US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

EL RIO ANTIGUO
RILLITO RIVER ENVIRONMENTAL RESTORATION

Documentation for Hydrologic Studies

PIMA COUNTY
DEPARTMENT OF TRANSPORTATION
& FLOOD CONTROL DISTRICT
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TUCSON, ARIZONA 85701-1207

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Pima County Department of Transportation and Flood Control District
Flood Control Engineering Division

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.01. Location

The project is located along the Rillito River reach (approximately 5 miles) from Craycroft Road to Campbell Avenue, north of the City of Tucson in Southeastern Arizona (Figure 1). Both banks of the Rillito River in the project reach are stabilized with soil cement protection, with the exception of a short reach on the south bank near Columbus Boulevard.

1.02. Purpose and Scope

This report presents without-project hydrology studies in support of the feasibility study for the El Rio Antiguo, Rillito River Environmental Restoration Project. The project encompasses the Rillito River reach from Craycroft Road to Campbell Road. The report presents basic hydrologic and physiographic characteristics of the project area, historical storms and floods of record, volume frequency analysis including balanced hydrographs for different frequencies, and discharge frequency analysis for the major tributaries joining the Rillito in the project reach.

1.03. Previous Reports

Previous hydrologic studies related to the project area were presented in the following reports:

(a). "Gila River and Tributaries, Design Memorandum, Rillito River, Tucson, Arizona, Bank Protection", U.S. Army Corps of Engineers, Los Angeles District, October, 1992.

(b). "Gila River and Tributaries, Rillito River, Tucson, Arizona, General Design Memorandum, Hydrology Appendix", U.S. Army Corps of Engineers, Los Angles District, September, 1988.

(c). "Rillito River & Associated Streams, Flood & Erosion Damage Reduction Study, Gila River & Tributaries, Interim 2, Hydrology Report", U.S. Army Corps of Engineers, Los Angeles District, January, 1984.

The reports (a) and (b) cited above update other prior hydrologic studies completed before 1988. Portions of the present study (Chapter 2 and 3) are adapted from reports (a) and (b).

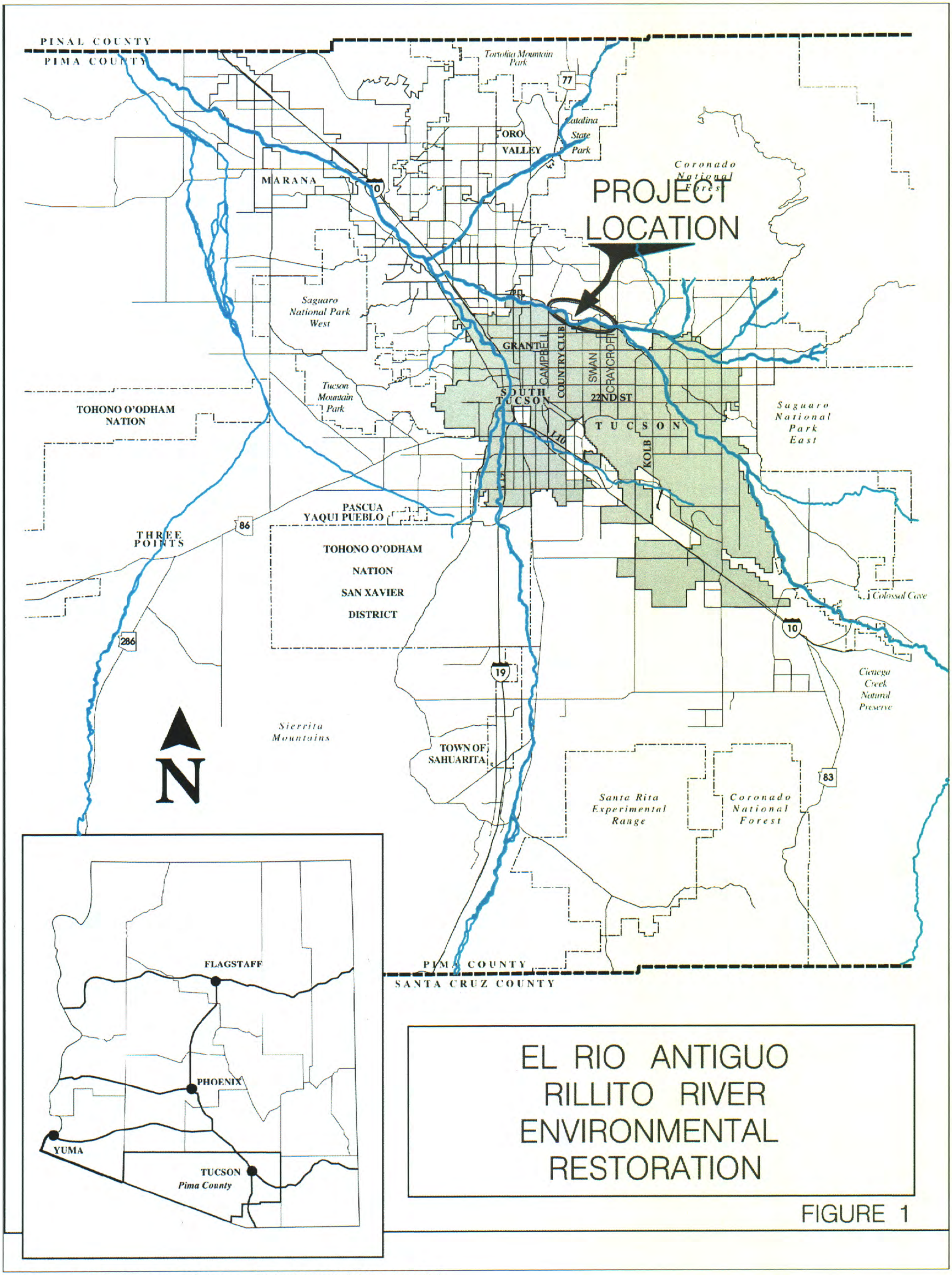

FIGURE 1

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2. DESCRIPTION OF DRAINAGE AREA

2.01 **Physiography and Topography**. The Rillito River is located in Pima County in Southeastern Arizona along the northern edge of the City of Tucson. The Rillito River is a tributary to the Santa Cruz River and drains 934 square miles of desert as well as mountain terrain. Tanque Verde Creek and Pantano Wash combine to form the Rillito River, which flows approximately 12 miles to the north of Tucson and empties into the Santa Cruz River. The drainage areas in this study can be classified as either desert valley or desert mountain, depending on the location. The Santa Catalina, Tanque Verde, and Rincon Mountains, with many peaks between 6000 and 9000 feet above mean sea level (MSL), rise to the north of the study area and extend to the east. Wide alluvial plains and valleys exist at the base of these ranges, which form the boundaries of Tanque Verde Creek. Broad, gently-sloping valleys to the south extend to the Whetstone, Empire, and Santa Rita Mountains as well as to the Canelo Hills, near the Mexican border. This area, which makes up the Pantano Wash basin, is characterized by wide valleys between rolling hills which gradually rise to elevations of about 7000 feet MSL, with one peak in the basin (Mt. Wrightson in the Santa Rita Mountains) over 9000 feet MSL. The streams draining the upper watersheds, all intermittent, descend the slopes of the mountains through a series of canyons and washes to the alluvial plains. The watercourse of the Rillito River is deeply entrenched and well-defined. During large floods, overtopping of the banks of most streams would be expected, thus inundating large areas of the flat, alluvial valleys.

The drainage area is bounded on the north by the Santa Catalina Mountains, on the east by the Tanque Verde, Rincon, and Whetstone Mountains, on the south by the Empire Mountains and Canelo Hills, and on the west by the Santa Rita Mountains. Between the mountain ranges, there are some low divides where the drainage boundary is indistinct. Elevations vary from 2300 feet MSL at the confluence of the Rillito River and Santa Cruz River to 9500 feet MSL at Mount Wrightson in the Santa Rita Mountains. The gradient of the channel ranges from about 300 feet per mile in the headwaters to about 20 feet per mile at the confluence. In general, development is sparse, except in the Tucson Metropolitan area. Drainage areas of Tanque Verde Creek and Pantano Wash, which combine to form the Rillito River, are described below.

a. Tanque Verde Creek. Tanque verde Creek drains an area to the northeast of Tucson that is approximately 241 square miles in extent. This area includes the southeastern flank of the Santa Catalina Mountains, and the northern portion of the Rincon and Tanque Verde Mountains. Tanque Verde Creek originates in the Tanque Verde Mountains and the northernmost edge of the Rincon Mountains. The creek is approximately 24 miles long from its origin to the Rillito River. Major tributaries emptying into Tanque Verde Creek are Sabino Creek (66 mi^2), Agua Caliente Wash (42 mi^2), and Canyon del Salto (8.2 mi^2). High elevations include Mt. Lemmon (9157 feet MSL) in the Catalinas, and Mica Mt. in the Tanque Verde Mountains (8666 feet MSL). The watercourse joins Pantano Wash to form the Rillito River at approximately 2440 feet MSL. Most of the watershed is sparsely populated. The existing channel is rocky, narrow, and winding in the Coronado National Forest. From Canyon del Salto to Agua Caliente Wash, the channel is sandy, from 100 to 200 feet wide, and 2 to 5 feet deep. At the Sabino Canyon Road bridge, the channel has an estimated capacity of 35,000 ft 3/s. In the vicinity of the southern end of Pantano Road, the north bank has been protected with rock placed in early 1979 by the Pima County Wastewater Management Department to protect a sewer interceptor line. Minor bank protection at the bridge abutments, damaged in March 1978, has been provided at the Sabino Canyon Road crossing. Sheet piling for a bank protection has been placed in the Tucson Country Club area. There is a sand and gravel operation in the channel just west of the Sabino Creek confluence.

(b). Pantano Wash. Pantano Wash flows from the edge of Santa Cruz County northerly to the Rillito River, north of Tucson. Most of this watercourse lies in Pima County, southeast of the present limits of the City of Tucson. The watershed drains an area of approximately 600 square miles southeast of Tucson. The highest elevation is on the western boundary at Mount Wrightson (9453 feet MSL) in the Santa Rita Mountains. The watercourse joins the Rillito River at approximately 2440 feet MSL. Outside the Tucson metropolitan area, the watershed is sparsely populated and is covered with typical upland desert flora. Pantano Wash is approximately 56 miles long from its origin in the Canelo Hills to where it joins the Tanque Verde Creek to form the Rillito River. In the Canelo Hills area, it is called Cienega Creek. From the Canelo Hills, the water course drops into the Empire Valley, flowing through rolling hills and grasslands dotted with cattle ranches. At Vail, the stream's name changes to Pantano Wash, and at that location the channel is narrow and winding. As the channel passes through the Tucson metropolitan area, it becomes wide and gently meandering, averaging about 200 feet in width and 8 to 10 feet in depth. The Tanque Verde Road bridge has been widened to about 250 feet at the bridge to accommodate a flow of 15,000 cfs. The average stream gradient for the basin is about 100 feet per mile.

2.02. **Geology.** The mountains within the Rillito drainage area are composed chiefly of coarsegrained metamorphic rocks, including gneiss, schist, granites, breccias, and various volcanic rocks such as basalt, andesite, and rhyolite. Sedimentary formations probably underlie the entire valley areas, and are covered with unconsolidated deposits of poorly sorted sand, gravel, and clay.

2.03. **Soils**. The mountain soils, which are generally shallow, contain a small amount of organic matter but are low in soluble salts. Many rock outcrop formations exist in the Santa Catalina, Tanque Verde, and Santa Rita Mountains. Soils in the valley areas derived from unconsolidated alluvium are high in soluble salts and contain less organic matter. They show little uniformity of texture or structural development. In the lower valley areas, the soils tend to be dense, with more or less compacted subsoils, whereas in the upper valley area, they are coarser and well drained. The streambed soils consist of loose sandy, gravelly, and stony materials and are exceptionally well drained.

2.04. **Vegetation.** Above an elevation of about 5000 feet, vegetation consists of ponderosa pine, fir, juniper, and oak scattered throughout a chaparral cover of manzanita, scrub oak, sagebrush, and greasewood. Typical desert vegetation such as scattered creosote bush, ocotillo, palo verde, ironwood, and cactus grow in the Whetstone and Empire Mountains and the lower slopes of the Rincon, Tanque Verde, Santa Rita, and Santa Catalina Mountains. In the desert valley, the watercourses are thinly lined with mesquite, ranging from stunted shrubs to small trees, while the remaining areas are covered with salt brush, creosote bush, pickleweed, and other typical desert flora. Agricultural developments exists mainly in the Lower Rillito area.

2.05. **Climate.** The climate of the drainage basin of the Rillito River and its tributaries ranges from that of a semi-arid high desert over the lower tow-thirds of the basin to semi-humid subarctic atop Mt. Lemmon (elevation 9157 feet) northeast of Tucson. The mean maximum/minimum temperatures in January in the Tucson area (Tucson Airport, University of Arizona, Tucson Magnetic Observatory) are about 65/36 degrees Fahrenheit (18/2 degrees Celsius), while the same figures for July are 101/73 degrees Fahrenheit (38/23 degrees Celsius). The extreme high and low temperatures expected in the basin would be about 115 degrees Fahrenheit (46 degrees Celsius) in the Tucson area and about -15 to -20 degrees Fahrenheit (-26 to -29 degrees Celsius) in the highest mountain valleys. Mean annual precipitation over the drainage basin ranges from about 11 inches (28 cm) in the southwest part of Tucson (a 1941-1970 National Weather Service normal of 11.05 inches at Tucson Airport) to more than 25 inches (64 cm) in the Santa Catalina, Rincon, and Whetstone Mountains along the eastern boundary of the drainage area, and more than 30 inches (76 cm) in the Santa Rita Mountains south of Tucson and north of Nogales – forming the southwestern corner of the Pantano Wash drainage. About 50 percent of the annual precipitation falls during months of July, August, and September, mostly as the result of heavy local summer thunderstorms, although tropical storms from off the west coast of Mexico can at times produce heavy general and local precipitation in southeastern Arizona during the period from mid-August through mid-October. Most of the remaining precipitation falls as the result of general winter-type storms. The driest time of the year is May and June. Winds in the area are normally not extreme, with generally light breezes from the south prevailing most of the year. The strongest winds usually come in thunderstorm downdrafts, where gusts of more than 70 miles per hour (113 km per hour) have been recorded. Three basic types of storms can affect the area, although some may consist of a combination of types. The following is a description of each type of storm.

a. General Winter Storms. Storms of this type normally move inland from the North Pacific Ocean, spreading general light to moderate precipitation over large areas. Although they can occur any time from late October through May, they are most common and generally heaviest from December through early March. These storms frequently last several days and may occur in series with only slight breaks between storms. They usually reflect orographic effects (lifting by mountains) to a great degree, so the mountains surrounding Tucson often receive from three to five times as much precipitation from winter storms as do the desert areas in or near Tucson. Snow frequently falls in the mountains above 6000 feet and occasionally falls at elevations below 3000 feet. Despite the normally low intensities of precipitation during general winter storms, the large aerial extent and the relatively long duration of these storms, sometimes combined with snowmelt from the mountains, can produce substantial volumes of runoff and high peak discharges on larger rivers

b. General Summer Storms. Storms of this type normally result from a flow of warm and very moist tropical air into the region from the southeast or south, including the Gulf of California (Sea of Cortez), the tropical Pacific Ocean south of Baja California, and to a slight extent, the Gulf of Mexico. Such storms over Arizona are often associated with tropical storms or hurricanes. General summer storms can occur any time from late June through mid-October, but are most frequent from August through early October. They usually last from one to three days and generally consist of numerous locally heavy storm cells embedded in more widespread, general light to moderate rain. Like their general winter counterparts, they usually reflect orographic influence, with higher mountains often receiving three to five times as much precipitation as do most of the desert areas. Some of the late September and October general storms can show characteristics of both the summer and winter types. The aerial extent and duration of general summer storm are usually somewhat less than that of general winter storms, gut intensities may be higher. Because infiltration rates are normally higher during summer than during winter, runoff volumes are usually lower than from winter events, but the peak flow on intermediate-sized streams may be higher.

c. Local Storms. Local storms consist of heavy downpours of rain over relatively small areas (up to about 300 square miles) for short periods of time (up to about 7 hours). They are usually accompanied by lightning and thunder, and are often referred to as "thunderstorms" or "cloudbursts". They can occur any time of the year, but are most prevalent and most intense during the summer months, July to September, when tropical moisture frequently invades Arizona from out of the south or southwest. During the latter part of the summer season they are often larger, of longer duration, and more apt to be associated with general summer storms. Runoff from local storms is usually of a high-peak, low-volume type, affecting mostly the smaller creeks and washes, and is characterized by a rapidly rising and receding hydrograph. They can result in serious flash floods, sometimes with loss of life and serious local property damage.

2.06. **Structures Affecting Flow.** No major dams and reservoirs exist in the study areas that contribute to flood control; however, channel improvements on some of the watercourses are providing some measure of flood protection. On the Tanque Verde Creek and the Rillito River this protection is in the form of bank stabilization measures to reduce erosion and associated channel instability. Various levels of bank protection have been placed at most of the bridge abutments to protect them. Most of this protection is in the form of rock rip-rap and rock and rail bank protection. In the vicinity of the southern end of Pantano Road, the north bank of Tanque Verde Creek has been protected with rock placed in early 1979 by the Pima County Wastewater Management Department to protect a sewer interceptor line. Major channel improvements, in the form of soil cement bank protection, have been made as follows: Tanque Verde Creek upstream and downstream of the Sabino Canyon Road

Bridge (approximately 6000 feet, both banks); soil cement bank protection has been constructed on both banks of the entire Rillito River reach from Craycroft Road to the Santa Cruz confluence, except on short reach (about 1200 feet) in the south bank between Alvernon Way and Columbus Boulevard (adjoining areas in this reach are undeveloped and owned by Pima County). No major flood control structures are in the Rillito River drainage basin. There are several small detention and diversion dams that have been constructed by local interests for irrigation, but they have no appreciable regulating effect on large floods.

2.07. **Runoff Characteristics**. Little streamflow occurs except during and immediately following relatively heavy precipitation because climatic and drainage area characteristics are not conducive to continous runoff. Because of steep gradients, streamflow in the mountains increases rapidly in response to high-intensity precipitation and causes debris-laden flash floods to debouch onto the valley plains below. The velocities and peaks are reduced, the debris is deposited, and a considerable amount of flow is lost to streambed percolation. Vegetation has a negligible effect on flood runoff, except where perennial grasses impede overland flow in the upper areas, such as that of Pantano Wash.

2.08. **Land Use.**

a. Present Land Use. Most of the land in the drainage area is government-owned (e.g., Coronado National Forest, Davis-Monthan Air Force Base, Saguaro National Monument, etc.) or held in trust by the Federal Government for the Indians. Currently, 86 percent of Pima County is rural and Indian reservations, 10 percent of the land is agricultural and ranching, and only 2 percent is urbanized, mainly in the Tucson Metropolitan area. Thus, present condition impervious cover for most of the area is approximately 5 percent to account for roads and rock outcrops. That portion of the Tucson Metropolitan area which drains to the Rillito River is estimated to have 10 percent impervious cover, mostly because of the large areas of open land between structures and lack of storm drain systems.

b. Future Land Use. Appreciable future development within the study area is expected only in the Tucson Metropolitan area, which is south of the project reach. No significant changes in land use are anticipated in the area north of the study reach.

3. HISTORICAL STORMS AND FLOODS

3.01. General

The Rillito River drainage area has experienced major storms and floods in 1878, 1887, 1887, 1891, 1905, 1906, 1908, 1929, 1935, 1940, 1954, 1958, 1965, 1978, 1983, and 1993. The largest floods (exceeding 10,000 cfs) for which records of peak discharges are available, occurred in 1914, 1921, 1929, 1935, 1940, 1965, 1978, 1983, and 1993. The October 1983 flood is the largest on record, with a peak discharge of 29,700 cfs.

3.02. **Storms and Floods of Record.** The largest flood of record on the Rillito River for many years was that of September 23, 1929, when a peak discharge of 24,000 cubic feet per second was measured. This was exceeded October 2, 1983 when a peak discharge of 29,700 cfs occurred. Little quantitative information is available about floods on Rillito River or in the study area prior to the Rillito River flood of December 23, 1914. It is known, however, that a very heavy thunderstorm hit the Tucson area in July 1878; that large summer thunderstorm floods occurred on Pantano Wash in July and September 1887, August 1888, and July 1908; and that a large winter flood occurred on Tanque Verde Creek in December 1906. Large floods also occurred in the Rillito River basin during widespread storms of 1891 and 1905. Other significant floods occurred in August 1935, August and December 1940, August 1958, and December 1965. Following are detailed descriptions of the largest floods occurring in the basin.

3.021. Storm and Flood of December 22-23, 1914. The month of December 1914 was generally wet throughout Arizona, probably as an indirect result of low-latitude north Pacific Ocean storms spawned by El Nino conditions (anomalously warm water in the eastern equatorial Pacific Ocean). There were minor storms December 1-2 and 11-13. These were followed by a major series of general winter storms that began on December 17 and lasted through December 24. Still another minor storm occurred December 27-28. It was the storm series of December 17-24 that produced the flooding in southeastern Arizona. It is hard to distinguish individual storms within the overall series, but the periods of December 18-19 and 22-23 appear to stand out as the heaviest of the nearly continuous 8-day rainfall. These heavier rain bands appear to coincide with the passage of cold fronts. To the north of Tucson, the first period of rain was heavier; to the south of Tucson, the second band was heavier. Some precipitation totals for December 17-24 in and near the Rillito Creek drainage area includes 8.29 inches at Rosemont (including 4.87 inches on December 22) 7.36 inches at Oracle, 5.08 inches at Tucson Campbell Magnetic Observatory, 5.00 inches at Tucson Indian Training School, 4.76 inches at Tucson (the primary Weather Bureau station), 4.66 inches at Vail, 4.39 inches at Nogales, Az and 4.20 inches in Elgin. Water ran high in many streams December 18-20, and because of the saturated ground and generally more intense rainfall, still much higher December 22-24. The peak discharge on Rillito River near Tucson (USGS Gauge No. 0948600) was 17,000 cfs on December 23. Most of this flow appears to have been contributed by Tanque Verde Creek.

3.022. Storm and Flood of July 30-31, 1921. The month of July 1921 was usually wet over nearly all of Arizona, as persistent general flow from out of the Mexican tropics brought numerous moderate to heavy thunderstorms to virtually the entire State. Frequent storms throughout the month served to saturate the ground and to start runoff in the various streams. The rainfall of the last few days of July was the apparent cause of the flooding that took place on the 31st. There were relatively few precipitation stations in and near the Rillito Creek drainage in 1921. Of those that were there, only two stations indicated significantly heavy rainfall to cause a flood. At the University of Arizona, Tucson, 1.43 inches were measured for the 24 hours ending in the late afternoon of July 31, while 1.15 and 1.00 inches, respectively, were measured at Oracle in the afternoons of July 30, and 31. Other rainfall for the same two days included 0.12 and 0.90 inches respectively at Tucson, 0.32 and 0.61 inches at Nogales, and 0.50 and 0.17 inches at Elgin (near) following 1.30, 2.98, and 0.97 inches July 27-29 at that station. An excerpt from the Tucson Citizen on Friday July 29 states, "Reports from Soldier Camp indicate that while Thursday's (July 28) rain was general, the Catalinas received the bulk of their rainfall on Wednesday (July 27), during which day 2.30 inches fell in that territory, while only 2 inches was measured after Thursdays downpour". The peak discharge on the Rillito Creek near Tucson is listed as 16,000 ft 3/s on July 31. Its origin is uncertain, but was probably primarily from Pantano Wash.

3.023. Storm and Flood of September 22-24, 1929. The middle and latter part of September 1929 brought a scattering of relatively heavy thunderstorms to many parts of Arizona. Perhaps aided by favorable overall atmospheric conditions associated with a minor El Nino in the eastern Pacific, there was deep flow of moist tropical air into Arizona from September 15 through September 25 of that year. A dissipating tropical storm apparently moved northwestwards through the Gulf of California into eastern Baja California, then northwestwards through the eastern part of California, bringing moderately heavy rainfall to that area and western Arizona, with lighter rain in southeastern Arizona. Another surge of moisture and thunderstorms hit southeast Arizona September 22-24. During this latter storm period, Tucson measured 3.40 inches, including 1.39 on the 23rd and 2.00 on the 24th. The University of Arizona recorded 3.38 inches for this same period, including 1.98 on September 23. Rosemont reported 0.92 inch on September 19 and no rain until 1.31 inches on September 25 (although, much if not all of that 1.31 could have fallen earlier: rainfall reports from cooperative observers can sometimes be delayed and the error not detected prior to publication of the data). Elgin (near) reported 1.19 inches for the storm period, and other stations in the drainage reported less than 1 inch. The peak discharge on Rillito River is listed as 24,000 cfs on September 23. Its origin is reported to have been Pantano Wash, although there were no measurements on Pantano Wash at that time.

3.024. Storm and Flood of August 19, 1954. According to available reports, this storm and resulting flood were the most severe of record in the Queen Creek drainage area (approximately 60 miles northeast of the Santa Rosa Wash area). Very moist, warm tropical air, that originated over the Gulf of Mexico, entered Arizona and New Mexico from the south during the storm period, accompanied by widespread thunderstorm activity. Precipitation intensities were high during the first 3 hours of the storm. An estimated 100 square miles of area (near the storm center) had over 5 inches of precipitation. No estimates of discharge are available for the Rillito Creek area. The peak discharge at the gauging station, Queen Creek at Whitlow Ranch damsite near Superior, Arizona (area 143 sq. miles) was estimated at 42,900 cubic feet per second.

3.025. Storm and Flood of December 17-19, 1978. In contrast to the storms and floods of earlier years, a great amount of information is available about the events of December 1978. The storm originated when a large low-pressure trough dropped southward off the California coast from out of the Gulf of Alaska. As the circulation around this low plunged deep into the tropics, a very deep and intense current of tropical moisture streamed northward into Arizona from a very active equatorial zone. The western edge of this moisture (moisture which was prominent on satellite photographs as an extremely bright, heavy cloud cover) was squeezed by an intensifying cold front as it edged very slowly eastward. This combination resulted in widespread moderate to heavy precipitation from the Mongolian Rim southward, including the Rillito Creek drainage and vicinity. Mountain uplift of this moist air resulted in considerable orographic precipitation, and the instability of the air mass resulted in some locally even heavier showers and thunderstorms. Palisade Ranger Station (elev. 7954 feet near the top of Mt. Lemmon northeast of Tucson) measured 8.52 inches for the storm, with 6.51 falling in the 24 hours ending at 1700 December 18. The gauge at Oracle 2 SE measured a storm total of 3.78 inches, including 2.7 inches for the 16 hours ending 1500 December 17. Santa Rita Experiment Range recorded 2.68 inches for storm, including 1.3 inches, for the 7 hours ending 1700 on December 18; Nogales, AZ received 2.19 inches altogether, including 1.39 inches for the 24 hours ending on December 18; Nogales 6 N reported a storm total of 2.01 inches. Tucson Camp Avenue Experiment Farm recorded 1.91 inches, including 1.60 inches December 18; Tucson Magnetic Observatory measured a storm total of 1.86 inches; Canelo 1 NW observed 1.72 inches; Tumacacori National Monument received 1.71 inches; Patagonia 2 observed 1.67 inches; the University of Arizona received 1.60 inches; Ruby Star Ranch recorded 1.16 inches; Tucson Airport measured 1.11 inches; and N Lazy H Ranch received only 1.05 inches. The peak discharge on Rillito Creek near Tucson was measured at 16,400 cfs on December 18. Contribution to this discharge were peaks of 12,7000 cfs on Tanque Verde Creek at Tucson (USGS Gauge No. 09484500) and 1530 cfs on Pantano Wash near Tucson (USGS gauge No. 09485500).

3.026. Storm and Flood of September 27-October 3, 1983. Following an unusually wet winter of 1982-1983 and abnormally heavy precipitation during the late summer of 1983, the week of September 27-October 3, 1983 brought a major storm to all of southeastern Arizona. A large and persistent low-pressure center developed off the southern California coast, with the counter-clockwise circulation around the low pumping abundant tropical moisture into eastern Arizona throughout the period. This moisture was enhanced by the presence of Tropical Storm Octave southwest of Baja California. Total storm rainfall in southeast Arizona ranged from 3.42 inches at Duncan to 11.30 inches at Blue River. There were unofficial reports of up to 15 inches of rain in some mountain areas. The University of Arizona, Tucson, measured 7.33 inches, while the gauge at Tanque Verde Creek observed 7.30 inches. In the mountains northeast of Tucson, Oracle Ridge Mine was the wettest in Pima County with 10.49 inches, while Mt. Lemmon had 8.90 inches. The heaviest rain of the storm generally occurred on October 1, when most stations received 40 to 60 percent of their storm total. The Mt. Lemmon total for October 1 was 5.10 inches–a value that exceeds the 100-year, 24-hour amount of 5.0 inches for that station (NOAA Atlas 2). This was the day when most of the tropical moisture from Octave entered the region. With ground already saturated from previous rainfall, runoff was high on nearly every stream in southeast Arizona. All-time record flows occurred on the San Francisco and upper Gila Rivers. Rillito River near Tucson (USGS Gauge No. 09486000) experienced an all-time record peak discharge of 29,700 ft cfs on October 2, 1983.

4. DESIGN/REGULATORY DISCHARGES FOR RILLITO

Discharge frequency analysis for the Rillito River is not included in this study, because design/regulatory discharges have already been established and approved by various agencies including the Corps of Engineers. A 100-year design discharge of 32,000 cfs is currently used and approved by FEMA (Federal Emergency Management Agency), Pima County Department of Transportation and Flood Control District, and the U.S. Army Corps of Engineers. Discharges for other frequencies, as given in FEMA's publication "Flood Insurance Study, Pima County, Arizona and Incorporated Areas" Volume 1 of 3 (February 8, 1999, Ref.7) are listed in the following table.

Location	Drainage Area (sq. Miles)	Peak discharges in cfs			
		10-yr	50-yr	100-yr	500-yr
Above confluence with Santa Cruz	935	12,500	23,000	32,000	62,000
First Avenue	892	12,500	24,000	32,000	64,000

5. VOLUME FREQUENCY ANALYSIS FOR RILLITO

5.1 General

This chapter presents the development of hypothetical hydrographs for various frequency events, referred to herein as balanced hydrographs, which will be used in the determination of average annual sediment deposition or scour in the study reach of the Rillito River. Since significant quantities of sediment could be transported by more frequent events other than the annual maximum flows, representative balanced hydrographs are developed from partial duration series, composed of all significant flows during the period of record, rather than limited to the maximum annual flow, in order to provide better estimate of average annual sediment deposition/scour (as described in Hydraulics Appendix). The following sections summarize the development of the balanced hydrographs as obtained from volume frequency analysis based on partial duration series of available stream flow data. The detailed development of the balanced hydrographs are presented in Appendix A (Development of Hydrology for Sedimentation Analysis).

5.2 Volume Frequency Analysis

A necessary first step for developing balance hydrographs is the volume frequency relationships. For reasons discussed in Section 5.1, partial duration series from available stream flow data was used to develop the volume frequency curves. For the Rillito River near Tucson, systematic daily flow record is available from the United States Geological Survey (USGS) for the period 1915-75. Using partial duration series from this data base, 1-day and 5-day maximum average flows are computed and listed in Table A-2 of Appendix A. The maximum duration of 5-days was selected from inspection of daily flow record which indicated that most of the volume of flood flow is contained within a 5-day period of contiguous runoff. Appendix A describes the detailed procedure for computing the 1-day and 5-day average discharges (Table A-2). Volume frequency curves are plotted in Figure A-2 of Appendix A, using 1-day and 5-day average flows and corresponding plotting positions listed in Table A-2.

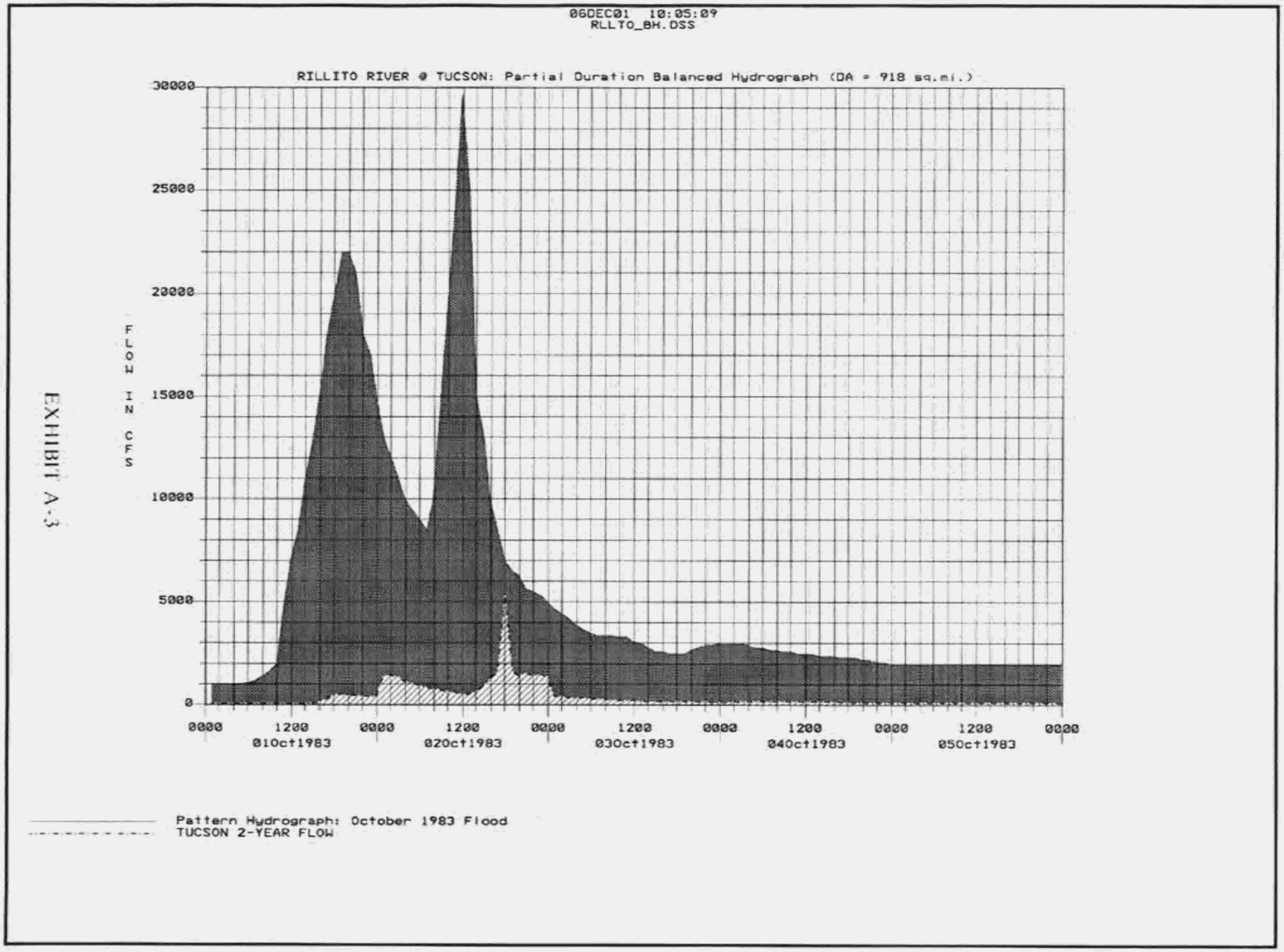
5.3 Balanced Hydrographs

Volume frequency curves described in Section 5.2 are used to develop balanced hydrographs of various frequencies (1-, 1.25, 2-, 5-, 10-, 25-, 50-, and 100-year). A balanced hydrograph represents a hypothetical flood event having the same probability of excedance for every duration of flow, and is a suitable tool for analyzing average volume of sediment transported during a flow event of given frequency. Using the procedure available in the HEC-1 program ("HB" Card) and the October 1983 flood as the "pattern" input hydrograph, balanced hydrographs are obtained from the volume frequency curves, as described in detail in Appendix A. Exhibits A-1 through A-8 in Appendix A show the plots of balanced hydrographs for various frequencies, and Table 2 presents the corresponding tabulations for these hydrographs.

Table 2
Balanced Hydrographs for Rillito

TIME	DATE	1-year flow (cfs)	1.25-year flow (cfs)	2-year flow (cfs)	5-year flow (cfs)	10-year flow (cfs)	50-year flow (cfs)	100-year flow (cfs)
0100	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,045.7
0200	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,045.7
0300	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,045.7
0400	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,045.7
0500	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,045.7
0600	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,045.7
0700	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,238.4	2,250.3
0800	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,362.3	2,454.8
0900	1-Oct-83	7.1	5.4	68.1	161.1	399.4	1,486.1	2,864.0
1000	1-Oct-83	7.1	5.4	68.1	161.1	439.3	1,733.8	3,273.1
1100	1-Oct-83	7.1	5.4	68.1	177.2	479.3	1,981.5	4,091.4
1200	1-Oct-83	7.1	5.4	74.9	193.3	559.2	2,476.9	10,228.5
1300	1-Oct-83	7.1	6.0	81.7	225.5	639.1	6,192.2	14,319.9
1400	1-Oct-83	7.8	6.5	95.3	257.7	798.8	8,669.1	17,388.5
1500	1-Oct-83	8.5	7.6	108.9	322.1	1,997.0	10,526.8	17,405.1
1600	1-Oct-83	10.0	8.7	136.1	805.3	2,795.9	10,536.8	16,829.7
1700	1-Oct-83	11.4	10.8	340.3	1,127.4	3,395.0	10,188.5	15,888.2
1800	1-Oct-83	14.2	27.1	476.4	1,368.9	2,947.8	9,618.5	15,722.1
1900	1-Oct-83	35.5	37.9	578.4	1,188.6	2,850.4	9,518.0	17,469.0
2000	1-Oct-83	49.8	46.0	502.2	1,149.3	2,690.9	11,304.3	19,215.9
2100	1-Oct-83	60.4	39.9	485.6	1,085.0	2,662.8	12,434.7	19,215.9
2200	1-Oct-83	52.5	38.6	458.5	1,073.7	2,683.6	12,434.7	18,342.4
2300	1-Oct-83	50.7	36.5	453.7	1,082.1	2,951.9	11,869.5	15,722.1
2400	1-Oct-83	47.9	36.1	457.2	2,528.0	2,951.9	10,173.8	14,848.6
0100	2-Oct-83	47.4	36.4	1,436.6	2,528.0	2,817.7	9,608.6	13,101.7
0200	2-Oct-83	47.8	1,044.6	1,436.6	2,413.1	2,415.2	8,478.2	11,354.8
0300	2-Oct-83	912.7	1,044.6	1,371.3	2,068.4	2,281.0	7,347.8	10,481.4
0400	2-Oct-83	912.7	997.1	1,175.4	1,953.5	2,012.7	6,782.6	9,607.9
0500	2-Oct-83	871.2	854.7	1,110.1	1,723.7	1,744.3	6,217.3	8,734.5
0600	2-Oct-83	746.7	807.2	979.5	1,493.8	1,610.1	5,652.1	8,297.8
0700	2-Oct-83	705.2	712.2	848.9	1,378.9	1,476.0	5,369.5	7,861.0
0800	2-Oct-83	622.3	617.3	783.6	1,264.0	1,341.8	5,086.9	7,424.3
0900	2-Oct-83	539.3	569.8	718.3	1,149.1	1,274.7	4,804.3	8,734.5
1000	2-Oct-83	497.8	522.3	653.0	1,091.7	1,207.6	5,652.1	13,101.7
1100	2-Oct-83	456.3	474.8	620.4	1,034.2	1,140.5	8,478.2	17,469.0
1200	2-Oct-83	414.8	451.1	587.7	976.7	1,341.8	11,304.3	21,836.2
1300	2-Oct-83	394.1	427.3	555.1	1,149.1	2,012.7	14,130.3	29,500.0
1400	2-Oct-83	373.4	403.6	653.0	1,723.7	2,683.6	24,000.0	21,836.2
1500	2-Oct-83	352.6	474.8	979.5	2,298.2	3,354.5	14,130.3	16,939.1
1600	2-Oct-83	414.8	712.2	1,306.0	2,872.8	13,500.0	10,961.3	17,942.8
1700	2-Oct-83	622.3	949.7	1,632.5	9,800.0	3,354.5	11,610.9	16,869.3
1800	2-Oct-83	829.7	1,187.1	5,400.0	2,872.8	2,999.7	10,916.2	17,388.5
1900	2-Oct-83	1,037.1	3,800.0	1,632.5	2,569.0	3,177.5	11,252.2	14,319.9
2000	2-Oct-83	3,050.0	1,187.1	1,459.9	2,721.2	2,987.4	8,669.1	13,297.1
2100	2-Oct-83	1,037.1	1,061.6	1,546.4	2,558.4	3,079.3	8,049.9	12,888.0

EXHIBIT A-3



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FLOW IN CFS
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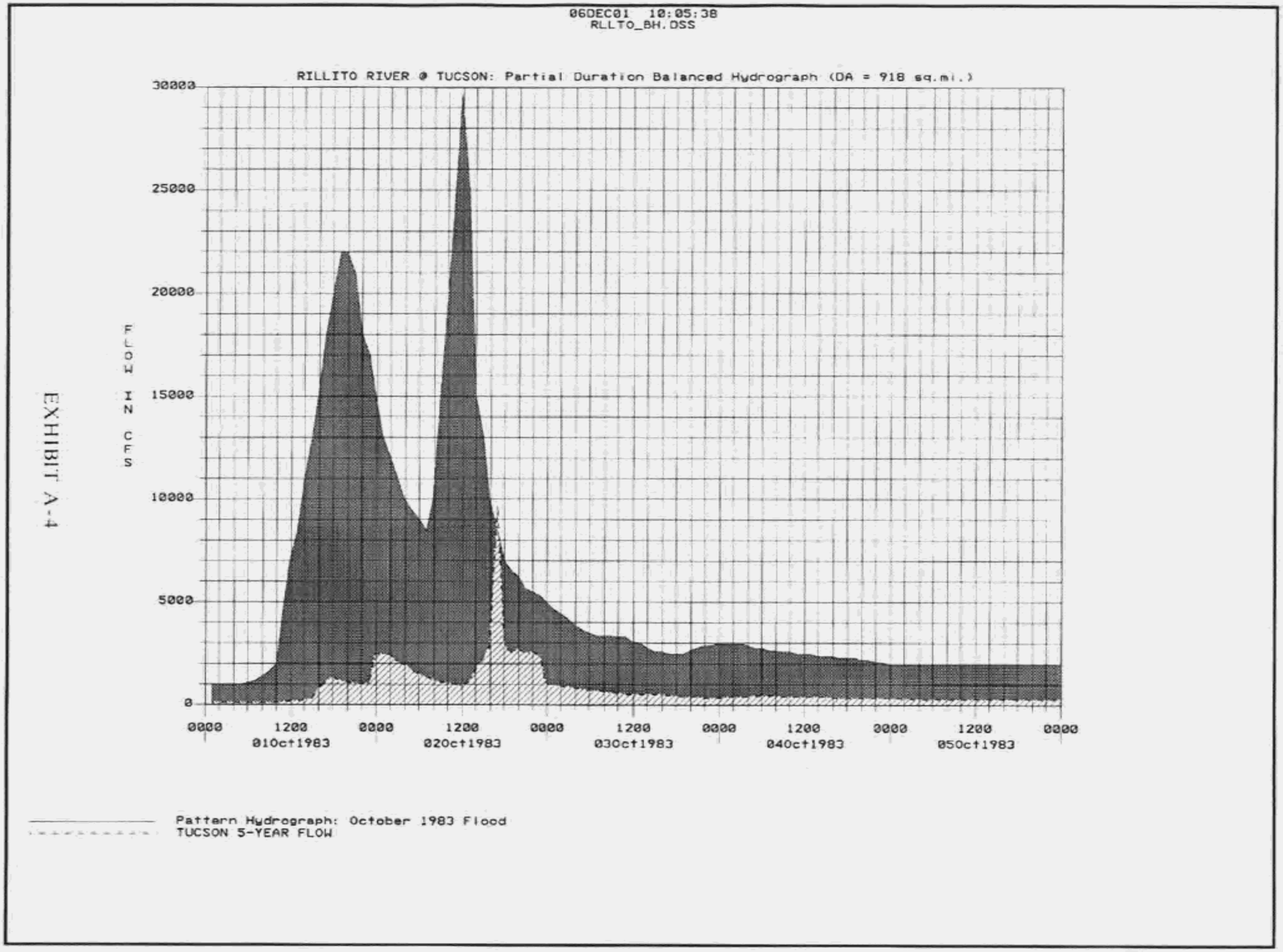
25000
20000
15000
10000
5000
0
0000 1200 0000 1200 0000 1200 0000 1200 0000 1200 0000
01Oct1983
02Oct1983
03Oct1983
04Oct1983
05Oct1983
Pattern Hydrograph: October 1983 Flood
TUCSON 2-YEAR FLOW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20000
15000
10000
5000
0
0000
1200
01Oct1983
0000
1200
02Oct1983
0000
1200
03Oct1983
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04Oct1983
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05Oct1983
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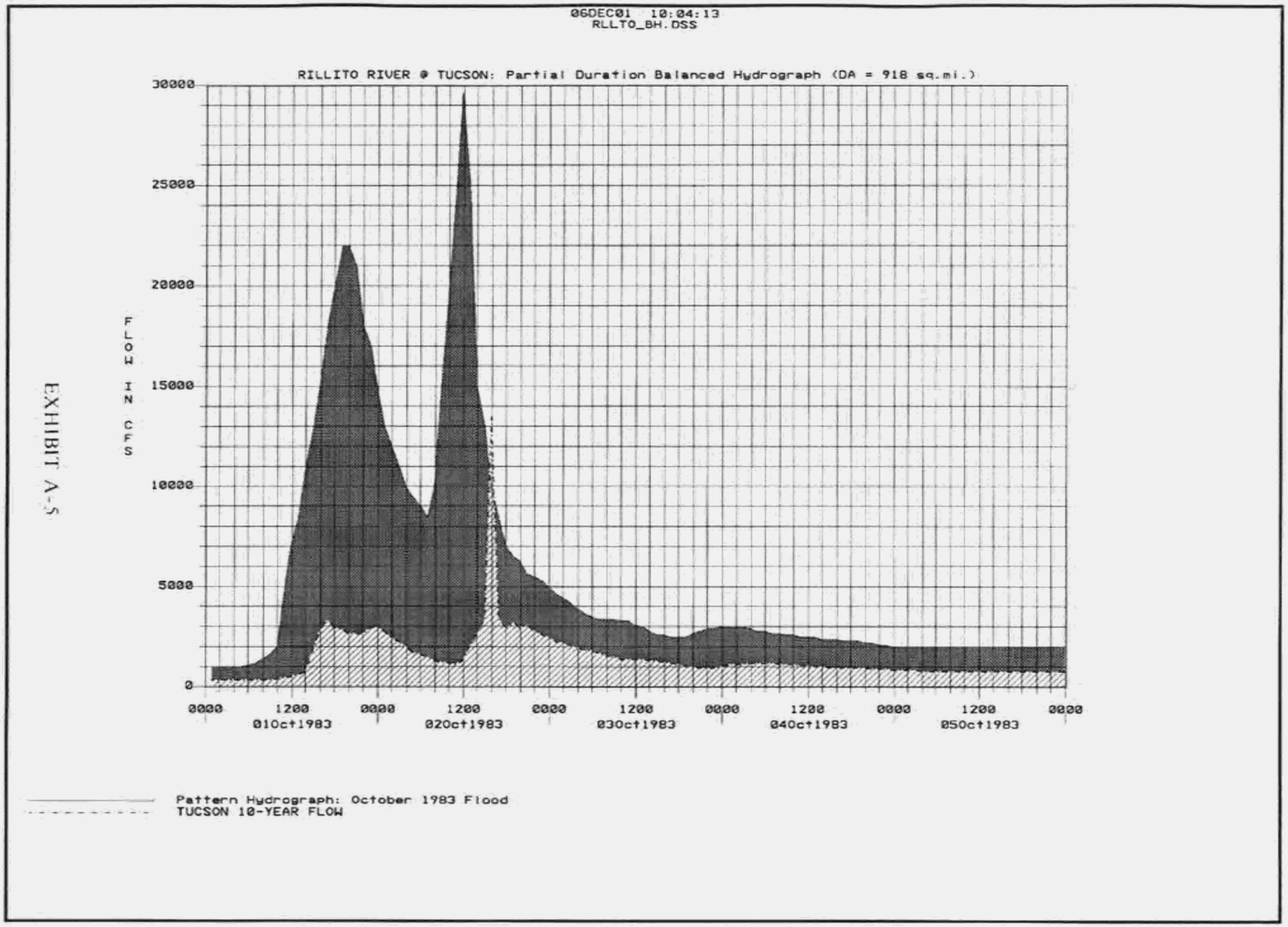
Pattern Hydrograph: October 1983 Flood
TUCSON 5-YEAR FLOW

EXHIBIT A-4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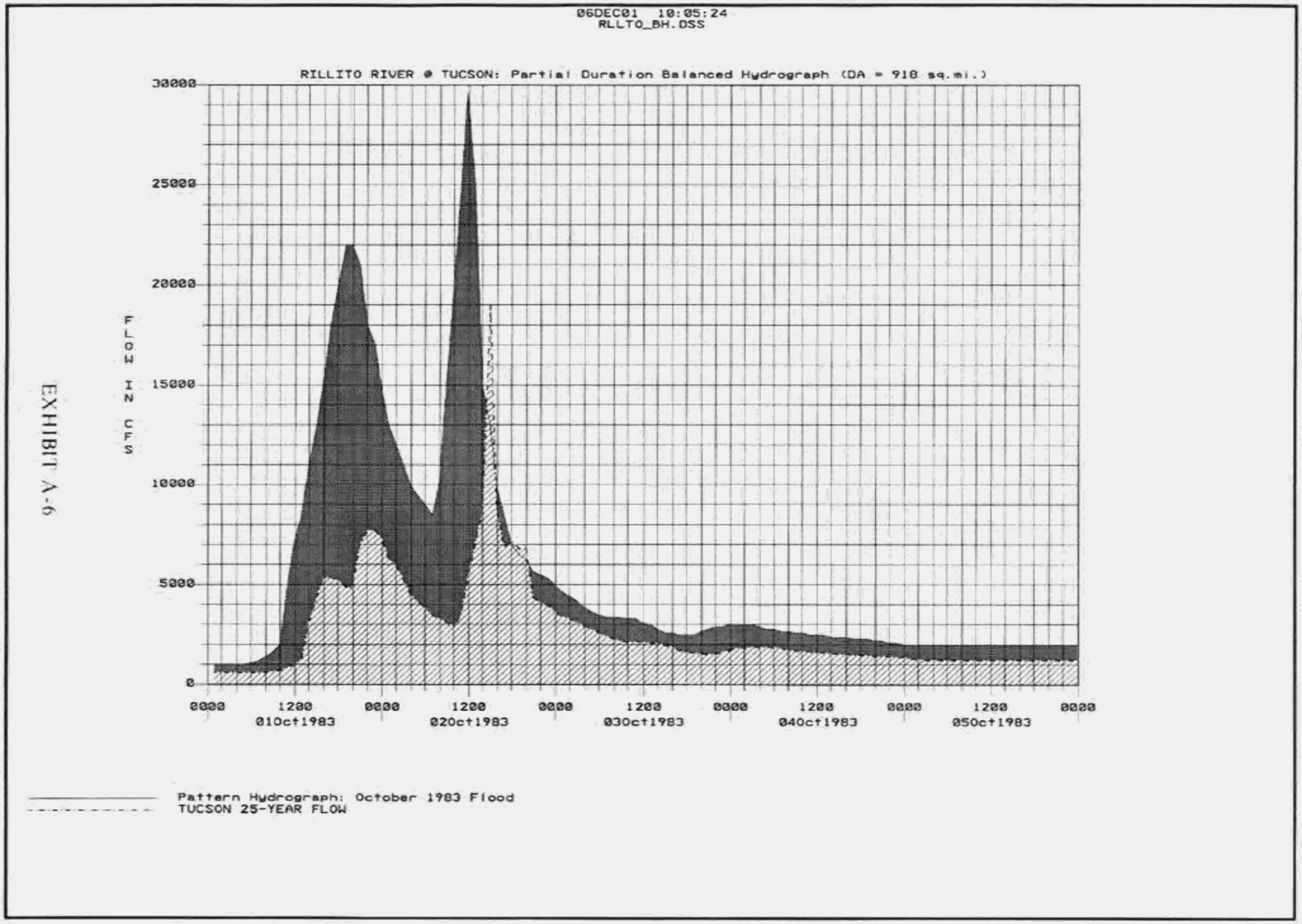
20000
15000
10000
5000
0
0000
1200
01Oct1983
0000
1200
02Oct1983
0000
1200
03Oct1983
0000
1200
04Oct1983
0000
1200
05Oct1983
0000
Pattern Hydrograph: October 1983 Flood
TUCSON 10-YEAR FLOW

EXHIBIT A-5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RILLITO RIVER @ TUCSON: Partial Duration Balanced Hydrograph (DA = 918 sq.mi.)
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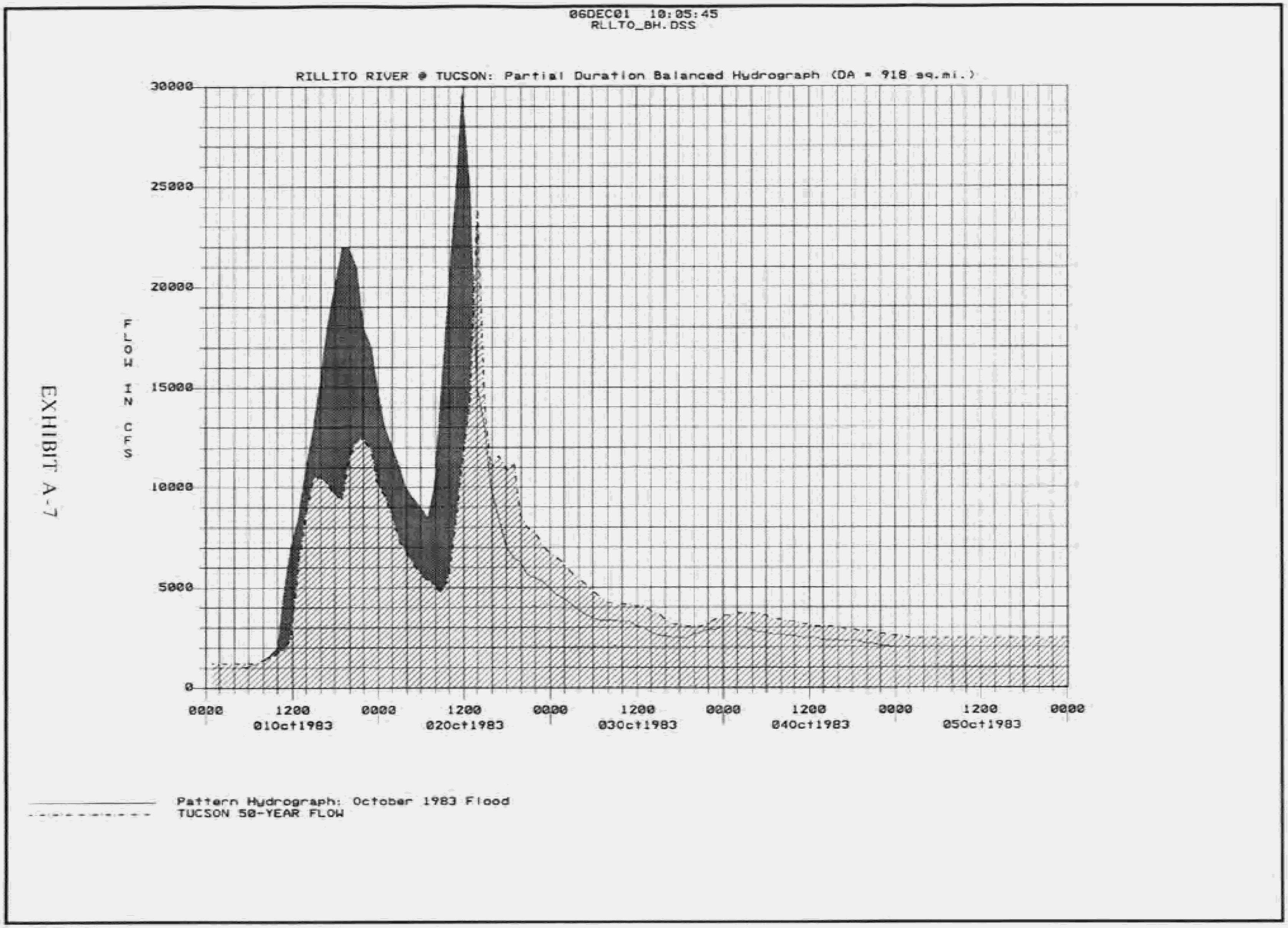
25000
20000
15000
10000
5000
0
0000
1200
01Oct1983
0000
1200
02Oct1983
0000
1200
03Oct1983
0000
1200
04Oct1983
0000
1200
05Oct1983
0000
Pattern Hydrograph: October 1983 Flood
TUCSON 25-YEAR FLOW

EXHIBIT A-6

EXHIBIT A-7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RILLITO RIVER @ TUCSON: Partial Duration Balanced Hydrograph (DA = 918 sq.mi.)
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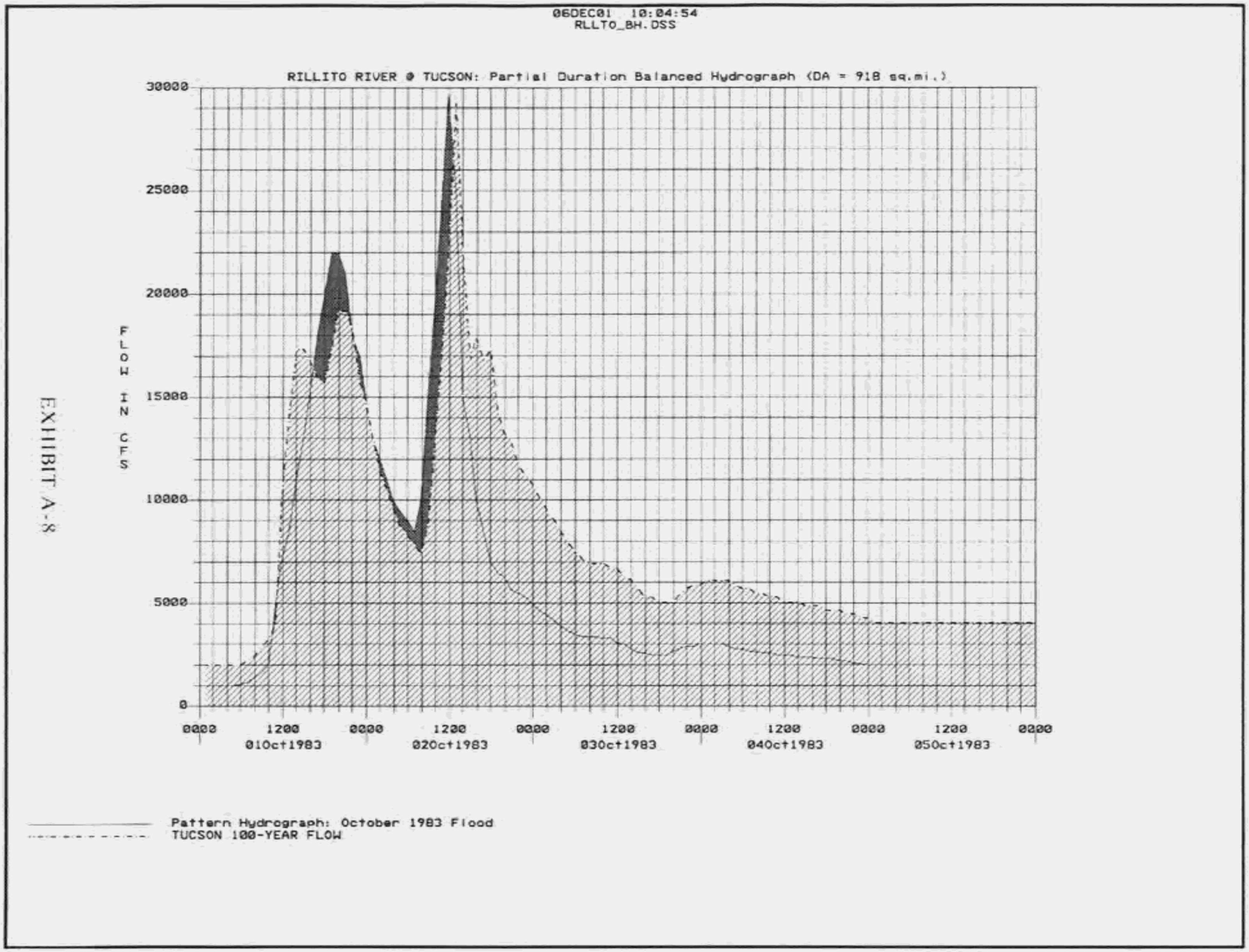
25000
20000
15000
10000
5000
0
0000
1200
0000
1200
0000
1200
0000
1200
0000
1200
0000
01Oct1983
02Oct1983
03Oct1983
04Oct1983
05Oct1983
Pattern Hydrograph: October 1983 Flood
TUCSON 50-YEAR FLOW

EXHIBIT A-8



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FLOW IN CFS
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25000
20000
15000
10000
5000
0
0000
1200
01Oct1983
0000
1200
02Oct1983
0000
1200
03Oct1983
0000
1200
04Oct1983
0000
1200
05Oct1983
0000
Pattern Hydrograph: October 1983 Flood
TUCSON 100-YEAR FLOW

Table 2 (Continued)
Balanced Hydrographs for Rillito

TIME	DATE	1-year flow (cfs)	1.25-year flow (cfs)	2-year flow (cfs)	5-year flow (cfs)	10-year flow (cfs)	50-year flow (cfs)	100-year flow (cfs)
2200	2-Oct-83	927.4	1,124.5	1,453.9	2,637.2	2,795.9	7,802.2	11,660.5
2300	2-Oct-83	982.4	1,057.2	1,498.7	2,394.4	2,596.2	7,059.1	11,251.4
2400	2-Oct-83	923.6	1,089.7	1,360.7	1,046.8	2,516.3	6,811.5	10,842.2
0100	3-Oct-83	952.1	989.4	442.3	1,014.6	2,276.6	6,563.8	10,228.5
0200	3-Oct-83	864.4	35.2	428.7	918.0	2,196.7	6,192.2	9,614.8
0300	3-Oct-83	46.2	34.1	387.9	885.8	2,116.9	5,820.7	9,103.4
0400	3-Oct-83	44.8	30.8	374.3	853.6	1,997.0	5,511.1	8,592.0
0500	3-Oct-83	40.5	29.8	360.7	805.3	1,877.2	5,201.5	7,978.3
0600	3-Oct-83	39.1	28.7	340.3	756.9	1,777.4	4,829.9	7,569.1
0700	3-Oct-83	37.7	27.1	319.8	716.7	1,677.5	4,582.3	7,160.0
0800	3-Oct-83	35.5	25.4	302.8	676.4	1,557.7	4,334.6	6,955.4
0900	3-Oct-83	33.4	24.1	285.8	628.1	1,477.8	4,210.7	6,955.4
1000	3-Oct-83	31.6	22.7	265.4	595.9	1,397.9	4,210.7	6,955.4
1100	3-Oct-83	29.9	21.1	251.8	563.7	1,358.0	4,210.7	6,750.8
1200	3-Oct-83	27.7	20.0	238.2	547.6	1,358.0	4,086.9	6,750.8
1300	3-Oct-83	26.3	18.9	231.4	547.6	1,358.0	4,086.9	6,341.7
1400	3-Oct-83	24.9	18.4	231.4	547.6	1,318.0	3,839.2	6,137.1
1500	3-Oct-83	24.2	18.4	231.4	531.5	1,318.0	3,715.3	5,728.0
1600	3-Oct-83	24.2	18.4	224.6	531.5	1,238.2	3,467.7	5,318.8
1700	3-Oct-83	24.2	17.9	224.6	499.3	1,198.2	3,220.0	5,318.8
1800	3-Oct-83	23.5	17.9	211.0	483.2	1,118.3	3,220.0	5,114.3
1900	3-Oct-83	23.5	16.8	204.2	450.9	1,038.5	3,096.1	5,114.3
2000	3-Oct-83	22.0	16.2	190.5	418.7	1,038.5	3,096.1	5,114.3
2100	3-Oct-83	21.3	15.2	176.9	418.7	998.5	3,096.1	5,421.1
2200	3-Oct-83	19.9	14.1	176.9	402.6	998.5	3,281.9	5,728.0
2300	3-Oct-83	18.5	14.1	170.1	402.6	998.5	3,467.7	5,932.5
2400	3-Oct-83	18.5	13.5	170.1	402.6	1,058.4	3,591.5	5,932.5
0100	4-Oct-83	17.8	13.5	170.1	426.8	1,118.3	3,591.5	6,137.1
0200	4-Oct-83	17.8	13.5	180.3	450.9	1,158.3	3,715.3	6,137.1
0300	4-Oct-83	17.8	14.3	190.5	467.0	1,158.3	3,715.3	6,137.1
0400	4-Oct-83	18.8	15.2	197.3	467.0	1,198.2	3,715.3	6,137.1
0500	4-Oct-83	19.9	15.7	197.3	483.2	1,198.2	3,715.3	5,932.5
0600	4-Oct-83	20.6	15.7	204.2	483.2	1,198.2	3,591.5	5,728.0
0700	4-Oct-83	20.6	16.2	204.2	483.2	1,198.2	3,467.7	5,728.0
0800	4-Oct-83	21.3	16.2	204.2	483.2	1,158.3	3,467.7	5,523.4
0900	4-Oct-83	21.3	16.2	204.2	467.0	1,118.3	3,343.8	5,523.4
1000	4-Oct-83	21.3	16.2	197.3	450.9	1,118.3	3,343.8	5,318.8
1100	4-Oct-83	21.3	15.7	190.5	450.9	1,078.4	3,220.0	5,318.8
1200	4-Oct-83	20.6	15.2	190.5	434.8	1,078.4	3,220.0	5,114.3
1300	4-Oct-83	19.9	15.2	183.7	434.8	1,038.5	3,096.1	5,114.3
1400	4-Oct-83	19.9	14.6	183.7	418.7	1,038.5	3,096.1	5,114.3
1500	4-Oct-83	19.2	14.6	176.9	418.7	998.5	3,096.1	4,909.7
1600	4-Oct-83	19.2	14.1	176.9	402.6	998.5	2,972.3	4,909.7
1700	4-Oct-83	18.5	14.1	170.1	402.6	998.5	2,972.3	4,909.7
1800	4-Oct-83	18.5	13.5	170.1	402.6	958.6	2,972.3	4,705.1

Table 2 (Continued)
Balanced Hydrographs for Rillito

TIME	DATE	1-year flow (cfs)	1.25-year flow (cfs)	2-year flow (cfs)	5-year flow (cfs)	10-year flow (cfs)	50-year flow (cfs)	100-year flow (cfs)
1900	4-Oct-83	17.8	13.5	170.1	386.5	958.6	2,848.4	4,705.1
2000	4-Oct-83	17.8	13.5	163.3	386.5	958.6	2,848.4	4,705.1
2100	4-Oct-83	17.8	13.0	163.3	386.5	918.6	2,848.4	4,500.6
2200	4-Oct-83	17.1	13.0	163.3	370.4	918.6	2,724.6	4,500.6
2300	4-Oct-83	17.1	13.0	156.5	370.4	918.6	2,724.6	4,296.0
2400	4-Oct-83	17.1	12.4	156.5	370.4	878.7	2,600.7	4,296.0
0100	5-Oct-83	16.3	12.4	156.5	354.3	878.7	2,600.7	4,091.4
0200	5-Oct-83	16.3	12.4	149.7	354.3	838.8	2,476.9	4,091.4
0300	5-Oct-83	16.3	11.9	149.7	338.2	838.8	2,476.9	4,091.4
0400	5-Oct-83	15.6	11.9	142.9	338.2	798.8	2,476.9	4,091.4
0500	5-Oct-83	15.6	11.4	142.9	322.1	798.8	2,476.9	4,091.4
0600	5-Oct-83	14.9	11.4	136.1	322.1	798.8	2,476.9	4,091.4
0700	5-Oct-83	14.9	10.8	136.1	322.1	798.8	2,476.9	4,091.4
0800	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
0900	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1000	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1100	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1200	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1300	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1400	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1500	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1600	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1700	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1800	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
1900	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
2000	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
2100	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
2200	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
2300	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4
2400	5-Oct-83	14.2	10.8	136.1	322.1	798.8	2,476.9	4,091.4

6. DISCHARGE FREQUENCY ANALYSIS FOR TRIBUTARIES

6.01 **Description of Tributaries**

Several significant tributaries join the Rillito River reach between Craycroft Road and Campbell Avenue. Six major tributaries joining the right (north) bank of the river reach are: Craycroft Wash, Flecha Caida Wash, Valley View Wash, Finger Rock Wash, Camino Real Wash and Campbell Wash. The left or south bank of the project reach receives flows from the three major tributaries: Alamo Wash, Alvernon Wash and Christmas Wash. The drainage areas of the tributaries joining the north bank of the Rillito contain mountainous and foothill areas with steep slopes at the upper watersheds, while the lower watersheds are relatively flat with low-density mostly residential developments. In contrast, the tributaries joining the south bank of the Rillito drain highly urbanized areas within metropolitan City of Tucson, and have much flatter channel slopes. Locations of the tributaries are shown in Figure 2 and drainage areas are listed in Table 3.

6.02 **Procedure**

There are no stream gauges on the tributary washes mentioned above, except for a limited recorded flow data available from a USGS (U. S. Geological Survey) Station on the Alamo Wash. The recorded flow data for the Alamo Wash covers only 15 years for the periods 1976-77, 1979-84, and 1986-92 and therefore is inadequate for analytical discharge frequency analysis based on recorded data. In view of this limitation, regional regression equations developed by the USGS will be utilized in the following analysis. In the previous study on the Rillito River by the Corps of Engineers ("Design Memorandum, Rillito River, Tucson, Arizona", October, 1992; Ref. 3), discharge frequency analysis for the tributaries employed regional equations developed by USGS in the report entitled "Estimation of Magnitude and Frequency of Floods in Pima County, Arizona, with Comparisons of Alternative Methods" (1984, Ref. 5). A similar study was completed recently by USGS ("Methods for Estimating Magnitude and Frequency of Floods in Southwestern United States", 1994, Ref. 6), which analyzed more recent stream flow data and developed new regional equations. Because the recent USGS (1994) study incorporated more recent stream flow data, the regional equations presented in the above-mentioned report (Ref. 6) will be utilized in the present analysis.

Figure 2

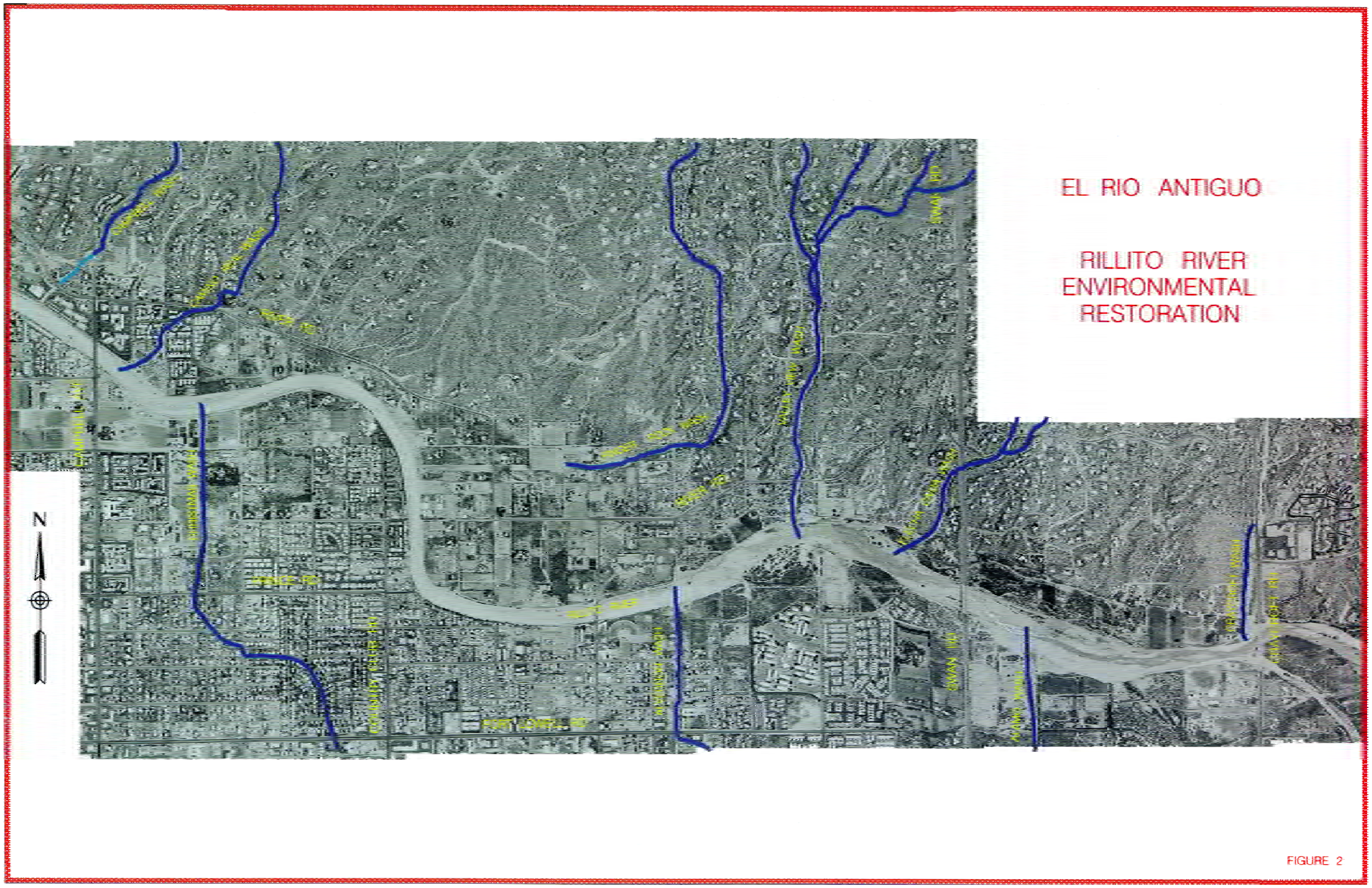

EL RIO ANTIGUO
RILLITO RIVER
ENVIRONMENTAL
RESTORATION
N
FIGURE 2

Table 3

Tributary Drainage Areas

Tributary	Drainage Area * (square miles)
Craycroft Wash	3.07
Flecha Caida Wash	1.47
Valley View Wash	4.11
Finger Rock Wash	6.09
Camino Real Wash	1.86
Campbell Wash	2.50
Alamo Wash	9.90
Alvernon Wash	3.32
Christmas Wash	3.32

* Source: Ref. 4 for Finger Rock Wash; Ref. 3 for other washes.

6.03 **N-year Discharges for Tributaries**

The following regional equations from the USGS report (1994, Ref. 6) are used to compute discharges for 2-year (Q2), 5-year (Q5), 10-year (Q10), 50-year (Q50), and 100-year (Q100) events:

$$\text{Log } Q_2 = 6.38\text{-}4.29\ A^{-0.06} \quad (1)$$

$$\text{Log } Q_5 = 5.78\text{-}3.31\ A\text{-}0.08 \quad (2)$$

$$\text{Log } Q_{10} = 5.68\text{-}3.02\ A\text{-}0.09 \quad (3)$$

$$\text{Log } Q_{50} = 5.57\text{-}2.59\ A^{-0.11} \quad (4)$$

$$\text{Log } Q_{100} = 5.52\text{-}2.42\ A^{-0.12} \quad (5)$$

where Q2, Q5, Q10, Q50, and Q100 are peak discharges in cfs, and A is drainage area in square miles. Using Equations (1) through (5) and drainage area values given in Table 3, discharges for different frequencies for the nine tributaries are computed and summarized in Table 4. Using the computed N-year discharge values given in Table 4, discharge frequency curves for the nine tributaries are plotted in Figures 3 through 11. As shown in these figures, discharge frequency curves are further adjusted for expected probability to account for the effects of uncertainty due to limited data used in the developments of the frequency curves. This "expected probability" adjustment was made using the procedure given in the U.S. Water Resources Council's Bulletin # 17B ("Guidelines for Determining Flood Flow Frequency", Ref. 8). Using Figures 3 through 11, tributary discharges adjusted for expected probability for various frequencies are summarized in Table 5.

Table 4

Computed N-Year Discharges for Tributaries

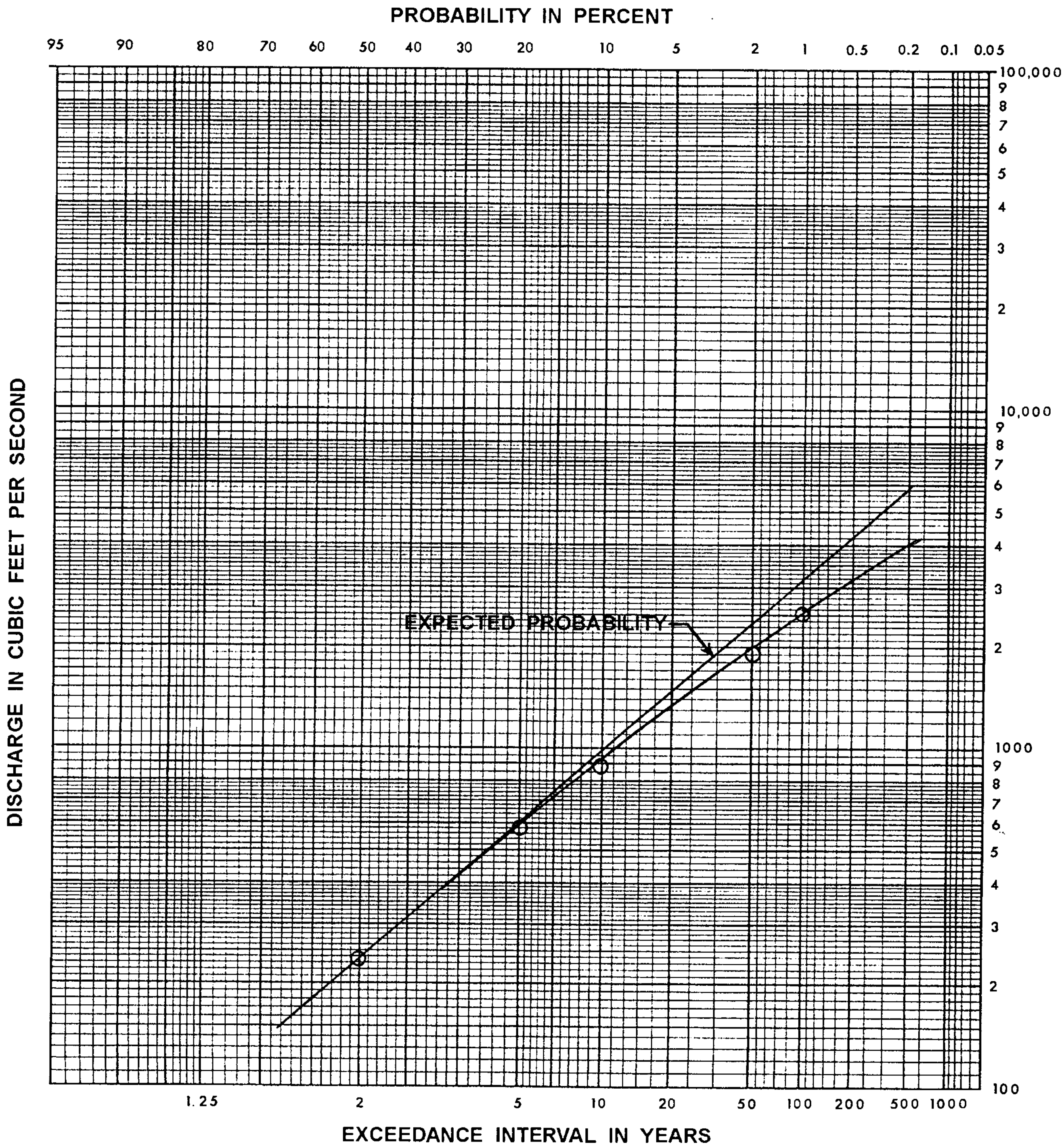
Tributary	N-Year discharges in cfs*				
	Q2	Q5	Q10	Q50	Q100
Craycroft Wash	234	568	891	1908	2540
Flecha Caida Wash	154	372	579	1223	1619
Valley View Wash	275	667	1049	2254	3003
Finger Rock Wash	339	823	1298	2798	3730
Camino Real Wash	176	427	667	1415	1878
Campbell Wash	209	506	793	1692	2249
Alamo Wash	438	1058	1671	3608	4809
Alvernon Wash	244	593	931	1996	2658
Christmas Wash	244	593	931	1996	2658

* Without adjustment for expected probability

Table 5

Tributary Discharges Adjusted for Expected Probability

Tributary	N-Year discharges in cfs				
	Q2	Q5	Q10	Q50	Q100
Craycroft Wash	234	600	1000	2350	3200
Flecha Caida Wash	154	380	620	1500	2100
Valley View Wash	275	680	1150	2800	3800
Finger Rock Wash	340	850	1400	3500	4900
Camino Real Wash	176	440	740	1800	2450
Campbell Wash	210	520	850	2100	2800
Alamo Wash	440	1120	1850	4300	6200
Alvernon Wash	244	640	1050	2500	3400
Christmas Wash	244	640	1050	2500	3400



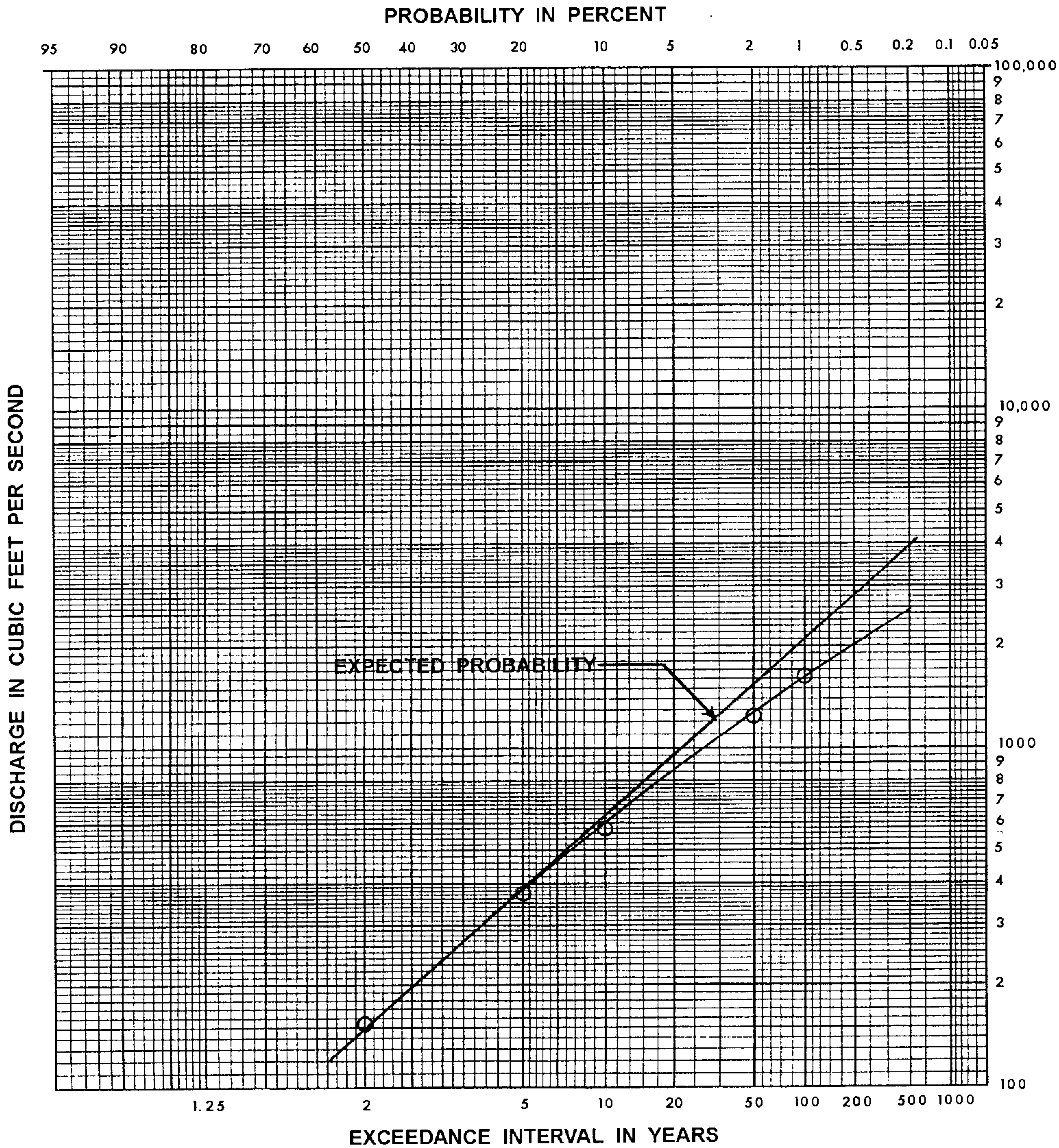
Drainage Area = 3.07 Square miles

DISCHARGE FREQUENCY CURVES

CRAYCROFT WASH

El Rio Antiguo
Rillito River Environmental
Restoration

Figure 3



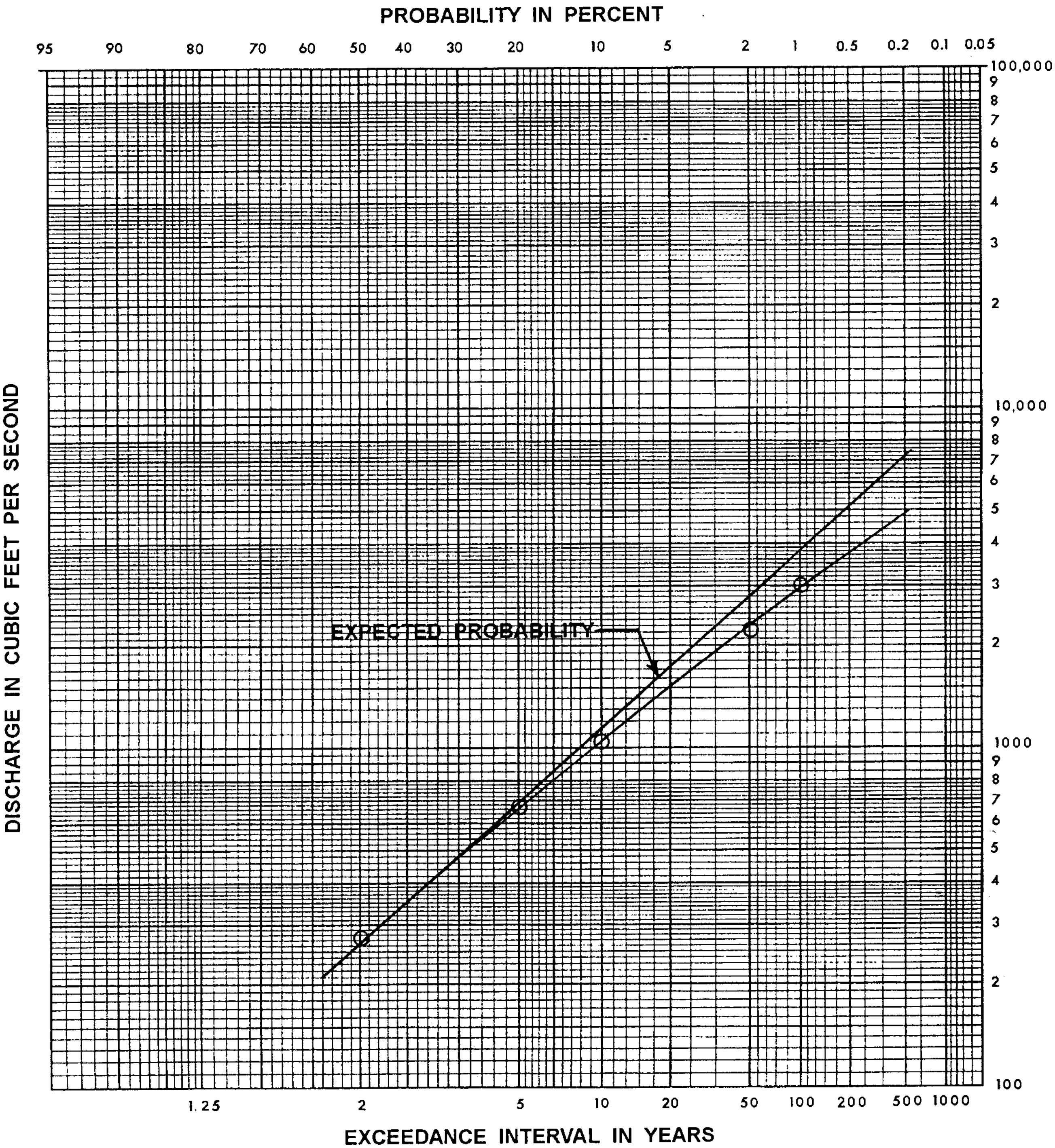
Drainage Area = 1.47 Square miles

DISCHARGE FREQUENCY CURVES

FLECHA CAIDA WASH

El Rio Antiguo
Rillito River Environmental
Restoration

Figure 4



Drainage Area = 4.11 Square miles

DISCHARGE FREQUENCY CURVES

VALLEY VIEW WASH

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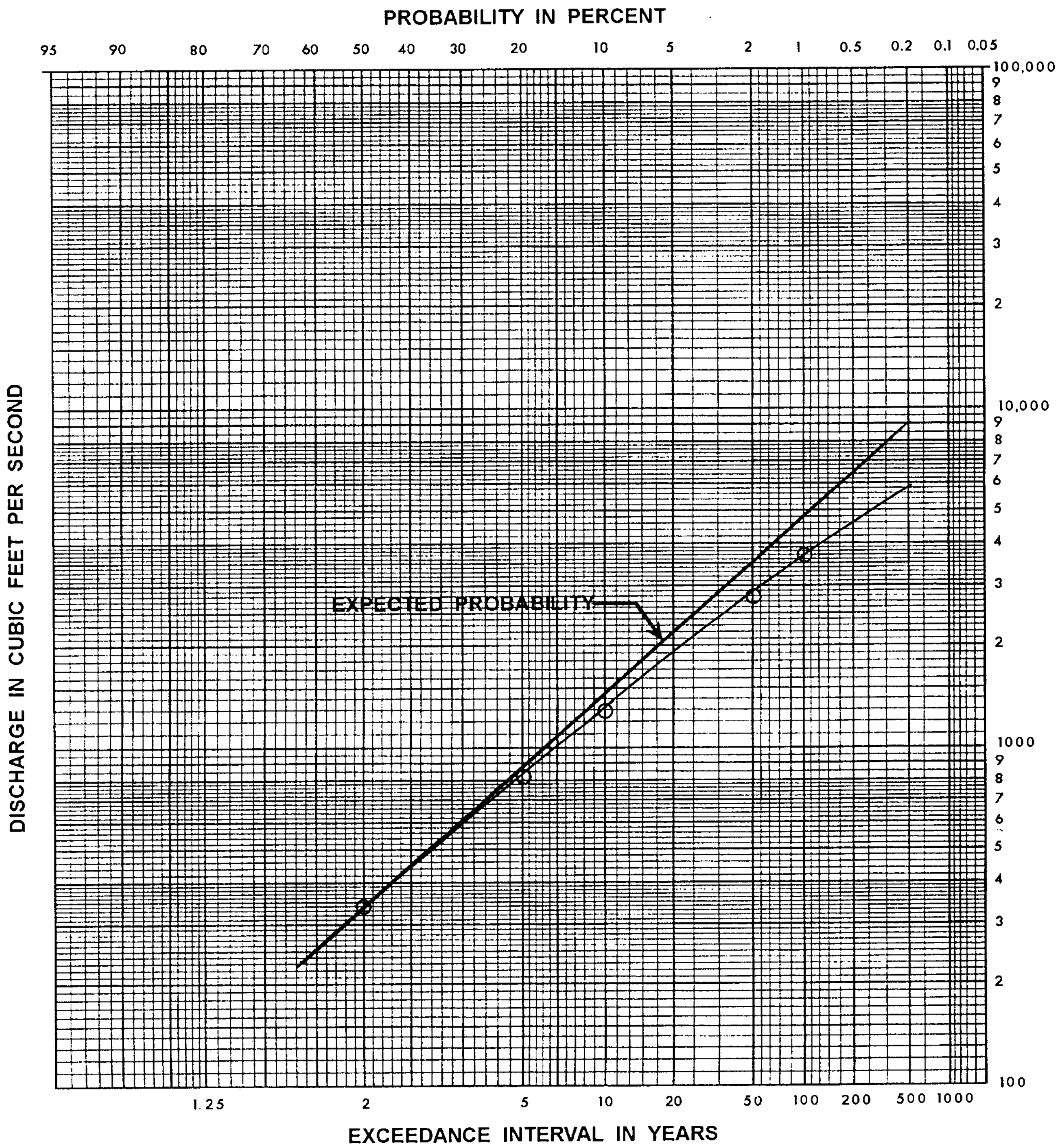
Rillito River Environmental
Restoration

Figure 5



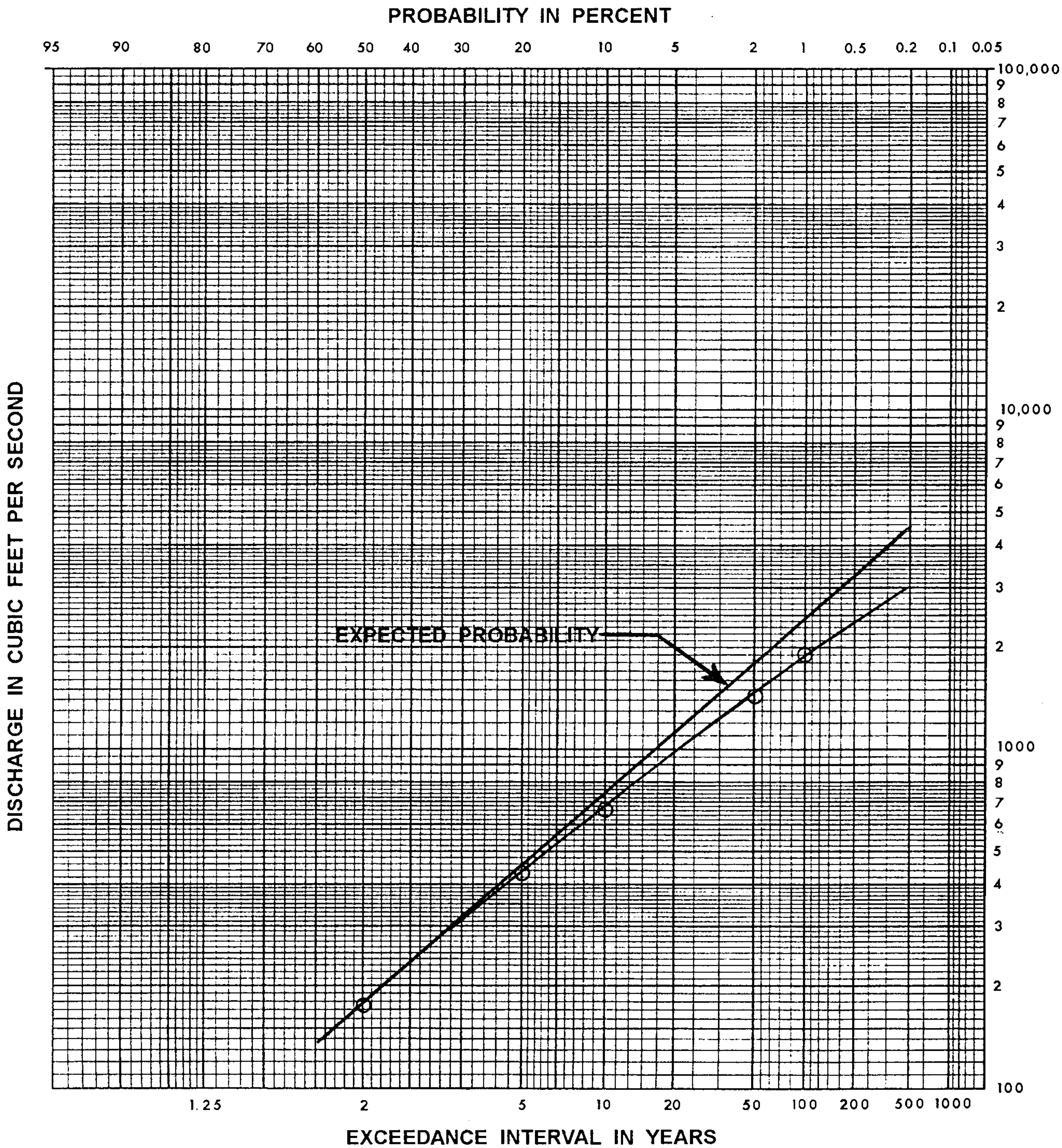
Drainage Area = 6.09 Square miles

DISCHARGE FREQUENCY CURVES

FINGER ROCK WASH

El Rio Antiguo
Rillito River Environmental
Restoration

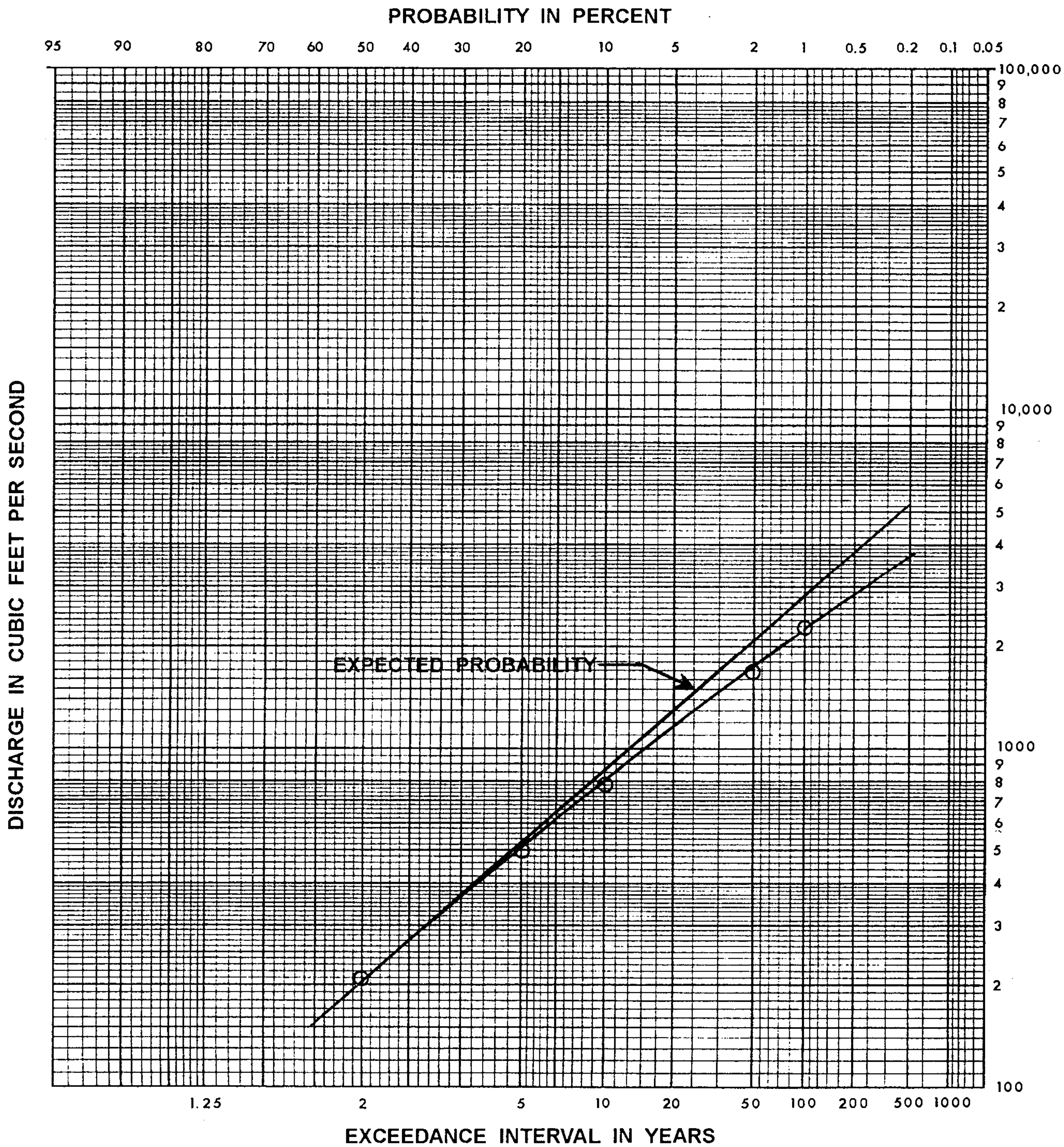
Figure 6



Drainage Area = 1.86 Square miles

DISCHARGE FREQUENCY CURVES
CAMINO REAL WASH
El Rio Antiguo Rillito River Environmental Restoration

Figure 7



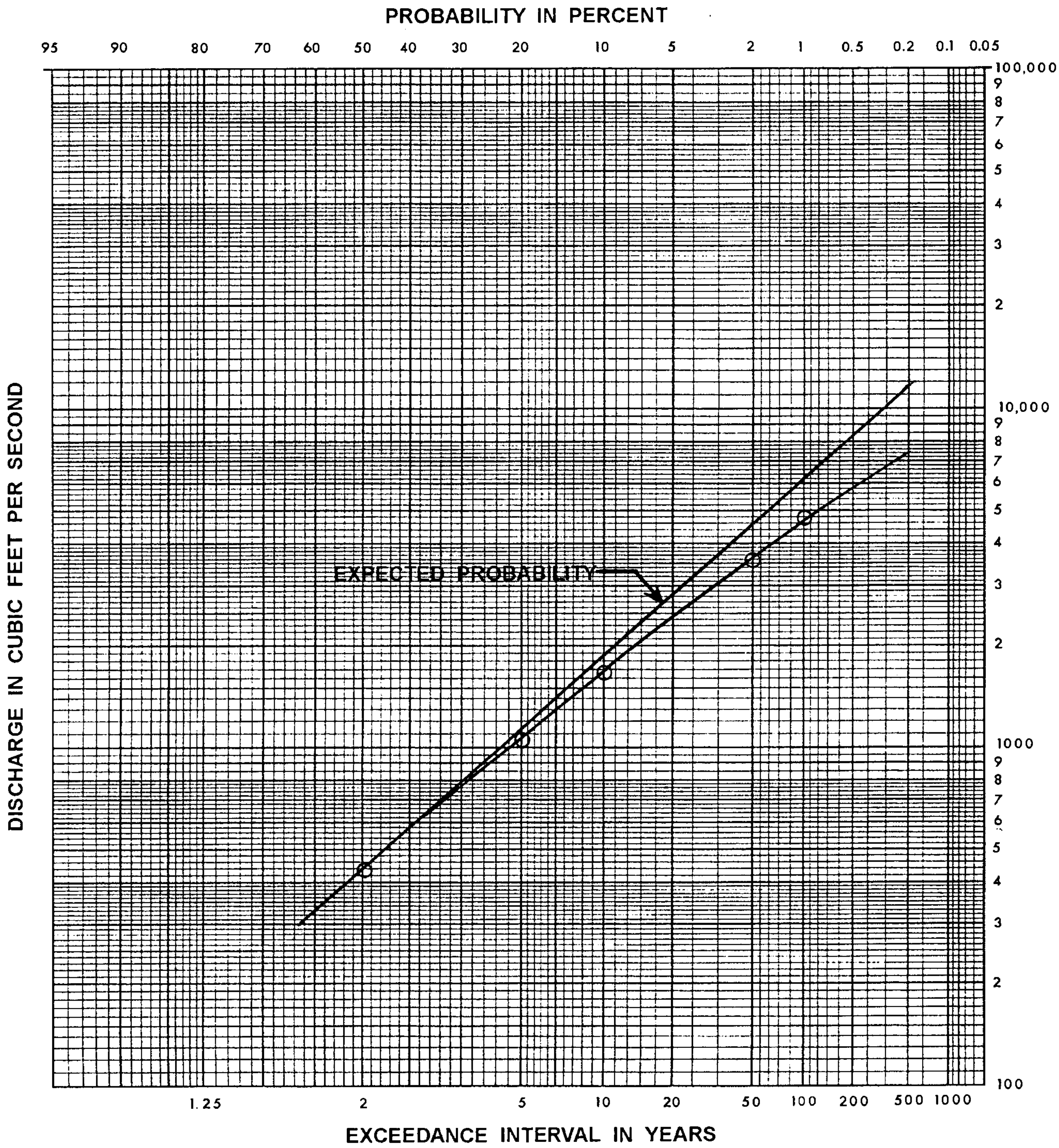
Drainage Area = 2.50 Square miles

DISCHARGE FREQUENCY CURVES

CAMPBELL WASH

El Rio Antiguo
Rillito River Environmental
Restoration

Figure 8



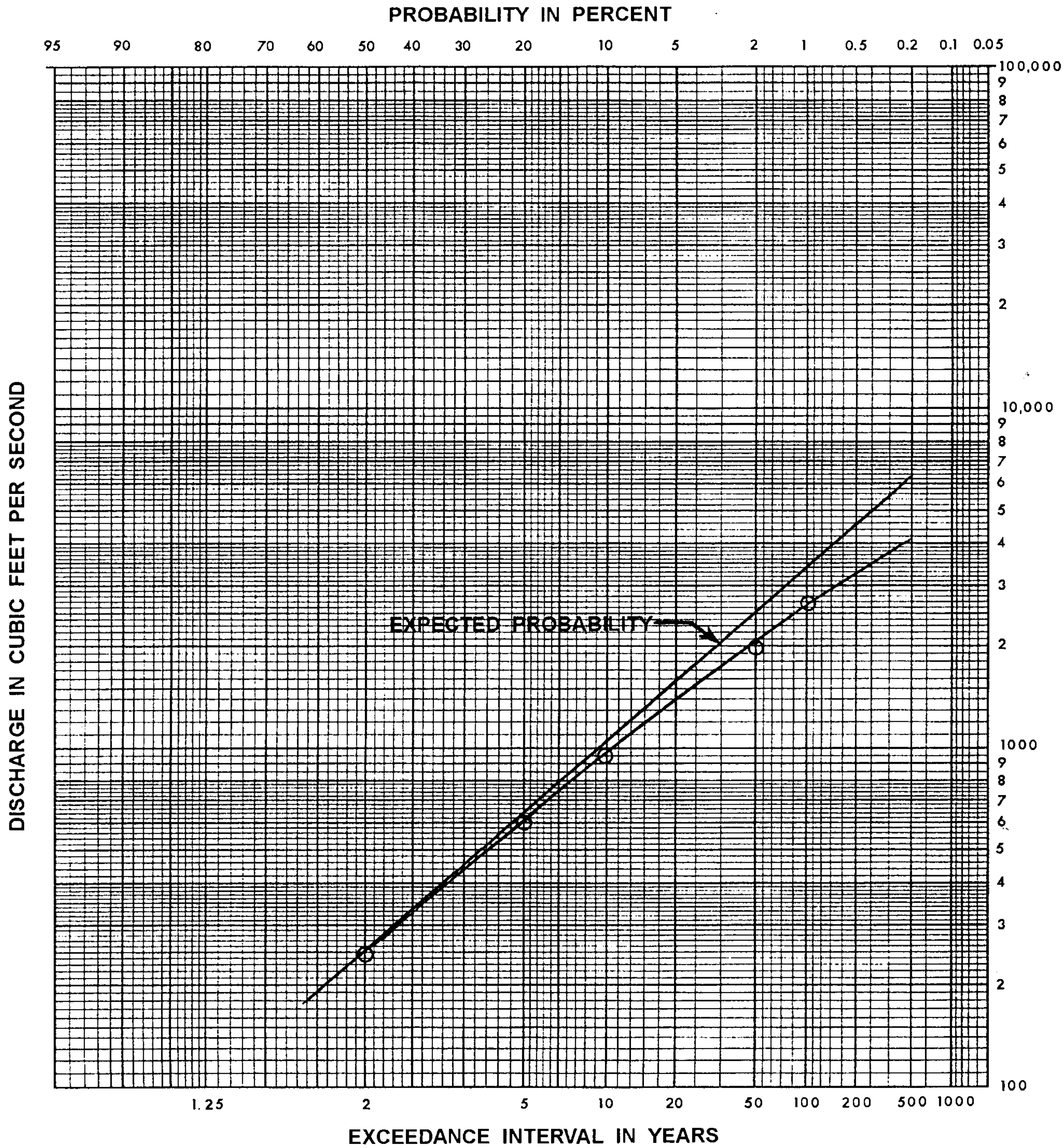
Drainage Area = 9.90 Square miles

DISCHARGE FREQUENCY CURVES

ALAMO WASH

El Rio Antiguo
Rillito River Environmental
Restoration

Figure 9



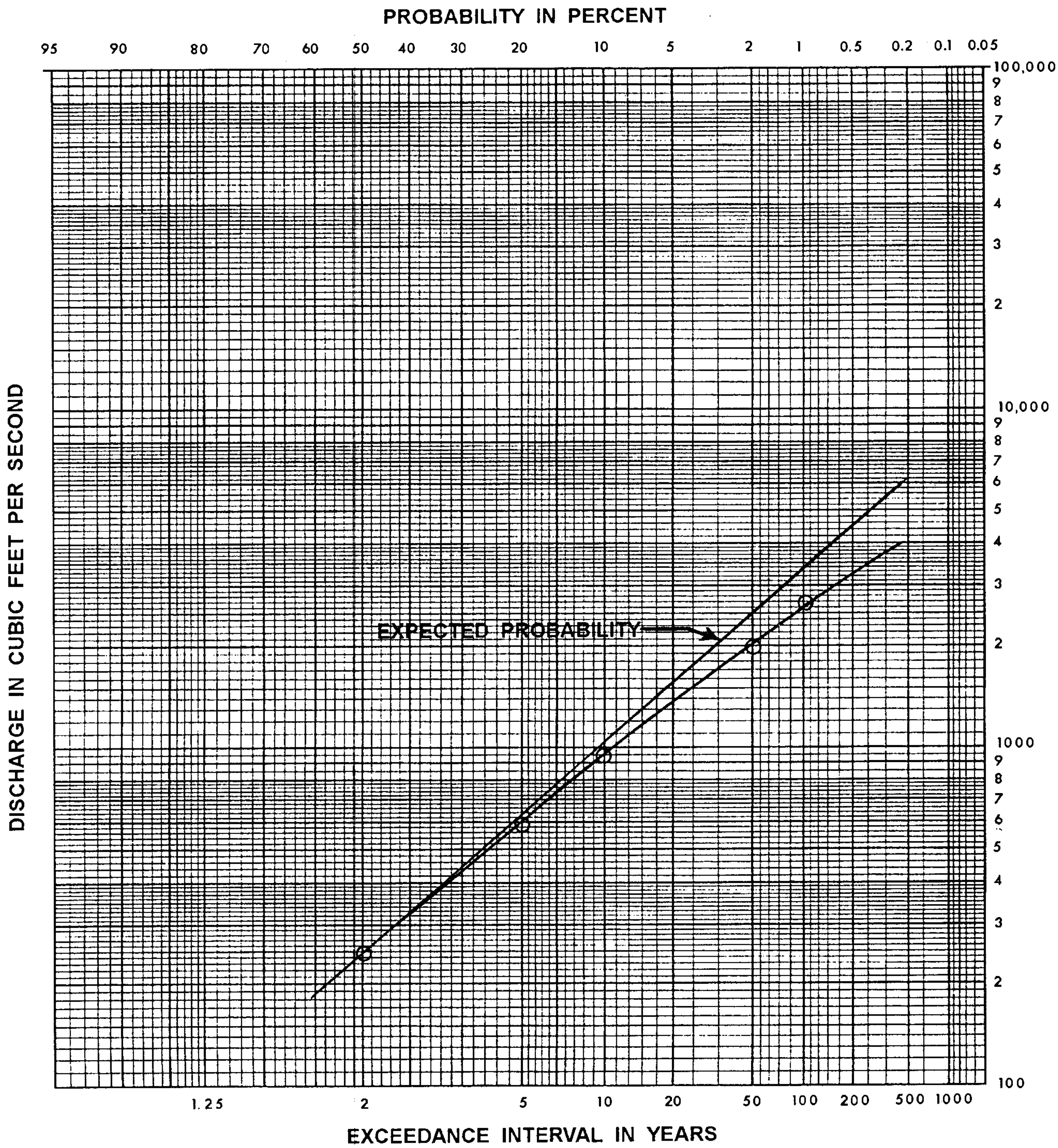
Drainage Area = 3.32 Square miles

DISCHARGE FREQUENCY CURVES

ALVERNON WASH

El Rio Antiguo
Rillito River Environmental Restoration

Figure 10



Drainage Area = 3.32 Square miles

DISCHARGE FREQUENCY CURVES

CHRISTMAS WASH

El Rio Antiguo
Rillito River Environmental
Restoration

Figure 11

7. REFERENCES

1. U.S. Army Corps of Engineers, "Rillito River & Associated Streams, Flood and Erosion Damage Reduction Study, Gila River & Tributaries, Interim 2, Hydrology Report", Los Angeles District, January, 1984.

2. U.S. Army Corps of Engineers, "Gila River & Tributaries, Rillito River, Tucson, Arizona, General Design Memorandum, Hydrology Appendix", Los Angeles District, September, 1988.

3. U.S. Army Corps of Engineers, "Gila River and Tributaries, Design Memorandum, Rillito River, Tucson, Arizona, Bank Protection", Los Angeles District, October, 1992.

4. U. S. Army Corps of Engineers, "Lower Finger Rock Wash, Tucson, Pima County, Arizona", Detailed Project Report, Section 205, Los Angeles District, September, 1996.

5. U.S. Geological Survey, "Estimation of Magnitude and Frequency of Floods in Pima County, Arizona with Comparisons of Alternative Methods", Water Resources Investigations report 84-4142, Tucson, Arizona, August, 1984.

6. U. S. Geological Survey, "Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States", Open File Report 93-413, Tucson, Arizona, 1994.

7. Federal Emergency Management Agency, "Flood Insurance Study, Pima County, Arizona and Incorporated Areas", Volume 1 of 3, February 8, 1999.

8. U.S. Department of the Interior, Geological Survey, "Guidelines for Determining Flood Flow Frequency", Interagency Advisory Committee on Water Data, Bulletin #17B of the Hydrology Subcommittee, March, 1982.

APPENDIX A

DEVELOPMENT OF HYDROLOGY FOR SEDIMENTATION ANALYSIS

APPENDIX A

DEVELOPMENT OF HYDROLOGY FOR SEDIMENTATION ANALYSIS

Table of Contents

Table of Contents (continued)

TABLES

FIGURES

EXHIBITS

Table of Contents (continued)

A-1. <u>INTRODUCTION.</u>

The information presented in this appendix was developed in order to provide sufficient streamflow information to enable determination of the average annual rate of sediment deposition or scour in the study reach of Rillito Creek. As described in the "Hydraulics Documentation", hypothetical hydrographs for single events (referred to herein as *Balanced Hydrographs*[1]), along with associated bed and suspended load volumes, were routed through the study reach of Rillito Creek. The sediment deposition or scour results for each hypothetical event were then numerically integrated against the annual exceedance probability to obtain a representative annual quantity of sediment deposition or scour. Since significant quantities of sediment could be transported due to events other than the annual maximum event, more representative hypothetical hydrographs were developed from *Partial Duration Series*[2], rather than *Annual Maximum Series.* For arid and semi-arid application, where streamflow during most times of the year, and during all of many years, is non-existent or very small, most sediment is transported by occasional events. Hence a *Partial Duration Series*, composed of all significant flood flows during the period of record, rather than limited to the greatest flow in each year, can provide a framework for an improved determination of the sediment transport characteristics and quantities in ephemeral streams. In order to better estimate of the total quantity of sediment transport in such streams, a correction factor to the probability-weighted sediment delivery can be developed. For simplicity, this factor can be defined as the ratio of the mean annual water volume (computed by integrating the annual discharge-frequency curve) to the mean annual water volume calculated directly from the observed/measured streamflow data. Since the *Partial Duration Series* by definition includes more of the significant events than an *Annual Maximum Series*, the mean annual water volume computed by integrating the discharge-frequency curve developed from the *Partial Duration Series*, provides a more accurate estimate of the mean annual discharge, and consequently, the mean annual sediment transport (i.e. deposition and scour).

Finally, since the objective of the sediment transport study is to ensure that the existing channel

1 *Balanced Hydrographs* were developed for the following frequencies: 1-, 1.25-, 2-, 5-, 10-, 25-, 50-, and 100-years.
2 *Partial Duration Series* is a series of independent runoff events, which may include both peak and duration discharges (volumes for specific time intervals such as 1-day, 2-day, etc.), comprising the largest events which have occurred within the observation period. In contrast an *Annual Maximum Series* is restricted to the single largest peak and duration discharges which occur in each year. Thus the *Partial Duration Series* includes the largest events within the *Annual Maximum Series*, but replaces smaller annual events with secondary events from years in which there may have been more than one significant discharge. Because of these differences, the two series are similar in the upper end (more rare events), but differ in the lower end (more frequent events). The discharge-frequency curve fitted to the *Partial Duration Series* is typically a composite curve for the duration desired. An analytical discharge-frequency curve is derived from the *Annual Maximum Series*, and subsequently, a graphical curve is fit through the *Partial Duration Series* data which transitions to the analytically-derived curve in the upper end, where both data sets are identical. A *Partial Duration Series*, as implied by the word "partial" may include all streamflow data above an arbitrary base, the largest N-events in an N-year period, or even more events than years of record. In this case the series was selected to include all events with a relative plotting position < 1.0, tantamount to including all events with a probability of occurrence up to 100% in any given year.

capacity is not compromised by the project, rather than evaluate the flood control benefits attributable to the project, the hydrology from which the runoff hydrographs were developed does not have to be updated to reflect the most recent streamflow record. Rather, *Balanced Hydrographs* have been based upon pre-existing volume-frequency analyses, expanded to include *Partial Duration Series* analysis, for reasons stated in the previous discussion. The following discussion documents the development of the synthetic floods (*Balanced Hydrographs*) used to determine the probability-weighted average annual discharge, the ratio of the probability-weighted average annual discharge to the observed/measured average annual discharge, and the average annual sediment transport.

A-2. VOLUME-FREQUENCY ANALYSIS.

In order to develop synthetic flood hydrographs (*Balanced Hydrographs)* for use in sediment transport computations, a necessary first step is to develop volume-frequency relationships for Rillito Creek. Since flood control benefits were not applicable to Rillito Creek as a function of this study, pre-existing volume-frequency relationships were adequate to perform the sediment transport analysis. **Note: a volume-frequency analysis is a discharge-frequency analysis incorporating a series of duration-discharges, e.g. peak or instantaneous flow, 1-day flow, 2-day flow, 3-day flow, etc. The resulting discharge-frequency relationships are typically displayed as a family of curves.** Durations are selected to provide adequate definition for the stream/drainage area of interest. Data is typically derived from annual maxima for each duration of interest, and represents the maximum average flow (or volume) from a contiguous set of observed discharges. The best source of contiguous duration data is a recording streamgage. For Rillito Creek near Tucson, recorded or systematic daily flow record is available from the United States Geological Survey (USGS) for the period from 1914 to 1975. Peak discharges are available from the USGS for the period from 1915 to the present at one of a series of closely situated gaging sites in the vicinity of Tucson, Arizona. For this current sediment transport analysis, volume-frequency relationships developed for the July 1990 Corps of Engineers Report, SANTA CRUZ RIVER, Hydrologic Documentation for Feasibility Studies, Lower Santa Cruz River Flood Control Study, Pinal County, Arizona, were selected for incorporation into this study (Plate 25 of that study).

Inspection of the daily flow record indicates that most of the volume of flood flow is contained within a 5-day period of contiguous runoff. The 5-day discharge-frequency curve developed for the 1990 report was integrated against annual probability of exceedance to estimate an *average annual runoff volume*. The resulting volume was approximately 3900 ac-ft. The measured average annual runoff volume including all flow at the gage was 11,660 ac-ft. Based upon the disparity in volumes (nearly two-thirds of the actual volume was unaccounted for when flow data is limited to the annual maximum 5-day volume), the annual exceedance relationships were modified to better account for smaller, but significant flows than are captured in an *Annual Maximum Series.* The recorded streamflow data was examined to compute, and subsequently extract, the largest duration-events[3] from the entire systematic record. Ultimately the *Partial Duration Series* peak data set included **81 events exceeding 3000 ft^3/s**. (By comparison, the 2-year, 5-day maximum flow rate from annual Maxima was only **1500 ft^3/s, and was exceeded by 61 events.**) Table A-1 below summarizes the *Partial Duration Series* instantaneous maxima and provides a comparison to *Annual Maximum Series* data.

TABLE A-1. *PARTIAL DURATION SERIES* DATA
Instantaneous Flow

MAXIMUM INSTANTANEOUS DISCHARGE, CFS
Rillito Creek (1915-1984), N=81years including historic data

Partial Duration Flows, Q > 3000 cfs				*Annual Maximum Series*		
Observed Discharge	Rank	Plotting Positions				
	m	*(m-0.30)/(N+0.40)*	*(2m-1)/(2N)*	*m*	*Q*	*PP*
29700	1	0.009		1	29700	0.0099
24000	2	0.021		2	24000	0.0241
17000	3	0.033		3	17000	0.0384
16400	4	0.045		4	16400	0.0526
16000	5	0.058		5	16000	0.0668
13400	6	0.070		6	13400	0.0810
13200	7	0.082		7	13200	0.0952
12400	8	0.095		8	12400	0.1094
10000	9	0.107		9	10000	0.1236
9900	10	0.119		10	9900	0.1378
9710	11	0.131		11	9710	0.1520
9500	12	0.144		12	9500	0.1662
9490	13	0.156		13	9490	0.1804
9420	14	0.168		14	9420	0.1946
9400	15	0.181		15	9400	0.2088
9290	16	0.193		16	9290	0.2230
9250	17	0.205		17	9250	0.2372
8930	18	0.217		18	8930	0.2514
8070	19	0.230		19	8070	0.2656
7800	20	0.242		20	7800	0.2798
7740	21	0.254		21	7740	0.2940
7710	22	0.267		22	7710	0.3082

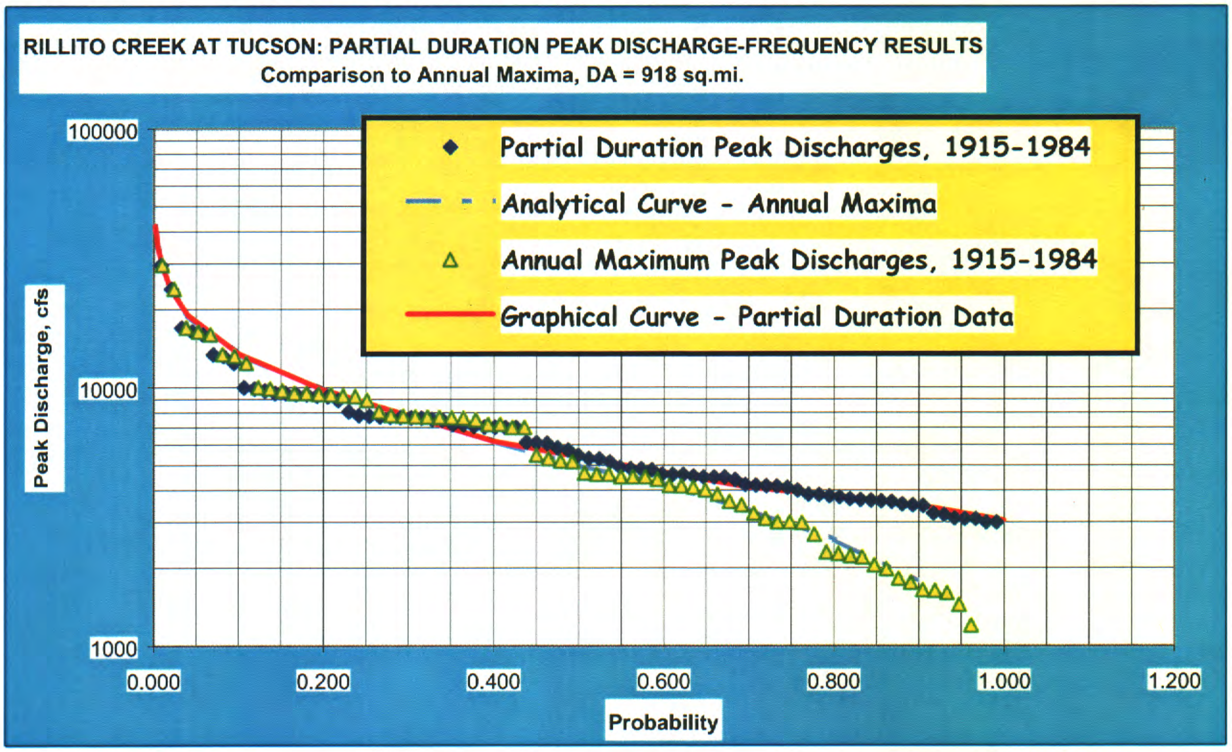
3 For this study, the duration-events were limited to the peak, 1-day, and 5-day flows, which provided sufficient volumetric and peak data to adequately describe synthetic flood hydrographs for use in this study.

MAXIMUM INSTANTANEOUS DISCHARGE, CFS *Rillito Creek (1915-1984), N=81years including historic data*						
Partial Duration Flows, Q > 3000 cfs				*Annual Maximum Series*		
Observed Discharge	Rank *m*	Plotting Positions *(m-0.30)/(N+0.40)*	*(2m-1)/(2N)*	*m*	*Q*	*PP*
7680	23	0.279		23	7680	0.3224
7660	24	0.291		24	7660	0.3366
7640	25	0.303		25	7640	0.3509
7620	26	0.316		26	7620	0.3651
7530	27	0.328		27	7500	0.3793
7500	28	0.340		28	7200	0.3935
7200	29	0.353		29	7200	0.4077
7200	30	0.365		30	7000	0.4219
7100	31	0.377		31	7000	0.4361
7040	32	0.389		32	5470	0.4503
7010	33	0.402		33	5300	0.4645
7000	34	0.414		34	5190	0.4787
7000	35	0.426		35	5160	0.4929
6140	36	0.439		36	4650	0.5071
6120	37	0.451		37	4600	0.5213
6100	38	0.463		38	4600	0.5355
5850	39	0.475		39	4500	0.5497
5740	40	0.488		40	4500	0.5639
5470	41	0.500	0.500	41	4500	0.5781
5320	42	0.512	0.512	42	4400	0.5923
5300	43	0.525	0.525	43	4160	0.6065
5160	44	0.537	0.537	44	4140	0.6207
4910	45	0.549	0.549	45	4100	0.6349
4850	46	0.561	0.562	46	4000	0.6491
4840	47	0.574	0.574	47	3850	0.6634
4800	48	0.586	0.586	48	3610	0.6776
4610	49	0.598	0.599	49	3500	0.6918
4600	50	0.611	0.611	50	3250	0.7060
4600	51	0.623	0.623	51	3100	0.7202
4540	52	0.635	0.636	52	3000	0.7344
4500	53	0.647	0.648	53	3000	0.7486
4500	54	0.660	0.660	54	2980	0.7628
4500	55	0.672	0.673	55	2690	0.7770
4400	56	0.684	0.685	56	2300	0.7912
4200	57	0.697	0.698	57	2270	0.8054
4180	58	0.709	0.710	58	2220	0.8196

MAXIMUM INSTANTANEOUS DISCHARGE, CFS *Rillito Creek (1915-1984), N=81years including historic data*						
Partial Duration Flows, Q > 3000 cfs				***Annual Maximum Series***		
Observed Discharge	Rank	Plotting Positions				
	m	*(m-0.30)/(N+0.40)*	*(2m-1)/(2N)*	*m*	*Q*	*PP*
4160	59	0.721	0.722	59	2200	0.8338
4140	60	0.733	0.735	60	2050	0.8480
4100	61	0.746	0.747	61	1980	0.8622
4000	62	0.758	0.759	62	1820	0.8764
3850	63	0.770	0.772	63	1750	0.8906
3840	64	0.783	0.784	64	1640	0.9048
3800	65	0.795	0.796	65	1630	0.9190
3760	66	0.807	0.809	66	1600	0.9332
3700	67	0.819	0.821	67	1440	0.9474
3670	68	0.832	0.833	68	1200	0.9616
3650	69	0.844	0.846	69	779	0.9759
3630	70	0.856	0.858	70	754	0.9901
3610	71	0.869	0.870			
3530	72	0.881	0.883			
3500	73	0.893	0.895			
3480	74	0.905	0.907			
3250	75	0.918	0.920			
3210	76	0.930	0.932			
3110	77	0.942	0.944			
3100	78	0.955	0.957			
3100	79	0.967	0.969			
3000	80	0.979	0.981			
3000	81	0.991	0.994			

A graphical comparison of the discharge-frequency curves developed from the *Partial Duration Series* and *Annual Maximum Series* data is provided on Figure A-1. The analytical curve fit to the *Annual Maximum Series* was generated using the HEC-FFA computer program, Flood Frequency Analysis, presuming a log-Pearson Type III distribution was applicable and following Bulletin 17b guidelines. The curve fit to the *Partial Duration Series* was a hybrid – consistent with the analytical curve for the range of ranked events which are identical (the 26 largest peak discharges for both series are the same), or nearly identical (the 31st largest peak discharge for the *Partial Duration Series* is 7100 ft^3/s, while for the *Annual Maximum Series* the corresponding peak discharge is 7000 ft^3/s), and then graphically constructed to fit the data for the range of ranked events which are dissimilar (plotting positions < 0.4, or 2.5 year return period).

FIGURE A-1. PEAK DISCHARGE-FREQUENCY CURVES



The 1-day and 5-day maximum average flows for the period from 1915 to 1975 were computed from the streamflow information (random, independent events were selected), and tabulated. These duration discharges were ranked according to magnitude and assigned plotting positions to coincide with those rankings. All events selected had a plotting position of 1.0 or less (1.0 would correspond to an approximate exceedance probability of 100% in any given year). Table A-2 (located on the following page) summarizes the *Partial Duration Series* 1- and 5-day average flows for the period of record.

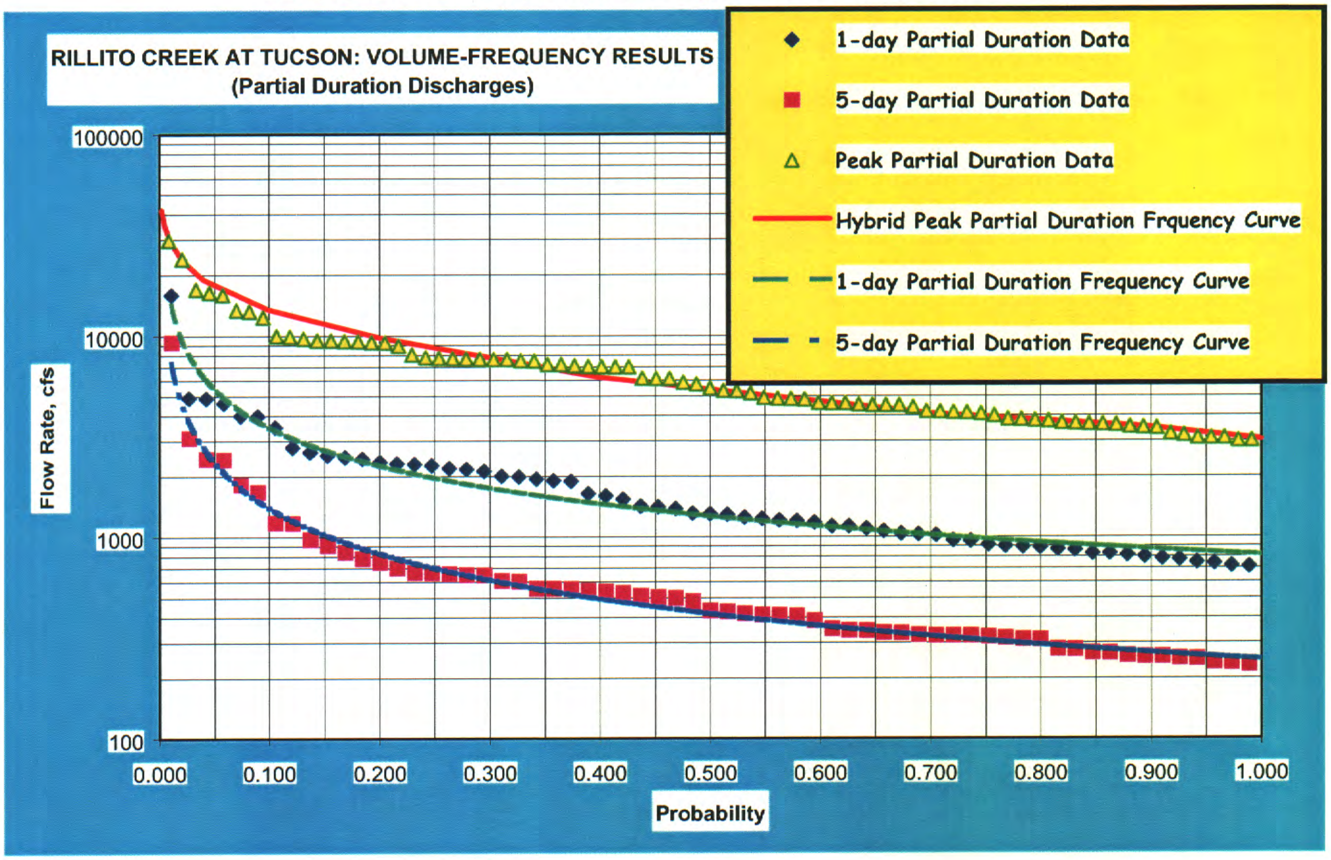
TABLE A-2. *PARTIAL DURATION SERIES* DATA
Duration Flow

RANK	MAXIMUM DURATION DISCHARGES, cfs 1-, 5-day Average Flows		
	Rillito Creek (1915-1975)		
m	1-day Ave (cfs)	5-day Ave (cfs)	Plotting Position *(m-0.30)/(N+0.40)*
1	16000	9300.0	0.011
2	4920	3106.0	0.027
3	4900	2446.0	0.043
4	4640	2424.0	0.058
5	4000	1820.0	0.074
6	3990	1671.6	0.090
7	3520	1176.6	0.106
8	2790	1170.2	0.121
9	2650	974.0	0.137
10	2550	908.2	0.153
11	2500	839.8	0.169
12	2450	782.4	0.185
13	2360	748.0	0.200
14	2320	702.0	0.216
15	2300	666.2	0.232
16	2270	664.4	0.248
17	2200	656.0	0.263
18	2170	649.2	0.279
19	2130	647.2	0.295
20	2010	605.1	0.311
21	1990	602.6	0.326
22	1940	554.8	0.342
23	1910	554.4	0.358
24	1890	554.0	0.374
25	1640	544.2	0.390
26	1600	537.0	0.405
27	1540	527.2	0.421
28	1420	511.2	0.437
29	1410	503.8	0.453
30	1380	497.4	0.468
31	1310	479.4	0.484
32	1300	432.0	0.500
33	1290	427.2	0.516
34	1250	418.4	0.532
35	1230	411.4	0.547

RANK	MAXIMUM DURATION DISCHARGES, cfs 1-, 5-day Average Flows		
	Rillito Creek (1915-1975)		
m	1-day Ave (cfs)	5-day Ave (cfs)	Plotting Position *(m-0.30)/(N+0.40)*
36	1210	411.2	0.563
37	1200	408.0	0.579
38	1180	385.4	0.595
39	1130	351.0	0.610
40	1130	344.2	0.626
41	1100	343.8	0.642
42	1070	336.4	0.658
43	1040	334.2	0.674
44	1030	328.0	0.689
45	1020	325.4	0.705
46	961	324.8	0.721
47	954	324.6	0.737
48	914	322.2	0.752
49	900	316.8	0.768
50	893	312.2	0.784
51	888	311.4	0.800
52	870	278.8	0.815
53	863	278.4	0.831
54	830	267.2	0.847
55	830	265.8	0.863
56	815	259.0	0.879
57	798	255.6	0.894
58	783	255.4	0.910
59	773	251.4	0.926
60	748	249.2	0.942
61	740	239.8	0.957
62	719	238.0	0.973
63	712	232.6	0.989
64	709	232.1	1.005

Volume-frequency curves were constructed to fit the data set, but retain the characteristics of the *Annual Maximum Series* results for the more remote events. The 5-day discharge-frequency curve developed from the *Partial Duration Series* was integrated against annual probability of exceedance to provide an improved estimate of the *average annual runoff volume*. The resulting volume was approximately 8560 ac-ft, an increase of approximately 120%, and a total much closer to the measured results at the gage (the Partial Duration results account for nearly 75% of the observed runoff, compared to only 33% using annual maxima). More directly, synthetic flood hydrographs developed from the Partial Duration data should provide a much-improved basis for determination of the average annual sediment transport. The peak discharge-frequency curve developed from Partial Duration data was compared to the peak discharge-frequency curve developed from annual maxima on Figure A-1. The family of volume-frequency curves developed from the Partial Duration data is displayed on Figure A-2.

FIGURE A-2. VOLUME-FREQUENCY CURVES



Note: The *average annual runoff* calculated from the Partial Duration, 5-day curve (above) is 8560 ac-ft); the measured average annual runoff is 11,660 ac-ft. The ratio (0.734) was determined in order to provide the relative proportion of average annual sediment transport accounted for in the routing of the discrete, synthetic flood events (*Balanced Hydrographs)*.

A-3. BALANCED HYDROGRAPH DEVELOPMENT.

A *Balanced Hydrograph* is a hypothetical flood event having the same probability of exceedance for every duration. As such, it is a convenient tool to analyze situations requiring both volumetric information, where storage may exert an influence (such as impoundments or channel routing and overflow mapping), as well as peak information, which is necessary for channel capacity determination and outlet sizing. *Balanced Hydrographs* are typically developed from volume-frequency relationships, in order to establish boundary conditions (i.e. duration discharges for each frequency of interest) for computation/interpolation of flow rate versus time. In this case the boundary conditions were limited to the peak discharge, and the 1- and 5-day average discharges for each frequency of interest (1-, 1.25-, 2-, 5-, 10-, 25-, 50-, and 100-year). For example, the boundary conditions to describe the 100-year *Balanced Hydrograph* (or 1% chance annual exceedance flood) were the 1% annual exceedance probability instantaneous discharge (29,500 ft^3/s), the 1% annual exceedance probability 1-day average discharge (15,000 ft^3/s), and the 1% annual exceedance probability 5-day average discharge (8000 ft^3/s) taken from the results of the Partial Duration analysis (please refer to Table A-3, below). Since each duration discharge is selected from a consistent family of frequency curves, and these duration discharges are used as boundary conditions, it is reasonable to assume that any intermediate duration flow rate (i.e. $I_{instantaneous} < I_{intermediate\ duration} < Q_{1\text{-}day}$, and $Q_{1\text{-}day} < I_{intermediate\ duration} < Q_{5\text{-}day}$) for any of these hypothetical flood hydrographs has the same frequency of exceedance.

TABLE A-3. *PARTIAL* DURATION SERIES DATA
Volume-Frequency Results

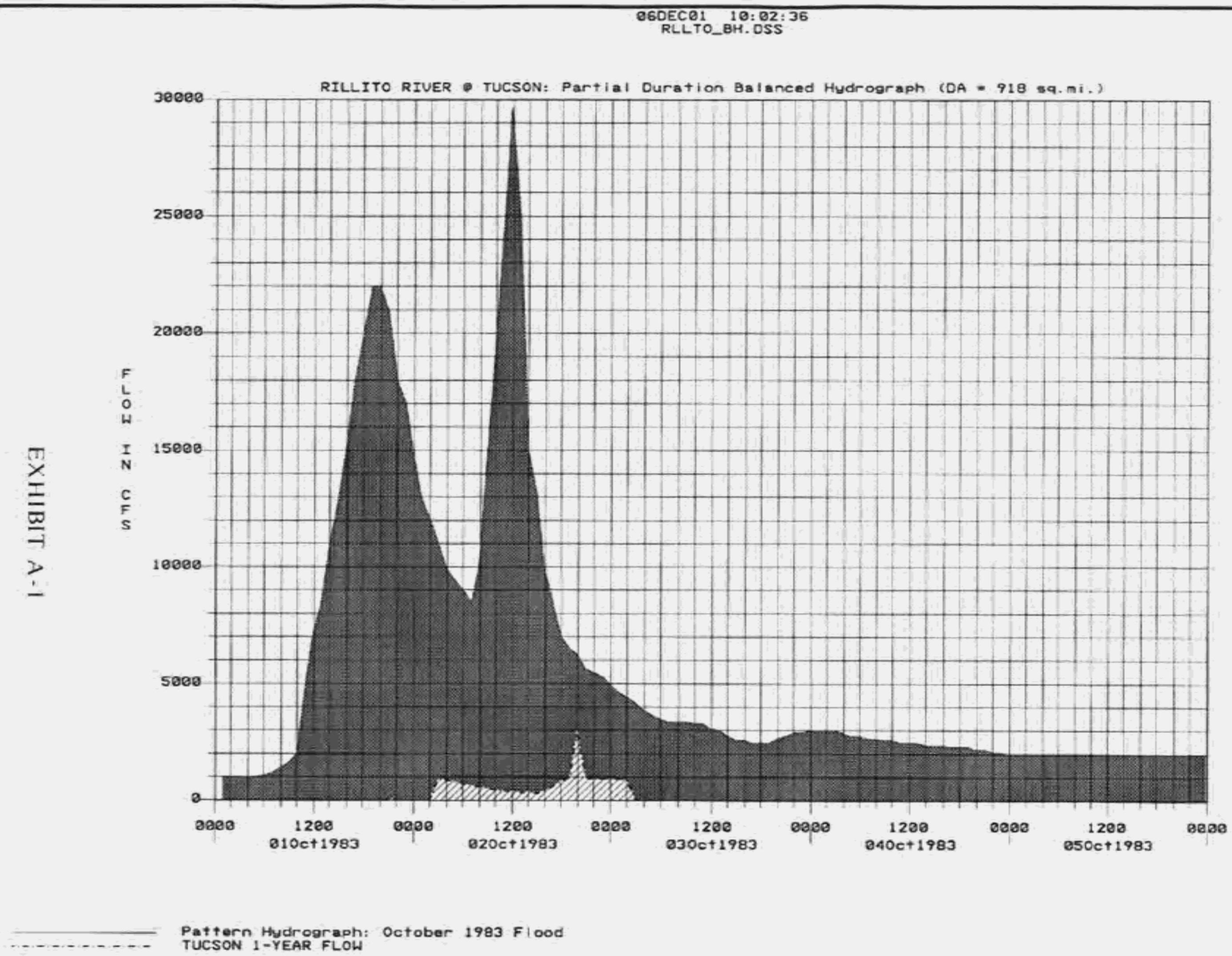
Frequency, years	Flow Duration		
	Instantaneous	1-Day	5-Day
100	29,500	15,000	8000
50	24,000	10,000	5000
25	19,000	6400	2800
10	13,500	2770	1500
5	9800	2300	840
2	5400	1300	420
1.25	3800	940	200
1	3050	810	180

Balanced Hydrographs can be developed in a variety of ways, including manual or graphical interpretation of the volume-frequency results. These synthetic floods can also be developed in an automated procedure using the HEC-1 Flood Hydrograph Package (The "HB-card" allows the user to input boundary conditions for automatic processing; when linked to a set of initial conditions, i.e. a "pattern" input hydrograph – in this case the 1983 flood was utilized - there is sufficient hydrologic information to compute the hydrograph ordinates for each event). Required input includes the computation interval and duration of flow, along with the aforementioned pattern hydrograph and boundary conditions. Use of the HEC-1 package allows easy graphical depiction of the resulting *Balanced Hydrographs* through use of the HEC-DSS (data storage system). *Balanced Hydrographs* for each of the synthetic flood events described are provided in Exhibits A-1 through A-8; each synthetic flood hydrograph is compared to the "pattern hydrograph" for informational purposes.

EXHIBITS

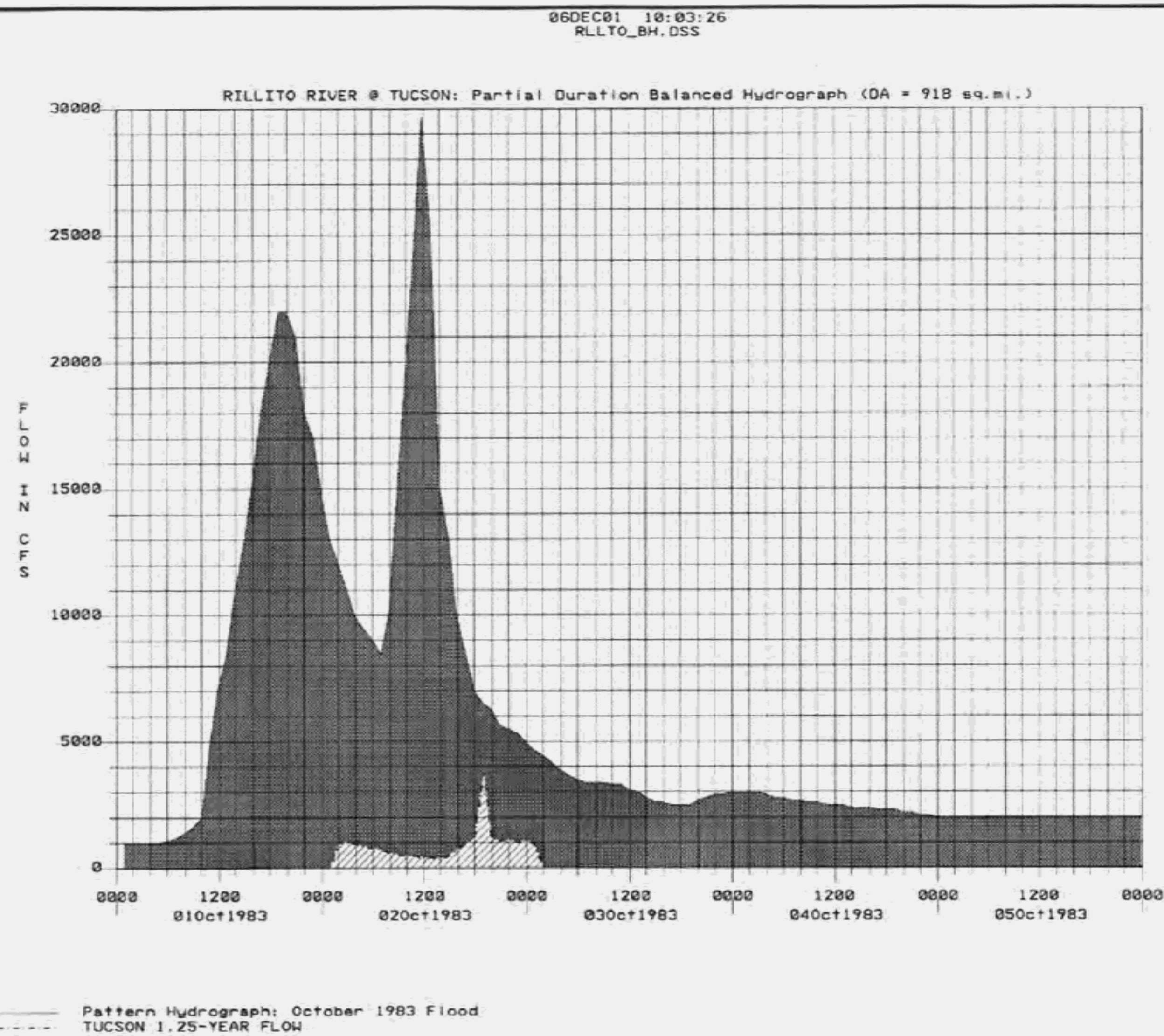
Balanced Hydrographs
[n = 1-, 1.25-, 5-, 10-, 25-, 50-, and 100-Year Events]

EXHIBIT A-1



06DEC01 10:02:36
RLLTO_BH.DSS
RILLITO RIVER @ TUCSON: Partial Duration Balanced Hydrograph (DA = 918 sq.mi.)
FLOW IN CFS
30000
25000
20000
15000
10000
5000
0
0000
1200
01Oct1983
0000
1200
02Oct1983
0000
1200
03Oct1983
0000
1200
04Oct1983
0000
1200
05Oct1983
0000
Pattern Hydrograph: October 1983 Flood
TUCSON 1-YEAR FLOW

EXHIBIT A-2


06DEC01 10:03:26
RLLTO_BH.DSS
RILLITO RIVER @ TUCSON: Partial Duration Balanced Hydrograph (DA = 918 sq.mi.)
FLOW IN CFS
30000
25000
20000
15000
10000
5000
0
0000
1200
01Oct1983
0000
1200
02Oct1983
0000
1200
03Oct1983
0000
1200
04Oct1983
0000
1200
05Oct1983
0000
Pattern Hydrograph: October 1983 Flood
TUCSON 1.25-YEAR FLOW