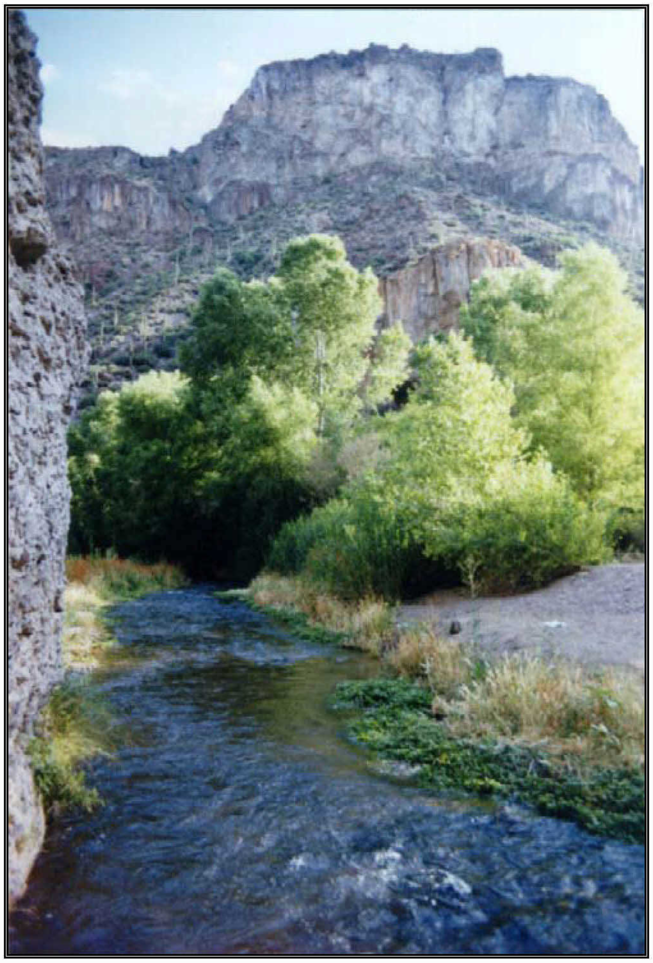
Aravaipa Canyon
Geohydrology Assessment

Final Report September, 2000



For

United States Fish and Wildlife Service
Contract Number 20181-99-C016

By

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Chapter 1:
Introduction

Aravaipa Creek is one of the few remaining perennial streams in Arizona. The creek and surrounding canyon are home to a variety of native aquatic and terrestrial plant and animal species, and include extensive reaches of rich riparian habitat. While much of the canyon is preserved and managed as the Bureau of Land Management's Aravaipa Canyon Wilderness, the privately held upland areas may be threatened by future mineral exploration, grazing, and development. Development and exploitation of these upland areas may impact surface water flows in protected reaches of Aravaipa Creek.

The US Fish and Wildlife Service (USFWS) commissioned the Aravaipa Canyon Geohydrology Assessment Study to evaluate potential impacts of changes in groundwater conditions and long-term geomorphic changes on habitat. The study was prepared by a team of consultants led by JE Fuller/ Hydrology & Geomorphology, Inc. (JEF), which was responsible for surface water hydrology and geomorphology. Ground Water Resources Consultants, Inc. (GWRC) was responsible for evaluation of regional geology and groundwater conditions. SWCA Environmental Consultants, Inc. (SWCA) role included evaluation of study results for potential impacts on fish habitat.

Objectives

The stated objectives of the Aravaipa Creek Geohydrology Assessment include the following:

- Collect available hydrologic data
- Evaluate groundwater/surface water interactions, and any possible link between upstream groundwater pumping and surface flows in the stream
- Evaluate trends indicated by the hydrologic data and determine possible causes for the observed trends
- Evaluate the potential for these trends to affect aquatic habitat
- Recommend additional studies, if necessary, to determine the causes of the trends and their possible effects on aquatic habitat

Study Location

The Aravaipa Creek study area is located in southeast Arizona, within Graham and Pinal Counties. While the study limits are confined to the canyon reaches currently under Federal management, the evaluation considered the entire stream from the San Pedro confluence to the headwaters above Klondyke.

Data Sources

The methods used in this study relied on a variety of existing information and field data. Existing information was collected from the following key sources:

- Arizona Department of Water Resources (ADWR)
- Arizona Geological Survey (AZGS)
- Arizona State University – Geology Department (ASU)
- Federal Emergency Management Agency (FEMA)
- U.S. Army Corps of Engineers – Los Angeles District (USACOE)
- U.S.D.A. – Soil Conservation Service (SCS or NRCS)
- U.S. Geological Survey – Water Resources Division (USGS Water Resources)
- U.S. Geological Survey – EROS Data Center (USGS - EROS)
- U.S. Bureau of Land Management (BLM)
- U.S. Bureau of Reclamation (BUREC)

Existing information collected for the study included the following:

- Historical and recent aerial photographs
- Historical and recent topographic maps
- Published and unpublished engineering reports
- Published detailed soils mapping
- Published and unpublished mapping of surficial geology
- Regional and local streamflow gaging records
- Regional and local precipitation records
- Groundwater level measurements

Field data collected for Aravaipa Creek included the following:
- Descriptions of channel bed and bank conditions
- Ground photographs of significant channel features
- Descriptions of watershed conditions
- Descriptions of significant tributaries

A listing of references used for the assessment is provided in the bibliography.

Limitations and Assumptions

Any technical analysis is limited by the data available, the contracted scope of services, and the assumptions of the methodologies used. For the Aravaipa Canyon Geohydrology Assessment, the following general limitations apply:

- Period of Record. Streamflow data are available for only a portion of the period of interest for the study area. Collection of additional streamflow data in the future will improve the accuracy of the hydrologic and geomorphic analyses.
- Hydrologic Data. Streamflow gaging data were available only at two locations near the study area. Actual hydrologic conditions vary considerably throughout the study area, and may not reflect conditions at the stream gages.
- Hydraulic Modeling. No detailed hydraulic models were prepared for the study.

- Topographic Mapping. No detailed topographic mapping was available for the study area.
- Sediment Continuity Modeling. No sediment transport modeling was performed for the study.
- Geotechnical Data. No geotechnical data were available for the study area.
- Scale of Analysis. This study considered approximately 36 miles (58 km) of river but focused on the approximately nine miles (14 km) of river in Aravaipa Canyon Wilderness Area. It is possible that more detailed evaluation of shorter reaches or specific sites could improve the accuracy of the predictions of past and future channel behavior.

Other assumptions and limitations of this evaluation are discussed in the following chapters for each of the specific methodologies used.

Report Overview

This report summarizes the methods used to evaluate the potential for lateral channel migration within the study area. Specific chapters in this report cover the following topics:

- Chapter 1 – Project overview and introductory information
- Chapter 2 – Geologic setting, watershed conditions, and climate
- Chapter 3 – Surface water records and trend analysis
- Chapter 4 – Groundwater records and trend analysis
- Chapter 5 – Geomorphic analysis of existing conditions and long-term trends
- Chapter 6 – Conclusions
- Chapter 7 – Bibliography

Chapter 2:
Geologic Setting & Watershed Conditions

Introduction

This study is focused on the stream channel and floodplain corridor of Aravaipa Creek, primarily in the federally managed canyon reach. However, natural streams are part of a larger dynamic system that includes watershed conditions and regional geology. This chapter provides the basic information about the following characteristics of the study area that affect the assessment:

- Watershed Description
- Geologic Setting
- Reach Definition

The interrelated watershed, geologic, and hydrologic characteristics of a stream combine to determine its unique geomorphology, which can be described using a stream classification system. This information can then be used to define specific stream reaches for more detailed analyses.

Watershed Characteristics

The Aravaipa Canyon basin drains approximately 541 miles^2 (1,401 km^2) of the Basin and Range Physiographic Province in southeastern Arizona (Figure 2-1). The watershed consists of a northwest-trending alluvial valley surrounded by fault-block mountains. The basin's boundaries are the Galiuro Mountains to the southwest, the Santa Teresa and Pinaleno Mountains to the northeast, and the Turnbull Mountains to the north. A topographic high to the southeast serves as a surface water divide between Aravaipa Valley and the northern Sulphur Springs Valley. Elevations on the basin's valley floor range from 4,300 feet (1311 m) above mean sea level at its southeastern end to 3,100 feet (945 m) above mean sea level at the entrance to Aravaipa Canyon. The surrounding mountains have elevations up to 7,500 feet (2,286 m) above mean sea level.

Aravaipa Creek flows through the Aravaipa Valley from the southeast to the northwest where it joins the San Pedro River. Aravaipa Creek is 55.4 miles (89.1 km) long from its origins to its confluence with the San Pedro River (Minckley, 1981). Of Aravaipa Creek's entire length, approximately 21 miles (34 km) in the vicinity of Aravaipa Canyon are perennial. The creek, ephemeral in its upper reaches, becomes perennial in Aravaipa Canyon where impermeable bedrock forces water through the canyon before becoming ephemeral again west of the canyon. The creek becomes perennial a short distance downstream from Stowe Gulch at Aravaipa Spring. Water appears very suddenly in the creek and reaches its full flow in a short distance. Gradients along Aravaipa Creek range from less than 0.3% slope near its source to 2.5% slope in short reaches of Aravaipa Canyon. Near the USGS gage station the gradient is approximately 0.9% slope

(Minckley, 1981). However, the overall gradient of Aravaipa Creek is generally less than 1.0%. The confluence with the San Pedro River is at an elevation of 2,150 feet (655 m) above mean sea level.

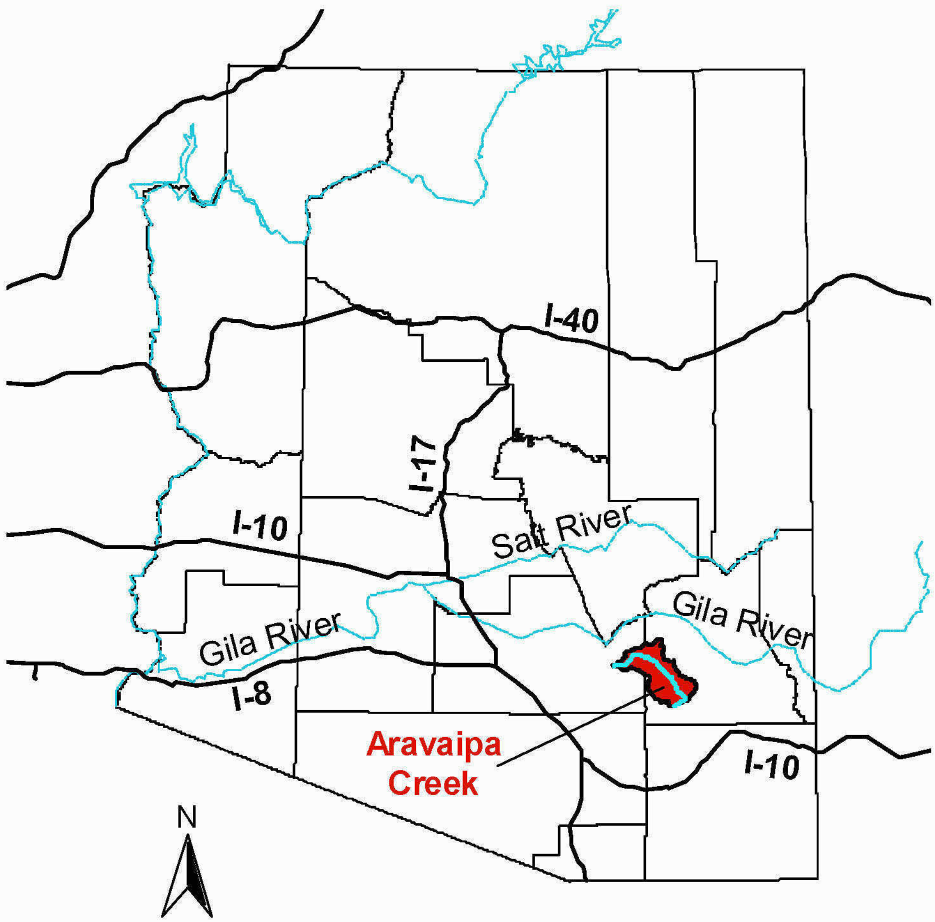

Figure 2-1. Map of Aravaipa Creek Location Within State of Arizona, USA

Geologic Setting

The Aravaipa Valley is bounded on the north and northeast by the Santa Teresa Mountains and on the south and southwest by the Galiuro Mountains. A generalized geologic map is shown on Figure 2-2. This map was compiled from geologic maps prepared by Simons (1964) and Krieger (1968a, 1968b).

Rock Types. The oldest rock unit shown on Figure 2-2 is the Pinal Schist, consisting principally of weakly metamorphosed graywackes, shales and volcanic rocks.

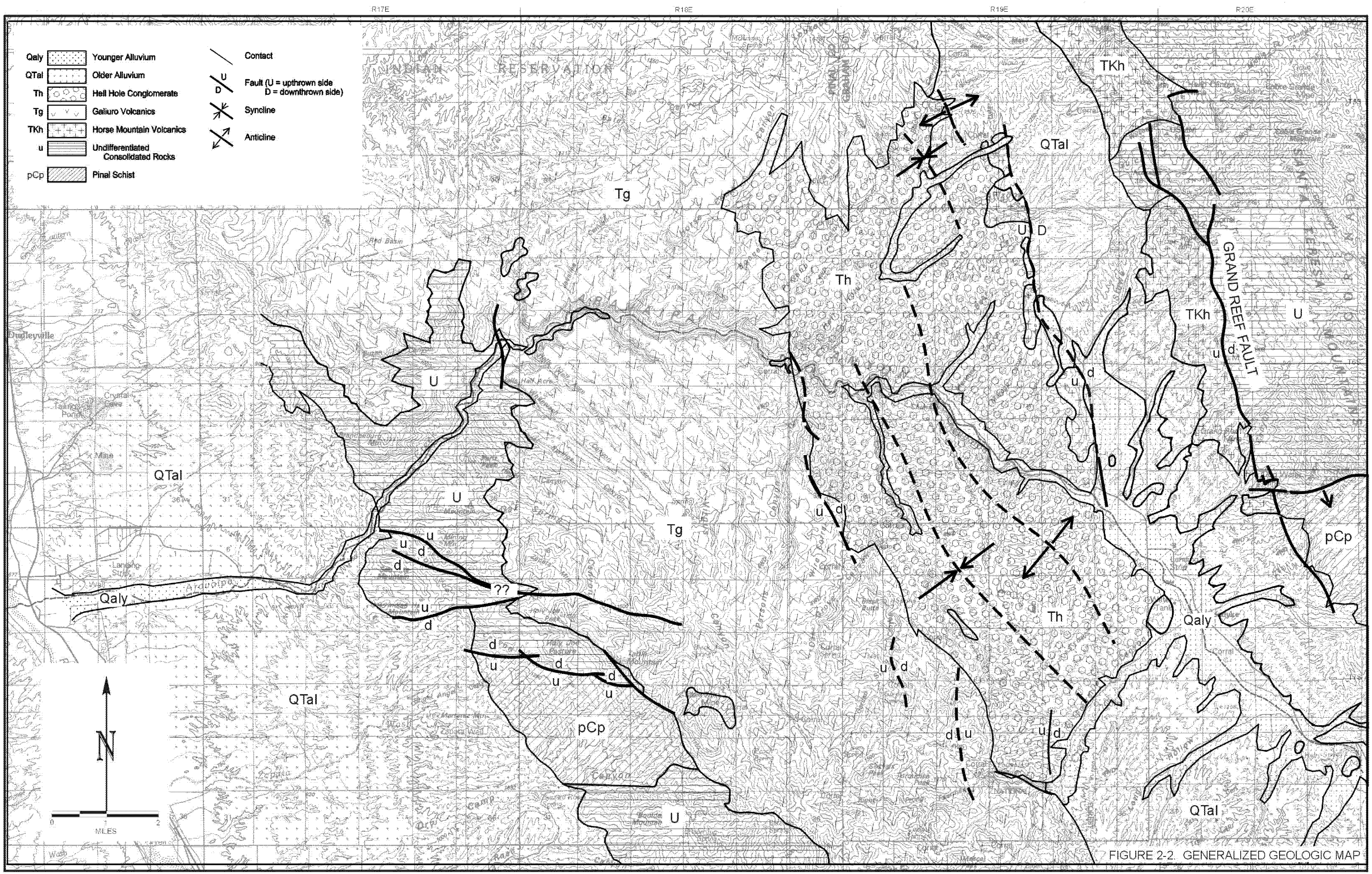

FIGURE 2-2. GENERALIZED GEOLOGIC MAP

A variety of undifferentiated rocks are shown on Figure 2-2. In the Santa Teresa Mountains, these undifferentiated rocks consist of Precambrian intrusive and metamorphic rocks, Paleozoic and Cretaceous sediments including the Bolsa quartzite, the Escabrosa limestone, the Horquilla limestone and the Pinkard Formation, and Tertiary intrusive rocks including the Santa Teresa granite and the Goodwin Canyon quartz monzonite. The undifferentiated rocks on the west side of the Galiuro Mountains consist principally of Precambrian intrusive and metasedimentary (the Dripping Springs quartzite and the Troy quartzite) rocks, Paleozoic sedimentary rocks (the Bolsa quartzite, the Abrigo Formation, the Martin Formation, the Escabrosa limestone and the Naco limestone) and Cretaceous-Tertiary intrusive and volcanic rocks.

The Horse Mountain Volcanics (Figure 2-2) occur on the southwest side of the Santa Teresa Mountains. The Horse Mountain Volcanics are composed predominantly of rhyolites and dacites with andesites in the basal portions of the section. The rocks consist principally of lavas with some tuffs. The age of the Horse Mountain Volcanics is estimated to be late Cretaceous to early Tertiary.

The Galiuro Volcanics are present in the Galiuro Mountains and extend north of Aravaipa Creek. The Galiuro Volcanics form most of the steep walls in Aravaipa Canyon. These volcanic rocks are approximately half andesites and half siliceous rocks. Both lavas and tuffs are present with the tuffs being generally more siliceous rocks than the lavas. The age of the Galiuro Volcanics is estimated to late Oligocene to early Miocene.

The Hell Hole Conglomerate, present on the eastern flank of the Galiuro Mountains and in the Aravaipa Valley, rests unconformably on the Galiuro Volcanics and, to a lesser extent, on the Horse Mountain Volcanics. The conglomerate is well indurated with angular to rounded pebbles, cobbles and boulders in a sandy matrix. The conglomerate is sufficiently indurated to form steep walls in the upstream portion of Aravaipa Canyon. The material in the conglomerate was derived mostly from the Galiuro Volcanics. The Hell Hole Conglomerate is estimated to be mid to late Tertiary in age.

The Older Alluvium is present on the southwest flank of the Santa Teresa Mountains, in the Aravaipa Valley, on the northeast flank of the Galiuro Mountains southeast of Four-Mile Creek and on the southwest flank of the Galiuro Mountains. The Older Alluvium is generally flat-lying and is composed of poorly or slightly consolidated sands and gravels. The clasts contained in the alluvium consist of Precambrian and Tertiary granites, Precambrian metamorphic rocks, Paleozoic sediments and volcanic rocks derived from the Santa Teresa and Galiuro mountains. The Older Alluvium is believed to be Pliocene to Pleistocene in age.

The Younger Alluvium is found in the stream channels of Aravaipa Creek and its tributaries. It consists of unconsolidated sands and gravels that may be slightly more than 100 feet (30 m) thick in places and up to one mile (1.6 km) wide (Ellingson, 1980). This unit is the principal source of water in Aravaipa Valley. The Younger Alluvium is of Holocene age.

Structure. The overall geologic structure of the study area is that of a northwest-trending alluvial basin, the Aravaipa Valley, bounded on the northeast by the intrusive and sedimentary rocks of the Santa Teresa Mountains and on the southwest by the volcanic rocks of the Galiuro Mountains. The maximum depth to bedrock in the central portion of the basin is on the order of 3,000 to 4,000 feet (914 to 1,219 m).

The primary structural features mapped in the area, including faults and folds, are parallel to the axis of the sedimentary basin. A number of major northwest-trending faults have been mapped in the Santa Teresa Mountains including the Grand Reef Fault (Figure 2-2). The Grand Reef Fault is a normal fault dipping steeply to the west-southwest and having as much as 1,300 feet (396 m) of displacement. Farther to the west are an anticline and syncline mapped in the Hell Hole Conglomerate. Dips on the northeast flank of the anticline are generally between 10 and 45° northeast. The Older Alluvium in Aravaipa Valley is relatively flat lying. The Galiuro Volcanics are gently dipping and are relatively unfaulted.

The basin is believed to have formed in the late Oligocene to early Miocene (Kruger and Johnson, 1994). Northeasterly movement along the Eagle Pass detachment fault, which originated near the Galiuro Mountains and dipped gradually to the northeast, denuded the area overlying the Pinaleño and Santa Teresa Mountains. Uplifting in the area of this tectonic denudation created the Pinaleño Mountains core complex and formed the Aravaipa basin between the Pinaleño and Galiuro Mountains. Although normal faults have been mapped along the margins of the basin, the formation of the basin is not primarily a result of large displacements along normal, mountain-front faults.

According to Melton (1960), the portion of Aravaipa Creek flowing through Aravaipa Canyon may represent an earlier antecedent drainage that originally flowed to the southwest. This drainage maintained its course and cut down through the rising Galiuro Mountains. Portions of the original drainage were subsequently captured by drainages, such as the San Pedro River, forming in the northwest-trending valleys created during basin and range faulting.

Reach Definitions

Based on the regional geology, geomorphology, and hydrology, Aravaipa Creek was divided into the following seven reaches for the purpose of this study:

- Klondyke Reach
- Nature Conservancy Reach
- Turkey Creek Reach
- Booger Canyon Reach
- Virgus Canyon Reach
- Aravaipa Ranches Reach
- San Pedro Reach

These reach names will be used throughout the remainder of this report. Table 2-1 summarizes the reach characteristics. A longitudinal profile of Aravaipa Creek illustrating the overall slope gradient is presented in Figure 2-3. Figure 2-4 is a map showing the reach limits.

Klondyke Reach. The most upstream reach of this study is the ephemeral portion of the creek upstream and downstream of Klondyke, Arizona. For the purpose of this study the Klondyke Reach is defined from approximately 2.4 miles (3.8 km) upstream of Haby Spring to Section 27, T. 6 S., R.19 E., for a total length of 11.77 miles (18.94 km). The valley in this reach ranges in width from approximately 1,000 feet (305 m) at its narrowest point near Haby Spring to approximately 4,000 feet (1,219 m) at its widest near Klondyke. In the Klondyke Reach the dry creek bed is approximately 150 feet (46 m) wide with gently-sloping to steep cut banks. Visual inspection at various points in this reach indicates that the bed surface is composed of cobbles (Wentworth scale, see Appendix A) approaching 9 inches (23 cm) diameter intermixed with sand and fine gravel (Wentworth scale). The overall stream gradient is 0.007 (0.7 % slope).

The Nature Conservancy Reach. The Nature Conservancy (TNC) Reach begins in Section 27, T. 6 S., R.19 E., and continues for approximately 4.28 miles (6.89 km). Aravaipa Creek emerges onto the surface in this reach for the majority of the time. The TNC Reach, therefore, is the most upstream reach to experience perennial flow. The TNC Reach is characterized as a distinct, narrow canyon that is relatively straight. The canyon in the TNC Reach is confined by hills on the right bank and by steeper walls on the left side. The canyon floor in TNC Reach is narrower than the floor in the Klondyke Reach and wider than the floor in the Aravaipa Canyon Wilderness Area downstream (Turkey Creek, Booger Canyon, and Virgus Canyon reaches), ranging between 400 to 1,200 feet (122 to 366 m) in width. Although the canyon has a sinuosity of about 1.2, Aravaipa Creek has a sinuosity of 1.01 on the valley floor of this reach. The overall stream gradient is 0.009 (0.9% slope). The TNC reach terminates just upstream of the Turkey Creek confluence.

Turkey Creek Reach. The Turkey Creek Reach is more sinuous than the TNC Reach and has steeper canyon walls. Aravaipa Creek is perennial in this reach. The reach limits extend from just upstream of the Turkey Creek confluence to the confluence of Deer Creek (Hell Hole Canyon), a total distance of approximately 2.42 miles (3.90 km). The canyon walls range in slope from approximately 42° to 90°. The valley floor is narrower here than in upstream reaches, with widths ranging between 400 and 480 feet (122 to 146 m). The sinuosity of Aravaipa Creek within the alluvial valley is 1.08, with a canyon sinuosity of about 1.5. The overall stream gradient in this reach is approximately 0.007 (0.7% slope). Field cross section AC-1 (Chapter 5) is located within Turkey Creek Reach, upstream of the Turkey Creek confluence.

Booger Canyon Reach. The Booger Canyon Reach is approximately 3.4 miles (5.5 km) long, extending from the Deer Creek confluence (Hell Hole Canyon) to the Horse Camp Canyon confluence. Aravaipa Creek is perennial in this reach. The valley floor ranges in width from 200 to 400 feet. The widest sections occur near Booger Canyon. Slopes of cliff walls range between 30° and 90°. The Booger Canyon Reach is less sinuous than the other Canyon reaches. The sinuosity of Aravaipa Creek in this reach is 1.07, while the sinuosity of the canyon is 1.1. In the Booger Canyon Reach the overall stream gradient is 0.008 (0.8% slope). Field cross section AC-2 (Chapter 5) is located midway along Booger Canyon Reach, just upstream of Booger Canyon.

Virgus Canyon Reach. The Virgus Canyon Reach runs from Horse Camp Canyon to Hell's Half Acre Canyon, for a total length of approximately 2.76 miles (4.44 km). Aravaipa Creek is perennial in this reach. The valley floor is relatively narrow, ranging between 80 feet (24 m) wide at constrictions to approximately 280 feet (85 m) wide near side canyon entrances. Slopes of the canyon walls range between 30° and 70°. The sinuosity of Aravaipa Creek on the valley floor of the Virgus Canyon Reach is 1.08, and the sinuosity of the canyon is 1.2. Overall stream gradient in the Virgus Canyon Reach is 0.01 (1.0% slope). Field cross section AC-3 is located in the Virgus Canyon Reach.

Aravaipa Ranches Reach. The Aravaipa Ranches Reach runs from Hell's Half Acre Canyon to Section 8, T. 7 S., R. 17 E. for a total length of approximately 7.68 miles (12.36 km). This is the most downstream reach of Aravaipa Creek that receives perennial flow. Canyon walls less steep than those in the Aravaipa Canyon Wilderness border the upstream portion of this reach of Aravaipa Creek. The canyon walls grade into gentler sloped hills on the downstream end of this reach. The canyon floor is between 375 feet (114 m) and 1,250 feet (381 m) wide in the Aravaipa Ranches Reach. The sinuosity of Aravaipa Creek and canyon is 1.09. Overall stream gradient in this reach is 0.008 (0.8% slope). The USGS gage is located approximately 0.8 miles (1.3 km) upstream of the downstream end of the reach.

San Pedro Reach. The San Pedro Reach runs from Section 8, T. 7 S., R. 17 E. to the confluence with the San Pedro River. The total length of the reach is approximately 6.2 miles (10.0 km). Aravaipa Creek flows through this reach intermittently. The stream valley is bordered by low hills and high terraces. The valley ranges between 2,000 feet (610 m) in width upstream and 4,000 feet (1,219 m) in width at the confluence with the San Pedro River. Aravaipa Creek's sinuosity in this reach is 1.09, with an overall stream gradient of 0.005 (0.5% slope).

Table 2-1. Aravaipa Creek.
Reach Descriptions Summary Table.

Reach Name	Length (miles)	Flow Type	Stream Sinuosity	Slope (%)	Valley Width (feet)	Valley Sides
Klondyke	11.77	ephemeral	1.05	0.7	1000-4000	Hills
TNC	4.28	perennial	1.01	0.9	400-1200	Steep canyon walls to hills
Turkey Creek	2.42	perennial	1.08	0.7	400-480	Very steep canyon walls
Booger Canyon	3.45	perennial	1.07	0.8	200-400	Very steep canyon walls
Virgus Canyon	2.76	perennial	1.08	1.0	80-280	Very steep canyon walls
Aravaipa Ranches	7.68	perennial	1.09	0.8	375-1250	Steep canyon walls to hills
San Pedro	6.20	intermittent	1.09	0.5	2000-4000	Hills to terrace

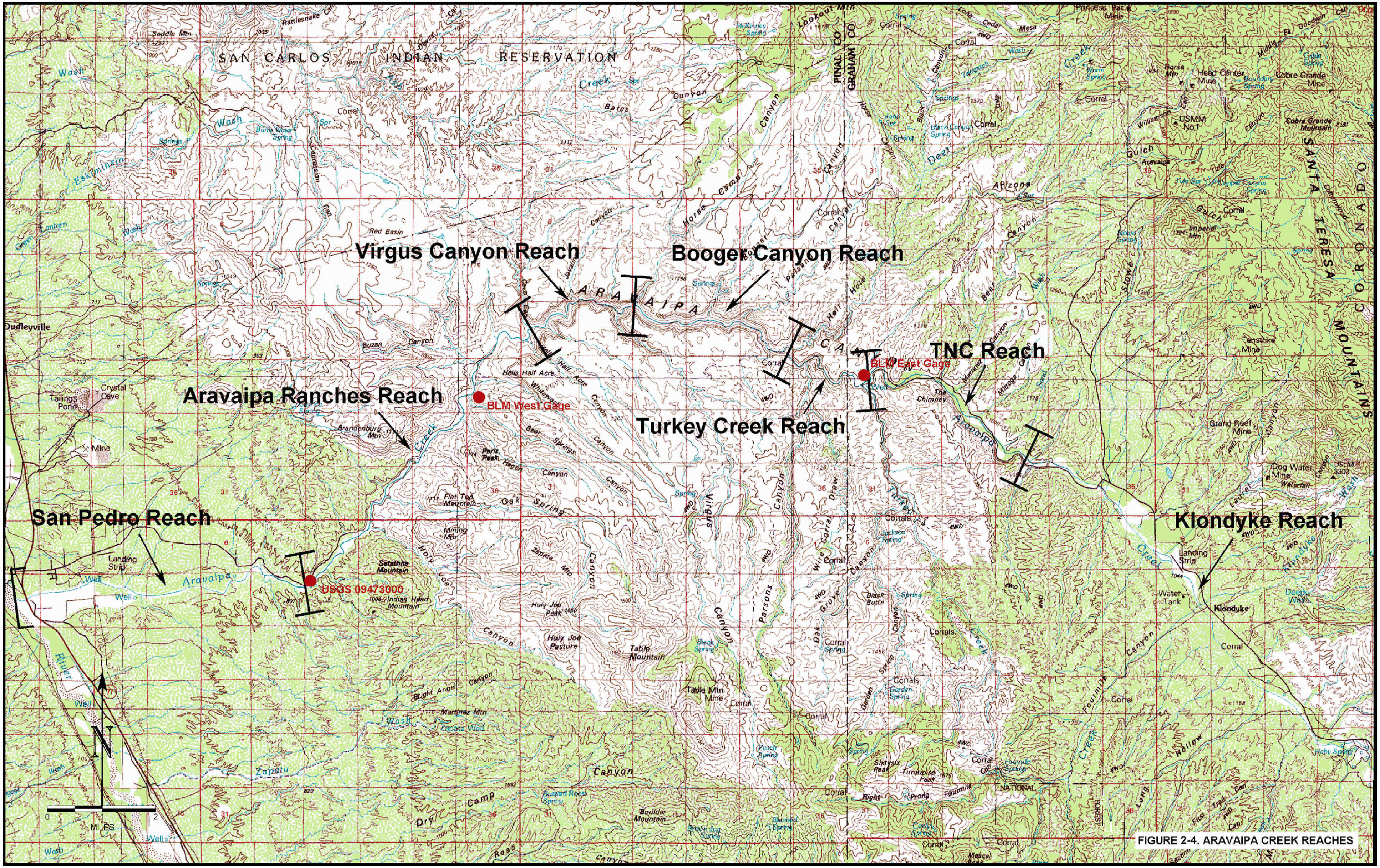

FIGURE 2-4. ARAVAIPA CREEK REACHES

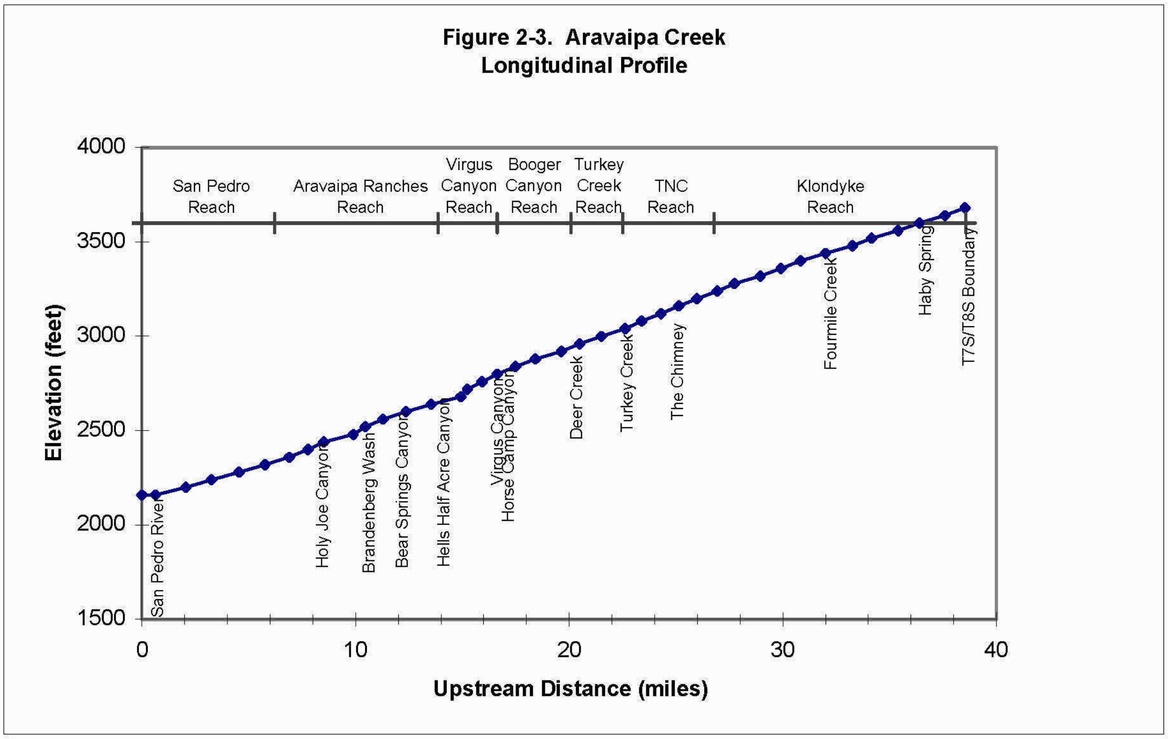
Figure 2-3. Aravaipa Creek
Longitudinal Profile
San Pedro Reach
Aravaipa Ranches Reach
Virgus Canyon Reach
Booger Canyon Reach
Turkey Creek Reach
TNC Reach
Klondyke Reach
San Pedro River
Holy Joe Canyon
Brandenberg Wash
Bear Springs Canyon
Hells Half Acre Canyon
Virgus Canyon
Horse Camp Canyon
Deer Creek
Turkey Creek
The Chimney
Fourmile Creek
Haby Spring
T7S/T8S Boundary
Elevation (feet)
4000
3500
3000
2500
2000
1500
0
10
20
30
40
Upstream Distance (miles)

Chapter 3:
Surface Hydrology

Introduction

The evaluation of the surficial hydrology of Aravaipa Creek was based on published USGS and BLM gage records, published precipitation records, and several cursory field measurements obtained by the project team during field visits.

Available Data

Gage data were available from the USGS and BLM.

USGS Gage. The United States Geological Survey (USGS) established a gage on Aravaipa Creek near Mammoth in 1931 (09473000). The USGS gage is located approximately 6.0 miles (9.7 km) upstream of Aravaipa Creek's confluence with the San Pedro River, and approximately 5.9 miles (9.5 km) downstream of the west border of the Aravaipa Wilderness (Figure 2-4). The gage provides a record of 44 water years[1], the longest record of daily flow for Aravaipa Creek. Measurements were recorded from May 1931 to December 1942,[2] and from May 1966 to the present. Official data for 1999 were not published by the USGS at the time this report was prepared, reducing the published period of record to 43 water years. The average mean daily discharge reported at the USGS gage is 34.7 cfs (1.0 m^3/sec), resulting in an average annual volume of 26,590 acre-feet/year, although the range of measured flow varies by more than three orders of magnitude.

BLM Gages. The BLM established gaging stations at the east and west ends of Aravaipa Canyon in August and September of 1980, respectively. The west gage is in Section 24, T.6 S., R. 17 E. and is approximately six miles upstream from the USGS gage. The east gage is in Section 19, T.6 S., R 19E, just upstream from the mouth of Turkey Creek (Figure 2-4). These gages, being close to the entrance and exit of the canyon, can potentially provide better information on streamflows in the canyon than the USGS gage, although the period of record is substantially shorter. Records from the west BLM gage are available for December 1981to April 1988, and are oriented at flows between 0 and 100 cfs (0.0 and 2.8 m^3/sec), with greater accuracy in the 10 to 40 cfs (0.3 to 1.1 m^3/sec) range (BLM 1988). Data recorded after this time have not been processed, are currently in raw form, and thus were not considered in detail for this study.

Additional gage data were collected at three index cross sections (See Chapter 5) established during field visits by JEF staff. These gage data are described in more detail in later sections of this chapter.

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[1] A water year is measured from October 1st of the previous calendar year through September 31st of the calendar year. For example, water year 1984 begins on October 1, 1983, and ends on September 31, 1984.
[2] No data were collected during July, August, and September 1941.

Applicability of USGS Gage Data to Aravaipa Canyon Flows

Due to the USGS gage's distance from the outlet of Aravaipa Canyon and the Aravaipa Wilderness, the gage data were evaluated to measure how accurately they reflect the flow regime occurring in the wilderness area. The potential for differences in flow rates between the USGS gage and the study reach is further complicated by historical irrigation diversions located downstream of the canyon. Differences between flow at the canyon exit and the USGS gage information were evaluated by comparing measurements from the BLM gage at the downstream end of the canyon and the USGS gage data for the years when both gages were operational. BLM gage records are available for the period between December 1981 and April 1988 on an intermittent basis, except for days with high flow or floods. The BLM and USGS records were compared using the following data sets:

- Comparison of flow duration curves
- Comparison of mean monthly discharges

Comparisons were made between measurements taken on the same day for the same portion of the hydrograph. The approximately 5.8 miles (9.3 km) between the BLM gage and the USGS gage are not enough to cause an appreciable delay in the hydrograph. If low flow velocities are assumed to be approximately 3 feet per second (0.9 m/sec),[3] the approximate travel time between the gages is three hours. This supports a same-day comparison of the two gages. Additional consideration must be given to gaps in the BLM gage records, most commonly of several days during high flows, although a gap in measurement occurred for several months due to destruction of the equipment in the flood of October 1983. Finally, comparison of flow rates gaged by JEF staff during field visits with USGS gage data is provided to evaluate the correlation of USGS data with flow rates in the inner and upper reaches of the Aravaipa Canyon Wilderness.

Comparison of Flow Duration Curves. Flow duration curves showing the percent time flow exceeds a given discharge for two periods of record are shown in Figure 3-1. The periods before and after the October 1983 flood are analyzed separately due to significant changes in channel characteristics resulting from the flood.

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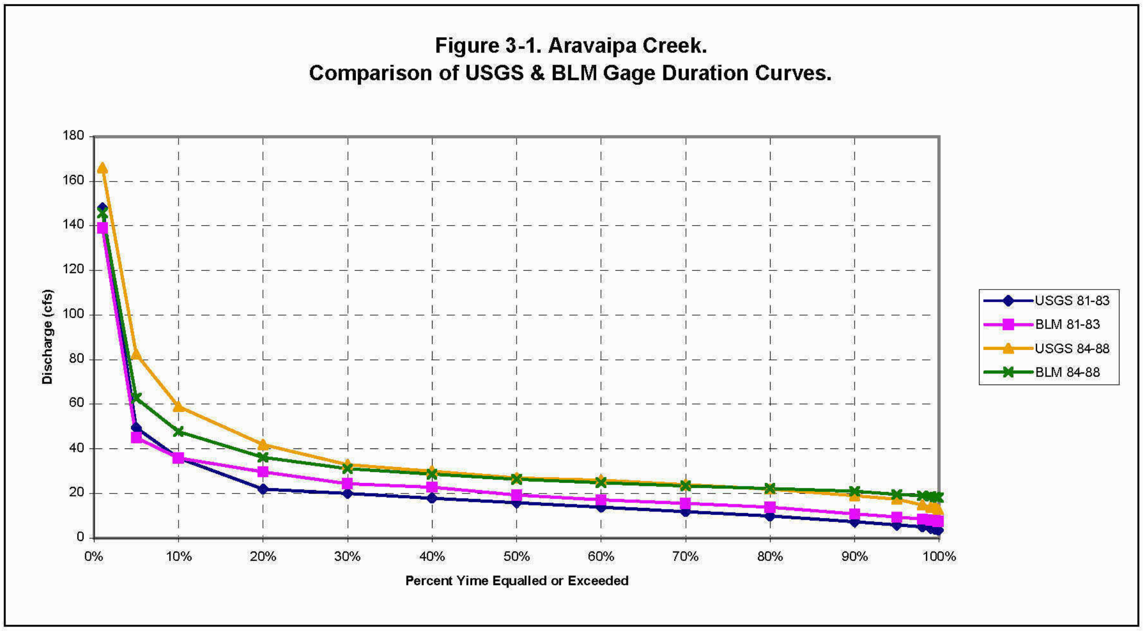
[3] Velocities measured by JEF personnel during field reconnaissance of July 2-5, 1999.



Several conclusions can be drawn from the data shown in Figure 3-1. First, the flow duration curves indicate that the 1984-1988 period was a period of higher sustained flow than the 1981-1983 period. Second, the flow duration curve for the 1981-83 period flows at the BLM gage is consistently higher than the curve for flows at the USGS gage during the same period by approximately 3 cfs (0.1 m^3/sec) (between 3.2 and 4.5 cfs for flows occurring more than 20% of the time). Third, the flow duration curves for the 1984-1988 period are essentially the same at the BLM and USGS gages, indicating very little difference between flow rates at the two sites. There are variations between the 1984-1988 flow duration curves at the highest (less than 20% of the time) and lowest discharges (greater than 95% of the time). In addition to the increase in sustained discharge, the flows recorded by the two gages came into closer alignment after the 1983 flood.

Comparison of Mean Monthly Discharge Records. Comparisons of the mean monthly discharges from the USGS and BLM gages were also made, as shown in Figures 3-2 and 3-3, and in Tables 3-1 and 3-2. For the 1981-1983 period, the BLM gage recorded higher mean monthly discharges than the USGS gage for ten months of the year. Measurements from the two gages were relatively close for the following four months: November, March, August, and September. The BLM gage recorded higher mean monthly discharges than the USGS gage for the following seven months: October, December, January, April, May, June, and July. During February the mean monthly discharge recorded by the USGS gage was higher than the discharge recorded by the BLM gage. Figure 3-2 compares the mean monthly discharges, while Table 3-1 presents the differences between the mean monthly discharges for the 1981 to 1983 period.

The USGS rates the records from the USGS gage as good, meaning the measurement is within 10% (+/- 5%) of the actual discharge. The BLM gage was monitored more frequently than the USGS gage, so presumably the number of actual flow measurements for comparison with gage readings would be more numerous. Thus, one can safely assume that the BLM gage measurements are at least as accurate as the USGS measurements, especially at discharges below 100 cfs (3 m^3/sec), which make up the vast majority of measurements. Based on the accuracy of these data, measurable differences in average discharge between the two sites occurred in every month except February, March, August, and September.

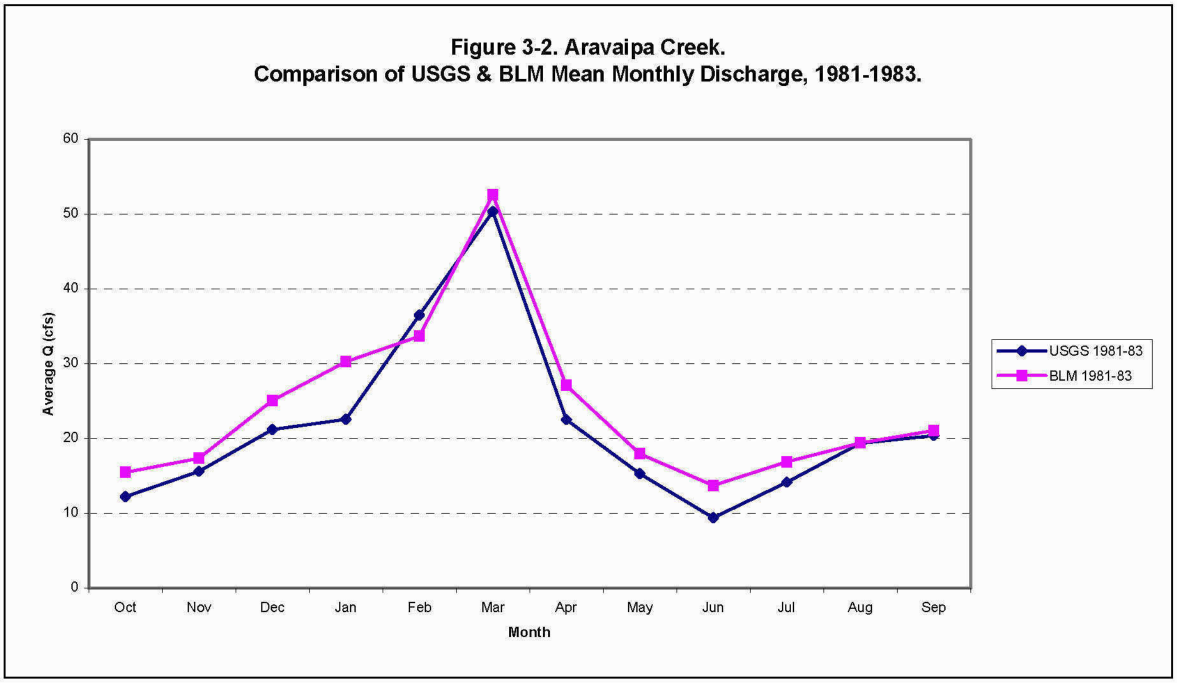


Table 3-1. Aravaipa Creek.
Comparison of USGS & BLM Mean Monthly Discharges, 1981-1983.

Month	BLM Gage (cfs)	USGS Gage (cfs)	Difference (BLM – USGS)	Higher Gage
OCT	15.5	12.3	+3.2	BLM
NOV	17.4	15.6	+1.8	BLM
DEC	25.1	21.3	+3.8	BLM
JAN	30.3	22.6	+7.7	BLM
FEB	33.7	36.5	+2.8	w/in error margin
MAR	52.6	50.4	+2.2	w/in error margin
APR	27.1	22.5	+4.6	BLM
MAY	18.0	15.3	+2.7	BLM
JUN	13.8	9.4	+4.4	BLM
JUL	16.9	14.2	+2.7	BLM
AUG	19.4	19.4	0.0	w/in error margin
SEP	21.1	20.4	+0.7	w/in error margin

The BLM and USGS recorded mean monthly discharges for 1984-1988 generally agree more closely than the 1981-1983 measurements. Figure 3-3 compares the mean monthly discharges, while Table 3-2 presents the differences between the mean monthly discharges.

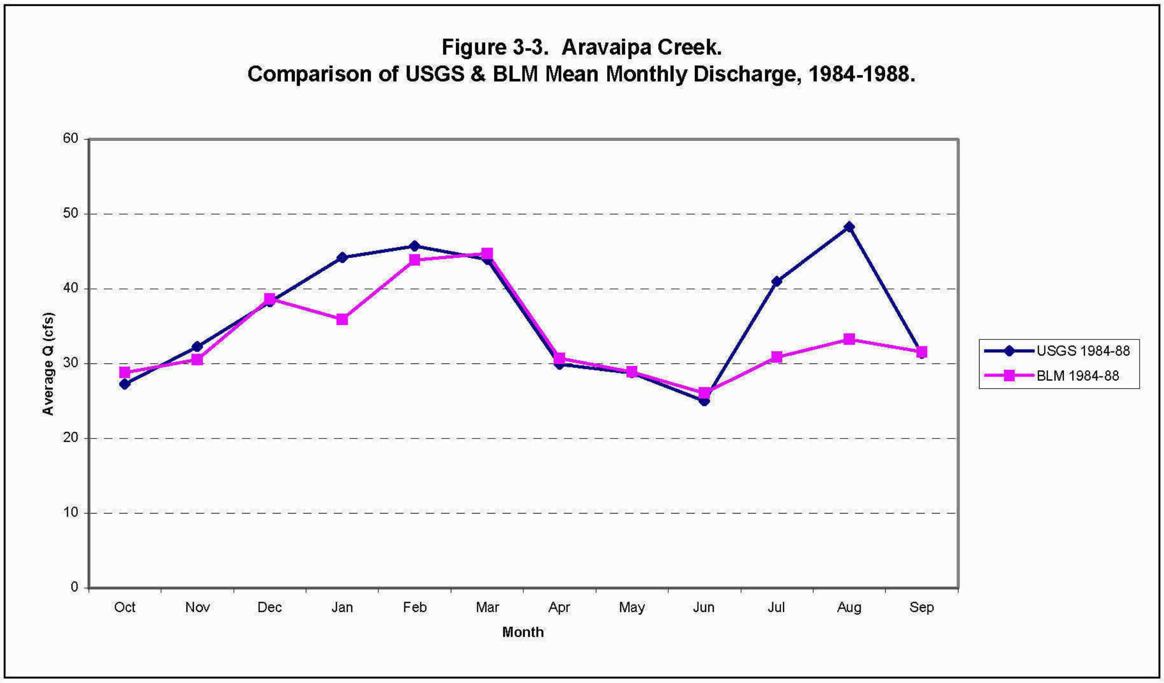


Table 3-2. Aravaipa Creek.
Comparison of USGS & BLM Mean Monthly Discharges, 1984-1988.

Month	BLM Gage (cfs)	USGS Gage (cfs)	Difference (BLM – USGS)	Higher Gage
OCT	28.9	27.3	+1.6	w/in error margin
NOV	30.6	32.3	-1.7	w/in error margin
DEC	38.7	38.4	+0.3	w/in error margin
JAN	36.0	44.2	-8.2	USGS
FEB	43.9	45.7	-1.8	w/in error margin
MAR	44.8	44.0	+0.8	w/in error margin
APR	30.8	30.0	+0.8	w/in error margin
MAY	28.9	28.8	+0.1	w/in error margin
JUN	26.1	25.0	-1.1	w/in error margin
JUL	30.9	41.0	-10.1	USGS
AUG	33.3	48.3	-15.0	USGS
SEP	31.6	31.4	+0.2	w/in error margin

Based on the published measurements at the gage sites described above, August is the only month that shows measurable differences in flow rate after 1984. However, the USGS gage recorded mean monthly discharges are larger than the BLM mean monthly discharges during January, July, and August. The greater differences can be explained by differences in the recorded discharges during July 1984, August 1984, and January 1985. The USGS gage records very high discharges during these three months. However, the rating curve for the BLM gage was not developed to accurately measure high discharges. The BLM measured discharge is most likely much lower than the actual discharge. If these high-flow months from 1984 were removed from the average, the differences between the recorded discharges of the USGS gage and the BLM gage would be much less, as shown in Table 3-3.

Table 3-3. Aravaipa Creek.
Comparison of USGS & BLM Revised Mean Monthly Discharges
for January, July, & August, 1984-1988.

Month	BLM Gage (cfs)	USGS Gage (cfs)	Difference (BLM – USGS)	Higher Gage
JAN (1986,87,88)	27.8	27.5	+0.3	w/in error margin
JUL (1985,86,87)	25.8	25.6	+0.2	w/in error margin
AUG (1985,86,87)	27.1	30.9	-3.8	USGS

Causes of Differences in Gage Data. The data indicate that prior to 1983 the measured discharges at the USGS gage were lower than those exiting Aravaipa Canyon. Several explanations for this change are proposed. First, according to Hardy et al. (1990), after the flood of October 1983, irrigation withdrawals from Aravaipa Creek between the BLM and USGS gages were reduced due to the retirement of irrigated acreage. The reduction in irrigated acreage could account for approximately 3 cfs (0.1 m^3/sec) of flow (Hardy et al. 1990).

A second explanation for the change in gage data differences is the destruction of riparian vegetation that occurred during the October 1983 flood. The flood removed many cottonwoods (*Populus fremontii*) and other vegetation from the banks of Aravaipa Creek within the canyon and between the BLM and USGS gage. Cottonwoods consume approximately 73 inches of water per acre for 100% density (Jackson et al. 1987). The reduction of large cottonwoods from the stream corridor could lead to a general increase in flow, illustrated by the duration curves in Figure 3-1, due to a reduction in the amount of water drawn from Aravaipa Creek between the two gages.

A third possible explanation for the flow change after 1983 is due to the accuracy of the rating curves for the two gages. The BLM rating curve was adjusted twice for a total of three curves used during 1981-1988. The first curve was used from December 1980 to June 1983, the second from May 1984 to March 1986, and the third from March 1986 to April 1988 (BLM, 1988). The USGS rating curve was also adjusted at least twice for a total of at least three curves used during 1981-1988. The USGS curves were dated to begin use October 1, 1984, and October 1, 1985. It could also be safely assumed that the USGS rating curve was adjusted after the October 1983 flood. The BLM gage was calibrated for discharges between 10 – 40 cfs (0.3 – 1.1 m^3/sec), therefore data regarding high flows are often lacking (BLM, 1988). The emphasis on lower flows also brings into question the accuracy of the rating curve for measurements of higher flows that occurred during the periods used for the evaluation.

JEF Field Data. JEF personnel measured stream discharge at three locations in Aravaipa Canyon using a MJP Geopacks flowmeter. Depth and velocity measurements were taken at approximately one-foot intervals across the creek at the cross sections. This spacing resulted in 21 readings at AC-1, 16 readings at AC-2, and 18 readings at

AC-3. Field records and discharge calculations are presented in Appendix A. Discharges were measured during July 2 through 5, 1999, and can be compared to USGS gage measurements to further calibrate the USGS gage to actual flow in the Aravaipa Wilderness Area (Table 3-4). Each field measurement was compared to two flow measurements from the USGS gage. The first USGS measurement was taken at the same time as the field measurement. The second USGS gage measurement incorporated a lag time based on average velocities observed in the field and the distance from the field cross section to the USGS gage. The USGS gage measurements are provisional.

Table 3-4. Aravaipa Creek.
Comparison of Field Measurements With USGS Records

Cross Section #	JE Fuller Field Data		USGS Gage Data			
	PM	AM	No Lag Time		Lag Time Included	
AC-1 (+13.4 hours to USGS)	July 2 (1830-1915)	July 3 (0930-1030)	July 2 (1830-1915)	July 3 (0930-1030)	July 3 (0800-0845)	July 3 (2300-2400)
	12.5 cfs	15.6 cfs	13 cfs	11.5 cfs	11 cfs	19.25 cfs
AC-2 (+9.5 hours to USGS)	July 3 (1830-1900)	July 4 (0715-0730)	July 3 (1830-1900)	July 4 (0715-0730)	July 4 (0400-0430)	July 4 (1645-1700)
	17.6 cfs	16.7 cfs	12 cfs	15 cfs	15.7 cfs	15 cfs
AC-3 (+6 hours to USGS)	July 4 (1900)	July 5 (0700-0730)	July 4 (1900)	July 5 (0700-0730)	July 5 (0100)	July 5 (1300-1330)
	14.4 cfs	17.1 cfs	14 cfs	13 cfs	12 cfs	14 cfs

The differences between the JE Fuller, Inc., field measurements and the USGS gage measurements are more consistent when the lag time is introduced, reducing the discharge difference to between 1.5 cfs (0.04 m^3/sec) and 3.1 cfs (0.09 m^3/sec). The only exception is an increase of 3.7 cfs (0.1 m^3/sec) between the AC-1 July 3 a.m. measurement and the corresponding USGS measurement. However, the increase can be explained by an intense local rainstorm that occurred the afternoon of July 3 while JE Fuller, Inc., personnel were in the vicinity of Deer Creek. Based on these data the USGS gage measures discharge approximately 2 cfs (0.06 m^3/sec) below the corresponding discharge in Aravaipa Canyon.

The analyses of BLM gage records and JEF field measurements relative to the USGS gage data support the conclusion that the USGS gage measurements are best interpreted as a minimum value of the flow in Aravaipa Canyon.

Field Observations

Discharge measurements were collected by JEF staff at three index cross sections within the Aravaipa Canyon Wilderness during the two field visits. The discharge data collected during these visits are summarized below.

Diurnal Variations. Slight diurnal variations were detected in the gage measurements conducted in July. Gage measurements were taken twice at three locations in Aravaipa Canyon. The first measurement was taken in the evening at approximately 7:00 p.m. The second measurement was taken the following morning, roughly 12 hours later. At AC-1, near Turkey Creek, discharge was greater in the morning hours than during the previous evening by 3.1 cfs (0.09 m^3/sec), or 24.9%. At AC-2, discharge was lower in the morning by 0.67 cfs (0.02 m^3/sec), a 3.8% decrease, probably due to increased flow for the evening measurement caused by afternoon rain showers. At AC-3, the discharge was higher in the morning by 2.7 cfs (0.08 m^3/sec), an 18.8% increase. The calculated discharges, cross-sectional areas, and mean velocities are presented in Table 3-5. In general, the field data support the conclusion that a small diurnal effect occurs, probably due to daytime water use by riparian species.

Table 3-5. Aravaipa Creek
Measured Discharges, July 2-5, 1999

		Evening (P.M.)	Morning (A.M.)
AC-1	Total Discharge (cfs)	12.5	15.6
	Total Area (ft^2)	7.1	8.6
	Mean Velocity (ft/sec)	1.8	1.8
AC-2	Total Discharge (cfs)	17.6	16.7
	Total Area (ft^2)	8.9	8.0
	Mean Velocity (ft/sec)	2.0	2.1
AC-3	Total Discharge (cfs)	14.4	17.1
	Total Area (ft^2)	9.3	9.3
	Mean Velocity (ft/sec)	1.6	1.8

Tributary Discharge Contributiuons. A very slight increase in flow was detected downstream of Deer Creek during the November field investigation.[4] Upstream of Deer Creek gage results indicated a flow of 22.5 cfs (0.64 m^3/sec), while downstream the flow was measured at 23.6 cfs (0.67 m^3/sec), an apparent increase of only 1.1 cfs (0.3 m^3/sec). Discharge calculations based on the measured field data can be found in Table 3-6.

Table 3-6. Aravaipa Creek
Measured Discharges, November 19, 1999

	Upstream of Deer Creek 2:30 – 3:20 p.m.	Downstream of Deer Creek 4:00 – 4:45 p.m.
Total Discharge (cfs)	22.5	23.6
Total Area (ft^2)	10.3	9.3
Mean Velocity (ft/sec)	2.2	2.5

Discharge measurements were taken only at the confluence of Deer Creek. However, flow was observed entering Aravaipa Creek from Paisano Canyon, Booger Canyon, Horse Camp Canyon, and Javelina Canyon. In these additional instances the flow stayed at the surface. Assuming that the flows were similar to Deer Creek contributions (even though the flows could have been higher since water remained at the surface), the total contribution from these tributaries was 5.5 cfs (0.16 m^3/sec) along the canyon's length. This value is comparable to the 7.1 cfs (0.20 m^3/sec) difference between discharges measured by the east-end and west-end BLM gages in December, January, February, and March 1981 – 1988.

[4] The observed November 1999 flow in Deer Creek never reached Aravaipa Creek at the surface, but sank into the alluvium several hundred feet upstream of the confluence.

Streamflow measurements made by JEF personnel during July 1999 indicate that the discharge at the west end of the canyon is only 1.5 to 1.9 cfs (0.04 – 0.05 m^3/sec) higher than discharge at the east end of the canyon (Table 3-5). The disparity between winter and summer discharges could be attributed to higher evapotranspiration rates during the summer months.

Hydrologic Trends

Variations in Aravaipa Creek's surface hydrology over seasonal, annual, and longer durations are examined in this section. For this report the period of record was divided into four shorter periods that can be used for comparison and analysis of long-term patterns. These periods were defined based on the nature of the available flow records and to generate consistent time divisions to determine if there were any recognizable trends in the period of record. The four time periods were divided as follows:

- 1932 to 1942
- 1967 to 1977
- 1978 to 1988
- 1989 to 1998

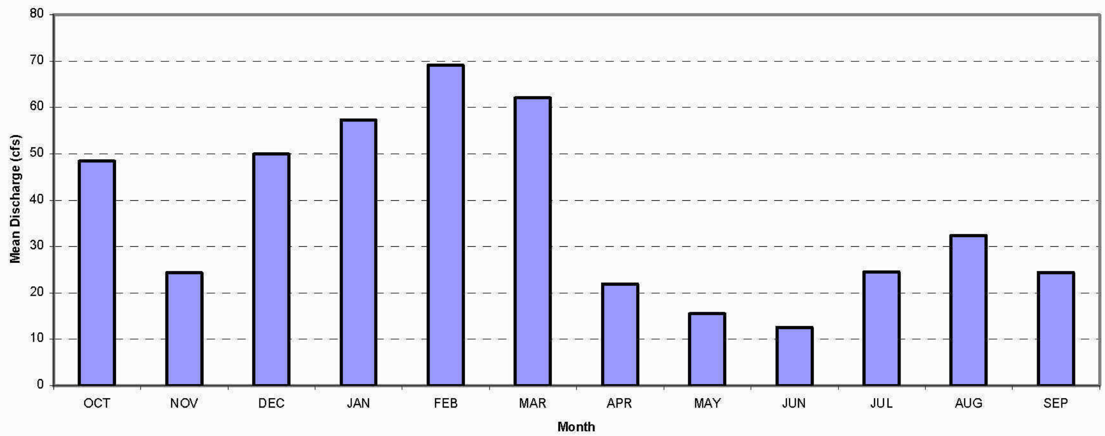
The first period consists of the first 'era' of continuous mean daily records, from 1932 to 1942. July, August, and September 1941 lack records in this first period. The remaining years, 1967 to 1998, are divided into three equivalent periods. These later divisions attempt to maintain the eleven-year length established by the first period. The year 1977 also conveniently marks the division of an apparent wet and dry cycle determined from regional analysis of streamflow and precipitation records. The last period is only ten years long because the USGS gage data for 1999 have not yet been published.

Comparisons of annual base flows, flow volumes, and duration curves show that Aravaipa Creek experienced its lowest recorded flows between the late 1960s and mid-1970s. The highest flows on record occurred during the 1980s. Flows have subsequently dropped but have not reached pre-1980s levels.

Annual and Seasonal Patterns

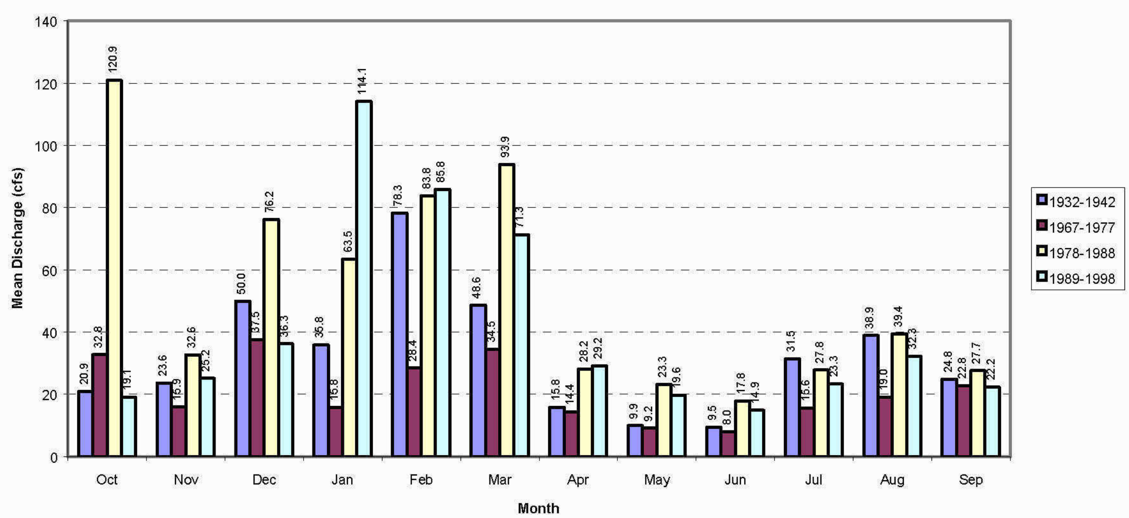
Mean Monthly Discharges. An annual wet-dry cycle dominates the flow in Aravaipa Creek. Aravaipa Creek is dominated by a wet winter and dry summer pattern. The wet winter season lasts from December through March, and the dry summer lasts from April to early July. Summer runoff occurs during the monsoon season in late July, August, and September. The month of October has an artificially high mean monthly flow due to the large volume of runoff associated with the flood of October 1983. Without the effect of that large flood, mean discharge during October would be 23.3 cfs (0.7 m^3/sec), more similar to September and November. Monthly discharge for Aravaipa Creek is presented in Figure 3-4. Typically, the wettest month is February. The driest month is June, which also is at the peak of irrigation diversions (BLM, 1988) and the second driest month in precipitation. The month with lowest average precipitation is May (Figure 3-14), which has the second lowest average runoff rate.

Figure 3-4. Aravaipa Creek.
Mean Monthly Discharges; 1932-1942, 1967-1998.



Long-term Variations in Mean Monthly Discharge. Mean monthly discharges for each of the four periods described above are presented in Figure 3-5. The discharges that occurred in the two latest periods are generally higher than those that occurred in the first two periods. This pattern suggests that Aravaipa Creek is currently in a wet period. The consistently higher discharge is also apparent in comparisons of base flow, duration curves and yearly volumes discussed in "Long Term Patterns" below.

Figure 3-5. Aravaipa Creek.
Comparison of Mean Monthly Discharges.



Event Frequencies and Durations. Differences between winter floods and monsoon-generated floods exist in both duration and frequency. To illustrate the difference, the water year was separated into four periods of three months each. Statistics were generated for the average number of high flow events in each season and the average duration of the high flow events. A rigorous analysis of flood hydrographs was not warranted for the study, thus high flows were defined as any flow greater than the base flow. The initiation and end criteria for the flow durations were also defined in relation to the base flow before and after the event. In the case of consecutive events, the lowest flow between the two peaks was considered the division of the two events. The values are presented in Table 3-7. The January through March season is equated to the winter season, and the July through September season is equated to the monsoon season. The winter season experiences an average of 4.9 events per season with an average duration of 5.5 days compared to the monsoon season, which experiences 6.8 events per season on average with an average duration of 2.1 days. In general, high flows caused by winter storms are less frequent but of a longer duration than monsoon-generated high flow events.

Table 3-7. Aravaipa Creek.
Seasonal Event Frequency and Duration.

Time Period	Fall		Winter		Spring		Monsoon	
	OCT-NOV-DEC		JAN-FEB-MAR		APR-MAY-JUN		JUL-AUG-SEP	
	Average # of Events	Average Duration (days)	Average # of Events	Average Duration (days)	Average # of Events	Average Duration (days)	Average # of Events	Average Duration (days)
1932-1942	2.1	4.6	4.3	4.5	0.9	3.8	8.9	1.7
1967-1977	2.4	3.0	1.7	3.6	0.6	2.0	5.6	2.1
1978-1988	4.7	4.6	7.8	6.6	2.1	7.2	7.3	2.6
1989-1998	2.9	5.1	5.8	7.2	1.4	9.3	5.3	2.0
All Years	**3.0**	**4.3**	**4.9**	**5.5**	**1.3**	**5.6**	**6.8**	**2.1**

Long-term Variations in Event Frequencies and Durations. The frequencies and durations of high flow events were greater during the latter two periods than during the first two periods (Table 3-7). The 1978-1988 period experienced the greatest number of flow events, but the 1989-1998 period had the longest duration events. The number of winter (January - March) events increased from an average of 3.0 per season in the pre-1978 periods to an average of 6.8 per season after 1978. The duration of these events also increased from an average of 4.1 days to 6.9 days. Spring (April - June) events also increased dramatically from pre-1978 to post-1978. The number of events per season increased from 0.75 on average to 3.5. Durations nearly tripled from 2.9 days on average to 8.25 days. With the exception of the October 1983 flood, there were no significant variations in the fall (October - December). Durations and frequencies also remained fairly constant in the monsoon season (July - September). These preliminary results suggest that the current wet period Aravaipa Creek is experiencing may be the result of wetter winters and summers.

Long Term Patterns

Changes in Base Flow. Ellingson (1980) estimates a base flow of 8,500 acre-feet per year. He arrived at this value from 10 years of USGS records, but fails to mention which years, except to say that there were examples of above average, average, and below average water years. Since Ellingson published his report in 1980, one can assume that perhaps his latest data were from 1979. The gage records for 1967-1979 are assumed to approximate Ellingson's data set for comparison purposes.

Since the flow hydrographs for Aravaipa Canyon are very complex and detailed base flow analysis is beyond the scope of this study, it was assumed that the minimum daily flow for each month was a reasonable estimate of the base flow for that month. The estimated monthly base flows were then summed to estimate the annual base flow. Using this technique, the base flow for 1967-1979 was estimated at 6,100 acre-feet per year, a value 28% less than Ellingson's reported value of 8,500 acre-feet per year.

Average annual base flow in Aravaipa Creek, based on data from the USGS gage collected between 1932-1940, 1942 and 1967-1998, is approximately 9,500 acre-feet/year. Base flows were calculated for each month using the minimum daily flow recorded for that month as a basis. The annual base flow was calculated as the sum of the monthly base flows. The base flow varies considerably between years, as shown in Figure 3-7, ranging from 3,200 acre-feet in 1977 to 27,500 acre-feet in 1993. Base flows after 1978, however, appear to be higher than those from earlier decades (Table 3-8). In fact, average base flows for the two most recent periods are more than twice as large as those in the earliest periods of the gage record, indicating that Aravaipa Creek is currently in a wet period.

Table 3-8. Aravaipa Creek. Average Annual Base Flow.

Period	Average Annual Base Flow (ac-ft/yr)
1932-1942	6,300
1967-1977	5,200
1978-1988	14,000
1989-1998	13,000
All Years	**9,500**

Base flow is strongly dependent on annual precipitation as seen in Figure 3-6. The base flows also vary considerably by season, being low in the summer months and high in the winter months (Figure 3-7). The base flows in the summer months are reduced from the winter month base flows by significant amounts of evapotranspiration, diversions, and groundwater pumping for irrigation. Thus, the "true" groundwater-supplied base flow is more likely to be reflected by the winter month base flows.

Figure 3-6. Aravaipa Creek.
Annual Base Flows and Precipitation.

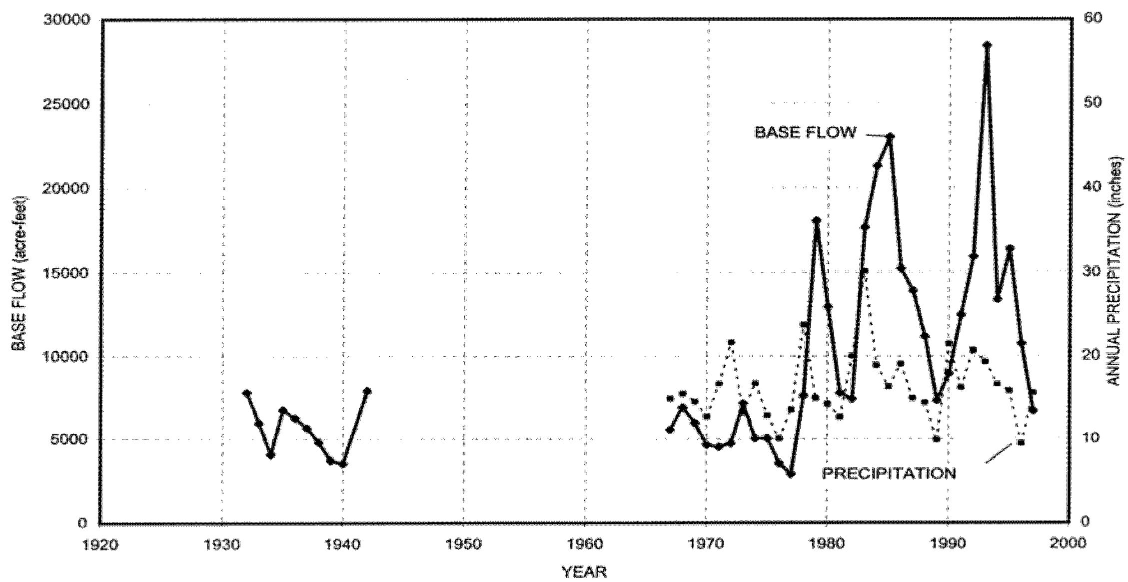
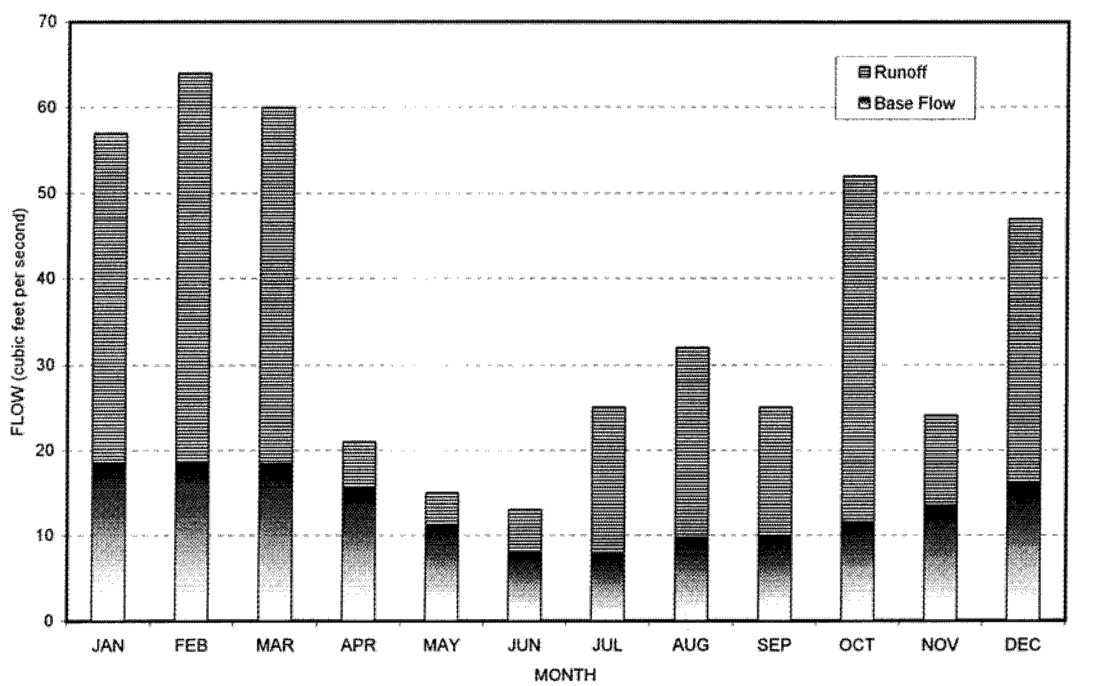


Figure 3-7. Aravaipa Creek.
Average Monthly Flows at USGS Gage.



Changes in Flow Durations Curves. The duration curves of the four periods can also be compared (Figure 3-8). The earliest periods (1932-42 and 1967-1977) have duration curves that are nearly identical except at high flows experienced less than 20% of the time. The 1978-1988 period shows the highest duration curve. The 1989-1998 duration curve is slightly lower than the 1978-1988 period curve. The relationship of flow duration curves is similar to the relationship of flow volumes, indicating that Aravaipa Creek is currently in a wet period. Flow duration data for Aravaipa Creek are given in Table 3-9.

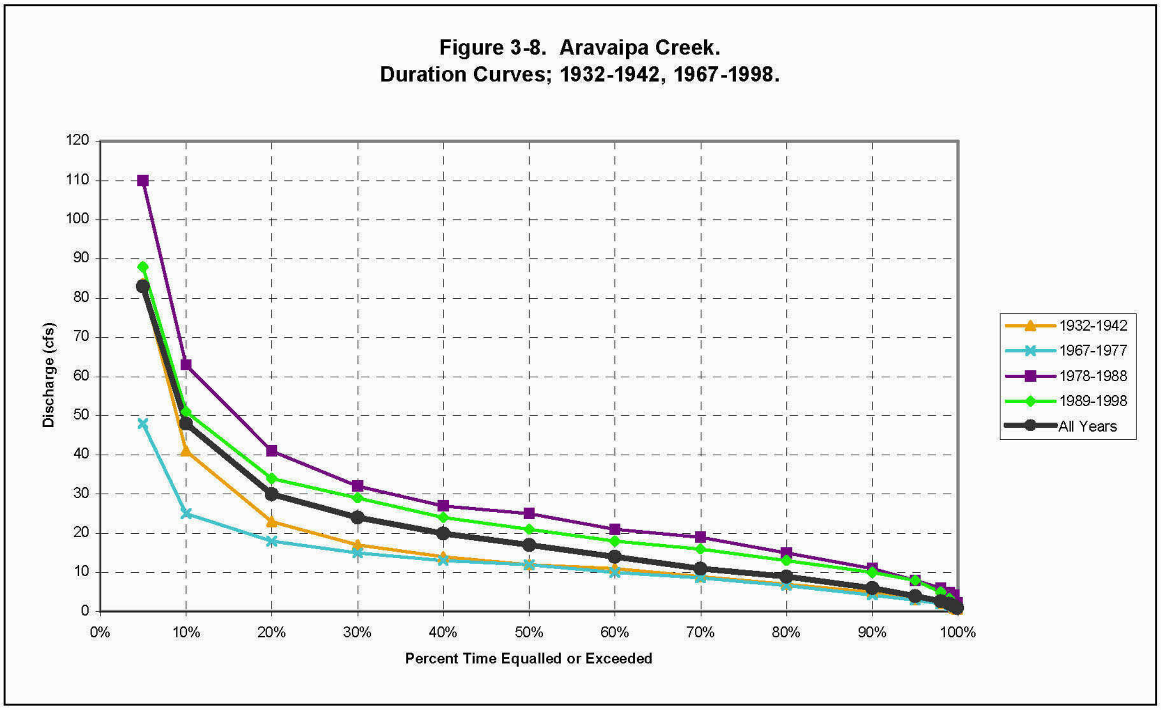
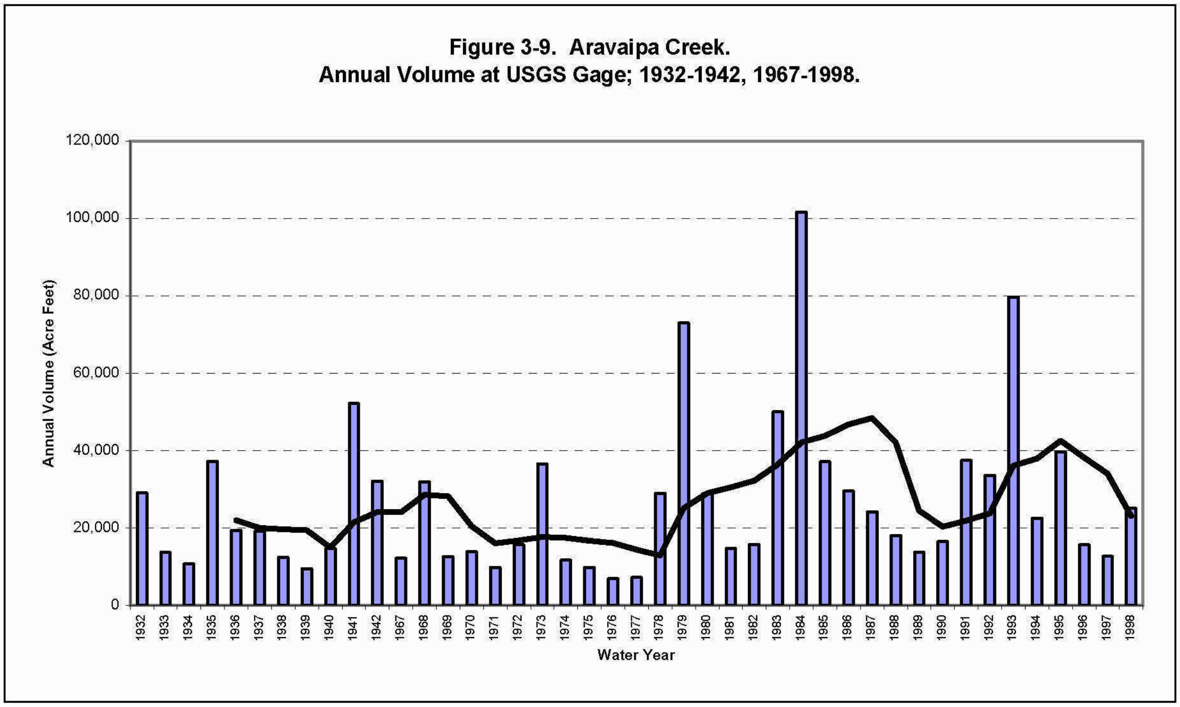


Table 3-9. Aravaipa Creek.
Mean Daily Discharge (cfs) Equaled or Exceeded for Indicated Percent of Time.

	1%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%	99.9%
1932-42	412	84	41	23	17	14	12	11	9.0	7.0	5.0	3.0	2.0	0.60
1967-77	224	48	25	18	15	13	12	10	8.6	6.6	4.2	2.9	1.5	0.97
1978-88	439	110	63	41	32	27	25	21	19	15	11	8.0	4.8	2.3
1989-98	476	88	51	34	29	24	21	18	16	13	10	8.0	3.4	1.5
1932-98	**384**	**83**	**48**	**30**	**24**	**20**	**17**	**14**	**11**	**9.0**	**6.0**	**4.0**	**2.0**	**0.98**

Changes in Flow Volume. Annual flow volumes can also be examined to determine long-term trends in Aravaipa Creek's flow regime. Annual flow volumes for the period of record are shown in Figure 3-9. The black line superimposed on the volume bars is a five-year moving average trend line. Although quite variable from year to year, like most streams in Arizona, a trend can be seen in the graph that flow volumes after 1978 are generally larger than those prior to 1978.



The ten water years that had the largest flow volumes are presented in Table 3-10. Four of the ten largest water volume years occur in the 1978-1988 period. Three are in the 1989-1998 period. Two are in the 1932-1942 period, and one is in the 1967-1977 period. Annual flow volumes are often greatly impacted by single large floods.

In these largest volume years, the largest volume flood for the year makes up approximately 30% of the annual volume on average. Two types of exceptions occur. The October flood in water year 1984 contributed 67% of the annual water volume. Conversely, the largest floods in water years 1983 and 1985 contribute only 15% and 8% respectively. Water years 1983 and 1985 had several flood events of similar magnitude. All the floods occurred between December and March with the exceptions of floods in October 1983 (water year 1984) and October 1972 (water year 1973). The receding limb of the 1983 water year flood hydrograph extended into the month of April.

Table 3-10. Aravaipa Creek.
Top Ten Water Years by Volume.

Rank	Water Year	Volume (acre-feet)	Largest Flood		
			Dates	Volume (acre-feet)	% of Annual Total
1	1984	101,700	10/1-10/23	67,868	67
2	1993	79,730	1/8-1/13	27,686	35
3	1979	73,018	12/18-12/27	28,126	39
4	1941*	52,175	12/30-1/8	14,194	27
5	1983	50,011	3/25-4/25	7,549	15
6	1995	39,683	1/5-1/11	9,923	25
7	1991	37,491	2/28-3/15	10,330	28
8	1935	37,267	2/6-2/14	8,071	22
9	1985	37,144	12/26-1/7	3,047	8
10	1973	36,597	10/18-10/24	9,800	27

*No record for July, August, & September

Annual average flow volumes for the four divisions of the period of record can be used to make sense of the highly variable flow volume patterns. The period of 1967-1977 experienced the lowest flow volumes on record. The 1978-1988 period is the wettest period on record. The 1989-1998 period is not as wet as the 1978-88 period but still much wetter than the 1930s and 1970s. Table 3-11 presents total volume of water measured by the USGS gage on Aravaipa Creek for the four divisions of the period of record.

Table 3-11. Aravaipa Creek.
Total Volume for Periods.

	Total Volume (acre-feet)	Average Volume (acre-feet)
1932 – 1942*	250,219	22,747
1967 – 1977	168,437	15,313
1978 – 1988	421,529	38,321
1989 – 1998	297,736	29,774
All Years	**1,137,921**	**26,463**

* No record for July, August, & September 1941

BLM Instream Water Rights: Comparison To Historical Mean Monthly Flows

In 1988 the BLM applied for instream water rights in the Aravaipa Wilderness Area for the benefit of the native fish species and the enhancement of the natural experience for hikers (BLM 1988). The instream flow application was based on Minckley's (1981) recommendations of a 15 cfs (0.4 m^3/sec) monthly average with high flow and low flow variations to simulate natural low flows in summer and occasional flushing flows to maintain suitable habitat. The final requests for instream flows are shown in Table 3-12.

Table 3-12. Aravaipa Creek.
BLM Instream Application.

Month	Discharge (cfs)	Month	Discharge (cfs)	Month	Discharge (cfs)	Month	Discharge (cfs)
OCT	15	**JAN**	20	**APR**	10	**JUL**	10
NOV	10	**FEB**	25	**MAY**	10	**AUG**	20
DEC	20	**MAR**	20	**JUN**	9	**SEP**	11

The gaged discharge estimates for Aravaipa Creek have generally met these recommendations during the four time periods defined above. The only deficiencies occurred during the 1967-1977 period. During that period the mean monthly discharge recorded at the USGS gage dropped below the recommended discharge for the following four months: January, May, June, and August. When averaged over the entire period of record, mean monthly flows have never dropped below the application discharges (Figure 3-10).

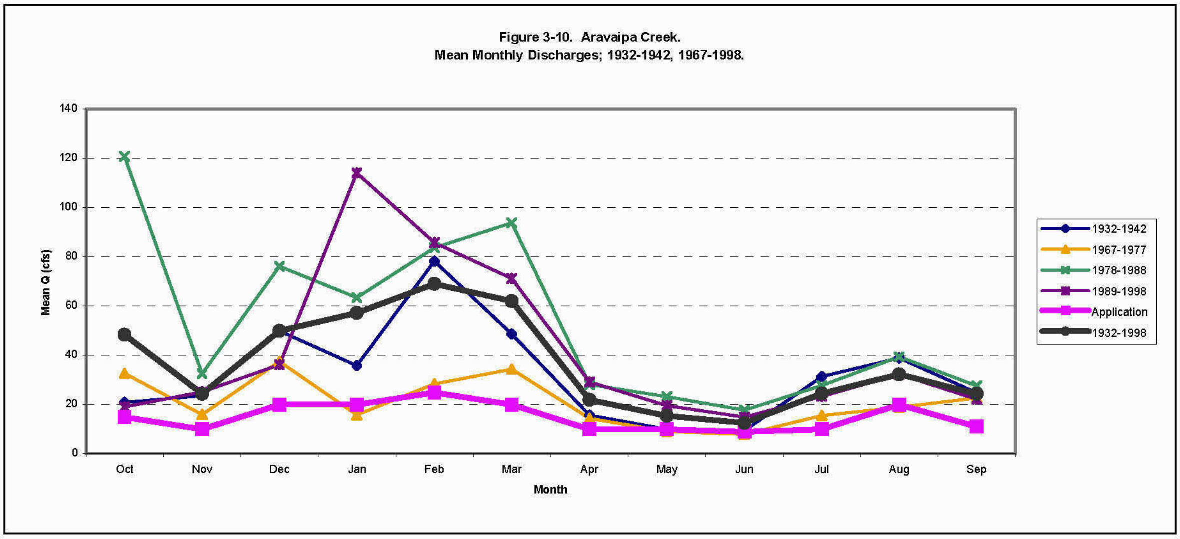


Figure 3-10. Aravaipa Creek.
Mean Monthly Discharges; 1932-1942, 1967-1998.

When the years are examined individually, however, it becomes apparent that many months during the 1932-1942 and 1967-1977 period did not meet the BLM recommendation. The 1932-1942 period was a relatively dry period with respect to the BLM recommended flow (Table 3-13). The mean monthly discharge did not meet the flow requirements in 48 of 132 months (36%). Possibly more important is that the low flow months were often consecutive. According to Turner and Tafanelli (1983), habitat availability for native species decreases dramatically when flows go below 10 cfs (0.3 m^3/sec). The historic hydrograph and the apparent stability of native fish over time contradicts this fact. For example, in 1934 Aravaipa Creek experienced low flow for seven consecutive months. And in 1939 Aravaipa Creek experienced ten consecutive months of low flow. These were extreme years. In all other cases flow lower than the BLM recommendation did not occur for more than three consecutive months. The native fish can and have tolerated these short-term low flows and have evolved to survive during these periods. Low flows may be beneficial in that the connection to the San Pedro River is lost, preventing non-natives from entering Aravaipa Creek. However, extended low flows lasting for several years could pose a problem for the survival of non-native fish.

Table 3-13. Aravaipa Creek.
Comparison of Mean Monthly Discharges to BLM Recommended Discharges, 1932-1942.

	Mean Monthly Discharge (cfs)											
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1932	28.6	48.5	82.3	25.3	155.9	32.4	18.0	12.3	9.3	36.2	26.7	10.4
1933	15.5	13.3	28.0	27.0	25.6	15.3	12.9	10.2	8.6	47.1	9.7	13.7
1934	21.5	11.9	11.6	10.4	11.3	11.2	8.7	6.1	5.2	27.9	42.5	8.6
1935	8.4	13.5	20.6	69.9	186.3	119.0	17.6	10.6	5.1	7.1	133.3	35.1
1936	10.7	18.5	15.6	34.9	90.5	29.2	14.8	8.2	4.9	36.0	22.2	37.8
1937	11.0	12.5	20.9	70.3	87.1	16.0	11.2	7.8	4.2	11.7	27.0	42.3
1938	7.6	10.9	14.4	12.8	17.5	65.6	10.6	6.4	5.1	16.7	21.3	15.3
1939	6.2	9.6	15.5	10.8	17.7	11.2	9.1	4.4	1.9	8.4	47.8	14.8
1940	31.2	8.7	14.0	10.1	44.7	10.3	7.3	5.4	40.1	8.4	39.2	25.8
1941	6.6	73.9	257.0	92.0	177.7	192.1	37.9	21.8	10.6	n/a	n/a	n/a
1942	82.1	38.7	69.7	30.6	47.1	32.9	25.4	16.1	9.0	115.1	19.6	44.4

…… = discharge below BLM recommendation

More than half the months during the 1967-1977 period experienced mean monthly discharges lower than the BLM recommended discharge (Table 3-14). Mean monthly discharges in 73 of 132 months, or 55 percent of the time, were below BLM recommendations. The flows were low for extended periods of time, more so than during the 1932-1942 period. Both 1976 and 1977 experienced nine months of consecutive low flow. Low flows often continued for four or five consecutive months on a regular basis.

Table 3-14. Aravaipa Creek.
Comparison of Mean Monthly Discharges to BLM Recommended Discharges, 1967-1977.

	Mean Monthly Discharge (cfs)											
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1967	13.9	16.8	16.3	18.5	15.9	13.7	12.3	9.4	5.6	25.1	17.5	37.7
1968	14.4	14.3	205.5	15.4	94.2	66.6	19.3	16.5	13.4	19.0	25.4	24.9
1969	12.1	16.4	40.9	19.3	14.1	18.9	12.6	11.5	6.1	9.4	23.4	24.1
1970	9.2	13.7	15.9	15.2	12.6	83.6	11.6	8.6	5.2	8.2	18.2	26.7
1971	14.6	10.5	9.7	10.2	11.4	9.5	10.7	6.8	3.7	13.3	41.1	21.7
1972	44.2	26.0	38.6	15.6	11.5	11.8	7.8	4.3	16.9	17.1	10.6	55.2
1973	200.9	28.0	30.2	21.4	98.5	113.8	41.3	16.6	24.9	15.1	12.0	5.4
1974	12.0	16.7	19.3	16.5	17.0	18.6	11.2	6.3	3.6	26.3	27.2	19.0
1975	24.4	14.5	13.3	12.8	14.8	22.9	16.9	9.5	3.6	11.8	7.8	10.2
1976	7.8	9.7	12.5	12.0	11.8	9.5	7.2	6.0	2.5	12.2	10.6	13.8
1977	7.0	8.7	10.7	17.1	11.1	10.0	7.7	5.2	2.3	13.8	14.8	11.9

…… = discharge below BLM recommendation

The two most recent periods are quite different than the earlier periods discussed above. However, even during the wettest period recorded, 1978-1988, nine of 132 months (7%) experienced mean monthly flow lower than the BLM recommendation (Table 3-15). During 1989-1998, mean monthly flows in 15 of 120 months (12.5%) were lower than the BLM recommended flow (Table 3-16). Extended periods of low flow never exceeded three months in duration.

Table 3-15. Aravaipa Creek.
Comparison of Mean Monthly Discharges to BLM Recommended Discharges, 1978-1988.

	Mean Monthly Discharge (cfs)											
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1978	8.5	10.5	10.5	39.5	77.5	226.7	15.1	13.3	12.1	17.1	37.4	13.1
1979	31.0	91.1	473.7	230.1	133.8	56.6	47.1	44.8	25.1	22.5	28.1	22.4
1980	25.9	27.4	27.8	45.5	175.5	54.8	27.6	21.2	15.6	18.2	26.4	19.5
1981	17.7	19.7	19.4	19.7	27.8	45.1	17.8	16.2	8.7	20.8	17.4	14.2
1982	12.6	12.4	15.7	48.9	32.3	29.1	14.2	10.9	6.2	7.6	45.2	26.7
1983	11.8	18.9	27.9	74.0	214.7	310.6	35.6	18.9	13.5	21.2	38.4	52.5
1984	1097.7	50.3	51.5	51.2	35.0	30.0	32.5	30.9	31.2	90.5	105.7	55.8
1985	33.9	39.1	100.6	106.0	84.3	51.3	41.3	33.0	29.8	27.8	44.3	25.2
1986	31.7	44.0	29.9	25.8	57.8	144.1	29.0	25.6	19.5	26.9	24.6	31.0
1987	41.5	25.2	50.7	30.1	51.3	61.4	29.6	25.7	19.4	21.0	21.5	24.4
1988	17.9	20.6	30.4	27.9	31.6	23.1	20.0	15.4	14.9	32.6	44.8	19.5

…… = discharge below BLM recommendation

Table 3-16. Aravaipa Creek. Comparison of Mean Monthly Discharges to BLM Recommended Discharges, 1989-1998.												
	Mean Monthly Discharge (cfs)											
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1989	24.5	22.3	22.5	40.9	11.4	12.9	14.6	7.3	5.9	14.0	30.6	19.8
1990	9.9	15.6	16.9	16.5	21.3	20.5	14.4	11.6	9.2	76.1	44.3	15.6
1991	12.4	13.8	39.7	44.2	20.6	349.4	40.4	18.5	14.9	16.4	23.4	21.0
1992	19.9	26.4	32.0	69.0	165.7	56.6	29.3	32.0	21.8	20.0	65.8	22.7
1993	21.5	28.7	108.6	681.8	153.0	78.9	53.1	39.9	35.6	32.7	42.7	40.0
1994	34.3	41.1	33.7	29.8	75.5	45.9	24.7	18.2	13.3	14.2	23.0	23.7
1995	18.2	45.2	51.2	199.8	157.8	49.5	31.4	29.8	20.3	16.7	21.7	22.8
1996	22.5	28.7	24.2	25.7	40.3	25.5	20.4	11.3	9.7	16.0	13.0	24.1
1997	16.0	16.9	21.3	23.1	26.5	31.0	15.2	8.3	6.5	4.7	27.6	13.9
1998	12.4	13.6	12.6	10.3	186.3	42.9	48.7	19.3	11.9	22.6	30.4	18.8
…… = discharge below BLM recommendation												

At present Aravaipa Creek is in a wet cycle. BLM recommendations for minimum mean monthly flows are being met on a consistent basis. Records of mean monthly discharge indicate, however, that Aravaipa Creek's flow has not always been as high as it currently is. A return to flow levels similar to those recorded in the 1930s, early 1940s, late 1960s, and 1970s might have serious consequences for endangered fish species in Aravaipa Creek. Extended low flows could lead to a reduction in available habitat.

Duration of Flow Magnitudes

Minckley (1981) found that average monthly flows between 0 cfs (0 m^3/s) and 20 cfs (0.57 m^3/s) allow adequate stability for the development and maintenance of diverse habitat for indigenous species. This report splits the optimum flows cited by Minckley into low flow (0 – 10 cfs; 0 – 0.3 m^3/sec) and optimum flow (10 – 20 cfs; 0.3 – 0.6 m^3/sec). The break point of 10 cfs (0.3 m^3/sec) is based on the BLM recommendations in which the lowest mean monthly discharge requested is 10 cfs (0.3 m^3/sec), except for 9 cfs (0.3 m^3/sec) in June. High flow is classified as flow between 20 – 35 cfs (0.6 – 1.0 m^3/sec), just slightly below the average mean daily flow of 37.2 cfs (1.1 m^3/sec) calculated from the 1932-1942,1967-1998 USGS gage records. Flows between 35 – 100 cfs (1 – 3 m^3/sec) are classified as floods.

Minckley (1981) classified flow rates above 100 cfs (2.83 m^3/s) as "destructive flooding." In its investigation of Aravaipa Creek, JEF considered destructive flooding in a geomorphic sense. Evidence of destruction would include significant changes in bed forms, changes in location of riffles and rapids, loss of overbank vegetation, changes in stream pattern, or degradation. None of these changes were observed to have occurred between the JEF field trips in July 1999 and November 1999. The largest mean daily discharge between the July and November field trips occurred on July 28. The mean daily discharge was 840 cfs (24 m^3/sec) and peak instantaneous discharge was 4,150 cfs (118 m^3/sec). Comparison of field observations by JEF personnel to USGS gage flow records for July to November 1999 indicate that a more appropriate level for destructive floods may be mean daily discharges greater than 800 cfs (23 m^3/sec) (See Chapter 5).

The durations of each of these flow categories are plotted on a cumulative bar graph for visual comparison (Figure 3-10). The long duration of dry years on the left side of the graph is deceptive because water years 1943 through 1966 are not included.

Figure 3-10. Aravaipa Creek.
Percent Time at Flow Levels.

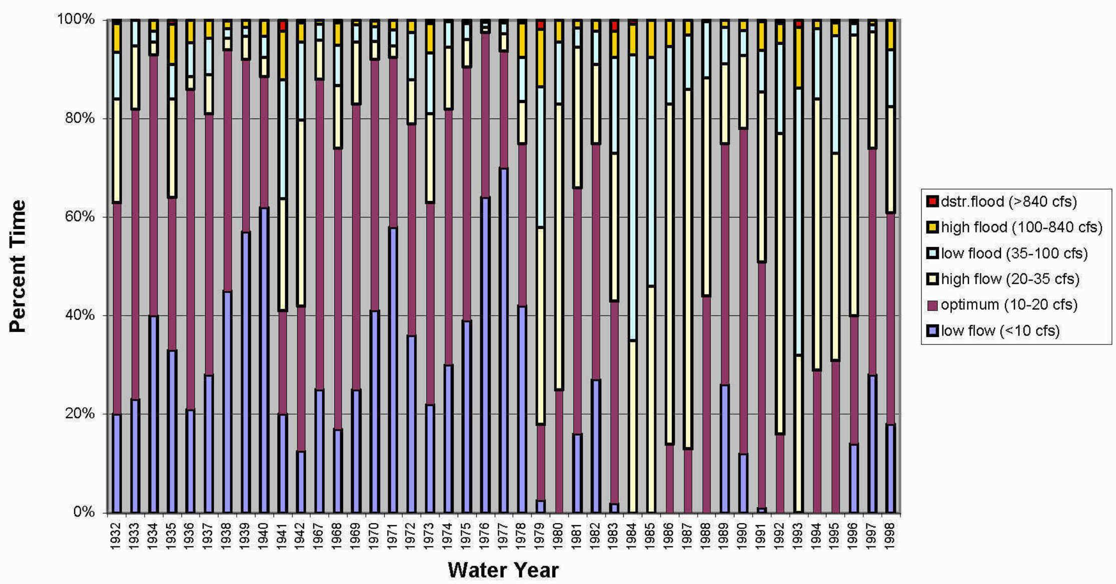


Figure 3-10 illustrates that low flows less than 10 cfs (0.3 m^3/sec) were very prevalent in the period prior to 1978. Percent time at which the flow was at optimum levels is generally similar to the low flow duration time. High flows, low floods, high floods, and destructive floods in total generally make up less than 20% of the flow duration in the period prior to 1978. The situation reverses itself in the period after 1978. The percent of time during which Aravaipa Creek is under the influence of high floods is similar to the pre-1978 condition, but destructive floods are more common after 1978. Periods of low floods and high flows are much more common after 1978, punctuated by relatively dry years approximately every seven years (1981 & 1982, 1989 & 1990, 1997 & 1998). The dry years follow a year of below average precipitation: 12.22 inches (31.04 cm) in 1981; 11.10 inches (28.19 cm) in 1989; 9.05 inches (22.99 cm) in 1996 (Figure 3-13). Continued monitoring of discharge levels is appropriate to determine whether the apparent seven-year pattern of alternating wet and dry cycles is maintained or whether the dry pre-1978 pattern will return.

Peak Discharges

The annual instantaneous peak flows and annual mean daily peak flows recorded by the USGS gage are illustrated in Figures 3-11 and 3-12 respectively.

Figure 3-11. Aravaipa Creek
Annual Peak Discharge, 1932-1941;1967-1996

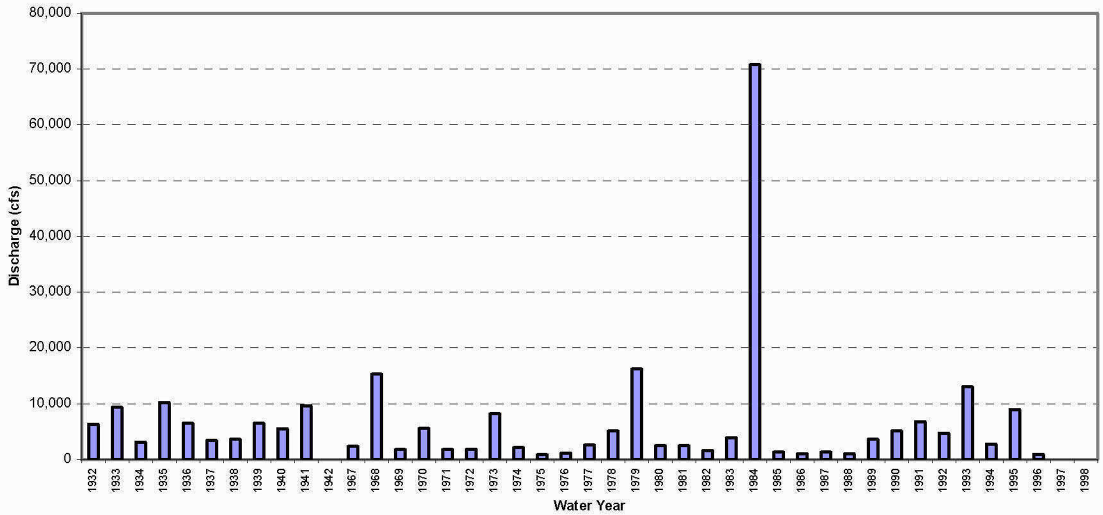
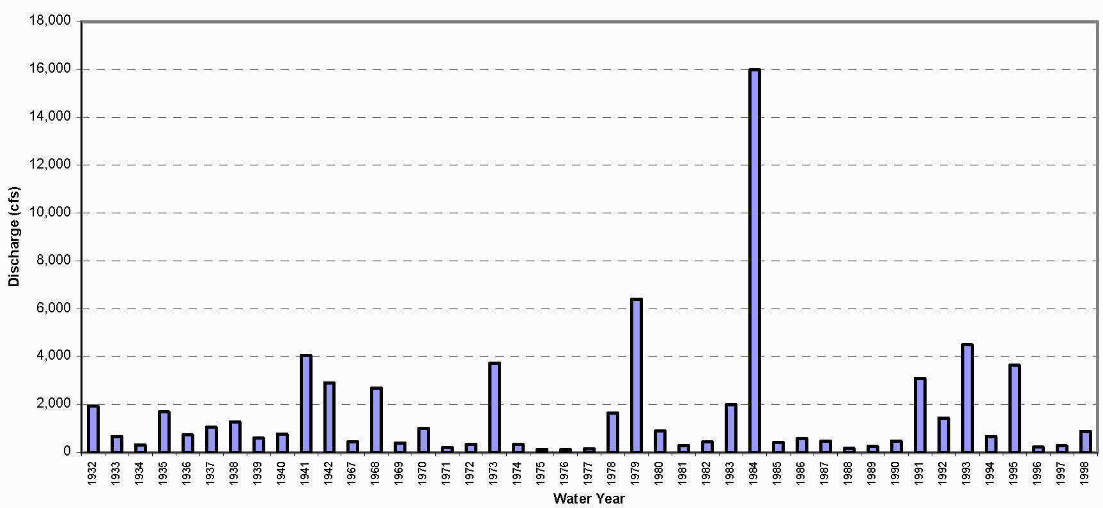


Figure 3-12. Aravaipa Creek.
Annual Peak Mean Daily Discharge; 1932-1942, 1967-1998



Both annual peak instantaneous discharge and annual peak mean daily discharge can be highly variable from one year to the next. Water year 1984 was characterized by exceptionally high flows. The flood of October 1983 peaked at 70,800 cfs (2,005 m^3/sec) according to USGS records and caused extensive damage to riparian vegetation and habitat along Aravaipa Creek. The flood's mean daily discharge equaled 16,000 cfs (453 m^3/sec) and 14,000 cfs (396 m^3/sec) on two consecutive days, October 1 and 2, 1983. The peak reported by USGS for the October 1983 flood is in dispute. An alternate study based on a combination of HEC-II flow modeling and field evidence estimated the peak discharge of the October 1983 flood at between 17,600 cfs (500 m^3/sec) and 23,000 cfs (650 m^3/sec) (Fuller and Roberts 1985). Two relatively low flow periods are represented on the graph. The first occurs between 1971 and 1977 and the second between 1984 and 1988. The ten largest mean daily discharges and instantaneous discharges are presented in Tables 3-17 and 3-18, respectively.

Table 3-17. Aravaiapa Creek. 10 Largest Mean Daily Discharges.

Rank	Discharge (cfs)	Date
1	16,000	10/01/1983
2	14,000	10/02/1983
3	6,400	12/18/1978
4	4,500	01/11/1993
5	4,000	12/19/1978
6	3,740	10/19/1972
7	3,640	01/05/1995
8	3,320	01/08/1993
9	3,100	03/02/1991
10	2,700	12/20/1967

Table 3-18. Araviapa Creek. 10 Largest Instantaneous Peak Flows.

Rank	Discharge (cfs)	Date
1	70,800	10/02/1983
2	16,200	12/18/1978
3	15,300	12/17/1967
4	13,000	01/11/1993
5	8,930	01/05/1995
6	8,200	10/19/1972
7	7,840	01/08/1993
8	6,760	03/02/1991
9	5,560	03/03/1970
10	5,260	02/15/1995

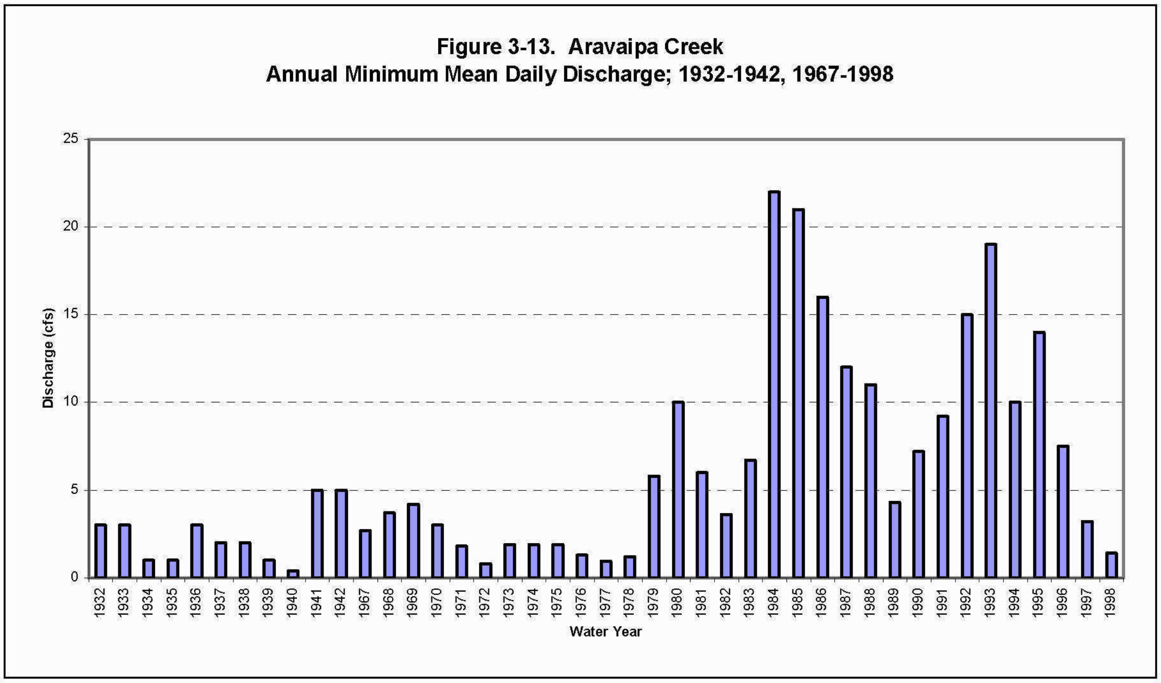
Estimated flood frequencies reported by USGS gage for Aravaipa Creek are shown in Table 3-19 (Pope et al. 1998). The ratio between less frequent peak discharges and more common low flows is a more important indicator of the amount of geomorphic change that occurs than the absolute magnitude of the flood discharge. The channel geometry of many rivers is adjusted to the most common flows such as bankfull stage or frequent, small magnitude floods. Significant geomorphic change generally occurs during floods that have discharges many times greater than the discharge normally experienced by the stream (Wolman and Miller 1960). A useful measure of the controlling geomorphic impact of floods is a comparison of the ratio between the 2-year instantaneous discharge (Q2) and the 100-year instantaneous discharge (Q100). The Q100:Q2 flood ratio for the study reach is 6.8. Ratios below 10 indicate that small floods, rather than large floods, have a controlling impact on channel morphology. This relationship is to be expected, since the perennial nature of Aravaipa Creek as it flows through Aravaipa Canyon allows the channel morphology to adjust to the more frequent, low flows. However, anecdotal and photographic evidence from the 1983 flood indicate that the largest floods can significantly modify the channel and canyon-bottom geometry and channel pattern.

Table 3-19. Aravaipa Creek. USGS Instantaneous Peak Discharge Estimates.

Frequency (yrs)	Exceedance Probability (%)	Discharge (cfs)
2	50	3,980
5	20	8,000
10	10	11,500
25	4	16,800
50	2	21,600
100	1	26,900

Minimum Discharges

Annual mean daily minimum flows recorded by the USGS gage are illustrated in Figure 3-13. The mean daily minimum flows have increased dramatically after 1978.



Precipitation Trends

Table 3-20 presents the total monthly precipitation at Klondyke from 1952 to 1998, which was compiled from several sources. The data from 1952 through May 1977 were obtained from the National Weather Service for the Aravaipa Ranger Station (#020344) and Klondyke 3 SE (#024698). Data from June 1977 through 1998 were obtained from the Bureau of Land Management (BLM) Klondyke station. Missing data from these two sources were reconstructed by using linear regression based on data from the National Weather Service stations at Fort Thomas (#023144), Winkelman 6 S (#029420) and San Manuel (#027530). Reconstructed data are indicated by an asterisk in Table 3-20.

Table 3-20. Aravaipa Creek. Monthly Total Precipitation (inches) at Klondyke, 1952-1998.													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
1952	1.95	0.76	1.92	1.01	0.09	0.67	1.72	2.86	1.15	0.00	2.20	0.77	15.10
1953	0.49	0.38	1.95	0.60	0.47	0.31	2.13	.99	0.00	0.10	0.39	0.60	8.41
1954	0.94	0.06	3.52	0.00	0.61	2.06	3.00	2.41	2.75	0.00	0.00	0.00	15.35
1955	2.60	0.40	0.02	0.00	0.00	1.05	3.84	2.48	0.22	0.00	0.00	1.00	11.61
1956	1.60	1.20	0.00	0.70	0.00	0.85	2.28	0.76	0.00	0.00	0.00	0.30	8.43
1957	3.17	1.20	1.57	0.42	0.88	0.15	3.08	3.12	0.00	1.15	1.15	1.48	19.51
1958	0.00	2.46	2.49	1.51	0.00	0.60	1.75	2.05	0.33	0.95	0.95	0.00	12.14
1959	0.00	1.02	0.00	0.00	0.00	0.00	2.63	2.26	0.30	0.45	0.45	2.53	11.74
1960	2.21	0.90	0.00	0.00	0.50	0.41*	1.68*	0.68*	0.62*	0.02	0.02	0.66	8.78
1961	1.61	0.09	0.50	0.00	0.00	0.90	1.82	3.58	3.35	1.56	1.56	3.85	18.97
1962	1.85	0.78	0.78	0.00	0.00	0.40	1.25	0.81	1.63	0.93	0.93	1.48	10.37
1963	0.96*	2.45	1.86	0.40*	0.19*	0.29*	.97*	6.59*	0.94*	0.83*	0.83*	0.34*	16.73
1964	0.66*	0.20*	1.07*	1.35*	0.19*	0.26*	2.10	2.12	3.12	0.75	0.75	1.92	15.14
1965	1.96	1.51	0.51	0.84	0.00	0.37	1.56	1.06	2.90	1.38	1.38	8.37	20.66
1966	0.97	1.80	0.89	0.00	0.00	0.96	1.72	5.73	4.05	1.96	1.96	0.91	19.48
1967	0.42	0.38	0.53	0.43	0.42	0.39	3.49	2.54	1.54	1.06	1.06	2.60	14.90
1968	0.41	2.04	1.73	0.00	0.00	0.00	2.69	4.05	0.00	1.83	1.83	2.41	15.47
1969	1.03	0.73	0.80	0.00	0.91	0.00	2.12	3.71	1.56	1.31	1.31	1.71	14.50
1970	0.00	0.88	3.30	0.45	0.00	0.36	1.72	1.53	2.08	0.00	0.00	0.91	12.71
1971	0.47	1.04	0.00	0.72	0.00	0.00	3.71	1.72	3.08	1.75	1.75	2.02	16.68
1972	0.00	0.00	0.00	0.00	0.18	2.79	1.41	2.39	6.49	1.53	1.53	1.38	21.63
1973	0.95	2.20	3.16	0.20	0.68	1.08	3.23	0.40	0.00	0.00	1.28	0.00	13.18
1974	2.35	0.24	1.34	0.33	0.00	0.00	4.90	2.54	1.43	2.51	0.50	0.60	16.74
1975	0.96	0.73	2.17	1.24	0.00	0.00	4.32	0.33	1.32	0.03	0.76	0.98	12.84
1976	0.52	1.49	0.59	1.32	0.44	0.00	1.34	0.71	1.85	0.87	0.35	0.59	10.07
1977	2.27	0.20	1.07	0.57	0.10	0.20	2.15	2.21	1.45	1.15	0.55	1.65	13.57
1978	3.30	2.71	1.78	0.46	0.83	0.48	1.03	1.30	1.66	3.50	2.51	4.21	23.77
1979	3.05	2.22	1.36*	0.36*	1.38*	0.88*	1.39*	1.49*	0.43	0.87	0.56	0.95	14.94
1980	2.32	3.93	1.71	0.31	0.10	0.16	1.23	2.28	1.18	0.36	0.11	0.55	14.24
1981	0.55	1.61	2.70	0.38	0.90	0.34	2.36	0.82	1.54	0.35	1.11	0.00	12.66
1982	3.99	1.90	1.95	0.08	0.99	0.00	1.12	3.57	1.99	0.00	2.70	1.76	20.05
1983	2.54	1.79	4.31	0.37	0.00	0.05	3.19	4.43	4.19	5.15	1.83	2.34	30.19
1984	0.56	0.03	0.00	1.38	0.23	0.71	4.88	3.68	1.41	0.69	1.05	4.32	18.94
1985	2.58	1.29	1.02	1.19	0.00	0.00	2.47	2.43	1.38	1.74	1.93	0.35	16.38
1986	0.55	0.60	3.67	0.00	0.04	0.70	2.07	3.58	2.14	2.24	1.34	2.15	19.08
1987	1.17	1.90	1.75	0.71	0.23	0.35	2.92	0.97	0.97	0.93	0.70	2.33	14.93
1988	0.74	0.67	0.03	2.05	0.00	0.74	1.85	2.95	2.08	1.55	1.45	0.29	14.40
1989	1.79	0.08	0.81	0.00	0.13	0.00	2.38	1.82	0.80	1.66	0.08	0.38	9.93
1990	1.36	1.74	1.55	0.05	0.00	0.06	5.79	3.89	2.25	0.23	1.10	3.44	21.46
1991	1.10	1.90	4.30	0.00	0.00	0.10	1.12	2.50	0.91	0.49	1.40	2.42	16.24
1992	2.06	2.70	2.19	0.26	2.68	0.38	3.13	2.58	0.47	0.09	0.14	4.00	20.68
1993	6.11	2.43	1.13	0.00	0.47	0.00	0.55	4.27	0.24	1.75	1.75	0.65	19.35
1994	0.04	1.90	1.80	0.33	0.60	0.31	0.48	3.60	1.41	1.32	2.24	2.63	16.66
1995	3.25	2.69	1.21	0.45	0.19	0.03	0.73	3.26	2.51	0.00	0.85	0.67	15.84
1996	2.27	0.80	0.27	0.05	0.00	0.10	1.32	0.75	1.97	1.05	0.65	0.25*	9.48
1997	2.85	1.90	0.06	0.05	0.41	0.20	0.46	5.88	0.56	0.25	0.96	2.02	15.60
1998	0.64	4.91	2.46	0.63	0.00	0.07	2.44	3.55	0.48	1.71	1.51	0.85	19.25
Avg	1.56	1.38	1.44	0.45	0.32	0.42	2.25	2.54	1.55	1.16	1.05	1.61	15.72

Total annual precipitation is presented in Table 3-20 and is shown on Figure 3-14. The average total annual precipitation at Klondyke is about 15.72 inches (39.93 cm) for the entire period of record. The driest year on record was 1953 with only 8.41 inches (21.36 cm); the wettest year was 1983 with 30.19 inches (76.68 cm). The annual rainfall totals trend slightly upward over the last 47 years. Comparisons of the average total annual precipitation can be made for periods similar to those used in the USGS gage data analysis (Table 3-21). The two most recent periods are slightly wetter than the two earliest periods. The percentage of years in which total annual precipitation was above average also increased over time. These trends correlate well with the increased discharges seen in the USGS gage record.

Figure 3-14. Aravaipa Creek.
Annual Precipitation at Klondyke.

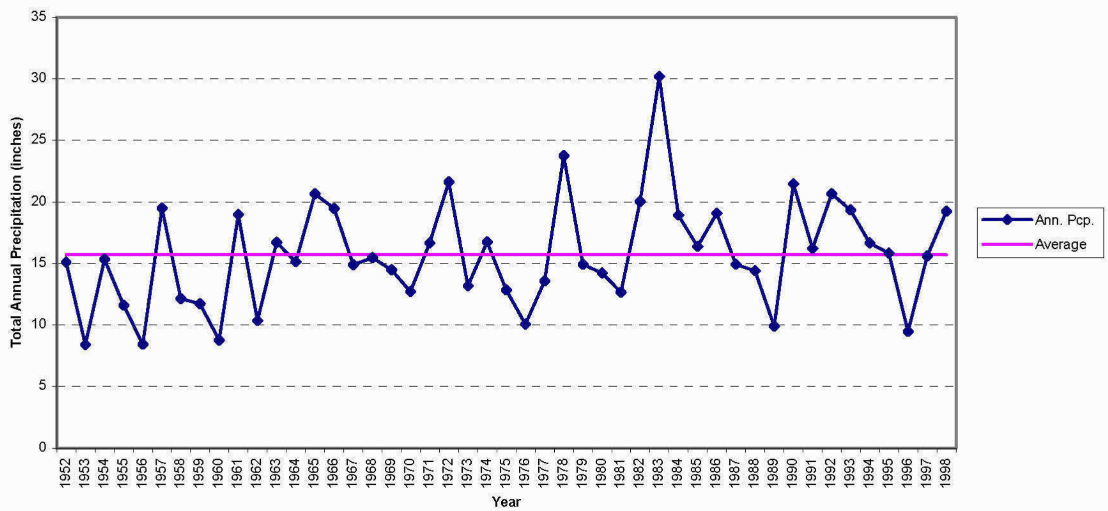


Table 3-21. Aravaipa Creek.
Variations in Total Annual Precipitation

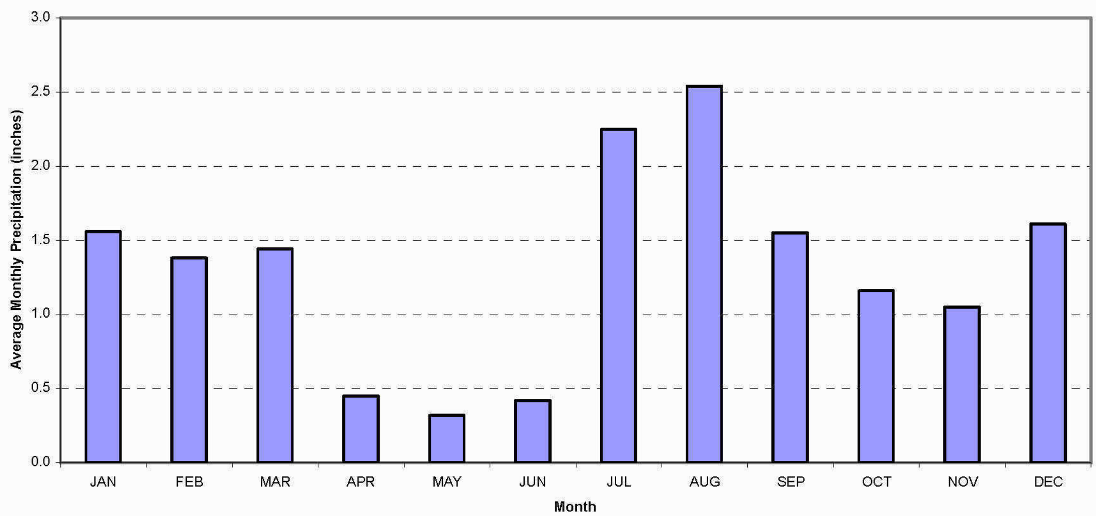
Period	# Years in Period	# Years Below Average[1]	# Years Above Average[1]	% Years Above Average[1]	Avg. Total Ann. Pcp. for Period
1952-1966	15	10	5	33	14.16
1967-1977[2]	11	8	3	27	14.75
1978-1988[2]	11	5	6	55	18.14
1989-1998[2]	10	3	7	70	16.45

[1] Average for entire period of record, 1952-1998
[2] Comparable to divisions of USGS gage period of record

Average monthly precipitation, based on 47 years of record, is presented in Table 3-20 and is shown on Figure 3-15. Monthly averages range from a low of about 0.32 inches

(0.81 cm) in May to a high of 2.54 inches (6.45 cm) in August. The wet summer and winter seasons are separated by relatively dry spring and fall seasons.

Figure 3-15. Aravaipa Creek.
Average Monthly Precipitation at Klondyke.



Conclusions

The USGS gage (09473000) provides the longest record of discharge on Aravaipa Creek. Two BLM gages are also located on Aravaipa Creek, one at the east end of the wilderness area upstream of Turkey Creek, and the second at the west end of the wilderness area. However, the period of record available from the two BLM gages is limited. The two BLM gages would likely provide a better record of actual flow in the canyon than the USGS gage. Comparisons of the USGS gage data, available west-end BLM gage data, and JEF discharge measurements in the canyon indicate that the USGS gage data are best used as a minimum discharge value for the canyon. Available data suggest that the USGS gage discharge measurements are approximately 3 cfs (0.1 m^3/sec) lower than the discharge at the western boundary of the wilderness area, on average.

The USGS gage records show that Aravaipa Creek experiences both seasonal and long-term flow variations. On a seasonal basis Aravaipa Creek experiences a bimodal flow distribution, with seasonal peaks in the winter months (January-March) and the monsoon season (July-September). Winter flows are less frequent than monsoon flows, but winter flows have a longer duration. The three winter months experience a total of 4.9 events on average compared to the monsoon season's 6.8 events. Winter flow durations are 5.5 days on average, whereas monsoon flow durations average only 2.1 days. Winter peak discharges are also greater than monsoon discharges in general. Late spring and early summer months (April-June) are the driest months, in terms of both discharge and precipitation.

Runoff from the winter flows dominates the annual flow pattern of Aravaipa Creek. Especially wet water years are generally the result of extremely large flows occurring during the winter months. The exception is water year 1984 in which the October 1983 flood contributed the most discharge to the annual total. Winter flows have dominated since water year 1979. From 1979 to 1998, only two years have seen a higher percentage of the annual flow come during the monsoon season (1988 and 1990). Monsoon flows tend to contribute a greater proportion to the annual volume during dry years. Prior to 1979, dry years in which the total annual volume was less than 19,000 acre-feet saw the majority of flow contributed by the monsoon season in 9 out of 14 years.

Analysis of the long-term data indicates that Aravaipa Creek is currently in a wet period. Average annual base flows for the last 21 years (1978-1998) are more than twice as large as base flows that occurred from 1932-1942 and from 1967-1977. Average annual volumes for the last 21 years (1978-1998) are roughly twice as large as the volumes experienced from 1932-1940 and from 1967-1977. Precipitation data from Klondyke support this pattern as well. Average total annual precipitation for 1978-1998 has been 2 to 4 inches (5 to 10 cm) greater than average total annual precipitation recorded for 1952-1977. The increases in precipitation combined with decreases in groundwater withdrawal (Chapter 4) appear to be the most plausible contributing factors resulting in the increase in discharge on Aravaipa Creek.

More important for terms of habitat are records of low flows through Aravaipa Canyon. Minckley (1981) proposed minimum low flows that would sustain habitat for native fish species in Aravaipa Creek. Historically, these minimum flow requirements have not always been met. During water years 1932-1942, the minimum flow requirements were not met in 48 of 132 months, or 36% of the time. During water years 1967-1977, the minimum flow requirements were not met in 73 of 132 months, or 55% of the time. The situation improved after 1978. During water years 1978-1988, the minimum flow requirements were not met in only nine of 132 months, or only 7% of the time. During water years 1989-1998, the minimum flow requirements were not met in 15 of 120 months, or 12.5% of the time. An isolated month of low flow below the minimum requirement is not as threatening to habitat as an extended period of low flow. Prior to 1978, extended periods of low flow reached nine to ten consecutive months in duration. After 1978, extended periods of low flow never lasted more than three consecutive months.

The flood ratio (Q100/Q2) for Aravaipa Creek is 6.8, indicating that small floods have a controlling impact on channel morphology. However, large floods can significantly modify the channel pattern and channel and canyon-bottom geometry (Chapter 5). The largest flood during the period of record for Aravaipa Creek occurred in October 1983. The instantaneous peak discharge was 70,800 cfs ((2,005 m^3/sec) according to the USGS gage, while mean daily discharges were 16,000 cfs (453 m^3/sec) and 14,000 cfs (396 m^3/sec) on two consecutive days. An alternate study based on a combination of HEC-II flow modeling and field evidence estimated the peak discharge of the October 1983 flood at between 17,600 cfs (500 m^3/sec) and 23,000 cfs (650 m^3/sec) (Fuller and Roberts 1985).

Chapter 4:
Groundwater

Introduction

The objective of the groundwater analyses was to evaluate groundwater and surface water interactions and any possible link between upstream groundwater pumping and surface flows in the stream. Groundwater information was derived from the Arizona Department of Water Resources Well Registry and the Groundwater Site Inventory.

Groundwater Data

Well Numbering System

The well numbering system used in this report follows the BLM's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the state into four quadrants. These quadrants are designated, counterclockwise, by the capital letters *A*, *B*, *C* and *D*, with *A* being in the northeast. The first digit of a well number indicates the township, the second digit indicates the range, and the third and fourth digits indicate the section in which the well lies. The lower case letters *a*, *b*, *c*, and *d* after the section number indicate the well location within the section. The first letter denotes the quarter section (160-acre tract), the second letter denotes the quarter-quarter section (40-acre tract), and the third letter denotes the quarter-quarter-quarter section (10-acre tract). These letters are assigned in a counterclockwise direction beginning with *a* in the northeast quadrant. Where more than one well is within a 10-acre tract, consecutive numbers, beginning with *1* are added as suffixes. In the example in Figure 4-1 well (A-1-4) 01aba1 lies in the northeast quadrant of the state, A, in Township 1, in Range 4 and in Section 1. Within Section 1, the well lies in the northeast 1/4 (a), of the northwest 1/4 (b) of the northeast 1/4 (a). The well is the first well (1) drilled in that 10-acre tract.

Wells are classified as either shallow or deep wells. Wells less than 150 feet (46 m) deep are considered shallow wells, while wells deeper than 150 feet (46 m) are considered to be deep wells.

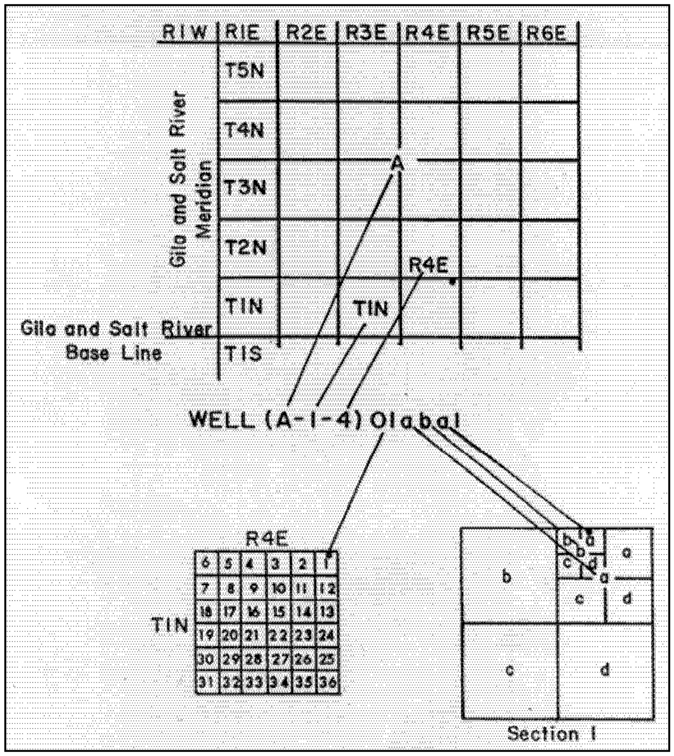


Figure 4-1. Example of well numbering system.

Water Levels and Hydraulic Gradients

A water table elevation contour map is presented in Figure 4-2. This map was developed from data obtained from the Arizona Department of Water Resources Well Registry and the Groundwater Site Inventory. Data from these sources pertaining to the study area are presented in Appendices B and C. Water level elevations measured between 1983 and 1996 were used to define contours in the southeastern portion of the map area. The water level elevations to the west of the canyon were collected primarily in 1966. If several water level measurements were available for a well, the most recent measurement was used. Data from wells with large standing columns of water, generally greater than 200 feet, were not used to develop the water table contours because water levels from those wells would not be representative of water table conditions. Although the data used to develop the water table elevation contours were collected over a series of years, the relatively steady state conditions in the Aravaipa basin, to be discussed later, allow the water table contours to be defined with some confidence. Because there are no historical groundwater data within Aravaipa Canyon, the locations of the water table elevation contours in this region were estimated using the average horizontal gradients from other portions of the creek. No suitable data were available outside the immediate vicinity of the creek to provide a broader assessment of the water table configuration in the valley.

Depths to water in wells along Aravaipa Creek range from less than ten feet to slightly over 80 feet. Figure 4-3 shows the depth to water along the creek. A comparison of the ground surface elevation with the water level elevation along Aravaipa Creek is presented

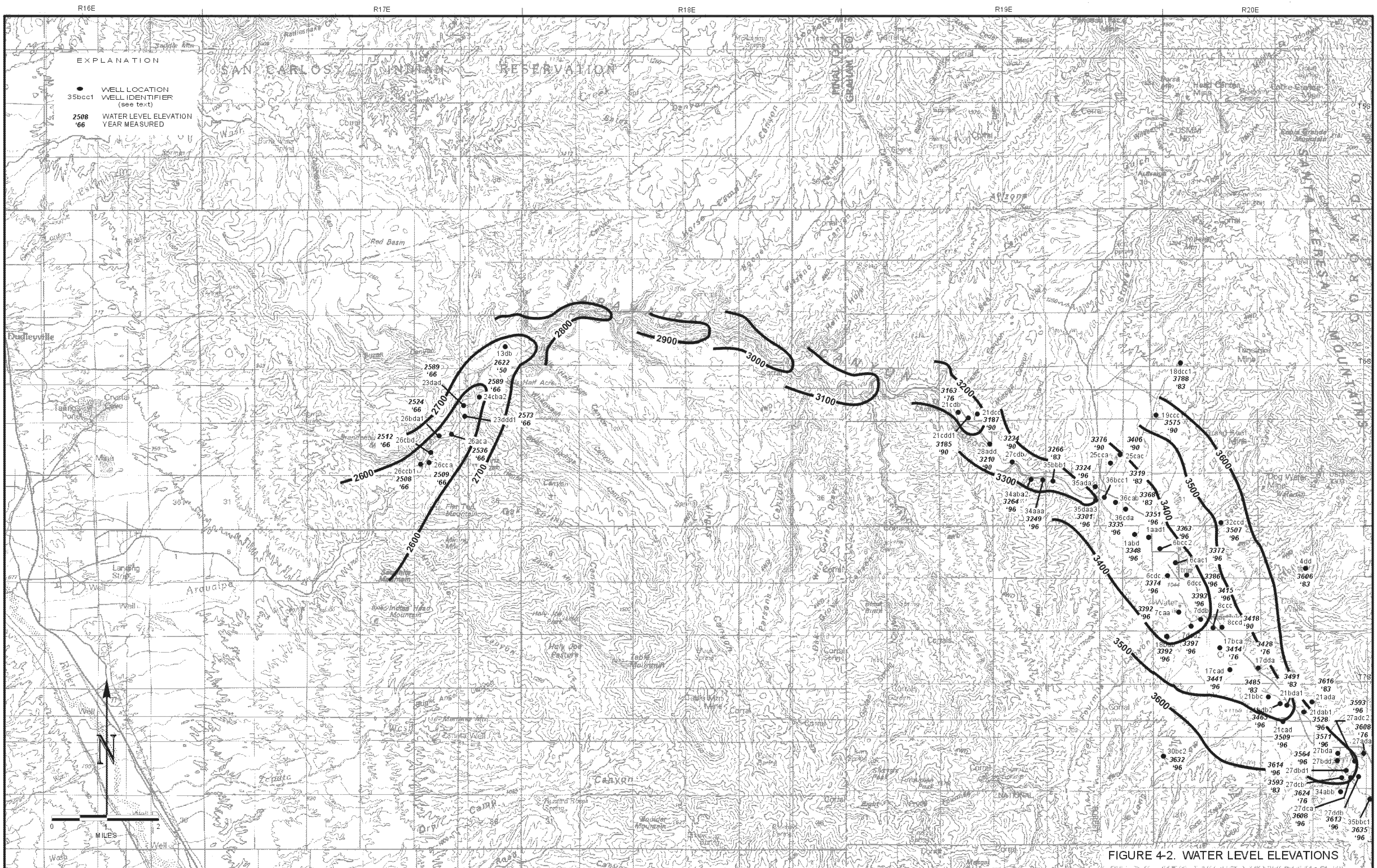
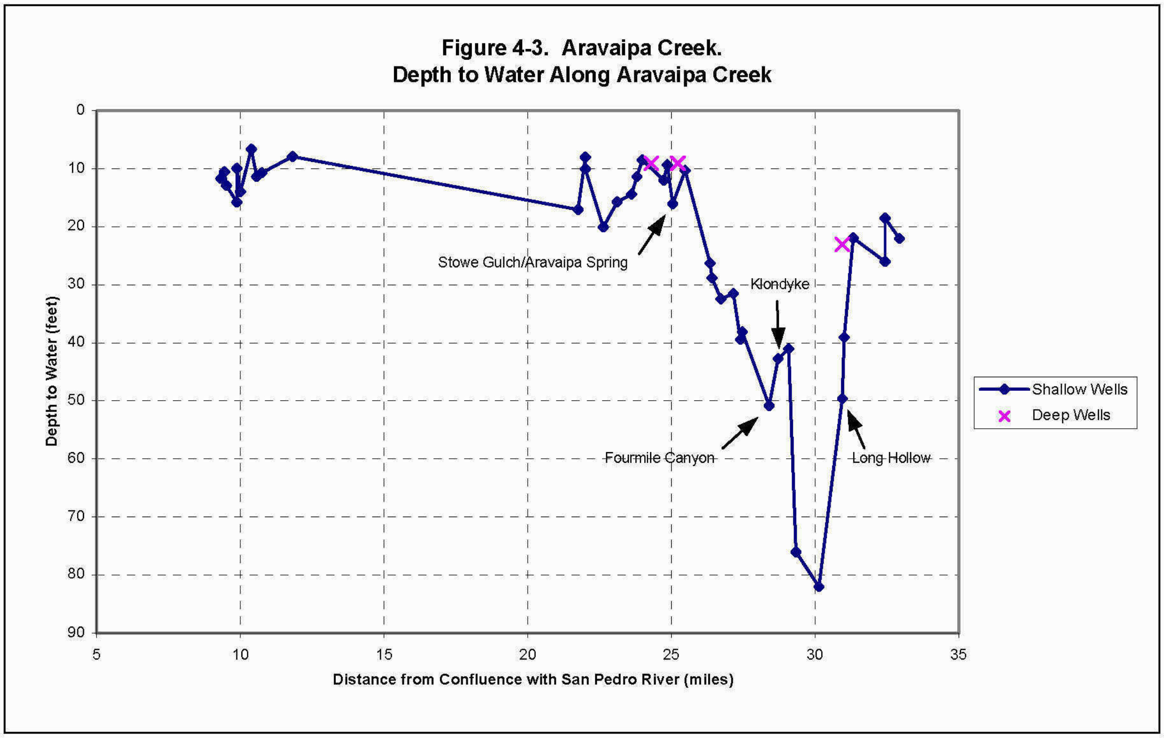
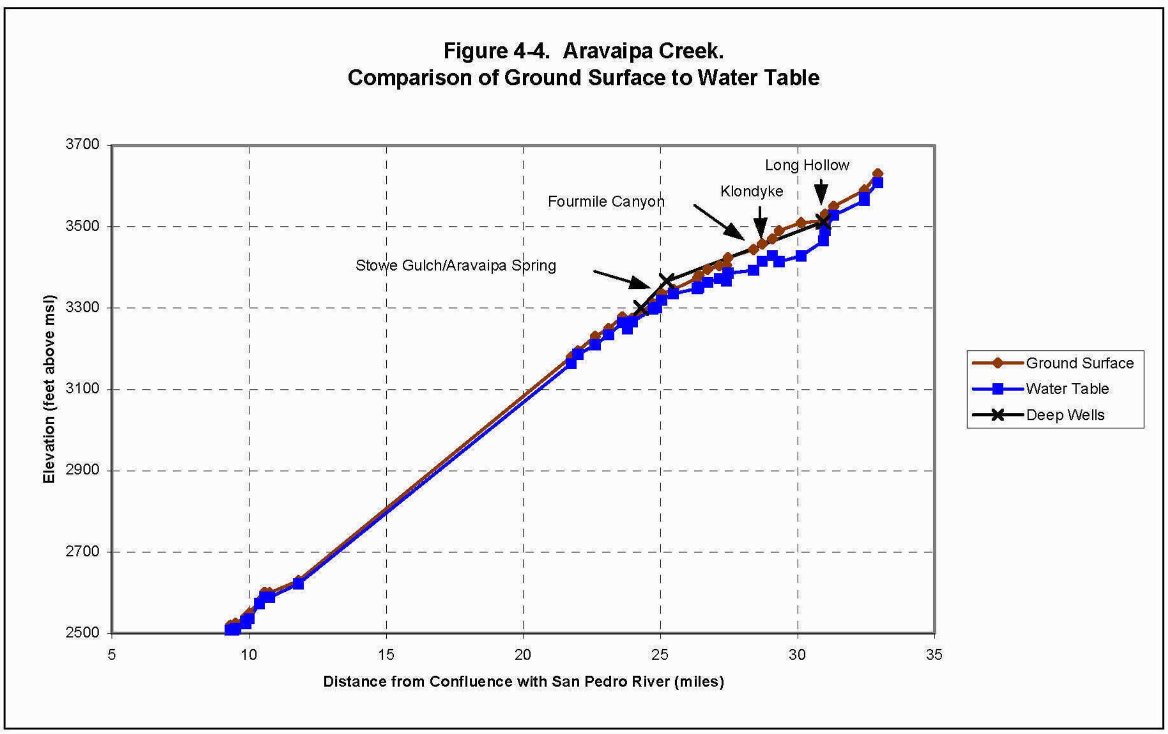


FIGURE 4-2. WATER LEVEL ELEVATIONS

in Figure 4-4. Moving downstream along the creek, the groundwater levels show a sharp decline near Long Hollow and then begin to rise until, in the vicinity of Stowe Gulch and Aravaipa Spring, the groundwater emerges and the stream becomes perennial (Figure 4-4).





The water level contours shown in Figure 4-2 indicate that groundwater flows laterally towards the creek. This water discharges to the stream channel alluvium and flows downstream either as subflow in the alluvium upstream from Aravaipa Spring or as surface water and subflow downstream of Aravaipa Spring.

At one location it was possible to compare the water level in a deep well with the water level in a nearby shallow well and thus obtain an indication of the vertical flow component of the groundwater. Well (D-07-20) 21bdb1 is 762 feet deep with a water level elevation of 3512 ft. msl, which is shallower than the water level in nearby well (D-07-20) 21bdb2, which is 150 feet deep, and has a water level of 3465 ft. msl. These water levels indicate an upward hydraulic gradient in the vicinity of the creek.

Sources of Water to Aravaipa Creek

The available water level data in Aravaipa indicate that both horizontal and vertical water level gradients cause groundwater to flow towards Aravaipa Creek. This groundwater discharges into Aravaipa Creek and flows downgradient and downstream as subflow in the channel fill alluvium or, below Aravaipa Spring, as surface flow.

In addition to direct contributions to the Aravaipa Creek channel from groundwater discharge, subflow or surface flow from tributaries may contribute to the creek. Adar (1984) found that, based on geochemical and mass balance evidence, nearly 50% of the flow at Aravaipa Spring came from Stowe Gulch. Turkey Creek generally contributes significantly to the creek. During a trip through Aravaipa Canyon on November 19-21, 1999, small amounts of surface flow, less than 25 gallons per minute (0.056 cfs), were observed in Deer Creek, Paisano Canyon, Booger Canyon, Horse Camp Canyon and Javelina Canyon. Several of these tributaries had surface flow into the creek during the time of the visit.

Water is contributed to the creek within Aravaipa Canyon. An estimate of this contribution was made based on instantaneous measurements collected by the BLM. Pairs of measurements from the east and west ends of the canyon made within three days of each other were available for each month of the year, except September, between 1981 and 1988. These data are presented in Appendix D. During the months of December, January, February and March, when evapotranspiration was at a minimum, the flows at the west end of the canyon averaged 7.1 cubic feet per second higher than those at the east end[1]. This increase in flow from east to west is attributed to groundwater entering the creek through springs and tributaries.

[1] Streamflow measurements made by JEF personnel during July 1999 indicate that the discharge at the west end of the canyon is only 1.5 to 1.9 cfs higher than discharge at the east end of the canyon.

Groundwater Use

Well inventory

More than 350 wells are present in the Aravaipa valley. Figure 4-5 shows a map of wells located within the study area of this report. Most of the wells in the Aravaipa valley are located in the recent alluvium in Aravaipa Creek. These wells can have high productivities, in some cases a thousand gallons per minute. These wells are primarily used for irrigation with lesser amounts used for stock watering and domestic use.

Water Rights

Water is available from the creek through water rights. In the reach upstream from the canyon, there are water rights totaling 2,579.31 acre-feet/year identified as coming from Aravaipa Creek. Of this, 2,291.81 acre-feet/year belong to The Nature Conservancy, the Defenders of Wildlife and the Arizona State Land Department with the remaining 287.5 acre-feet/year belonging to private individuals or businesses. Additional water rights claim water in tributaries to Aravaipa Creek. Upstream from the canyon, water rights totaling 2,492.04 acre-feet/year were identified on tributaries to Aravaipa Creek. Of this, 2,296.61 acre-feet/year belong to private individuals or businesses and 195.43 acre-feet/year belong to the Arizona State Land Department, the BLM and The Nature Conservancy.

Impacts of Groundwater Use on Creek Flow

The total annual quantity of water available for use through water rights upstream of Aravaipa Canyon is nearly 5,100 acre-feet/year of which approximately 2,600 acre-feet/year belong to private individuals and are likely to be used for irrigation. These water rights are exercised primarily through pumping of wells in the recent channel fill alluvium and diversions from the creek. Owners of these wells have filed surface water rights to protect their rights to pump wells that may impact appropriable surface water in Aravaipa Creek or its tributaries. It is assumed that The Nature Conservancy, the Defenders of Wildlife, the BLM and the Arizona State Land Department do not consumptively use a significant amount of their water rights as they are largely for instream flow.

Of the 2,600 acre-feet/year potentially used for irrigation, it is unknown how much of that is actually used each year. The irrigation use takes place primarily in the Younger Alluvium along Aravaipa Creek. The irrigation returns, that water not consumptively used by evapotranspiration, would remain in the Younger Alluvium and contribute to the creek subflow. Thus, it is consumptive use that is of primary interest in evaluating the impacts of upstream irrigation of base flows in Aravaipa Creek. It is unknown how much water is pumped from wells located in Aravaipa Creek that is not associated with a registered water right.

Based on interviews with valley residents, Adar (1984) estimated that annual pumpage in Aravaipa Creek between Haby Spring and the canyon was approximately 1,700 acre-feet from the Younger Alluvium. He estimated pumpage for the entire creek above the canyon at 2,400 acre-ft/year which is reasonably close to the water rights of 2,600 acre-ft/year. These estimates represent total pumpage, not consumptive use.

Groundwater usage upstream of Aravaipa Canyon can be ascertained by estimating the total irrigated acreage and multiplying by the estimated consumptive use per acre. Acreages of fields were measured from a series of air photos taken in 1978 and 1984. The scale on the photos was 1:24,000. The total acreage of fields between Haby Springs and the east end of the canyon was approximately 270 acres. This total includes all areas that have been irrigated historically, not necessarily those fields currently in production. Consumptive use for alfalfa, a high water use crop, is approximately 3.4 acre-feet per acre per year. This estimate was taken from the Third Management Plan, 2000-2010, Santa Cruz Active Management Area (Arizona Department of Water Resources, 1999). The Santa Cruz Active Management Area was used because elevations and climate there are generally similar to those in the Aravaipa valley. Consumptive use on the 270 acres of irrigated fields between Haby Spring and the canyon, assuming all available area is planted with alfalfa, is estimated to be approximately 900 acre-feet/year.

During the months when plants are actively growing, they use substantial amounts of water and reduce the creek flow. An estimate was made for the amount of evapotranspiration occurring between Aravaipa Spring and the west end of the canyon. This estimate was made using instantaneous flow measurements taken by the BLM at the locations of the east and west stream gages (Appendix D). Pairs of measurements from the east and west ends of the canyon made within three days of each other were available for each month of the year, except September, between 1981 and 1988. These measurements showed the differences in flow rates between the east and west ends of the canyon. As discussed previously, the flows at the west end of the canyon averaged 7.1 cubic feet per second higher than those at the east end during December through March, primarily as a result of groundwater contributions within the canyon. During the months of June, July, August, and October, however, the flows at the west end averaged 0.5 cubic feet per second lower than those at the east end. No data were available for September. The change of 7.6 cubic feet between the winter and summer flow differences between the two gages is attributed to evapotranspiration. Evapotranspiration losses through the canyon during June through October, therefore, are estimated to be 2,300 acre-feet/year. The riparian growth extends approximately 5.9 miles upstream from the east gage and results in an estimated 1,500 acre-feet/year of additional evapotranspiration for a total of about 3,800 acre-feet/year.

An overall estimation of the impacts of groundwater use can be made from water level measurements taken from wells over time. Figure 4-6 shows water levels in shallow wells over a period of years from 1949 to 1998. Shallow wells are those less than 150 feet deep. Shallow wells for which sufficient data were available are all located along Aravaipa Creek upstream of the canyon. Although changes in the water levels are modest, most of the wells demonstrate a slight increase in groundwater levels between

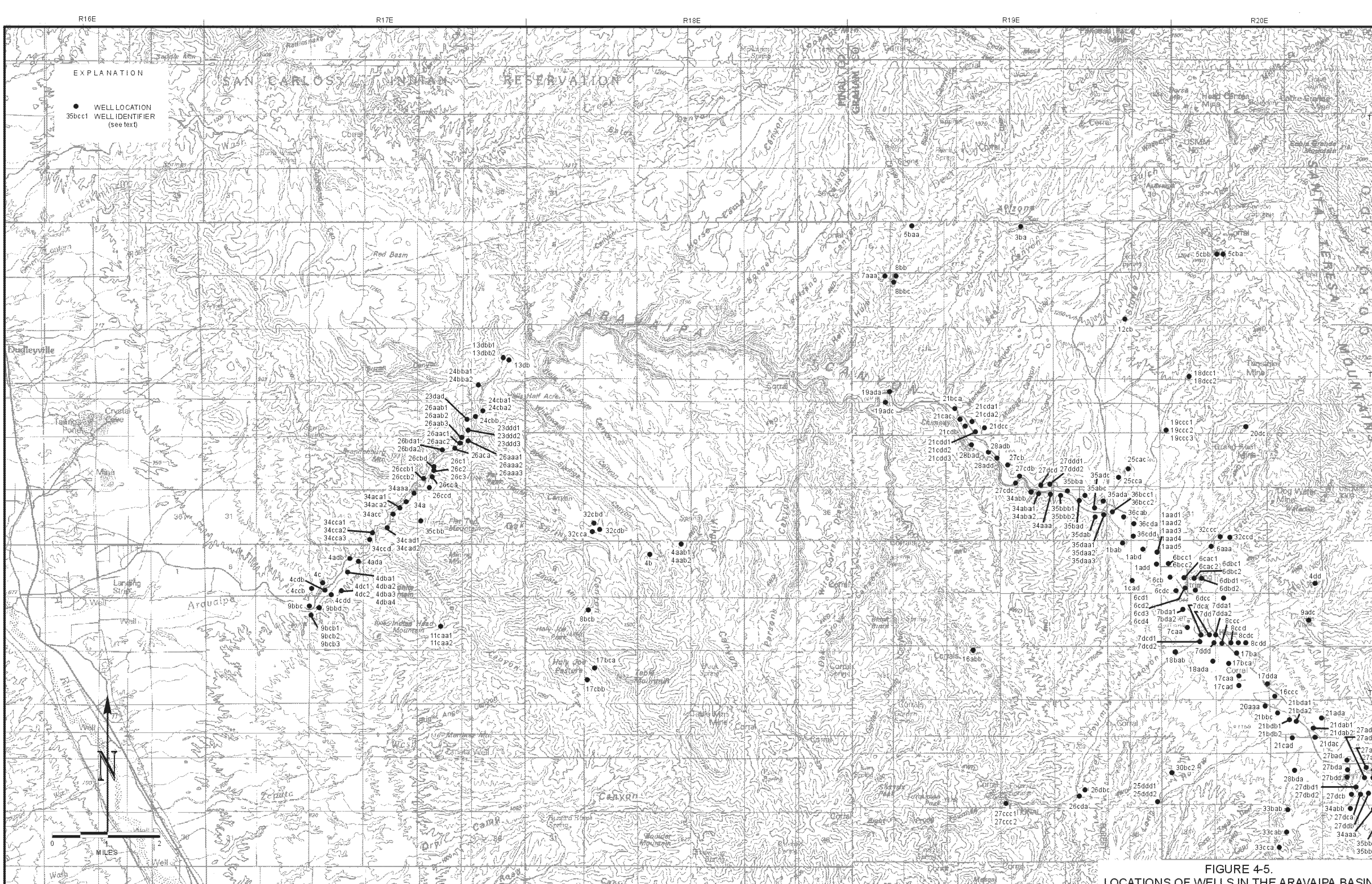
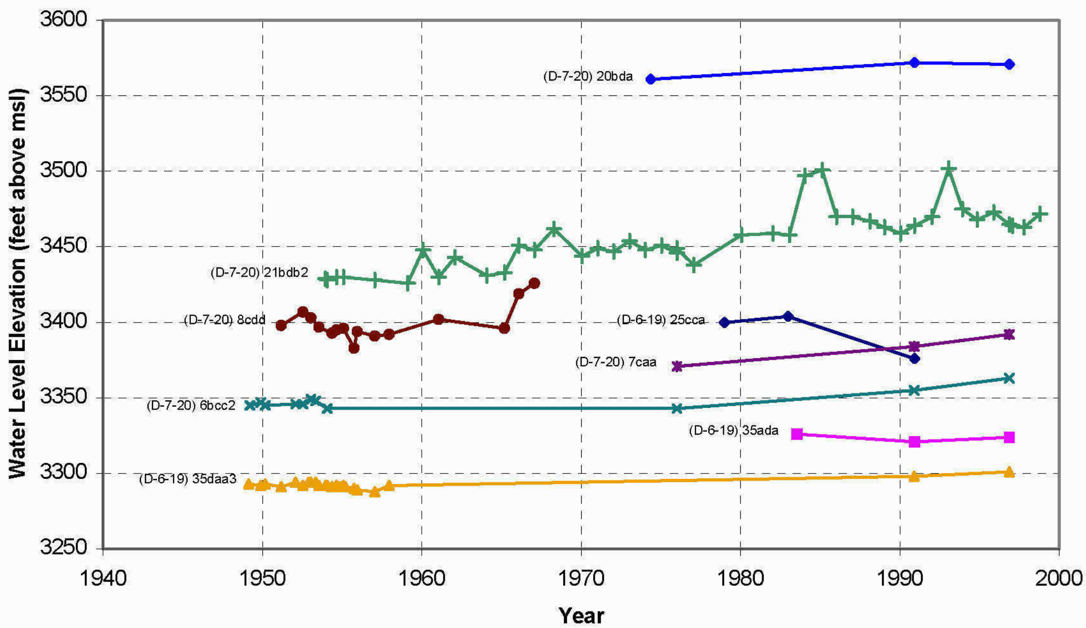


FIGURE 4-5.
LOCATIONS OF WELLS IN THE ARAVAIPA BASIN

1950 and 1998. The water level in well (D-7-20)21bdb2 remained relatively constant between 1967 and 1977, the driest period according to the surface hydrology analysis (Chapter 3). The water levels rise after 1978, which corresponds to increased flows recorded by the USGS gage (Chapter 3). The two exceptions to this trend are wells (D-6-19)25cca, which shows a decline, and (D-6-19)35ada, which remains nearly constant. These wells are located near the point where the creek becomes perennial and the water levels may be constrained by the ground surface.

Figure 4-6. Aravaipa Creek.
Water Level Elevations in Shallow Wells



Although there were limited data for deep wells, a few locations have pairs of groundwater level measurements separated by six or more years that may provide an indication of long-term water level changes. These measurements are presented in Table 4-1. Two of the wells showed rises in water levels of 9 and 12 feet and the third well showed a decline of 7 feet.

Table 4-1. Aravaipa Creek.
Groundwater Level Variation with Time in Deep (>150 feet) Wells.

Well ID	Year	Water Level Elevation (feet above msl)	Year	Water Level Elevation (feet above msl)
(D-7-20) 7dcd2	1990	3388	1996	3397
(D-7-20) 21bda1	1960	3479	1983	3491
(D-7-20) 27ddb	1990	3620	1996	3613

In summary, water levels in wells in the Aravaipa Valley may have shown a slight rise over time, indicating that past and current groundwater use are less than annual recharge.

In addition, due to the relatively small changes in water levels, the basin may be considered to be in a steady-state condition.

Assessment and Analysis

Currently, the basin appears to be in a nearly steady-state condition. Base flows in the creek appear to be relatively constant or increasing over the past two decades. Water levels in wells also appear to be steady or rising slightly during this period. Thus, current water use in the upper portion of the Aravaipa Valley does not appear to exceed groundwater recharge. However, given the scale of the increase in surface flows since 1978, the effects of increased long-term groundwater use could be masked by the relatively wetter climate during this period.

The potential to change the existing conditions of groundwater usage in the near future is limited. Increased irrigation poses a potential threat to maintaining the creek flows. Crop irrigation uses large amounts of water. This water use occurs in the summer months when the creek flows are already at their lowest. Furthermore, any increased irrigation is likely to be supplied by wells pumping subflow in the Younger Alluvium and pumping from such wells would therefore have a direct impact on creek flows.

It appears, however, that irrigation in Aravaipa Valley may have decreased over the years. Floods in 1978 and 1983 destroyed some acreage that had been farmed as well as some of the irrigation ditches and headgates. Although some of these facilities have been rebuilt, the level of irrigation may not be as high now as it was earlier in the century.

Housing development and increased domestic use of water pose another potential threat to the flow in Aravaipa Creek. Most of the private land in the valley is located near the creek and the increased water use would most likely be supplied by wells in the Younger Alluvium. The immediate danger of this threat appears relatively low, however. It is believed that the population of the valley has declined with time based on the general overall decline in ranching and mining in the area. In addition, most of the land in the valley is State land and is not open for immediate development (Figure 4-7).

Large-scale development of the water resources in the basin for industries outside the basin is another possible threat. Currently, there appear to be no major wells pumping significant quantities of water from the Older Alluvium. Most of the Older Alluvium wells are low yield stock wells. It is uncertain if an intensive water exploration program could develop sufficient water to be of interest to outside parties. Because most of the valley is State land (Figure 4-7), any major water developments would be delayed subject to negotiations with the state. Furthermore, because of the instream water rights held by the BLM and others, any new water developments would be required to demonstrate that they would not affect those prior water rights.

The creek flows are buffered somewhat from upstream developments in that significant amounts of water are supplied to the creek from sources that are relatively protected. Stowe Gulch is believed to supply nearly half the water in Aravaipa Spring and is

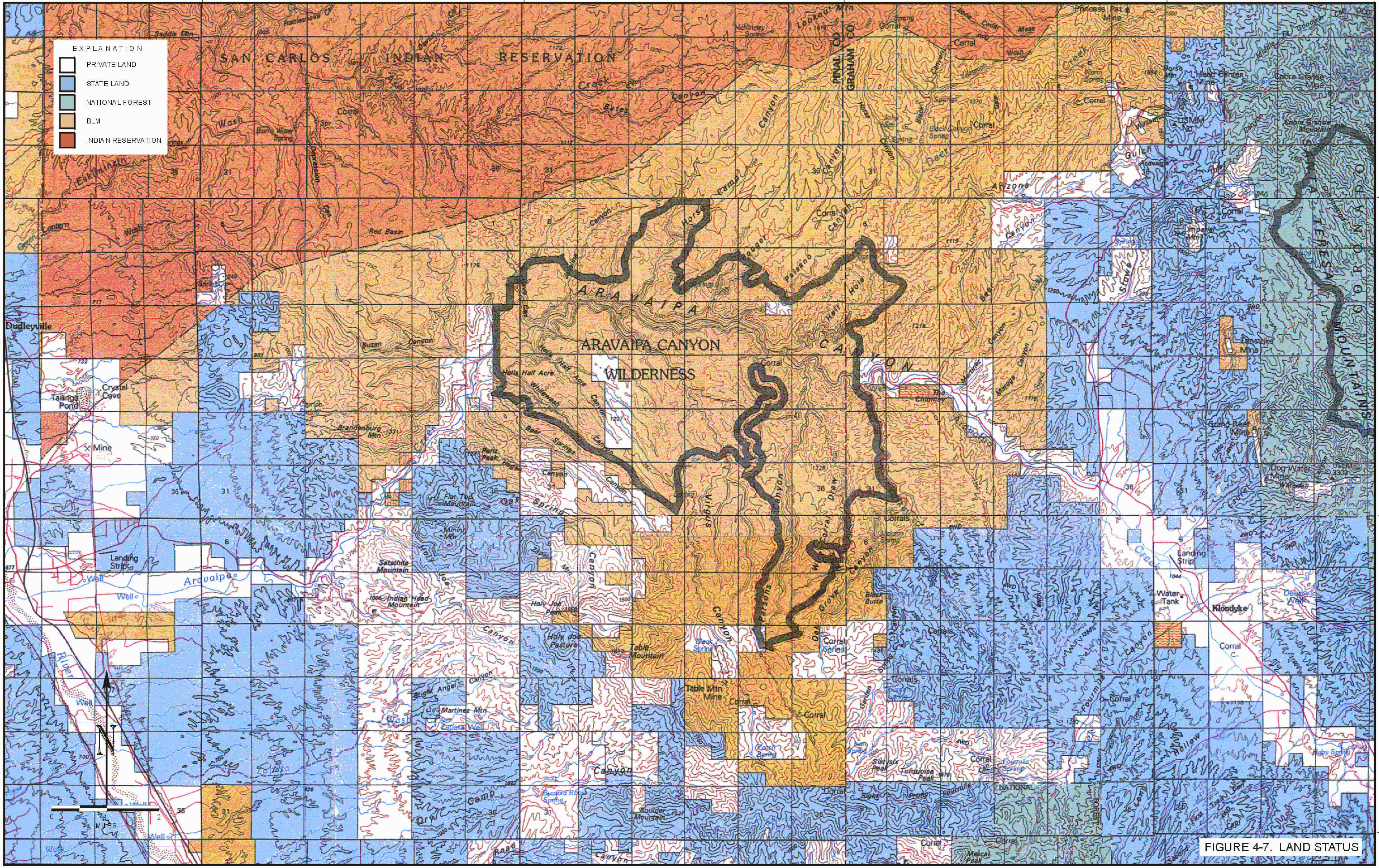


FIGURE 4-7. LAND STATUS

downstream of the majority of the basin with little private land. Turkey Creek, on BLM land, and Aravaipa Canyon itself supply significant amounts of water to the creek and are unlikely to experience major development.

Natural climatic variations, especially in precipitation, pose an additional threat to the creek. As was shown in Chapter 3, base flows in the creek are greatly dependant on precipitation. A series of dry years will greatly reduce flow in the creek. Certainly such events have happened in the past without permanent damage to the system. The real problems would occur if such events were compounded with substantial development of the water resources upstream.

Chapter 5:
Geomorphology

Introduction

The geomorphic analysis consisted of consideration of field observations and measurements, historical data, and comparison of ground and aerial repeat photography.

Field Assessment

JE Fuller, Inc. (JEF), personnel made two trips through Aravaipa Canyon. The first of these trips was conducted on July 2-5, 1999, and the second on November 19-22, 1999. The purpose of these trips was to evaluate the geomorphic characteristics of Aravaipa Creek within the Aravaipa Canyon Wilderness Area in both a qualitative and quantitative manner. During the July trip, gaging was also performed at three locations along the creek at two times, evening and morning, to determine if there was any diurnal variation in flow. Gaging was conducted above and below Deer Creek during the November field trip to determine any contributions that Deer Creek makes to the flow of Aravaipa Creek.

General. Based on visual inspection, the streambed generally consisted of clasts less than one inch (2.54 cm) in diameter. Some of the more coarse riffles are made of coarse pebbles[1] approximately 2 inches (5.08 cm) in diameter. Sidebars are for the most part made up of gravel-sized[1] particles. Boulders[1] are common in rapids, but these do not occur often. The occurrence of rapids is more frequent downstream of Virgus Canyon. Riffles are for the most part well sorted, as smaller sand-sized particles are concentrated in mid-channel bars. The mid-channel bars are moving downstream, but their forms were persistent at the discharges observed. The gravel sidebars were much more stable than the mid-channel bars in the flows observed. The largest particle size observed moving by saltation was approximately 0.025 inches (0.6 mm) in diameter.

Although not a true indicator of suspended load, visual observation showed that the water was clear and not heavily laden with sediment. There were clouds of muddier water downstream of sand bars[1], but visible concentrations of these suspended sediments were dispersed a few tens of feet downstream of the point of origin.

In several locations bedrock outcrops confined the stream position. Bedrock banks generally manifested themselves as vertical cliffs. Other typical banks included the vegetated overbank consisting of finer alluvium that began at the water's edge or the gravel bar. Less common was the sand bar. All but the highest terraces showed evidence of inundation by large flows. In most cases the evidence of high flows consisted of bent vegetation. Occasionally there was a perched channel on the overbank. There were very few large trees along the near bank. This would seem to indicate that the majority of the canyon floor is susceptible to periodic erosion. Large trees on the higher overbanks near

[1] Refer to Grain Size Classification Table in Appendix E.

Turkey Creek had exposed roots approximately two feet (0.6 m) above the current ground level, indicating a net loss in valley floor elevation.

Observations at Index Cross Sections. Three index cross sections were established within the study area in July, as shown on Figure 5-1.

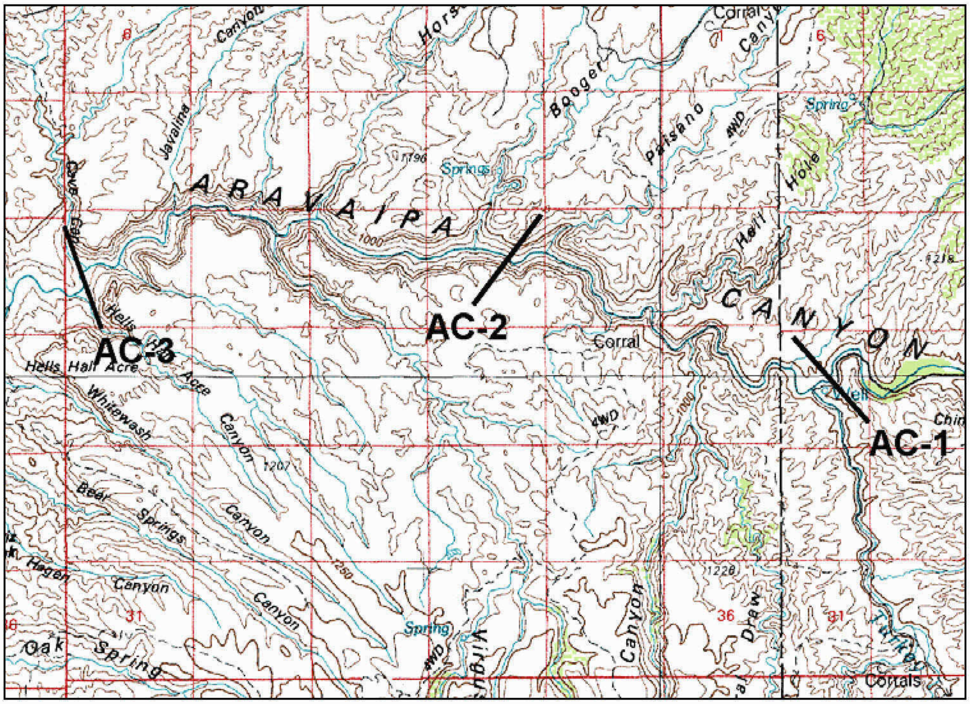


Figure 5-1. Map of Aravaipa Canyon indicating index cross section locations (AC-1, AC-2, & AC-3).

AC-1 (Upstream of Turkey Creek). A vertical cliff of welded volcanic tuff makes up the right bank at cross section AC-1 (Figure 5-2). The left bank consists of a floodplain approximately six feet in width and a terrace approximately four feet above the floodplain. Moderately cohesive silts[1] to fine sands[1] make up the bank material. The most probable means of bank failure is grain-by-grain erosion following vegetation removal during high discharges. In July, there were no indicators of active erosion such as exposed roots or cut banks along the stream at this location. In November, a low cut bank was evident on the left bank following the monsoon season events[2].

The flow characteristics observed in July were as follows: width was 21.5 feet (6.6 m), average depth was approximately 0.5 feet (0.15 m), and surface velocity was 3.9 feet per second (1.2 m/s). The cross section is in a very long riffle located in a generally straight section of the creek. Using the Wolman (1954) pebble count method, the average size of bed material was determined to be 0.54 inches (1.37 cm); the D50[3] size was determined

[1] Refer to Grain Size Classification Table in Appendix E.
[2] Maximum instantaneous discharge at USGS gage was 4,150 cfs (Table 5-5).
[3] The D50 size is the diameter at which 50% of the bed particles are smaller and 50% are larger.

to be 0.36 inches (0.91 cm). The bed particles were subangular and planar in shape. The bed was armored to the July discharge.

There is a noticeable difference between vegetation on the floodplain and terrace at cross section AC-1. The floodplain is covered by a very dense growth of young willow and alder. Vegetation on the terrace includes older and larger (40-50 feet tall) sycamores (*Platanus)*, cottonwoods (*Populus)*, and alders (*Alnus)*. Watercress (*Nasturtium)* and other small leafy plants lined the channel margins.

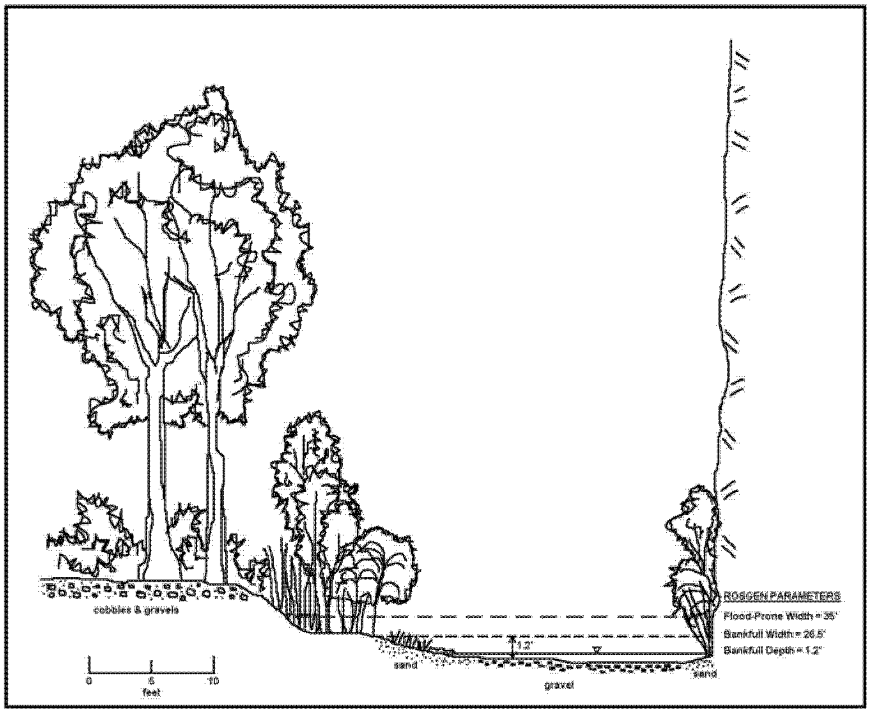


Figure 5-2. Sketch of cross section AC-1 looking downstream, July 1999.

AC-2 (Downstream of Booger Canyon). The left bank of cross section AC-2 (Figure 5-3) consisted of a narrow gravel bar behind which rose a vertical cliff of gray volcanics with large vesicles (1-4 inches). Lichens were visible on the cliff face above 10 feet (3 m). The lichens could be an indicator of historical high flow levels. The right bank consisted of a sand and gravel bar approximately 40 feet (12.2 m) in width. The bar had several elevations, the highest of which can be considered floodplain based on upstream and downstream vegetation at the same elevation. Beyond the bar there is a terrace approximately three feet higher in elevation. There were overbank channel remnants on this higher surface. The bank material was non-cohesive gravelly sand. The most probable means of bank failure is grain-by-grain erosion during high discharges. In July, there were no indicators of active erosion at the cross section. However, 200 feet (61 m) downstream there was an undercut root mat. There were also additional exposed roots in the local area but not at the cross section. By November, the gravel bar that made up a portion of the left bank had been almost completely obliterated.

The flow characteristics observed in July were as follows: width was 14.4 feet (4.4 m), average depth was approximately 0.75 feet (0.23 m), and surface velocity was 3.5 feet per second (1.1 m/s). The cross section is located at a meander in a sinuous reach of Aravaipa Creek. The creek upstream and downstream of the cross section is essentially one long riffle. There are no real pools except for occasional scour holes. Using the Wolman (1954) pebble count method, the average size of bed material was determined to be 1.59 inches (4.04 cm); the D50 size was determined to be 0.60 inches (1.52 cm). The bed particles were round to sub-rounded and planar in shape.

The sand and gravel bar lacks any significant vegetation. Vegetation downstream of the cross section at the same elevation as the gravel bar consists of dense young willows and occasional young cottonwoods. Vegetation on the terrace includes older and larger cottonwoods approximately 30 feet (9 m) tall as well as a dense understory of willows and tamarisk. Low grasses and other leafy plants lined the channel margins in July but were absent in November.

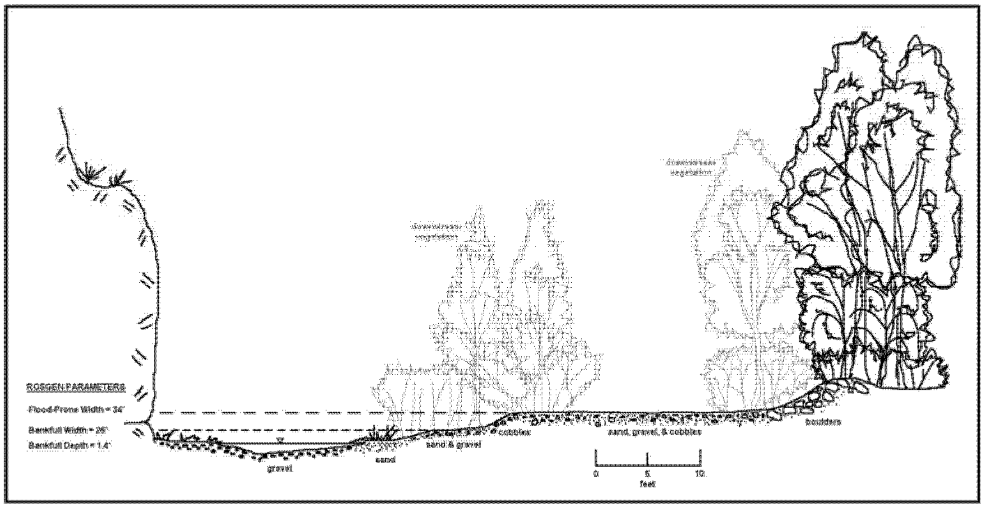


Figure 5-3. Sketch of cross section AC-2 looking downstream, July 1999.

AC-3 (Downstream of Cave Canyon). A vertical cliff of very hard, highly jointed red metamorphic rock makes up the left bank of cross section AC-3 (Figure 5-4). Calcium carbonate stains were observed on the cliff at 1.5 and 4.0 feet (0.5 and 1.2 m) above the water surface that could be indicators of former long-term surface or subsurface elevations. A series of terraces makes up the right bank. The right bank consists of non-cohesive gravels and cobbles. The most probable means of bank failure is grain-by-grain erosion during high discharges. Bent vegetation that had since re-sprouted was located on the bank indicating that flows at one time were high and most likely did erosive work.

The flow characteristics observed in July were as follows: width was 12.5 feet (3.8 m), average depth was approximately 1.0 feet (0.3 m), and surface velocity was 2.3 feet per second (0.7 m/s). The cross section is located at a meander in a sinuous reach of Aravaipa Creek. The cross section is in a canyon riffle, with several boulders forming a small rapid just upstream. Using the Wolman (1954) pebble count method, the average size of bed material was determined to be 0.37 inches (0.94 cm); the D50 size was determined to be 0.24 inches (0.61 cm). The bed particles were round and planar in shape. The bed was armored to observed discharges.

Grasses, watercress, and other leafy aquatic plants lined the channel margin on the right bank in July, but were absent in November. Dense young willows lined the slope break between the bank cobbles and the first terrace. Tamarisks (*Tamarix)* were found on the intermediate terraces. Vegetation on the highest terraces included cottonwoods and mesquites (*Prosopis)*.

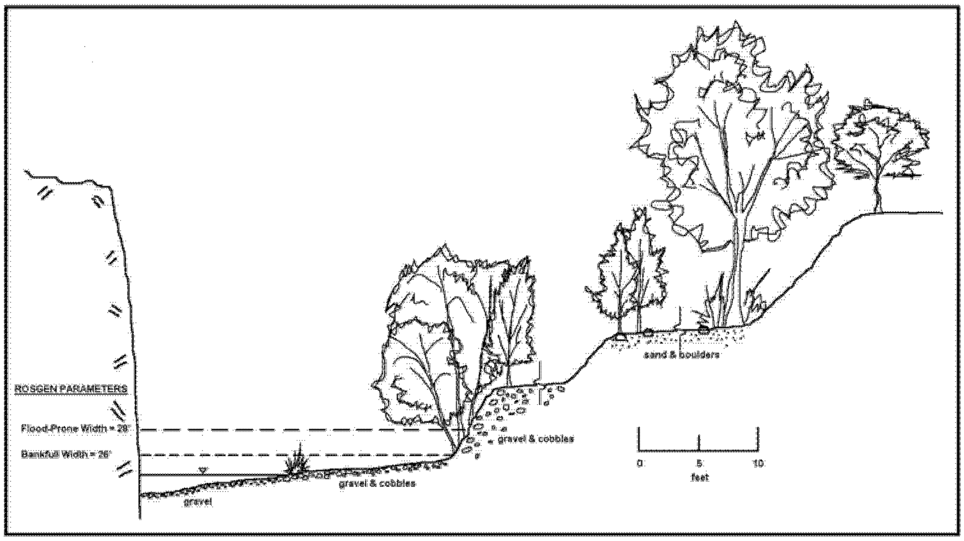


Figure 5-4. Sketch of cross section AC-3 looking downstream, July 1999.

Conclusions Based on Field Observations. Narrow confines of the canyon prevent water from spreading out as would happen on a wider floodplain. As width reaches a maximum with increasing discharge, depth and velocity must increase. An increased velocity will increase the capacity and competence of the flow, allowing more and larger particles to be transported. With larger discharges the unconsolidated overbanks will be more prone to erosion. The exposed tree roots (two feet above the ground surface) observed near Turkey Creek would seem to support the conclusion that the overbanks are highly susceptible to erosion, especially in the narrow confines of the canyon. Thus most of the riparian habitat, excluding only the highest terraces, is prone to reshaping by large floods. The sediment removed from the overbanks could be deposited downstream on the overbanks, floodplain, or on the streambed.

During the field trip of November 18-21, 1999, particles of less than 0.025 inches (0.6 mm) were observed in saltation. Flows of approximately 23 cfs (0.65 m^3/sec) observed during the November trip were sufficient to transport sand-sized particles along the bed. The mid-channel bars and ribbons in which the particles were concentrated were mobile, but their form was persistent at the flows observed. Flows of this magnitude are apparently sufficient to maintain a fairly healthy bed environment, providing areas of sand and armored bed for life cycle needs of various species.

Field observations suggest the following model of geomorphic behavior on Aravaipa Creek. Large floods such as the devastating 1983 flood strip vegetation from the banks and overbanks. The violent removal of vegetation disturbs the overbank sediments and leaves them susceptible to erosion. The resulting erosion lowers the floodplain elevation. Vegetation gradually recolonizes the floodplain after the flood. More frequent smaller floods do not cause damage to the riparian vegetation. Velocities on the overbank are thus slowed in the denser vegetation, allowing for sediments to be deposited on the floodplain. In this manner the floodplain is gradually rebuilt until the next destructive flood.

Rosgen Classification

The Rosgen (1996) system of stream classification attempts to place reaches of streams in categories that reflect the physical characteristics of the particular reach and at a particular time. The Rosgen classification system has been widely used and applied to perennial streams in order to better understand their current state, and to some extent their future stability. The classification is based on the bankfull width and other measured stream characteristics. The classifications alone provide some information about the stream that may be useful for planners and resource managers.

Level I Rosgen Classification. Aravaipa Creek is located within a Type IV Valley according to Rosgen's classification. Rosgen defines Type IV valleys as "classic meandering, entrenched or deeply incised, and confined landforms directly observed as canyons and gorges with gentle elevation relief and valley-floor gradients often less than 2%." Rosgen type F streams are most often found in these environments, although type C streams are often observed when the valley floor is wide enough to accommodate both the channel and floodplain (Rosgen 1996).

Level II Rosgen Classification. Data for Level II Rosgen classifications are derived from field observations and measurements taken by JEF personnel during July 2-4, 1999. Additional data were measured from USGS 7.5" topographic maps.

The Rosgen classification scheme relies on several geomorphic characteristics to classify the stream. These include the following:

- Entrenchment Ratio
- Width:Depth Ratio
- Sinuosity
- Channel Slope
- Bed Material Size

Entrenchment Ratio. The entrenchment ratio is a measure of the width of the water surface at twice bankfull stage relative to the bankfull width. Araviapa Creek presents unique problems when calculating the entrenchment ratio. One side of the creek is often adjacent to nearly vertical bedrock canyon walls while the opposite bank is a gently sloping alluvial surface. Thus when considering the entrenchment factor for the Rosgen classification scheme, it was determined to exclude the canyon wall bank and use only the alluvial bank side of the creek. If the nearest canyon walls are considered in the entrenchment, Araviapa Creek can be considered well-entrenched (Rosgen F Class). Within the valley alluvium only, the creek is only moderately entrenched (Rosgen B Class). See also representative cross section figure in Rosgen (1996) p. 5-22.

For example, at a stage of approximately 1.2 feet (0.4 m), the bankfull width at cross section AC-1 is approximately 27 feet (8.2 m), or 13.5 feet (4.1 m) to the centerline of the water surface. At a stage of 2.4 feet (0.7 m) the top width of the water from the alluvial bank to the centerline of the water surface would be approximately 21 feet (6.4 m). The ratio of 21 feet (6.4 m) to 13.5 feet (4.1 m) is 1.6. See Table 5-1 for entrenchment values of the three Aravaipa cross sections. Entrenchment ratios were measured directly during the July 1999 field visit

Width:Depth Ratio. The width:depth ratio is the ratio of the bankfull width to the mean depth. For example, the mean depth of the bankfull channel at cross section AC-1 is 1.2 feet (0.4 m). The bankfull width is 27 feet (8.2 m). These values result in a width:depth ratio of 22.5. Width:depth ratios for the Aravaipa Creek cross sections are presented in Table 5-1.

Sinuosity. Sinuosity is a measure of the curvature of the stream in plan view. The sinuosity is determined by the ratio of stream length to valley length. Measurements of the stream length and valley length were recorded off 7.5" USGS topographic maps for approximately a half-mile both upstream and downstream of the cross section. Valley length was determined by manually drawing a line midway between the contours representing the canyon walls and measuring the line's length. The topographic maps were deemed sufficient after comparison to 1993 aerial photographs showed that the course of Aravaipa Creek was generally the same. The sinuosity for Aravaipa Creek may be underestimated, however, because the USGS topographic maps may "smooth out" some of the smaller meanders. Sinuosity values for the Araviapa Creek cross sections are presented in Table 5-1.

Channel Slope. Slope values for Araviapa Creek are also measured off the USGS 7.5" topographic maps. The slope was measured from the first contour line *that crossed Aravaipa Creek* upstream of the cross section to the first contour *that crossed Aravaiap Creek* downstream. The resulting slope measurements are presented in Table 5-1.

Bed Material Size. Bed material size was sampled in the field using the Wolman (1954) pebble count method. The D50 particle size value was calculated from the collected data and used to classify the bed material size. The D50 particle size and classification for each cross section are presented in Table 5-1.

Table 5-1. Aravaiapa Creek. Rosgen Classification Parameters.				
		AC-1 (Turkey Creek)	**AC-2 (Booger Canyon)**	**AC-3 (Virgus Canyon)**
Entrenchment Ratio		1.6	1.5	1.1
Width/Depth Ratio		22.5	22.1	9
Sinuosity	Stream	1.075	1.067	1.072
	Canyon	1.5	1.1	1.2
Channel Slope		0.01 (1%)	0.007 (0.7%)	0.006 (0.6%)
Bed Material Size		Gravel (RB Bedrock)	Gravel (LB Bedrock)	Gravel (LB Bedrock)
Rosgen Class		B4c	B4c	F4

Rosgen Classification. Aravaipa Creek best fits either an F4 or B4c stream classification in the Rosgen scheme. The physical parameters of the F and B classifications are similar except for the entrenchment ratio. Rosgen (1996) defines B4 stream types as moderately entrenched channels, usually having gradients of between 2% and 4%. However, the subclass B4c allows for slopes lower than 2%. Channel materials are dominated by gravel with lesser amounts of boulders, cobbles, and sand. The B4c stream type is considered relatively stable and is not a high sediment supply stream channel. The F4 stream type is associated with deeply entrenched, structurally controlled, gentle gradient valleys and gorges. The F4 can also be associated with highly weathered bedrock involving a combination of river downcutting and uplift of valley walls. The channel material is dominated by gravel with some cobble and sand accumulations.

Aravaipa Creek presents what could be called a composite cross section. One bank at each of the cross sections is a steep canyon wall; the other bank is a more gently sloping alluvial fill bank. The classification of the stream is therefore biased towards the short reaches of the stream where flow is against the bedrock canyon walls. There are many sections of the creek that do not flow against bedrock, and are only moderately entrenched in the valley floor alluvium.

There are difficulties in the classification of Aravaipa Creek with the Rosgen system, specifically with the B4c classification. According to Rosgen, type B streams do not occur in Type IV valleys like Aravaipa Canyon. The measured sinuosities of the reaches also tend to be lower than what is accounted for in either the F or B Rosgen classifications. This may be due to the fact that sinuosities were measured from the USGS 7.5" topographic maps rather than in the field where smaller meanderings would be detectable. However, Moody and Odem (1999) found that Arizona streams generally exhibit less sinuosity than the Rosgen method accounts for in its classification scheme.

It is problematic that Aravaipa Creek does not fit precisely into any of Rosgen's classification categories, as it casts doubt on the subsequent predictions of stream behavior. Nevertheless, Rosgen's assertion that B4 streams are stable seems to be upheld by the July and November observations by JEF in which channel changes were minimal. Qualitative observations over the entire length of Aravaipa Creek in the canyon, when compared to Minckley's (1981) description of the creek bed, also suggest that the stream is reasonably stable over longer time periods. However, large floods such as the October

1983 and the January 1993 floods often interrupt the stability of Aravaipa Creek. These large floods have the ability to do significant amounts of geomorphic work, reshaping the bed and banks of the creek. Evidence for the changes that occurred on Aravaipa Creek can be found in aerial photos of Aravaipa Creek taken in 1984, after the October 1983 flood, and in ground photos taken shortly after the January 1993 flood. These photos are discussed and compared to more recent photos later in this chapter.

Aravaipa Creek appears to be relatively stable during periods of low to normal flows, which coincides with the stability implied by the Rosgen classification. Significant geomorphic change occurs during the infrequent, high flows. Thus, changes in Aravaipa Creek's morphology are dominated more by large floods than suggested by Rosgen. Therefore, although an adequate system for classifying the current state of Aravaipa Creek, the Rosgen system is not particularly useful for assessing historical channel change or predicting future response.

Historical Data

Hadley et al. (1991) prepared an ethnoecological survey report for Aravaipa Canyon that included investigations into the environmental change that occurred along Aravaipa Creek between 1870 and 1970. The report concluded that Aravaipa Creek changed little between 1920 and 1960, but the character of the creek changed much after 1960.

Between 1920 and 1960, intermittent farms and associated cattle grazing kept the understory clear of brush, producing an agricultural and pastoral pattern along the banks of the creek. The bed of Aravaipa Creek during this time was sandy with many pools. Residents recalled children walking for miles on the sandy creek bed. Pools were associated with the bordering large sycamores and were up to twenty feet deep (Hadley et al. 1991). It is hard to imagine where these pools would have been located based on observations of Aravaipa Creek's current state.

Aravaipa creek was often used as a route for people traveling from one end of the canyon to the other. Residents recalled east-end farmers driving wagons through the canyon en route to Winkelman. One 1925 trip in particular was recalled as presenting little difficulty. Travelers easily traversed steep drop offs in the canyon by building rock ramps (Hadley et al 1991).

Irrigators interviewed by Hadley et al. (1991) provided channel and bed descriptions for Aravaipa Creek between 1920 and 1960. According to these eyewitnesses, the bed of Aravaipa Creek during this time underwent constant minor change. Periodic floods sometimes deposited sediment on the bed, and at other times removed sediment and deposited it downstream, leading to little net change over the 40-year period. The banks remained relatively stable, possibly due to the practice of planting willow borders along the banks. A history of the flow regime that contributed to this relatively stable condition in Aravaipa Canyon was developed from oral and written accounts (Table 5-2).

Table 5-2. Aravaipa Creek. Event Chronology, 1919 – 1954. Reported by Hadley et al. (1991)	
Year	Event
1919	Flood
1922	Flood
1923	Flood in upper Aravaipa
1926	Flood on the San Pedro River and west-end Aravaipa
1926-30	Relatively wet years
1933-34	Drought
1935	Good rains followed by flood
1940	December flood
1946	September flood
1954	Summer (monsoon?) flood heard 20 minutes before it arrived

United States Geological Survey (USGS) records available for this period include mean daily records from May 1, 1931 to December 31, 1942. These data support the drought of 1933-34, the flood of 1935, and the flood of December 1940 listed above. Estimated peak discharges for 1919, 1920, and 1921 are also available from USGS. The USGS estimated a peak discharge of 20,000 cfs (566 m^3/sec) during the flood of August 2, 1919 (Table 5-3).

Table 5-3. Aravaipa Creek. Peak Discharges, 1919-1942.	
Date	Instantaneous Peak Discharge (cfs)
8/2/1919	20,000 (est.)
1/5/1920	7,400 (est.)
7/31/1921	12,000 (est.)
8/5/1935	10,200
1940	9,600

Although residents reported very little change in the character of Aravaipa Creek, changes adjacent to the creek and floodplain were occurring that probably had significant impacts on the creek during the 1960s. Between 1920 and 1960 agricultural development increased on the east end of the canyon below the emergence point of the perennial reach of Aravaipa Creek. Farmers removed substantial underbrush and kept the land cleared. Many large cottonwoods and sycamores were also cut down. This decrease in vegetation may have increased the probability that runoff would remove sediment from the floodplain, contributing to the maintenance of the sandy, easily traversed bed. The loss of large cottonwoods and sycamores and their associated root networks may have also primed the banks and floodplains of Aravaipa Creek for extensive erosion and degradation. To mitigate losses of the larger trees many farmers lined the banks with willows, a practice that may have begun prior to the 1900s. The potential for erosion was increased in the late 1940s and 1950s, however. Human impacts on Aravaipa Creek accelerated due to the introduction of bulldozer technology. Residents straightened the channel and removed more of the large trees that lined the banks. Straightened channels allowed for faster water velocities. Combined with decreased bank stability due to the lack of bank-lining vegetation disturbed by the bulldozers, the stage was set for increased erosion and downcutting.

The 1960s saw great change in the geomorphic character of Aravaipa Creek. The decade began with a large flood in 1963 (Hadley et al. 1991). Prior to 1963, residents claim that the irrigation ditches and fields along Aravaipa Creek had never washed out, nor had the channel deepened. Although previous floods had caused damage to houses along the creek and drowned some cattle, none had the drastic geomorphic effects associated with the flood of 1963. Through interviews, Hadley et al. (1991) determined that the flood of 1963 was comparable to the floods of 1978 and 1983. No records are available for the 1963 discharge. For comparison, the USGS reported the instantaneous peak discharge for the 1978 flood as 16,200 cfs (459 m^3/sec) on December 18, 1978, and the instantaneous peak discharge for the 1983 flood as 70,800 cfs (2,005 m^3/sec) on October 2, 1983. In addition to the large flood of 1963, several flood events were recorded by the USGS gage in the late 1960s and early 1970s, with several ranking in the top ten events on record (Table 5-4).

Table 5-4. Aravaipa Creek.
USGS Recorded Events, Late 1960s – Early 1970s.

Event	Peak Instantaneous Discharge		Peak Mean Daily Discharge	
	cfs	Date	cfs	Date
December 1967	15,300	12/17/67	2,700	12/20/67
March 1970	5,560	3/3/70	1,020	3/3/70
October 1972	8,200	10/19/72	3,740	10/19/72
February-April 1973	N/A	N/A	890	2/22/73

In May or June 1964 Dr. W.L. Minckley reportedly drove the entire length of Aravaipa Canyon in a 1955 Chevrolet automobile without having to build rock ramps. Several years later Mr. Rodney Engard recreated Dr. Minckley's trip with a four-wheel drive vehicle (Hadley et al. 1991). The flood of 1963 apparently reworked the channel to a smoother condition. In addition to the smoothing of the channel bed, the creek bed cut down and the floodplain widened during the 1960s. By the early 1970s, the extent of downcutting and entrenchment had become apparent to life-long residents. Residents recalled that prior to 1970, Aravaipa Creek ran deep water much less often. An increase in gravel deposits and the disappearance of deep holes were also noticed.

The distribution and type of riparian vegetation also changed during the 1960s. The amount of acreage in active cultivation along Aravaipa Creek decreased during the 1960s. Populations of invader species such as cockleburs (*Xanthium)*, salt cedars *(Tamarix)*, and "water maples" that farmers had previously cut down increased (Hadley et al. 1991).

In 1976, Minckley measured the physical characteristics of a portion of Aravaipa Creek. The measured reach began 3.0 km upstream of the western boundary of the Wilderness Area and ended 3.0 km downstream of Wood's Ranch (Figure 5-5). At that time riffles and rapids dominated the examined reach of Aravaipa Creek. Pools made up 12 % of the length. Riffles made up 79%, and rapids made up 9%. In the canyon 73% of the channel length was measured as a single channel. Downstream of the canyon, the channel was nearly evenly split between a single channel (54%) and a braided pattern (46%)

(Minckley 1981). Qualitative observations by JEF personnel in 1999 found that Aravaipa Creek exhibited essentially the same physical characteristics noted by Minckley; that is, the creek was for the most part a single channel dominated by riffles. Despite the destructive floods of October 1983 and January 1993 and a move to a wetter period with larger flow volumes, Aravaipa Creek has apparently maintained a fairly consistent character since the major changes of the 1960s.

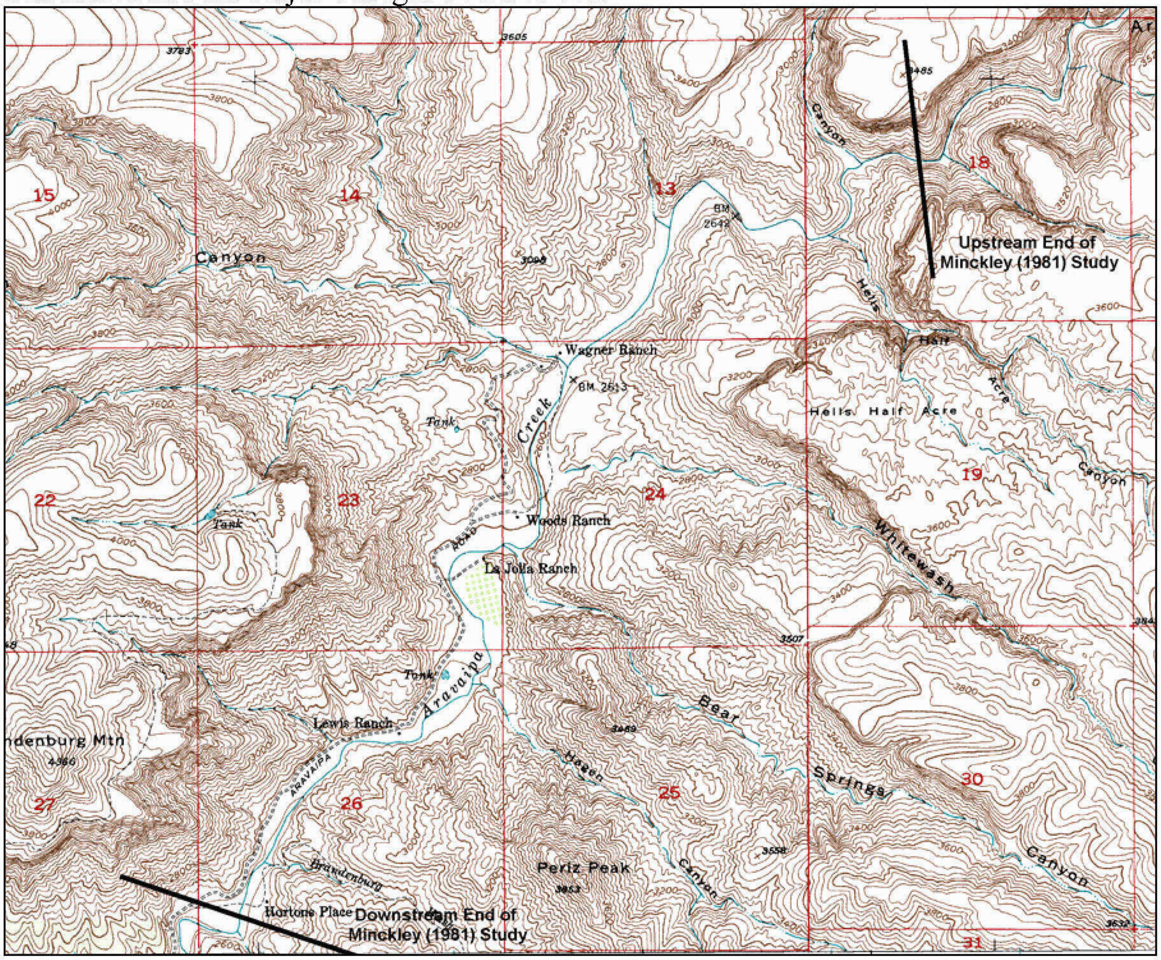


Figure 5-5. Map showing upstream and downstream limits of Minckley's (1981) survey.

The cycle of sediment distribution in Aravaipa Creek was qualitatively observed to be similar to other streams (Minckley 1981). Scouring high flows deplete the fine sediments except in the low gradient reaches. Continuous low flows move the remaining fine sediments downstream into the steeper canyon reaches. The fine sediments newly deposited in the steeper gradient reaches are subsequently removed by the next high flow. After a flood the larger disturbed sediments on the channel bottom continue to move downstream. This action leads to sorting and compaction of sediments of similar size, and eventual armoring of the streambed. The first large flood of the late 1970s (1978 rather than 1977 as suggested by Hadley et al. (1991)) washed much of the sediment out of the creek and deposited it on fields by the San Pedro River.

Ground Photograph Interpretation

Changes from July 1999 to November 1999

JEF personnel conducted two field reconnaissance trips through Aravaipa Canyon. The first occurred on July 2-5, 1999; the second occurred November 19-21, 1999. JEF personnel established the three index cross sections described above. Photographic documentation was produced for each cross section during the July field trip. During the November field trip, JEF personnel took photos recreating the views from the July trip. The same views from approximately four months apart can be used to qualitatively evaluate the changes that occur in Aravaipa Creek over a short time period. Combined with flow data from the downstream USGS gage at Mammoth, we can make reasonable estimates of the changes expected from a particular discharge.

The USGS gage downstream of Aravaipa Canyon recorded seven periods of above average flow (37.2 cfs, 1.1 m^3/sec). The largest discharge occurred on July 28, and elevated flows continued until July 31. Higher than average mean daily and instantaneous peak discharges are listed by date in Table 5-5.

Table 5-5. Aravaipa Creek.
High Flows, July – November, 1999.

Date	Mean Daily Discharge (cfs)	Instantaneous Peak Discharge (cfs)	Date	Mean Daily Discharge (cfs)	Instantaneous Peak Discharge (cfs)
7/15/99	157	1080	7/28/99	840	4150
7/16/99	54	95	7/29/99	120	185
7/19/99	48	115	7/30/99	60	N/A
7/22/99	99	390	7/31/99	40	N/A
7/23/99	69	152	8/10/99	50	133
7/24/99	55	127	8/28/99	430	1900
7/25/99	40	N/A	8/29/99	129	1190
			8/30/99	119	1430
			9/1/99	116	647

Cross Section AC-1. Three pairs of photos best illustrate the changes that occurred at cross section AC-1 just upstream of Turkey Creek (Figures 5-1). The first pair (Figures 5-6a and 5-6b) looks upstream toward the BLM gage (not visible in photographs). The island near the left bank (photo right) appears to have moved downstream since July and has been split by flow. Some of the vegetation in the photo background has changed slightly. Several trees visible in the July photo (Figure 5-6a) are not present in the November photo (Figure 5-6b). Although the trees have lost most of their foliage, which can be deceiving, close examination reveals that several trunks were removed between July and November. Several discharge events between July and November may have contributed to the removal of the bar material and removal of the trees and other vegetation. The single 4,150 cfs (118 m^3/sec) instantaneous event of July 28, 1999, may have removed the gravel bar and the covering vegetation. Alternately, the combination of the larger flood with several smaller floods may have cumulatively affected the bar, resulting in the observed changes.

Figure 5-6a. Looking upstream at cross section AC-1. Photo date: July 2, 1999.

Figure 5-6b. Looking upstream at cross section AC-1. Photo date: November 19, 1999.

Looking downstream in figures 5-7a and 5-7b, the most obvious difference is that the right bank (photo right) bar and vegetation was completely eliminated due to the flows that occurred between July and November. An additional change to the streambed is the new mid-channel island (bar) in the center of the channel downstream.

Figure 5-7a. Looking downstream at cross section AC-1. Photo date: July 2, 1999.

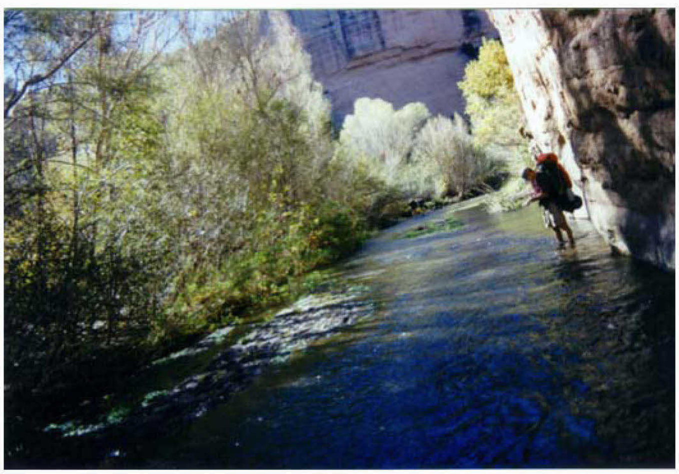


Figure 5-7b. Looking downstream at cross section AC-1. Photo date: November 19, 1999.

The third set of photos illustrating the changes that occurred in this portion of Aravaipa Creek focuses on the left bank (Figures 5-8a and 5-8b). In July, the water's edge is several feet from the larger vegetation, at the base of a gradual slope down to the water surface. In November, the larger vegetation is nearer the water's edge. The bank slope has changed from a gradual slope to a steeper cutbank. Additionally, although the water surface elevation in November was slightly higher than in July, based on waterline on right bank bedrock in photos the left side of the channel visible in the photos is shallower in November than in July.

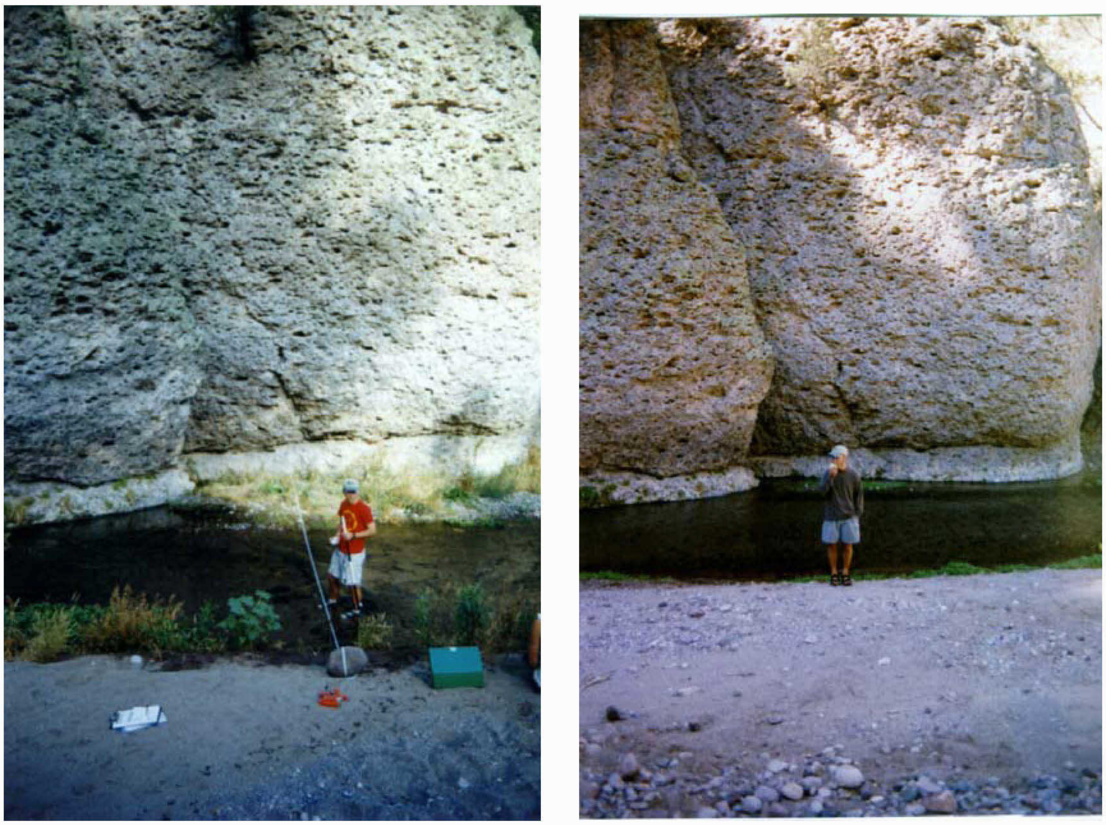
Figure 5-8a. Looking at cross section AC-1 left bank. Photo date: July 2, 1999.

Figure 5-8b. Looking at cross section AC-1 left bank. Photo date: November 19, 1999.

The channel bed of Aravaipa Creek at cross section AC-1 was quite mobile under the flows experienced between July and November. Bars and islands were eliminated or reshaped. Bank vegetation on the left bank may provide some stability and erosion resistance

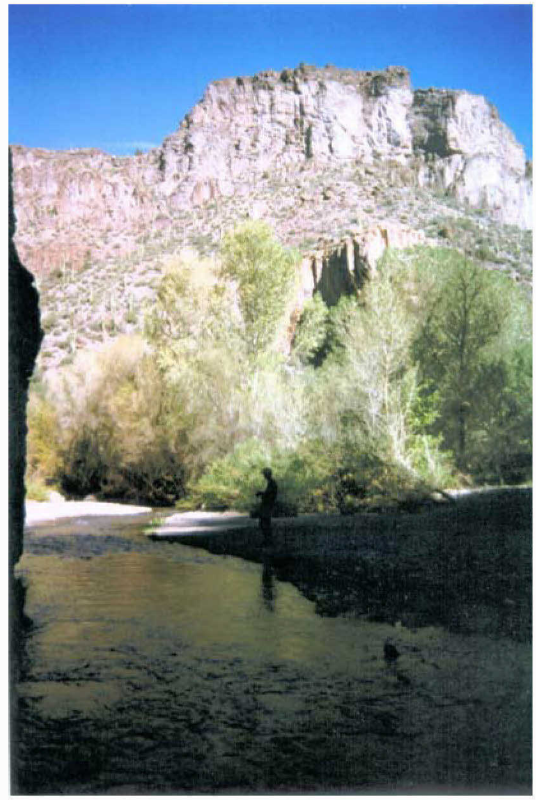
Cross Section AC-2. Cross section AC-2 is located between Paisano and Booger canyons (Figure 5-1). The left bank consists of a bedrock cliff. The right bank is a meander bar consisting of alluvial sediment. Three photo pairs illustrate the changes that occurred at this cross-section over the four-month period between July and November.

Figures 5-9a and 5-9b look across Aravaipa Creek, directly at the left bank. The vegetated bar on the left bank, in front of the bedrock outcrop, is no longer present in the November photo. These figures illustrate the amount of sediment in the bar that had to be moved by the flows between July and November. The particle size on the right bank in the foreground of the photos is also of interest. Note that there are more large particles visible on the surface of the bank in November than in July. The change in particle size distribution on the surface hints at the mobility of the sediments that are not in the creek bed itself. The bar must have been inundated at some time between July and November and been subjected to flow that caused the movement of the particles.



Figures 5-9a (left) and 5-9b (right). Looking at left bank, cross section AC-2. 5-8a Photo date: July 3, 1999. 5-8b Photo date: November 20, 1999.

A second view of this portion of Aravaipa creek focuses on the right bank looking downstream (Figures 5-10a and 5-10b). Bank vegetation has changed considerably from July to November. The grassy vegetation mat present in July is not present in November. The change is most likely due to scour and not seasonal changes, since no evidence of dead or dormant vegetation is present in the November photo. Any sediment under the plants in the July photo also appears to have been washed away, as the shape of the bank is slightly different. The slope of the bank has also changed. The slope in November has a more gradual slope down to the water rather than the steeper slope break apparent in July.

Figures 5-10a (left) and 5-10b (right). Looking downstream at cross section AC-2. 5-9a Photo date: July 3, 1999. 5-9b Photo date: November 20, 1999.

Cross Section AC-3. Cross section AC-3 is located just downstream of Cave Canyon (Figure 5-1). The left bank at the cross section is bedrock, while upstream of the cross section the left bank is a root mat overhang. Just upstream of the cross section there are several large boulders in the streambed. The left bank is a cobble bar.

Figures 5-11a and 5-11b illustrate some of the changes that occurred at this cross section. The cobble size on the right bank bar remains consistent between the two photos. Visual matching between the original photos indicates, however, that individual rocks moved slightly between July and November. Vegetation has also changed dramatically. Just as at cross section AC-2, the changes are more likely due to scour rather than seasonal changes as no dead or dormant vegetation remains along the bank.

Figure 5-11a. Looking downstream at cross section AC-3. Photo date: July 4, 1999.

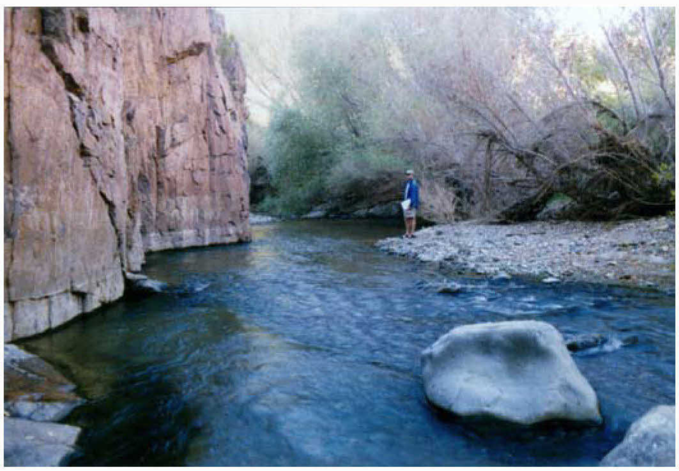


Figure 5-11b. Looking downstream at cross section AC-3. Photo date: November 20, 1999.

There is a riffle/rapid sequence with large boulders just upstream of cross section AC-3 (Figures 5-12a and 5-12b). A large boulder visible in the photo rests against the right bank in the July photo (Figure 5-12b). In the November photo this boulder can be seen resting in the center of the channel (Figure 5-12a). Based on field measurements this boulder moved approximately eight feet. Other boulders of similar size did not move. The high flows that occurred between July and November may not have moved the boulder directly. The flows may have moved material that the large boulder was resting on, thus undermining the boulder and causing it to move.

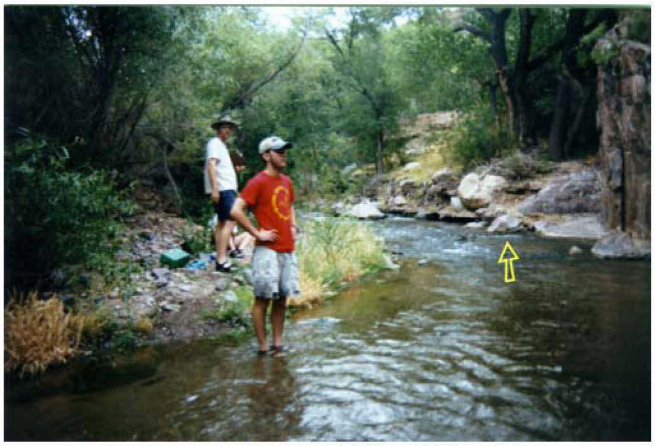


Figure 5-12a. Looking upstream at cross section AC-3. Photo date: July 4, 1999. Yellow arrow indicates boulder that moved between July and November.

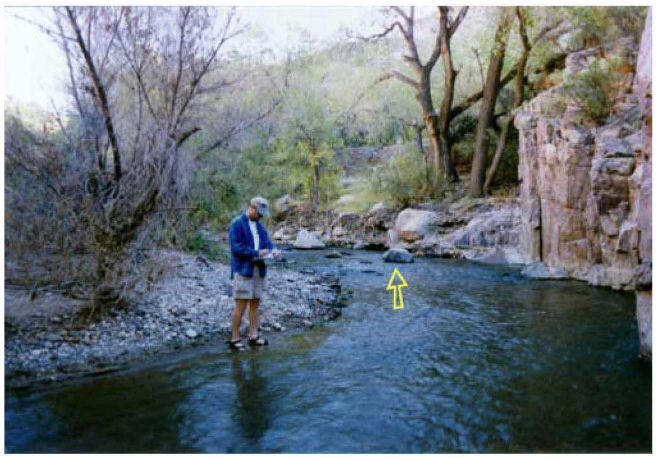


Figure 5-12b. Looking upstream at cross section AC-3. Photo date: November 20, 1999. Yellow arrow indicates boulder that moved between July and November.

Conclusions. The primary finding of the repeat photography is that individual bed forms in Aravaipa Creek are quite mobile at peak instantaneous discharges approaching 4,150 cfs (118 m^3/sec) and mean daily discharges approaching 840 cfs (24 m^3/sec). Bars at two of the cross sections were eliminated, and mid-channel bars were altered extensively. Boulders of approximately three feet in diameter also moved as shown by repeat photography at AC-3, possibly due more to smaller bed material movement rather than direct movement. On a local scale these changes are quite noticeable, however field observations of the entire length of Aravaipa Creek indicate that the net changes are negligible. The creek's position, the character of its bed forms, and the size of its bed material were not drastically altered. Although the amount of bank lining vegetation was reduced at the marked cross sections, the density of bank lining vegetation at other locations along the creek was comparable to that seen in July. Seasonality must also be considered when comparing the vegetation in the photos. Based on field observations the geomorphic character of Aravaipa Creek is relatively stable at instantaneous peak discharges reaching 4,150 cfs (118 m^3/sec) and mean daily discharges of 840 cfs (24 m^3/sec). This correlation of flow and channel change pushes upward Minckley's (1981) 100 cfs (3 m^3/sec) estimate of destructive flooding.

Changes from 1993 to 1999

Ms. Sally Stefferud of the US Fish and Wildlife Service provided photographs of Aravaipa Creek shortly after the flood of January 1993, which had a peak discharge of 13,000 cfs (368 m^3/sec). JEF personnel recreated some of the USFWS photos during the field trip of November 1999 for comparison of channel changes over a six-year period.

The Nature Conservancy Manager's Crossing. The Nature Conservancy Manager's crossing (Figures 5-13a and 5-13b) was photographed in 1993 and 1999. The 1999 photographs illustrate that the riparian vegetation is capable of recovering in a relatively short time span. Young trees including cottonwoods were located on the left bank (closer to photo point-of-view) and a mid-channel bar in 1999. The exposed cut bank on the right bank was also vegetated by grasses. The vegetation provides some measure of erosion control, at least against the discharges that occurred between 1993 and 1999.

Figure 5-13a. 1993 view, looking upstream and at the right bank of Aravaipa Creek at TNC manager's crossing.

Figure 5-13b. 1999 view, looking upstream at right bank of Aravaipa Creek at TNC manager's crossing.

The photographs also show that while the riparian vegetation is recovering along the high flow channel, the low flow channel is moving laterally and changing its course. Upstream of the road crossing the stream moved away from the right bank, as there is a noticeable distance between the cut bank and the new riparian vegetation (Figure 5-13b). Downstream of the road crossing the channel moved closer to the right bank (photo right in Figures 5-14a and 5-14b). Aravaipa Creek has also turned from a sediment choked braided creek as seen in 1993, to a single channel in 1999.

Figure 5-14a. 1993 view looking downstream at the left bank of Aravaipa Creek at TNC Manager's crossing.

Figure 5-14b. 1999 view looking downstream at left bank of Aravaipa Creek at TNC manager's crossing.

Chimney Rock Vicinity. Figures 5-15a, 5-15b, 5-16a, and 5-16b are photographs of Aravaipa Creek in 1993 and 1999 near Chimney Rock. Comparison of the photos reveals that only minor channel changes have occurred in the last six years. The size distribution of bed material appears to have remained the same. The channel has experienced some minor shifts in lateral position, but a mid channel bar visible in 1993 is also visible in 1999 (Figures 5-15a and 5-15b).

Figure 5-15a. 1993 view looking downstream Aravaipa Creek in the vicinity of Chimney Rock.

Figure 5-15b. 1999 view looking downstream Aravaipa Creek in the vicinity of Chimney Rock.

In Figure 5-16a, a small cut bank is visible on the right bank of the channel (photo left). By 1999 (Figure 5-16b) the bank has assumed a gentler slope, and the channel has shifted its course slightly to the left (photo right). There has also been some growth of small near-channel vegetation between 1993 and 1999. Overall not much change occurred on this reach of Aravaipa Creek between 1993 and 1999.

Figure 5-16a. 1993 view looking upstream Aravaipa Creek in the vicinity of Chimney Rock.

Figure 5-16b. 1999 view looking upstream Aravaipa Creek in the vicinity of Chimney Rock.

East Entrance of Aravaipa Wilderness Area. The third area in which photographic views were recreated is located at the east entrance to Aravaipa Wilderness. The flood of 1993 apparently eroded parts of the high terrace bank extensively, as suggested by the exposed roots in Figure 5-17a. By 1999 (Figure 5-17b) the cut banks had become less severe, probably helped along by maintenance crews removing the exposed roots. The 1993 flood did not visibly damage the larger trees on the terrace. Surface vegetation along the cut bank was completely ripped out, however. By 1999 vegetation had grown back on the terrace surface and along the base of the terrace bank. Small saplings are also visible along the terrace bank consistent with the size of new trees upstream at TNC manager's crossing. The high-water mark indicated by flotsam in the 1993 photo was approximately eight feet (2.4 m) above the road surface.

Figure 5-17a. 1993 view; east boundary of Aravaipa Canyon Wilderness Area.

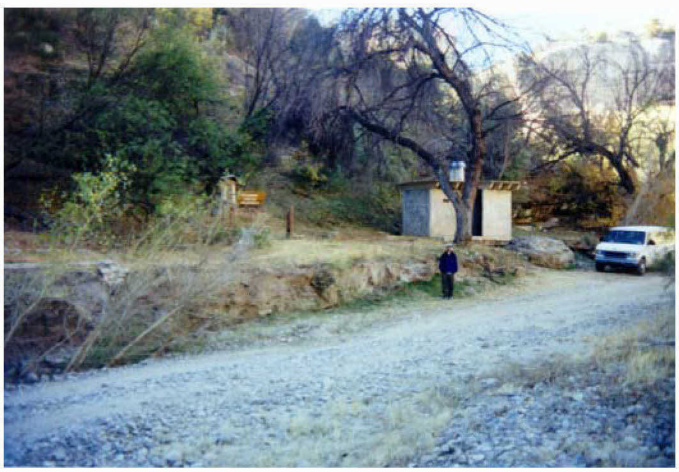


Figure 5-17b. 1999 view; east boundary of Aravaipa Canyon Wilderness Area.

Conclusions. Repeat photography spanning the 1993 to 1999 period suggests that riparian habitat can make a significant recovery in six years. The channel bed changed from a sediment choked braided stream immediately after the 1993 flood to what is probably a more normal condition: a single gravel bed channel with occasional islands. Bank vegetation also made a significant comeback, with grasses colonizing cutbanks and floodplain surfaces and cottonwoods reaching approximately 20 feet (6 m) in height.

Long-term Channel Changes Based on Aerial Photo Interpretation

Aerial photographs from four time periods were acquired for Aravaipa Creek. The first set from 1958 covers the reach of Aravaipa Creek from its confluence with the San Pedro River to Section 8, T. 7 S, R. 17 E (near the proposed fish barrier site). The second set from 1978 covers the length of Aravaipa Creek from its confluence with the San Pedro River to the vicinity of Hell's Half Acre (Section 13, T. 6 S, R. 17 E). The third set of photos from 1984 covers the length of the creek from Section 8, T. 7 S, R. 17 E (the proposed fish barrier site) to just downstream of Klondyke on the east end of Aravaipa

Valley. The fourth set of aerial photographs was taken in 1993 and covers the canyon reach of Aravaipa Creek. From the aerial photography sets described above the comparisons listed in Table 5-7 can be made.

Table 5-7. Aravaipa Creek. Reaches of Aerial Photo Comparison.	
1958 – 1978	San Pedro confluence to proposed fish barrier
1978 – 1984	Proposed fish barrier to Hell's Half Acre
1984 – 1993	LaJolla Ranch to upstream of Aravaipa Wilderness east entrance (TNC land)

1958-1978, San Pedro confluence to proposed fish barrier

The San Pedro reach of Aravaipa Creek is important for considerations regarding the proposed fish barrier. This most downstream reach is usually dry. Only the larger or sustained flows reach this portion of Aravaipa Creek, so changes that occur along this reach are the cumulative result of occasional large floods. USGS gage records and oral histories indicate that four floods occurred during the period between the photo dates of February 1958 and September 1978. These events occurred in 1963, December 1967, March 1970, and October 1972 (Table 5-4). Photo comparisons of this reach indicate that the banks are prone to erosion and the creek bed is prone to large lateral migration. This behavior must be taken into account when considering the location of the proposed fish barrier. The changes on this reach of the creek are illustrated by four sets of paired aerial photos. Refer to Figure 5-18 for locations of the photo comparisons.

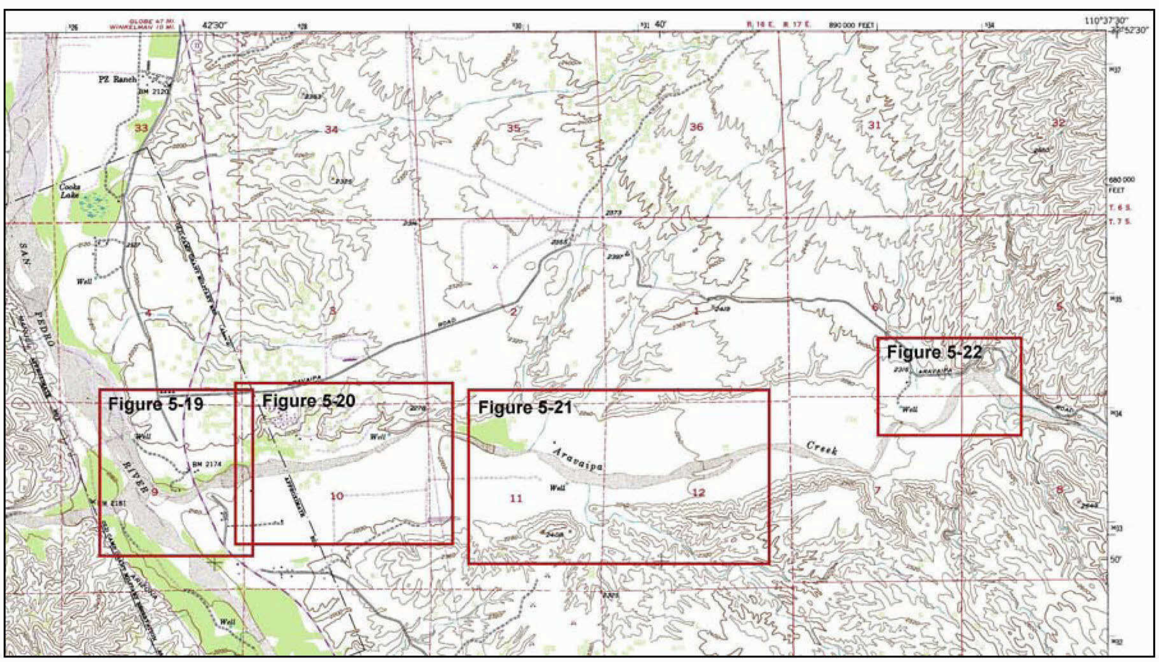
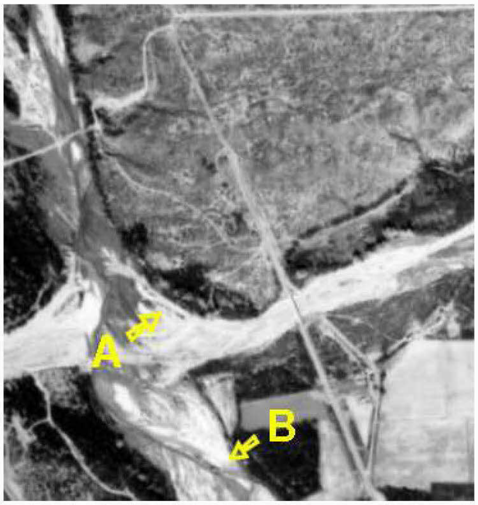


Figure 5-18. Location map showing aerial photo extents for 1958-1978 comparisons. Adapted from USGS Lookout Mountain, Arizona, 7.5' USGS quadrangle.

San Pedro Confluence. Over the twenty-year period between 1958 and 1978, vegetation encroached into the floodplain at Aravaipa Creek's confluence with the San Pedro River (Figure 5-19). The total area (A) covered by vegetation in 1978 *increased by* 300,850 ft^2 (27,950 m^2). The San Pedro River also changed remarkably between 1958 and 1978 (B). The decrease in width of the active channel from approximately 670 ft (204 m) to 138 ft (42 m) may be a reflection of changes in climate pattern and subsequent changes in discharge regime for the watercourses in the southeastern part of Arizona. The width of Aravaipa Creek's bed remained fairly constant, however.



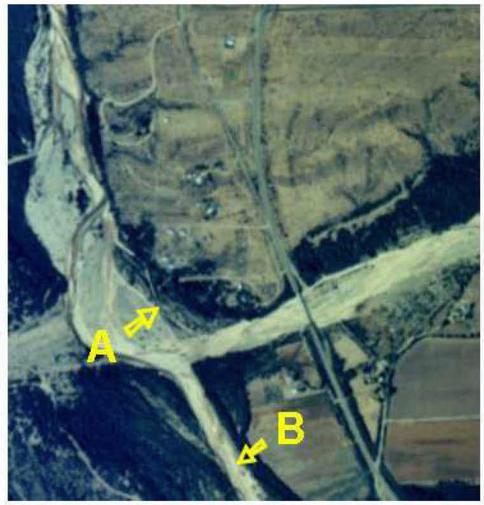
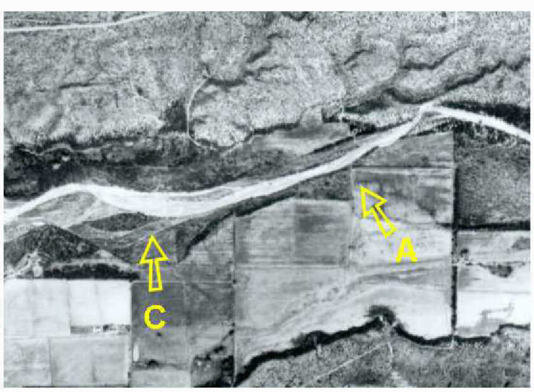


Figure 5-19. Comparison of Aravaipa Creek/San Pedro confluence. 1958 photo on right. 1978 photo on left.

Lower Aravaipa Creek Floodplain Erosion. Approximately one mile upstream of the San Pedro confluence, Aravaipa Creek shifted course and eroded portions of the left bank floodplain (Figure 5-20). The channel at this location moved 328 ft (100 m) to the left (south) between 1958 and 1978 (A). The total area eroded by the channel movement was approximately 313,230 ft^2 (29,100 m^2). About 1200 ft (366 m) downstream of the erosion, a bar approximately 125,940 ft^2 (11,700 m^2) in area formed in the channel (B). At the same location the active channel again shifted to the left, eroding approximately 110,440 ft^2 (10,260 m^2) of vegetated overbank (C).



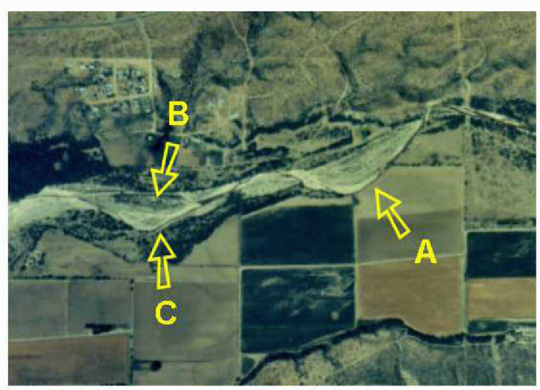


Figure 5-20. Comparison of 1958 and 1978 photos illustrating erosion potential on lower Aravaipa Creek. 1958 photo on right. 1978 photo on left.

Lower Aravaipa Creek Channel Migration. Aravaipa Creek has also shown a tendency to shift its course dramatically in the lateral direction. Figure 5-21 compares photos from 1958 and 1978. The active channel moved 690 ft (210 m) across the floodplain from the south to the north side of the floodplain. Immediately upstream and downstream of this large shift, the channel remained relatively stable and in the same location, with only slight shifts in mid channel bars.

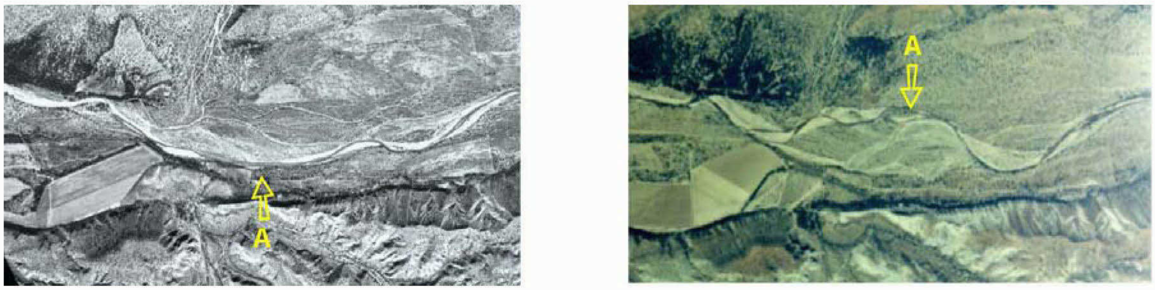


Figure 5-21. Comparison of 1958 and 1978 photos showing magnitude of lateral channel migration on lower Aravaipa Creek. 1958 photo on right. 1978 photo on left.

Lower Aravaipa Creek Point Bar Alterations. Channel change also occurred where Aravaipa Creek leaves relatively confining hills and flows into the wider floodplain (Figure 5-22). Aravaipa Creek cut through a point bar at this location, possibly using a small abandoned channel visible in the 1958 photo as its starting point to erode into the bar (A). Also, an area of approximately 472,530 ft^2 (43,900 m^2) on the point bar was scoured of vegetation. Downstream of the point bar, the channel migrated toward the right bank, removing approximately 113,670 ft^2 (10,560 m^2) of material (B). The active channel width increased from 164 ft (50 m) to 328 ft (100 m) on the east edge of the comparison photos (C).

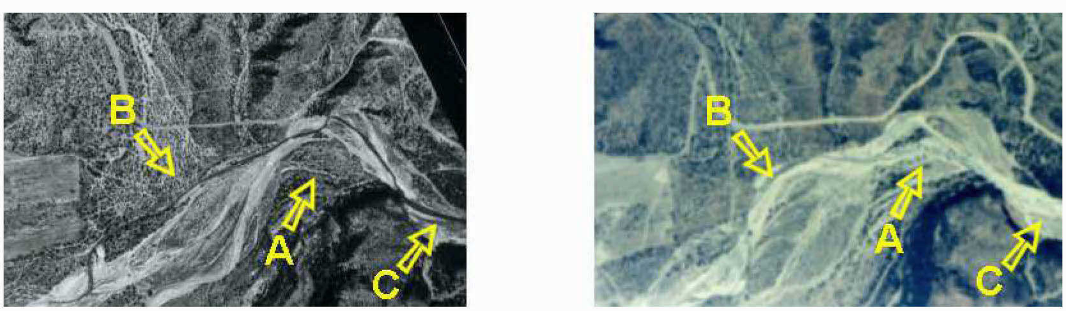


Figure 5-22. Comparison of 1958 and 1978 photos showing channel change on lower Aravaipa Creek. 1958 photo on right. 1978 photo on left.

1978-1984, Proposed fish barrier to Hell's Half Acre

The flow in Aravaipa Creek between the proposed fish barrier and the western boundary of the Wilderness Area is perennial. Perennial flows generally maintain channel form. JEF staff observations indicate that large magnitude channel changes are most likely the result of large flood events exceeding 4,150 cfs (118 m^3/sec) instantaneous discharge and

840 cfs (24 m^3/sec) mean daily discharge. Between September 1978 and October 1984 two floods of similar or greater magnitude swept down Aravaipa Creek. The first occurred on December 18-19, 1978, and the second occurred on October 1-2, 1983. The 1984 photos most likely show the channel changes resulting from the devastating flood of October 1983, which include shifts in stream location and removal of riparian vegetation. The changes on this reach of the creek are illustrated by four sets of paired aerial photos. Refer to Figures 5-23 and 5-24 for locations of the photo comparisons.

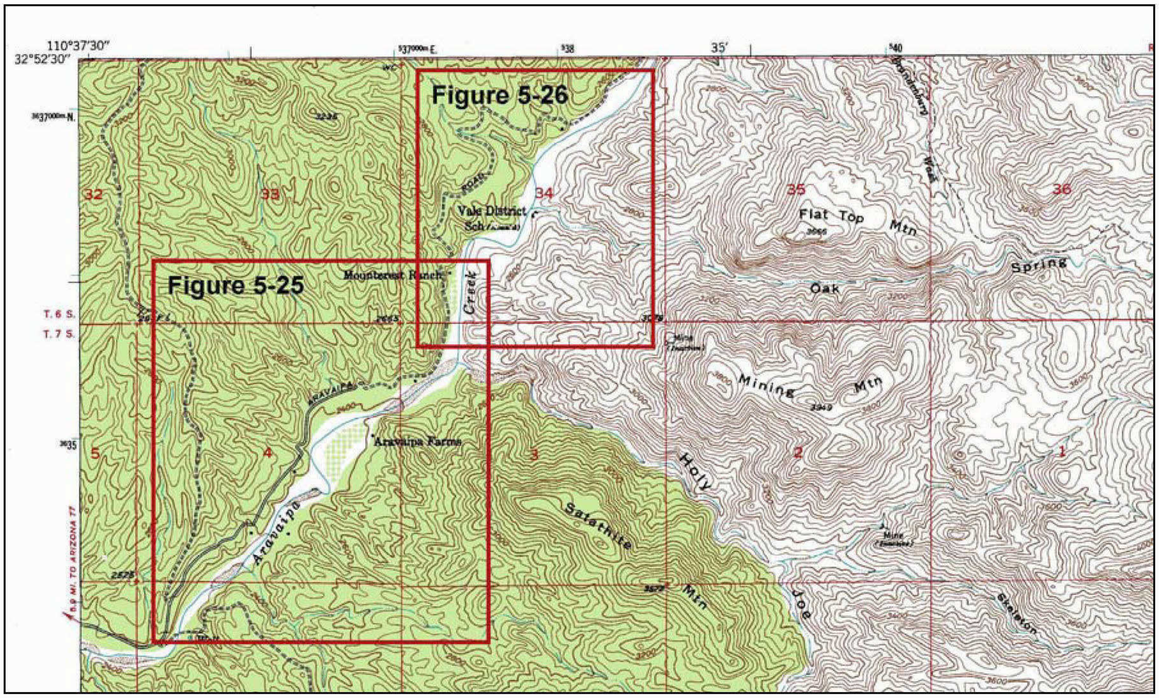


Figure 5-23. Location map showing aerial photo extents for 1978-1984 comparisons. Adapted from USGS Holy Joe Peak, Arizona, 7.5' USGS quadrangle.

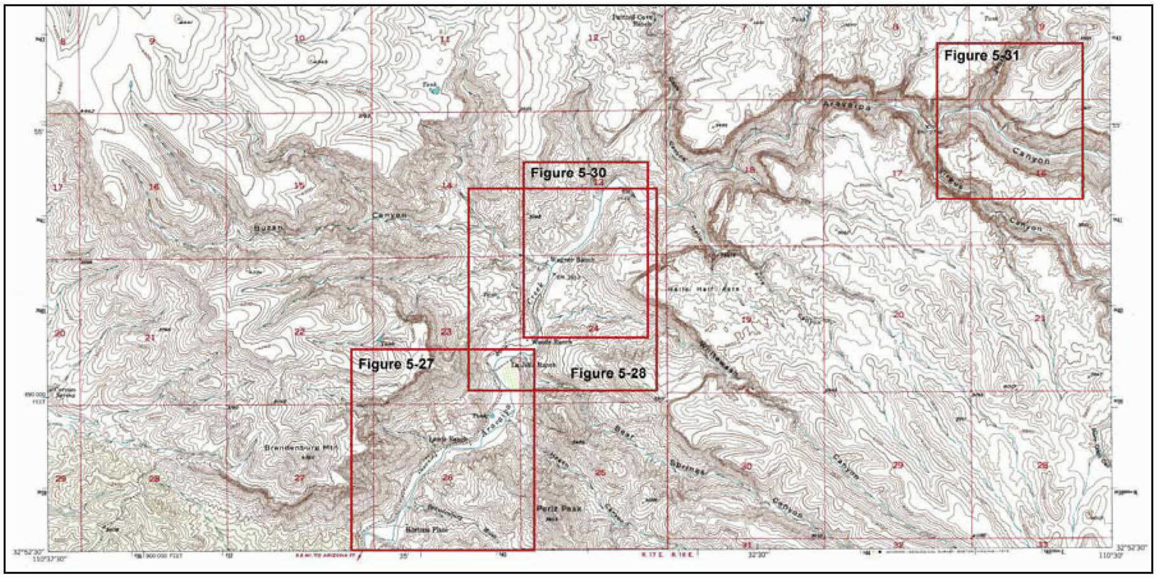


Figure 5-24. Location map showing aerial photo extents for 1978-1984 and 1984-1993 comparisons. Adapted from USGS Brandenburg Mountain, Arizona, 7.5' USGS quadrangle.

Aravaipa Farms. Figure 5-25 compares Aravaipa Creek upstream and downstream of Aravaipa Farms (open area near center of photos). The flood of October 1983 removed many of the large trees that lined the bank of Aravaipa Creek downstream of Aravaipa Farms. These trees lined approximately 1970 ft (600 m) of the right bank (A). The removal of these trees may make the floodplain more susceptible to erosion, however available data do not allow for comparisons after post-1984 floods. A line of trees approximately 350 meters long and adjacent to Aravaipa Farms appears to have survived the October 1983 flood (B). These trees probably provide some resistance to erosion, as Aravaipa Creek does not appear to have eroded into the fields of Aravaipa Farms. Just downstream of Aravaipa Farms a bar approximately 109,790 ft^2 (10,200 m^2) in area was stripped of its vegetative cover (C). Remarkably, Aravaipa Creek did not migrate laterally to any large extent downstream of Aravaipa Farms. Upstream, however, the creek changed its location within the floodplain quite drastically. The creek moved approximately 328 ft (100 m) toward the left side of the floodplain, ending up against the hill near Aravaipa Farms (D). In the process of the lateral channel shift, the vegetated portion of the floodplain seen in the 1978 photograph was completely stripped of vegetation. Just upstream of this change, the creek moved approximately 246 ft (75 m) toward the right bank and the adjacent road (E). There were also minor shifts in the mid-channel bars throughout this portion of the creek.

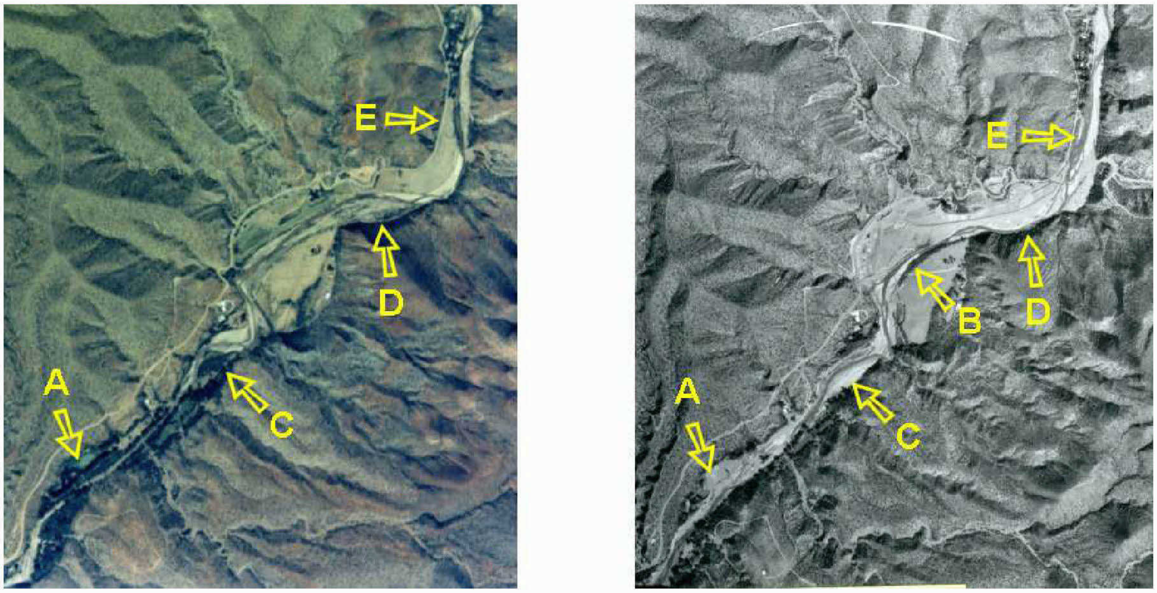


Figure 5-25. Comparison of channel changes between 1978 and 1984 in the vicinity of Aravaipa Farms. 1978 photo on left. 1984 photo on right.

Mountcrest Ranch to Horton's Place. Channel changes between Mountcrest Ranch and Horton's Place are similar to those that occurred near Aravaipa Farms. Figure 5-26 compares the 1978 and 1984 photographs. A line of trees approximately 2490 ft (760 m) in length was removed from both the left and right bank of Aravaipa Creek (A). Aravaipa Creek eroded a portion of the right bank approximately 37,140 ft^2 (3,450 m^2) in area (B). The erosion was accompanied by shifts in the channel's position.

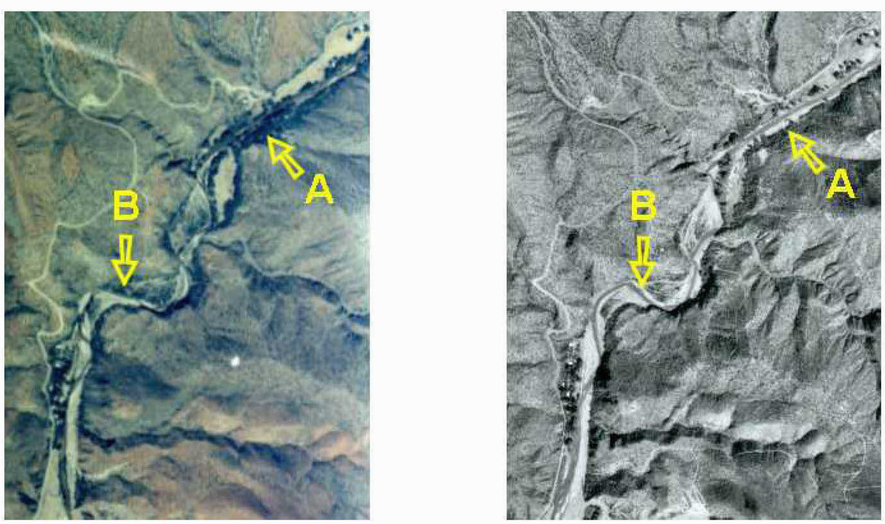


Figure 5-26. Comparison of 1978 and 1984 channel changes between Mountcrest Ranch and Horton's Place. 1978 photo on left. 1984 photo on right.

Horton's Place to La Jolla Ranch. Between Horton's Place and Lewis Ranch (Figure 5-27) Aravaipa Creek moved approximately 308 ft (94 m) towards the right bank, eliminating about 378,890 ft^2 (35,200 m^2) of vegetated bank and threatening to completely wash out the road (A). The October 1983 flood smoothed the meanders in this section of Aravaipa Creek. In the process of this smoothing, the flood also eliminated the vegetation from a 58,120 ft^2 (5400 m^2) bar (A). Downstream of La Jolla Ranch, the active channel of Aravaipa Creek increased in width from approximately 66 ft (20 m) to 246 ft (75 m) (B). Aravaipa Creek also took on a braided pattern temporarily.

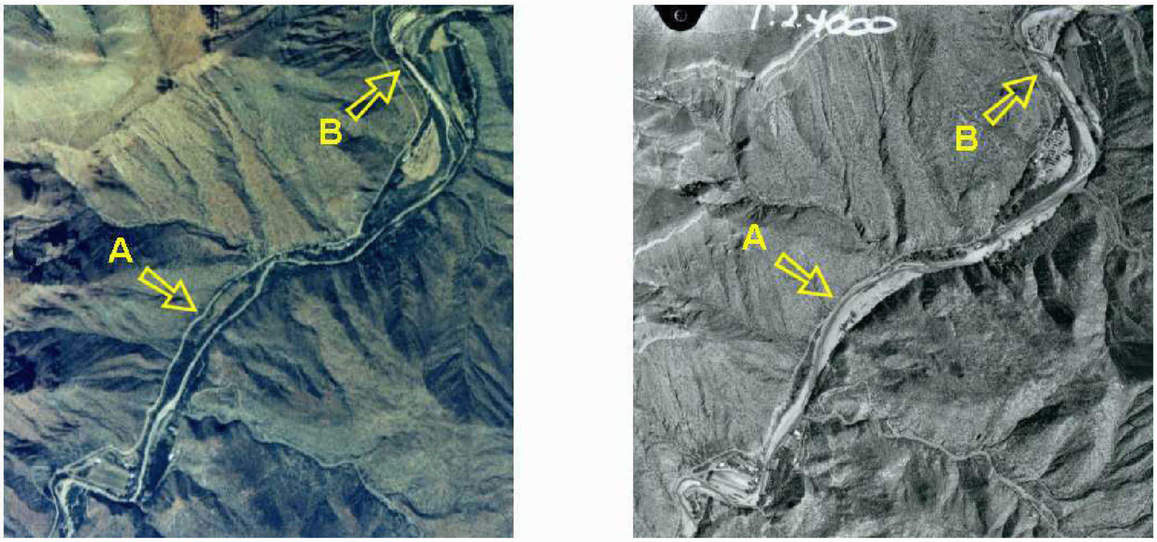


Figure 5-27. Comparison of 1978 and 1984 photos between Horton's Place and La Jolla Ranch. 1978 photo on left. 1984 photo on right.

La Jolla Ranch to Hell's Half Acre. Changes in vegetation dominate this section of Aravaipa Creek (Figure 5-28). On the left bank, adjacent to and upstream of Wagner Ranch, approximately 3,150 ft (960 m) of bank-lining trees were eliminated (A). Two sand bars were left in their place (B). The downstream bar is approximately 53,820 ft^2 (5,000 m^2) in area, and the upstream bar is approximately 46,820 ft^2 (4,350 m^2) in area.

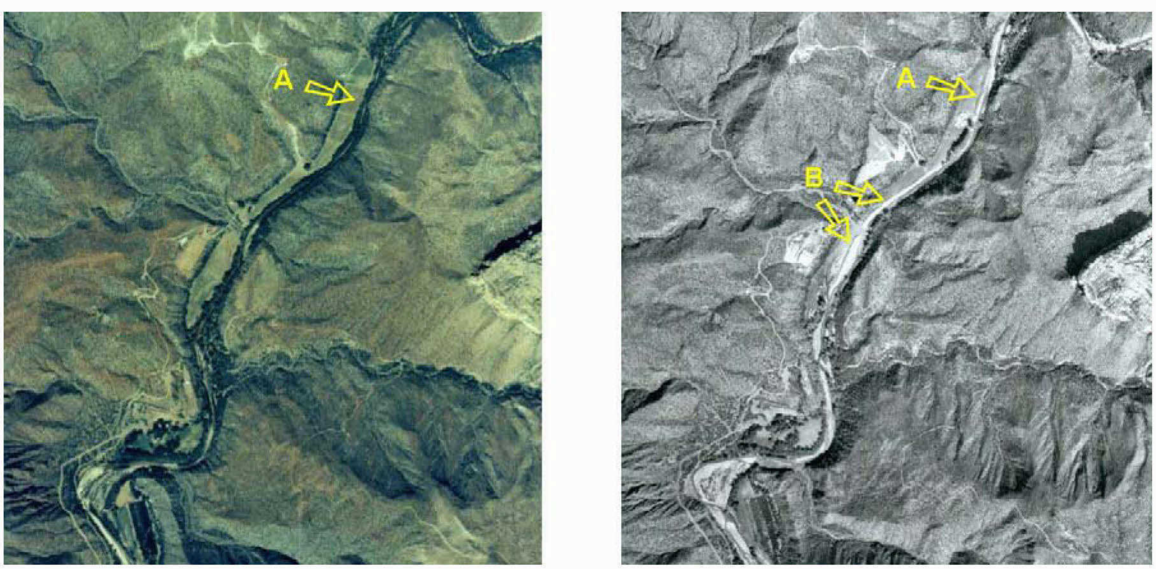


Figure 5-28. Comparison of 1978 and 1984 photos between La Jolla Ranch and Hell's Half Acre. 1978 photo is on the right. 1984 photo is on the left.

1984 – 1993, La Jolla Ranch to Upstream of East End of Canyon Wilderness

Aerial photography from October 1984 and January 1993 is available for Aravaipa Canyon. The floodplain in the canyon is limited in width by the steep bedrock walls of the canyon. In many places the creek flows directly against the canyon walls, so that lateral movement is also limited. Accordingly, changes observed in the canyon reaches are generally changes in overbank vegetation. This is not to say that additional changes do not occur. Changes such as aggradation and degradation may occur, but these changes are not readily apparent on the aerial photos.

Four flood events occurred between October 1984 and January 1993. The largest of the four events occurred the day before the 1993 photos were taken. The USGS estimated an instantaneous discharge of 13,000 cfs (368 m^3/sec) and a mean daily discharge of 4,500 cfs (127 m^3/sec) for January 11, 1993. The date of occurrence and the magnitude of each flood are summarized in Table 5-8.

Table 5-8. Aravaipa Creek.
Major Floods Between October 1984 and January 1993.

Date	Mean Daily Discharge (cfs)	Peak Instantaneous Discharge (cfs)
3/2/1991	3,100	6,760
2/13/1992	1,440	n/a
8/24/1992	1,020	n/a
1/11/1993	4,500	13,000

The water surface visible in the 1993 photos correlates with an estimated mean daily discharge of 845 cfs (24 m^3/sec). Although the water surface is wider than it would normally appear due to elevated discharge, it is significant that much of the vegetation remains on visible overbank areas. The 1984 photos indicate that the destruction experienced by the riparian habitat after the flood of October 1983 was greater than the destruction that occurred in 1993. These photos provide a good contrast between the destruction wrought by a 70,000 cfs (1,982 m^3/sec) flood, which occurred in October 1983, and a 13,000 cfs (368 m^3/sec) flood, which occurred in January 1993. The six photo comparison pairs are discussed below. Refer to Figures 5-24 and 5-29 for locations of the photo comparisons.

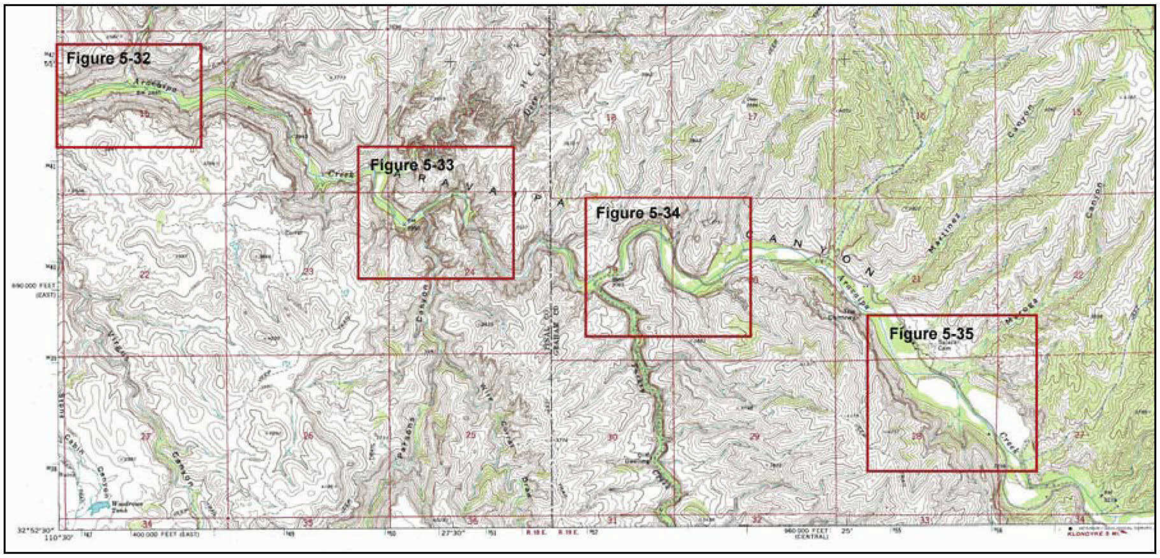
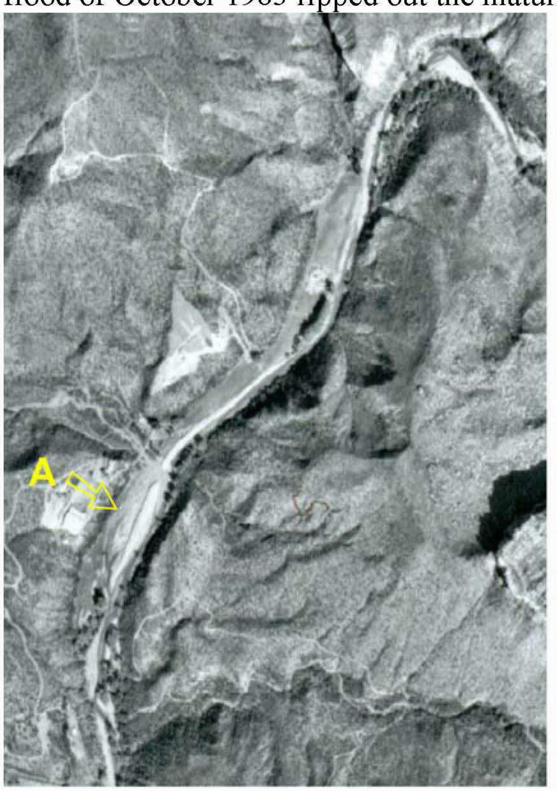


Figure 5-29. Location map showing aerial photo extents for 1984-1993 comparisons. Adapted from USGS Booger Canyon, Arizona, 7.5' USGS quadrangle.

La Jolla Ranch to Hell's Half Acre. Changes between 1984 and 1993 in this photo comparison are generally seen as recovery of vegetation (Figure 5-30). The channel has remained in the same position. Vegetation has recovered the floodplain behind the bars created in the 1983 flood (A). The January 1993 flood has reshaped the sand bars only minimally, if at all. Young trees can be seen growing along the right bank where the flood of October 1983 ripped out the mature trees (B).



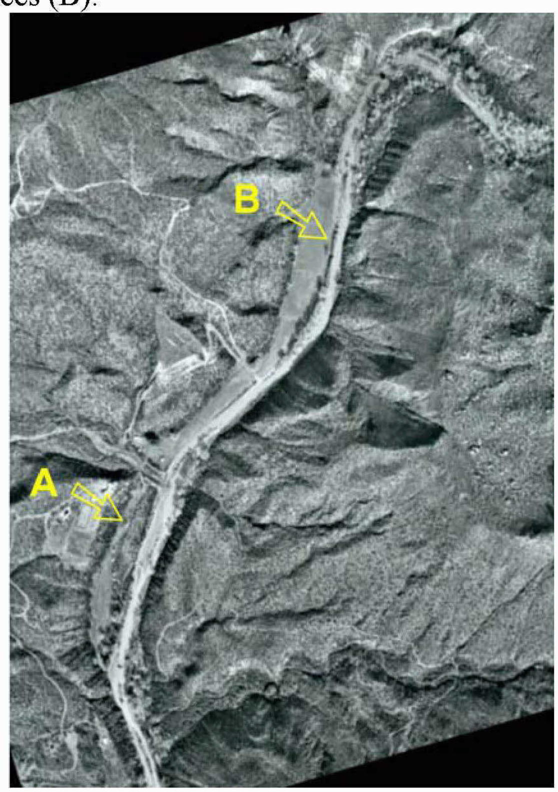


Figure 5-30. Comparison of 1984 and 1983 photos between La Jolla Ranch and Hell's Half Acre. 1984 photo is on left. 1993 photo is on right.

Horse Camp Canyon. Changes in this section of Aravaipa Creek are generally manifested as the formation and revegetation of bars associated with the creek's recovery after the October 1983 flood (Figure 5-31). After the October 1983 flood, the channel flowed through a band of unvegetated sandy to gravelly material. Within the channel, Aravaipa Creek occasionally took on a braided pattern after the 1983 flood. Two bars that had been stripped bare by the 1983 flood had been revegetated by 1993 (A). The most downstream of these bars appears to have increased in size slightly to approximately 69 ft (21 m) at its widest. In conjunction with the bar's increase in size, Aravaipa Creek appears to have shifted slightly towards the left bank.

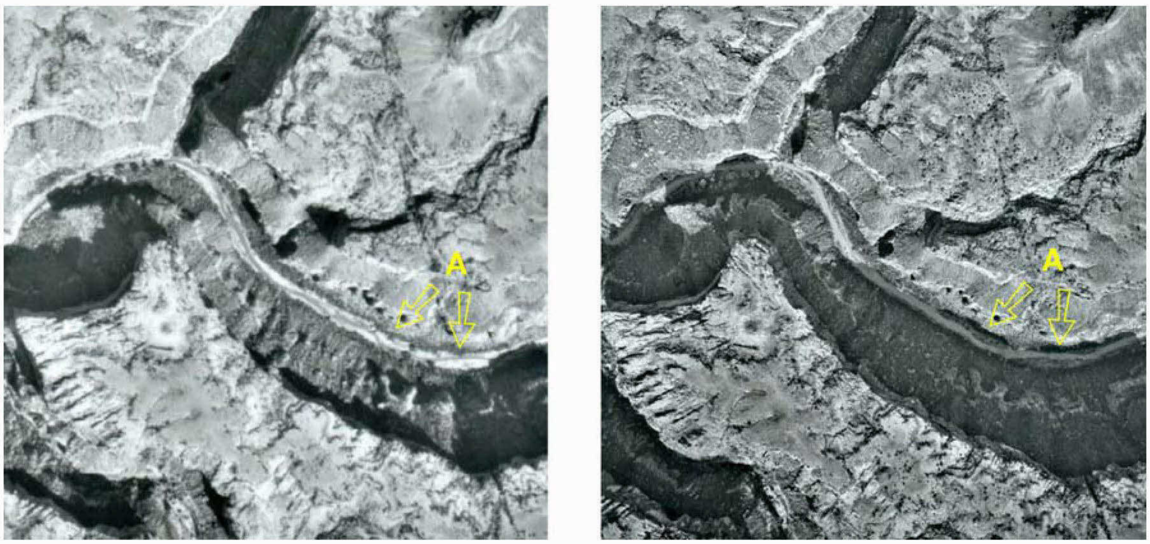


Figure 5-31. Comparison of 1984 and 1983 photos near Horse Camp Canyon. 1984 photo is on left. 1993 photo is on right.

Booger Canyon. The side bar on the right bank just downstream of Booger Canyon increased in size between 1984 and 1993 (Figure 5-32). The bar increased in width by 46 ft (14 m) and added an additional 20,450 ft^2 (1,900 m^2) in area (A). The additions occurred on the downstream end of the bar. The bar is in a position that makes it susceptible to erosion because it lies partially on the cut bank side of one of Aravaipa Creek's meanders.

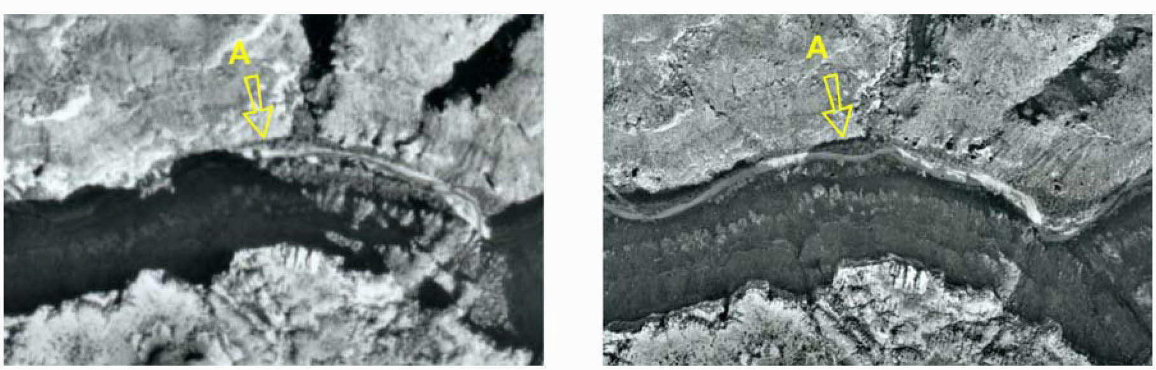


Figure 5-32. Comparison of 1984 and 1993 photos of the Booger Canyon vicinity. 1984 photo is on the left. 1993 photo is on the right.

Parsons Canyon and Hell Hole. Very few changes occurred in this portion of Aravaipa Canyon between 1984 and 1993 (Figure 5-33). No lateral movement of the channel can be detected. A general recovery of vegetation after the October 1983 flood can be seen.

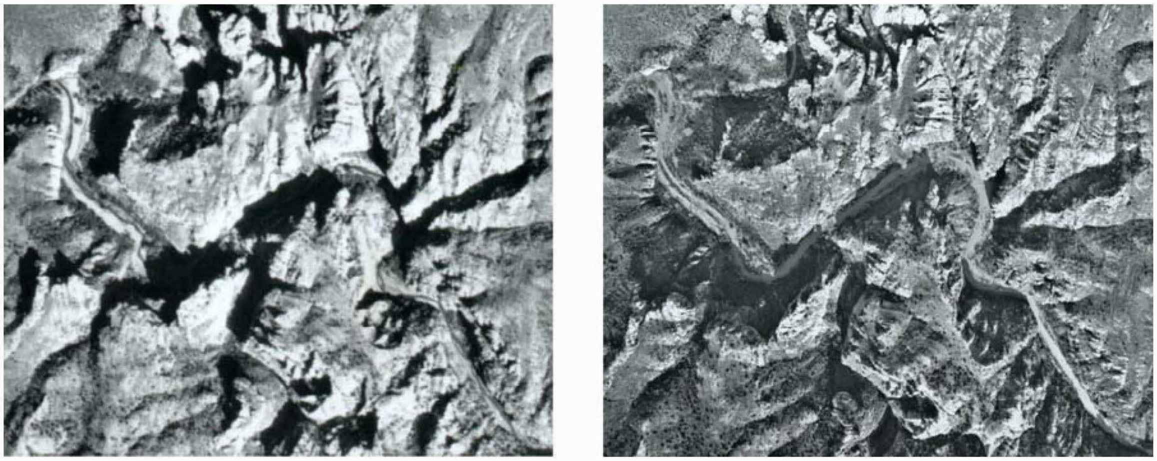


Figure 5-33. Comparison of 1984 and 1993 photos in the vicinity of Parsons Canyon and Hell Hole. 1984 photo is on the left. 1993 photo is on the right.

Turkey Creek Bend. Just as in other sections of the canyon, Aravaipa Creek's lateral position in the vicinity of Turkey Creek remained relatively constant between 1984 and 1993 (Figure 5-34). The overbank that was wiped clear of vegetation in the October 1983 flood has been revegetated by 1993. The flood that occurred the day before the 1993 photos were taken appears to have had little effect on the recovered vegetation.

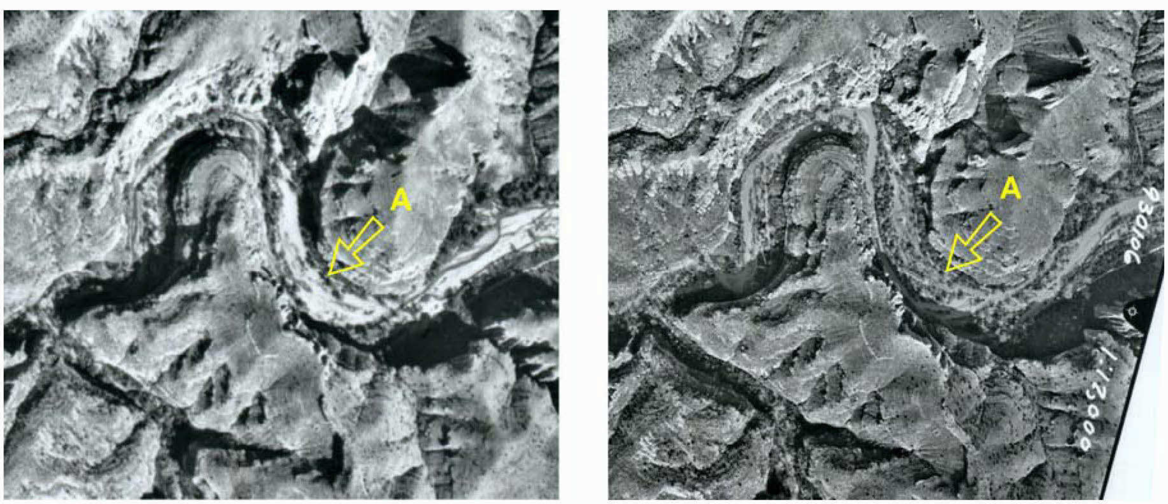
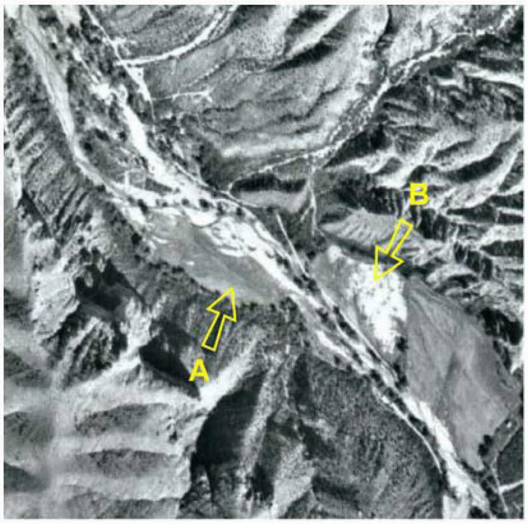


Figure 5-34. Comparison of 1984 and 1993 photos in the vicinity of Turkey Creek. 1984 photo is on the left. 1993 photo is on the right.

Salazar Cemetery Vicinity. This part of Aravaipa Creek is not in the confining section of the Canyon (Figure 5-35). Here the canyon walls are farther apart than downstream providing a larger floodplain area in which Aravaipa Creek can potentially move. In the 1984 photo Aravaipa Creek is a braided ribbon in an unvegetated, sandy to gravelly bed.

The width of the bed ranges between 115 ft (35 m) to 262 ft (80 m). Floodplain areas are present on both the left bank (A) and right bank (B) of Aravaipa Creek at this location. In 1984 the areas are light gray to white in color, indicating a lack of vegetation. By 1993 vegetation had covered both floodplain areas. Additionally, the January 1993 flood eroded a portion of the left bank floodplain (C) equaling approximately 278,250 ft^2 (25,850 m^2).



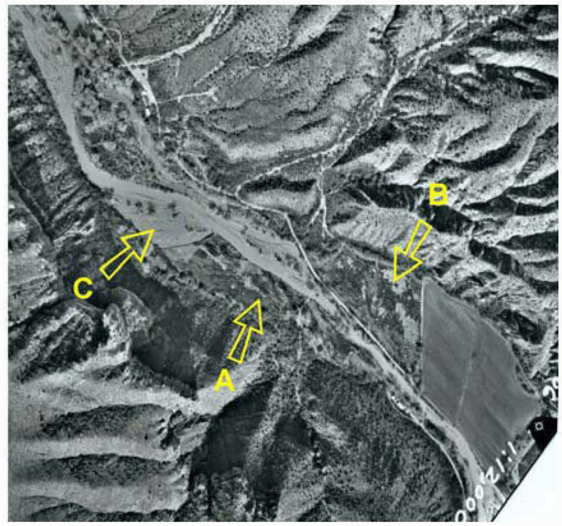


Figure 5-35. Comparison of 1984 and 1993 photos in the vicinity of the Salazar Cemetery. 1984 photo is on the left. 1993 photo is on the right.

Conclusions

Aravaipa Creek between the San Pedro River and Hell's Half Acre (generally the canyon entrance) is less stable in the lateral direction than within the steep-walled Canyon. Aerial photographs provide evidence of a channel that is subject to large lateral movements. Large lateral shifts, especially after large flood events, could be a concern for any fish barrier structure placed across the creek in an area not confined on both sides by bedrock outcrops. Within Aravaipa Canyon the creek is more stable in the lateral directions. However, large floods are very damaging to the riparian vegetation along the creek banks. The reduction in vegetation makes the banks and floodplains more susceptible to erosion. Increased erosion would lead to increased sediment supply in the creek, possibly covering the gravel beds with finer sediments for a time after a large flood.

Assessment

Field investigations and photo interpretation suggest that the entire width of the canyon bottom in the wilderness area is susceptible to erosion. Photographic evidence and field observation suggests that the majority of the canyon bottom, with the exception of the highest elevation surfaces, has been inundated by floods. Slope breaks between terraces above Aravaipa Creek exhibited signs of erosion such as exposed roots. On the floodplain and terrace surfaces, exposed tree roots were up to two feet above the ground surface. Field observations by JEF personnel indicate that small flood events can reshape or eliminate local-scale features such as gravel and sand bars.

Historically, large floods initiate the most noticeable channel change. Natural events such as the 1963, 1983, and 1993 floods have the biggest effect on the morphology of Aravaipa Creek. Nevertheless, the significance of smaller floods and average flows should not be ignored. In fact, the smaller floods and average flows function to maintain the channel morphology or slowly move the creek back to previous conditions after a devastating flood. Average flows continuously reshape the creek bed, as JEF personnel observed sand bars in motion during flows of approximately 20 cfs (0.6 m^3/sec). Small floods on the order of 800 cfs (23 m^3/sec) eliminate and reshape specific bars and islands, but do not change the overall character of the creek. Average flows and small floods are essential in maintaining the health of Aravaipa Creek's channel bed habitats.

The following conceptual model for the natural cycle of morphologic behavior on Aravaipa Creek is proposed. Large floods such as the devastating 1983 flood strips vegetation from the banks and overbanks. The violent removal of vegetation disturbs the overbank sediments and leaves them susceptible to erosion. The resulting erosion lowers the floodplain elevation. Vegetation gradually recolonizes the floodplain after the flood. More frequent smaller floods do not cause damage to the riparian vegetation. Velocities on the overbank are thus slowed in the denser vegetation, allowing for sediments to be deposited on the floodplain. In this manner the floodplain is gradually rebuilt until the next destructive flood.

Anecdotal evidence suggests that human impacts on the morphology of Aravaipa Creek were greater prior to 1963. Settlers along the creek between the 1920s and 1960s initiated vegetation changes. The changes included clearing fields and understory brush for cropping and grazing. They also cut down large bank-lining trees and replaced them with rows of willows. The residents also straightened the channel, especially after the mid-1940s. These changes could have exacerbated the destructive effect of the 1963 flood, although there is no conclusive evidence to support this theory. Human impacts appear to have declined after the 1960s. The BLM's designation of Aravaipa Canyon as a wilderness area, the Nature Conservancy's acquisition of land bordering both ends of the canyon, and a declining population have contributed to the reduction of human impacts on Aravaipa Creek.

Conclusions that the groundwater levels in upper Aravaipa Valley are steady or increasing slightly tend to suggest that average flows will remain relatively constant. Sustained flows similar to those in the most recent years will continue to maintain the current morphologic character of the creek. However, a large flood caused by severe storm runoff, similar in magnitude to the 1983 or 1993 floods, could drastically alter Aravaipa Creek's morphologic character and riparian habitats.

Chapter 6:
Conclusions

The primary objectives of the Aravaipa Creek Geohydrology Assessment included the following:

- Evaluate trends indicated by the hydrologic data and determine possible causes for the observed trends
- Evaluate groundwater/surface water interactions, and any possible link between upstream groundwater pumping and surface flows in the stream
- Evaluate the potential for these trends to affect aquatic habitat
- Recommend additional studies, if necessary, to determine the causes of the trends and their possible effects on aquatic habitat

The conclusions reached as a result of this study are summarized in the following paragraphs.

Surface Water Hydrology

Gages. The USGS gage (09473000) provides the longest record of discharge on Aravaipa Creek. Two BLM gages located on Aravaipa Creek probably better depict actual flow rates in the canyon than the USGS gage, but the BLM data cover only a limited period of record and have not yet been reduced to a usable format. Comparisons of the USGS gage data, available west-end BLM gage data, and JEF discharge measurements in the canyon indicate that the USGS gage data is best used as a minimum discharge value for the canyon. Available data suggest that the USGS gage discharge measurements are approximately 3 cfs (0.08 m^3/sec) lower than the discharge at the western boundary of the wilderness area for discharges between approximately 10 and 20 cfs (0.28-0.57 m^3/sec).

Daily Patterns. Limited data were available for analysis of daily flow fluctuation. Gaging conducted by the JEF team indicates a slight diurnal variation occurs in the canyon.

Tributary Contributions. Tributaries flowing into Aravaipa Creek in the canyon reaches contribute slightly to the baseflow. Discharge increases from the east end to the west end are greater in the winter than in the summer, due to a combination of more inflow from the tributaries and less evapotranspiration during the winter months.

Seasonal Patterns. Analysis of the gage data indicates that Aravaipa Creek experiences both seasonal and long-term flow variations. Aravaipa Creek is dominated by winter (January-March) and monsoon (July-September) high flows, separated by low flow summers (April-June). Winter flows are less frequent than monsoon flows, but generally have a longer duration. Winter periods experience an average of 4.9 events, with an average duration of 5.5 days. Monsoon periods experience an average of 6.8 events, with an average duration of only 2.1 days. In general, winter peaks are greater than monsoon peaks.

Long-term trends. Analysis of the long-term data indicates that Aravaipa Creek is currently in a wet period. Average annual base flows for the last 21 years (1978-1998) are more than twice as large as base flows that occurred from 1932-1942 and from 1967-1977. The average annual volumes for the last 21 years (1978-1998) are roughly twice as large as the volumes experienced from 1932-1940 and from 1967-1977. Precipitation data from the area support the conclusions regarding long-term flow variation as well. Average total annual precipitation for 1978-1998 was two to four inches (50-100 mm) higher than average total annual precipitation recorded from 1952-1977. The combination of increases in precipitation and decreases in groundwater withdrawal, independent of any geomorphic change in the canyon, are the primary contributing factors to the high base flows currently measured in Aravaipa Creek. Further study of the relationship between these contributing factors is needed (see below).

Long-term changes in the seasonal patterns are also evident. Winter events increased in both duration and frequency of occurrence during the wet periods, from an average of 3.0 events lasting 4.1 days each prior to 1978 to an average of 6.8 events lasting 6.9 days each. Winter flows have dominated since water year 1978. Sixteen of the 21 years between 1978 and 1998 have had the majority of the annual volume produced during the winter months. From 1978 to 1998, only two years have seen a higher percentage of the annual flow come during the monsoon season (1988 and 1990).

There is no clear trend in duration and occurrence of monsoon events between the dry and wet periods. Durations and number of events per season remained relatively constant. However, monsoon flows tend to contribute a greater proportion to the annual volume during dry years. During the 1932-42 and 1967-77 periods, the majority of the annual volume was produced during the monsoon season in nine out of 22 years. All nine of the monsoon dominated years had below average annual volumes.

BLM Minimum Flow Recommendations. Prior to 1978, Aravaipa Creek did not meet Minckley's (1981) estimate of recommended flows as often as it did after 1978. During the period from 1932-1942, discharge in Aravaipa Creek was below the recommended flow for 48 of 132 months, or 36% of the time. Extended periods of low flow lasted for up to 10 consecutive months (1939). During the 1967-1977 period Aravaipa Creek did not meet recommended minimum flows in 73 of 132 months, or 55% of the time. Extended periods of low flow lasted for up to nine consecutive months (1976 and 1977). During the wettest period recorded, 1978-1988, nine of 132 months, or 7% of the time, experienced mean monthly flow lower than the BLM recommendation. During 1989-1998, mean monthly flows in 15 of 120 months, or 12.5% of the time, were lower than the BLM recommended flow. Extended periods of low flow never exceeded three months in duration during the most recent periods.

Flood Ratio. The flood ratio (Q100/Q2) for Aravaipa Creek is 6.8, indicating that small floods exert a stronger control on channel morphology than other streams in Arizona.

However, the historical record clearly demonstrates that large floods can significantly modify the channel pattern and channel and canyon-bottom geometry. The largest flood during the period of record for Aravaipa Creek occurred in October 1983. The instantaneous peak discharge was between 17,600 cfs and 70,800 cfs, depending on the study one references.

Groundwater

Current Conditions. Currently, the basin appears to be in a nearly steady-state condition. Base flows in the creek appear to be relatively constant or increasing over the past two decades, supporting the conclusion of a contemporary wet period. Water levels in wells also appear to be steady or rising slightly during this period. The slight increases are likely a function of more precipitation and less withdrawal, however the extent to which each of these impacts affects groundwater levels is unclear because groundwater withdrawals decreased at the same time precipitation increased.

The following interactions are apparent from the groundwater investigation. Precipitation influences both groundwater levels and surface water runoff. Groundwater levels are influenced by precipitation and groundwater withdrawals. Baseflow is influenced by groundwater levels and surface water runoff. The magnitude of the interactions is less clear.

Future Development. The potential to change the existing conditions of groundwater usage in the near future is limited. Increased irrigation poses a potential threat to maintaining the creek flows if large volumes of groundwater are withdrawn from the upper basin. Irrigated agricultural water use occurs in the summer months when the creek flows are already at their lowest. Since irrigation is likely to be supplied by groundwater pumping, irrigation would have a direct impact on creek flows in the canyon.

However, irrigation in the Aravaipa Valley may have decreased in the past 25 years. Floods in 1978 and 1983 destroyed farmland, irrigation ditches and headgates reducing the irrigation acreage. Although some of these facilities have been rebuilt, it is believed that the level of irrigation is not as high as it was earlier in the century.

Housing development and increased domestic use of water pose another potential threat to the flow in Aravaipa Creek. Most of the private land in the valley is located near the creek and would most tap near-stream groundwater for domestic use. However, given that the population of the valley has declined with time, and that most of the land is managed by the State Trust, the potential for increased water use by future residential development is low.

Large-scale development of the water resources in the basin for industries outside the basin is another possible threat. No major wells pumping significant quantities of water were identified during this study. Most of the deep wells are low yield stock wells. It is uncertain if an intensive water exploration program could develop sufficient water to be of interest to outside parties. Because most of the valley is State Trust land, any major water developments would be delayed subject to negotiations with the state. Also, because of the instream water rights held by the BLM and others, any new water developments would be required to demonstrate that they would not affect those prior water rights.

Sources of Creek Flow. The creek flows are buffered somewhat from upstream developments in that significant amounts of water are supplied to the creek from sources that are relatively protected. Stowe Gulch is believed to supply nearly half the water in Aravaipa Spring, is downstream of the majority of the upper basin, and has little private land. Turkey Creek, on BLM land, and Aravaipa Canyon itself supply significant amounts of water to the creek and are unlikely to experience major development.

Climatic Variations. Natural climatic variations, especially in precipitation, pose an additional threat to surface flow in the creek. Base flows in the creek are greatly dependent on precipitation, as shown by the hydrologic analysis summarized above. A greater risk to surface flows would exist if harmful climatic fluctuations occurred in conjunction with new development of the water resources upstream.

Geomorphology

Geomorphic Impacts of Floods and Average Flow. Floods are the major agent of significant channel change along Aravaipa Creek. Major changes in channel morphology occurred during the 1963 and 1983 floods, and to a lesser extent during the 1993 flood. Field investigations and photo interpretation suggest that the entire width of the canyon bottom in the wilderness area is susceptible to erosion and reshaping during the largest floods. Acknowledgement of the destructive capability of large floods on Aravaipa Creek is not meant to dismiss the significance of smaller floods and average flows on the low flow channel morphology. Small floods up to the bankfull discharge apparently maintain the current conditions or allow for gradual change back to the pre-flood conditions.

The amount of change initiated by a large flood is likely a function of when the flood occurs. If the flood occurs during a dry period, such as the 1963 flood that occurred after a nine-year interval of no significant floods, then major channel changes occur. The 1963 flood apparently reorganized a large volume of sediment deposited in the creek during the no-flood period, smoothing the bed of Aravaipa Creek, and making Minckley's 1964 car trip possible. In contrast, the 1983 flood occurred during a wet cycle after large floods in 1978 and 1979 had flushed much of the available sediment from Aravaipa Creek. Consequently, the flood of 1983 was capable of moving more of the base material rather than accumulated sediment.

Average flows continuously reshape the creek bed, as documented by the project team during the course of the study. JEF personnel observed sand bars in motion during flows of approximately 20 cfs. At these flow rates, individual sediment particles move but the bedforms are persistent. Small floods on the order of 800 cfs eliminate and reshape bars and islands locally, but do not change the overall character of the creek. Average flows and small floods are essential in maintaining the health of Aravaipa Creek's channel bed habitats.

Lateral Migration. Aravaipa Creek is not prone to significant rates of lateral migration within the Canyon due to the confining bedrock walls of the canyon. Downstream of the canyon, however, aerial photo evidence indicates that Aravaipa Creek is prone to significant rates of lateral erosion and channel migration. Design of the fish barrier should account for this lateral migration potential. The barrier abutments should be founded in bedrock or otherwise protected, or flanking and frequent replacement of the structure should be expected. The Bureau of Reclamation addressed these concerns in their designs (personal communication with Sally Stefferud, USFWS).

Magnitude of Destructive Flooding. Minckley (1981) estimated the magnitude of destructive flooding as any mean daily discharge over 100 cfs. Based on our geomorphic analyses completed for this report, we estimate that the minimum mean daily discharge for destructive flooding is approximately 800 cfs. The USGS gage recorded an instantaneous discharge of 4,150 cfs and a mean daily discharge of 840 cfs on July 28, 1999. Despite the recorded flows, the overall character of Aravaipa Creek was the same during July 2-4, 1999 and again during November 19-21, 1999. There were minor local variations such as elimination of some small gravel bars and some bank-lining vegetation at index cross sections, but the overall character of the stream did not change.

Conceptual Model of Geomorphic Cycle. The following conceptual model for the natural cycle of morphologic behavior on Aravaipa Creek is proposed based on the preliminary geomorphic analyses summarized in this report. Large floods such as the devastating 1983 flood strips vegetation from the channel banks and floodplains. The violent removal of vegetation disturbs the overbank sediments and leaves them susceptible to erosion. Subsequent floods remove these sediments and lower the floodplain elevation. Vegetation gradually recolonizes the floodplain during periods of more frequent smaller floods that do not remove riparian vegetation. Vegetative growth in the floodplain slows floodplain velocities, causing sediment deposition and gradually rebuilding the floodplain until the next destructive flood.

Human Impacts. Anecdotal evidence suggests that human impacts on the morphology of Aravaipa Creek were greater prior to 1963. Settlers along the creek between the 1920s and 1960s initiated vegetation changes including clearing fields and understory brush for cropping and grazing. They also cut down large trees along the banks and replaced them with rows of willows to provide better erosion protection. The residents also straightened the channel, especially after the mid-1940s. These changes could have exacerbated the destructive effect of the 1963 flood, although there is no conclusive evidence to support this theory. Human impacts appear to have declined after the 1960s. The BLM designation of Aravaipa Canyon as a wilderness, the Nature Conservancy's acquisition of land on both the eastern and western ends of the canyon, and a declining population have contributed to the reduction of human impacts on Aravaipa Creek.

Future Conditions. Conclusions that the groundwater levels in upper Aravaipa Valley are steady or increasing slightly tend to suggest that average flows in Aravaipa Creek will remain relatively constant or increase. Sustained flows similar to those in the most recent years will continue to maintain the current morphologic character of the creek, including a healthy variety of habitats for native species. However a large flood caused by severe storm runoff, similar in magnitude to the 1983 or 1993 floods, could drastically alter Aravaipa Creek's morphologic character and riparian habitats for short time periods.

Habitat

Both floods and low flow periods impact the aquatic ecosystem in Aravaipa Creek, affecting the native and non-native fish communities. Hydrologic impacts that alter available habitat, food base abundance, instream cover, and other factors have been part of the natural Aravaipa ecosystem. However, long-term data indicate that Aravaipa Creek can return to pre-flood conditions in a relatively short time. The similarities between current streambed conditions and Minckley's (1981) descriptions illustrate Aravaipa Creek's relative stability, especially considering the magnitude of the October 1983 flood.

Flooding may be beneficial to the native fishes by limiting the ability of non-native fishes to become established. Low flow periods have also been a common historic feature of the Aravaipa Creek system with little long-term negative effects to the fish community. Low flows may even be beneficial in that the intermittent nature of the lower reaches of Aravaipa Creek prevents the immigration of non-native fishes from the San Pedro River.

At present, low flow related declines in available habitat do not appear to be a limiting factor for the native fish community in Aravaipa Creek, since both precipitation and discharge are at levels well above historical averages. However, the possibility of a return to previous low baseflow levels should not be dismissed. Accordingly, anthropogenic changes that may draw down the baseflow of Aravaipa Creek must be evaluated and monitored to prevent catastrophic declines in baseflow below natural historic levels.

Recommendations/Future Studies

The conclusions summarized above are based on the limited scope of services approved for this study. Additional study of the following topics is warranted to better clarify and understand the Aravaipa Creek stream system and the interaction between surface and ground water flows and the geomorphology.

The recommended base flow field monitoring program consists of nine components. They are:

1. BLM Data Collection. Continue to monitor stream flows at the BLM's east and west stream gaging stations. These stations provide excellent long-term monitoring stations. Data from these stations provide the measurements of base flow against which all other monitoring data are to be compared. The differences

in flows between the east and west stations can be used to refine the estimates of evapotranspiration and canyon contributions to base flow that were presented in this study. Both of these factors appear to be major factors affecting base flow.

2. BLM Flow Data. BLM stream flow data from the east gage should be analyzed and evaluated. Much of the data from these stations is in raw form and needs to be converted to stream flows. Flow measurements need to be calculated from these charts and analyzed in conjunction with the data from the west gage. There is a considerable amount of valuable information on these charts and they potentially provide the best stream flow data available for analyzing the hydrology within Aravaipa Canyon.

3. Precipitation Data. A precipitation gaging network should be established. Precipitation was shown to be strongly related to base flow and may be the dominant factor affecting base flow. The precipitation records for the Aravaipa Basin are poor. Records are available from a single station in the basin. Those records had gaps in the data and reconstructed data based on data from outside the basin were used to fill the gaps. Because of the importance of precipitation on base flow, a network of gages, recording daily rainfalls, should be established. Daily rainfalls are important to use in conjunction with the stream gaging data to assess surface runoff events and arrive at accurate estimates of base flow.

4. Irrigation Data. Irrigated acreage in Aravaipa Valley should be measured and monitored. Current groundwater pumping may affect base flow. The majority of the groundwater pumped in the basin is used for irrigation. It is unlikely that the pumpage can be determined directly because any pumping records kept are not public information. However, the pumpage and, more importantly, the consumptive use of groundwater can be obtained by measuring the irrigated acreage and identifying the crops being grown. These measurements would be required only once or twice per year. Establishing long-term trends in irrigation water use, however, is important to use with the other long-term records relating to base flow.

5. Groundwater Monitoring. A suite of existing wells should be selected to establish a groundwater monitoring network. Base flows are a function of groundwater conditions and groundwater levels measured in wells are a measure of groundwater conditions. Water levels in wells reflect the cumulative effects of rainfall and groundwater pumping. Water levels collected quarterly from a network of carefully selected wells screened in the Younger Alluvium and the Older Alluvium can be used to identify changes in the contributions to base flow from various sources. For example, water levels from the Younger Alluvium collected upstream from Stowe Gulch may show a decline at the beginning of the irrigation season resulting in a corresponding decrease in the component of base flow originating from subflow in the Younger Alluvium. Water levels in the Older Alluvium may be reflective of precipitation trends and might be relatively unaffected by groundwater pumpage because the irrigation wells do not generally

pump from the Older Alluvium. These data will provide the base line of information from which to assess future changes.

6. Tributary Inflow. The contribution of surface and subsurface flow from tributaries to Aravaipa Creek should be more thoroughly evaluated. Stowe Gulch and Turkey Creek probably contribute significantly to the base flow of Aravaipa Creek. Quantifying the inputs from major tributaries may prove useful in attempting to manage water resources in the basin. Water development in and near significant source tributaries might warrant greater attention than development of water resources elsewhere. Evaluation of the tributary inputs could be performed based on a chemical mixing approach similar to that used by Adar (1984) or based on establishing hydraulic properties of the alluvial material and hydraulic gradients of groundwater flow. Stream gaging of Turkey Creek would also be useful.

7. Streamflow Losses. Evapotranspiration losses within Aravaipa Creek should be evaluated through a program of seasonal and diurnal in-stream gaging. As shown in this study, a large amount of water is lost annually to evapotranspiration. These losses affect base flow within the canyon. The evapotranspiration losses can be quantified more accurately using data from the BLM's stream gaging stations.

8. Emergence Point Monitoring. The emergence point of surface flows in Aravaipa Creek should be continuously monitored as an inexpensive method to determine seasonal, annual, and long-term fluctuations of the groundwater levels near the perennial reach.

9. Groundwater Modeling. A modeling study of groundwater withdrawal and recharge and their impact on flow would provide better insight into the relationships of precipitation, groundwater withdrawals, and base flow. The model could include various changes that might occur such as increasing, decreasing, or steady precipitation combined variously with increasing, decreasing, or steady groundwater withdrawals. Modeled conditions would provide an idea of changes to expect in base flow as conditions change. The model could provide limits to observe on groundwater withdrawal in times of low precipitation to avoid low flow situations seen in 1932-1942 and 1967-1977.

The recommended geomorphology monitoring program consists of four components. They are:

1. Aerial Photograph Analysis. Channel changes visible on aerial photos should be compared relative to seasonal and long-term fluctuations in runoff. A more detailed study of morphologic changes on Aravaipa Creek as a result of large flows or extended low flows may reveal more detailed insights into the geomorphic behavior the creek than were revealed in this preliminary study.

2. Index Cross Section Monitoring. Index cross sections established during the course of this study should be monitored over the long-term. Site visits should occur on a regular, seasonal basis, and after large flow events. It is suggested that investigations of the cross section occur in the summer before monsoons and after winter flows, and again in October or November after the monsoons but before the winter storms. Changes observed could be compared to flow records for the intervening period. Long-term changes and channel recovery after large floods would also be apparent from sequential photographs. To mitigate admitted bias in sampling in this study, consider establishing additional cross sections on parts of Aravaipa Creek not adjacent to bedrock cliffs.

3. Watershed Analysis. The geomorphic analysis should be extended to the watershed to relate historical land treatment variation to fluctuations in channel morphology. Potential impacts on surface flows and fish habitat from increased grazing, mining, or development could be assessed through hydrologic and geomorphic modeling.

The recommended species monitoring program consists of two components. They are:

1. Continued Species Monitoring. Future monitoring should include relationships between abundance and distribution of non-native fishes and the timing of hydrologic connections between Aravaipa Creek and the San Pedro River.

2. Historical Analysis of Non-Native Species Occurrences. An historical evaluation of timing of connectivity (and/or frequency) between Aravaipa Creek and the San Pedro River and abundance of non-native fishes in Aravaipa Creek

Chapter 7:
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Appendix A

Aravaipa Creek Discharge Calculations by JEFuller, Inc.

Aravaipa Creek: AC-1 (July 2, 1999; 6:28 to 7:10 p.m.)														
Distance (Station) (ft)*	Width (ft)	Water Depth (in)*	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
1.75	0.5	---	---	---	---	---	---	---	---	---	---	---	---	---
2.75	1	2.50	0.21	0.04	0.2	1.149	---	---	---	---	---	---	---	---
3.75	1	3.75	0.31	0.15	0.5	1.067	366	60	366	0.36	1.19	1.11	0.31	0.35
4.75	1	4.75	0.40	0.23	0.6	1.000	463	60	463	0.45	1.46	1.46	0.40	0.58
5.75	1	5.00	0.42	0.25	0.6	1.000	631	60	631	0.59	1.93	1.93	0.42	0.80
6.75	1	4.60	0.38	0.22	0.6	1.000	766	60	766	0.70	2.31	2.31	0.38	0.89
7.75	1	4.75	0.40	0.23	0.6	1.000	744	60	744	0.69	2.25	2.25	0.40	0.89
8.75	1	5.25	0.44	0.27	0.6	1.000	759	60	759	0.70	2.29	2.29	0.44	1.00
9.75	1	5.40	0.45	0.28	0.6	1.000	720	60	720	0.66	2.18	2.18	0.45	0.98
10.75	1	4.90	0.41	0.24	0.6	1.000	787	60	787	0.72	2.37	2.37	0.41	0.97
11.75	1	5.00	0.42	0.25	0.6	1.000	688	60	688	0.64	2.09	2.09	0.42	0.87
12.75	1	4.60	0.38	0.22	0.6	1.000	773	60	773	0.71	2.33	2.33	0.38	0.89
13.75	1	4.40	0.37	0.20	0.5	1.067	724	60	724	0.67	2.19	2.05	0.37	0.75
14.75	1	4.25	0.35	0.19	0.5	1.067	838	60	838	0.77	2.51	2.35	0.35	0.83
15.75	1	5.50	0.46	0.29	0.6	1.000	579	60	579	0.54	1.79	1.79	0.46	0.82
16.75	1	5.00	0.42	0.25	0.6	1.000	519	60	519	0.49	1.62	1.62	0.42	0.67
17.75	1	5.00	0.42	0.25	0.6	1.000	271	60	271	0.28	0.92	0.92	0.42	0.38
18.75	1	4.80	0.40	0.23	0.6	1.000	137	60	137	0.17	0.55	0.55	0.40	0.22
19.75	1	4.00	0.33	0.17	0.5	1.067	227	60	227	0.24	0.80	0.75	0.33	0.25
20.75	0.875	4.60	0.38	0.22	0.6	1.000	274	60	274	0.28	0.93	0.93	0.34	0.31
21.5	0.375	---	---	---	---	---	---	---	---	---	---	---	---	---
													Total Discharge (cfs):	12.47
													Total Area (ft^2):	7.08
													Mean Velocity (ft/sec):	1.76
													Observed Surface Velocity (ft/sec)	3.85

* Data measured in field.

Aravaipa Creek: AC-1 (July 3, 1999; 9:30 to 10:20 a.m.)														
Distance (Station) (ft)*	Width (ft)	Water Depth (in)*	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
0.5	0.625	0.80	0.07	n/a[1]	0.4[2]	1.108	18[4]	60	18	0.07	0.21	0.19	0.04	0.01
1.75	1.125	1.80	0.15	n/a[1]	0.4[2]	1.108	180[3]	60	180	0.20	0.67	0.60	0.17	0.10
2.75	1	3.60	0.30	0.13	0.4	1.108	359	60	359	0.36	1.17	1.06	0.30	0.32
3.75	1	4.50	0.38	0.21	0.6	1.000	440	60	440	0.43	1.40	1.40	0.38	0.52
4.75	1	5.35	0.45	0.28	0.6	1.000	625	60	625	0.58	1.91	1.91	0.45	0.85
5.75	1	5.80	0.48	0.32	0.7	0.953	574	60	574	0.54	1.77	1.86	0.48	0.90
6.75	1	5.90	0.49	0.33	0.7	0.953	696	59	708	0.65	2.15	2.25	0.49	1.11
7.75	1	6.40	0.53	0.37	0.7	0.953	626	60	626	0.58	1.92	2.01	0.53	1.07
8.75	1	6.60	0.55	0.38	0.7	0.953	728	60	728	0.67	2.20	2.31	0.55	1.27
9.75	1	6.20	0.52	0.35	0.7	0.953	828	60	828	0.76	2.48	2.61	0.52	1.35
10.75	1	5.70	0.48	0.31	0.6	1.000	705	59	717	0.66	2.17	2.17	0.48	1.03
11.75	1	6.70	0.56	0.39	0.7	0.953	368 / 362[5]	30	730	0.67	2.21	2.32	0.56	1.29
12.75	1	5.40	0.45	0.28	0.6	1.000	399 / 412[5]	30	811	0.74	2.44	2.44	0.45	1.10
13.75	1	4.40	0.37	0.20	0.5	1.067	380 / 391[5]	30	771	0.71	2.32	2.18	0.37	0.80
14.75	1	4.80	0.40	0.23	0.6	1.000	380 / 394[5]	30	774	0.71	2.33	2.33	0.40	0.93
15.75	1	4.80	0.40	0.23	0.6	1.000	401 / 396[5]	30	797	0.73	2.40	2.40	0.40	0.96
16.75	1	5.60	0.47	0.30	0.6	1.000	313 / 294[5]	30	607	0.57	1.86	1.86	0.47	0.87
17.75	1	5.00	0.42	0.25	0.6	1.000	146 / 165[5]	30	311	0.32	1.04	1.04	0.42	0.43
18.75	1	4.80	0.40	0.23	0.6	1.000	141	60	141	0.17	0.56	0.56	0.40	0.22
19.75	1	4.50	0.38	0.21	0.6	1.000	121 / 122[5]	30	243	0.26	0.84	0.84	0.38	0.32
20.75	1	4.60	0.38	n/a[1]	0.6[2]	1.000	49[6]	60	49	0.09	0.30	0.30	0.38	0.12
21.75	0.685	2.80	0.23	---	---	---	---	---	---	---	---	---	---	---
22.12	0.185	0.00	0.00	---	---	---	---	---	---	---	---	---	---	---
													Total Discharge (cfs):	15.57
													Total Area (ft^2):	8.60
													Mean Velocity (ft/sec):	1.81
													Observed Surface Velocity (ft/sec):	3.85

* Data measured in field.
[1] No direct velocity measurement taken. Water was too shallow for instrument to function.
[2] Assume ratio is same as the measured value used for revolution estimations.
[3] Estimated revolutions. 50% of adjacent measurement of 359 revolutions.
[4] Estimated revolutions. 10% of adjacent estimate of 180 revolutions.
[5] Two observations lasting 30 seconds each were recorded. The average of the two observations was multiplied by 2 to calculate revolutions/minute.
[6] Estimated revolutions. 20% of adjacent measurement of 243 revolutions/minute.

Aravaipa Creek: AC-2 (July 3, 1999; 6:25 to 6:53 p.m.)														
Distance (Station) (ft)*	Width (ft)	Water Depth (in)*	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
13.9	0.3	0.0	0.0	---	---	---	---	---	---	---	---	---	---	---
14.5	0.8	3.50	0.29	0.13	0.4	1.108	60	60	60	0.10	0.33	0.30	0.23	0.07
15.5	1	7.50	0.63	0.46	0.7	0.953	346	60	346	0.35	1.13	1.19	0.63	0.74
16.5	1	8.70	0.73	0.56	0.8	0.871	683	60	683	0.63	2.08	2.38	0.73	1.73
17.5	1	12.00	1.00	0.83	0.8	0.871	492	60	492	0.47	1.54	1.77	1.00	1.77
18.5	1	11.20	0.93	0.77	0.8	0.871	662	60	662	0.62	2.02	2.32	0.93	2.16
19.5	1	9.30	0.78	0.61	0.8	0.871	732	60	732	0.68	2.21	2.54	0.78	1.97
20.5	1	9.30	0.78	0.61	0.8	0.871	758	60	758	0.70	2.29	2.63	0.78	2.04
21.5	1	8.60	0.72	0.55	0.8	0.871	554	60	554	0.52	1.72	1.97	0.72	1.41
22.5	1	8.00	0.67	0.50	0.8	0.871	797	60	797	0.73	2.40	2.75	0.67	1.83
23.5	1	6.30	0.53	0.36	0.7	0.953	726	60	726	0.67	2.20	2.31	0.53	1.21
24.5	1	6.50	0.54	0.38	0.7	0.953	627	60	627	0.59	1.92	2.02	0.54	1.09
25.5	1	6.50	0.54	0.38	0.7	0.953	527	60	527	0.50	1.64	1.72	0.54	0.93
26.5	1	5.70	0.48	0.31	0.6	1.000	359	60	359	0.36	1.17	1.17	0.48	0.56
27.5	0.875	4.50	0.38	0.21	0.6	1.000	---	---	---	---	0.1[1]	0.10	0.33	0.03
28.25	0.375	0.0	0.0	---	---	---	---	---	---	---	---	---	---	---
												Total Discharge (cfs):		17.55
												Total Area (ft^2):		8.86
												Mean Velocity (ft/sec):		1.98
												Observed Surface Velocity (ft/sec):		3.48

* Data measured in field.

[1] Estimated value.

Aravaipa Creek: AC-2 (July 4, 1999; 7:20 to 7:28 a.m.)														
Distance (Station) (ft)*	Width (ft)	Water Depth (in)*	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
13.9	1.3	0.00	0.00	---	---	---	---	---	---	---	---	---	---	---
16.5	2.8	8.70	0.73	0.56	0.8	0.871	423	60	423	0.41	1.35	1.55	2.03	3.14
19.5	3	9.30	0.78	0.61	0.8	0.871	436	60	436	0.42	1.39	1.59	2.33	3.70
22.5	3	8.00	0.67	0.50	0.8	0.871	946	60	946	0.86	2.81	3.23	2.00	6.46
25.5	3	6.50	0.54	0.38	0.7	0.953	648	60	648	0.60	1.98	2.08	1.63	3.37
28.5	1.5	0.00	0.00	---	---	---	---	---	---	---	---	---	---	---
												Total Discharge (cfs):		16.68
												Total Area (ft^2):		7.98
												Mean Velocity (ft/sec):		2.09
												Observed Surface Velocity (ft/sec):		3.48

* Data measured in field.

Aravaipa Creek: AC-3 (July 4, 1999; approx. 7:00 p.m.)

Distance (Station) (ft)*	Width (ft)	Water Depth (in)*	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)*	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
0.3	0.25	20.20	1.68		---	---	---	---	---	---	---	---	---	---
0.8	0.50	21.00	1.75		0.8	0.871	249	30	498	0.47	1.54	1.66	0.88	1.45
					0.2	1.149	290	30	580	0.54	1.77			
1.3	0.50	20.00	1.67		0.8	0.871	215	30	430	0.41	1.36	1.57	0.83	1.31
					0.2	1.149	294	30	588	0.55	1.79			
1.8	0.50	19.00	1.58		0.8	0.871	205	30	410	0.40	1.30	1.55	0.79	1.23
					0.2	1.149	296	30	592	0.55	1.80			
2.3	0.50	17.90	1.49		0.8	0.871	233	30	466	0.44	1.46	1.60	0.75	1.19
					0.2	1.149	284	30	568	0.53	1.74			
2.8	0.50	17.00	1.42		0.8	0.871	229	30	458	0.44	1.43	1.53	0.71	1.09
					0.2	1.149	265	30	530	0.50	1.63			
3.3	0.50	16.00	1.33		0.8	0.871	287	30	574	0.54	1.75	1.67	0.67	1.12
					0.2	1.149	258	30	516	0.49	1.59			
3.8	0.50	15.10	1.26		0.8	0.871	211	30	422	0.41	1.33	1.16	0.63	0.73
					0.2	1.149	479[1]	30						
4.3	0.60	13.90	1.16		0.8	0.871	198	30	396	0.38	1.26	1.50	0.70	1.04
					0.2	1.149	283	30	566	0.53	1.73			
5.0	0.85	10.25	0.85		0.6	1.000	282	30	564	0.53	1.73	1.73	0.73	1.25
6.0	1.00	7.50	0.63		0.6	1.000	260	30	520	0.49	1.61	1.61	0.63	1.00
7.0	1.00	6.25	0.52		0.6	1.000	243	30	486	0.46	1.51	1.51	0.52	0.79
8.0	1.00	5.40	0.45	0.28	0.6	1.000	261	30	522	0.49	1.61	1.61	0.45	0.72
9.0	1.00	5.10	0.43	0.26	0.6	1.000	255	30	510	0.48	1.58	1.58	0.43	0.67
10.0	1.00	4.50	0.38	0.21	0.6	1.000	230	30	460	0.44	1.44	1.44	0.38	0.54
11.0	0.65	3.60	0.30	0.13	0.4	1.108	205	30	410	0.40	1.30	1.17	0.20	0.23
11.3	0.85	3.25	0.27	---	---	---	---	---	---	---	---	---	---	---
12.7	0.70	0.00	0.00	---	---	---	---	---	---	---	---	---	---	---

Total Discharge (cfs): 14.36
Total Area (ft^2): 9.26
Mean Velocity (ft/sec): 1.55
Observed Surface Velocity (ft/sec): 2.30

* Data measured in field.

[1] Questionable measurement. Did not use to calculate discharge.

Aravaipa Creek: AC-3 (July 5, 1999; 7:02 to 7:26 a.m.)

Distance (Station) (ft)*	Width (ft)	Water Depth (in)*	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
0.3	0.25	20.20	1.68		---	---	---	---	---	---	---	---	---	---
0.8	0.50	21.00	1.75		0.8	0.871	307	30	614	0.57	1.87	1.93	0.88	1.69
					0.2	1.149	331	30	662	0.61	2.00			
1.3	0.50	20.00	1.67		0.8	0.871	288	30	576	0.54	1.76	1.86	0.83	1.55
					0.2	1.149	325	30	650	0.60	1.97			
1.8	0.50	19.00	1.58		0.8	0.871	267	30	534	0.50	1.64	1.83	0.79	1.45
					0.2	1.149	335	30	670	0.62	2.02			
2.3	0.50	17.90	1.49		0.8	0.871	288	30	576	0.54	1.76	1.94	0.75	1.44
					0.2	1.149	351	30	702	0.64	2.11			
2.8	0.50	17.00	1.42		0.8	0.871	283	30	566	0.53	1.73	1.89	0.71	1.34
					0.2	1.149	339	30	678	0.62	2.04			
3.3	0.50	16.00	1.33		0.8	0.871	281	30	562	0.52	1.72	1.87	0.67	1.25
					0.2	1.149	334	30	668	0.61	2.02			
3.8	0.50	15.10	1.26		0.8	0.871	276	30	552	0.52	1.69	1.90	0.63	1.20
					0.2	1.149	352	30	704	0.64	2.12			
4.3	0.60	13.90	1.16		0.8	0.871	236	30	472	0.45	1.47	1.75	0.70	1.21
					0.2	1.149	335	30	670	0.62	2.02			
5.0	0.85	10.25	0.85		0.6	1.000	287	30	574	0.54	1.75	1.75	0.73	1.27
6.0	1.00	7.50	0.63		0.6	1.000	338	30	676	0.62	2.04	2.04	0.63	1.27
7.0	1.00	6.25	0.52		0.6	1.000	318	30	636	0.59	1.93	1.93	0.52	1.00
8.0	1.00	5.40	0.45	0.28	0.6	1.000	572	60	572	0.53	1.75	1.75	0.45	0.79
9.0	1.00	5.10	0.43	0.26	0.6	1.000	252	30	504	0.48	1.56	1.56	0.43	0.66
10.0	1.00	4.50	0.38	0.21	0.6	1.000	284	30	568	0.53	1.74	1.74	0.38	0.65
11.0	0.65	3.60	0.30	0.13	0.4	1.108	253	30	506	0.48	1.57	1.41	0.20	0.28
11.3	0.85	3.25	0.27	---	---	---	---	---	---	---	---	---	---	---
12.7	0.70	0.00	0.00	---	---	---	---	---	---	---	---	---	---	---

Total Discharge (cfs): 17.06
Total Area (ft^2): 9.26
Mean Velocity (ft/sec): 1.84
Observed Surface Velocity (ft/sec): 2.30

* Data measured in field.

Aravaipa Creek: Upstream of Deer Creek (November 19, 1999; 2:30 to 3:20 p.m.)													
Distance (Station) (ft)*	Width (ft)*	Water Depth (ft)*	Vel. Obs. Depth (ft)*	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
21	0.7	.05	n/a[1]	0.2[2]	0.871	44	60	44	0.09	0.29	0.33	0.04	0.01
22	1	0.09	n/a[1]	0.2[2]	0.871	89	60	89	0.13	0.41	0.47	0.09	0.04
23	1	0.16	n/a[1]	0.2[2]	0.871	222	60	222	0.24	0.79	0.90	0.16	0.14
24	1	0.22	0.05	0.2	0.871	444	60	444	0.43	1.41	1.62	0.22	0.36
25	1	0.27	0.10	0.4	1.108	536	60	536	0.51	1.67	1.50	0.27	0.41
26	1	0.32	0.15	0.5	1.067	425	60	425	0.41	1.35	1.27	0.32	0.41
27	1	0.44	0.22	0.5	1.067	728	60	728	0.67	2.20	2.06	0.44	0.91
28	1	0.53	0.27	0.5	1.067	748	60	748	0.69	2.26	2.12	0.53	1.12
29	1	0.58	0.29	0.5	1.067	875	60	875	0.80	2.61	2.45	0.58	1.42
30	1	0.63	0.32	0.5	1.067	897	60	897	0.82	2.68	2.51	0.63	1.58
31	1	0.67	0.34	0.5	1.067	1122	65	1036	0.93	3.07	2.87	0.67	1.92
32	1	0.63	0.32	0.5	1.067	1048	60	1048	0.94	3.10	2.90	0.63	1.83
33	1	0.63	0.32	0.5	1.067	1049	60	1049	0.95	3.10	2.91	0.63	1.83
34	1	0.60	0.30	0.5	1.067	965	60	965	0.87	2.87	2.69	0.60	1.61
35	1	0.50	0.25	0.5	1.067	889	60	889	0.81	2.65	2.49	0.50	1.24
36	1	0.40	0.23	0.6	1.000	708	60	708	0.65	2.15	2.15	0.40	0.86
37	1	0.08	n/a[1]	0.6[2]	1.000	142	60	142	0.17	0.56	0.56	0.08	0.04
38	1	0.05	n/a[1]	0.6[2]	1.000	71	60	71	0.11	0.36	0.36	0.05	0.02
39	1	0.00	n/a[1]	0.6[2]	1.000	0	60	0	0.00	0.00	0.00	0.00	0.00
40	1	0.02	n/a[1]	0.4[2]	1.108	68	60	68	0.11	0.36	0.32	0.02	0.01
41	1	.06	n/a[1]	0.4[2]	1.108	137	60	137	0.17	0.55	0.49	0.06	0.03
42	1	.12	n/a[1]	0.4[2]	1.108	342	60	342	0.34	1.12	1.01	0.12	0.12
43	1	0.17	n/a[1]	0.4[2]	1.108	615	60	615	0.57	1.89	1.70	0.17	0.29
44	1	0.29	0.12	0.4	1.108	683	60	683	0.63	2.08	1.87	0.29	0.54
45	1	0.43	0.26	0.6	1.000	732	60	732	0.68	2.21	2.21	0.43	0.95
46	1	0.43	0.22	0.5	1.067	830	60	830	0.76	2.49	2.33	0.43	1.00
47	1	0.43	0.22	0.5	1.067	837	63	797	0.73	2.40	2.25	0.43	0.97
48	1	0.43	0.22	0.5	1.067	790	60	790	0.72	2.38	2.23	0.43	0.96
49	1	0.47	0.24	0.5	1.067	632	60	632	0.59	1.93	1.81	0.47	0.85
50	1.3	0.48	0.24	0.5	1.067	545	60	545	0.52	1.69	1.58	0.62	0.99
												Total Discharge (cfs):	22.47
												Total Area (ft^2):	10.31
												Mean Velocity (ft/sec):	2.18

Aravaipa Creek: Downstream of Deer Creek (November 19, 1999; 4:00 to 4:45 p.m.)													
Distance (Station) (ft)*	Width (ft)	Water Depth (ft)	Vel. Obs. Depth (ft)	Ratio Obs D:Water D (nearest tenth)	Coefficient for standard vertical-velocity curve	Revolutions*	Time (sec)*	Revolutions/ Minute	Velocity at Obs. D (m/sec)	Velocity at Obs. D (ft/sec)	Mean Velocity in Vertical (ft/sec)	Area (ft^2)	Discharge (cfs)
8	1.7	0.22	n/a[1]	0.5[2]	1.067	375	60	375	0.37	1.21	1.14	0.37	0.43
9	1	0.48	0.24	0.5	1.067	749	60	749	0.69	2.26	2.12	0.48	1.02
10	1	0.58	0.29	0.5	1.067	855	60	855	0.78	2.56	2.40	0.58	1.39
11	1	0.58	0.29	0.5	1.067	1125	60	1125	1.01	3.32	3.11	0.58	1.80
12	1	0.75	0.38	0.5	1.067	1136	60	1136	1.02	3.35	3.14	0.75	2.35
13	1	0.82	0.41	0.5	1.067	1081	60	1081	0.97	3.19	2.99	0.82	2.45
14	1	0.80	0.40	0.5	1.067	1088	60	1088	0.98	3.21	3.01	0.80	2.41
15	1	0.83	0.42	0.5	1.067	1089	60	1089	0.98	3.21	3.01	0.83	2.50
16	1	0.85	0.43	0.5	1.067	1023	60	1023	0.92	3.03	2.84	0.85	2.41
17	1	0.84	0.42	0.5	1.067	1006	60	1006	0.91	2.98	2.79	0.84	2.35
18	1	0.76	0.38	0.5	1.067	1077	60	1077	0.97	3.18	2.98	0.76	2.27
19	1	0.63	0.32	0.5	1.067	726	60	726	0.67	2.20	2.06	0.63	1.30
20	1	0.57	0.29	0.5	1.067	383	60	383	0.38	1.24	1.16	0.57	0.66
21	1	0.34	n/a[1]	0.5[2]	1.067	230	60	230	0.25	0.81	0.76	0.34	0.26
22	0.8	0.10	n/a[1]	0.5[2]	1.067	38	60	38	0.08	0.27	0.25	0.08	0.02
												Total Discharge (cfs):	23.61
												Total Area (ft^2):	9.28
												Mean Velocity (ft/sec):	2.54

* Data measured in field.

[1] No direct velocity measurement taken. Water was too shallow for instrument to function.

[2] Assume ratio is same as the measured value used for revolution estimations.

Appendix B

Aravaipa Canyon Well Inventory

USGS LOCATION	REGIS-TRATION #	OWNER	WATER USE	WELL DEPTH	WATER LEVEL	CASING DEPTH
D-06-17 13 DB			IRRIGATION	12		
D-06-17 13 DBB1	55-620719	MULVANIA,R L	IRRIGATION			
D-06-17 13 DBB2	55-643406	BLM-SAFFORD DISTRICT,	STOCK			
D-06-17 23 DAD			DOMESTIC	17		
D-06-17 23 DDD1	55-619593	NATURE CONSERVANCY,	DOMESTIC			
D-06-17 23 DDD2	55-806874	GORMAN, CATHERINE,J	IRRIGATION	42	10	40
D-06-17 23 DDD3	55-806875	GORMAN, CATHERINE,J	IRRIGATION	42	10	40
D-06-17 24 BBA1	55-620716	MULVANIA,R L	IRRIGATION			
D-06-17 24 BBA2	55-620720	MULVANIA,R L	DOMESTIC			
D-06-17 24 CBA1			DOMESTIC	23		
D-06-17 24 CBA2			DOMESTIC	24		
D-06-17 24 CBB	55-619594	NATURE CONSERVANCY,	DOMESTIC			
D-06-17 26 AAA1			DOMESTIC			
D-06-17 26 AAA2	55-806631	O'NEIL, JAMES,T	IRRIGATION			
D-06-17 26 AAA3	55-806632	O'NEIL, JONES,T	IRRIGATION			
D-06-17 26 AAB1	55-806629	O'NEIL, JONES T.,	DOMESTIC			
D-06-17 26 AAB2	55-806630	O'NEIL, JAMES T.,	DOMESTIC			
D-06-17 26 AAB3	55-806633	O'NEIL, JONES,T	IRRIGATION			
D-06-17 26 AAC1	55-806620	LARSEN, MARY,K	IRRIGATION			
D-06-17 26 AAC2	55-806621	LARSEN, MARY,K	DOMESTIC			
D-06-17 26 ACA			DOMESTIC			
D-06-17 26 BDA1			DOMESTIC	54		
D-06-17 26 BDA2			UNUSED			
D-06-17 26 C1	55-612948	CATLIN,D G	IRRIGATION	30	12	30
D-06-17 26 C2	55-618440	ARAVAIPA ENTERPRISE,	IRRIGATION	29	14	19
D-06-17 26 C3	55-618441	ARAVAIPA ENTERPRISE,	IRRIGATION	28	12	28
D-06-17 26 CBD			DOMESTIC			
D-06-17 26 CCA			DOMESTIC	37		
D-06-17 26 CCB1	55-603731	LUEBBERMANN, TONY,	DOMESTIC	42	19	42
D-06-17 26 CCB2			DOMESTIC	21		
D-06-17 26 CCD	55-507524	ARAVAIPA ENTERPRISE,	IRRIGATION			
D-06-17 34 A	55-637284	WHITE,J	DOMESTIC	20	18	14
D-06-17 34 AAA	55-528476	WHITE,,J O	IRRIGATION	54	15	54
D-06-17 34 ACA1	55-648741	BARASSI,L	DOMESTIC	35	12	35
D-06-17 34 ACA2	55-648742	BARASSI,L	DOMESTIC	25	3	
D-06-17 34 ACC	55-528178	BARASSI, LOUIS,W	IRRIGATION	62	15	58
D-06-17 34 CAD1	55-522863	JONES II, DAN,	DOMESTIC	54	22	54
D-06-17 34 CAD2	55-529934	BRASELY, SHERRIE,	DOMESTIC	54	27	54
D-06-17 34 CCA1	55-603062	YOUNG,L	IRRIGATION	32	12	32
D-06-17 34 CCA2	55-603063	YOUNG,L	DOMESTIC	38	22	38
D-06-17 34 CCA3	55-637752	YOUNG,L B	DOMESTIC	39	22	39
D-06-17 34 CCD	55-623331	YOUNG,H D	DOMESTIC	46	20	46
D-06-17 35 CBB		KENNICOTT COPPER CO		1000		
D-06-18 32 CBD		BROS. WOOD	STOCK	500		
D-06-18 32 CCA	55-615445	BLM-PHOENIX DISTRICT,	STOCK			500
D-06-18 32 CDB	55-644967	BLM-SAFFORD DISTRICT,	STOCK	500	468	73
D-06-19 03 BA	55-608762	CLARIDGE, WILFORD,H	STOCK	110	90	12
D-06-19 05 BAA	55-615446	BLM-PHOENIX DISTRICT,	DOMESTIC			
D-06-19 07 AAA	55-616473	BLM-PHOENIX DISTRICT,	DOMESTIC			
D-06-19 08 BB	55-646753	DECKER RANCHES,	DOMESTIC	250	100	220
D-06-19 08 BBC	55-615447	DECKER RANCHES,	DOMESTIC	223	110	204
D-06-19 12 CD	55-608765	CLARIDGE, WILFORD,H	DOMESTIC	120	90	120
D-06-19 19 ADA	55-619600	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 19 ADC	55-619601	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 21 CAC	55-537630	TAPIA, DANIEL & DALE,	DOMESTIC	50	22	50

USGS LOCATION	REGIS- TRATION #	OWNER	WATER USE	WELL DEPTH	WATER LEVEL	CASING DEPTH
D-06-19 21 CBA	55-619599	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 21 CDA1	55-642966	TAPIA,V S	DOMESTIC	17	10	17
D-06-19 21 CDA2	55-642968	MIRANDA,R	DOMESTIC	17	15	15
D-06-19 21 CDB			DOMESTIC			
D-06-19 21 CDD1			UNUSED			
D-06-19 21 CDD2			DOMESTIC			
D-06-19 21 CDD3	55-649375	PACHECO,A A	DOMESTIC	20	15	
D-06-19 21 DCC	55-619598	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 25 CAC	55-806346	AGRO LAND & CATTLE,	INDUSTRIAL	134	75	
D-06-19 25 CCA	55-803711	COBRA RANCH	DOMESTIC	91	45	91
D-06-19 27 CB	55-608767	CLARIDGE, WILFORD,H	DOMESTIC	25	12	25
D-06-19 27 CDB			DOMESTIC			
D-06-19 27 CDC	55-619596	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 27 DCD	55-619595	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 27 DDD1	55-549021	STAMPFER, MARTHA,	DOMESTIC	86	60	86
D-06-19 27 DDD2	55-803496	COVEY, ASALEE,L	DOMESTIC	9	9	
D-06-19 28 ADB		CLAY TURMBELL	DOMESTIC			
D-06-19 28 ADD	55-619597	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 28 BAD	55-642967	BLM-PHOENIX DISTRICT,	DOMESTIC	19	16	12
D-06-19 34 AAA	55-619592	NATURE CONSERVANCY,	DOMESTIC			
D-06-19 34 ABA1			UNUSED			
D-06-19 34 ABA2		JOHN FRANZONE	DOMESTIC			
D-06-19 34 ABB	55-645898	BRYCE,D	DOMESTIC	30		30
D-06-19 35 ABC	55-619590	DEFENDERS WILDLIFE,	IRRIGATION			
D-06-19 35 ADA		COBRA RANCH	DOMESTIC	35	20.4	
D-06-19 35 ADC			STOCK			
D-06-19 35 BAD			IRRIGATION	150		
D-06-19 35 BBA	55-619591	NATURE CONSERVANCY,	IRRIGATION			
D-06-19 35 BBB1		CLAY TURNBULL	DOMESTIC	49	6	
D-06-19 35 BBB2			UNUSED			
D-06-19 35 DAA1	55-805781	BATES, DANIEL M,	DOMESTIC			
D-06-19 35 DAA2	55-805782	BATES, DANIEL M,	IRRIGATION	20		
D-06-19 35 DAA3		COBRA RANCH	DOMESTIC			
D-06-19 35 DAB		COBRA RANCH	UNUSED			
D-06-19 36 BCC1	55-803712	AGRO LAND & CATTLE,	DOMESTIC	47	14	47
D-06-19 36 BCC2	55-806345	AGRO LAND & CATTLE,	DOMESTIC			
D-06-19 36 CAB	55-500877	AGO LAND & CATTLE,	IRRIGATION	116	11	116
D-06-19 36 CDA		COBRA RANCH	IRRIGATION			
D-06-19 36 CDD			IRRIGATION			
D-06-20 05 CBA	55-615448	AZ STATE LAND DEPT,	STOCK	25	15	8
D-06-20 05 CBB	55-608764	CLARIDGE, WILFORD,H	STOCK	25	15	8
D-06-20 18 DCC1	55-615449	AZ STATE LAND DEPT,	STOCK	100		
D-06-20 18 DCC2	55-647917	DOWDLE, GLEN,H	DOMESTIC			
D-06-20 19 CCC1	55-615450	AZ STATE LAND DEPT,	STOCK	110	100	
D-06-20 19 CCC2	55-647918	DOWDLE, GLEN,H	DOMESTIC			
D-06-20 19 CCC3			STOCK			
D-06-20 20 DC	55-503082	OWENS,D	DOMESTIC			
D-06-20 32 CCC	55-647920	DOWDLE, GLEN,H	DOMESTIC			
D-06-20 32 CCD	55-615451	AZ STATE LAND DEPT,	STOCK	90	25	
D-07-17 04 ADA	55-545355	GELDMACHER, DONALD,	DOMESTIC	43	22	43
D-07-17 04 ADB	55-610274	DORTCH, WILLIS R	IRRIGATION	50	14	50
D-07-17 04 C	55-618156	RUBIN,J W	IRRIGATION	25	12	25
D-07-17 04 CCB	55-802040	BURGE, JESSE & ANN,	IRRIGATION	405	300	
D-07-17 04 CDB	55-545614	HARRIS, JERRY,W	DOMESTIC	257	165	257
D-07-17 04 CDD	55-610253	B M & R M MILLER,	STOCK	67	18	65

USGS LOCATION	REGIS-TRATION #	OWNER	WATER USE	WELL DEPTH	WATER LEVEL	CASING DEPTH
D-07-17 04 DBA1	55-651292	FARNEY, WILLIAM & F,	IRRIGATION	15	10	15
D-07-17 04 DBA2	55-651293	FARNEY,W C	IRRIGATION	15	10	15
D-07-17 04 DBA3	55-651294	FARNEY,W C	DOMESTIC	30	25	30
D-07-17 04 DBA4	55-651295	SAMOYLOFF,R	DOMESTIC	30	25	30
D-07-17 04 DC1	55-617034	WALLACE,A N	IRRIGATION	40	6	45
D-07-17 04 DC2	55-617035	WALLACE,A N	DOMESTIC	20	10	20
D-07-17 09 BBC	55-086759	WOOD,CLIFFORD,	DOMESTIC	171	46	171
D-07-17 09 BBD	55-610252	MILLER, CATHERINE,B	IRRIGATION	76	18	70
D-07-17 09 BCB1	55-802041	WOOD,C C	IRRIGATION	65	9	65
D-07-17 09 BCB2	55-806141	NEWTON, EDWARD,B	DOMESTIC	65	18	65
D-07-17 09 BCB3	55-806142	NEWTON, EDWARD,B	DOMESTIC	65	120	65
D-07-17 11 CAA1	55-610254	MILLER, CATHERINE,B	DOMESTIC	200	6	180
D-07-17 11 CAA2	55-610255	MILLER, CATHERINE,B	STOCK	150		150
D-07-18 04 AAB1	55-615481	BLM-PHOENIX DISTRICT,	STOCK	610	275	
D-07-18 04 AAB2			DOMESTIC	605		
D-07-18 04 B	55-644966	BLM-SAFFORD DISTRICT,	STOCK	606	570	606
D-07-18 08 BCB			STOCK			
D-07-18 17 BCA	55-610258	MILLER, CATHERINE,B	STOCK			84
D-07-18 17 CBB	55-610256	MILLER, CATHERINE,B	STOCK			40
D-07-19 01 AAD1			UNUSED			
D-07-19 01 AAD2			DOMESTIC			
D-07-19 01 AAD3	55-647915	DOWDLE, GLEN,H	DOMESTIC			
D-07-19 01 AAD4	55-647916	DOWDLE, GLEN,H	DOMESTIC			
D-07-19 01 AAD5	55-803710	AGRO LAND & CATTLE,	IRRIGATION	125	20	125
D-07-19 01 ABD		COBRA RANCH	IRRIGATION			
D-07-19 01 ADD	55-604946	SOLLERS, W. BILL,	STOCK	150	60	150
D-07-19 01 BAB	55-643369	HABY RANCH,	STOCK			
D-07-19 01 CAD	55-615482	AZ STATE LAND DEPT,	STOCK	270	125	
D-07-19 16 ABB	55-615483	AZ STATE LAND DEPT,	STOCK	16	12	
D-07-19 25 DDD1	55-612042	ROUSE, KIRRILLA,B	STOCK	560	80	560
D-07-19 25 DDD2	55-615484	AZ STATE LAND DEPT,	STOCK	563	470	563
D-07-19 26 CDA	55-552109	LACKNER, EDDIE,	STOCK	107	73	107
D-07-19 26 DBC	55-552104	LACKNER, EDDIE,	DOMESTIC	215	75	199
D-07-19 27 CCC1	55-612030	ROUSE, KIRRILLA,B	IRRIGATION	85		85
D-07-19 27 CCC2	55-612031	ROUSE, KIRRILLA,B	IRRIGATION	85		85
D-07-20 04 DD			STOCK	715		
D-07-20 06 AAA	55-568344	BARNARD, LORI AND MIKE	DOMESTIC			
D-07-20 06 BCC1	55-604947	SOLLERS, W. BILL,	STOCK	150	60	150
D-07-20 06 BCC2		L STANFORD	UNUSED	80		
D-07-20 06 CAC1			UNUSED			
D-07-20 06 CAC2			UNUSED			
D-07-20 06 CB	55-608758	STODDARD, JOHN,H	STOCK	160	25	160
D-07-20 06 CD1	55-564995	ARIZONA DEPT OF ENVIROMEN	NONE	66	45	
D-07-20 06 CD2	55-608757	CLARIDGE, WILFORD,H	MINING	215	21	215
D-07-20 06 CD3	55-608759	CLARIDGE, WILFORD,H	STOCK	140	22	140
D-07-20 06 CD4	55-608760	CLARIDGE, WILFORD,H	STOCK	120	22	120
D-07-20 06 CDC			UNUSED			
D-07-20 06 DBC1			UNUSED			
D-07-20 06 DBC2	55-646404	SCHNELL,J H	DOMESTIC	110	40	110
D-07-20 06 DBD1	55-087459	SCHNELL,J	DOMESTIC			
D-07-20 06 DBD2	55-503101	SCHNELL,J	DOMESTIC			
D-07-20 06 DCC	55-647919	DOWDLE,G H	DOMESTIC			
D-07-20 07 BDA1	55-643368	HABY RANCH,	STOCK			
D-07-20 07 BDA2			STOCK			
D-07-20 07 CAA	55-643367	HABY RANCH,	STOCK			

USGS LOCATION	REGIS-TRATION #	OWNER	WATER USE	WELL DEPTH	WATER LEVEL	CASING DEPTH
D-07-20 07 DCA			UNUSED			
D-07-20 07 DCD1	55-643366	HABY RANCH,	DOMESTIC			
D-07-20 07 DCD2		BILL SOLLERS	DOMESTIC	160		
D-07-20 07 DDA1	55-645601	LUEPKE, JOHN,	DOMESTIC	100	60	100
D-07-20 07 DDA2		WHITING	DOMESTIC			
D-07-20 07 DDB		ALAN JERERY	DOMESTIC			
D-07-20 07 DDD	55-525719	SOLLERS, BILL,	DOMESTIC	160	80	160
D-07-20 08 BBB		CLARIDGE		92		
D-07-20 08 CCC		GRAHAM COUNTY	DOMESTIC			
D-07-20 08 CCD			DOMESTIC			
D-07-20 08 CDC	55-645604	KAIBAB INDUSTRIES,	STOCK	120	65	85
D-07-20 08 CDD		WEATHERSBY	UNUSED			
D-07-20 09 ADC	55-645602	KAIBAB INDUSTRIES,	STOCK	360	200	360
D-07-20 12 ACC	55-645606	KAIBAB INDUSTRIES,	STOCK	80	20	80
D-07-20 14 CDC	55-805995	AZ STATE LAND DEPT,	STOCK		100	
D-07-20 16 CCC	55-645607	KAIBAB INDUSTRIES,	DOMESTIC	110	58	100
D-07-20 17 BA	55-805785	KAIBAB INDUSTRIES,	STOCK			
D-07-20 17 BCA			STOCK			
D-07-20 17 CAA	55-604312	LECOUNT, KAREN C	STOCK	100	35	100
D-07-20 17 CAD	55-604312	KAIBAB INDUSTRIES	STOCK	100		
D-07-20 17 DDA			IRRIGATION			
D-07-20 18 ADA	55-571726	HABY RANCH PARTNERSHIP	DOMESTIC			
D-07-20 18 BAB	55-643403	BLM-SAFFORD DISTRICT,	RECREATION	139	111	139
D-07-20 20 AAA	55-553455	CAVENDER, MICHAEL & SUSAN	DOMESTIC	100	48	100
D-07-20 21 BBC	55-613297	CAVENDER, MICHAEL,J	IRRIGATION	150	84	136
D-07-20 21 BDA1	55-613296	CAVENDER, MICHAEL,J	IRRIGATION	152	51	132
D-07-20 21 BDA2	55-645605	CAVENDER, MICHAEL & SUSAN	STOCK	100	27	100
D-07-20 21 BDB1	55-613295	CAVENDER, MICHAEL,J	IRRIGATION	762	27	762
D-07-20 21 BDB2			IRRIGATION	150		
D-07-20 21 CAD	55-604314	LECOUNT, KAREN C	STOCK	75	35	75
D-07-20 21 DAB1			UNUSED			
D-07-20 21 DAB2			STOCK			
D-07-20 21 DAC	55-645603	KAIBAB INDUSTRIES,	STOCK	100	50	80
D-07-20 25 DAB				847		
D-07-20 26 CBA	55-542345	LACKNER, HAROLD,	DOMESTIC	90	12	90
D-07-20 27 ADA		CARL BOTT		90	16	
D-07-20 27 ADB	55-627558	HUGHES,P	STOCK			180
D-07-20 27 ADC1	55-627559	HUGHES,P	DOMESTIC			35
D-07-20 27 ADC2		ZACHEK	DOMESTIC			
D-07-20 27 ADD1		ZACHEK	UNUSED			
D-07-20 27 ADD2			IRRIGATION			
D-07-20 27 BAD	55-604313	LECOUNT, KAREN C	DOMESTIC	100	35	100
D-07-20 27 BDA	55-604311	LECOUNT, KAREN C	IRRIGATION	110	30	110
D-07-20 27 BDD	55-650401	HUFF,J W	DOMESTIC	100		100
D-07-20 27 DAA1	55-615486	AZ STATE LAND DEPT,	IRRIGATION	25	25	25
D-07-20 27 DAA2		ZACHEK	IRRIGATION			
D-07-20 27 DAD	55-627557	HUGHES,P	IRRIGATION			250
D-07-20 27 DBD1		ZACHEK	UNUSED	95		
D-07-20 27 DBD2		SONG OF THE DESERT 3		180	9.5	
D-07-20 27 DCA	55-624814	LACKNER, HAROLD,	STOCK	80	25	80
D-07-20 27 DCB		CLARIDGE		78		
D-07-20 27 DDB		CARL BOTT	IRRIGATION	180		
D-07-20 28 BDA		CLARIDGE		102		
D-07-20 30 BC2	55-542344	HAROLD LACKNER	DOMESTIC	90		
D-07-20 33 BAB	55-615487	AZ STATE LAND DEPT,	STOCK			

USGS LOCATION	REGIS- TRATION #	OWNER	WATER USE	WELL DEPTH	WATER LEVEL	CASING DEPTH
D-07-20 33 CAB	55-615488	AZ STATE LAND DEPT,	STOCK			
D-07-20 33 CCA	55-615489	AZ STATE LAND DEPT,	STOCK			
D-07-20 34 AAA	55-624813	LACKNER, HAROLD,	IRRIGATION	90	30	90
D-07-20 34 ABB		ANDERSON	IRRIGATION			
D-07-20 35 BBC1		LACKNER	DOMESTIC			
D-07-20 35 BBC2	55-624819	LACKNER, HAROLD,	STOCK	65	35	65
D-07-20 35 BBD	55-542344	LACKNER, HAROLD,	DOMESTIC	145	22	140
D-07-20 35 BDA	55-604888	HARALSON,A E	IRRIGATION	80	30	

Appendix C

Groundwater Levels in Aravaipa Canyon Wells

USGS LOCATION	DATE MEASURED	DEPTH TO WATER	WATER ELEVATION
D-06-17 13 DB	10/10/50	7.86	2622
D-06-17 23 DAD	4/15/66	11.34	2589
D-06-17 23 DDD1	4/13/66	6.62	2573
D-06-17 24 CBA2	4/15/66	10.67	2589
D-06-17 26 ACA	4/13/66	13.9	2536
D-06-17 26 BDA1	4/13/66	15.75	2524
D-06-17 26 BDA2	4/13/66	9.89	2530
D-06-17 26 CBD	4/12/66	12.86	2512
D-06-17 26 CCA	4/12/66	10.52	2509
D-06-17 26 CCB1	4/12/66	11.66	2508
D-06-19 21 CDB	1/7/76	17	3163
D-06-19 21 CDD1	12/5/90	10.02	3185
D-06-19 21 DCC	12/5/90	8	3187
D-06-19 25 CAC	12/5/90	44.3	3406
D-06-19 25 CCA	1/1/79	45	3400
D-06-19 25 CCA	1/1/83	41	3404
D-06-19 25 CCA	12/5/90	64.2	3376
D-06-19 27 CDB	12/5/90	15.7	3234
D-06-19 28 ADB	1/7/76	12	3218
D-06-19 28 ADD	12/5/90	20.04	3210
D-06-19 34 AAA	12/5/90	10.47	3250
D-06-19 34 AAA	11/21/96	11.33	3249
D-06-19 34 ABA2	12/5/90	13.93	3264
D-06-19 34 ABA2	11/21/96	14.38	3264
D-06-19 35 ADA	7/22/83	24	3326
D-06-19 35 ADA	12/5/90	29.5	3321
D-06-19 35 ADA	11/21/96	26.2	3324
D-06-19 35 ADC	1/7/76	14	3346
D-06-19 35 BAD	5/11/53	8.98	3301
D-06-19 35 BBB1	5/20/58	6	3269
D-06-19 35 BBB1	7/19/83	8.5	3266
D-06-19 35 DAA3	2/23/49	17.15	3293
D-06-19 35 DAA3	11/27/49	17.7	3292
D-06-19 35 DAA3	3/9/50	17.3	3293
D-06-19 35 DAA3	3/13/51	18.72	3291
D-06-19 35 DAA3	2/5/52	16.45	3294
D-06-19 35 DAA3	7/18/52	17.8	3292
D-06-19 35 DAA3	12/1/52	15.98	3294
D-06-19 35 DAA3	1/20/53	15.58	3294
D-06-19 35 DAA3	5/11/53	16.46	3294
D-06-19 35 DAA3	7/23/53	17.78	3292
D-06-19 35 DAA3	12/18/53	18.48	3292
D-06-19 35 DAA3	1/25/54	18.19	3292
D-06-19 35 DAA3	5/20/54	18.82	3291
D-06-19 35 DAA3	8/24/54	17.75	3292
D-06-19 35 DAA3	11/16/54	18.67	3291
D-06-19 35 DAA3	2/1/55	18.45	3292
D-06-19 35 DAA3	3/23/55	19.25	3291
D-06-19 35 DAA3	10/6/55	20.4	3290
D-06-19 35 DAA3	12/18/55	20.55	3289
D-06-19 35 DAA3	1/25/57	22.4	3288
D-06-19 35 DAA3	12/18/57	18.17	3292

USGS LOCATION	DATE MEASURED	DEPTH TO WATER	WATER ELEVATION
D-06-19 35 DAA3	12/4/90	11.8	3298
D-06-19 35 DAA3	11/21/96	9.3	3301
D-06-19 35 DAB	12/4/90	12.54	3297
D-06-19 35 DAB	11/21/96	11.93	3298
D-06-19 36 BCC1	10/1/73	14	3321
D-06-19 36 BCC1	7/19/83	16	3319
D-06-19 36 CAB	2/1/82	11	3364
D-06-19 36 CAB	7/19/83	7	3368
D-06-19 36 CDA	12/4/90	14.27	3331
D-06-19 36 CDA	11/21/96	10.31	3335
D-06-20 05 CBB	1/1/66	10	4750
D-06-20 18 DCC1	10/1/67	35	3848
D-06-20 18 DCC1	7/19/83	95	3788
D-06-20 19 CCC1	12/4/90	91.55	3575
D-06-20 32 CCD	12/4/90	33	3507
D-06-20 32 CCD	11/21/96	32.6	3507
D-07-18 04 AAB2	8/1/67	400	3920
D-07-19 01 AAD1	12/4/90	35.42	3345
D-07-19 01 AAD1	11/20/96	28.8	3351
D-07-19 01 ABD	12/4/90	27.19	3347
D-07-19 01 ABD	11/20/96	26.23	3348
D-07-20 04 DD	7/21/83	13.5	3606
D-07-20 06 BCC2	3/23/49	50.05	3345
D-07-20 06 BCC2	11/27/49	48.05	3347
D-07-20 06 BCC2	3/9/50	50.05	3345
D-07-20 06 BCC2	2/5/52	48.79	3346
D-07-20 06 BCC2	7/18/52	49.4	3346
D-07-20 06 BCC2	1/20/53	46.14	3349
D-07-20 06 BCC2	5/11/53	47.23	3348
D-07-20 06 BCC2	1/25/54	51.65	3343
D-07-20 06 BCC2	1/7/76	51.6	3343
D-07-20 06 BCC2	12/4/90	40.31	3355
D-07-20 06 BCC2	11/20/96	32.4	3363
D-07-20 06 CAC1	11/20/96	31.5	3372
D-07-20 06 CDC	12/5/90	39.44	3366
D-07-20 06 CDC	11/20/96	31.4	3374
D-07-20 06 DCC	12/4/90	47.6	3376
D-07-20 06 DCC	11/20/96	38.1	3386
D-07-20 07 CAA	1/7/76	79.1	3371
D-07-20 07 CAA	12/3/90	66.2	3384
D-07-20 07 CAA	11/20/96	57.6	3392
D-07-20 07 DCD2	12/3/90	81.8	3388
D-07-20 07 DCD2	11/20/96	73.1	3397
D-07-20 07 DDA2	11/20/96	52.6	3405
D-07-20 07 DDB	12/3/90	59.9	3384
D-07-20 07 DDB	11/20/96	50.8	3393
D-07-20 08 BBB	1/1/65	35	3485
D-07-20 08 CCC	11/19/96	42.7	3415
D-07-20 08 CCD	12/5/90	51.6	3418
D-07-20 08 CCD	11/19/96	41	3429
D-07-20 08 CDD	3/13/51	72.38	3398
D-07-20 08 CDD	7/18/52	63.45	3407

USGS LOCATION	DATE MEASURED	DEPTH TO WATER	WATER ELEVATION
D-07-20 08 CDD	1/20/53	66.8	3403
D-07-20 08 CDD	7/23/53	72.57	3397
D-07-20 08 CDD	5/20/54	76.96	3393
D-07-20 08 CDD	8/24/54	74.73	3395
D-07-20 08 CDD	2/1/55	73.89	3396
D-07-20 08 CDD	10/6/55	86.52	3383
D-07-20 08 CDD	12/18/55	76.31	3394
D-07-20 08 CDD	1/25/57	79.13	3391
D-07-20 08 CDD	12/18/57	77.53	3392
D-07-20 08 CDD	1/26/61	67.53	3402
D-07-20 08 CDD	3/12/65	74.04	3396
D-07-20 08 CDD	2/3/66	51.13	3419
D-07-20 08 CDD	2/2/67	44.17	3426
D-07-20 17 BCA	1/7/76	76	3414
D-07-20 17 CAD	11/19/96	50.9	3441
D-07-20 17 DDA	1/7/76	82	3428
D-07-20 18 BAB	11/20/96	87.4	3392
D-07-20 21 ADA	7/21/83	13.5	3616
D-07-20 21 BBC	7/22/83	43	3485
D-07-20 21 BDA1	3/1/60	51	3479
D-07-20 21 BDA1	7/22/83	39	3491
D-07-20 21 BDB1	7/22/83	23	3512
D-07-20 21 BDB2	12/14/53	86.39	3429
D-07-20 21 BDB2	1/25/54	86.94	3428
D-07-20 21 BDB2	8/24/54	84.83	3430
D-07-20 21 BDB2	2/1/55	85.02	3430
D-07-20 21 BDB2	1/25/57	87.15	3428
D-07-20 21 BDB2	2/12/59	89.32	3426
D-07-20 21 BDB2	2/3/60	66.64	3448
D-07-20 21 BDB2	1/26/61	84.75	3430
D-07-20 21 BDB2	2/6/62	72.24	3443
D-07-20 21 BDB2	2/7/64	83.6	3431
D-07-20 21 BDB2	3/12/65	82.34	3433
D-07-20 21 BDB2	2/3/66	64.22	3451
D-07-20 21 BDB2	2/2/67	66.81	3448
D-07-20 21 BDB2	4/23/68	53	3462
D-07-20 21 BDB2	1/27/70	71.02	3444
D-07-20 21 BDB2	1/20/71	66.2	3449
D-07-20 21 BDB2	1/19/72	67.83	3447
D-07-20 21 BDB2	1/23/73	61.2	3454
D-07-20 21 BDB2	1/15/74	67.3	3448
D-07-20 21 BDB2	1/24/75	64.1	3451
D-07-20 21 BDB2	1/7/76	69	3446
D-07-20 21 BDB2	1/8/76	65.8	3449
D-07-20 21 BDB2	2/2/77	76.6	3438
D-07-20 21 BDB2	1/29/80	56.7	3458
D-07-20 21 BDB2	1/21/82	56.4	3459
D-07-20 21 BDB2	1/27/83	56.7	3458
D-07-20 21 BDB2	1/25/84	17.7	3497
D-07-20 21 BDB2	2/20/85	13.9	3501
D-07-20 21 BDB2	1/16/86	45.2	3470
D-07-20 21 BDB2	1/15/87	45	3470

USGS LOCATION	DATE MEASURED	DEPTH TO WATER	WATER ELEVATION
D-07-20 21 BDB2	2/23/88	48.3	3467
D-07-20 21 BDB2	1/18/89	51.6	3463
D-07-20 21 BDB2	1/24/90	56	3459
D-07-20 21 BDB2	12/5/90	51.3	3464
D-07-20 21 BDB2	1/14/92	44.9	3470
D-07-20 21 BDB2	1/27/93	12.9	3502
D-07-20 21 BDB2	12/10/93	40.5	3475
D-07-20 21 BDB2	11/9/94	46.8	3468
D-07-20 21 BDB2	11/30/95	42.3	3473
D-07-20 21 BDB2	11/19/96	49.6	3465
D-07-20 21 BDB2	2/3/97	50.7	3464
D-07-20 21 BDB2	10/27/97	52.5	3463
D-07-20 21 BDB2	10/28/98	43.1	3472
D-07-20 21 CAD	12/5/90	41.3	3510
D-07-20 21 CAD	11/19/96	42.1	3509
D-07-20 21 DAB1	12/4/90	21.1	3529
D-07-20 21 DAB1	11/19/96	21.9	3528
D-07-20 21 DAB2	11/19/96	21.6	3528
D-07-20 27 ADA	4/8/69	14.03	3616
D-07-20 27 ADA	1/7/76	22	3608
D-07-20 27 ADC2	12/6/90	5.39	3595
D-07-20 27 ADC2	11/19/96	7	3593
D-07-20 27 ADD1	12/6/90	10.52	3591
D-07-20 27 ADD1	11/19/96	10.1	3592
D-07-20 27 BDA	5/22/74	28.2	3561
D-07-20 27 BDA	12/6/90	17.2	3572
D-07-20 27 BDA	11/19/96	18.5	3571
D-07-20 27 BDD	12/6/90	16.5	3574
D-07-20 27 BDD	11/19/96	26	3564
D-07-20 27 DAA1	12/6/90	11.86	3813
D-07-20 27 DAA1	11/19/96	10	3815
D-07-20 27 DBD1	11/19/96	16.3	3614
D-07-20 27 DBD2	7/21/83	12.2	3611
D-07-20 27 DCA	12/6/90	9.92	3615
D-07-20 27 DCA	11/19/96	17.4	3608
D-07-20 27 DCB	11/1/79	18	3587
D-07-20 27 DCB	7/1/83	12	3593
D-07-20 27 DDB	12/6/90	10.42	3620
D-07-20 27 DDB	11/19/96	17.4	3613
D-07-20 28 BDA	8/30/47	20	3600
D-07-20 30 BC2	11/18/96	18.4	3632
D-07-20 34 ABB	1/7/76	26	3624
D-07-20 35 BBC1	3/7/91	20.65	3632
D-07-20 35 BBC1	11/18/96	18.1	3635
D-07-20 35 BDA	12/6/90	28.2	3638
D-07-20 35 BDA	11/18/96	23.1	3643

Appendix D

BLM Gage Instantaneous Flow Measurements
(from Appendix 1, BLM 1988)

APPENDIX 1
Monthly/Semi-monthly Streamflow Measurements at East and West Aravaipa Streamgaging Stations

East Aravaipa Date	East Aravaipa CFS	West Aravaipa Date	West Aravaipa CFS
1979			
03/14/79	33.2		
03/20/79	31.2		
04/02/79	36.7		
04/23/79	34.3		
05/10/79	28.1		
05/30/79	29.4		
06/13/79	29.5		
06/27/79	33.0		
07/11/79	23.0		
07/18/79	20.9		
08/16/79	29.8		
10/23/79	24.0		
1980			
06/20/80	21.6		
06/26/80	18.6		
07/15/80	21.4		
07/17/80	13.5		
07/22/80	20.3		
07/29/80	24.3		
08/06/80	26.0		
10/24/80	14.7		
		12/12/80	28.0
12/19/80	21.3		

East Aravaipa Date	East Aravaipa CFS	West Aravaipa Date	West Aravaipa CFS
1981			
03/10/81	23.1	03/13/81	32.9
		04/16/81	23.2
06/02/81	16.8	06/04/81	10.2
07/08/81	14.1		
		07/17/81	34.3
		09/09/81	17.4
10/23/81	14.6		
		10/28/81	13.6
		11/23/81	16.3
12/24/81	16.1		
12/31/81	15.5		
1982			
01/15/82	20.5		
01/29/82	17.3	01/27/82	24.5
02/24/82	18.8		
03/02/82	17.5	03/05/82	23.8
03/12/82	16.7		
		04/09/82	23.8
04/27/82	12.3		
05/13/82	16.0		
05/24/82	10.8		
06/04/82	11.9		
06/09/82	9.2		
07/06/82	6.8	07/09/82	7.8
07/20/82	10.8		
08/03/82	17.3		
		08/31/82	17.8
09/22/82	7.8		
		09/29/82	16.1
10/09/82	12.6		
10/19/82	10.2	10/16/82	14.3
		10/31/82	16.6
11/05/82	9.2		
		11/13/82	15.6
12/02/82	14.9		
12/18/82	9.9		

East Aravaipa		West Aravaipa		East Aravaipa		West Aravaipa	
Date	CFS	Date	CFS	Date	CFS	Date	CFS
	1983				1984		
01/04/83	16.5			01/10/84	31.0		
01/22/83	10.1	01/24/83	23.4	01/22/84	33.1		
02/11/83	21.2			02/27/84	37.9		
02/15/83	26.2	02/18/83	32.3	04/03/84	27.5		
02/28/83	17.2			04/17/84	36.3		
		03/10/83	38.3	04/30/84	30.7		
		04/02/83	43.9			05/02/84	37.1
04/08/83	26.7	04/12/83	43.9	05/14/84	33.1		
		04/17/83	44.3				
04/29/83	17.0			06/11/84	30.1	06/15/84	31.6
				06/22/84	25.3		
		05/01/83	27.4	07/04/84	26.7		
05/16/83	16.6	05/15/83	27.4	07/16/84	26.7	07/15/84	41.5
		05/29/83	22.3				
				08/04/84	34.4		
						08/10/84	43.4
06/04/83	18.5						
06/17/83	17.9	06/13/83	21.9	08/24/84	66.8		
06/29/83	10.0	06/30/83	11.1	09/13/84	37.0		
						09/19/84	34.2
07/12/83	20.8						
		07/18/83	19.9	10/01/84	30.7		
						10/06/84	31.2
07/22/83	27.5						
		07/30/83	32.4	10/16/84	29.3		
						10/21/84	30.7
						11/04/84	31.4
08/09/83	21.9			11/02/84	30.4		
08/29/83	25.2	08/28/83	23.0	11/16/84	27.9		
09/14/83	20.7			11/20/84	30.0		
		09/25/83	28.5	12/10/84	29.2	12/05/84	34.4
				12/22/84	47.0	12/19/84	46.2
10/18/83	40.0						
11/17/83	33.4						
11/22/83	28.7						
11/25/83	30.5						
12/07/83	43.7						
12/12/83	34.6						

East Aravaipa Date	CFS	West Aravaipa Date	CFS	East Aravaipa Date	CFS	West Aravaipa Date	CFS
		1987			1988		
01/05/87	25.6	01/04/87	25.1	01/04/88	22.7		
01/11/87	26.5					01/10/88	23.0
		01/19/87	25.8	01/19/88	24.8	01/23/88	27.8
		01/31/87	45.6	02/01/88	20.6		
						02/07/88	34.2
02/01/87	25.9			02/15/88	21.3		
		02/13/87	26.9	02/28/88	21.8	02/28/88	22.9
02/20/87	25.9						
03/02/87	30.6	03/01/87	94.7				
03/16/87	30.5	03/14/87	40.7			03/13/88	22.2
03/30/87	23.6	03/29/87	28.6			03/20/88	22.3
				04/04/88	19.6	04/03/88	19.9
04/13/87	26.2	04/11/87	26.4	04/19/88	19.8	04/17/88	20.9
04/27/87	23.6					04/29/88	23.2
		05/03/87	24.7				
05/11/87	21.8			05/04/88	18.0		
		05/17/87	23.1			05/15/88	20.0
05/25/87	23.5	05/29/87	21.1				
06/08/87	22.5						
		06/14/87	21.4				
06/22/87	21.0						
		06/28/87	20.6				
07/06/87	20.2						
		07/12/87	19.0				
07/20/87	21.7						
		07/26/87	18.9				
08/03/87	25.0						
		08/09/87	22.3				
08/17/87	22.7						
		08/23/87	21.9				
08/31/87	21.6						
		09/07/87	21.9				
09/14/87	21.8						
		09/20/87	19.6				
09/28/87	21.6						
		10/04/87	20.1				
10/12/87	21.6						
		10/18/87	23.3				
10/28/87	23.2						
		11/02/87	26.5				
11/10/87	22.2						
11/23/87	21.3						
12/07/87	22.0	12/06/87	23.7				
12/21/87	24.1	12/20/87	44.2				

Appendix E

Clastic Sediment Size Chart

Classification of clastic sediments by grain size[1]

Size Class	**Diameter**
Boulder	
---	256.0 mm (25.6 cm/10.08 in/0.840 ft)
Cobble	
---	64.0 mm (6.4 cm/2.52 in/0.210 ft)
Pebble	
---	2.0 mm (0.2 cm/0.078 in)
Very coarse sand	
---	1.0 mm
Coarse sand	
---	0.5 mm
Medium sand	
---	0.25 mm
Fine sand	
---	0.125 mm
Very fine sand	
---	0.0625 mm
Coarse silt	
---	0.031 mm
Medium silt	
---	0.0156 mm
Fine silt	
---	0.0078 mm
Very fine silt	
---	0.0039 mm
Clay	

[1] Based on Wentworth Size Classes (Folk 1974; Compton 1985)