PHOENIX CITY STREAMS, ARIZONA

AGUA FRIA RIVER

HYDROLOGY

U.S. ARMY CORPS OF ENGINEERS

LOS ANGELES

April 1981

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HYDROLOGY

I. INTRODUCTION

1.01 PURPOSE AND SCOPE. This report presents hydrology for the Agua Fria River in support of General Design Memorandum studies for the Phoenix City Streams project. It was written to permit technical review and comment by interested local agencies before inclusion in a more comprehensive hydrology design memorandum (part 2 of reference 1) for the complete Phoenix project. The report has three major objectives: (1) to outline the basic meteorologic and hydrologic characteristics of the study area; (2) to present the methods and techniques used to model the runoff process and to determine discharge frequency relationships; and (3) to provide standard project flood and discharge frequencv values at selected locations for future conditions of development with the authorized flood control plan. Peak discharges are given in table 1.

1.02 AUTHORIZED PLAN OF IMPROVEMENT. The authorized plan for flood control comprises five major structural elements: Dreamy Draw Dam on Dreamy Draw, Cave Buttes Dam on Cave Creek, Adobe Dam on Skunk Creek, New River Dam on New River, and the Arizona Canal Diversion Channel.

1.03 PREVIOUS REPORTS.

a. The most recent Corps of Engineers reports containing hydrology for the Agua Fria River are "Gila River Basin, New River and Phoenix City Streams, Arizona, Design Memorandum No. 2, Hydrology, Part 1," dated October 1974 (ref. 1) and "Gila River Basin, New River and Phoenix City Streams, Arizona, Design Memorandum No. 3, General Design Memorandum - Phase I, Plan Formulation, Appendix 1," dated March 1976 (ref. 2).

b. Described herein are revisions to the parts of these reports that deal with the Agua Fria River, necessitated by a change in analysis after the floods of 1978-80 regarding the ability of Waddell Dam to control large floods. Waddell Dam was previously considered capable of controlling most of the runoff from the drainage area above it; thus, only runoff from below the dam would contribute to peak flows in the Agua Fria River reaching Avondale. The floods of 1978-80 and a careful evaluation of historical floods have clearly shown this not to be the case.

II. GENERAL DESCRIPTION OF DRAINAGE AREA

2.01 BASIN DESCRIPTION

a. The Agua Fria River originates over 7,000 feet above sea level in the mountains of central Arizona and flows southward for over 100 miles before emptying into the Gila River 15 miles west of downtown Phoenix at elevation 910. The course of the river is nearly equidistant between two parallel mountain ranges, the Black Hills-New River Mountains and the Bradshaw Mountains, that form the eastern and western boundaries, respectively, of the drainage area. The river gradient ranges from about 300 feet per mile in the headwaters to about 70 feet per mile at Waddell Dam and to about 10 feet per mile at the Gila River.

b. The Agua Fria watershed above the New River confluence comprises about 1,650 square miles, 1,459 square miles of which are above Waddell Dam. The subarea above Waddell Dam ranges in elevation from over 7,000 feet to 1,600 feet. The lower reaches of the subarea consist of a rather broad, nearly level stream valley bordered by rugged mountains; the upper portion of the subbasin is dominated by fairly high mountains and steep ridges leading to Mingus Mountain, the highest part of the watershed. Vegetation varies from native grass and desert shrubs at the lower elevations to pine forests with considerable understory growth in the higher mountains. Depths of soil are mostly shallow with frequent rock outcroppings.

c. Below Waddell Dam, the contributing drainage area was assumed to be fully urbanized for future conditions.

2.02 RUNOFF CHARACTERISTICS. None of the major tributaries to the Agua Fria River flow perennially. Runoff generally occurs only during and immediately following relatively heavy precipitation because climatic and drainage area characteristics are not conducive to continuous runoff. Significant runoff can occur in the summer months (June through mid-October) as a result of summer storms, both local and general. High flows in the lower part of the river normally only occur when large general storms cause Waddell Dam to spill.

2.03 AUTHORIZED STRUCTURES AFFECTING RUNOFF. The major structural elements of the authorized plan will only affect the Agua Fria River below its confluence with New River. The dams will decrease large flows normally reaching the Agua Fria River from the New River and are designed to compensate for the diversion of flow by the Arizona Canal Diversion Channel. Maximum design outflows from the dam outlets are as follows:

(1) Dreamy Draw Dam: 220 cfs.

(2) Cave Buttes Dam: 486 cfs.

(3) Adobe Dam: 1,890 cfs.

(4) New River Dam: 2,665 cfs.

2.04 EXISTING AND PROPOSED STRUCTURES AFFECTING RUNOFF

a. Proposed Interstate 10 (I-10) Collector Channel. The Arizona Department of Transportation is planning to extend the I-10 Freeway east from the existing Agua Fria River bridge to Black Canyon Highway (I-17). A proposed collector channel immediately north of and parallel to the planned freeway would convey flood flows from 27th Avenue to the Agua Fria River, draining an urbanized area of about 45 square miles. Designed for a maximum peak flow of about 9,300 cfs, the channel would not contribute significantly to large peak flows in the Agua Fria River because runoff collected by this channel will normally have emptied into the Agua Fria River well before the peak of the mainstem flood arrives.

b. Waddell Dam. Waddell Dam (completed in 1927), which is under the jurisdiction of the Maricopa County Municipal Water Conservation District (MCMWCD) No. 1, is about 30 miles north-northwest of downtown Phoenix and about 32 miles upstream of Avondale. About 1,459 square miles of watershed drain into Waddell Dam; this is approximately two-thirds of the Agua Fria River drainage above Avondale. The dam's purpose is water conservation, and, according to oral communication with MCMWCD No. 1, if sufficient water is available, the normal water surface is at the top of the closed spillway gates (gage height 170). If the reservoir is full to normal water surface when a large storm occurs, releases would be made such that outflow would approximate inflow until the spillway gates are fully open. Larger outflows would then be governed by the spillway rating. Pertinent characteristics of the dam are shown on plate 1; elevation-storage-outflow relationships used in this study are given in table 2. Although the sector gate is currently inoperable, it was assumed operable for this study.

c. McMicken Dam. McMicken Dam (completed in 1956) was constructed by the Corps of Engineers about 25 miles northwest of downtown Phoenix. The dam controls runoff from 238 square miles of the Trilby Wash basin. Reservoir capacity at spillway crest was approximately 19,300 acre-feet when constructed. (No recent surveys have been undertaken.) Although the dam has been breached because of safety considerations, it was assumed repaired for this study. Maximum design outflow is 4,450 cfs.

III. PRECIPITATION AND RUNOFF

3.01 PRECIPITATION RECORDS. The U.S. Geological Survey and the National Weather Service operate a large network of precipitation gages in the Phoenix area (see ref. 1), several of which are in and adjacent to the Agua Fria River basin. The most important gage for the purposes of this study is the Prescott gage (standard gage from 1865 to 1937; recording gage from 1938 to present).

3.02 STREAMFLOW RECORDS. Runoff records are available for 5 streamgages on the Agua Fria River (see table 4). Annual maximum data for the gages are listed in tables 5 through 9.

3.03 STORMS AND FLOODS OF RECORD. Little is known about floods on the Agua Fria River, or Arizona in general, during the early-to-mid-1800's. Rainfall records and/or historical accounts indicate that sizable floods probably occurred in January 1862, January 1874, February 1890, February 1905, and November 1905. More historical information, including peak discharge estimates, is available for the floods of February 1891, January 1915, January 1916, July 1917, November 1919, September 1922, and February 1927. Brief descriptions of the historical storms and floods of February 1891, February and November 1905, January 1915, January 1916, July 1917, November 1919, September 1922, and February 1927, together with selected floods since Waddell Dam was completed, are given in the following subparagraphs.

a. Storms and Floods of 16-23 February 1891. The floods of late February 1891 were severe on the Agua Fria, Hassayampa, and other central Arizona rivers. The February 1891 precipitation totals included 5.96 inches at Prescott, 4.81 at Granite Reef Dam, and 3.90 at Peoria. Virtually all of the month's total fell in two periods: 16-19 and 22-23 February. Rainfall amounts at Prescott for the two periods were 2.86 and 3.05 inches, respectively. Farley's Camp, Arizona reported 4 inches of rain in 9 hours on 23 February. The average rainfall depth over the Gila River drainage above Gillespie Dam during the period 16-23 February is estimated to have been about 4 inches, and the relatively few records available indicate that rainfall and runoff anomalies were greater in the Central Arizona basins than in the southern parts of the Gila drainage. Some snow fell during the early portions of the first of the two storms. The melting of this and earlier-fallen snow during the latter parts of the first storm and during the second storm combined with the heavy rainfall to produce severe flooding on the San Francisco, Salt, Verde, Agua Fria, Hassayampa, and lower Gila Rivers (ref. 7). On 19 February, an estimated peak discharge of 80,000 cfs occurred on the Agua Fria River (ref. 5).

b. Storms and Floods of February 1905. During the early months of 1905, Arizona experienced a prolonged wet period, with recurring moderate to heavy rains and some locally severe flooding. Snow levels fluctuated considerably during the period, and snowmelt contributed at times to the runoff. The four monthly precipitation totals for January-April included 4.74, 7.92, 6.17, and 3.81 inches at Prescott; 3.24, 3.83, 3.27, and 2.16 inches at Granite Reef Dam; 3.31, 4.64, 2.38, and 2.59 inches at Phoenix. The heaviest periods of precipitation occurred in mid-January, early February and mid-March.

c. Storm and Flood of 25-28 November 1905. The month of November 1905 was unusually wet throughout Arizona, as a series of abnormally deep Pacific storms swept into the Territory from out of the northwest. The most intense of these occurred from 25 to 28 November, with the heaviest rain falling on the 26th and 27th. Prescott measured a total of 8.68 inches for the month, of which 3.52 inches fell 26-27 November. Snow levels during the 25-28 November storm were moderately high (7,000-8,000 feet) at the beginning and fell to moderately low elevations (4,000-6,000 feet) near the end. Because of the preceeding storms, ground conditions were very favorable by 25 November for low infiltration and heavy runoff. The unusually heavy early-season snow cover in the middle and high elevations, provided by the earlier November storms, led to large-scale melting during at least the first two days of the 25-28 November storm. These factors contributed to severe flooding on central Arizona Rivers.

d. Storm and Flood of 28-30 January 1915. Following a very wet period in late December 1914, the first three weeks of January 1915 was generally cool and dry. A pair of light storms affected Arizona 22-25 January, and this was followed by a single heavy storm with high snow levels 28-30 January. Total precipitation in this storm exceeded 2 inches at many central Arizona stations, and some mountain locations measured over 5 inches. Most of the precipitation fell on 29 January. The high-intensity rain combined with the melting of mountain snows (left over from December 1914) to create large peak discharges on rivers in central Arizona. The peak on the Agua Fria River above the site of Lake Pleasant is estimated (refs. 5, 7) to have been 60,000 cfs on 29 January.

e. Storms and Floods of January 1916. The month of January 1916 produced some of the worst flooding in the history of Arizona. Conditions leading toward these floods began in December 1915, when several cold storms dropped

. heavy snow on the central Arizona mountains. The storm at the end of the month was especially heavy, and snow remained on the ground as low as 3,000 feet. Snow depths in the Agua Fria and Hassayampa drainages ranged from 12 to 44 inches on 31 December 1915. Scattered light precipitation fell 6-11 January 1916, and this was followed by two very heavy storm periods 14-21 and 25-30 January. The storms of January 1916 swept into southern California from out of the northwest, then curved eastward across Arizona, bringing alternately cool Pacific air from west of Canada and warm, tropical air from southwest of Baja California. Snow levels during the storm rose to well above 9,000 feet at times but briefly lowered near the end of each storm period to below 5,000 feet. Throughout most of central Arizona, the first storm period was generally heavier by about 50 per cent than the second period, but rainfall over the Agua Fria drainage was slightly heavier during the second period. Total precipitation in the Agua Fria drainage area above the site of Lake Pleasant from 15 through 21 January 1916 ranged from about 3 inches in rain-sheltered valleys to approximately 7.5 inches over the mountains east of the river. Nearly 11 inches fell in the Mazatzal Mountains northeast of Phoenix. During the second storm period, 25-30 January, the total precipitation in the Agua Fria drainage ranged from less than 1.5 inches in the far northeast corner of the basin to about 8 inches in the Bradshaw Mountains south of Prescott. Because of the saturation of the ground at lower elevations and the unusually heavy snow cover at middle and higher elevations, both of which resulted from the heavy, cold December 1915 storms, reinforced by the lighter 6-11 January 1916 storm, conditions were extremely favorable for maximum runoff when the late January 1916 storms hit. The heavy rainfall from these storms combined with rapid snowmelt to produce some of the worst floods of record on many Arizona streams. On the Agua Fria River near the site of Lake Pleasant, a peak discharge of 105,000 cfs was estimated by the USGS to have occurred on 28 January 1916.

f. Storm and Flood of 24-30 July 1917. The entire month of July 1917 was unsettled and showery throughout Arizona. Considerable saturation of the ground occurred as the result of the storms 1-23 July. From 24 through 30 July, a series of heavier, more widespread thunderstorms struck the State. Some rainfall totals for this period in and near the Agua Fria drainage included 4.42 inches at Castle Hot Springs, 3.61 inches at Crown King, 2.71 inches at Canon (near the present Black Canyon station), and 2.03 inches at Ashdale Ranger Station, but only 0.72 inches at Prescott. Most of the heaviest precipitation fell in one or two bursts during the period 26-29 July. No short-term intensities are available. The peak discharge on the Agua Fria near the site of Lake Pleasant is estimated to have been 80,000 cfs on approximately 27 July (exact date uncertain) (refs. 5, 7).

g. Storms and Floods of 22-28 November 1919. After a very wet July, a normal August, and a very wet September and October, the month of November 1919 was unusually wet, with nearly all of the precipitation concentrated from 18 through 28 November. The storms of 22-24 and 26-28 November were especially heavy. Ashdale Ranger Station measured 5.00 inches 25-27 November (no daily breakdown available), while Kingman measured 6.03 inches 27-28 November (again no daily values available). Prescott reported a 23-28 November total of 6.23 inches, including 4.28 on the 27th and 1.13 on the 28th. Sycamore Ranger Station in the Agua Fria drainage listed a 21-28 November total of 7.76 inches, with 2.65 and 2.42 inches on 27 and 28

November, respectively. The storm of 22-24 November brought a considerable amount of tropical air into Arizona, and snow levels rose to above 10 000 feet. During the 26-28 November storm, the snow levels began around 8,000-9,000 feet, lowered to 6,000-7,000 feet by the 27th, then plunged to below 5,000 feet on the 28th, as a subarctic air mass swept southward into the State behind the storm. The largely saturated ground could accept very little additional moisture by the time of the 26-28 November storm. There was some snow on the ground primarily above 7,000 feet, left over from the unusually cool storms for 23-26 October and 7-9 November. The saturation of the ground and the melting of this snow by the warm rains of 22-24 November contributed to heavy runoff. The peak discharges of the entire storm period generally followed the heavy burst of rain centered around the 27th. On the Agua Fria River near the site of Lake Pleasant, a maximum discharge of 105,000 cfs (equalling the record high value estimated in January 1916) is estimated by the USGS to have occurred on 27 November.

h. Storm and Flood of 1-2 September 1922. Following some spotty, heavy thunderstorms on 30 and 31 August 1922, a fairly general storm with heavy thunderstorms embedded struck the southwestern and west-central portions of Arizona on 1-2 September. Walnut Grove reported a total of 3.60 inches of rain, with 3.50 inches on the 2nd. Canon reported 2.50 inches on the 2nd, and Prescott measured 2.43 inches for the 72 hours ending early 3 September. A peak discharge of 60,000 cfs is estimated to have occurred on the Agua Fria River near the site of Lake Pleasant (refs. 5, 7).

i. Storms and Flood of 11-17 February 1927. Practically all of the precipitation of the month of February 1927 was concentrated into a single

7-day period, from the 11th through the 17th. During that period, Prescott measured 10.57 inches; Ashdale Ranger Station, 9.48; Walnut Grove, 8.45; Sycamore Ranger Station, 5.95; and Roosevelt, 5.58. Natural Bridge reported 3.50 inches on 16 February, and the daily totals observed at Prescott on the mornings of 15, 16, and 17 February were 2.50, 3.00, and 2.64 inches, respectively. The storms moved into Arizona from the west to southwest, with progressively more tropical moisture entering the storm systems as time progressed. The snow levels in central Arizona started out about 6,000 feet, lowered briefly to near 5,000 feet by 13 February, then rose to 8,000-9,000 feet by 16-17 February. There had been some snow on the ground above 5,000-6,000 feet prior to the storm. This was augmented by the snowfall during the first part of the storm period, then was largely melted off below 8,000 feet during the latter portions of the storm period. The ground at lower elevations was far from saturated at the beginning of the mid-February 1927 storm period because of below normal precipitation between 26 December 1926 and 11 February 1927. The rainfall of 11-14 February, however, resaturated the soil; and these ground conditions combined with the melting snow to favor heavy runoff 15-19 February. The peak discharge on the Agua Fria River above Lake Pleasant in February 1927 (date unknown) is estimated to have been 62,000 cfs (ref. 6).

j. Storm and Flood of 26-29 August 1951. The storm of 26-29 August 1951 was one of the heaviest on record at many Arizona locations. The storm developed as the remnants of an old Gulf of Mexico hurricane crossed the Mexican mainland and turned northward toward Arizona on 26 August, combining with moisture outflow from a tropical storm west of Baja California. General moderate rainfall, with heavy thunderstorms embedded, spread northward through

Arizona on 26 and 27 August. At most stations, the maximum 24-hour rainfall occurred between approximately midday of the 27th and midday of the 28th and accounted for about 65 per cent of the total storm precipitation. Precipitation generally tapered off during the afternoon of the 28th and ended on the 29th, although a few locations experienced a secondary burst of rain during the morning of the 29th. The total 26-29 August precipitation in and near the Agua Fria drainage ranged from 3.85 inches at Phoenix and 3.95 inches at Prescott to 13.55 inches at Crown King. A total of 6.94 inches was observed at Waddell Dam. Because antecedent precipitation during August 1951 was relatively abundant, the ground in most areas was partially saturated at the beginning of the 26-29 August storm. This factor and the high precipitation intensities on 27 and 28 August combined to produce heavy runoff in many areas, with significant flooding in some locations north and west of Phoenix. The maximum 1-day inflow to Lake Pleasant, 23,144 cfs, occurred on 29 August (see table 4).

k. Storm and Flood of 3-7 September 1970. The storm began 3 September in southern Arizona, as moisture outflow from tropical storm Norma, west of Baja California, began to move into Arizona from the south. Showers pushed northward across the State on 4 September, becoming heavy at times. On 5 September, a strong cold front moved across Arizona from out of the west, triggering a 12- to 24-hour period of rain that reached unprecedent intensities at some stations. Precipitation tapered off rapidly late 5 September, and only a few light showers lingered 6-7 September. Total storm precipitation in central Arizona ranged from less than 1 inch around Coolidge to nearly 12 inches in the Sierra Ancha Mountains northeast of Roosevelt Reservoir. Numerous other stations recorded from 5 to 8 inches during the heaviest 24 hours (mostly on 5 September). In and near the Agua Fria River drainage, the storm total ranged from 1.78 inches at Prescott to 7.01 inches at Crown King. The latter station recorded 4.50 inches in the 24 hours ending at 1800 on the 5th. A large portion of the maximum 24-hour precipitation fell within 4 to 6 hours. Much of central Arizona had received substantial precipitation during the first 3 to 4 weeks of August 1970, and the ground was partially saturated in most areas and moderately conducive to runoff at the beginning of the September 1970 storm. By the time of the heaviest burst of rain on 5 September, conditions were favorable for heavy runoff. Thus, the high intensities of rain that occurred on the 5th resulted in extensive flooding, with some streams recording all-time maximum discharges. On the Agua Fria River near Rock Springs, the peak discharge on 5 September 1970 was 40,100 cfs. On the Hassayampa River at Box Dam site, near Wickenburg, the 58,000 cfs recorded on 5 September 1970 is more than twice the previous known maximum of 27,000 cfs, which is estimated to have occurred in February 1927 and which occurred again in August 1951.

l. Storms and Flood of 27 February - 6 March 1978. The 1977-1978 winter season was unusually wet throughout Arizona. Periods of heavy rainfall occurred from late December through mid-February, causing some flooding at times. After about 10 dry days, a very deep low-latitude storm moved slowly into Arizona from out of the southwest between 27 February and 3 March. The storm was warm, with snow levels remaining around 8,000 feet or higher, and strong southerly winds generated very heavy precipitation over and near the mountains of central Arizona. After a break of about 48 hours, a more moderate, somewhat cooler storm, with snow levels 6,000-7,000 feet, hit northern and central Arizona 5-6 March. Total precipitation for the entire storm period 27 February - 6 March ranged from less than 2 inches south of Phoenix to well over 15 inches in the Bradshaw, Mazatzal, and Sierra Ancha Mounains northwest to northeast of Phoenix. Workman Creek reported a total of 16.15 inches with nearly 9 inches of that in a 36-hour period from 0000 hours 1 March to 1200 hours 2 March. Crown King measured 13.89 inches, with daily amounts 1 and 2 March of 4.87 and 3.38 inches, respectively. The total for the storm at Rock Springs was 9.65 inches, with 5.73 inches recorded between 1600 hours 1 March and 1600 hours 2 March (a value nearly an inch above the 100-year, 24-hour precipitation of 4.8 inches for that location). Prescott measured only 3.75 inches for the storm period. Saturated ground and some melting of previously fallen snow combined with the heavy 1-2 March burst of rain to produce record floods in many parts of central Arizona. On the Agua Fria River near Rock Springs, the peak discharge on 2 March was 39,500 cfs--barely short of the previous record of 40,100 cfs established in September 1970. On the Agua Fria River at Waddell Dam (inflow to Lake Pleasant), a peak discharge of 47,000 cfs on 2 March 1978 has been estimated by MCMWD No. 1.

m. Storm and Flood of 16-20 December 1978. On 16 and 17 December 1978, an upper-level low pressure center west of Baja California combined with a deep low pressure trough dropping southward from the Gulf of Alaska, and the circulation around the resulting system brought great quantities of tropical moisture from the equatorial Pacific Ocean northward into Arizona, triggering heavy rainfall throughout most of the State. The orographic uplift of this moist flow by the mountains of central Arizona created especially heavy precipitation, with snow levels generally 8,000-10,000 feet or higher. Total storm precipitation in central Arizona ranged from less than 2 inches south of Phoenix to 9-10 inches over the higher mountains. In and near the Agua Fria drainage, Crown King measured 8.35 inches, while Rock Springs recorded 4.14 inches, and Prescott recorded only 2.55 inches. Nearly all of the precipitation fell during a 36-hour period from 1200 hours 17 December to 2400 hours 18 December. There was some melting of previously fallen snow. This combined with a partially saturated ground surface (frozen in some high-elevation areas because of an intense early December 1978 cold spell) to produce heavy runoff on 18 and 19 December. Large storages in the major reservoirs carried over from the unusually wet 1977-1978 season, along with very heavy rainfall 10-15 and 23-27 November 1978, resulted in the rapid filling of these reservoirs during the early stages of the 16-20 December 1978 runoff. Therefore, large releases down the Salt and Agua Fria Rivers became necessary before the December 1978 inflow had significantly subsided. A preliminary USGS peak discharge on Agua Fria River near Rock Springs (18 December) was 52,800 cfs. On the Agua Fria River at Waddell Dam (Lake Pleasant inflow), a peak discharge of 79,500 cfs on 19 December 1978 was estimated by the MCMWD No. 1; the maximum release from Waddell Dam reached a peak of 60,000 cfs on 19 December, according to the Water District. The preliminary peak discharge at El Mirage was 58,000 on 19 December.

n. Storms and Floods of 13-22 February 1980. The 1979-1980 winter rainfall season was characterized by several series of low-latitude storms that moved into Arizona from out of the west and southwest (similar to those of 1978). The heaviest and most concentrated series occurred from 13 through 22 February 1980, when six warm, heavy storms moved across the State in rapid succession, bringing unprecedented 10-day rainfall to many areas. Total central Arizona precipitation during the storm period of 13-22 February ranged from less than 2 inches in areas south and west of Phoenix to more than

13 inches in several of the higher mountain regions. Much of the Salt, Verde, and Agua Fria River drainages above the major reservoirs received more than 7 inches. At Crown King, a total of 16.63 inches was observed during the 10-day period. The heaviest of the six-semi separated bursts occurred from late 14 February through early 15 February and from late 19 February through early 20 February. Saturated ground and generally high snow levels (7,000-10,000 feet) contributed to extreme runoff in many portions of the State. The peak discharge on the Agua Fria River at Waddell Dam (inflow to Lake Pleasant) on 20 February 1980 was estimated by the MCMWD No. 1 to be 73,300 cfs. The releases from Lake Pleasant necessitated by the massive inflow reached a peak outflow of 73,300 cfs on 20 February. The preliminary peak discharge at El Mirage was 37,400 cfs on 19 February. A total of 295,630 acre-feet of runoff flowed into Lake Pleasant during February 1980, nearly all of this amount during the last half of the month.

IV. SYNTHESIS OF STANDARD PROJECT FLOOD

4.01 GENERAL. The standard project flood (SPF) represents the flood that would result from the most severe combination of meteorologic and hydrologic conditions considered reasonably characteristic of the region. It normally is larger than any past recorded flood in the area, and can be expected to be exceeded in magnitude only on rare occasions.

4.02 STANDARD PROJECT STORM.

a. General. Assuming Waddell Dam full to normal water surface (top of closed spillway gates), the general summer storm of 26-29 August 1951 was determined to be the storm with the most severe flood peak and volume producing depth-area-duration relationship that may reasonably be expected to occur over the central portion of Arizona for which detailed rainfall information is available. The storm brought heavy precipitation to southern Yavapai and northeastern Maricopa Counties.

b. Storm Transposition. The transposition of the August 1951 storm over the study area was accomplished by: (1) expressing the actual rainfall amounts in the 1951 storm as percentages of 100-year, 24-hour rainfall; (2) constructing an isopercentual map based on those percentages; and (3) transposing the isopercentual lines over the basin in a way that would result in the most total rainfall over the drainage area. Although the 100-year, 24-hour precipitation includes precipitation from both local and general summer storms, its use as a storm transposition factor was considered reasonable in view of: (1) the fact that the August 1951 storm consisted of numerous local storm cells as well as general precipitation and (2) the relatively short distance and similarity of terrain over which the storm was transposed. Also, the total storm depth resulting from transposition by 100-year, 24-hour precipitation differs by only a small percentage from total storm depths produced by using the 2-year, 24-hour or 10-year, 24-hour precipitation as a transposition factor.

c. Rainfall-Intensity Pattern. One hour was selected as the smallest time interval for which rainfall intensities would be required in developing the standard project flood. The pattern of rainfall intensities was based upon the mean of the hourly percentage distributions of the August 1951 storm at the Phoenix Weather Bureau and Poland Junction gages.

d. Antecedent Rainfall. The standard project storm is a general summer event. Antecedent ground conditions considered reasonable for standard project flood computations were established by assuming previous summer general storm(s) had occurred in the weeks prior to, but not immediately preceeding the standard project precipitation. Hence, infiltration rates would be considerably lower than would be expected on a dry watershed; however, depression storage and interception losses would still need to be satisfied. Paragraph 4-03c presents the quantitative loss rate function used for standard project flood computations.

4.03 DETERMINATION OF RAINFALL-RUNOFF RELATIONSHIPS.

a. General. Regional unit hydrograph and loss rate studies for the Phoenix region are described in detail in reference 1. Reconstitution of 22 observed flood events was accomplished to determine applicable relationships between rainfall and runoff for use in computing hypothetical flood hydrographs. Adopted rainfall-runoff relationships, based on the aforementioned regional study, are discussed below.

b. Unit Hydrographs. The unit hydrograph procedure used by the Los Angeles District has its basis in an S-graph, which is the time distribution of runoff as a function of basin lag time. Lag time is defined as the time in hours for 50 percent of the total volume of runoff of the unit hydrograph to occur. The basin lag time can be approximated for ungaged watersheds by the use of the lag relationship presented on plate 2. The basin n-value is a variable in the equation for lag time that permits adjustment of lag time depending on type of ground cover and other characteristics affecting basin response to effective rainfall.

(1) S-Graphs. The concentration of excess rainfall in the study area can be described by two S-Graphs, a valley and a mountain. These S-graphs are presented on plates 3 and 4. The Phoenix Valley S-Graph was derived from reconstitutions at the following locations: New River at Bell Road; Skunk Creek near Phoenix; Cave Creek at Phoenix; Agua Fria Tributary at Youngtown and Queen Creek Tributary at Apache Junction. Similarly, the Phoenix Mountain S-Graph was derived from the New River near Rock Springs and New River at New River reconstitutions. The use of the Phoenix Mountain or Phoenix Valley S-Graph adequately describes the time distribution of runoff from watersheds in the study region.

(2) Basin n-Value. Basin n-values derived from the reconstituted unit hydrographs were used as a general guide to establish standard project flood basin n-values for the study area. Adjustments, based on judgement, were made to consider the influence of any basin characteristics that affect the lag time of the watershed.

c. Rainfall Loss Rate Function. Based on the HEC loss rate parameters derived from the reconstitutions, the following values were chosen:

STRKR = 0.40 DLTKR = 1.5 RTIOL = 2.0 ERAIN = 0

A graphical representation of this loss rate function is shown on plate 5. The initial portion of this loss rate function has a high loss rate indicative of a dry watershed in which the loss of interception and depression storage, as well as high initial infiltration rate, must be satisfied before rainfall excess becomes available for runoff. The more slowly decreasing portion of the loss rate function seeks to describe the slowly decreasing infiltration rate as a function of accumulated loss. The HEC loss rate function accounts for the effects of urbanization by reducing the effective loss rate in direct proportion to the percent impervious cover. Also shown on plate 5 is the loss rate function used for general storm standard project flood computations. Loss rate parameters were established as STRKR = 0.30, DLTKR = 1.0, RTIOL = 2.0, ERAIN = 0. Paragraph 4-02d describes the antecedent ground conditions chosen for general storm standard project floods. Appropriate adjustments to the dry watershed loss rate function were made on the basis of the established antecedent ground conditions.

d. Base Flow and Snowmelt. Base flow is considered negligible for this study area as runoff occurs only as a direct response to relatively high intensity rainfall. Allowance for snowmelt is inappropriate in this region for storms occurring in the summer season.

4.04 FLOOD ROUTING.

a. Flood routing on the Agua Fria River, both reservoir and channel, was accomplished by the Modified Puls routing procedure. Elevation-storage relationships used for Waddell Dam were based on a July 1965 survey. Elevation-spillway discharge relationships were taken from original design Drawing No. 1507. Elevation-storage-spillway discharge data are tabulated in table 2.

b. Elevation-storage relationships for each river reach listed in table 3 were developed from 1972 Corps of Engineers topographic maps. Although an incomplete 1980 survey shows noticeable differences in the lower flow portion of the river, the changes are not expected to significantly influence the routing of large flows. Elevation-outflow relationships for each reach were computed using Manning's equation and average cross-section for the reach.

4.05 CHANNEL PERCOLATION. Based on studies described in reference 1, a channel percolation rate of 0.2 acre-foot per wetted acre was used in this study.

4.06 COMPUTATION OF STANDARD PROJECT FLOOD.

a. Stream System Analysis.

(1) The stream system analysis approach to computation of design floods involves division of a study area into subbasins that are homogeneous with respect to hydrologic and meteorologic factors, and routing and combining of the flood hydrographs generated from each subbasin to determine the design flood at a desired concentration point. Subdividing a watershed permits more

accurate modeling of the runoff process, as variations in topography and urbanization, as well as changes in channel characteristics, may be incorporated into the hydrologic description of the basin. A schematic flow diagram is shown on plate 6.

(2) Standard project flood was computed by centering the standard project storm in the most critical flood producing manner. Application of the rainfall loss rate described previously to standard project precipitation enables determination of the rainfall excess. The rainfall excess is then applied to the subbasin unit hydrograph to produce the subbasin flood hydrograph. Combining and routing of subbasin flood hydrographs to the desired concentration point completes the computation of a standard project flood. Waddell Dam was assumed full to top of closed spillway gates at the beginning of the standard project flood (see para. 5.04).

b. Standard Project Flood Peak Discharges. Standard project flood peak discharges, computed as described above, are presented in table 1.

V. DISCHARGE FREQUENCY ANALYSIS

5.01 GENERAL.

a. Discharge frequency analysis in the study area involved determination of peak discharge frequency values with the authorized plan of improvement for future conditions of development. The major purpose of the analysis was to determine design discharges, SPF and 100-year flood, for the Agua Fria River from the New River confluence to Avondale. However, values for other locations on the river were necessarily determined also.

b. The analysis was complicated by the existence of Waddell Dam and the lack of long-term streamflow records below the dam. The available records on the Agua Fria River are given in tables 4 through 9. The records at Avondale and El Mirage are not only short but, except for 1978-80, occurred during a relatively dry period. Therefore, discharge frequency values at points of interest were determined by routing n-year "balanced hydrographs," developed from Waddell Dam inflow volume frequency relationships, through the dam and downstream, adding in local flows as appropriate.

5.02 WADDELL DAM INFLOW FREQUENCY ANALYSIS.

a. Data Used. Waddell Dam inflow volume frequency relationships were developed, as far as possible, from a statistical analysis of the record given in table 5. An attempt to fill gaps in the recorded flows at Waddell Dam by correlation with the Mayer streamgage record failed to yield usable results. Several peak discharge estimates, made by the Corps of Engineers and others, have been published (ref. 5, 6, and 7). These estimates were evaluated and, based on raingage records and flow records from other streamgages in the region, considered reasonable. Additional estimates were made for this study by correlating peak discharge with maximum 1-day volume, and maximum 1-day volume with maximum 2 day and 3-day volumes. Estimation of peak flows less than about 20,000 cfs was not attempted because correlation of peak discharge vs. maximum 1-day volume decreases as volume decreases. These estimates are intended for use only in this study.

b. Peak Inflow Frequency Analysis. Peak inflow frequency relationships were derived by ranking and plotting estimated and recorded peak discharges greater than about 20,000 cfs, using median plotting positions, and fitting by eye a smooth curve through the plotted points. The magnitude of SPF and PMF were also used as guides. The adopted curve is shown on plate 7. In order to maximize use of available data and extend the historical period of record to 1891, the relative magnitude of peak flows for the period 1892-1914 had to be established. Runoff records in the Gila River basin and Prescott raingage records (dating from 1866) indicate that large peaks in this period probably only occurred in February and November of 1905. Based on these records, November 1905 was ranked third largest peak since 1891 and February 1905 was ranked eight largest.

c. Volume Inflow Frequency Analysis

(1) The maximum 1-day, 2-day, and 3-day volume inflow frequency curves shown on plates 8 through 10 were determined from a statistical analysis of the volume data given in table 5. No information is available for water year 1926, but rainfall records and data from other streamgages in the region suggest no extraordinary flood event occurred in that water year. Hence, the record was considered a "broken" record--1915-25, 1927-80.

(2) Curves for each duration were derived using statistical procedures described in references 3 and 4. Skew coefficients of -0.3 for maximum 1-day volume and -0.4 for maximum 2-day and 3-day volumes were adopted after considering the shape of the peak discharge frequency curve; the computed skew coefficients for the neighboring Verde River at Tangle Creek streamgage; SPF maximum 1-day, 2-day, and 3-day volumes, and the generalized peak discharge skew coefficients given in reference 4. (For the period 1889-1980, computed skew coefficients for maximum 1-day, 2-day, and 3-day volumes on the Verde River range from -0.3 to -0.4.)

(3) The data, plotted using median plotting positions, fit the computed curves well at the lower end, but are almost always above the curve at the upper end. However, Prescott raingage records and the limited available runoff data prior to 1915 indicate the period from 1866-1914 to be, in general, dryer than the period of record. If the historical period of record were assumed to extend back to 1866, and a few large peaks were included to account for a few wet years, the plotting positions for the values actually used in the analysis would be shifted to the right, more closely matching the analytical curves.

(4) Plate 11 shows a comparison of the peak curve and the three volume curves.

5.03 BALANCED HYDROGRAPHS.

a. An n-year "balanced hydrograph" is one that is of equal severity for all critical durations. Severity is expressed in terms of exceedance frequency. Thus, a 100-year balanced hydrograph has a 100-year peak discharge, 100-year maximum 1-day volume, 100-year maximum 2-day volume, etc. Inflow balanced hydrographs in this study were derived from the previously discussed volume frequency relationships, using the SPF hydrograph as a pattern hydrograph.

5.04 BALANCED HYDROGRAPH ROUTING.

a. Routing through Waddell Dam and down the Agua Fria River was accomplished by the Modified Puls method. (See para. 4.04.) Before the reservoir routings of the n-year balanced hydrographs could be performed, operating policy and starting water surface elevation (WSE) had to be established. The operating policy used in this study was based on discussions with the operator, MCMWCD No. 1, and can be stated as follows:

(1) No spillway releases until the WSE reaches the top of the closed spillway gates (gage height = 170 feet).

(2) At WSE = 170 feet, spillway releases will be made such that outflow = inflow up to the spillway capacity. (See also para. 2.04 b.)

b. The starting WSE for the n-year flood balanced hydrograph routings was determined from a study of the potential "fill and significant spill" frequency assuming the dam, completed in 1927, were in place during the entire period of record--1915-80. Table 10 shows the years in which a significant spill actually occurred or very likely would have occurred if the dam had been in place. Note in table 10 that the flood volume was sufficient to fill an empty reservoir or refill a partially full reservoir and still produce a large peak outflow. (Spills in water years 1941, 1966, and 1968 were not considered significant.) For the 59 years of record (1915-80), significant spills would have occurred 7 times, or about once every 8 years on the average. From Prescott raingage records for the 1866-1914 period and limited runoff records in the Gila River basin, one could conclude that significant spills probably would also have occurred in water years 1891, 1905, 1906, and 1927 (the wettest water year on record at the Prescott gage). Thus, if the dam had existed for the 115 year periods between 1866 and 1980, which is considered more representative than the wetter 1915-80 period, the significant spill return period would be about 10 years. Therefore, the starting WSE was assumed to be at the top of the closed spillway gates at the beginning of all balanced hydrograph routings for return periods of 10 years or greater.

5.05 RESULTS. Using the procedures described above, n-year peak discharges were determined for concentration points of interest along the Agua Fria River for future conditions of development with the recommended plan. These values are given in table 1.

5.06 COMPARISON WITH PREVIOUS STUDIES. Table 11 shows a comparison of discharges for previous studies (ref. 1, 2, and 5) and the current study. (References 1 and 2 are considered basically the same study.) The large differences between current study and references 1 and 2 are due mainly to the changed analysis with respect to Waddell Dam's capability to control large floods. Differences between the current study and reference 5 are largely because of available data and different analytical procedures.

BIBLIOGRAPHY

1. Gila River Basin, New River and Phoenix City Streams, Arizona, Design Memorandum No. 2, Hydrology, Part 1, U.S. Army Engineer District, Los Angeles, Corps of Engineers, October 1974.

2. Gila River Basin, New River and Phoenix City Streams, Arizona, Design Memorandum No. 3, General Design Memorandum--Phase I, Plan Formulation, Appendix 1, U.S. Army Engineer District, Los Angeles, Corps of Engineers, March 1976.

3. Statistical Methods in Hydrology, Leo R. Beard, Hydrologic Engineering Center, U.S. Army Corps of Engineers, January 1962.

4. Guidelines for Determining Flood Flow Frequencies, Bulletin 17A, Water Resources Council, November 1977.

5. Flood Plain Information, Agua Fria River, Maricopa County, Arizona, Corps of Engineers, U.S. Army, Los Angeles, March 1968.

6. Report of Committee No. 2, J. Lippencott, State of Arizona, 1929.

7. Report on Survey, Flood Control, Gila River and Tributaries above Salt River, Arizona and New Mexico, U.S. Army Corps of Engineers, Los Angeles, December 1, 1945.

TABLE 1

PEAK DISCHARGES

Location	SPF (cfs)	500-Year Flood (cfs)	100-Year Flood (cfs)	50-Year Flood (cfs)	25-Year Flood (cfs)	10-Year Flood (cfs)
AGUA FRIA RIVER:						
Inflow - Waddell Dam	158,000	190,000	135,000	110,000	90,000	60,000
Outflow - Waddell Dam	158,000	182,000	135,000	110,000	90,000	60,000
Bell Rd.	151,000	182,000	115,000	87,000	60,000	37,000
U/S New River Confl.	135,000	177,000	90,000	66,000	48,000	30,000
D/S New River Confl.	142,000	184,000	95,000	69,000	50,000	32,000
Camelback Rd.	142,000	184,000	95,000	69,000	50,000	31,000
Indian School Rd.	140,000	183,000	94,000	69,000	49,000	30,000
McDowell Rd.	137,000	182,000	91,000	68,000	48,000	29,000
I-10 Fwy.	135,000	181,000	91,000	68,000	48,000	29,000
Avondale	131,000	179,000	90,000	67,000	47,000	28,000
Gila River	130,000	179,000	89,000	67,000	47,000	27,000 ←

TABLE 2

ELEVATION-STORAGE-OUTFLOW RELATIONSHIPS

WADDELL DAM(1)

Gage Height (ft)	Storage(2) (A.F.)	Spillway(3) (cfs)
170	157,600	155,000
172	163,000	180,000
174	169,000	205,000
175.67	175,000	225,000

(1) See plate 1.

(2) July 1965 Survey.

(3) Drawing No. 1507.

TABLE 3

PERTINENT CHANNEL ROUTING DATA

AGUA FRIA RIVER

Reach	Length (ft)	Average Velocity* (fps)	Approximate Travel Time* (hrs)	NRCHS	Percolation Loss* (cfs)
Waddell Dam to Bell Rd.	86,000	8.0	3.0	3	500
Bell Rd. to Grand Ave.	12,100	6.6	0.5	1	200
Grand Ave. to Glendale Ave. (New River Confl.)	35,400	5.4	1.8	1	700
Glendale Ave. (New River Confl.) to I-10 Fwy.	25,000	5.8	1.2	1	600
I-10 Fwy. to Hwy. 80 (85)	9,000	4.6	0.5	1	200
Hwy. 80 (85) to Gila River	21,200	5.5	1.1	1	400

*For large flood.

TABLE 4

STREAMGAGING STATIONS IN AGUA FRIA RIVER BASIN

USGS Gage No.	Location	Drainage Area (sq. mi.)	Period of Record	Maximum Peak Discharge Date	Maximum Peak Discharge cfs
09512500[4]	Agua Fria River near Mayer	588	1940-80	2-19-80	34,900[1]
09512800[4]	Agua Fria River near Rock Springs	1,130	1970-80[2]	2-19-80	59,000[1]
				2-19-1891	64,000
				1-28-16	84,000
				7-27-17	64,000
				11-27-19	85,000
09513650[4]	Agua Fria River at El Mirage	1,637 278[3]	1963-80	12-19-78	58,000[1]
09513970[4]	Agua Fria at Avondale	2,013 554[3]	1960-80	2-20-80	42,000[1]
09313500[5]	Lake Pleasant at Waddell Dam	1,459	1915-20[4] 1928-80[6]	12-19-78	79,500[1]
				2-19-1891	80,000
				1-28-16	105,000
				7-27-17	80,000
				11-27-19	105,000

(1) Preliminary
(2) Historical estimates in 1891, 1915-20, 1922, 1924.
(3) Below Waddell Dam
(4) Source: USGS (Watstore)
(5) Volumes only.
(6) Source: MCMWCD No. 1

TABLE 5

MAXIMUM ANNUAL STREAMFLOW DATA
AGUA FRIA RIVER AT WADDELL DAM

Water Year	Peak Discharge			Maximum Volume						
				1-Day		2-Day		3-Day		
	Date	cfs	Source of Data(1)	Date	cfs	Date	cfs	Date	cfs	Source of Data(1)
1891	2/19/1891	80,000	A		-		-		-	
1905	2/ /05	-	B1		-		-		-	
1906	11/ /05	-	B1		-		-		-	
1912	-	28,450	C		-		-		-	
1915	1/29/15	60,000	A, D	1/29/15	20,000	1/29-30/15	17,500	1/29-31/15	12,300	F, (1213), (1313)
1916	1/28/16	105,000	A, D, (1733)	1/18/16	50,000	1/18-19/16	35,500	1/17-19/16	29,200	F, (1213), (1313)
1917	7/27/17	80,000	A, D	7/18/17	22,800	1/17-18/17	18,600	7/17-18/17	13,300	F, (1213), (1313)
1918	8/6/18	39,600	A, D	8/10/18	4,270	8/10-11/18	2,420	8/10-12/18	1,920	F, (1213), (1313), (479)
1919	9/8/19	53,5[illegible]0	A, D	9/8/19	8,430	9/8-9/19	4,725	9/8-10/19	3,010	F, (1213), (1313)
1920	11/27/19	105,000	A, D, (1733)	-	60,000	-	35,000	-	23,000	B2
1921	-	15,450	C	-	2,000	-	620	-	540	B2
1922	9/2/22	60,000	A, D	-	20,000	-	13,000	-	9,500	B2
1923	-	26,300	C	-	5,000	-	2,000	-	1,600	B2
1924	12/27/23	39,000	A	-	9,500	-	4,800	-	3,700	B2
1925	-	18,600	C	-	2,700	-	900	-	800	B2
1927	2/ /27	62,000	C	-	21,000	-	15,000	-	10,000	B2
1928		-		8/2/28	2,340	8/1-2/28	877	8/1-3/28	166	E
1929		-		9/5/29	2,257	9/4-5/29	1,363	9/3-5/29	148	E
1930		-		8/11/30	1,372	8/7-8/30	1,041	3/17-19/30	839	E
1931	-	43,000	B2	2/14/31	11,115	2/14-15/31	10,042	2/13-15/31	7,626	E
1932	-	26,000	B2	2/19/32	4,753	2/18-19/32	3,780	2/18-20/32	3,138	E
1933		-		1/21/33	1,783	1/21-22/33	1,186	1/21-23/31	903	E, (1313)
1934		-		8/25/34	841	8/24-25/34	635	8/24-26/34	477	E, (1313)
1935	-	21,000	B2	2/8/35	3,336	2/7-8/35	3,257	2/7-9/35	3,078	E, (1313)
1936		-		8/26/36	1,933	8/26-27/36	1,030	8/25-27/36	698	E, (1313)
1937	-	44,000	B2	3/17/37	11,721	2/7-8/37	9,227	2/7-9/37	6,525	E, (1313)
1938	-	38,000	B2	3/4/38	8,886	3/4-5/38	5,219	3/3-5/38	3,803	E, (1313)
1939		-		9/7/39	2,346	9/6-7/39	1,740	9/12-14/39	1,334	E, (1313)
1940		-		2/3/40	841	2/3-4/40	587	2/2-4/40	392	E, (1313)
1941	-	41,000	B2	3/2/41	10,404	4/13-14/41	7,758	4/12-14/41	6,801	E, (929)
1942		-		9/5/42	576	9/5-6/42	369	9/5-7/42	260	E, (959)
1943	-	24,000	B2	8/3/43	4,081	8/2-3/43	2,114	8/2-4/43	1,428	E, (979)
1944		-		2/25/44	2,258	2/25-26/44	1,743	2/25-27/44	1,519	E, (1009)
1945		-		8/11/45	1,047	3/16-17/45	816	3/16-18/45	677	E, (1039)
1946		-		9/18/46	469	9/18-19/46	333	9/18-20/46	246	E, (1059)
1947		-		8/9/47	1,185	8/9-10/47	648	8/8-10/47	433	E, (1089)
1948		-		8/7/48	1,264	8/6-7/48	700	8/5-7/48	583	E, (1119)
1949		-		1/14/49	2,037	1/14-15/49	1,248	1/14-16/49	966	E, (1149)
1950		-		10/19/49	1,622	10/19-20/49	891	10/18-20/49	610	E, (1179)
1951	-	66,000	B2	8/29/51	23,144	8/28-29/51	19,138	8/28-30/51	15,377	E, (1209)
1952	-	26,000	B2	1/19/52	4,917	1/18-19/52	2,881	1/18-20/52	2,147	E, (1243)

TABLE 5 (Continued)

Water Year	Peak Discharge: Date	Peak Discharge: cfs	Peak Discharge: Source of Data[1]	Maximum Volume 1-Day: Date	1-Day: cfs	2-Day: Date	2-Day: cfs	3-Day: Date	3-Day: cfs	Source of Data[1]
1953		-		7/18/53	293	7/18-19/53	200	7/17-19/53	160	E, (1283)
1954		-		3/23/54	1,918	3/23-24/54	1,456	3/22-24/54	1,300	E, (1343)
1955		-		8/4/55	1,378	7/24-25/55	1,024	7/24-26/55	737	E, (1393)
1956		-		7/26/56	547	7/31-8/1/56	298	7/31-8/2/56	214	E, (1443)
1957		-		1/28/57	1,785	1/27-28/57	1,779	1/27-29/57	1,298	E, (1513)
1958	-	20,000	B2	9/13/58	3,058	9/12-13/58	2,055	9/12-14/58	1,487	E, (1563)
1959		-		8/5/59	927	8/5-6/59	828	8/5-7/59	590	E, (1633)
1960	-	27,000	B2	12/26/59	5,025	12/25-26/59	3,987	12/25-27/59	2,889	E, (1713)
1961		-		9/19/61	1,142	9/19-20/61	608	9/18-20/61	406	E, WA
1962		-		3/23/62	237	3/23-24/62	177	3/22-24/62	155	E, WA
1963		-		8/26/63	1,371	8/26-27/63	1,158	8/26-28/63	836	E, WA
1964		-		8/3/64	1,521	8/2-3/64	933	8/1-3/64	726	E, WA
1965	-	23,000	B2	4/4/65	3,976	4/4-5/65	3,268	4/4-6/65	2,457	E, WA
1966	-	41,000	B2	12/23/65	10,276	12/10-11/65	6,625	12/22-24/65	4,760	E, WA
1967		-		12/8/66	1,576	12/7-8/66	1,040	12/7-9/66	806	E, WA
1968	-	46,000	B2	12/19/67	12,700	12/19-20/67	10,015	12/19-21/67	6,999	E, WA
1969		-		9/5/69	715	1/26-27/69	656	1/26-28/69	529	E, WA
1970	9/6/70	50,100	B3	9/6/70	9,545	9/5-6/70	5,749	9/5-7/70	4,004	E, WA
1971		-		8/21/71	856	8/20-21/71	584	8/26-28/71	452	E, WA
1972		-		8/13/72	421	8/13-14/72	300	8/12-14/72	207	E, WA
1973	10/7/72	22,000	B3	10/7/72	7,222	10/7-8/72	4,120	10/6-8/72	2,772	E, WA
1974		-		7/19/74	462	7/19-20/74	301	7/18-20/74	212	E, WA
1975		-		10/3/74	184	10/3-4/74	132	10/3-5/74	97.7	E, WA
1976	2/10/76	30,900	B3	2/10/76	6,411	2/9-10/76	4,107	2/9-11/76	3,034	E, WA
1977		-		8/24/77	160	8/24-25/77	114	8/24-26/77	77.1	E, WA
1978	3/2/78	47,000	E*	3/2/78	25,405	3/2-3/78	21,043	3/1-3/78	18,143	E, WA
1979	12/19/78	79,500	E*	12/19/78	31,820	12/18-19/79	18,655	12/18-20/78	13,479	G
1980	2/20/80	73,300	E*	2/20/80	38,293	2/20-21/80	26,441	2/20-22/80	21,569	G

(1) Sources of Data:

- A - "Flood Plain Information, Agua Fria River, Maricopa County, Arizona," March 1968 (ref. 5).
- B1 - Estimated for ranking purposes only.
- B2 - Based on correlation of peak discharge vs. maximum 1-day volume. For use only in this study.
- B3 - Based on Rock Springs gage (DA = 1,130 sq. mi.). For longer flows, peak at Waddell Dam (DA = 1,459) is approximately 1.25 times peak at Rock Springs gage. Ratio of drainage areas is about 1.28.
- C - Report of Committee No. 2, J. Lippincott, State of Arizona, 1929 (ref. 6).
- D - "Report on Survey, Flood Control, Gila River and Tributaries above Salt River, Arizona and New Mexico," December 1, 1945 (ref. 7).
- E - Maricopa County Municipal Water Conservation District No. 1.
- E* - Preliminary estimate by MCMWCD No. 1.
- F - USGS WATSTORE.
- G - Preliminary USGS estimate.
- ( ) - Number in parenthesis is USGS water supply paper number
- WA - Annual USGS water supply paper for Arizona.

TABLE 6

MAXIMUM ANNUAL STREAMFLOW DATA(1)
AGUA FRIA RIVER NEAR MAYER

Water Year	Date	Peak Discharge cfs	Water Year	Date	Peak Discharge cfs
1940	6/26/40	5,920	1962	9/13/62	2,470
1941	3/1/41	13,000	1963	8/19/63	12,800
1942	8/6/42	6,280	1964	7/24/64	9,000
1943	9/25/43	3,500	1965	4/4/65	7,470
1944	9/16/44	3,810	1966	12/10/65	12,100
1945	7/27/45	2,620	1967	8/19/67	6,960
1946	7/22/46	4,920	1968	12/19/67	3,850
1947	8/16/47	1,610	1969	8/7/69	2,490
1948	8/4/48	6,830	1970	9/5/70	19,800
1949	1/13/49	2,460	1971	9/25/71	7,280
1950	7/17/50	2,170	1972	8/12/72	6,800
1951	8/28/51	8,180	1973	10/7/72	10,700
1952	1/18/52	7,500	1974	7/20/74	740
1953	7/8/53	5,510	1975	7/27/75	2,190
1954	9/3/54	4,570	1976	2/9/76	9,700
1955	8/3/55	12,800	1977	8/23/77	5,480
1956	7/25/56	6,880	1978	3/1/78	9,900
1957	8/13/57	2,710	1979	12/18/78	18,300
1958	6/21/58	4,620	1980	2/19/80	34,900(2)
1959	8/4/59	9,700			
1960	8/8/60	4,820			
1961	7/22/61	10,200			

(1) Source: USGS WATSTORE (1940-79)

(2) Preliminary

TABLE 7

MAXIMUM ANNUAL STREAMFLOW DATA[1]
AGUA FRIA RIVER NEAR ROCK SPRINGS

Water Year	Date	Peak Discharge cfs
1891	2/19/91	64,000
1915	1/29/15	48,000
1916	1/28/16	84,000
1917	7/27/17	64,000
1918	8/6/18	32,000
1919	9/8/19	43,000
1920	11/27/19	85,000
1922	9/2/22	48,000
1924	12/27/23	31,000
1970	9/5/70	40,100
1971	8/25/71	3,750
1972	8/13/72	2,620
1973	10/7/72	17,600
1974	8/2/74	1,900
1975	7/8/75	2,490
1976	2/9/76	24,700
1977	8/24/77	2,390
1978	3/2/78	39,500
1979	12/18/78	52,800
1980	2/19/80	59,000[2]

(1) Source: USGS WATSTORE (1891-1979)
(2) Preliminary

TABLE 8

MAXIMUM ANNUAL STREAMFLOW DATA[1]
AGUA FRIA RIVER AT EL MIRAGE

Water Year	Date	Peak Discharge cfs
1963	9/ /63	700
1964	7/30/64	2,500
1965	10/16/64	500
1966	8/10/66	2,900
1967	-	0
1968	12/19/67	2,520
1969	9/13/69	600
1970	9/05/70	5,000
1971	8/ /71	250
1972	6/ /72	10
1973	10/07/72	20
1974	8/05/74	460
1975	11/02/74	50
1976	-	0
1977	-	0
1978	3/02/78	9,870
1979	12/19/78	58,000[2]
1980	2/19/80	37,400[2] ?

(1) Source: USGS WATSTORE (1963-78)

(2) Preliminary

TABLE 9

MAXIMUM ANNUAL STREAMFLOW DATA (1)
AGUA FRIA RIVER AT AVONDALE

Water Year	Date	Peak Discharge cfs
1960	12/25/59	4,700
1961	-	0
1962	-	0
1963	8/ /63	63
1964	8/01/64	3,000
1965	4/04/65	460
1966	12/23/65	800
1967	-	0
1968	12/20/67	20,000
1969	-	0
1970	8/06/70	20,600
1971	8/21/71	8,200
1972	7/17/72	5,180
1973	10/07/72	5,000
1974	-	0
1975	-	0
1976	-	0
1977	-	0
1978	3/02/78	13,100
1979	12/19/78	30,000 (2)
1980	2/20/80	42,000 (2)

(1) Source: USGS WATSTORE (1960-78)

(2) Preliminary

TABLE 10

WADDELL DAM - YEARS OF PROBABLE SPILL

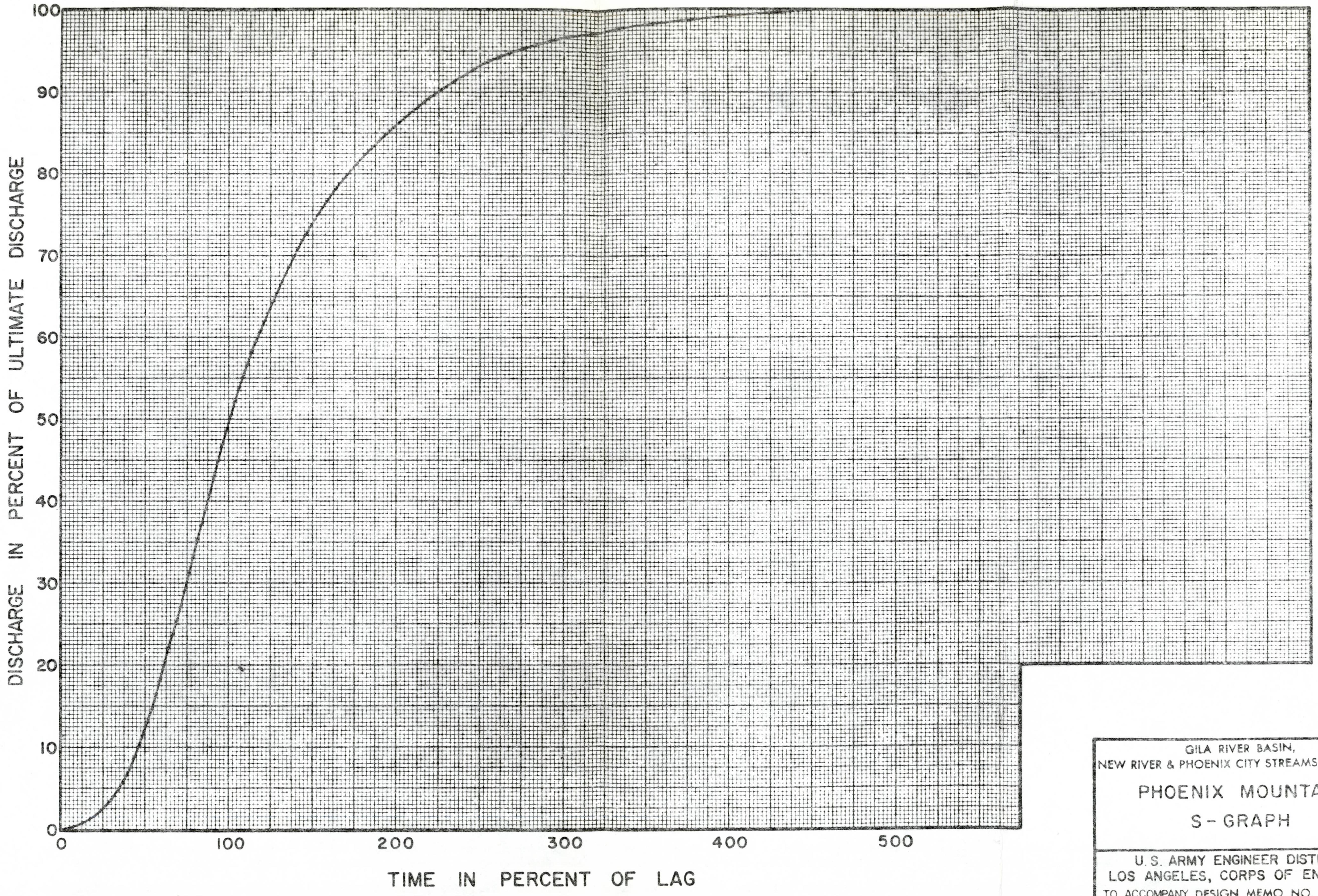
Water Year	Runoff (ac-ft)	Source	Fill Empty Reservoir & Significant Spill	Refill Reservoir & Significant Spill
1916	481,100 (342,000 in 15 days/Jan)	(1313)	X	
1917	240,400 (161,000/April-July)	(1313)		X
1918	49,310	(1313)		
1919	90,570 (69,000/July-Sept)	(1313)		X
1920	--	(1313) Prescott Raingage		X
1978	221,800 (164,000 in Mar)	MCMWCD No. 1, USGS	X	
1979	292,400 (260,240 Jan-April)	MCMWCD No. 1, USGS	X	
1980	375,846 (295,625 in Feb)	MCMWCD No. 1, USGS	X	

TABLE 11

PEAK DISCHARGES
COMPARISON WITH OTHER STUDIES

Location	SPF (cfs)	100-Year Flood (cfs)	50-Year Flood (cfs)	25-Year Flood (cfs)
AGUA FRIA RIVER:				
at Bell Rd.	140,000(1) 78,000(2) 151,000(4)	73,000(1) 54,000(2) 115,000(4)	- 40,000(2) 87,000(4)	- 29,000(2) 60,000(4)
U/S of conf. with New River	150,000(1) 80,000(3) 135,000(4)	77,000(1) 43,000(3) 90,000(4)	- 31,000(3) 66,000(4)	- 21,000(3) 48,000(4)
D/S of conf. with New River	* 82,000(3) 142,000(4)	* 45,000(3) 95,000(4)	* 32,000(3) 69,000(4)	* 21,000(3) 50,000(4)
at Avondale	* 78,000(3) 131,000(4)	* 43,000(3) 90,000(4)	* 30,000(3) 68,000(4)	* 20,000(3) 47,000(4)

(1) FPI Report - 1968 (ref. 5).
(2) Part I Hydrology DM (ref. 1).
(3) Phase I GDM (ref. 2).
(4) Current.
\- FPI values not available.
* FPI values not compariable.

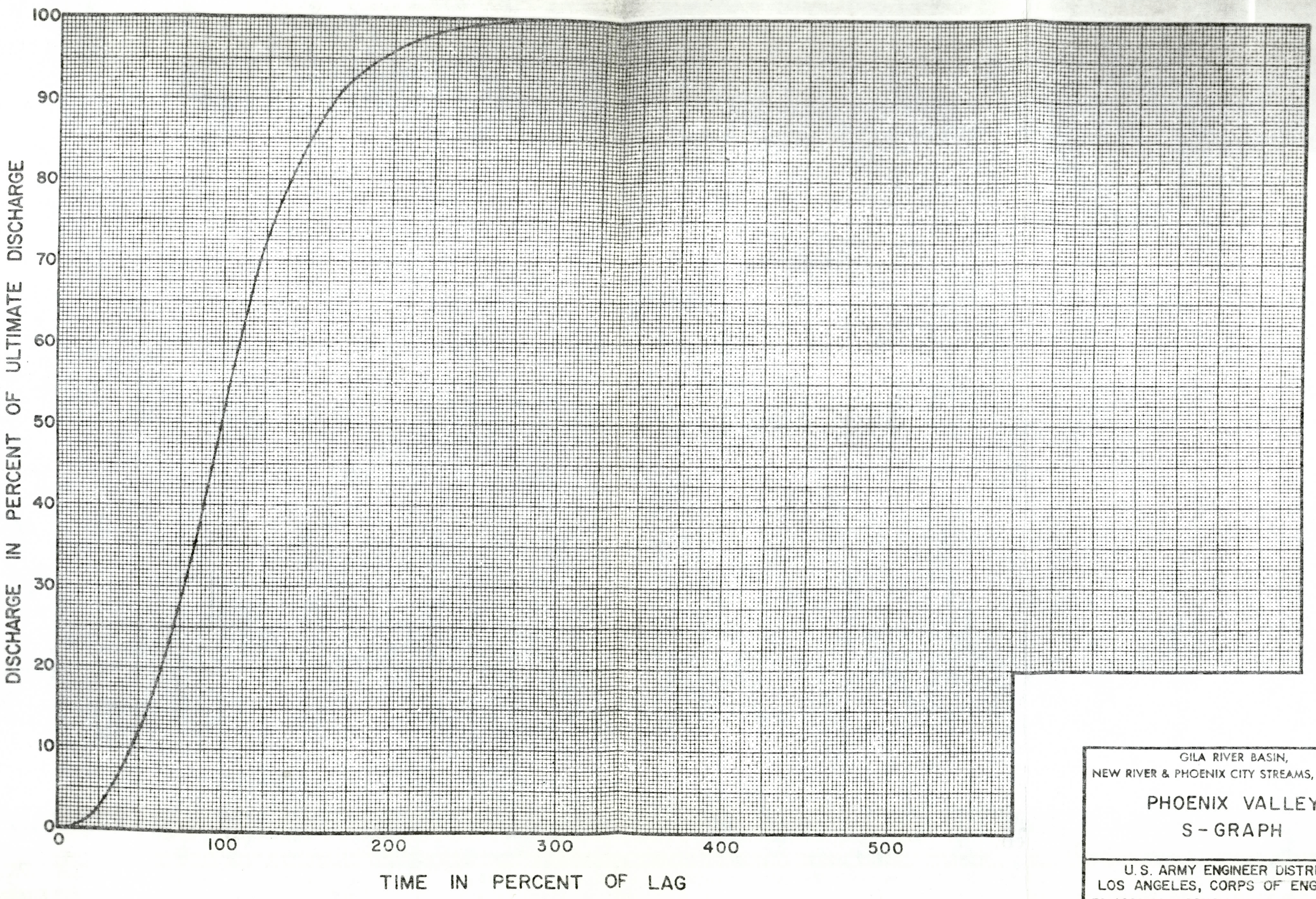


GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, ARIZONA

PHOENIX MOUNTAIN
S-GRAPH

U.S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS
TO ACCOMPANY DESIGN MEMO NO. 2

PLATE 1



GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, ARIZONA

PHOENIX VALLEY
S-GRAPH

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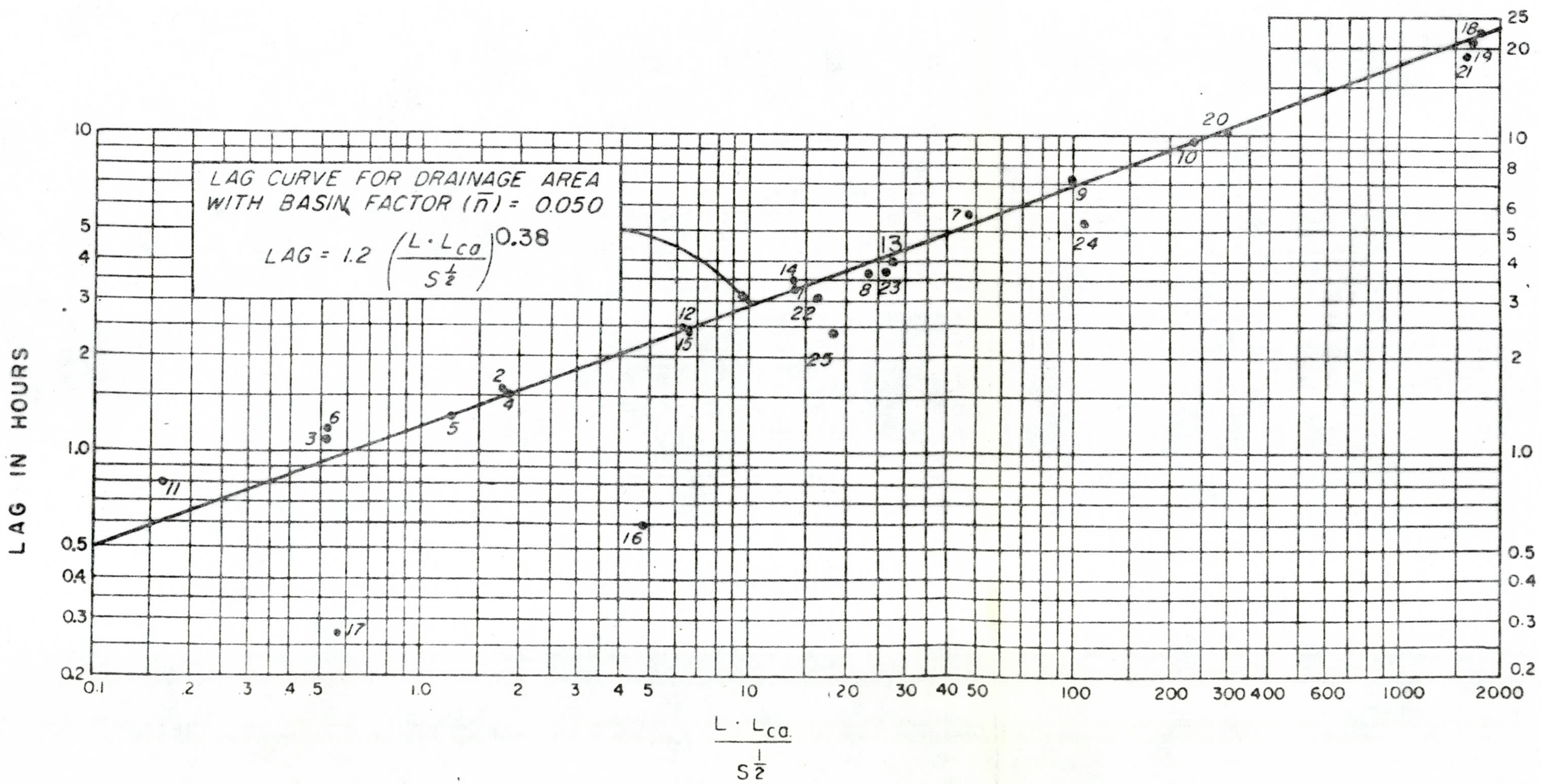
		CONTRIBUTING AREA SQ. MI.	L MILES	L_{ca} MILES	S FT/MI.	LAG HOURS	ESTIMATED $\bar{n}$
1.	SAN GABRIEL RIVER AT SAN GABRIEL DAM, CALIF.	162.0	23.2	11.6	350	3.3	0.050
2.	WEST FORT SAN GABRIEL RIVER AT COGSWELL DAM, CALIF.	40.4	9.3	4.3	450	1.6	.050
3.	SAN ANITA CREEK AT SANTA ANITA DAM, CALIF.	10.8	5.8	2.5	690	1.1	.050
4.	SAN DIMAS CREEK AT SAN DIMAS DAM, CALIF.	16.2	8.6	4.8	440	1.5	.050
5.	EATON WASH AT EATON WASH DAM, CALIF.	9.5	7.3	4.4	600	1.3	.050
6.	SAN ANTONIO CREEK NEAR CLAREMONT, CALIF.	16.9	5.9	3.0	1,017	1.2	.055
7.	SANTA CLARA RIVER NEAR SAUGUS, CALIF.	355.0	36.0	15.8	140	5.6	.050
8.	TEMECULA CREEK AT PAUBA CANYON, CALIF.	168.0	26.0	11.3	150	3.7	.050
9.	SANTA MARGARITA RIVER NEAR FALLBROOK, CALIF.	645.0	46.0	22.0	105	7.3	.055
10.	SANTA MARGARITA RIVER AT YSIDORA, CALIF.	740.0	61.2	34.3	85	9.5	.055
11.	LIVE OAK CREEK AT LIVE OAK DAM, CALIF.	2.3	2.9	1.5	700	0.8	.070
12.	TUJUNGA CREEK AT BIG TUJUNGA DAM, CALIF.	81.4	15.1	7.3	290	2.5	.050
13.	MURRIETA CREEK AT TEMECULA, CALIF.	220.0	27.2	10.3	95	4.0	.050
14.	LOS ANGELES RIVER AT SEPULVEDA DAM, CALIF.	152.0	19.0	9.0	145	3.5	.050
15.	PACOIMA WASH AT PACOIMA DAM, CALIF.	27.8	15.0	8.0	315	2.4	.050
16.	ALHAMBRA WASH ABOVE SHORT STREET, CALIF.	14.0	9.5	4.6	85	0.6	.015
17.	BROADWAY DRAIN ABOVE RAYMOND DIKE, CALIF.	2.5	3.4	1.7	100	0.28	.015
18.	GILA RIVER AT CONNOR NO. 4 DAM SITE, ARIZ.	2840.0	131.0	71.0	29	21.5	.050
19.	SAN FRANCISCO RIVER AT JUNCTION WITH BLUE RIVER, ARIZ.	2000.0	130.0	74.0	32	20.6	.050
20.	BLUE RIVER NEAR CLIFTON, ARIZ.	790.0	77.0	37.0	65	10.3	.050
21.	SALT RIVER NEAR ROOSEVELT, ARIZ.	4310.0	160.0	66.0	45	18.6	.050
22.	NEW RIVER AT ROCK SPRINGS, ARIZ.	67.3	20.2	9.7	141	3.1	.045
23.	NEW RIVER AT NEW RIVER, ARIZ.	85.7	23.2	13.6	145	3.7	.045
24.	NEW RIVER AT BELL ROAD, ARIZ.	187.0	47.6	20.7	83	5.3	.037
25.	SKUNK CREEK NEAR PHOENIX, ARIZ.	64.6	17.6	10.0	89	2.4	.033



GUIDE FOR ESTIMATING BASIN FACTOR ($\bar{n}$)

$\bar{n}$=0.200: DRAINAGE AREA HAS COMPARATIVELY UNIFORM SLOPES AND SURFACE CHARACTERISTICS SUCH THAT CHANNELIZATION DOES NOT OCCUR. GROUND COVER CONSISTS OF CULTIVATED CROPS OR SUBSTANTIAL GROWTHS OF GRASS AND FAIRLY DENSE SMALL SHRUBS, CACTI, OR SIMILAR VEGETATION. NO DRAINAGE IMPROVEMENTS EXIST IN THE AREA.

$\bar{n}$=0.050: DRAINAGE AREA IS QUITE RUGGED, WITH SHARP RIDGES AND NARROW, STEEP CANYONS THROUGH WHICH WATERCOURSES MEANDER AROUND SHARP BENDS, OVER LARGE BOULDERS, AND CONSIDERABLE DEBRIS OBSTRUCTION. THE GROUND COVER, EXCLUDING SMALL AREAS OF ROCK OUTCROPS, INCLUDES MANY TREES AND CONSIDERABLE UNDERBRUSH. NO DRAINAGE IMPROVEMENTS EXIST IN THE AREA.

$\bar{n}$=0.030: DRAINAGE AREA IS GENERALLY ROLLING, WITH ROUNDED RIDGES AND MODERATE SIDE SLOPES. WATERCOURSES MEANDER IN FAIRLY STRAIGHT, UNIMPROVED CHANNELS WITH SOME BOULDERS AND LODGED DEBRIS. GROUND COVER INCLUDES SCATTERED BRUSH AND GRASSES. NO DRAINAGE IMPROVEMENTS EXIST IN THE AREA.

$\bar{n}$=0.015: DRAINAGE AREA HAS FAIRLY UNIFORM, GENTLE SLOPES WITH MOST WATERCOURSES EITHER IMPROVED OR ALONG PAVED STREETS. GROUND COVER CONSISTS OF SOME GRASSES WITH APPRECIABLE AREAS DEVELOPED TO THE EXTENT THAT A LARGE PERCENTAGE OF THE AREA IS IMPERVIOUS.

TERMINOLOGY

L = LENGTH OF LONGEST WATERCOURSE

L_{ca} = LENGTH ALONG LONGEST WATERCOURSE, MEASURED UPSTREAM TO POINT OPPOSITE CENTER OF AREA

S = OVER-ALL SLOPE OF LONGEST WATERCOURSE BETWEEN HEADWATER AND COLLECTION POINT.

LAG = ELAPSED TIME FROM BEGINNING OF UNIT PRECIPITATION TO INSTANT THAT SUMMATION HYDROGRAPH REACHES 50% OF ULTIMATE DISCHARGE.

$\bar{n}$ = VISUALLY ESTIMATED MEAN OF THE n (MANNING'S FORMULA) VALUES OF ALL THE CHANNELS WITHIN AN AREA.

NOTE:
TO OBTAIN THE LAG (IN HOURS) FOR ANY AREA, MULTIPLY THE LAG OBTAINED FROM THE CURVE BY:

$\frac{\bar{n}}{0.050}$ OR $20\bar{n}$

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, ARIZONA

LAG RELATIONSHIPS

U.S. ARMY ENGINEER DISTRICT
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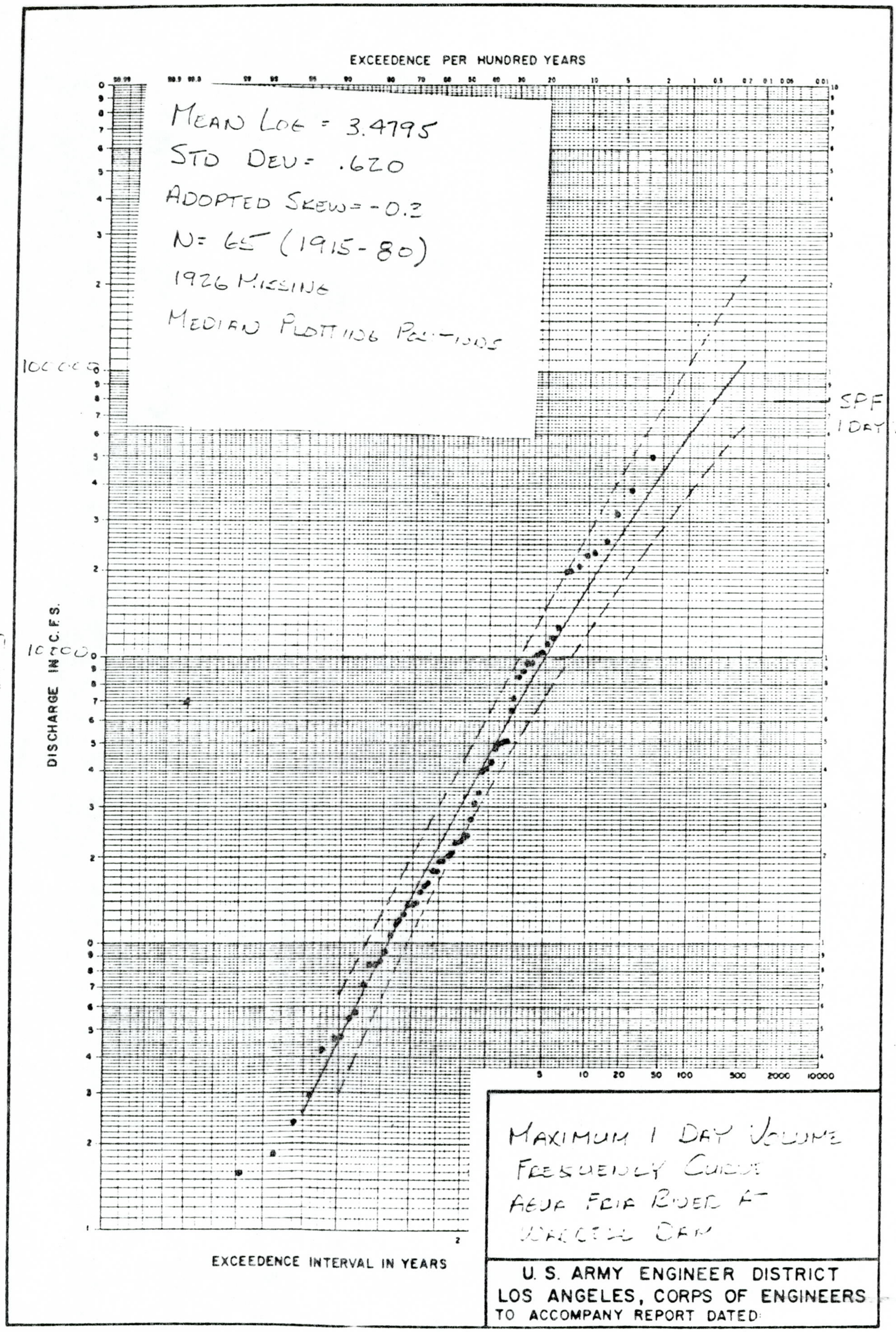
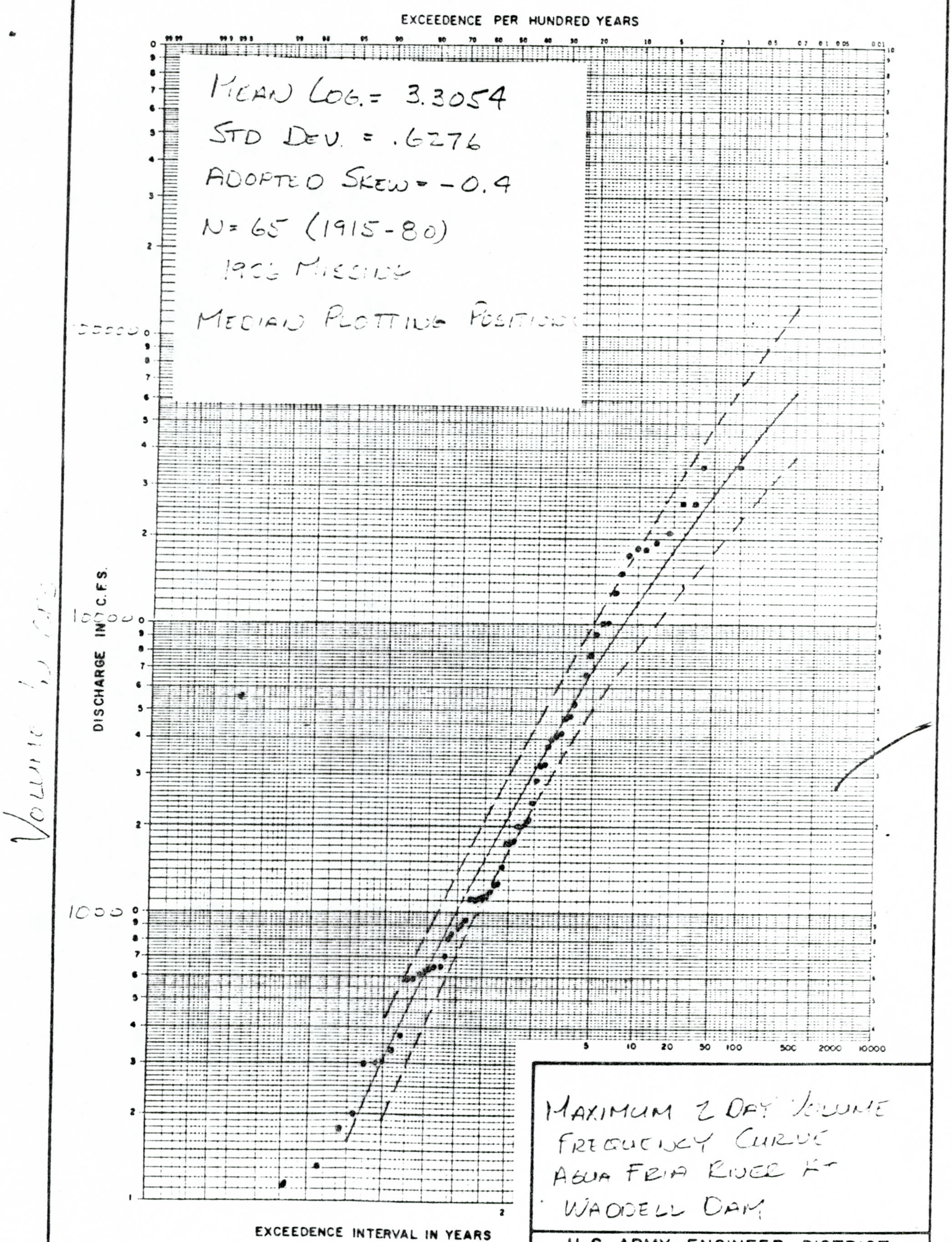


EXCEEDENCE PER HUNDRED YEARS
MEAN LOG = 3.4795
STD DEV = .620
ADOPTED SKEW = -0.3
N= 65 (1915-80)
1926 MISSING
MEDIAN PLOTTING POSITIONS
100 000
10 000
DISCHARGE IN C.F.S.
EXCEEDENCE INTERVAL IN YEARS
MAXIMUM 1 DAY VOLUME
U. S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS
TO ACCOMPANY REPORT DATED

Plate



MAXIMUM 2 DAY VOLUME
FREQUENCY CURVE
AGUA FRIA RIVER AT
WADDELL DAM

U. S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS
TO ACCOMPANY REPORT DATED

Plate 9