain locally by the uppermost unit of Tertiary volcanic rocks. The undifferentiated Cretaceous(?) rocks are locally faulted against younger rocks.

Cretaceous(?) volcanic rocks and intrusive porphyritic rocks are reported from four exploratory drill holes in the south end of Turtle Mountain. In three drill holes northeast and east of The Meadows (pl. 1), the Cretaceous(?) rocks were penetrated at altitudes ranging from about 3,300 to 3,500 feet. These altitudes are generally a few hundred feet lower than those at the top surfaces of Cretaceous(?) rocks in the Gila Mountains.

No Cretaceous(?) rocks were found at a depth of 2,015 feet or at an altitude of about 2,000 feet, in a hole drilled on the surface trace of the Turtle Mountain fault in the NE¼NW¼NW¼ sec. 10, T. 6 S., R. 28 E., about 2 miles southeast of The Meadows.

The explanatory drill hole in SE¼NE¼NE¼ sec. 33, T. 5 S., R. 28 E., entered a thick clastic unit below Tertiary(?) volcanic rocks. This clastic unit is reported to be composed principally of fragments of Cretaceous(?) andesite and monzonite porphyry. About 1,600 feet of bedded clastic material was penetrated without reaching its base. The top of the clastic unit is at an altitude of about 3,750 feet. This unit apparently represents deposition in an erosional basin which was cut on Cretaceous(?) rocks and could range in age from Cretaceous(?) to early Tertiary.

Cretaceous(?) rocks are not known to be water bearing in the Bonita Creek area. An exploratory drill hole, in the SW¼NW¼SE¼ sec. 5, T. 6 S., R. 27 E., penetrated about 2,300 feet of Cretaceous(?) rocks and was reported as "dry" (Ray Robinson, oral communication, 1957). Another mining exploration hole on the west side of the Gila Mountains and outside the mapped area, in the SW¼SW¼ NE¼ sec. 16, T. 6 S., R. 27 E., also was reported to be dry when drilled during the summer of 1956 (Ray Robinson, oral communication, 1957). In February 1957 there was water in the hole but it could not be determined whether this was residual drilling water or water from the rocks. The exploratory drill holes east of The Meadows at the south end of Turtle Mountain also were reported to be dry.

The Cretaceous(?) rocks, however, cannot be considered everywhere to be non-water-bearing. A small stock well, less than half a mile southwest of the exploration hole in the NE¼SW¼SW¼ sec. 16, T. 6 S., R. 27 E., was finished in the Cretaceous(?) volcanic rocks and is reported to be a "steady" small producer.

TERTIARY(?) ROCKS

Volcanic and sedimentary rocks of Tertiary(?) age comprise a large part of the exposed rocks in the lower Bonita Creek area (pl. 1). These rocks are separated into 4 units—the 3 lower units are predominantly volcanic and the upper unit is predominantly an alluvial conglomerate composed of volcanic fragments.

The three volcanic units, referred to as the lower, middle, and upper units, have been differentiated for reconnaissance mapping purposes. The following sections, measured on the west front of Turtle Mountain, seem to represent the volcanic units:

Section 1. Tertiary(?) volcanic units along the ridge half a mile northwest of, and parallel to, section A–A′ *(pl. 1), N½ sec. 36, T. 4 S., R. 27 E.*

	Thickness (feet)
Tertiary(?):	
Erosion surface.	
Upper volcanic unit (dips 3°–6° E.):	
Basalt and andesite: flows 10 to 50 ft thick, having well-developed top and bottom flow breccias; few interbedded discontinuous conglomerate lenses as much as 20 ft thick; forms prominent cliff	1,200±
Total upper volcanic unit	1,200±
Angular unconformity. Covered.	50±
Middle volcanic unit (strike N. 20° W., dip 20° NE.):	
Tuff, sandy, and tuffaceous sandstone: white to gray; thin-bedded; forms slopes and ledges	20
Tuffaceous breccia and lapilli agglomerate: tawny-brown; contains fragments of andesite, felsite, and basalt(?); interbedded with thin gray tuffaceous sandstone; forms slopes except for individual beds which form cliffs as much as 10 ft high	200±
Total middle volcanic unit (includes covered zone at top)	270±

	Thickness (feet)
Tertiary (?)—Continued	
Basalt dike (fault zone?).	
Lower volcanic unit (strike N. 20° W., dip 20° ±NE.):	
Andesite: flows 10 to 20 ft thick; brick-red to purple-gray; includes flow breccias and rarely, breccia agglomerate lenses; forms uniform slopes	900±
Tuffaceous breccia and agglomerate: reddish-orange to reddish-brown; interbedded conglomerate lenses containing Cretaceous(?) rock fragments and fragments of felsite and andesite; forms alternate slopes, ledges, and cliffs	300±
Conglomerate: gray; pebble to boulder; subrounded to rounded; matrix muddy (tuffaceous?); fragments predominantly of gray tuff; minor quantities of Cretaceous(?) volcanic rocks; forms slopes	50±
Total lower volcanic unit	1,250±
Total Tertiary(?) volcanic units	2,720±
Angular unconformity.	
Cretaceous(?) volcanic rocks.	

Section 2. Tertiary(?) volcanic units on prominent ridge about half a mile south of, and along a line parallel to, section B–B′ *(pl. 1), NE¼ sec. 19, T. 5 S., R. 28 E.*

	Thickness (feet)
Tertiary(?):	
Erosion surface.	
Upper volcanic unit (dips 3°–6° E.):	
Basalt and andesite: flows similar to those described in section 1	500±
Total upper volcanic unit	500±
Erosion surface.	
Middle volcanic unit (dips 4°–5° E.):	
Rhyolite and felsite: flows and breccias; individual flows as much as 200± ft thick, massive, lenticular; gray to light-blue; forms cliffs	600±
Tuff and tuffaceous sandstone: white to gray; laminated to thin-bedded, as much as 2 ft thick; pumiceous and felsitic fragments common; forms slopes	20±
Agglomerate: brick-red to moderate reddish, brownish-orange; lapilli to breccia; crudely bedded; andesitic fragments predominant: forms slopes and ledges	100±
Basalt and andesite: purplish- to dark-gray; in thin flows with intercalated conglomerate and breccia lenses; forms slopes	100±
Conglomerate: olive-green; granule to small cobble; subrounded; fragments of Cretaceous(?) rocks common; contains thin beds of graywacke sandstone; poorly exposed; forms slopes	30±

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	Thickness (feet)
Tertiary (?)—Continued	
Middle volcanic unit (dips 4°–5° E.)—Continued	
Tuff and agglomerate: light-gray on fresh surface, weathers buff to yellow-green; lichen splotches common; contains andesitic and felsitic fragments as large as small cobbles but generally less than 1 in.; pumiceous material common; individual beds as much as 15 ft thick; basal member, as much as 4 ft thick, is laminated; other units massive; forms conspicuous cliff	50±
Total middle volcanic unit	900±
Lower volcanic unit (dips 4°–5° E.):	
Andesite: flows; brick-red to dark-gray; discontinuous lenses of tuffaceous sandstone and conglomerate, often brick red; forms steep rounded slopes with some individual flows appearing as ledges	1,000±
Total lower volcanic unit	1,000±
Total Tertiary (?) volcanic units	2,400±
Probable fault.	
Basaltic conglomerate.	

In general, the two lower volcanic units appear to be conformable, although locally, as in upper Coyote Canyon, the contact between them is angular. The upper volcanic unit rests at an angle upon an erosion surface cut on the two lower volcanic units. Where the middle unit is absent, it is difficult to delineate the rocks of the lower volcanic unit from those of the upper. Small erosional and angular unconformities exist within each of the volcanic units, particularly the lower and middle units. These are in the nature of diastems and indicate local deformation of the volcanic beds and short erosional intervals inherent to volcanic processes.

The sedimentary unit of the Tertiary (?) rocks is a moderately thick alluvial conglomerate deposited on an erosional surface cut on the underlying volcanic rocks.

The three volcanic units are roughly the equivalent of the threefold sequence of older Tertiary volcanic rocks briefly described by Bromfield and Shride (1956, p. 627) and are probably equivalent to the upper part of the Clifton volcanic series described by Lindgren (1905).

LOWER VOLCANIC UNIT

Rocks of the lower volcanic unit crop out along the lower slopes of Turtle Mountain, in small patches along upper Coyote Creek, at the south end of the Gila Mountains, and in slivers along fault zones. The lower volcanic unit consists predominantly of andesite flows and breccia, agglomerate, and associated conglomerate. The flows include several varieties of gray to brick-red fine-grained to vesicular andesite. The breccia, agglomerate, and associated conglomerate occur in lenticular beds from a few inches to several feet thick. They contain cinders, bombs, and flow fragments in a matrix of coarse to fine volcanic sand and tuff. The grain size diminishes upward in the section. Upon weathering, the flows characteristically break down to a loose rubble of clinkers.

The lower vocanic unit overlies Cretaceous(?) volcanic rocks at the north end of the area along Midnight Canyon. Here the unit contains a basal conglomerate made up of fragments of Cretaceous(?) igneous rocks, particularly pebbles and cobbles of a medium-grained tuff. The lower volcanic unit is presumed also to make up a large but undetermined part of the undifferentiated Tertiary(?) volcanic rocks in the exploratory drill holes at the south end of Turtle Mountain. The base of the Tertiary(?) volcanic rocks in four of these holes ranges in altitude from about 3,300 to 3,600 feet. This range in altitude suggests that in this area the erosion surface upon which the Tertiary(?) rocks were deposited had only a moderate amount of relief.

The contact between the lower and middle volcanic units is nearly conformable. The contact between the lower and upper volcanic units is generally unconformable, although south and east of the Claridge Ranch the two units are difficult to delineate. At the south end of the Gila Mountains, flows of the upper volcanic unit overlie cinder agglomerate and agglomeratic tuff of the lower volcanic unit with a distinct angular unconformity.

The observed thickness of the unit is about 500 feet at the south end of the Gila Mountains and about 1,250 feet north of Midnight Canyon. In the exploratory drill holes in the Turtle Mountain area east of The Meadows, the thickness of the probable equivalents of the lower volcanic unit is also about 1,200 feet. Along section *A–A′* (pl. 2) the lower volcanic unit may be as much as 2,500 feet thick but this thickness is probably excessive due to unrecognized faulting. Apparently a similar thickness occurs in the exploratory drill hole in NE¼NW¼ NW¼ sec. 10, T. 6 S., R. 28 E., but the thickness here may be excessive due to the proximity of the Turtle Mountain fault.

The lower volcanic unit yields water in limited quantities to small ephemeral springs on the high slopes of Turtle Mountain. Some of the breccia agglomerate and the interflow breccia zones probably are porous enough to transmit water but they have not been tested by wells.

MIDDLE VOLCANIC UNIT

Volcanic rocks predominantly of rhyolitic or felsitic composition form the middle volcanic unit. These are exposed widely in the northern part of the mapped area and in thin discontinuous erosional remnants along the west front of the Gila Mountains (pl. 1). The most extensive exposure of the lower part of this unit is along the middle slopes of the central part of the west front of Turtle Mountain in the vicinity of sec. 19, T. 5 S., R. 28 E. (See section 2, p. 13–14.) The uppermost part is best exposed along Coyote Creek in the NE¼ sec. 28, T. 5 S., R. 27 E.

The rocks of the middle volcanic unit form massive cliffs, rugged peaks, and steep slopes at Turtle and Gila Mountains. Along Bonita Creek and some of its major tributaries such as Johnny and Coyote Creeks, the unit forms at least part of steep 300- to 600-foot canyon walls. In the northwestern part of the area, however, the unit has been beveled to form a part of the old erosional surface of the high plains between Turtle and Gila Mountains.

The middle volcanic unit includes two principal varieties of rocks—massive rhyolitic or felsitic flows, and stratified tuff, tuffaceous sandstone, and agglomerate. The massive flows seem to lie between two sequences of the bedded tuffaceous rocks.

Along the central part of the west front of Turtle Mountain, the basal unit is a bedded tuff that forms a ledge, conspicuous because of its light-yellow-green weathered surface. Overlying the basal tuff are bedded tuffaceous sandstone, conglomerate, andesitic and basaltic flows, and agglomerate. This lower tuffaceous sequence is about 300 feet thick along the west front of Turtle Mountain.

The lower tuffaceous sequence is overlain by rhyolitic or felsitic flows which are massive, intricately fractured, and range from white to blue gray, generally weathering gray or light brown. The flows are associated in many places with breccia composed of large angular felsite fragments that are welded together apparently without matrix and the interstices form an open network. The maximum thickness of the rhyolitic flows is about 600 feet along the west front of Turtle Mountain.

Along the west front of the Gila Mountains, beds of white to dark-gray or purplish-black tuffaceous sandstone rest directly on Cretaceous(?) rocks. The beds of tuffaceous sandstone are from 1 to 3 feet thick and, although laminated, they lack other features suggestive of deposition by running water. The tuff beds as much as 3 feet thick completely lack alluvial sedimentary structures. Interbedded conglomerate lenses are as much as 5 feet thick, and contain fragments derived from the underlying rocks including andesite, felsite, pumice, and Cretaceous(?) volcanic rocks, both mineralized and nonmineralized. The interbedded conglomerate lenses have small-scale cut-and-fill structures and crossbedding. The uppermost tuffaceous beds generally range in thickness from 10 feet along the west front of the Gila Mountains to 150 feet in Coyote Canyon.

The rocks of the middle volcanic unit are overlain by the lava flows of the upper volcanic unit and by the Tertiary volcanic conglomerate. Where the upper contact involves stratified deposits of the middle volcanic unit, the contact is an angular unconformity; however, where only massive rhyolitic flows are exposed, the attitude of the middle volcanic unit cannot be determined and only an erosional contact can be seen.

The thickness of the middle volcanic unit ranges from about 10 feet in some of the eroded remnants along the Gila Mountains to about 900 feet along the central part of the west slope of Turtle Mountain. The uppermost tuffaceous beds are absent along the west slope of Turtle Mountain and the composite section may be 1,000 feet or more thick.

These rocks are not known to yield any water in the area—partly because they lie above the water table. The breccia and intensely fractured flows, however, are structurally favorable for the storage and movement of ground water. Along Bonita Creek, where locally the unit lies below the surface flow of the creek, its water-bearing qualities have not been tested.

UPPER VOLCANIC UNIT

The most extensive and conspicuous rocks in the area crop out in the upper volcanic unit which forms the upper several hundred feet of cliffs that make up the crest of Turtle Mountain and much of the crest and northeast slope of the Gila Mountains. The unit is exposed below the volcanic conglomerate between the Gila River and Johnny Creek (pl. 1). It consists of thin- to thick-bedded gray volcanic flows, intercalated conglomerate lenses, and some interbedded tuff.

Samples from test hole 2 in the SE¼SW¼NW¼ sec. 5, T. 6 S., R. 28 E., 325 feet upstream from the north end of the infiltration gallery, show an alternation of flows and conglomerate lenses in the part of the upper volcanic unit penetrated by the drill (p. 18). The top of this test hole lies about 475 feet stratigraphically below the top of the upper volcanic unit exposed in this vicinity.

The upper volcanic unit lies on an erosion surface that is cut on all older rocks in the area and has a maximum relief of about 200 feet. Where the flows of the upper volcanic unit are in contact with flows of the lower volcanic unit, it is difficult to delineate the two except on the basis of topography. Along the canyon of Bonita Creek, the unit is overlain by the Tertiary(?) volcanic conglomerate or lenses of tuff; elsewhere it forms the topmost unit in the section. The upper volcanic unit generally dips 3° to 7°, NE.

Samples from test hole 2 in SE¼ SW¼ NW¼ Sec. 5, T. 6 S., R. 28 E., Bonita Creek, Ariz.

Material	Thickness (feet)	Depth (feet)
Channel deposits	74	74
Gray andesite; no effervescence in HCl	26	100
Conglomerate containing partly rounded fragments of gray welded tuff and andesite or basalt; much coarse sand and granules; weak effervescence in HCl	18	118
Gray andesite; weak effervescence in HCl	22	140
Conglomerate containing small pebbles of gray andesite and silicified tuffaceous sand or welded tuff; strong to weak effervescence in HCl	15	155
Fractured(?) gray andesite; weak to strong effervescence in HCl	18	173
Gray andesite, reported as "very hard;" no effervescence in HCl	2	175
Total	175	

The estimated maximum thickness of the upper volcanic unit is 1,200 feet, although in many areas it is much less due to erosion.

Ground water from the upper volcanic unit is known only in the vicinity of the infiltration gallery. The test well drilled above the infiltration gallery produced a reported 1,215 gpm and about 141 feet of drawdown from this unit, and near the infiltration gallery water is reported to issue from flows of the upper volcanic unit a few feet below the level of the surface of the channel fill (G. A. Rhoads, oral communication, 1956).

A hole drilled into the upper volcanic unit in sec. 2, T. 6 S., R. 27 E. to a reported depth of 505 feet located no water at the time of drilling in 1951 and there was no water in the hole in March 1957. The bottom of the hole is at an altitude of about 3,650 feet and the altitude of Bonita Creek nearest the well, about 1.3 miles northeast, is 3,600 feet. It is possible that this hole was not drilled deep enough to reach the water table.

Exploratory wells along Eagle Creek, a stream somewhat parallel to, and about 7 miles northeast of, Bonita Creek, tapped rocks similar to those of the upper volcanic unit, and yielded water under some artesian head in quantities ranging generally from 10 to 1,000 gpm (D. H. Orr, oral communication, 1956).

The ground water in the upper volcanic unit and its relationships to ground water in the Quaternary channel fill are more fully discussed in the section "Ground water in the upper volcanic unit."

VOLCANIC CONGLOMERATE UNIT

In the valley between the Gila Mountains and Turtle Mountain, well-indurated volcanic conglomerate crops out over large areas and is particularly well exposed in the many steep-walled canyons. The exposures are separated into two general areas by a broad ridge formed by the upper volcanic unit between the mouths of Johnny Creek and Midnight Canyon and the south end of The Box (pl. 1).

The basal beds of the volcanic conglomerate lie conformably on an erosion surface of little local relief cut on the underlying upper volcanic unit. Locally, the basal beds are composed of tuff. The basal lenses of the volcanic conglomerate generally reflect the composition of the underlying rock and the matrix of the lenses is tuffaceous and light brown.

The volcanic conglomerate is composed predominantly of fragments of the Tertiary(?) volcanic rocks. The fragments are subangular to subrounded and range in size from granules to large boulders. The fragments are set in a matrix of coarse sand largely of volcanic composition. The individual lenses are a few inches to several feet thick and the contact between them is sharp. Except in the basal units, the lensing is attenuated and individual beds no more than 2 feet thick may be traced from 100 to 300 feet. Cut-and-fill structures are scarce and fluvial crossbedding is rare. Most of the unit is well indurated but calcite is locally present along stream courses, particularly in small fractures and in beds having a coarse matrix. The conglomerate is commonly capped by a caliche zone a few feet thick, composed in part of reworked fragments of the conglomerate.

The volcanic conglomerate unit is moderately resistant to weathering and stands in nearly vertical cliffs or steep slopes a few tens of feet to nearly 700 feet high. The unit is more than 700 feet thick in the southeastern part of the area, but northward and northwestward it feathers out onto the unconsolidated rubble on the underlying volcanic rocks.

The upper part of the volcanic conglomerate in most areas underlies the present erosion surface, except along the Gila River where it is disconformably overlain by the granite and basalt conglomerate and younger alluvial deposits.

Interbedded tuff.—Discontinuous tuff lenses, ranging from a few inches to about 60 feet in thickness, occur along the contact between the flows of the upper volcanic unit and the volcanic conglomerate and within the volcanic conglomerate. At the lower end of the valley, the tuff lenses are as much as three-fourths of a mile long. They are similar in appearance and texture to the tuff beds of the middle volcanic unit and contain similar fragmental material.

The tuff beds commonly include a lower unit, consisting of a few feet of thin-bedded to laminated water-laid tuffaceous sand and intercalated thin-bedded structureless tuff, and an upper unit of unstratified tuff. Both units contain fragments, as large as small pebbles, of gray felsitic rock similar to that in the middle volcanic unit. The fragments are slightly waterworn in the lower unit and sharply angular in the upper. Along the strike, the tuff lenses grade into tuffaceous pebble conglomerate containing mafic fragments, and a few feet farther along they become indistinguishable from the surrounding volcanic conglomerate. Sand and pebble dikes as wide as several inches are well developed in the tuff, particularly in the upper Dry Creek.

These beds were mapped separately to assist in defining the geologic structure within the volcanic conglomerate unit because they show more clearly than the conglomerate itself that the faulting and fracturing within them are on a small scale.

Age and correlation.—The volcanic conglomerate unit is continuous with the lower 300 feet of one of the type sections of Gila conglomerate described by Gilbert (1875). The lower 300 feet of this section is separated from the upper part by an abrupt change in composition. Farther to the west, at the south end of the Gila Mountains, the relief between the lower and upper parts of the section is as much as 200 feet. The upper part of these deposits was shown by Van Horn [3] to interfinger with lakebed deposits of late Pliocene and Pleistocene age. The volcanic conglomerate, therefore, is considered to be older than late Pliocene. Because the texture and composition of the volcanic conglomerate and the overlying beds are so similar, the general depositional conditions in the area probably remained about the same through the deposition of both units. For this reason, the volcanic conglomerate is not considered to be much older than the overlying deposits—possibly no older than Pliocene.

Water-bearing characteristics.—Most of the volcanic conglomerate unit lies above the gradient of Bonita Creek and the water table, and except for one seep it is not known to be water bearing. This seep is in Spring Canyon in sec. 20, T. 6 S., R. 28 E. Here seepage in the wash bottom and wetted wall occurs along a reach of about 300 feet. The walls are wet for several inches above the streambed at the upper end and more than 7 feet at the lower end. The wetted area generally follows the bedding but is not limited to a single lens. It is immediately upstream from a large northeastward-trending fracture which apparently acts as a barrier to the downstream movement of the water and forces it to the surface.

Although this single seep shows that the volcanic conglomerate is at least locally capable of transmitting water, the exposed sections of the volcanic conglomerate in most areas seem to be virtually impermeable except along open fractures. Potholes along wash bottoms

[3] Van Horn, W. L., op. cit.

that cut into this unit commonly hold rainwater or runoff until it is evaporated.

TERTIARY AND QUATERNARY ROCKS

GRANITE AND BASALT CONGLOMERATE

Deposits of alluvial conglomerate containing granitic and basaltic fragments crop out on the bluffs along the Gila River within the area mapped (pl. 1) and in the Safford Valley. They are here referred to as the granite and basalt conglomerate. Their areas of exposure are discontinuous, separated by deeply incised washes.

The rocks of this unit are composed predominantly of basaltic and felsitic volcanic fragments, but are distinguished from the underlying volcanic conglomerate by included red granite and quartzitic fragments and by being less well indurated. The granite, although uncommon, is conspicuous because of its red color and high degree of rounding. The quartzitic fragments include maroon crossbedded quartzite and granule quartzite, angular pebble conglomerate, and siliceous volcanic pebble conglomerate.

Near the mouth of Bonita Creek, the contact between the granite and basalt conglomerate and the underlying volcanic conglomerate is transitional, marked chiefly by the abrupt appearance of red granite. At the south end of the Gila Mountains, however, beds of the granite and basalt conglomerate fill a 200-foot-deep valley, cut along the contact between the volcanic conglomerate and older volcanic rocks. Along Dry Creek, in the SW¼ sec. 20, T. 6 S., R. 28 E., the granite and basalt conglomerate fills a channel cut through about 200 feet of volcanic conglomerate and into the tuff bed overlying the top flow of the upper volcanic unit. The irregular surface that was cut on the volcanic conglomerate prior to the deposition of the granite and basalt conglomerate, and the differences in composition, are evidence for the separation of the two units.

The granite and basalt conglomerate beds are virtually horizontal and overlap onto the volcanic conglomerate and older volcanic rocks in the southwestern part of the area. In sec. 10, T. 6 S., R. 28 E., they are partly cut by, and partly overlap, the Turtle Mountain fault. They are generally 400 feet thick in the southwest corner of the area mapped and thin to the north and northeast until they disappear.

The granite and basalt conglomerate interfingers with, and grades into, finer grained deposits in the Safford Valley. The finer grained deposits were shown by Van Horn[4] to contain late Pliocene (Blancan) and Pleistocene (Kansan?) fauna, stratigraphically within 100

[4] Van Horn, W. L., op. cit.

feet of each other. Throughout this 100-foot interval the deposits show no essential change in character, and are considered to reflect continuous deposition. Farther west they grade into lakebed and playa deposits and were considered by Knechtel (1936, 1938) to be Gila conglomerate. Heindl (1958) shows that the use of the term "Gila conglomerate" is impractical in any detailed investigation of valley-fill deposits, and the writers have delineated the volcanic conglomerate and granite and basalt conglomerate units for this reason.

In the mapped area, the granite and basalt conglomerate is above the water table. To the west in the Safford Valley, deposits that interfinger with, and grade into, the granite and basalt conglomerate contain ground water under artestian pressure (Turner and others, 1946).

QUATERNARY ROCKS

TERRACE DEPOSITS

Deposits of poorly consolidated cobble to boulder conglomerate lie in discontinuous patches 30 to 50 feet above the level of the Gila River and some of its larger tributaries. These gravel deposits are from 10 to 30 feet thick and are composed of fragments from all underlying rocks and some types not known to crop out in the area. They rest with an erosional or low angular unconformity on the volcanic and granite and basalt conglomerate beds and on remnants of flows of the upper volcanic unit. The gravel deposits lie on benches above the present flood plain of the Gila River, but are considered to be older than the flood plain. These deposits are considered to be Pleistocene in age because they overlie the granite and basalt conglomerate of Pliocene and Pleistocene age and are older than the Pleistocene and Recent flood-plain deposits of the Gila River.

Not all deposits that are related to these terraces have been mapped. Among the unmapped deposits are gravel beds that are composed predominantly of basalt fragments and which cover the tops of many of the mesas. These were derived from the adjoining mountains before incision of the present drainage pattern. This is shown by many of the mesas, such as the ones in secs. 4 and 24, T. 5 S., R. 27 E., whose surfaces are now completely cut off from the mountains by drainages developed around their apices. These deposits are characteristically coarser than the underlying volcanic conglomerate unit. The unmapped deposits also include extensive areas of well-consolidated and deeply incised talus scree along steep slopes of the mountains.

The terrace deposits are above the water table everywhere within the area mapped.

YOUNGER ALLUVIAL DEPOSITS

Only the more extensive deposits of younger alluvium have been mapped. These include flood-plain and channel deposits along the Gila River, channel fill along Bonita Creek and its larger tributaries, and some talus deposits along upper Coyote Creek and the south end of the Gila Mountains.

The channel fill along Bonita Creek consists predominantly of unconsolidated pebble, cobble, and boulder gravel in a sandy or silty matrix. The deposits were laid down as discontinuous lenses, commonly containing thin zones of sandy silt. The fragments are derived from the rocks exposed in the area, and in addition contain red granite, quartzite, and rarely, limestone. These fragments are traceable to the upper reaches of Bonita Creek; some tributaries of this creek dissect Precambrian granite and Paleozoic sedimentary rocks. The channel fill along Bonita Creek is 74 feet thick at The Meadows and at least 67 feet thick at the Safford Municipal Utilities' wells.

The flood-plain deposits are considered to be late Pleistocene to Recent in age, because of their similarity to flood-plain deposits elsewhere in southeastern Arizona (Hunt, 1953). The flood-plain deposits in the Safford Valley have been shown to range from 20 to 100 feet in thickness (Feth, *in* Halpenny, 1952, p. 46).

The flood-plain and channel deposits of the younger alluvium form the principal source of ground water in the Bonita Creek area and their hydrologic characteristics are discussed separately in the section "Ground water," page 32.

STRUCTURE

The geologic structure of the lower Bonita Creek area consists of northwestward-trending fault blocks whose scarps face southwest (pl. 1). Included within the area are parts of the northeast slope of the Gila Mountain block on the west and the eroded scarp of the Turtle Mountain block on the east. The uppermost deposits on both blocks dip at low angles in a general northeasterly direction and on the Gila Mountain block, part of which underlies the valley of Bonita Creek, they have a low component of dip to the southeast. Folding is minor compared with faulting, but some small-scale folds occur within the Tertiary volcanic rocks and a broad syncline warps the Tertiary rocks. There is some suggestion of broad regional warping in the uplifted blocks, but these structures were not delineated in this study. Minor fractures are common in all rocks in the area.

The deformation discussed in this report is not specifically dated. Because the granite and basalt conglomerate unit of late Pliocene to early Pleistocene age is nearly undisturbed, the deformation is arbitrarily dated as middle to late Tertiary. Evidence for the structural history prior to the deposition of the Tertiary(?) volcanic rocks is obscure and is not delineated in this report. The deformation involving the Tertiary(?) rocks is divided into three periods: (a) earlier than the upper volcanic unit; (b) later than the upper volcanic and earlier than the volcanic conglomerate units; and (c) later than the volcanic conglomerate unit. These periods of deformation seem to be part of the development of the tilted fault-block structure of the area.

DEFORMATION EARLIER THAN THE UPPER VOLCANIC UNIT

A period of faulting prior to the deposition of the flows of the upper volcanic unit is recorded by the Midnight fault which separates Cretaceous(?) rocks and the middle volcanic unit and is covered by rocks of the upper volcanic unit at its west end. As the thickness of the older and middle volcanic units varies considerably, the vertical displacement on the fault is estimated to be more than 500 feet. Subsequent movement along this fault is indicated at the mouth of Midnight Canyon where the volcanic conglomerate is faulted against rocks of the middle volcanic unit. The vertical displacement here is less than 100 feet. The west-northwest trend of this fault is unique in the area. At its east end, the fault is covered by broken blocks of the younger volcanic unit that may reflect either the more recent faulting or merely slumping, and is apparently cut off by the younger Turtle Mountain fault zone.

Locally, beds of the lower and middle volcanic units are tilted at angles of about 10° to 35° below the flat to low-dipping flows of the upper volcanic unit. At least a part of this deformation may reflect high initial dips, possibly the result of deposition on an irregular surface. Where these dips occur in fine-grained tuffaceous sandstone, they reflect local warping. Although exposures in which dips could be measured reliably are scattered, the persistence of the angular unconformity between the middle and upper volcanic units in both the Gila and Turtle Mountains suggests that the deformation of beds older than the upper volcanic unit is regional.

DEFORMATION LATER THAN THE UPPER VOLCANIC UNIT AND EARLIER THAN THE VOLCANIC CONGLOMERATE UNIT

Small-scale faulting followed the eruption of the upper volcanic unit and preceded the deposition of the volcanic conglomerate. Faults of this period of movement are well exposed along Bonita Creek, particularly near the infiltration gallery. Here northeastward-trending faults within the upper volcanic flows show vertical displacements of about 30 feet with the downthrown sides to the southeast. The volcanic conglomerate was deposited on an erosional surface that truncated the fault trace.

These small northeast faults are believed to be associated with the development of the general tilted fault-block structure of the area for two reasons: First, these faults are parallel to, and have about the same amount of displacement and distribution as, later minor faults that cut the volcanic conglomerate and appear to be related to the Turtle Mountain fault; the second reason is more tenuous. Within the upper volcanic unit on the Gila Mountain block, an increase southeastward in the ratio of interbedded conglomerate to volcanic flow suggests an original gradient in that direction. The volcanic conglomerate is limited in outcrop to the central part of the depressed area between the Gila and Turtle Mountains. A synclinal warp in this area, therefore, may have existed prior to the deposition of the volcanic conglomerate as an expression of warping or differential movement along the general line of the Turtle Mountain fault.

DEFORMATION LATER THAN THE VOLCANIC CONGLOMERATE UNIT

The main movement along the Turtle Mountain fault, which uplifted the Turtle Mountain mass relative to the Gila Mountain block, occurred after the deposition of the volcanic conglomerate. The Gila Mountain block remained comparatively stable as the dips on the volcanic conglomerate do not differ appreciably from what must have been their original attitude. The Turtle Mountain fault is considered to be definitely younger than the volcanic conglomerate because the volcanic conglomerate adjacent to the fault contains a high percentage of middle volcanic unit fragments, instead of a high percentage of basaltic fragments, which should be expected from a contemporaneously rising adjacent basalt ridge. This faulting continued late enough to cut some, but not all, of the granite and basalt conglomerate.

The faulting extends from the Gila River to Midnight Canyon and has a general N. 40° W. trend. North of Midnight Canyon the trend is chiefly northward, and the throw on the fault diminishes until, at the north edge of the area mapped, the apparently undisturbed volcanic conglomerate overlies rocks of the lower volcanic unit. Faulting of about the same type, direction, and magnitude is exposed northwest of the area mapped and may be part of a general zone of faulting here expressed by the Turtle Mountain fault.

These faults have brought rocks of the younger volcanic unit and the volcanic conglomerate into contact with Cretaceous(?) rocks and those of the lower and middle volcanic units. Although the Turtle

Mountain fault seems to cut off the older Midnight fault, nearly contemporaneous movement along the Midnight fault was sufficient to separate the volcanic conglomerate into two areas (pl. 2).

FRACTURING

Fractures are common in all rocks in the area. Along with small-scale faulting, it accounts for the many smaller drainage features and gashlike, nearly vertical gullies. Much of the fracturing may involve small-scale movement, but this is difficult to locate because of the lack of marker beds. Fractures are particularly extensive in the volcanic flows. Much of the fracturing trends northeastward, but it also trends east and north. Along upper Dry Creek, many nearly vertical fractures in the tuff beds are filled with sand and gravel to form pebble dikes as much as several inches wide.

WATER RESOURCES

The known water resources of the lower Bonita Creek area are limited to the surface flow in Bonita Creek, a few intermittent springs, and the ground water within rocks of the upper volcanic unit and the Quaternary younger alluvial deposits that fill the channel of Bonita Creek.

The principal use of water is for municipal, domestic, and stock purposes. The water supply obtained for the Safford Municipal Utilities is far in excess of that used for other purposes. There are only two ranch headquarters along lower Bonita Creek, and a total of about 300 head of cattle in the valley. Water for the cattle on the broad slopes of the Bonita Creek area is either hauled or pumped from Bonita Creek and piped to troughs.

The water resources of the Gila River and its flood plain within the area mapped are not considered in this report, except insofar as they bear on the supply for the lower Bonita Creek area.

SURFACE WATER

BONITA CREEK

The total drainage area of Bonita Creek includes about 370 square miles, of which only 60 square miles are within the mapped area. The drainage basin is bounded by mountains on its southwest and northeast sides, and a broad open flat at the north end. Altitudes along Bonita Creek range generally from 3,200 to 5,000 feet and the adjacent mountains rise to altitudes of 6,000 to 7,000 feet. The flow in Bonita Creek is intermittent about 2½ miles north of the San Carlos Indian Reservation boundary. In this area Bonita Creek canyon is cut through rocks of the volcanic conglomerate into the basaltic flows of the upper volcanic unit. Water emerges from the channel fill near this contact, and from this point to the mouth of Johnny Creek, Bonita Creek is perennial except in the driest years. Below the mouth of Johnny Creek, the flow is continuous except in the immediate vicinity of the infiltration gallery where the creek is generally dry for several weeks before the beginning of the summer floods. The surface flow in lower Bonita Creek is apparently augmented by discharge from small seeps and springs which may represent upstream losses.

South of the mouth of Johnny Creek, Bonita Creek is confined to The Box, a narrow gorge about 2 miles long cut in nearly horizontal basaltic flows (pl. 1). Here the canyon is about 400 to 800 feet deep, the lower 200 feet of which is nearly vertical. In this reach the channel is generally less than 100 feet wide, and in some places it is less than 50 feet wide.

Torrential floods occur during the summer and may last from a few hours to a few days. Local ranchers report that the creek has been known to rise 5 feet in 15 minutes. From floodmarks at the mouth, a maximum runoff of 17,000 cfs in August 1915 was computed by Olmstead (1919). Other individual peaks of as much as 1,000 cfs are reported (Grover and others, 1933, p. 134). Less than 1 cfs flows during May and June before the start of the summer rains.

A series of continuing seepage measurements was begun in January 1955 by the Safford Municipal Utilities to determine gains and losses of surface flow at the successive gaging points. Monthly measurements, except during the summer floods, were made downstream at 13 stations located at about 1-mile intervals from above the mouth of Johnny Creek to near the mouth of Bonita Creek. These stations are numbered consecutively downstream, and their locations are shown on plates 1 and 2. Stations 1 to 4 are in The Box; station 5 is at the south end of the rhyolite exposure; station 9 is at the infiltration gallery; station 11 is immediately below the mouth of Goat Canyon; and station 13 is about 1,000 feet above the mouth of Bonita Creek.

Monthly losses and gains in flow at successive stations during 1956 are shown in figure 4. The pattern of flow from the head of The Box to the mouth is similar throughout most of the year for which records are available. The flow increases markedly to about 6.5 cfs, in the upper reaches of The Box, and a progressive overall decline to station 10, about half a mile below the gallery area. Below this station flow increases slightly and again diminishes toward the mouth. Between the peak flows at station 2 in The Box and the infiltration gallery, there was an average loss of about 4 cfs during 1956. The gain below

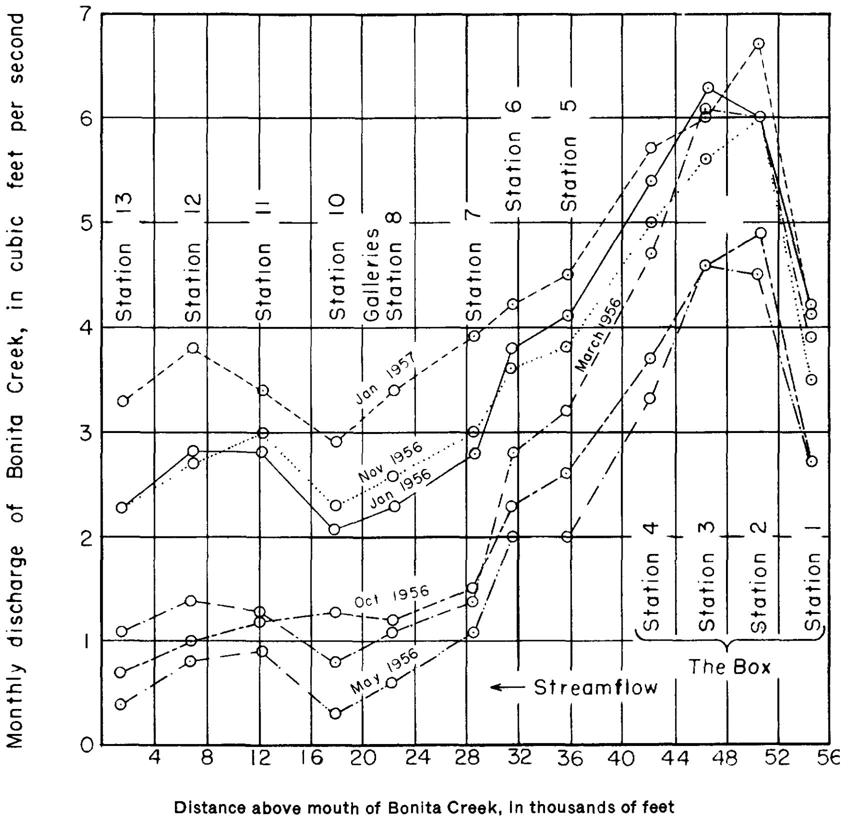

Figure 4.—Changes in the flow of Bonita Creek, January 1956 to January 1957 at gaging stations 1–8, and 10–13, below Johnny Creek.

the infiltration gallery averaged less than 1 cfs, and this gain was almost entirely lost by the time the flow reached station 13.

In figure 5 the losses and gains in flow at selected stations are plotted to show monthly fluctuations. The monthly fluctuations for the 2-year period January 1955 to January 1957 follow a similar pattern at all stations shown. The highest sustained flow is during November through February, and it decreases to a low flow before the onset of the summer rains and floods which continue sporadically through August. No measurements of flow were made during the summers. The flow subsides during September and October following the summer floods, and rises sharply again in November after the killing frosts.

The monthly measurements cannot be used to estimate annual discharge because they do not include summer floodflows. Miscellaneous measurements made on the flow of Bonita Creek prior to 1955 are insufficient to be used as a basis for comparing the 1955 and 1956 discharge data with those of earlier years. However the amounts of

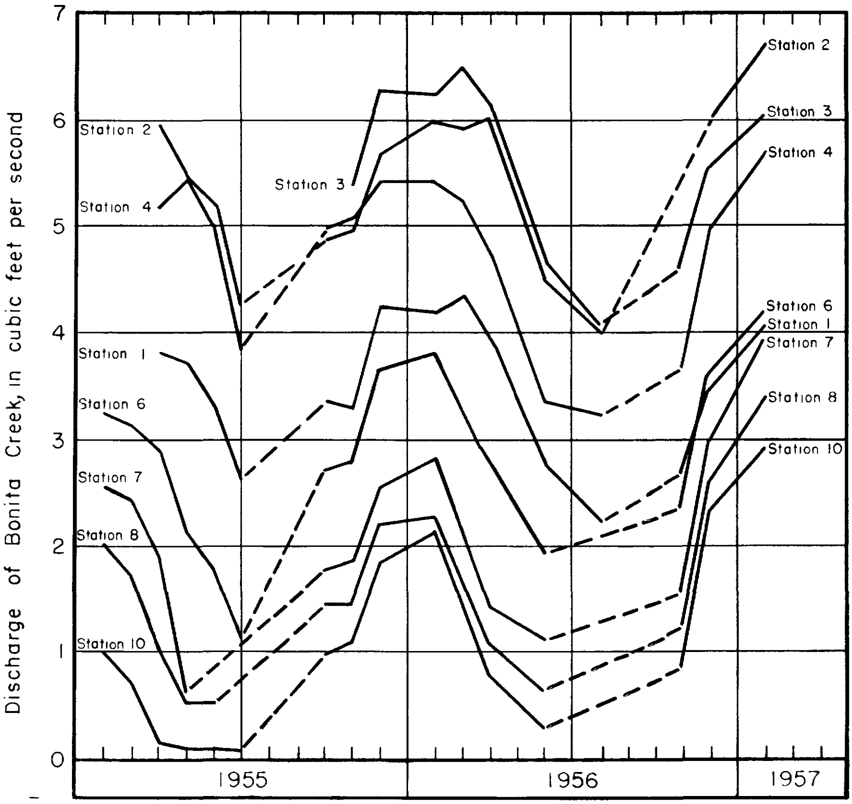

FIGURE 5.—Hydrograph of monthly discharge of Bonita Creek at selected gaging stations 1–4, 6–8, and 10, below Johnny Creek, January 1955 to January 1957. Dashed line indicates flow not measured, and includes periods of floodflow.

discharge measured in 1955 and 1956 were undoubtedly affected by the drought which began in 1942 (Searles, 1951).

Other creeks in the area, tributary to Bonita Creek and the Gila River, are ephemeral and flow only during and after rains. No data are available regarding the amount of their flows.

A seep, causing a short reach of perennial flow in Spring Canyon in the NW¼ sec. 20, T. 6 S., R. 28 E., is estimated to produce between about 5 and 40 gpm, depending on the time of year.

RELATIONSHIP OF PRECIPITATION TO RUNOFF

Precipitation in the area averages about 12 inches per year. It has been estimated that in the psysiographic province which includes the Bonita Creek area about one-tenth of the total precipitation in the mountain areas becomes runoff (Halpenny and others, 1952, p. 17). Available records and estimates of annual discharge, floodflow, and

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diversions at the infiltration gallery suggest that the discharge from Bonita Creek is less than this estimate of runoff.

The graphs of annual precipitation and runoff (figs. 2, 5) show that the increased winter runoff begins in November, whereas the winter precipitation generally begins in December. This anomaly is apparently related to the first killing frost, which generally occurs in late October or early November. When the growing season ends and plants cease drawing water to meet transpiration needs, the flow of Bonita Creek increases by about ½ to 1 cfs.

GROUND WATER

Within the lower Bonita Creek area, almost all data on ground water were obtained from the channel of Bonita Creek. Along Bonita Creek, ground water occurs in rocks of the upper volcanic unit and within the alluvial channel fill. Small springs and seeps, at or slightly above the level of the creekbed, are present in rocks of the upper volcanic and volcanic conglomerate units.

Elsewhere in the area, the Tertiary(?) volcanic rocks yield water in limited quantities to small ephemeral springs on the high slopes of Turtle Mountain. No ground water is known to occur in Cretaceous(?) rocks within the mapped area although quantities sufficient for domestic or stock supplies are obtained from these rocks on the west slopes of the Gila Mountains. The Pliocene and Pleistocene granite and basalt conglomerate and the Quaternary terrace deposits in the area are above the water table.

The late Quaternary channel fill along Bonita Creek is the principal aquifer in the area. Shallow wells within it have sustained yields of as much as about 280 gpm. It contains the infiltration gallery which produced about 1,500 gpm in 1957.

The lower Bonita Creek area dips generally southeastward, both topographically and structurally. The water table within the channel fill along Bonita Creek slopes in this general direction and, although confirmatory data are lacking, this is probably also true within the upper volcanic unit.

GROUND WATER IN THE UPPER VOLCANIC UNIT

Data regarding the water-bearing properties of the upper volcanic unit are available only from test hole 2, one of two test holes drilled in the SE¼SW¼NW¼ sec. 5, T. 6 S., R. 28 E. These holes were drilled in 1957 following the completion of the fieldwork and the data reported herein were collected by the Safford Municipal Utilities.

Test hole 1 is 317 feet upstream from the upper end of the infiltration gallery. It is 60 feet deep, contains 20-inch casing perforated its full length and is connected to the infiltration gallery by a 12-inch siphon. It lies entirely within the channel alluvium. Test hole 2 was drilled 8 feet north of test hole 1 to a depth of 175 feet and penetrated alternate volcanic and sedimentary rocks below a 74-foot thickness of channel fill. Test hole 2 was constructed with a 16-inch casing set within 20-inch casing; the 20-inch casing was open to water in both the channel fill and the upper volcanic unit and the 16-inch casing was virtually sealed off from the water in the channel fill and was open only to water in the upper volcanic unit. No information is available as to whether the ground water in the test hole from the upper volcanic unit occurred within the volcanic flows, the sedimentary beds, or both. At excavations along the canyon walls made during the construction of the infiltration gallery, ground water issued from fractures in the volcanic rocks below the surface of the channel fill (G. A. Rhoads, oral communication, 1956).

The water level within the 16-inch casing in test hole 2 was about 5 inches higher than the water level in the annular opening between the 16-inch and 20-inch casings, which stood at about the same level as the water level in test hole 1. The water level in the 16-inch casing was about 10 feet below the surface of the channel fill before the beginning of the pumping tests.

Two short-term pumping tests were made by the Safford Municipal Utilities on test hole 2. During the first test, water obtained within the 16-inch casing came from the rocks of the upper volcanic unit. For the second test, the 16-inch casing was removed and water was obtained from both the upper volcanic unit and the channel alluvium.

The first test yielded 1,200 gpm for 6 hours with a drawdown of about 141 feet, indicating a specific capacity of about 8.5 gpm per foot of drawdown. During this test, the water level in test hole 1 had a drawdown of about 0.5 feet, indicating either that the seal at the base of the 20-inch casing was not entirely effective or that there was some movement across the boundary between the channel fill and the volcanic rocks. Comparison of the data from the two pumping tests, however, suggests that about 90 percent of the ground water produced during the test came from the rocks of the upper volcanic unit. During the first pumping test, the discharge from the infiltration gallery was not noticeably reduced.

During the second pumping test, the channel alluvium and the upper volcanic unit together yielded 1,600 gpm for 6 hours with a drawdown of 18.7 feet, indicating a specific capacity of about 85 gpm per foot of drawdown. The drawdown in test hole 1 during the second test was about 6.3 feet and discharge from the infiltration gallery is reported to have been reduced about 50 gpm.

The ground water in the upper volcanic unit near the infiltration gallery seems to be in an aquifer separate from the channel fill, although locally water can move from one aquifer to the other where the contact is permeable. The irregular distribution of fractures and void spaces in the upper volcanic unit, comparatively wide exposure in recharge areas, and the presence of ground water within and near the infiltration gallery suggests that further exploration for limited quantities of ground water within this unit may be justified.

GROUND WATER IN THE YOUNGER ALLUVIUM OF THE CHANNEL FILL OF BONITA CREEK

The channel fill of Bonita Creek lies in a trough carved in rocks of the middle and upper volcanic units and the volcanic conglomerate. The trough is from about 30 to more than 200 feet wide and is 74 feet deep at the gallery and at least 67 feet deep near the mouth of Bonita Creek. Within the mapped area, Bonita Creek is chiefly perennial.

Along Bonita Creek, the sources of ground water are the influent surface flow, underflow within the channel fill from above the San Carlos Indian Reservation boundary, and very small additions by direct precipitation. In general, the ground water within the channel fill moves along a gradient parallel to the slope of the surface channel.

The water-bearing properties of the channel fill are controlled principally by two factors, the differences in the permeability of the materials forming the individual lenses of the alluvium and the shape of the deposit. The differences in permeability control the movement of water through the channel fill and the capacity of the fill to transmit water. The thin, elongated, shoestring shape of the deposit, confined as it is within the almost impermeable trough, contains a small volume of sediments and, therefore, a small amount of good water in storage. The small cross-sectional area of the deposit also limits the amount of ground water that can move downward.

PERMEABILITY OF THE YOUNGER ALLUVIUM OF THE CHANNEL FILL OF BONITA CREEK

The wide range in permeability of the discontinuous interfingering lenses of gravel, sand, and silt is demonstrated by different rates of infiltration from the surface flow of Bonita Creek. The alternation of saturated and unsaturated zones within the channel fill, and the presence of temporary springs in the terrace gravel also reflect the range of permeability.

During the pumping test on the Safford Municipal Utilities' wells near the mouth of Bonita Creek, the surface flow receded about 1,000 feet upstream from the pumped well after 24 hours of pumping. In contrast, the surface flow across the infiltration gallery remained unchanged before and during a test in which the gallery discharged about 2,000 gpm. These widely contrasting rates of infiltration from surface flow, reacting to the removal of ground water from the channel fill, are interpreted as being due to differences in the permeability of the channel-fill materials.

Trenching the infiltration gallery to about 10 feet below the surface along a line parallel to, and within 5 feet of, the flowing creek showed the following sequence of alluvial materials:

	Thickness (feet)
Surface.	
Gravel:	
1. Sand and gravel, saturated	3.5
2. Silty sand containing pebbles, nearly dry	5
3. Pebble and boulder gravel, saturated, grades upward into unit 2	1.5+
Covered.	
Total thickness of gravel exposed	10

The unsaturated zone between the saturated sand and gravel at the surface and lower saturated alluvium was reported at other excavations made near the gallery area (G. A. Rhoads, oral communication, 1956). The infiltration gallery lies within the lower saturated zone.

Temporary springs issuing from the terrace gravels, channel banks, and previously used channel beds are common along Bonita Creek at levels from a few inches to a few feet above the present course of the creek. The springs are probably caused by water that is diverted from its downward movement through the channel fill by relatively impermeable zones and moves laterally through the more permeable material. At places the more permeable zones intersect the surface and the water issues as temporary springs or seeps.

AQUIFER TESTS OF THE CHANNEL FILL

An aquifer test was made by the Safford Municipal Utilities at the infiltration gallery in October 1955. The gallery was shut off for 24 hours during which the aquifer was allowed to recover. After 24 hours, the water level at the gallery had risen to within 13.5 feet of the surface, about 2.5 feet above the gallery pipelines. The gallery lines were then reopened and the rate of drawdown was measured at both the lower and upper ends of the gallery and at both sand traps (fig. 3). The flow of water from the gallery during this test was metered at a rate of about 2,000,000 gpd. At the end of about 5 hours the water levels became almost stabilized. The rates of drawdown suggest a coefficient of transmissibility of about 600,000 gpd per foot for that part of the aquifer above the pipelines. The flow in Bonita Creek above the gallery remained virtually unchanged during this test.

Additional data on the hydraulic characteristics of the channel fill were obtained from a pumping test conducted on the Safford Municipal Utilities' wells on Bonita Creek, in sec. 21, T. 6 S., R. 28 E., in July 1956. The pumped well and observation wells are about 1,000 feet above the mouth of Bonita Creek (pl. 1) and their detailed relationships are shown in figures 6 and 7. The two wells are 280 feet apart; the pumped well is about 58 feet from the west wall and 98 feet from the east wall of the canyon; the observation well is about 47 feet from the west wall and 153 feet from the east wall of the canyon. Each well is about 67 feet deep, penetrates channel fill, and has an 18-inch perforated steel casing to the bottom. The canyon walls are composed of comparatively impervious conglomerate layers interbedded with basaltic flows of the upper volcanic unit. The total depth of the channel fill is not known as the wells did not reach bedrock. During the pumping test the siphon connecting the two wells (fig. 7) was shut off.

During a preliminary test the pumped well discharged about 1,050 gpm for 212 minutes with a drawdown of 64.2 feet in the pumped well and a drawdown of 3.5 feet in the observation well. The pump began to suck air and the pumping rate was reduced to 380 gpm and allowed to pump another 148 minutes. The specific capacity of the well during this test was about 16 gpm per foot of drawdown.

Two days following the preliminary test, a 24-hour aquifer test was run at a nearly constant discharge rate of 280 gpm after the first 48 minutes. During this test the pumped well had a drawdown of 6.8 feet and the observation well had a drawdown of 2.5 feet. The specific capacity during this test was about 40 gpm per foot of drawdown.

The observed drawdown and recovery data (figs. 8, 9) showed the effects of the location of the pumped and observation wells in a narrow channel bordered by virtually impermeable walls. Application of the Theis nonequilibrium and the Cooper-Jacob modified nonequilibrium formulas to both the drawdown and recovery data provided a wide range of apparent coefficients of transmissibility (T) and storage (S). The method of image wells (fig. 6) provided assumed coefficients of transmissibility and storage which were substituted into the basic equations to obtain computed drawdown and recovery. The assumption of a coefficient of transmissibility of 3.5×10^5 and a coefficient of storage of 0.08 gave the closest check against the observed drawdown and recovery data (figs. 8, 9).

The modification of Darcy's formula, $Q=TIW$ (in which Q is the quantity of underflow, in gallons per day; T is the coefficient of transmissibility, in gallons per day per foot; I is the hydraulic gradient,

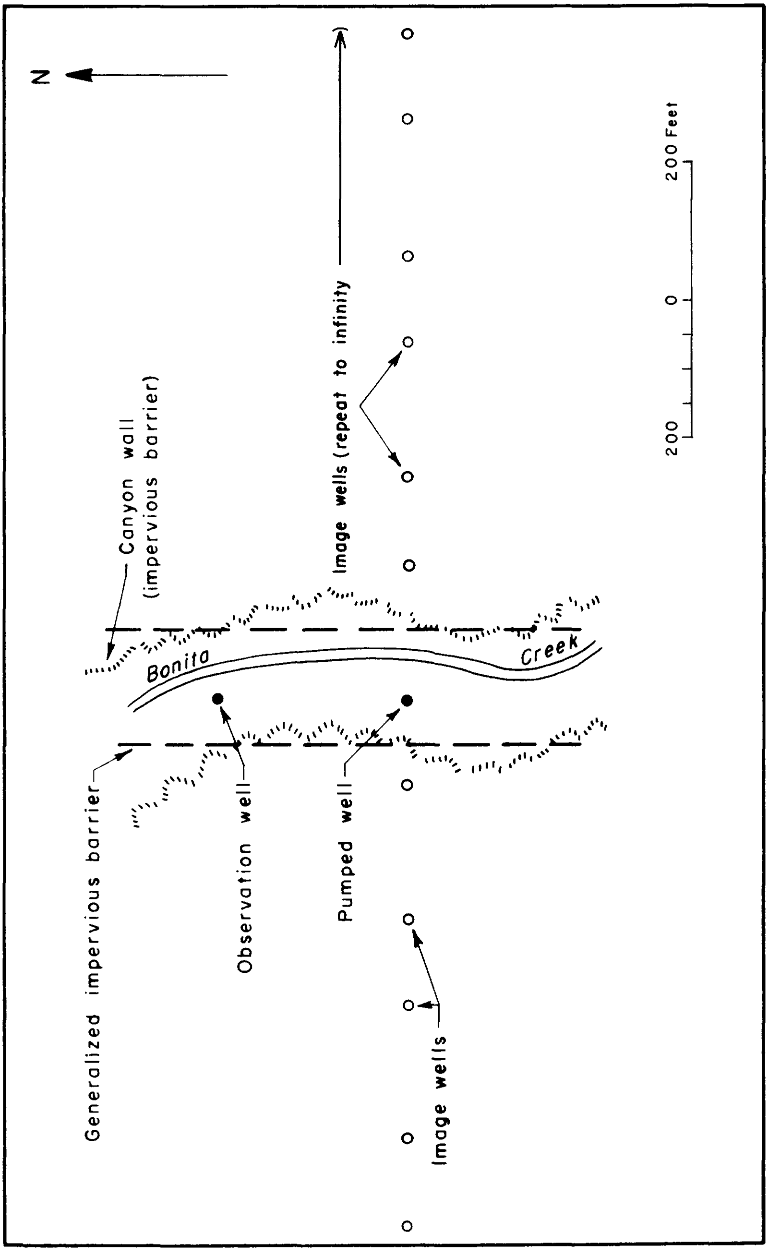

FIGURE 6.—Plan of image-well system for a discharging well along a perennial stream enclosed by two parallel impervious barriers, Safford Municipal Utilities' wells, sec. 21, T. 6 S., R. 28 E., Graham County, Ariz.

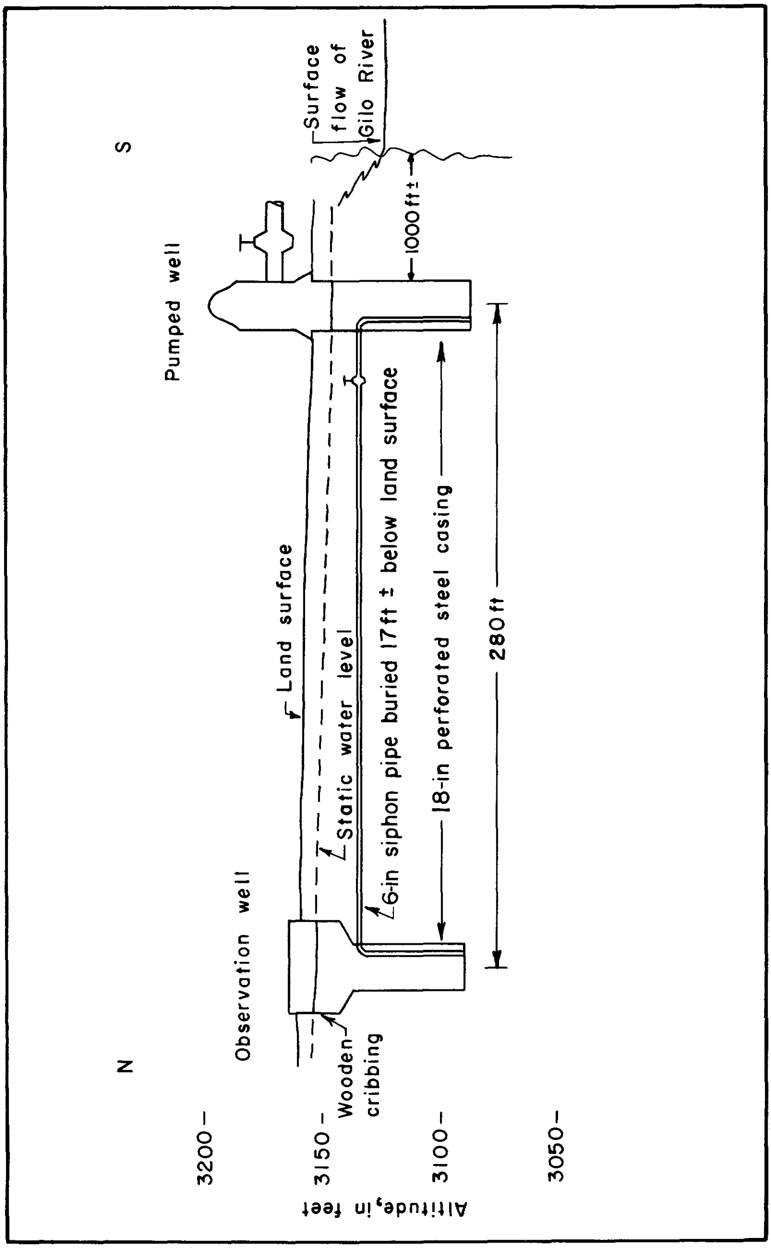

FIGURE 7.—Sectional view of the Safford Municipal Utilities' wells and pipelines, sec. 21, T. 6 S., R. 28 E., Graham County, Ariz.

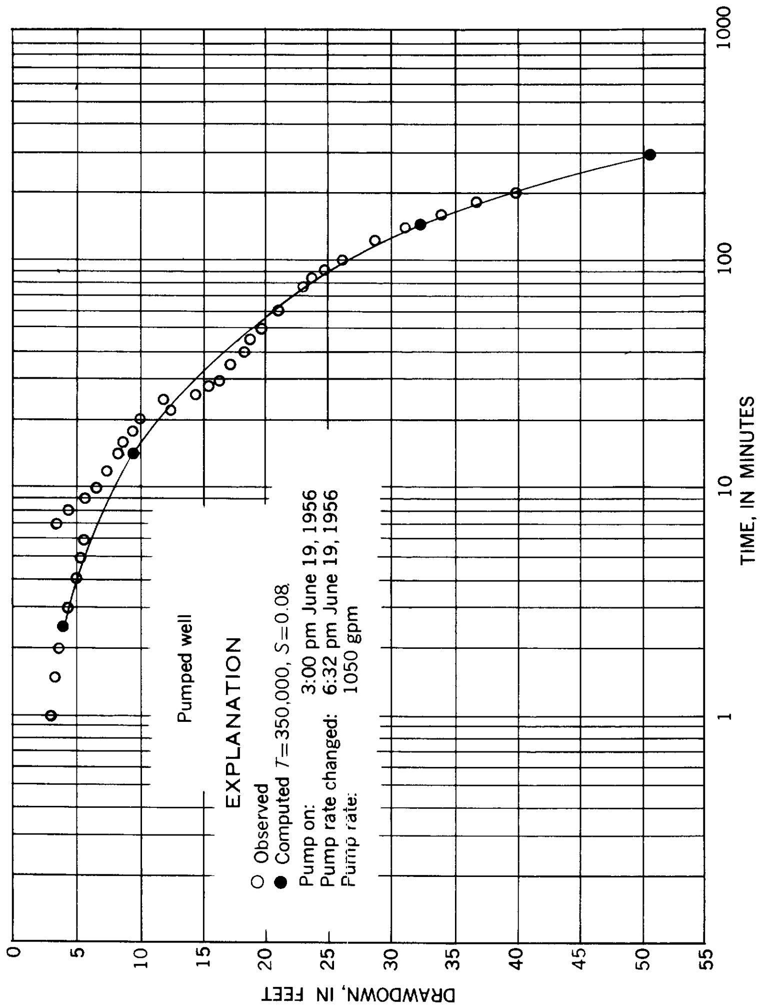

FIGURE 8.—Plot of drawdown-test data, pumped well, Safford Municipal Utilities' well site, Graham County, Ariz.

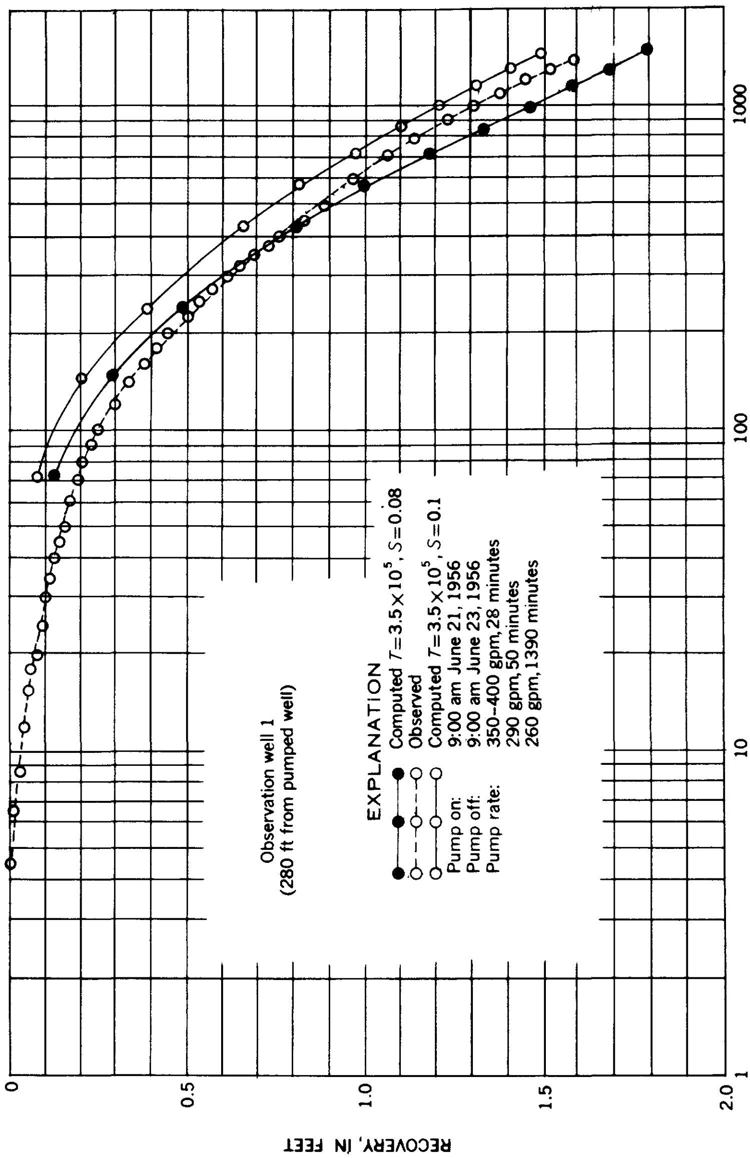

FIGURE 9.—Recovery-test data, observation well, Safford Municipal Utilities' well site, Graham County, Ariz.

in feet per mile; and *W* is the width of the aquifer, in feet) provides an estimate of underflow. Substituting the estimated value of $T=3.5\times10^5$, the hydraulic gradient of $I=40$ feet per mile and the approximate width of $W=200$ feet into the formula gives an estimated underflow of about 500,000 gpd, or nearly 0.8 cfs. This suggests that the sustained pumping of about 280 gpm, or about 400,000 gpd, during the pumping test was intercepting a large part of the underflow in lower Bonita Creek.

A comparison of the computed underflow near the mouth of Bonita Creek with the discharge from the channel fill at the infiltration gallery suggests that the gallery taps from about 6 to 7 times more water than is computed for the underflow downstream. The amount of underflow above the gallery is either several times the amount of underflow below it (that is, the gallery is intercepting underflow) or there is another source for a large part of the water obtained at the gallery.

RECHARGE

Recharge in the lower Bonita Creek area is from influent seepage, underflow, and possibly direct precipitation. Lower Bonita Creek is chiefly perennial and influent seepage from it probably occurs over much of its length. However, influent seepage does not occur at the same rate over its full length, as illustrated by the contrast of infiltration in the vicinity of the gallery and at the wells near the mouth of Bonita Creek. (See p. 32–33.)

Some of the larger tributary streams contain channel fill about 100 feet wide and the channel deposits are locally recharged following storm runoff. This water is discharged by underflow or infiltrates into the underlying rocks. Smaller tributaries are virtually without channel fill. In these, water was observed to stand in pools for nearly 3 weeks following the winter rains of 1956–57, except where the channels crossed fracture planes. Along the fracture planes, there were no pools even where the moving water had developed small potholes. Recharge from surface flow to the rocks older than the channel fill apparently is concentrated along fractures.

All the Tertiary(?) rocks are extensively fractured, and part of the runoff moving across their surface may descend to the water table.

A quantitative estimate of recharge can be attempted at this time only for the water in the channel fill along Bonita Creek. It may be assumed that total discharge is about equal to the total recharge, because no water is removed from storage. Three major elements of discharge—underflow into the Gila River, losses due to evapotranspiration, and diversion at the infiltration gallery—are estimated in the following section, "Discharge." These total about 3,500 acre-feet per year, and this total is probably in the magnitude of the total recharge to the channel fill along Bonita Creek.

DISCHARGE

Natural discharge of ground water in the lower Bonita Creek area occurs as evapotranspiration, effluent seepage, and underflow. Artificial discharge occurs through wells and the infiltration gallery.

Evapotranspiration of ground water in the lower Bonita Creek area is believed to be limited to the channel of Bonita Creek except near seeps and springs. Elsewhere, the depth to water seems to be sufficiently great so that the loss of ground water by evapotranspiration may be considered negligible.

The bottom of Bonita Creek canyon ranges in width from less than 30 to about 300 feet, averaging about 150 feet. Plant growth along this reach of about 13 miles is moderately thick. Following the early killing frosts in the late fall in 1955 and 1956 (fig. 5) the flow of Bonita Creek increased about 0.5 to 1 cfs or about 500 acre-feet per year. This may be considered as an approximate measure of the transpiration losses along Bonita Creek during the growing season. The amount of evaporation losses, on the basis of an average wetted width of about 20 feet and the stillwater evaporation rate at Safford of about 65 inches per year, is estimated to be 150 acre-feet per year. The amount lost by underflow into the Gila River has been estimated to be 500,000 gpd (p. 39), or about 500 acre-feet. The amount of natural discharge of ground water along lower Bonita Creek is rounded to about 1,200 acre-feet per year.

Data from the Safford Municipal Utilities indicate that the infiltration gallery during 1939–56 had a low discharge of about 900 acre-feet in 1944 and a high discharge of about 2,500 acre-feet in 1953 (fig. 10). The average discharge during 1939–52 was about 1,200 acre-feet per year. After the installation of the second pipeline, the average discharge rose to about 2,300 acre-feet per year during 1953–56.

Discharge of ground water from wells in the area (table 3) is negligible. The only well of moderate yield is the Safford Municipal Utilities' well near the mouth of Bonita Creek which is used for only a few weeks during the summer except for monthly pumping for a few hours to make certain the installation is ready for emergency purposes. The total discharge from this well is unknown, but is probably less than 100 acre-feet per year.

The total natural and artificial discharge of ground water in the lower Bonita Creek area is estimated to be about 3,500 acre-feet per year.

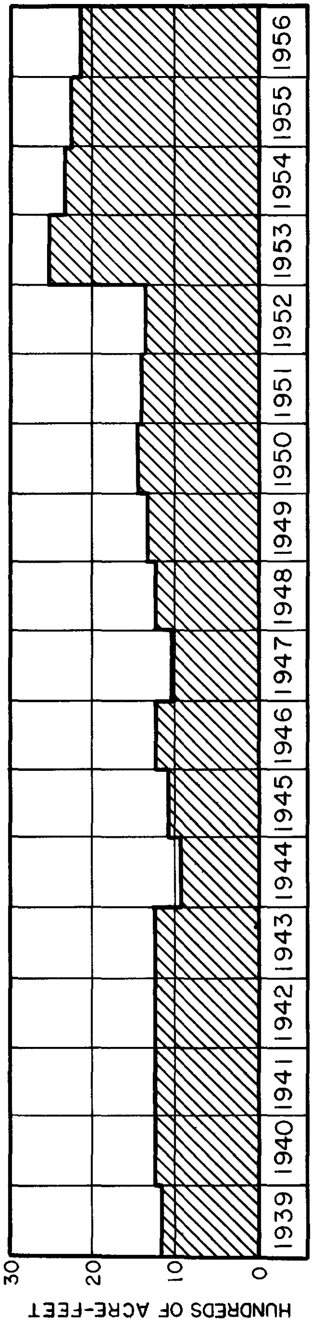

FIGURE 10.—Annual discharge from the Safford Municipal Utilities' infiltration gallery, 1939–56.

CHEMICAL QUALITY

Samples of water from wells, springs, surface flow, and the infiltration gallery in Bonita Creek were analyzed for chemical quality during this investigation. In addition the Safford Municipal Utilities supplied analyses of water made earlier by private laboratories. These are given in table 4. Analyses showed the water sampled to be moderate in mineral content and hardness. The silica content is high in proportion to the total mineral content. The range of selected chemical constituents and properties of water are given in table 2.

The analyses were examined to determine the possible sources of the water from the infiltration gallery. The localization of small-scale faulting and the quantities of water obtained from the infiltration gallery suggested that a source other than surface flow and underflow within the channel might be present. However, the small number of analyses, the uniformity of the chemical composition of the water samples, and the small range of the dissolved solids do not warrant any conclusion regarding sources.

According to published standards (U.S. Public Health Service, 1946; Wilcox, 1948), the water of the lower Bonita Creek area is suitable for domestic and agricultural purposes. The only objectionable properties are the high silica content and the hardness. The fluoride content is within the 1.5-ppm limit set by the Public Health Service.

TABLE 2.—*Range of selected chemical constituents and properties of water in the lower Bonita Creek area*

Properties	Gallery	Wells	Springs	Surface flow
Dissolved solids (ppm)	281–437	252–462	258–384	265–401
Silica (ppm)	40–54	40–72	24–57	23–72
Hardness as $CaCO_3$ (ppm)	166–190	170–207	112–198	152–168
Percent sodium	23	5–33	23–42	26–31
Specific conductance (micromhos at 25° C)	317–415	419–423	374–459	371–395

WATER REGIMEN ALONG LOWER BONITA CREEK

The general relations of surface- and ground-water flow along Bonita Creek are shown diagrammatically in figure 11. In addition to precipitation, water enters the area as surface flow and as underflow in Bonita Creek channel fill and the underlying volcanic rocks. At the head of The Box, where the channel fill is constricted, underflow in the channel fill is forced to the surface, increasing the amount of surface flow. Below The Box, the channel fill broadens and possibly deepens, and part of the surface flow returns as underflow. Most of the return

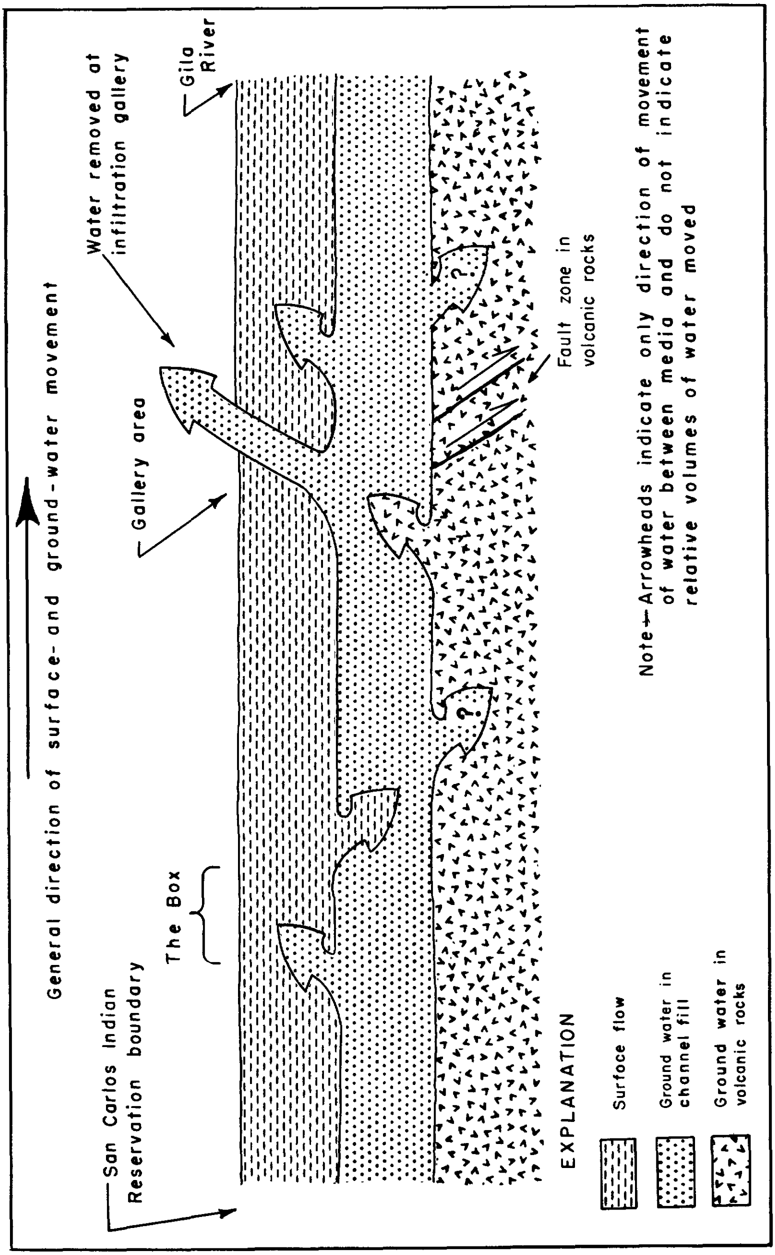

FIGURE 11.—Probable surface-flow and underflow relations along lower Bonita Creek, Ariz.

is probably to the channel fill, but some of it may enter permeable zones in the bordering volcanic rocks. Near the gallery, a small zone of faulting in the volcanic rocks apparently acts as a barrier to the movement of ground water within the volcanic rocks and diverts the water into the channel fill. Most of this water is removed at the infiltration gallery and piped to Safford. The balance of the underflow, including increments from influent surface flow, continues to the Gila River. Below the gallery a second, smaller increase in surface flow suggests a local reduction of the water-bearing capacity of the channel fill. Downstream the surface flow again gradually decreases.

G. B. Smith, engineer with the Safford Municipal Utilities, noted that the total maximum surface flow in The Box is probably accounted for by (a) surface flow into the Gila River, (b) underflow into the Gila River, (c) evapotranspiration, and (d) diversion by the infiltration gallery. He also points out that the 1-cfs and 0.7-cfs increases in surface flow in 1956 and 1957 approximate the amount of decrease in the gallery production for these years.

The infiltration of surface water into the channel fill along Bonita Creek is not uniform. The heterogeneity of the sediments, the interlensing, and the varying amounts of silt in individual lenses suggest that movement of ground water through the fill is concentrated along more permeable zones rather than being uniform through the fill as a whole.

Examination of chemical analyses of surface, underflow, seep, and gallery water failed to disclose any significant difference either in chemical content or proportions of constituents.

It is therefore concluded that most of the water obtained at the infiltration gallery is surface flow and underflow entering the lower Bonita Creek area in and beneath the channel of Bonita Creek. Ground water in the volcanic rocks underlying the channel fill seems to be in a separate aquifer, although locally, as in the vicinity of the infiltration gallery, ground water from the volcanic rocks moves along fractures into the channel fill.

The capacity of the channel fill to transmit and store water is limited by its long narrow shape and small cross-sectional area. Although the volume of water that can move through the saturated fill is limited by the small cross-sectional area, the comparatively high permeability of the materials permits the drainage, possibly in a matter of months, of the water presently in storage. In other words, the amount of water in storage is small compared to the rate at which it can drain out of the sediments and, without almost continuous recharge, the water level in the channel fill would drop rapidly. The water of the channel fill is replenished almost entirely by surface flow and by infiltration from adjacent volcanic rocks.

CONCLUSIONS

The lower Bonita Creek area lies on the back slope of a tilted fault block between the Gila Mountains and Turtle Mountain. The rocks in this basin include undifferentiated Cretaceous(?) igneous and sedimentary rocks, Tertiary(?) volcanic rocks and alluvium, Tertiary and Quaternary alluvium, and late Quaternary alluvium.

The late Quaternary channel fill is the principal known water-yielding material in the area, although ground water in moderate quantities is also contained within rocks of the upper unit of the Tertiary(?) volcanic rocks. Small quantities of water are obtained from ephemeral springs in the Tertiary(?) volcanic and sedimentary rocks. The rocks of the lower and middle volcanic units have not been tested but are in part structurally favorable to containing ground water. The Cretaceous(?) rocks virtually are non-water-bearing in the area.

No continuous records are available regarding the long-term characteristics of surface flow in Bonita Creek and the only consecutive measurements of surface flow in Bonita Creek were collected during a period of drought. Except for summer floods, the flow of Bonita Creek in 1955 and 1956 averaged about 6 cfs within The Box and less than 2 cfs at the mouth. The losses in surface flow between The Box and the infiltration gallery amounted to about 4 cfs, about equal to the amount diverted by the gallery and lost by evapotranspiration.

Although the channel fill is the principal aquifer in the area at this time, its capacity to store and transmit water is limited by its small volume and cross section. The capacity of the channel fill to yield large amounts of water depends entirely on sustained replenishment by influent seepage from surface flow and underflow moving into the area through the channel fill and from water in the adjacent rocks.

Records of earlier production indicate that the gallery at one time was capable of yielding about 4,500,000 gpd, or about 5,000 acre-feet per year. The average production for the 1953–56 period was about 2,300 acre-feet per year. The loss in productivity may be due partly to silt accumulating around the pipe perforations, the effect of the current drought, or depletion of water in storage in the volcanic rocks.

Near the gallery the channel fill is about 75 feet thick, about 65 feet of which is saturated. The infiltration gallery is set at about 7 feet below the water table and removes about 2,300 acre-feet per year. The data available are insufficient to estimate the amount of water that is available in the saturated channel fill below the level of the gallery.

The water below the level of the gallery is not known to reappear in Bonita Creek as surface flow or as underflow in the channel fill and is presumed to move across permeable zones from channel fill to the volcanic rocks. There are no known springs along the Gila River between the Turtle and Gila Mountains that could account for this water, although seepage from the volcanic rocks may be dissipated into the underflow of the Gila River along a broad front and not be readily discernible.

The underflow in the channel fill near the mouth of Bonita Creek is about 0.8 cfs. Steady pumping of the wells near the mouth of Bonita Creek at rates of more than about 300 gpm may eventually create a cone of depression that could reach the Gila River; the normal gradient would thus be reversed to divert underflow of the Gila River up into the channel fill of Bonita Creek.

The 100 feet of the upper volcanic unit immediately underlying the channel fill in the gallery area has a specific capacity of about 8.5 gpm per foot of drawdown. There may be several hundred feet of the upper volcanic unit below the bottom of test hole 2, and the amount of water in storage in this unit and the underlying volcanic rocks is unknown.

Present information suggests that additional water supplies could be obtained from the alluvial deposits of the channel fill of Bonita Creek and the underlying rocks by (a) clearing the Bonita Creek channel of vegetation, (b) renewing the gravel packing around the infiltration gallery, (c) intercepting additional amounts of underflow in the alluvial fill by wells or by lowering the infiltration gallery, and (d) pumping water from the volcanic rocks below the alluvial fill of the Bonita Creek channel. The additional quantities of water that may be obtained by clearing vegetation from the Bonita Creek channel are in the magnitude of about 0.5 to 1 cfs, or about 350 to 700 acre-feet per year. The following tests are suggested for obtaining information needed to make quantitative estimates of the additional amounts of water that could be provided by the other suggested methods:

1. A pumping test of the full thickness of alluvial fill in the gallery area to obtain a better estimate of the amount of underflow entering the gallery area from all sources. The test should be run at a pumping rate and for a length of time sufficient for water levels in the aquifer to reach virtual equilibrium.
2. Pumping tests of the full thickness of alluvial fill above and below the gallery to provide an estimate of underflow entering and leaving the gallery area through the channel fill.
3. A pumping test to determine the aquifer properties of the upper volcanic unit at depths greater than those presently tested.
4. A well above The Box, penetrating the rhyolite below the alluvial gravel, to determine the local water-bearing characteristics of the rhyolite.

5. Determination of changes in base flow of the Gila River between the Turtle and Gila Mountains to locate, if possible, the water moving out of the volcanic rocks into the channel fill of the Gila River.

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TABLE 3.—*Record of wells, boreholes,*

Location	Type	Topography	Altitude [1] (feet)	Construction data: Diameter of well: Top (inches)	Construction data: Diameter of well: Bottom (inches)	Construction data: Depth of well (feet)	Construction data: Cased to— (feet)	Aquifer
T. 4 S., R. 27 E.: SW¼SW¼ NE¼ sec. 34	Dug well	Canyon bottom.	3,950	6	6	15	15	Quaternary gravel.
T. 5 S., R. 27 E.: NW¼SW¼ SW¼ sec. 11	Spring	do	3,900					do
SE¼SW¼ NW¼ sec. 36	do	do	3,550					do
T. 6 S., R. 27 E.: SE¼NE¼ NE¼ sec. 2	Drilled well	High-level terrace.	4,170	8	8	505	10	
SW¼NW¼ SE¼ sec. 5	Mining exploration hole.	Canyon bottom.	4,800	4	1½	2,300		
SW¼SW¼ NE¼ sec. 16	do	High foothills.	4,120	4		182		
NE¼SW¼ SW¼ sec. 16	Drilled well	do	3,900	6				
T. 6 S., R. 28 E.: SE¼SW¼ NW¼ sec. 5-1	do	Canyon bottom.	3,500	20	20	60	60	Quaternary gravel.
SE¼SW¼ NW¼ sec. 5-2	do	do	3,500	20	16	175	81	Quaternary gravel and Tertiary(?) upper volcanic unit.
SW¼NW¼ SE¼ sec. 5.	Spring	Canyon wall.	3,500					Tertiary(?) upper volcanic unit.
NW¼SW¼ sec. 9.	do	Canyon bottom.	3,400					Quaternary gravel.
SW¼NW¼ SE¼ sec. 16.	Dug well	do	3,230	10	10	10	10	do
NE¼NW¼ NW¼ sec. 20.	Spring	Narrow canyon.	3,450					Tertiary(?) volcanic conglomerate.
SE¼SE¼NE¼ sec. 21.	Dug well	Canyon bottom.	3,200	18	18	67	67	Quaternary gravel.
NE¼NE¼ SE¼ sec. 21.	do	do	3,200	18	18	67	67	do

See footnotes at end of table.

and springs in the lower Bonita Creek area

Hydrologic data				Use of water	Remarks
Static water level		Yield			
Depth (feet)	Date of measurement	Rate (gpm) [2]	Date of measurement		
Filled in	Mar. 6, 1957				
		10–15E	Nov. 5, 1956		Johnny Creek spring; chemical analysis of water in table 4.
		1E	Nov. 6, 1956	Domestic	Claridge Ranch spring, unimproved; chemical analysis of water in table 4.
Dry	Feb. 28, 1957				Drilled in upper volcanic unit. Never reached projected water table.
do	Nov. 1, 1956				Drilled in Cretaceous(?) volcanic rocks.
143.1	Feb. 28, 1957				Drilled in Cretaceous(?) volcanic rocks, west of mapped area.
42.5	July 19, 1956			Stock	Do.
6.1	Apr. 21, 1957	400E	July 1957	Public supply.	Flowed at 400± gpm into infiltration gallery through siphon set at about 12 ft below static water level; pumped as much as 1,800± gpm during construction of siphon to hold water level at 19 ft below surface (about 13 ft drawdown).
10.1	Nov. 29, 1957	1,200M	December	Test well	Located 8 ft upstream from well 1; 20-in casing set on top of upper volcanic unit 74 ft below surface, perforated below 30 ft; 80 ft of unperforated 16-in casing to 6 ft below top of upper volcanic unit effected shutoff of water in Quaternary gravel. Upper volcanic unit rocks alone yielded 1,215 gpm with 141 ft of drawdown; Quaternary gravel and upper volcanic rocks together yielded 1,615 gpm with 18.7 ft of drawdown. Well-cutting samples available from 80 to 175 ft.
		(?)	Nov. 13, 1956		Birdbath spring; large wetted area, without measurable yield; chemical analysis in table 4.
		5E	do		Gillespie pasture spring; chemical analysis in table 4.
4.1	Feb. 28, 1957			Domestic (standby).	Water level is 0.4 ft above level of surface flow in Bonita Creek. Yield reported adequate for domestic and stock purposes.
		5–40E		Stock	Spring Canyon spring; chemical analysis in table 4.
6.4	June 19, 1956			Public supply.	Discharge by siphon into well NE¼NE¼SE¼ sec. 21.
8.5	do	380M	June 19, 1956	do	Safford Municipal Utilities' standby well; chemical analysis of water in table 4.

TABLE 3.—*Record of wells, boreholes, and springs*

Location	Type	Topography	Altitude [1] (feet)	Construction data: Diameter of well: Top (inches)	Construction data: Diameter of well: Bottom (inches)	Construction data: Depth of well (feet)	Construction data: Cased to— (feet)	Aquifer
T. 5 S., R. 28 E.:								
NW¼NE¼ NW¼ sec. 32.	Mining exploration hole.	Canyon bottom.	4,750	-------	-------	1,692	-------	-------
SE¼NE¼ NE¼ sec. 33.	-----do------	Canyon in mountains.	4,600	-------	-------	2,324	-------	-------
NW¼SW¼ SW¼ sec. 33.	-----do------	In mountains.	4,500	-------	-------	1,302	-------	-------
T. 6 S., R. 28 E.:								
NW¼NW¼ NW¼ sec. 3.	-----do------	Canyon bottom.	4,150	-------	-------	2,500	-------	-------
NE¼NW¼ NW¼ sec. 10.	-----do------	High-level terrace.	4,050	-------	-------	2,015	-------	-------

[1] Altitudes are approximate, interpolated from 200-foot contours of preliminary 1:200,000 map.
[2] E, estimated; M, measured.

in the lower Bonita Creek area—Continued

Hydrologic data				Use of water	Remarks
Static water level		Yield			
Depth (feet)	Date of measurement	Rate (gpm) [2]	Date of measurement		
Dry					In Tertiary(?) volcanic rocks to 1,392 ft; in Cretaceous(?) monzonite porphyry, 1,392 to 1,692 ft.
do					In Tertiary(?) volcanic rocks to 834 ft; in Cretaceous(?) or early Tertiary clastic rock, 834 to 2,324 ft.
do					In Tertiary(?) volcanic rocks to 1,002 ft; in Cretaceous(?) monzonite porphyry, 1,002 to 1,302 ft.
do					In Tertiary(?) volcanic rocks to 872 ft; in Cretaceous(?) andesite, 872 to 2,072 ft; unreported, 2,072 to 2,500 ft.
do					Drilled on trace of Turtle Mountain fault; in Tertiary(?) volcanic rocks to bottom of hole.

TABLE 4.—*Analyses of water from surface flow,*

[Analyses in parts per

Location	Locations along Bonita Creek	Distance [1] (miles)	Source of analysis [2]	Source of sample	Date of collection	Temperature (°F)	Silica (SiO_2)
T. 3 S., R. 26 E.:							
SW¼SW¼ sec. 35	North of mapped area.	21.0	U	Well	July 20, 1956	64	40
T. 4 S., R. 27 E.:							
NW¼NW¼ sec. 18	do.[3]	17.5	U	Surface flow.	July 19, 1956	72	45
T. 5 S., R. 27 E.:							
SW¼NW¼SW¼ sec. 11	Gaging station 1	10.3	U	do	Nov. 5, 1956	61	56
NW¼SW¼SW¼ sec. 11		10.2	U	Spring	do	66	57
SE¼SW¼NW¼ sec. 36	Claridge Ranch	6.0	C	do	Mar. 5, 1955	----	41
Do	do	6.0	U	do	Nov. 6, 1956	64	51
T. 6 S., R. 28 E.:							
SW¼SW¼NW¼ sec. 5		4.3	C	Surface flow.	Mar. 5, 1955	----	44
SW¼SE¼NW¼ sec. 5		4.1	U	do	Nov. 13, 1956	58	51
Do		4.0	U	Stilling well.	do	70	3.9
Do	The Meadows	3.9	C	Surface flow.	Feb. 20, 1934	----	44
NE¼NW¼SE¼ sec. 5	Weiland sand trap	3.7	C	Gallery	Jan. 2, 1948	----	47
Do	do	3.7	C	do	Mar. 5, 1955	----	40
Do	do	3.7	C	do	June 27, 1955	----	----
SE¼NW¼SE¼ sec. 5	Kline sand trap	3.6	U	do	Nov. 13, 1956	65	54
SW¼NW¼SE¼ sec. 5		3.5	U	Spring	do	62	54
NW¼SW¼ sec. 9	Gaging station 11	2.3	C	do	Mar. 5, 1955	----	24
Do	do	2.3	U	do	Nov. 13, 1956	61	52
SE¼SE¼NE¼ sec. 21		.7	C	Well	Nov. 15, 1948	----	63
NE¼NE¼SE¼ sec. 21		.7	U	do	June 23, 1956	72	56
SW¼NW¼SW¼ sec. 22		.0	C	Surface flow.	Mar. 5, 1955	----	23
NE¼NW¼NW¼ sec. 20	Spring Canyon [4]	--------	C	Spring	do	----	25
Do	do.[4]	--------	U	do	Nov. 13, 1956	73	55

[1] Approximate distances measured upstream from the mouth of Bonita Creek.
[2] U, U.S. Geological Survey; C, commercial.

wells, and springs in the Bonita Creek area

million, except as indicated]

Iron (Fe) total	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio (*SAR*)	Specific conductance (micromhos at 25° C)	pH
										Parts per million	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
0.03	50	20	4.8	240	0	6.8	6	0.2	6.4	252	0.34	207	10	5	0.1	419	7.3
------	36	15	31	222	0	21	6	1.4	2.3	267	.36	152	0	31	1.1	371	7.2
------	36	19	25	246	0	7.8	7.0	.6	.5	273	.37	168	0	24	.8	394	7.7
------	47	19	27	283	0	7.0	8.5	.6	.4	306	.42	196	0	23	.8	459	7.1
------	40	18	21	254	0	5.0	4.0	.4	------	384	.52	172	0	------	------	------	7.3
------	39	20	25	259	0	7.8	7.5	.6	.6	278	.38	180	0	23	.8	426	7.4
------	38	18	32	235	14	10	8.0	.4	------	401	.55	168	------	------	------	------	8.2
------	34	19	26	242	0	8.0	7.5	.6	.1	265	.36	163	0	26	.9	395	8.1
------	14	14	35	180	0	6.0	7.5	.6	2.9	173	.24	92	0	45	1.6	317	7.3
------	37	19	------	------	------	------	11	------	------	383	.52	------	------	------	------	------	------
------	45	19	29	273	0	10	12	.4	------	437	.59	190	------	------	------	------	7.4
------	35	19	22	244	0	5.0	6	.4	------	373	.51	166	------	------	------	------	7.6
.02	38	18	19	------	------	9.0	7.0	.5	1.2	302	.41	172	------	------	------	------	------
------	38	20	25	252	0	9.9	8.5	.6	.6	281	.38	177	0	23	.8	415	7.6
------	33	20	26	243	0	8.4	8.5	.6	.5	270	.37	164	0	26	.9	400	7.4
------	35	19	29	254	0	10	8.0	.2	------	381	.52	164	------	------	------	------	7.2
------	43	22	26	284	0	8.0	8.0	.6	.4	300	.41	198	0	22	.8	459	7.5
------	30	23	44	276	0	10	12	.4	------	462	.63	170	------	------	------	------	7.8
.35	37	19	38	257	0	24	10	1.4	.6	312	.42	170	0	33	1.3	423	7.1
------	36	18	33	240	19	0.0	6.0	.4	------	378	.52	162	------	------	------	------	8.5
------	25	12	39	212	7	5.0	4.0	.4	------	332	.45	112	------	------	------	------	------
------	27	12	39	224	0	8.4	5.0	.6	1.3	258	.35	117	0	42	1.6	374	7.5

[3] Source of perennial flow.
[4] Not located on Bonita Creek.

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