RAINFALL TABLE 2

STANDARD SCS 24-HOUR, TYPE II DISTRIBUTION
CUMULATIVE RAINFALL TABLE
(REVISED MAY 1982)

TIME INCREMENT
0.2500

0.0	0.0020	0.0050	0.0080	0.0110
0.0140	0.0170	0.0200	0.0230	0.0260
0.0290	0.0320	0.0350	0.0380	0.0410
0.0440	[illegible]	0.0520	0.0560	0.0600
[illegible]	[illegible]	[illegible]	0.0760	0.0800
[illegible]	[illegible]	[illegible]	0.1000	0.1050
[illegible]	[illegible]	[illegible]	0.1250	0.1330
[illegible]	[illegible]	[illegible]	0.1630	0.1720
[illegible]	[illegible]	[illegible]	0.2180	0.2360
[illegible]	[illegible]	[illegible]	0.6630	0.7070
[illegible]	[illegible]	[illegible]	0.7910	0.8040
[illegible]	[illegible]	[illegible]	0.8420	0.8490
[illegible]	[illegible]	0.8690	0.8750	0.8810
[illegible]	[illegible]	0.8980	0.9030	0.9080
[illegible]	0.9180	0.9220	0.9260	0.9300
[illegible]	0.9380	0.9420	0.9460	0.9500
0.9530	0.9560	0.9590	0.9620	0.9650
0.9680	0.9710	0.9740	0.9770	0.9800
0.9830	0.9860	0.9890	0.9920	0.9950
0.9980	1.0000	1.0000	1.0000	1.0000

...Control use Rainfall Depth in inches and Rainfall Duration of 1.0.
...this table is Form #271, Page F-7.

...ers Manual NTIS, May 1982

TABLE 1. Ordinates of the SCS Type I and Type II Precipitation Distributions

Storm Time (hours)	Precipitation Ratio Type I			Precipitation Ratio Type II	
0.0	0.000	1	0	0.0000	
0.5	0.008	7	.005	0.0053	
1.0	0.017	13	.011	0.0108	
1.5	0.026	19	.016	0.0164	
2.0	0.035	25	.022	0.0223	
2.5	0.045	31	.028	0.0284	
3.0	0.055	37	.035	0.0347	
3.5	0.065	43	.041	0.0414	
4.0	0.076	49	.048	0.0483	
4.5	0.087	55	.056	0.0555	
5.0	0.099	61	.068	0.0632	Not .068
5.5	0.122	67	.071	0.0712	
6.0	0.125	73	.080	0.0797	
6.5	0.140	79	.089	0.0887	
7.0	0.156			0.0984	
7.5	0.174			0.1089	
8.0	0.194			0.1203	
8.5	0.219			0.1328	
9.0	0.254			0.1467	
9.5	0.303			0.1625	
10.0	0.515			0.1808	
10.5	0.583			0.2042	
11.0	0.624			0.2351	
11.5	0.654			0.2833	
12.0	0.682			0.6632	
12.5	0.705			0.7351	
13.0	0.727			0.7724	
13.5	0.748			0.7989	
14.0	0.767			0.8197	
14.5	0.784			0.8380	
15.0	0.800			0.8538	
15.5	0.816			0.8676	
16.0	0.830			0.8801	
16.5	0.844			0.8914	
17.0	0.857			0.9019	
17.5	0.870			0.9115	
18.0	0.882			0.9206	
18.5	0.893			0.9291	
19.0	0.905			0.9371	
19.5	0.916			0.9446	
20.0	0.926			0.9519	
20.5	0.936			0.9588	
21.0	0.946			0.9653	
21.5	0.955			0.9717	
22.0	0.965			0.9777	
22.5	0.974			0.9836	
23.0	0.983			0.9892	
23.5	0.992			0.9947	
24.0	1.000			1.0000	

Source: McCuen, A Guide to Hydrologic Analysis Using SCS Methodology, Prentice Hall, 1982

COMPARISON OF DESIGN RAINFALL CRITERIA FOR THE SOUTHWEST

George V. Sabol[1]
Kenneth A. Stevens[1]

Abstract

The design of drainage and flood control facilities or the management of floodplains for alluvial fans is extremely sensitive to the design rainfall criteria that is used as input to the hydrologic model. The results of a study using several combinations of design rainfall criteria in deterministic rainfall-runoff models of watersheds is presented. The results indicate that some of the more commonly used design rainfall criteria may not adequately represent the rainfall characteristics of the southwest. It is concluded that design rainfall criteria for the southwest must represent both the spatial and temporal characteristics of regional severe storms if valid models for use on alluvial fans are to be developed and used.

Introduction

Rainfall induced floods are the result of a severe storm over the contributing watershed. Often, in flood hydrology, these storms are classified as either local storms or general storms. Local storms are typically short duration, high intensity rainfalls of limited areal distribution. They often are of 1-hour duration or less and are virtually always less than 6-hours unless associated with a larger storm system. In the southwest, they often are less than 25 square miles with 100 square miles as a large local storm. The size limit for an independent local storm is usually considered to be less than 500 square miles. General storms are large systems that are often associated with frontal activity.

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General storms are lower intensity, longer duration storms that cover very large areas. In the southwest, the local storm is usually the critical design event except for large watersheds and major watercourses.

Since the majority of drainage and flood control facilities are for smaller drainage areas, there is the need to adequately define the spatial and temporal distribution of local storms. Alluvial fans and alluvial plains are common landforms in the southwest that are undergoing development. These watersheds are usually small and therefore the local storm would constitute the critical flood producing event.

Design rainfall criteria are often contained in regional drainage design criteria, but often such criteria are not available and the hydrologist or engineer must develop or adopt prudent design rainfall criteria. Often the criteria contained in regional drainage design criteria or the criteria that is adopted is from generalized relations that have been published by various federal agencies. Such generalized criteria may not have been developed for severe local storms in the southwest and the use of such criteria could result in overdesign or underdesign. No studies are known to have been performed or published that compare various design rainfall criteria for local storms in the southwest. The four selected design rainfall criteria are summarized in Table 1.

These criteria have been compared only at the 100-year return period using the rainfall depth-duration statistics for Phoenix, Arizona. These rainfall depths for durations from 1-hour to 24-hours were obtained from NOAA Atlas 2 (Miller and others, 1973), and the rainfall depths for durations less than 1-hour were derived by revised short-duration rainfall ratios by NOAA (Arkell and Richards, 1986).

The comparisons have been made by modeling eight synthetic watersheds using the HEC-1 Flood Hydrology Program (U.S. Army Corps of Engineers, 1988). The eight synthetic watersheds vary in size from 0.1 square mile to 500 square miles, and the watershed characteristics have been selected to be representative of natural (undeveloped) watersheds that typically occur in Arizona and much of the southwest. The SCS Dimensionless unit hydrograph was used for all watersheds, and the Green and Ampt infiltration equation with a surface retention loss was used based on information in the Maricopa County Hydrologic Design Manual.

The equivalent uniform depth of rainfall for each of the synthetic watersheds using the four design rainfall criteria are shown in Table 2. The difference in rainfall depths are due to two reasons. First, two of the distributions (HYP and SCS) are for 24-hour durations and the other two distributions (HRM and MC) are for 6-hour durations. Second, different depth-area reduction curves have been used as indicated in Table 1. From Table 2 it is noted that there is very little reduction in rainfall depth using the depth-area reduction curve from NOAA Atlas 2 (HYP and SCS criteria). The areal distribution for local storms in the southwest is much more limited than the NOAA Atlas 2 depth-area reduction curve represents. Both the HMR and MC have fairly comparable rainfall depths although the depth using HMR diminishes more quickly with increasing area than the MC criteria.

The rainfall excess from the HEC-1 models is shown in Table 3. The rainfall excess is a function of both the method to calculate rainfall losses and the temporal distribution of the rainfall itself. Several facts are observed from Table 3: First, using the SCS criteria, there is little difference in rainfall excess with size of drainage area. This is not reasonable for local storms in the southwest. Second, both the HYP and SCS criteria result in similar estimates of rainfall excess for watersheds larger than 100 square miles while the HYP results in greater rainfall excess for smaller watersheds. This is because of the greater rainfall intensities for short durations in the hypothetical distribution. Third, both the HMR and MC criteria result in similar rainfall excess as the HYP criteria for watersheds smaller than 1 square mile. Fourth, the rainfall excess using HMR criteria diminishes a little quicker than the MC criteria for larger watersheds. Both the HMR and MC criteria result in reduction of rainfall excess with increasing watershed area as would be anticipated for local storms on watersheds in the southwest.

Table 4 shows the maximum rainfall intensity for the computation interval that was used. These are areally averaged intensities and obviously are much greater for small areas with small computation intervals than large areas where larger computation intervals are used. Several facts are observed from Table 4: First, the HYP criteria has the highest, short-duration rainfall intensity. This is because depth-duration statistics are input for 5 minutes and 10 minutes, whereas the shortest interval of rainfall input that was digitized from the distributions for the other three criteria is

15 minutes. Second, the areally averaged maximum rainfall intensities for the SCS criteria are virtually uniform for all watersheds from 0.1 to 500 square miles. This is not reasonable for local storms. Third, the HMR criteria results in somewhat higher rainfall intensities than the MC criteria for small watersheds (less than 10 square miles), and the intensities are about the same for areas larger than about 50 square miles. Fourth, all four criteria result in similar rainfall intensities in the range of 25 to 100 square miles.

Table 5 shows the peak discharge for each synthetic watershed from the HEC-1 models. Notice that for both the HYP and SCS criteria that the peak discharges continually increase for increasingly larger watersheds. For both the HMR and MC criteria, the peak discharges reach a maximum for watersheds between 25 and 100 square miles. That size is a practical limit of the rainfall excess producing portion of local storms, and reduced peak discharges past 100 square miles is the result of areally averaging the storm rainfall over the entire watershed.

CONCLUSIONS

1. The depth-area reduction curve in NOAA Atlas 2 is inappropriate for local storms in the southwest.
2. The hypothetic distribution with the NOAA Atlas 2 depth-area reduction curve will probably result in overestimation of design discharges for watersheds larger than about 10 square miles.
3. The SCS Type II distribution with the NOAA Atlas 2 depth-area reduction curve will probably result in underestimation of design discharges for watersheds smaller than 25 square miles and overestimation of design discharges for watersheds larger than 100 square miles.
4. The procedure in Hydrometeorologic Report No. 49 can probably be used to develop reasonable design rainfall criteria for watersheds smaller than 25 square miles.
5. The procedure for developing local storm design rainfall criteria as contained in the Maricopa County Hydrologic Design Manual results in flood discharges that increase with increasing area up to about 100 square miles and then decreasing discharges for areas larger than about 100 square miles.
6. Design rainfall criteria that are based on the analysis of regional data and historic storms are superior to generalized criteria. Both the HMR and the MC criteria were developed in this manner.

7. Design rainfall criteria that are based on the analysis of an appropriate regional, severe storm will probably yield more reliable flood estimates than either generalized criteria or regionalized criteria. The MC criteria fits this conclusion. Specific design rainfall criteria should be developed based on historic storms when data are available.

TABLE 1
Comparison of rainfall **depths**

Rainfall Criteria	Equivalent Uniform Depth of Rain, in inches							
	Area, in square miles							
	0.1	1	10	25	50	100	250	500
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HYP	3.93	3.92	3.88	3.82	3.74	3.66	3.58	3.58
SCS	3.93	3.92	3.88	3.82	3.74	3.66	3.58	3.58
HMR	3.25	3.25	2.85	2.59	2.33	2.01	1.49	1.13
MC	3.22	3.22	3.03	2.87	2.77	2.58	2.22	1.84

TABLE 2
Comparison of rainfall **excesses**

Rainfall Criteria	Rainfall Excess, in inches							
	Area, in square miles							
	0.1	1	10	25	50	100	250	500
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HYP	1.81	1.80	1.70	1.56	1.39	1.19	1.04	1.02
SCS	1.22	1.22	1.19	1.16	1.12	1.09	1.05	1.05
HMR	1.62	1.62	1.15	.86	.60	.36	.03	0.0
MC	1.70	1.58	1.19	.94	.80	.62	.34	0.1

TABLE 3
Comparison of rainfall **intensities**

Rainfall Criteria	Maximum Rainfall Intensity, in inches/hour							
	Area, in square miles							
	0.1	1	10	25	50	100	250	500
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HYP	9.0	8.4	5.5	3.3	2.9	2.5	2.1	2.0
SCS	3.0	3.0	3.0	2.9	2.8	2.8	2.7	2.7
HMR	7.4	7.4	5.4	2.9	2.1	1.8	1.1	0.8
MC	5.8	4.8	2.6	2.0	1.8	1.5	1.1	0.8

TABLE 4
Comparison of peak **discharges**

Rainfall Criteria	Peak Discharge, in cfs — Area, in square miles							
	0.1	1	10	25	50	100	250	500
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HYP	260	1,640	6,060	8,220	10,600	14,200	18,500	26,500
SCS	142	1,075	4,260	6,140	8,560	12,900	18,700	27,300
HMR	267	1,560	4,080	4,530	4,520	4,250	600	0
MC	250	1,370	4,050	4,960	6,050	7,270	6,140	2,300

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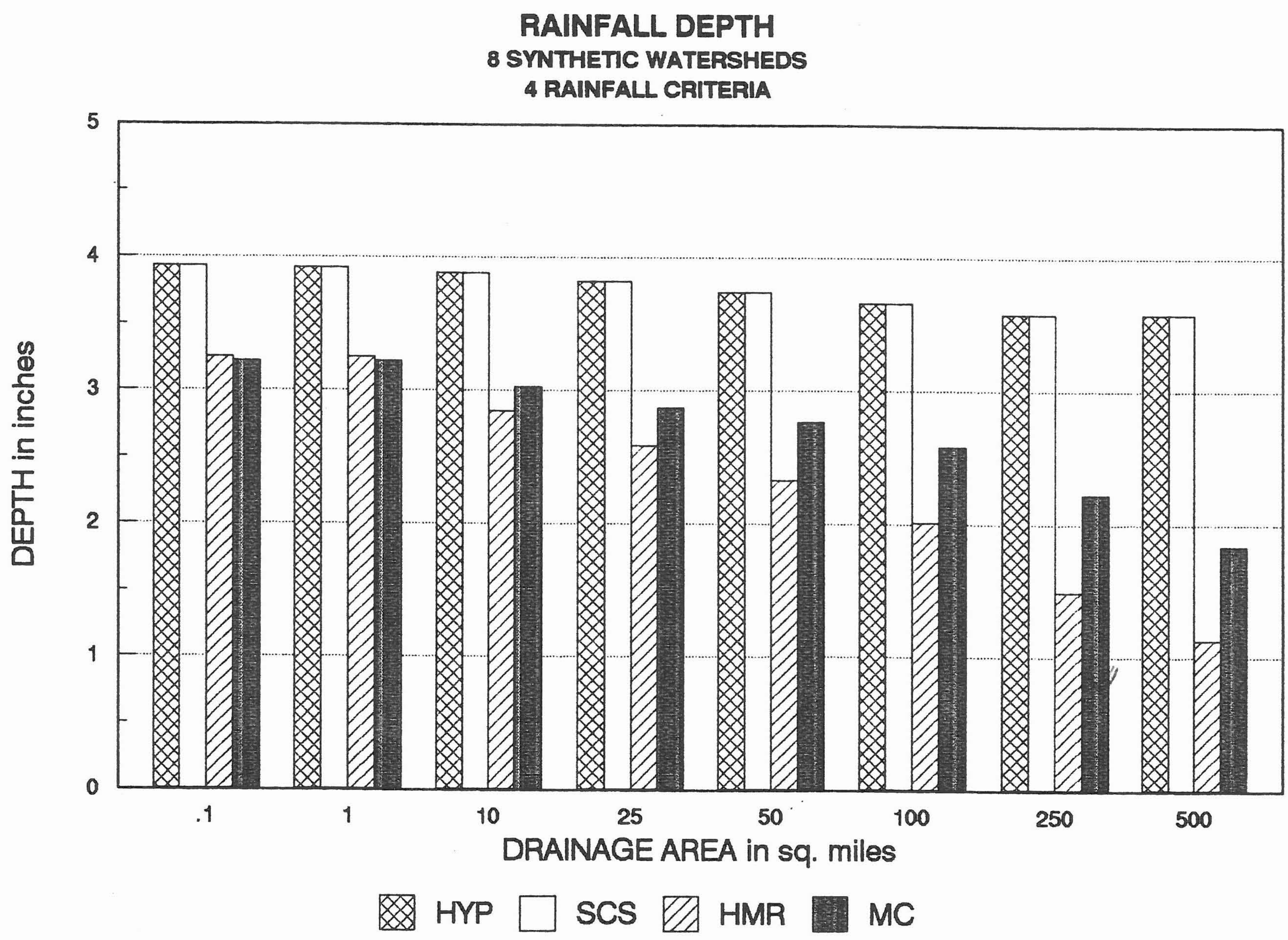
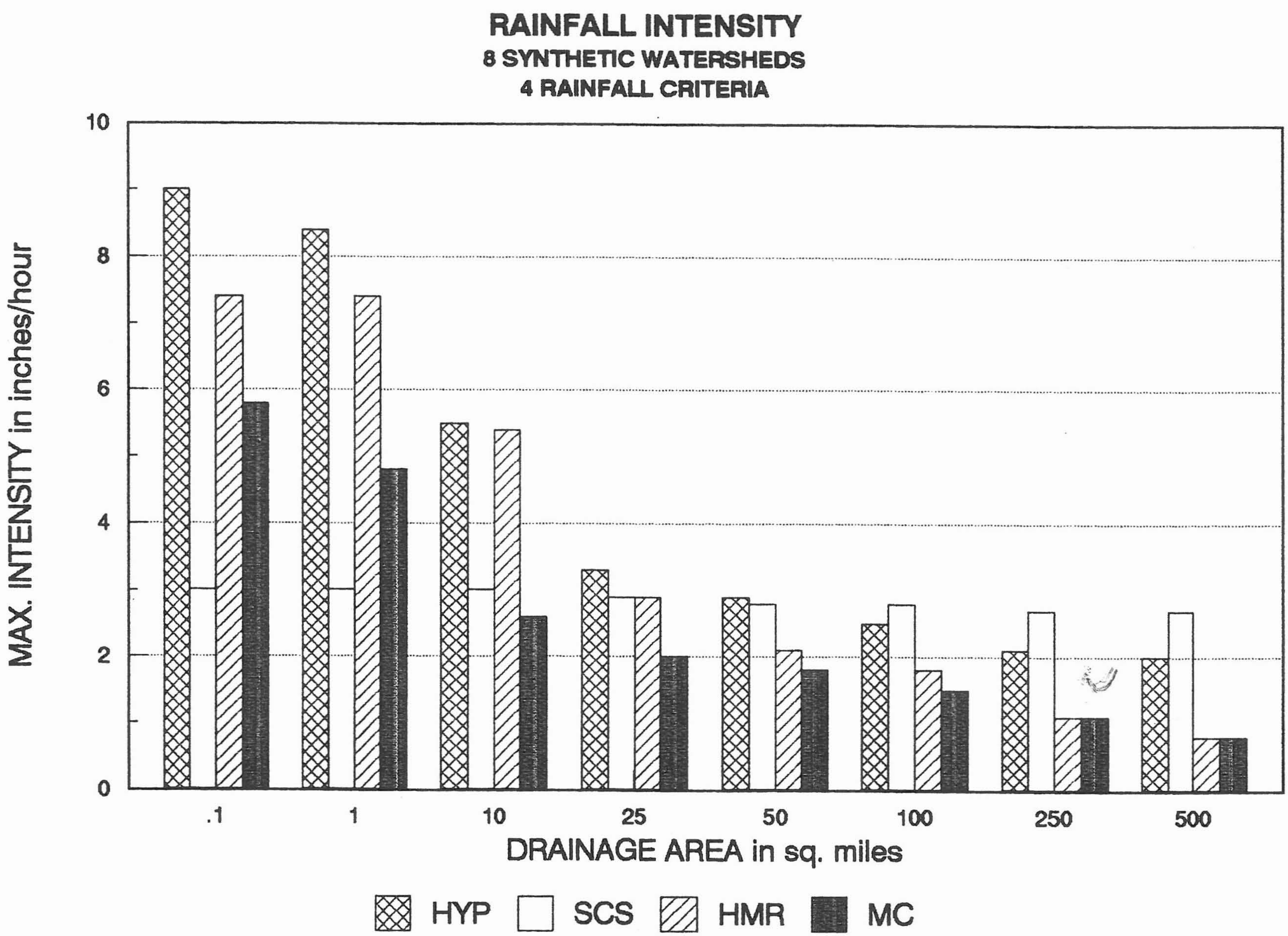
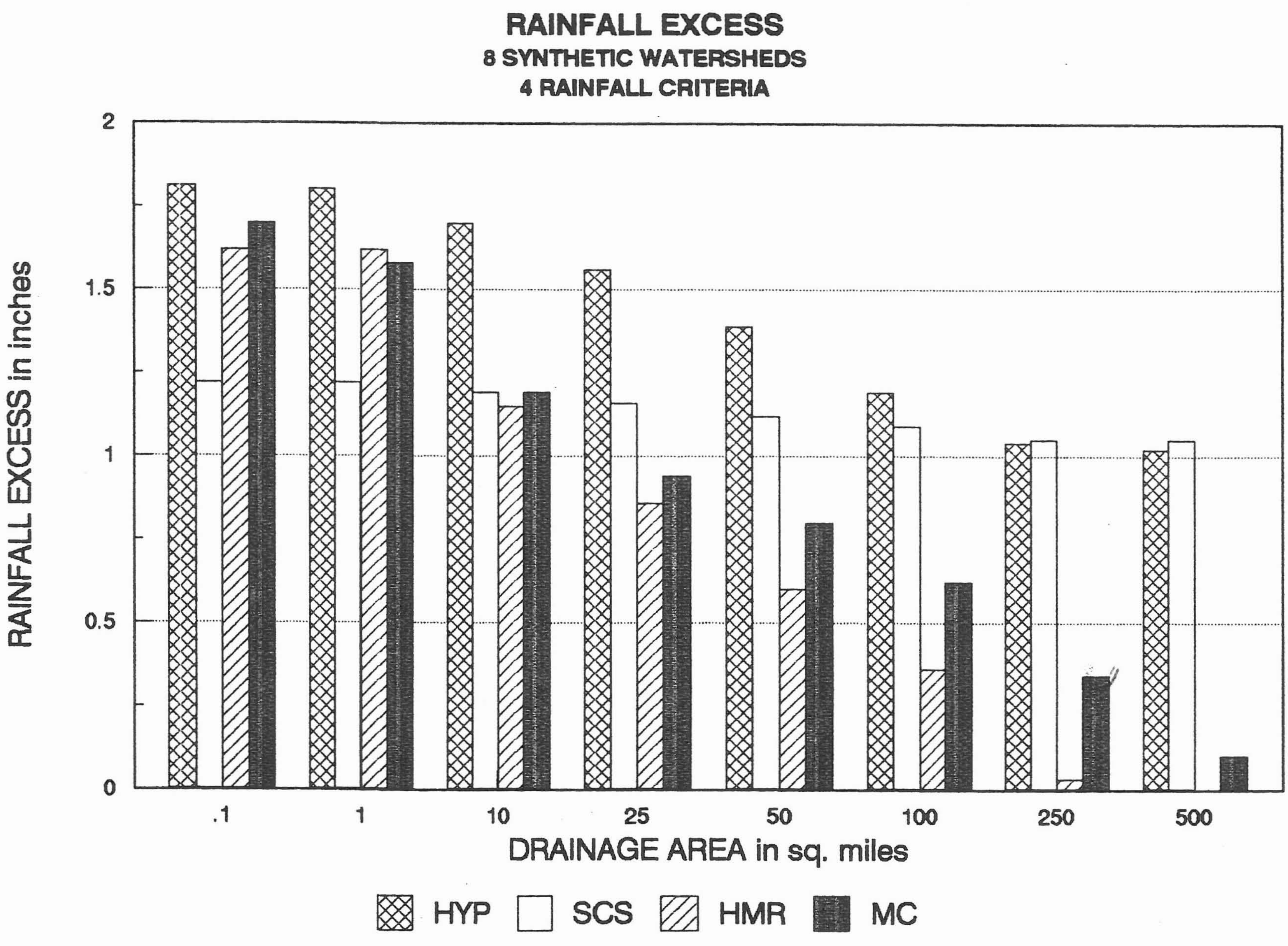
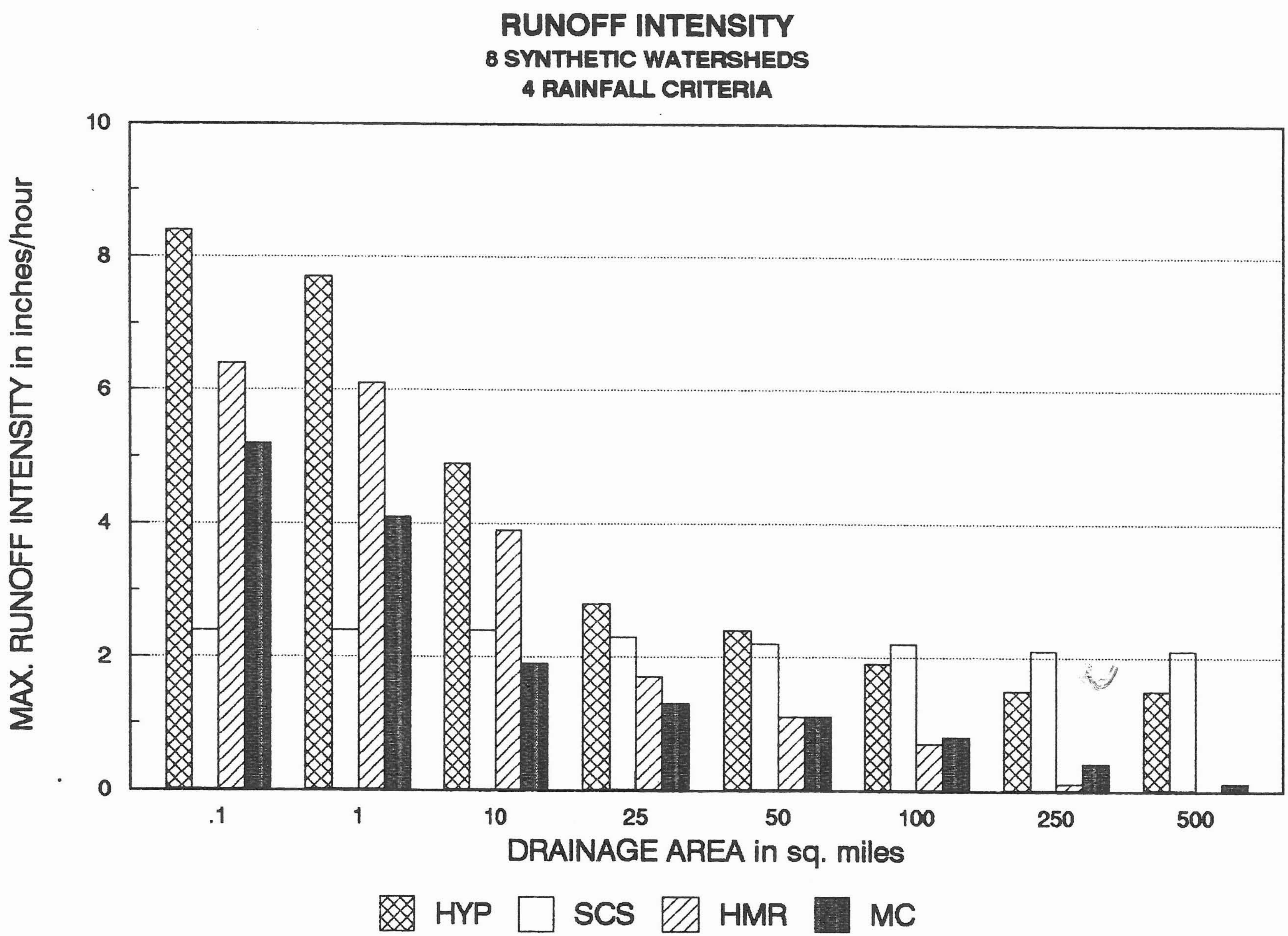


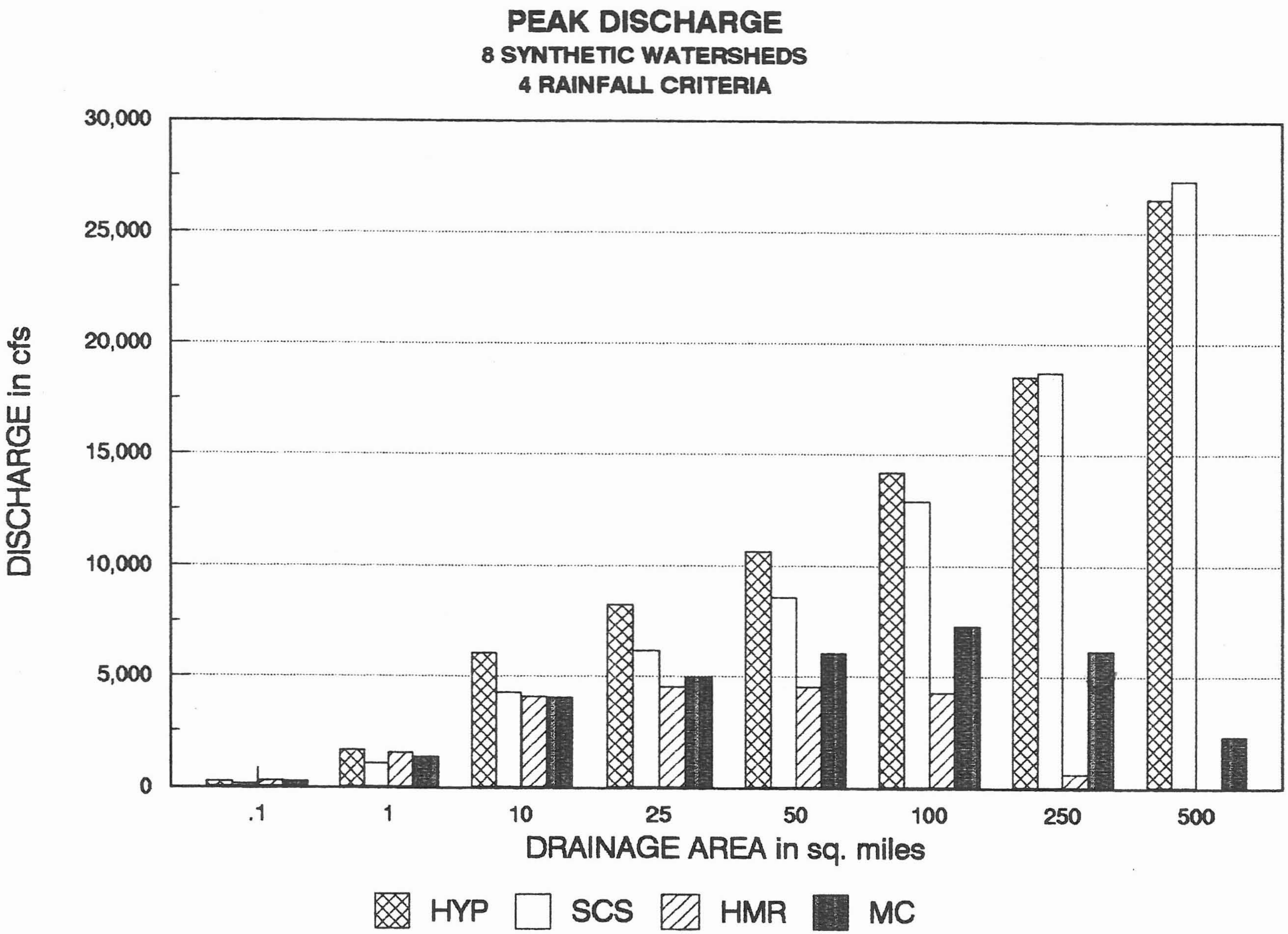
RAINFALL DEPTH
8 SYNTHETIC WATERSHEDS
4 RAINFALL CRITERIA
DEPTH in inches
0
1
2
3
4
5
.1
1
10
25
50
100
250
500
DRAINAGE AREA in sq. miles
HYP
SCS
HMR
MC


RAINFALL INTENSITY
8 SYNTHETIC WATERSHEDS
4 RAINFALL CRITERIA
MAX. INTENSITY in inches/hour
0
2
4
6
8
10
.1
1
10
25
50
100
250
500
DRAINAGE AREA in sq. miles
HYP
SCS
HMR
MC



RAINFALL EXCESS
8 SYNTHETIC WATERSHEDS
4 RAINFALL CRITERIA
RAINFALL EXCESS in inches
2
1.5
1
0.5
0
.1
1
10
25
50
100
250
500
DRAINAGE AREA in sq. miles
HYP
SCS
HMR
MC


RUNOFF INTENSITY
8 SYNTHETIC WATERSHEDS
4 RAINFALL CRITERIA
MAX. RUNOFF INTENSITY in inches/hour
10
8
6
4
2
0
.1
1
10
25
50
100
250
500
DRAINAGE AREA in sq. miles
HYP
SCS
HMR
MC


PEAK DISCHARGE
8 SYNTHETIC WATERSHEDS
4 RAINFALL CRITERIA
30,000
25,000
20,000
15,000
10,000
5,000
0
DISCHARGE in cfs
.1
1
10
25
50
100
250
500
DRAINAGE AREA in sq. miles
HYP
SCS
HMR
MC

PART 1
RAINFALL

Introduction

The 1985 Task Force for storm drainage management formed under the auspices of the Flood Control District of Maricopa County determined that the effort proceed in three phases:

Phase 1 - Research, evaluate, develop and produce uniform policies and standards for drainage of new development within Maricopa County.

Phase 2 - Establish a Stormwater Drainage Design Manual for use by all jurisdictional agencies within the County.

Phase 3 - Prepare an in-depth evaluation of regional rainfall data and establish precipitation design rainfall guidelines and isopluvial maps for the County.

Phase 1 resulted in Uniform Drainage Policies and Standards for Maricopa County, February 1987 (Appendix 1-A). Phase 2 was executed in two parts: Phase 2A resulted in the publication of the Hydrologic Design Manual for Maricopa County, Arizona, September 1990, for which this Documentation Manual was prepared. Phase 2B will result in the publication of the Drainage Design Manual. Phase 3 is presently (1991) being initiated by the Hydrometeorology Branch, Office of Hydrology, National Oceanic and Atmospheric Administration. A project description and scope-of-work for the NOAA rainfall study is provided in Appendix 1-B.

The Phase 1 study resulted in the adoption of the 2-hr, 100-yr rainfall as the criteria to be applied in the design of retention/detention facilities in Maricopa County. No other design rainfall criteria were defined or recommended in Phase 1.

Phase 2A resulted in the definition of design rainfall criteria that are to be used in Maricopa County. The development of that rainfall criteria is documented, herein.

At the completion of Phase 3, the rainfall criteria from Phase 2A will need to be reevaluated as a consequence of that study (by NOAA) and changes to the rainfall criteria as contained in the Hydrologic Design Manual may be warranted as a result of Phase 3. Absent the results of Phase 3 during the conduct of Phase 2A, all available results of regional rainfall studies were considered in the preparation of the design rainfall criteria.

Depth-Duration-Frequency Statistics

The most current and technically defensible source of rainfall depth-duration-frequency (D-D-F) statistics for Maricopa County is the NOAA Atlas 2 for Arizona (Miller and others, 1973), and that source was selected to define the rainfall depths for use in the County. The only deviation from the procedures in NOAA Atlas 2 is that the more current short-duration rainfall ratios from Arkell and Richards (1986) (Appendix 1-C) are to be used.

Isopluvial maps are contained in the Hydrologic Design Manual for various durations and return periods (frequencies) and these were extracted without modification directly from NOAA Atlas 2. The rainfall depths for the usual analyses required in the County can be taken directly from these isopluvial maps. However, there may be situations where D-D-F statistics are needed for special hydrologic studies or other purposes. In those situations, the procedures in NOAA Atlas 2 can be used along with the short-duration rainfall ratios from Arkell and Richards. Alternatively, a computer program (PREFRE) is available that will generate a D-D-F table. The PREFRE program is based on the procedures in NOAA Atlas 2 along with the Arkell and Richards paper, and the PREFRE program should be used in lieu of hand-calculations to minimize errors and to increase reproducibility among various users. A PREFRE program disk and User's Manual (U.S. Bureau of Reclamation, 1988) is provided in Appendix 1-D.

Storm Pattern

Background

The storm pattern defines the time distribution of the design rainfall of given duration and frequency over a particular drainage area. The development and the selection of the appropriate storm pattern for design purposes in Maricopa County resulted in the consideration of the following rainfall time distributions (storm duration is shown in parentheses):

SCS Type II (24-hr)
SCS Type II-A for New Mexico (24-hr)
SCS spillway design storm (6-hr)
Corps of Engineers (1974), Phoenix and vicinity (7-hr)
Corps of Engineers (1984), Queen Ck. and vicinity storm (8-hr)
Corps of Engineers (1988), Clark Co., Nevada (6-hr)
City of Phoenix (24-hr)
Kingman, Arizona, Master Drainage Plan (3-hr)
Clark Co., Nevada, Flood Control Master Plan (3-hr)
Hypothetical (any duration desired).

Of these, several received addition evaluation and these are briefly described below.

There have been many time distributions that have been developed and used to describe design rainfalls in the United States and Arizona. Notably among these are the Type I and Type II distributions of the U.S. Department of Agriculture, Soil Conservation Service (SCS). These are 24-hour distributions that have been developed for use in large geographic regions of the United States. These distributions are based on generalized rainfall depth-duration relations obtained from Weather Bureau technical papers and were not developed specifically for Arizona. Type I represents regions with a maritime climate. Type II represents regions in which the high rates of runoff from small areas are usually generated from thunderstorms that are imbedded in larger storm systems. These distributions are described in SCS Technical Paper 149 (Kent, 1973).

A family of Type II-A distributions was developed by the Albuquerque, New Mexico office of the SCS in 1973 and revised to a single Type II-A distribution in 1985. This was to reflect the more intense, shorter duration rainfalls that generally occur in New Mexico rather than in many other regions of the United States. One of these Type II-A distributions was often adopted, possibly with some modifications, for use in other states. A version of a

Type II-A distribution has been used in Arizona for various purposes by individuals and agencies; although such a distribution was never verified for Arizona.

The City of Phoenix adopted a 24-hour rainfall distribution in 1977 that is similar to the SCS Type II. The basis for this distribution is unknown and this distribution has been reviewed for the City of Phoenix (Tipton and Kalmbach, Inc., 1986). The peak rainfall intensity for the City of Phoenix distribution has a duration of 1 hour which is not characteristic of regional, severe rainfall.

The Corps of Engineers, Los Angeles District, analyzed rainfall data and developed rainfall time distributions for three flood studies in Arizona and nearby areas; Phoenix and vicinity (1974 and 1982), Clark County, Nevada (1988), and Imperial Valley, California (1980). These studies were performed for the purpose of developing standard project storms but, in some cases, have been used to describe storms of specified frequencies.

The Corps of Engineers, Los Angeles District, reanalyzed the 19 August 1954 Queen Creek storm in 1984 resulting in a distribution of 8-hour duration. The distribution has five Pattern Nos. with the selection of Pattern No. as a function of drainage area. Pattern No. 1 is for point rainfall and Pattern No. 5 is for an area of 540 sq. miles (personal communication, Dr. Charles Pyke, U.S. Army Corps of Engineers, Los Angeles District). This storm distribution is referred to as the Queen Creek and vicinity, 8-hr storm pattern (1984), and was never published by the Corps (see Appendix 1-E).

The hypothetical distribution of various durations was considered and several attempts to define a satisfactory rainfall pattern by this method were attempted. However, a method to devise a hypothetical distribution that was believed to simulate regionally representative rainfalls could not be devised.

Two decisions were made that resulted in the development and adoption of the storm pattern criteria that is shown in the Manual. First, the decision was made that the rainfall criteria should reflect the major flood producing storms that are characteristic of the region. This resulted in the decision that the design rainfall criteria should be based on the representation of local storms for drainage areas less than 100 sq. miles. Local storms are short duration, high intensity storms of limited areal extent and the storm pattern should, to the extent possible, represent these characteristics. Second, the decision was made that the storm pattern should be based on regionally observed severe storms rather than from generalized relations that were developed from rainfall data that may not be representative of storms in the County.

After further review of the available storm pattern criteria, it was noted that the Corps of Engineers rainfall criteria (1974 and 1982) is based on the analysis of the 19 August 1954 Queen Creek storm. The Corps' criteria results in the representation of rainfall spatial and temporal characteristics that are similar to observed local storm characteristics.

A meeting was held with the Los Angeles District, U.S. Army Corps of Engineers for the purpose of determining the data and analyses that went into the development of the Corps' storm pattern. Documentation on the meeting with the Corps is contained in Appendix 1-E. From the information that was obtained in that meeting, the 6-hr storm patterns as shown in the Manual were developed.

<u>Development of 6-hr Storm Patterns</u>

The 6-hr storm patterns as shown in the Manual are based on the Corps' 7-hr storm patterns with the following modifications:

1. the Corps' Pattern No. 6 was deleted,
2. the Corps' Pattern No. 1 was replaced by a hypothetical distribution,
3. a duration of 6 hours was used, and
4. a relation to select Pattern No. as a function of drainage area was developed.

These modifications were made as described, or justified, in the following:

The Corps used Pattern No. 6 for drainage areas that are in excess of 1,000 sq. mi. This is larger than will be required for a local storm criteria as to be provided in the Manual, and therefore, Pattern No. 6 was deleted.

For small drainage areas, the short duration, high intensity rainfalls result in the maximum flood discharges. The Corps' Pattern No. 1 does not reflect the short duration rainfall intensities that are indicated in the D-D-F statistics of NOAA Atlas 2 or Arkell and Richards. Therefore, use of the Corps' Pattern No. 1 could result in underestimation of flood discharges for small areas. A new Pattern No. 1 was developed by nesting rainfall depths of various durations in the same manner that the hypothetical distribution is developed. Pattern No. 1 is not symmetric but rather is delayed by 45 minutes (the maximum 15-minute rainfall intensity occurs between 3 hrs 45 min and 4 hrs. The 3- to 6-hr rainfall depth is distributed such that it occurs in the intervals 0 to 2 1/4 hrs and 5 1/4 hrs to 6 hrs. The rainfall D-D-F statistics were taken for the Phoenix Skyharbor Airport location from NOAA Atlas 2 and Arkell and Richards. Pattern No. 1 was made dimensionless by dividing all 15-min accumulated rainfall depths by the total 6-hr rainfall.

The Maricopa County Pattern Nos. 2 through 5 are modifications of the Corps' Pattern Nos. 2 through 5. The first hour of rainfall was truncated, leaving a 6-hr duration rainfall. The remaining 6-hr distributions were normalized to a total of 100% at 6 hrs. The resulting distributions were then drawn on a graph along with the new Pattern No. 1 (offset hypothetical distribution), and the Pattern Nos. 2 through 5 distributions were graphically smoothed to conform to the general shape of Pattern No. 1. The modifications to the Corps' 7-hr rainfall distributions and the resulting Maricopa County Pattern Nos. 2 through 5 are shown in Table 1-1.

The procedure to select the appropriate Pattern No. for a drainage area was developed as follows: The Corps shows a figure (Plate 20) of Pattern No. as a function of drainage area and the 10-yr, 6-hr rainfall depth, and the Corps used that figure to select the Pattern No. Subsequent to the development of that procedure, the Corps has been performing similar analyses where the Pattern No. is selected as a function of drainage area only (see for example the Clark County, Nevada study (1988)). Therefore, a graph of Pattern No. as a function of drainage area was developed to be consistent with the newer Corps procedures. This was done by plotting Pattern No. versus drainage area from Plate 20 for a 10-yr, 6-hr depth of 2.36 inches (the Queen Creek storm center 10-yr, 6-hr rainfall statistic). The results of this are shown in Figure 1-1. Notice that the points plot in a nearly straight line for larger areas but that the points deviate from a straight line for areas less than about 10 sq. miles. Also, note that the smallest Pattern No. for a drainage area of 1 sq. mi. is about 2.4. In developing a procedure to be used for selecting the Pattern No., the following were applied:

1. the limiting areal extent of local storms is about 500 sq. miles (this is supported by the results of the Hydrometeorological Report for Arizona (Hansen and others, 1984)),
2. the hypothetical distribution (Pattern No. 1) should only be applied to small drainage areas, and
3. a straight line can be fit to the upper part of the data points in Figure 1-1.

The relation that was adopted for selecting Pattern No. as a function of drainage area is shown in Figure 1-1. That relation was established by setting Pattern No. 5 at 500 sq. miles and Pattern No. 1 at 0.5 sq. miles, and by connecting the two points with a straight line. Pattern No. 1 is to be used for all areas less than or equal to 0.5 sq. mile.

Development of the 2-hr Storm Distribution

The 100-yr, 2-hr distribution (for retention/detention) is the hypothetical distribution (Pattern No. 1) for a 2-hr duration. The rainfall depths for 5-, 10-, 15-, 30-, 60-, and 120-min durations were calculated from NOAA Atlas 2 and the Arkell and Richards (1986) paper for the Phoenix Skyharbor Airport location. The distribution is a symmetric nesting of these rainfall depths, and was made dimensionless by dividing the rainfall mass diagram by the 100-yr, 2-hr rainfall depth.

Depth-Area Reduction

The original efforts to define rainfall depth-area reduction factors for use in the County focused on previously published depth-area reduction curves.

The following depth-area relations were identified and investigated:

1. the curve in NOAA Atlas 2 (Appendix 1-F)
2. the curves that were developed through the analysis of rainfall data for the Walnut Gulch Experimental Watershed near Tombstone, Arizona (Osborn and others, 1980), (Appendix 1-G), and
3. the curves that are presented in NWS HYDRO-40 for Arizona and western New Mexico (Zehr and Myers, 1984) (Appendix 1-H).

Numerous comparisons of the depth-area curves were made (Appendix 1-I). Prior to the adoption of the selected storm patters as previously described, there were extensive investigations of various combinations of rainfall time distributions and depth-area curves. Subsequent to the adoption of the storm patterns that are based on the Corps' analysis of the 19 August 1954 Queen Creek storm, it was decided that the depth-area reduction curve should be the depth-area reduction curve that was developed by the Corps for that same storm (U.S. Army Corps of Engineers, 1974, Plate 14) (Appendix 1-J). That decision was based largely on the philosophy that both the temporal and spatial characteristics of the design storm should be based on the same consistent criteria; that is, the historic 19 August 1954 Queen Creek storm.

Comparisons of Time Distributions and Depth-Area Curves

An analysis of the use of various combinations of rainfall time distributions and depth-area reduction curves was performed and the results of that study are summarized in a publication (Sabol and Stevens, 1990) (Appendix 1-K).

<u>Reviews</u>

The following individuals have contributed to the technical review, advising, or information compilation for the design rainfall section:

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Table 1-1

Construction of Maricopa County Pattern Nos. 2 through 5
from the Corps' Pattern Nos. 2 through 5

6-HOUR RAINFALL MASS CURVES (PATTERN #2 TO #5)

(all values in percent)

Time (hrs)	7-hr Pat.#2	6-hr Pat.#2	6-hr Pat.#2	7-hr Pat.#3	6-hr Pat.#3	7-hr Pat.#4	6-hr Pat.#4	7-hr Pat.#5	6-hr Pat.#5
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0:00	0.0			0.0		0.0		0.0	
0:15	0.3			0.5		0.8		1.1	
0:30	0.6			1.2		2.0		2.8	
0:45	1.0			2.0		3.0		4.0	
1:00	1.7	0.0	0.0	3.0	0.0	4.2	0.0	5.5	0.0
1:15	2.3	0.6	0.9	4.0	1.5	5.6	2.1	7.0	2.4
1:30	2.9	1.2	1.6	5.0	2.0	7.0	3.5	8.8	4.3
1:45	3.7	2.0	2.5	6.0	3.0	8.5	5.1	10.4	5.9
2:00	4.8	3.1	3.4	7.0	4.8	10.0	7.1	12.0	7.8
2:15	5.3	3.6	4.2	8.5	6.3	11.8	8.7	14.2	9.8
2:30	6.6	4.9	5.1	10.0	7.6	13.4	10.5	16.0	11.9
2:45	7.0	5.3	5.9	11.0	9.0	15.0	12.5	18.0	14.1
3:00	8.0	6.3	6.7	12.5	10.5	17.0	14.3	20.0	16.2
3:15	9.0	7.3	7.6	14.0	11.9	18.5	16.0	21.0	18.6
3:30	10.0	8.3	8.7	15.2	13.5	20.2	17.9	24.5	21.2
3:45	11.0	9.3	10.0	17.0	15.2	22.5	20.1	27.0	23.9
4:00	12.2	10.5	12.0	18.8	17.5	24.5	23.2	29.5	27.1
4:15	15.0	13.3	16.3	21.8	22.2	27.8	28.1	33.0	32.1
4:30	21.0	19.3	25.2	27.5	30.4	34.0	36.4	39.5	40.8
4:45	32.5	30.8	45.1	38.0	47.2	44.0	50.0	49.0	51.5
5:00	60.0	58.3	69.4	60.0	67.0	60.0	65.8	60.0	62.7
5:15	80.0	78.3	83.7	76.0	79.6	75.0	77.3	70.0	73.5
5:30	87.5	85.8	90.0	84.5	86.8	82.0	84.1	79.5	81.4
5:45	92.5	90.8	93.8	89.5	91.2	87.5	88.8	85.2	86.4
6:00	95.5	93.8	95.0	93.0	94.6	91.0	92.7	89.5	90.7
6:15	97.0	95.3	96.3	95.0	96.0	93.5	94.5	92.5	93.0
6:30	98.5	96.8	97.5	97.0	97.3	96.0	96.4	95.5	95.4
6:45	99.0	97.3	98.8	98.5	98.7	98.0	98.2	97.5	97.7
7:00	100.	98.3	100.	100.	100.	100.	100.	100.	100.

Notes:

1. Column No. 1 is time according to the Corps' distributions. For the Maricopa County distributions, subtract 1 hr from the time.
2. The Corps' distributions are shown in Columns No. 2, 5, 7 and 9.
3. Column 3 shows the Corps' Pattern No. 2 distribution after the truncation of the first hour rainfall.
4. Column 4 shows the Maricopa County Pattern No. 2 after adjusting the distribution to 100% (dividing all coordinate values by 98.3%), and after smoothing to Pattern No. 1.
5. Columns 6, 8 and 10 are the Maricopa County distributions constructed in a manner similar to that for Pattern No. 2.

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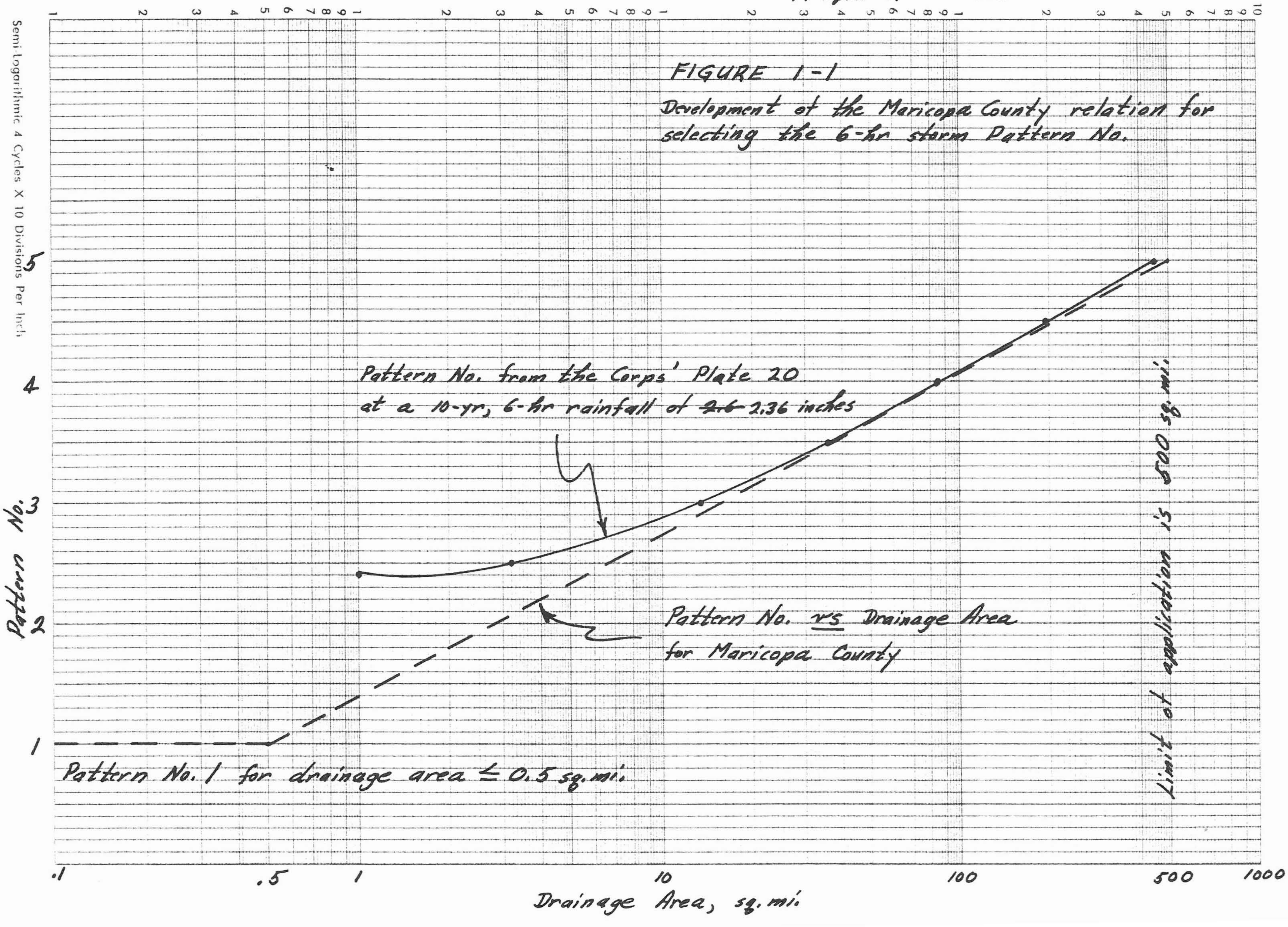

FIGURE 1-1

Development of the Maricopa County relation for selecting the 6-hr storm Pattern No.

APPENDICES

PART 1 - RAINFALL

1-A Uniform Drainage Policies and Standards for Maricopa County, February 1987

1-B Project description and scope-of-work for the NOAA rainfall analysis

1-C Short Duration Rainfall Relations for the Western United States (Arkell and Richards, 1986)

1-D PREFRE Program disk and Users' Manual (U.S. Bureau of Reclamation, 1988)

1-E Documentation on meeting with the U.S. Army Corps of Engineers, Los Angeles District, September 1988

1-F Depth-area reduction curve from NOAA Atlas 2

1-G Rainfall/Watershed Relationships for Southwestern Thunderstorms (Osborn and others, 1980)

1-H Depth-Area Ratios in the Semi-arid Southwest United States, NWS HYDRO-40 (Zehr and Myers, 1984)

1-I Comparisons of depth-area curves

1-J Queen creek depth-area reduction curve (U.S. Army Corps of Engineers, 1974)

1-K Comparison of Design Rainfall Criteria for the Southwest (Sabol and Stevens, 1990)

APPENDIX 1-A

Uniform Drainage Policies and Standards for Maricopa County, February 1987

Please insert a copy of the Uniform standards --- document here.

APPENDIX 1-A

Uniform Drainage Policies and Standards for Maricopa County, February 1987

Please insert a copy of the Uniform Standards --- document here.

APPENDIX 1-B

Project description and scope-of-work for the NOAA rainfall analysis

To be added when
I receive it from
John Vogel @ NOAA

APPENDIX 1-C

Short Duration Rainfall Relations for the Western United States
(Arkell and Richards, 1986)

Reprinted from the Preprint Volume of the Conference on Climate and Water Management-A Critical Era and Conference on the Human Consequences of 1985's Climate, August 4-7, 1986, Asheville, N.C. Published by the American Meteorological Society, Boston, Mass.

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SHORT DURATION RAINFALL RELATIONS FOR THE WESTERN UNITED STATES

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1. INTRODUCTION

Long records of short-duration (less than 1 hr) precipitation observations necessary to estimate precipitation-frequency amounts are only available for a relatively small number of stations. This dearth of data has made the development of generalized short-duration estimates difficult, especially in the western United States where station density is particularly low and where significant meteorological variation can occur over short distances. The first short duration precipitation-frequency estimates for the western United States were based on very limited data (U.S. Weather Bureau 1953, 1954). Later, Hershfield (1961) developed precipitation-frequency maps for the entire continental United States and used uniform ratios to relate the shorter-duration amounts to longer-duration amounts. By relating the shorter durations to a longer duration that had significantly greater station density, the detailed depiction of the spatial variation of the longer duration could effectively be incorporated into the shorter duration estimates. This approach was based on the assumption that the variation of the ratio fields was smoother than was the variation of the absolute values themselves.

Miller et al. (1973), hereafter referred to as NOAA Atlas 2, developed a technique to treat spatial variations in mountainous areas and applied it in the western United States. Miller et al. chose to adopt Hershfield's nationally averaged ratios for short durations. Frederick et al. (1977) developed isoheytal maps of short-duration precipitation-frequency amounts instead of ratios for the eastern and central United States. They limited their study to the largely nonorographic portions of the United States where meteorological variation was modest and where data density was generally highest. Finally, Frederick and Miller (1979) studied short-duration precipitation-frequency amounts in the state of California. In spite of the relatively high station density, they decided to develop regional ratios rather than maps depicting the spatial variation of the short-duration estimates because of the large meteorological variability within the state.

The present study develops short duration precipitation-frequency ratios for the 10 western states not included in either Frederick et al. (1977) or Frederick and Miller (1979): Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming. The ratios relate 5-, 10-, 15-, and 30-minute precipitation-frequency amounts to 1-hour amounts from NOAA Atlas 2. We addressed a number of problems in developing these ratios. First, the station density was lower (17,000 mi^2/station) compared to the eastern and central United States (12,000 mi^2/station) and California (600 mi^2/station). Second, the rugged topography, ranging from sea level to over 14,000 ft, imposed limitations on the data's applicability, especially since most stations tended to represent lower elevations. Third, there are wide variations in climatology within the study area.

2. THE DATA

The data used in this study are the largest annual precipitation amounts for 5-, 10-, 15-, 30- and 60-minute durations. The amounts for each duration for a given year were not necessarily from the same storm, but rather were the largest amounts for that year, regardless of date of occurrence.

The locations of the 61 stations included in this study are shown in figure 1. Of these, 55 had at least 15 years of data at all durations. Six stations had less than 15 years and were used only on a limited basis; three stations were significantly above the surrounding terrain and were used only for comparative purposes. The earliest data records go back to 1896 and the most recent data were through 1984. The average number of years with data for stations with 15 years or more of data was approximately 45 years at all durations.

Each station record was examined to see if significant changes in location and elevation occurred. Fifteen stations moved during their periods of record by more than the nominal distance and elevation cutoffs of 5 miles and 200 feet. These 15 moves were further examined with

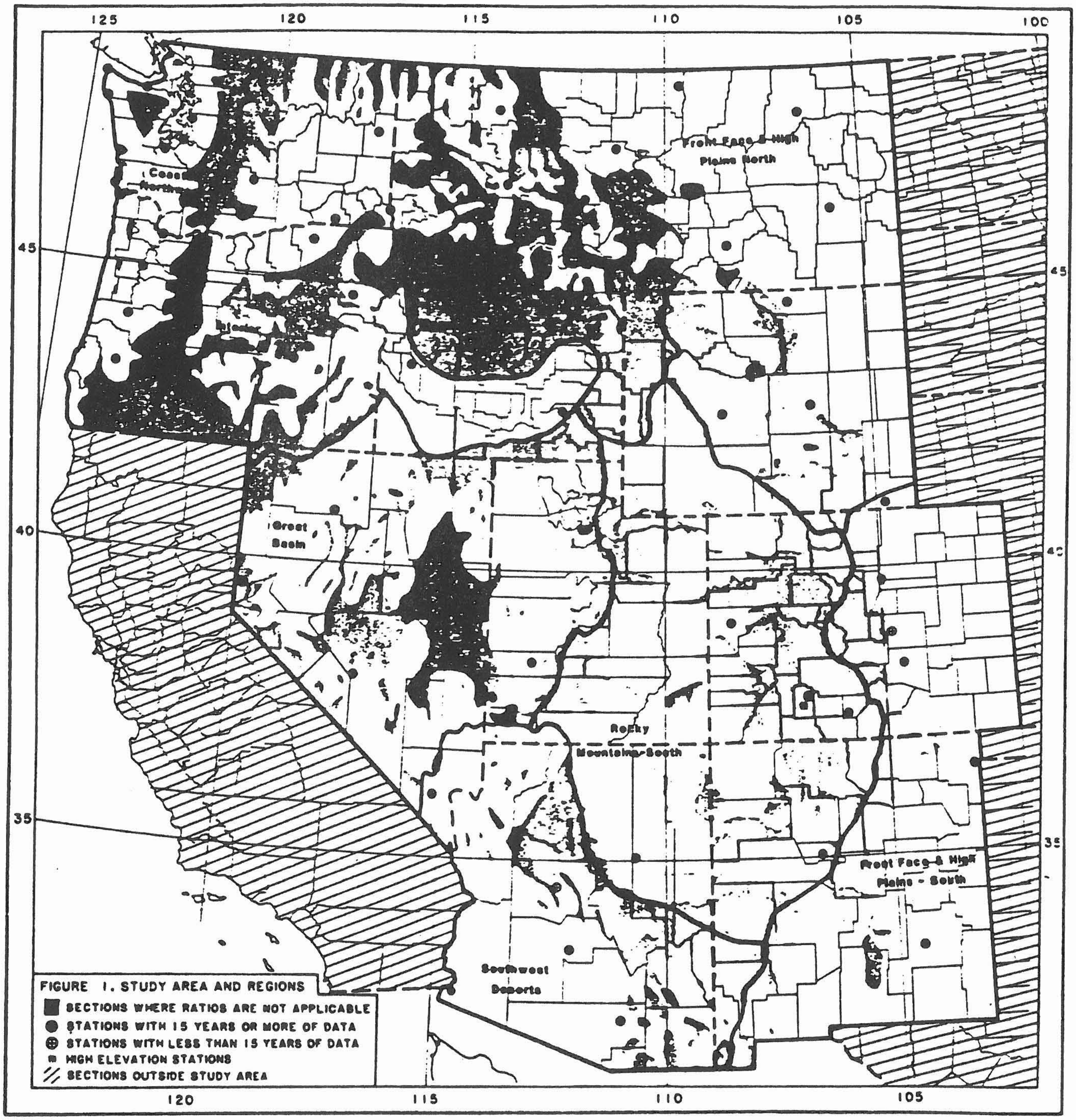

FIGURE 1. STUDY AREA AND REGIONS

respect to changes in terrain, local climatology, and urban/rural character. If, for example, a station moved 8 miles, but that move was on flat terrain with no adjacent mountains, then the relocation was probably not of climatological significance. On this basis, 7 stations made significant moves.

A detailed examination of these 7 stations revealed no consistent biases attributable to the station moves. Any possible biases were apparently smaller than the natural variability of the data themselves. Maximum short-duration amounts tended to vary more from one year to the next at most locations than did the longer duration amounts, such as 24-hour observations. In addition, no discernable biases were found that could be attributed to urban influences.

We also considered the possibility of secular trends. For example, we examined the question of whether the data from one station for the period 1900 to 1940 could be compared to the data for a second station which covered the period 1940 to 1980. Significant long-term secular trends were not evident and it was concluded that non-overlapping records were comparable.

3. PRECIPITATION-FREQUENCY STATISTICS

Frequency values were determined for all durations by fitting the data to the Fisher-Tippett Type I distribution using the Gumbel fitting technique (Gumbel 1958). Additional statistics, including skew and standard deviation, were computed for all stations. These statistics were useful as guides to understand similarities and differences in the precipitation frequencies of different stations and different regions. For example, standard deviations were larger in the southwest deserts than in the coastal northwest due to the difference between the sporadic summertime convective character of the first region and the more regular wintertime stratiform character of the second.

Ratios of 5-, 10-, 15- and 30-minute amounts to 1-hour amounts were computed for all 61 stations for the 2- and 100-year return periods. Due to the use of ratios, no correction was necessary to convert from annual to partial duration series. The next step was to average these ratios over geographic regions.

4. DETERMINATION OF REGIONS

The study area was divided into the 8 regions shown in figure 1 and listed in table 1. The determination of the number of regions involved a balance between two opposing factors. First, the regions had to be large enough to include an adequate number of stations within each to provide statistically stable results by virtue of large sample size. Second, the regions had to be small enough so that each region adequately represented a climatologically homogeneous area. The discussion below outlines how the regional boundaries were determined.

The ratios for each duration were plotted on maps for both the 2- and 100-year return periods. By plotting the ratios and finding the similarities and differences between adjoining stations, a first pass was made at determining the regions. Regional breakdowns of the western states based on climatological factors considered in previous studies were also examined. In addition, several other factors were considered. One such factor was the seasonal distribution of rainfall, ranging from the winter maximum/summer minimum in the Pacific Northwest, to the spring-summer maximum/winter minimum of the High Plains, to the less varied distribution in sections of the Intermountain Region. A second climatological factor was the seasonal distribution of thunderstorm activity, a prime producer of large short duration values. A third factor was the 6 hour and derived 1 hour patterns from NOAA Atlas 2. Other aspects of a more general nature included maximum rainfall patterns and principal paths of moisture inflow for storms producing large precipitation amounts.

We also examined the regional frequency of occurrence by month of annual maximum 1-hour amounts. For example, the maximum 3 consecutive months for 1-hour events in the Coastal Northwest is October through December, while in the Interior Northwest it is from June through August despite the fact that July and August are generally the months of lowest total rainfall. For both these regions, the proportion of the total number of annual events occurring in the most active 3-month period is lower than for other regions, being only 55 and 60 percent, respectively. This contrasts with the Rocky Mountains-South and the Southwest Deserts where upwards to 90 percent of the largest 1-hour amounts occurred during the most active 3 consecutive months, July through September.

The last significant factor in determining the regions was topography. In the general sense, topography is well correlated with the climatology discussed above and thus is not a separate factor. However, on a more detailed scale, the topography helps delineate the regional boundaries. For example, the crest of the Cascades separates the Coastal Northwest from the Interior Northwest in a well-defined fashion. Other geographic boundaries are not as well defined. There is no sharp discontinuity delineating the boundary between the northern and southern sections of the Front Face and High Plains. However, the northern boundary of the South Platte River Basin was chosen because this represents an approximate east-west division between where the Front Face of the Rocky Mountains changes from a north-south orientation in New Mexico and Colorado to a northwest-southeast orientation in Wyoming and Montana. This change in orientation influences the availability of moisture inflow to the two regions. The Front Face and High Plains could have been divided into three or more regions since the ratios gradually changed from south to north. However, the necessity of having enough stations per region to obtain stable ratios argued against this decision.

In some cases it was difficult to choose exact boundaries because a given station had statistical, climatological, and topographic similarities to two adjoining regions. Such was the case for Flagstaff, Arizona, which sits on top of a rim that separates the Southwest Deserts from the Rocky Mountains-South. Due to the greater similarity in the frequency statistics to the Southwest Deserts, it was included in that region, and the region boundary was drawn just to the north of Flagstaff.

5. REGIONAL RATIOS

Ratios were averaged over each region by weighting the individual stations by their length of record. The 2-year values were analyzed first because they were less susceptible than the 100-year values to sampling fluctuations resulting from the relatively short record lengths. The trends between regions, between durations, and between return periods were of primary interest. We attempted to minimize sampling variability by maintaining continuity and consistency in these trends.

Another consideration was comparisons with previous studies. U.S. Weather Bureau (1953, 1954) presents short-duration estimates for the western states for 3 regions: West of the Coastal Ranges, east of the Coastal Ranges and west of 115°W, and between 105° and 115°W. In both Hershfield (1961) and NOAA Atlas 2, short-duration ratios do not vary by region, but rather are based on national averages.

Table 1.—Five, 10-, 15- and 30-minute ratios for 2- and 100-year return periods

Region No.	Region	2-Year Return Period 5 minutes	10	15	30	100-Year Return Period 5 minutes	10	15	30
		Ratios to 1 Hour							
1	Coastal Northwest	.30	.45	.56	.73	.36	.53	.64	.82
2	Interior Northwest	.35	.53	.64	.81	.37	.56	.67	.85
3	Rocky Mountains-North	.38	.57	.68	.84	.35	.55	.67	.84
4	Front Face and High Plains-North	.39	.58	.69	.85	.37	.56	.69	.87
5	Great Basin	.34	.51	.61	.81	.34	.52	.63	.84
6	Rocky Mountains-South	.35	.54	.65	.83	.32	.50	.62	.81
7	Front Face and High Plains-South	.33	.51	.62	.83	.29	.46	.59	.81
8	Southwest Deserts	.34	.51	.62	.82	.30	.46	.59	.80

The final consideration was comparability to information for locations adjacent to the study area. Taking such information into account accomplished two goals. First, it contributed to the degree of consistency and continuity between this study and other reports. Second, it provided additional insight into the variation of the ratios in this report, providing anchors, so to speak, at the study area boundaries. For areas east of the study region, we compared our results to Frederick et al. (1977) and for California we related our results to Frederick and Miller (1979). In addition, we developed frequency estimates for several stations with short-duration data in surrounding states. Fourteen stations were analyzed for this purpose, 10 in the Plains States and 4 in California. Most of these stations were close enough to be directly comparable to adjacent stations within the study area, while a few were chosen at greater distances from the boundaries to provide some idea of the trend in ratios leading up to the study area.

It was concluded that the ratios in this report were consistent with previous studies. The final ratios are listed in Table 1. A comparison between these ratios and those from NOAA Atlas 2 and Weather Bureau (1953, 1954) is shown in Table 2.

6. APPLICATION OF RATIOS

The ratios derived in the above analysis are based on stations whose elevations tended to be in the lower sections of each region. To extrapolate these statistics to much higher elevations would be a questionable undertaking, because of the complex effects of slope, funneling, and rain shadows that often occur in these areas. As such, the ratios are not applicable to all elevations within each region, but rather to a general range of elevations. The ranges of applicable elevation, approximately 3,000 to 3,500 ft in most areas, are summarized in table 3. In a few cases, areas are excluded that contain stations included in the analysis. The regional ratios were reviewed in light of this fact, and it was determined that no adjustments were necessary.

Areas of non-applicability, based on elevation and location considerations, are shown in figure 1 as shaded areas. These areas are based primarily on smoothed contour maps of the western states. Due to the generalized nature of the contours, there are isolated sections, primarily at the edge of shaded areas, where the ratios might be applicable. Conversely, there are isolated peaks and high elevations which are not shown as part of any shaded areas, but which may, in fact, be non-applicable areas.

Table 2.—Ratios compared to other reports

Dur. (min)	This Report*	NOAA Atlas 2	Weather Bur. (1953, 1954)*
	Ratio to 1 Hour		
5	.34	.29	.32
10	.52	.45	.49
15	.64	.57	.59
30	.82	.79	.78

*Averaged over all regions and for all return periods

Note: Comparisons are for illustrative purposes only. Each report covers a different geographic area, and averaging is done without regard to size of region or specific return periods involved.

Table 3.—Applicable elevations within regions

Region No.	Generally Applicable elevations (ft)
1	0-2500
2	50-3000 Columbia Basin to 2500-5500 SE
3	2000-5000 N to 4000-7000 S
4	2000-5000 N to 4000-7000 S
5	3500-7000
6	4500-8000 N to 3500-7000 S
7	4000-7500 N to 3500-7000 S
8	3000-6500 mountains to 100-3500 deserts

"SHORT DURATION RAINFALL RELATIONS FOR THE WESTERN U.S."
FROM ARKELL and Richards, 1986

As discussed in section 5, ratios do not necessarily change abruptly at all regional boundaries, such as is the case along the crest of the Cascades. Probably the most gradual change is between the two halves of the Front Face and High Plains. Most other regional boundaries are better defined by local topography and climatology. Ratios for locations close to most boundaries are probably best estimated by taking into account neighboring ratios to some extent.

In many cases, it might be desirable to find values for a return periods between 2 and 100 years, or for durations different than those given in this report. To do this it is first necessary to compute the absolute values for the standard durations and return periods for the location in question. This can be done using the ratios in this report and 1-hour values determined from NOAA Atlas 2 in conjunction with the two graphs shown in figures 2 and 3. Figure 2, a probability grid based on the Fisher-Tippett distribution, is used to interpolate return periods. Figure 3, a standard semi-log scale, is used to interpolate durations.

Three examples are given below to illustrate the interpolation procedures. The first is for return period, the second for duration, and the third for both return period and duration. The location chosen is Twin Falls, Idaho, and the source used to determine the 1-hour values is NOAA Atlas 2 (the 1-hour values were derived from the 6-hour maps using the appropriate regression equations). The 2- and 100-year 1-hour values are 0.33 and 0.92 inches. Using the ratios in this report from the Interior Northwest, the 2-year return period values for 5, 10, 15 and 30 minutes are 0.12, 0.17, 0.21. and 0.27 inches, and the 100-year return period values are 0.34, 0.52, 0.62 and 0.78 inches.

In the first example, the 10-year return period is found for the 15-minute duration. The 2- and 100-year return period values of 0.21 and 0.62 inches are plotted in figure 2 (line C), and the 10-year value of 0.38 is read off the Y-axis. In the second example, the 20-minute duration is found for the 2-year return period. The 5-, 10-, 15- and 30-minute, and 1-hour values of 0.12, 0.17, 0.21, 0.27 and 0.33 inches are plotted in figure 3 (line A) and a best fit curve, which can usually be approximated with a straight line, is drawn through these points. The 20-minute value of 0.24 inches is then read off the Y-axis. In the third example, the 20-minute duration is found for the 10-year return period. First, the 10-year values for the standard durations are found in figure 2 (lines A through E), the results being 0.21, 0.31, 0.38, 0.48 and 0.57 inches. These five durations are then plotted figure 3 (line B), to obtain a 20-minute value of 0.42 inches.

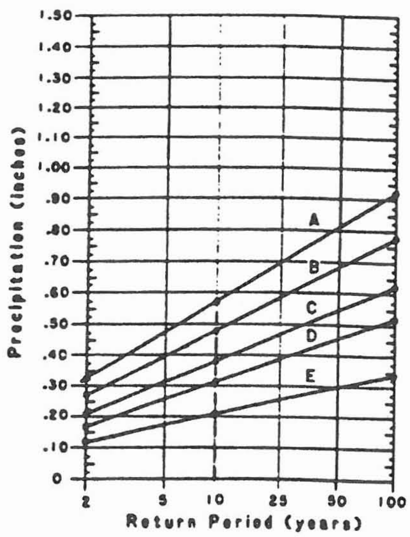

Figure 2.—Example of return period interpolation.

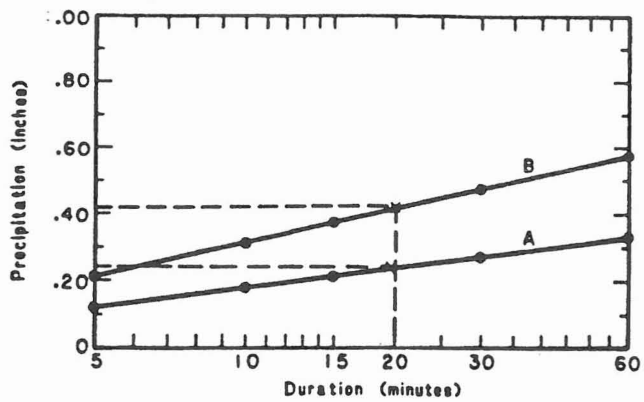

Figure 3.—Example of duration interpolation.

7. DISCUSSION OF RESULTS

The relatively high ratios encountered throughout the 10 states examined in this study, as compared to the remainder of the country, result from differences in the precipitation climatology. In all regions except the Coastal Northwest, the continental regime, including the lack of available moisture in the lee of mountain barriers, is a significant factor. The result is high short duration rainfall rates which are difficult to maintain for periods as long as 1 hour, thus causing relatively high ratios. Almost all of these events occur in late spring and summer thunderstorms that are not associated with the larger storm systems more typical of winter. Within a given region, all durations between 5 minutes and 1 hour display approximately the same seasonality.

Even the Coastal Northwest has relatively high ratios when compared to coastal California, although the mechanisms here are different. The northern coast receives considerably more rain on an annual basis than does the southern coast. Much of this rain is of a non-convective nature with steady rain over periods of several hours, as opposed to convective events on the on the order of an hour, somewhat more typical of the southern coast. Therefore, 1-hour amounts tend to be slightly lower in the north. On the other hand, maximum short-duration rates for 5- to

30-minute periods show less variation from north to south. The combination of comparable 5- to 30-minute rates with generally lower hourly rates produces somewhat higher ratios in the north. Maximum short-duration values along the northern coast occur most often in the fall and early winter at all durations, and often result from convective shower and thunderstorm activity embedded in or associated with synoptic scale storm systems. However, isolated summer thunderstorms occasionally produce significant events.

The climate of the western states is controlled primarily by two features, and these in turn affect the climatology of short-duration events. First is the semi-permanent high pressure system that sits off the California Coast, moving south in winter and north in summer. This system affects the westernmost part of the study area most directly, producing a pattern of wet winters and dry summers. This is true both to the west and east of the Cascades, although annual rainfall is considerably less to the east due to the sheltering effect of the mountains. The second feature, dominating the eastern part of the study area, is moisture from the Gulf of Mexico, which produces an almost opposite seasonal trend of wet springs and summers and relatively drier winters. In the spring, the Atlantic sub-tropical high pressure system extends westward into the Gulf and sets up a southerly flow of moist air into the high plains and eastern Rockies which is generally maintained through the summer. The climate of the southwest deserts is affected to some degree by both of these features. The Gulf of Mexico influence contributes to a summer maximum in precipitation and the Pacific influence causes a secondary winter maximum.

The eastern half of the study area tends to have the largest short-duration amounts in terms of absolute values. This is due to the inflow of Gulf moisture occurring during the warm season, which is the time of maximum convective potential, combined with the continental regime which favors short-duration convection.

Ratios in the study area tend to increase from west to east in the north, from the Coastal Northwest to the Front Face and High Plains-North. They increase from south to north in the two Front Face and High Plains regions. They also tend to increase in a southeast to northwest direction from the Front Face and High Plains-South to the Interior Northwest and Rocky Mountains-North. Looking outside the study area, ratios increase from California northward into the Coastal Northwest, and increase westward from the plains into the two Front Face and High Plains Regions. Climatically, the trends reflect the increasingly continental regime and decreasing availability of moisture moving east away from the Pacific Ocean and north and west away from the Gulf of Mexico. As a result of these trends, the highest ratios are generally found in the Front Face and High Plains-North and the lowest ratios in the Coastal Northwest and also the Front Face and High Plains-South and Southwest Deserts.

8. SUMMARY

A series of 64 ratios were developed for ten western states to be used in conjunction with 1-hour values from NOAA Atlas 2. With these ratios, precipitation-frequency estimates can be determined for 5-, 10-, 15-, and 30-minute durations for return periods of 2 and 100 years in each of eight regions. Some areas within each region were excluded due to elevation and exposure considerations.

The results show ratios that are generally higher than in most other sections of the country. These differences are well explained by climatological factors. Although these results appear meteorologically consistent, caution must be exercised when using them because of the small size of the data sample and the meteorological complexity of the study area.

9. ACKNOWLEDGEMENTS

Funding for this work was provided by the U.S. Department of Agriculture, Soil Conservation Service, as part of their watershed protection and flood prevention program. Liason with the sponsoring agency was maintained with Robert Rallison and Norman Miller.

We also want to thank Helen Rodgers for editorial work and layout of the paper, and Roxanne Johnson for preparation of the figures.

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APPENDIX 1-G

Rainfall/Watershed Relationships for Southwestern Thunderstorms

(Osborn and others, 1980)

Rainfall/Watershed Relationships for Southwestern Thunderstorms

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ABSTRACT

DEPTH-AREA relationships for thunderstorm rainfall were developed from 20 years of record from dense raingage networks in Arizona and New Mexico, using the National Weather Service method described in NOAA Atlas 2. The relationships are compared with similar previously published ones. Relationships also were developed to indicate the distribution of storm rainfall over a watershed. This information could be valuable to agencies, groups, and individuals involved in water resources design and evaluation for climatologically similar areas.

INTRODUCTION

The National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), published a precipitation frequency atlas, NOAA Atlas 2 (Miller et al., 1973) for the Western United States, which consisted of a series of volumes, one for each Western state. Volumes 4 (New Mexico) and 8 (Arizona) are of particular interest in this study. A value read from the isopluvial maps in each of these volumes "is the value for that point and the amount for that particular duration which will be equalled or exceeded, on the average, once during the period of time indicated on the individual map." Also, there is a depth-area monogram in each volume to be used to estimate average rainfall over watersheds of up to 1000 km², given the average point value over the basin.

The depth-area curves in NOAA Atlas 2 were developed, by necessity, from groupings of closely spaced recording raingages available in the published data of the regular cooperative network of the NWS. No groupings sufficiently closely spaced for this purpose were available in the Southwest. Significant regional and frequency variations were not detected in the available data from the remainder of the United States. Fig. 1 shows the curve published for Arizona and New Mexico, but derived from regions outside the Southwest. These are based on 2-yr data, but are meant to be applied to all return periods up to 100 years (Miller et al., 1973).

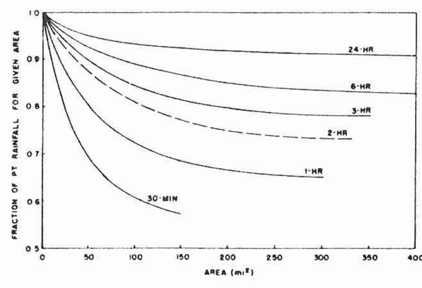

FIG. 1 Point-to-area conversion ratios for selected durations (Fig. 14, NOAA Atlas 2), 2-h interpolated.

In this paper we use records from dense recording raingage networks, operated by the USDA, Southwest Rangeland Watershed Research Center at the Walnut Gulch Experimantal Watershed near Tombstone, AZ, and the Alamogordo Creek Experimental Watershed near Santa Rosa, New Mexico (Fig. 2), to develop new depth-area curves. We believe the new curves are applicable to southwestern watersheds of similar climates for rainfall durations from 30 min to 6 h over areas up to 200 km². We compared these new curves with the NOAA Atlas 2 curves. Complete descriptions of the experimental watersheds and their instrumentation have been given by Renard (1970) and the Agricultural Research Service (1971). Gage density in each basin is about 1 per 3 km².

For many design problems on Southwestern watersheds, information is needed to supplement the type of information provided in NOAA Atlas 2. Most rain-produced runoff from small Southwest rangeland watersheds results from intense, short-lived thunderstorms of limited areal extent (Osborn and Laursen, 1973). Also, in many cases, an estimate of the distribution of the storm rainfall over the area is important in estimating the runoff from the storm. In a final section of this paper, distribution curves are developed from selected Walnut Gulch and Alamogordo Creek data.

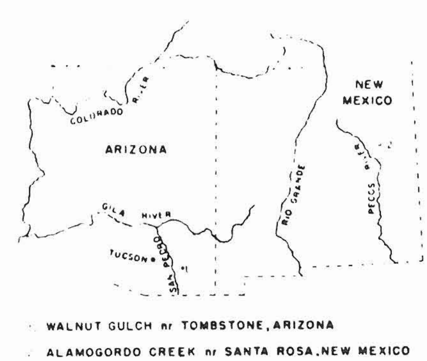

FIG. 2 Location of USDA-SEA-AR experimental watersheds.

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TABLE 1. MAXIMUM ANNUAL RAINFALL FREQUENCIES (mm) ESTIMATED BY FITTING SEVERAL FREQUENCY DISTRIBUTIONS TO 20 YEARS (1957-76) OF DATA FOR WALNUT GULCH

	Log normal			Pearson Type III			Log-Pearson Type III			Gumbel		
	30-min	1-h	2-h	30-min	1-h	2-h	30-min	1-h	2-h	30-min	1-h	2-h
						2-yr						
Basin average	14.0	17.0	18.4	15.0	17.9	19.2	14.8	18.0	19.3	14.1	16.9	18.3
RG #3	21.1	25.0	27.2	22.0	24.7	27.1	21.6	24.8	27.3	21.2	25.2	27.3
RG #33	25.8	29.9	31.2	25.0	29.2	30.6	24.6	28.3	29.8	26.2	30.2	31.5
RG #66	22.7	26.1	28.6	24.0	27.6	29.5	22.8	26.4	28.4	23.1	26.4	28.9
						10-yr						
Basin average	20.9	24.7	25.8	19.5	23.1	24.5	19.9	23.3	24.5	21.1	24.9	26.2
RG #3	32.9	40.0	43.2	31.8	40.3	43.2	32.3	40.2	43.1	34.1	43.4	46.3
RG #33	43.1	49.2	50.8	45.0	51.4	52.7	44.0	50.2	51.8	49.0	55.7	56.9
RG #66	38.4	43.0	47.0	37.3	41.5	46.6	38.2	42.7	47.2	40.3	44.8	50.1
						100-yr						
Basin average	28.9	33.5	34.1	22.4	26.8	28.2	23.0	26.1	27.2	29.8	34.8	36.0
RG #3	47.4	58.6	63.1	40.4	59.2	61.9	42.3	60.9	62.1	50.2	66.0	70.0
RG #33	65.5	50.8	75.5	71.3	79.5	80.1	81.5	93.4	92.8	77.5	87.5	88.7
RG #66	58.9	64.7	70.5	49.5	53.7	63.8	57.1	61.7	72.1	61.7	67.8	76.5

POINT-TO-AREA CURVES

Basic Method

The method used by NWS for developing the point-to-area curves, shown in Fig. 1, was described in detail in U.S. Weather Bureau Technical Paper No. 29 (1958). Briefly, the technique for developing point-to-area curves for a particular duration consisted of the following steps.

1 Annual maximum rainfall amounts were listed by duration for each station in the groups of closely spaced, recording raingages.

2 Similarly, annual maximum rainfall amounts for various durations over areas of several sizes were determined. Areal depths are the average of the gages within the area. These annual maximum areal values did not necessarily occur on the same day as the maximums at individual stations.

3 The same type of frequency distribution was fitted to the annual maximums at each gage and for each area.

4 For a given frequency, the point values within each area were averaged (assuming negligible climatological gradients within the network).

5 The ratios of areal to averaged point values at equal frequencies or return periods defined the point-to-area curve.

Frequency Distribution

The NWS uses the Gunbel extreme value procedure (Gumbel, 1958) for fitting of the Fisher-Tippett Type I distribution for developing rainfall frequency maps and depth-area curves. The choice of this frequency distribution is partly based on work that showed that for the continental United States, this distribution fitted maximum annual point rainfalls fairly well (Hershfield and Kohler, 1960) and was slightly better than some other standard methods used in predicting frequencies for independent samples not used in deriving the curves (Hershfield, 1962). For a limited check on frequency distributions applicable to the data of this study, we fitted Walnut Gulch and Alamogordo Creek basin average and selected station maximum annual storm rainfall with log normal, Pearson Type-III, log Pearson Type-III, and the Gumbel fitting of the Fisher-Tippett Type I frequency distributions, by the method of moments. An illustrative portion of these values for Walnut Gulch are listed in Table 1.

By visually comparing plotted points with computed curves for the several distributions, we concluded that for the data as a whole, the Gumbel distribution seemed to fit best. For this reason and for continuity with previous NWS work, it was selected for this study.

The Gumbel fitting is based on the concept that a series of values, all of which are maximums from independent samples of equal and sufficient size, drawn from the same population (e.g., annual maximum rainfalls), conforms to the probabillity distribution of a dimensionless "reduced variate", y, if suitably scaled. The term y is defined by its probability distribution as:

$$y_{Pr} = -\ln(-\ln Pr) \quad [1]$$

where Pr is the probability that a reduced variate, y, chosen at random, will be less than or equal to the particular value, y_{Pr}. Following an example given by the National Bureau of Standards (1953), this distribution is fitted to a sample of size N of a real variable, X, by assuming the common plotting position formula

$$Pr = \frac{m}{N+1} \quad [2]$$

applies to both y and X, where m is rank from lowest to highest. In principle, a linear regression fit is made to the N pairs, X_m, y_m, where X_m's are from the sample and the y_m's are found by substituting equation [2] into equation [1]. This may be simplified by using precomputed tables, which require only the mean and standard deviation of the X's and the sample size N as input. The steps and tables for the simplified procedure are listed by the World Meteorological Orgainzation (1974).

The relatively small values of some of the annual maximums lead to one additional empirical test. At the same stations in Table 1, we applied the Gumbel fitting of the extreme value distribution to the 20 highest rains, regardless of year of occurence (partical duration series), with the thought in mind that "partial duration" storms in an arid climate might be regarded as extremes for this distribution. However, by visual inspection, use of the partial duration series did not improve the fit compared

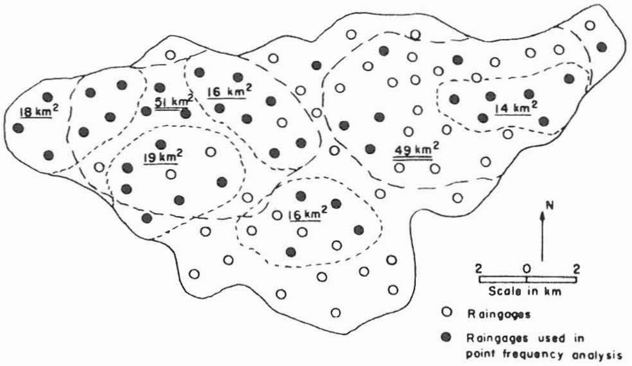

FIG. 3 Recording raingage network and subwatersheds used in determining frequency distributions for Walnut Gulch.

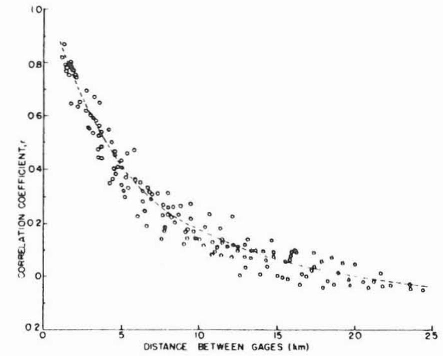

FIG. 4 Correlation coefficients for rainfall amounts for selected pairs of gages on Walnut Gulch.

to the annual series, at least in this case. For this reason, and because the original work was based on annual series, the partial duration series was not used.

Walnut Gulch Curves

Recording raingage records for the period 1957-1976 on and immediately adjacent to the Walnut Gulch Experimental Watershed were used in this study. Gages were added as funds became available through 1965, when the network of 80 gages was completed, as shown in Fig. 3. The 26 gages with a full period of record, are more concentrated on the lower (western) end of the watershed. Therefore, subareas for analysis were chosen mostly on the lower half of the watershed where the records are longest and the gages closest together.

In constructing representative areas (second step of "basic method"), raingages were assumed to represent rainfall within an 0.8 km (one-half-mile) radius. Area outlines were drawn by connecting the imaginary circular areas around each station, tangentially. Areal average rainfalls were obtained by averaging amounts from all existing gages within each area. As gages were added to each area, they were included in the areal average. The raingages were fairly well spaced in most years, so all were given equal weight in averaging areal rainfall. Obviously, the averages are more uncertain in the early years of fewer gages, particularly before 1960. Annual maximum rains were determined for each of 20 years (1957-1976), and the frequency distribution fitted separately for areas of 176, 51, 49, 18, 19, 16, 15, 14 and zero (point) km² (fig. 3), for durations of 30, 60, 120 and 360 min.

Gages used for point frequency comparison to areal values are indicated in Fig. 3. Only gages with no more than 2 yr of missing record were used for this. The few missing years (at 14 of the 40 gages) were filled in by interpolation of annual maximums from adjacent stations. As it turned out, using 20 gages with complete records gives almost the same result as using 40 gages with some estimated record. As stated, there was an uneven distribution of raingages on Walnut Gulch during the early years of record. For better distribution, six of the gages on the lower end of the watershed were omitted in the point analysis comparison with 176 km² area.

The variability of estimating based on point records is illustrated in Table 2. Estimated rainfall amounts for annual series for varying durations and frequencies based on records from 6 raingages were compared. For example, the 100-yr, 1-h rainfall estimate at raingage 33 is about double that of raingage 31. The two gages are only 2 miles apart, and both records are excellent.

As an indicator of the scale of the phenomenon being investigated, correlation coefficients were compared at Walnut Gulch between rains at selected pairs of gages with varying distance between them (Fig. 4). The correlation is for storm depths during 1961-72, when at least one of the two storm gage totals equalled or exceeded 5 mm. No storm had a duration longer tha 2 h. The curve is fitted by eye.

As a check on possible non-random distribution of rainfall on Walnut Gulch, estimated 100-yr, 1-h rainfall amounts were plotted against gage elevation (Fig. 5). The range of values is greater on the lower end of the watershed where there were more gages, but there is certainly no clear evidence of higher or lower average values within the 450 m elevation range on the watershed.

Depth-area curves were constructed through the plotted points (1.0 for zero) for 2-, 10- and 100-yr return periods for durations of 30, 60, 120 and 360 min (Figs. 6-9) by using a method suggested by one of the authors (Myers) for a least squares fit to:

$$r = 1 - M \exp\left[-a\left(\frac{A}{A_o}\right)^{b}\right]^{-1} \quad \text{[3]}$$

TABLE 2. COMPARISON BETWEEN PREDICTED RAINFALL AMOUNTS (mm) FOR ANNUAL SERIES FOR VARYING DURATIONS AND FREQUENCIES USING SIX DIFFERENT STATION RECORDS ON WALNUT GULCH

	2-yr			10-yr			100-yr		
	30-min	1-h	2-h	30-min	1-h	2-h	30-min	1-h	2-h
RG #1	21.8	25.4	26.8	37.3	50.1	55.0	56.5	80.9	90.2
RG #33	26.2	30.2	31.5	49.0	55.7	56.9	77.5	87.5	88.7
RG #66	23.1	26.4	28.9	40.3	44.8	50.1	61.7	67.8	76.5
RG #3	21.2	25.2	27.3	34.1	43.4	46.3	50.2	66.0	70.0
RG #31	19.9	22.1	23.2	30.5	33.5	34.8	43.8	47.6	48.7
RG #70	23.2	28.6	32.3	39.6	49.2	57.6	59.8	74.9	89.4

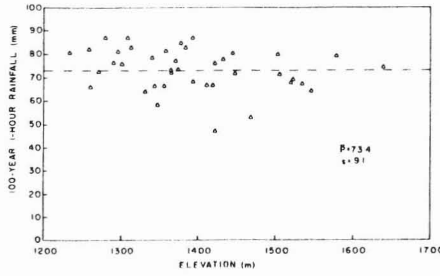

FIG. 5 Comparison of estimates of 100-yr, 1-h rainfall amounts with elevation for selected raingages on Walnut Gulch.

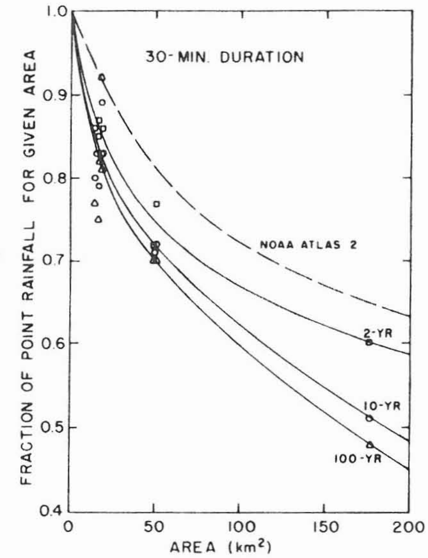

FIG. 6 Point-to-area conversion ratios for 30-min duration rainfalls for selected frequencies on Walnut Gulch.

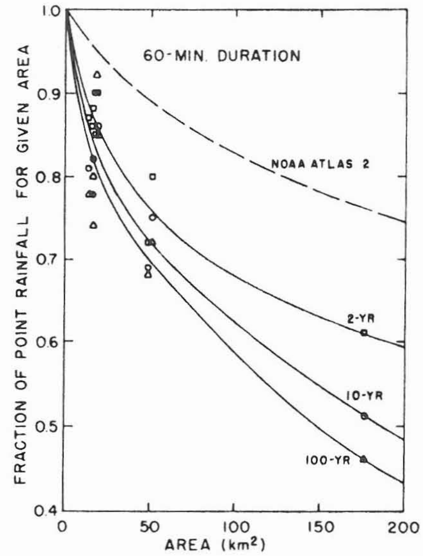

FIG. 7 Point-to-area conversion ratios for 60-min duration rainfalls for selected frequencies on Walnut Gulch.

where r is depth-area ratio for area A in km², A_o is a unit area of 1 km², and M, a, and b are fitting constants. The curves were extrapolated to 200 km², reasonable limit based on available data. The curves lie well below the NOAA Atlas 2 curves, show more change with frequency, and show less change with duration.

To highlight the change with the duration, the 2- and 100-yr event curves from Figs. 6-9 are replotted together on Fig. 10. The difference between the 30-, 60- and 120-min curves for a given frequency are small, and could be due to sampling variation. However, there are real differences between the families of curves of the 2-yr and 100-yr events. Clearly, the curves are consistent with features of summer thunderstorm rain in southwestern Arizona with the following characteristics: (a) the airmass thunderstorms are of short duration and limited areal extent, and (b) the extreme events tend to be confined to about the same areal extent as lesser events. Thus, up to about 2 h, depth-area ratios do not increase with duration. When storms move and deposit their heaviest precipitation some distance apart in succeeding h, area-point differences necessarily are reduced with increasing duration. The NOAA Atlas 2 depth-area curves reflect this characteristic. Many storms move fairly rapidly across the Walnut Gulch watershed, but these fast-moving events do not produce the maximum annual events. In the case of Walnut Gulch, the curves for respectively longer return periods plot below shorter return periods, because the standard deviation, which is most influential on the longer return periods in the Gumbel method, is less for the watershed averages than for point values.

Based on topography, the similarity of point rainfall frequencies, subjective experiences in observing thunderstorms, and qualitative confirmation from a few small watershed networks (with less record than Walnut

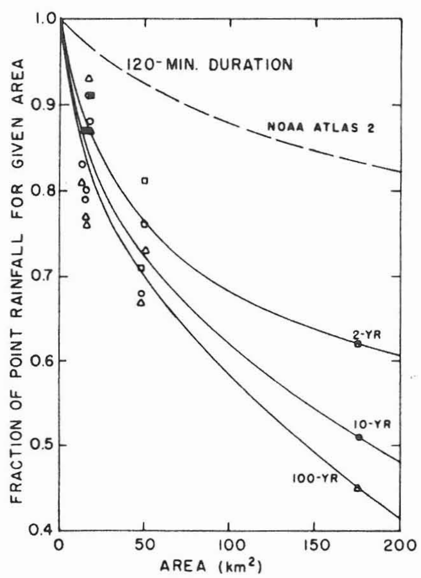

FIG. 8 Point-to-area conversion ratios for 2-h duration rainfalls for selected frequencies on Walnut Gulch.

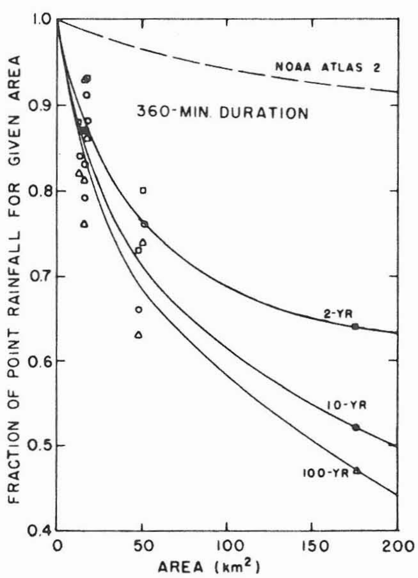

FIG. 9 Point-to-area conversion ratios for 6-h duration rainfalls for selected frequencies on Walnut Gulch.

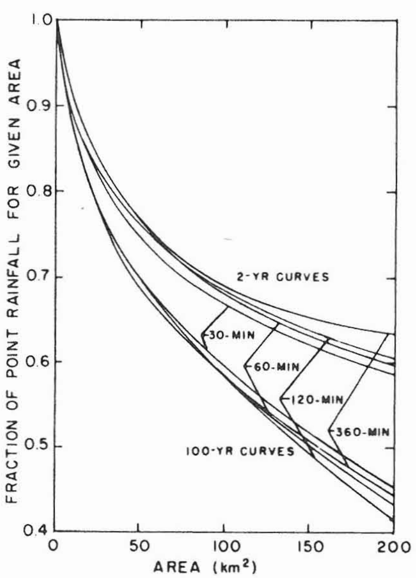

FIG. 10 Comparison of point-to-area rainfall ratios for 2-yr and 100-yr events for Walnut Gulch.

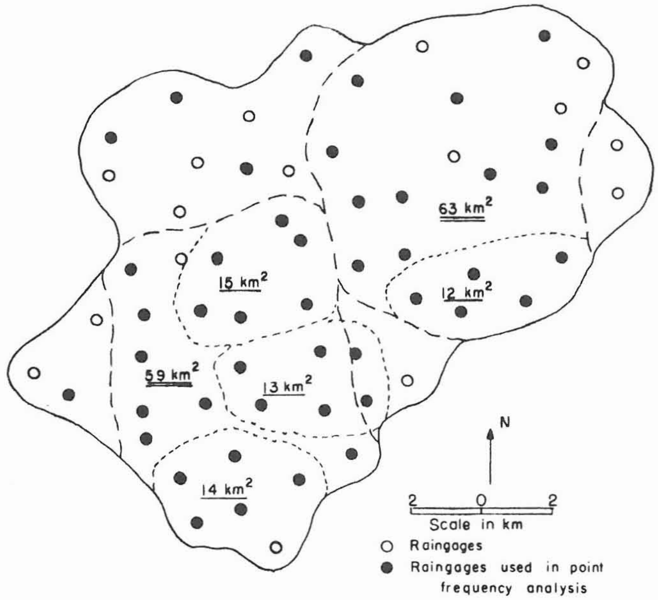

FIG. 11 Recording raingage network and subwatersheds used in determining frequency distributions for Alamogordo Creek.

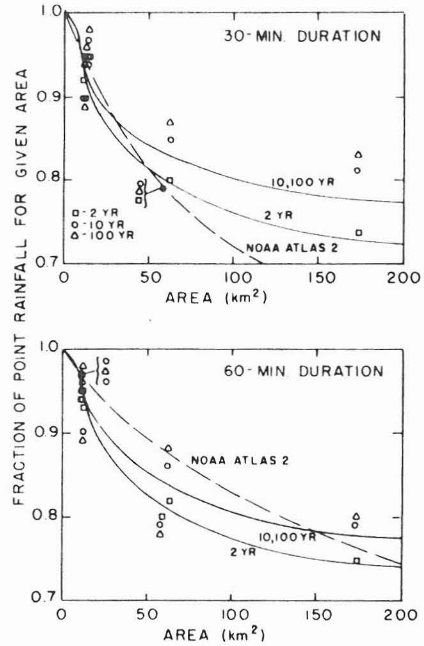

FIG. 12 (top) Point-to-area conversion ratios for 30-min duration rainfalls for selected frequencies on Alamogordo Creek.

FIG. 13 (bottom) Point-to-area conversion ratios for 60-min duration rainfalls for selected frequencies on Alamogordo Creek.

Gulch), the depth-area curves for Walnut Gulch are believed to be characteristic of much of southwestern Arizona, southwestern New Mexico, and north central Mexico.

Alamogordo Creek

The Alamogordo Creek Watershed data were analized identically to that for Walnut Gulch for 174, 59, 63, 15, 12, 13, 14 and 0 km² areas. The network is depicted in Fig. 11 along with the sub-areas. The average values were derived from all gages within the respective boundaries. Twenty-one well spaced gages with complete 20-yr records (1957-1976) were used to develop point frequencies for comparison to the 174 km² area, and all the indicated gages for the sub-area comparisons. For the latter, the same rules and procedures were used as for Walnut Gulch. In this case, the computed 100-yr depth-area curve lay above the 10-yr curve, but the difference was so slight that its reality is uncertain, and the 10-yr and 100-yr curves have been combined. The resulting depth-area curves are in Figs. 12-15.

The amounts and distributions of thunderstorm rainfall on the Alamogordo Creek Watershed are typical of the high plains in eastern New Mexico and western Texas. The extreme events can occur from either pure air-mass thunderstorms (as on Walnut Gulch) or a combination of frontal activity and convective heating (which is unusual on Walnut Gulch). The rainfalls that are largest both in area covered and depth result from the latter situation. Because of this, for similar durations and frequencies, maximum rainfall on Alamordo Creek is about 10 to 15 mm greater than that on Walnut Gulch.

The major events on Alamogordo Creek also cover larger areas than those on Walnut Gulch, and depth-area ratios were considerably higher than those on Walnut Gulch. Infact, for a 30-min duration the depth-area curve from NOAA Atlas 2 lies generally below the Alamogordo Creek curves (Fig. 12). For longer durations, Alamordo Creek curves decreased more rapidly than the NOAA Atlas 2 curves to a maximum difference at about 80 km², and then they approach the NOAA Atlas 2 curves. The range of annual average maximum watershed rainfall amounts varies much more on Alamogordo Creek than on Walnut Gulch because of the occasional massive frontal convective event. Average watershed rainfall was more variable than average point rainfall or area-to-point depth-area ratios for longer

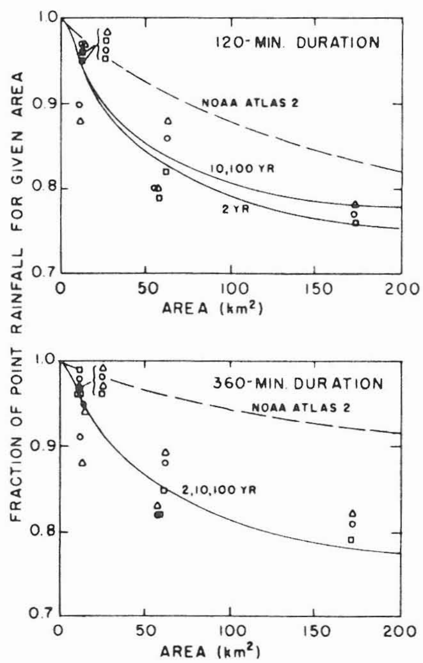

FIG. 14 (top) Point-to-area conversion ratios for 2-h duration rainfalls for selected frequencies on Alamogordo Creek.

FIG. 15 (bottom) Point-to-area conversion ratios for 6-h duration rainfalls for selected frequencies on Alamogordo Creek.

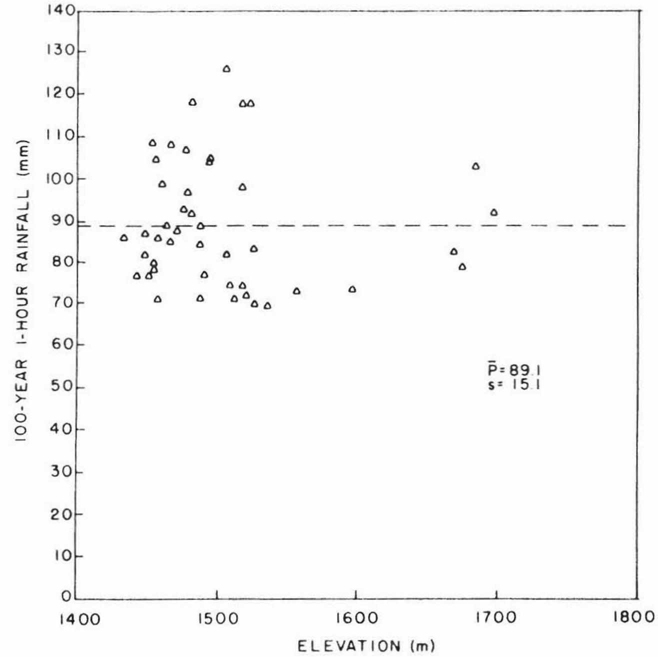

FIG. 16 Comparison of estimates of 100-yr, 1-h rainfall amounts with elevation for selected raingages on Alamogordo Creek.

return periods were greater than for shorter return periods.

Estimated 100-yr, 1-h rainfall amounts were plotted against gage elevation as a check on the assumption of random rainfall distribution on Alamogordo Creek (Fig. 16). Again, the range of values is greater at the lower elevations where there were more gages, but there is certainly no clear evidence of higher or lower values within the 300 m elevation range on the watershed.

DISTRIBUTION OF STORM RAINFALL

Once the engineer or hydrologist has determined the average watershed rainfall from the point frequency value and depth-area curve, there is still the question of the distribution of rainfall within the watershed during the storm. This is needed for runoff prediction based on the precipitation. For example, the 100-yr, 1-h rainfall at a fixed point within a watershed is significantly less than the largest 1-h rainfall expected once in 100 years somewhere within that watershed. Curves were developed from the Walnut Gulch and Alamogordo Creek raingage records for 50- and 150-km² watersheds to indicate this maximum as well as the watershed rainfall distribution in terms of the fraction of the watershed covered by percentages of the basic average (Figs. 17 and 18). The curves are averaged from the five storms on each basin with the largest total storm average basin rainfall in 20 yr. The curves do not necessarily apply to lesser storms expected on the average more often than once in about 5 yr.

As examples of the application of the curves for Walnut Gulch, the 100-yr, 1-h point rainfall averaged over the 40 stations in Fig. 3 is 75 mm (from tabulation not shown). From Fig. 7, the corresponding depth-area ratio for 150 km² is 0.50—average watershed rainfall would be about 38 mm. From Fig. 17, the maximum rainfall at some point within the watershed would be about 110 mm, and only 40 percent of the watershed would be covered by 38 mm or more of rainfall. Similarly, the 100-yr, 1-h point rainfall for Alamogordo Creek is about 90 mm. From Fig. 13, the depth-area ratio is 0.78—the average watershed rainfall is 70 mm. From Fig. 18, the maximum point rainfall at some point within the watershed would be about 140 mm, and about 40 percent of the watershed would be covered by 70 mm of rainfall or more. Similar curves were developed for rainfall distributions with 50 km² basins and are shown on Figs. 17 and 18.

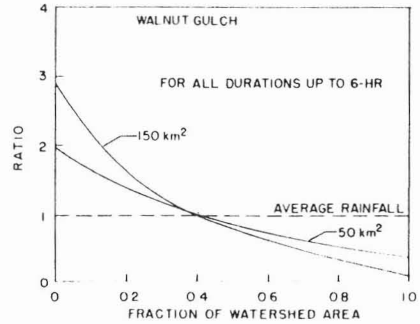

FIG. 17 Fraction of watershed equal to or exceeding average storm rainfall for Walnut Gulch.

The storms, from which Figs. 17 and 18 are derived, are in the 5- to 25-yr return period range. Based on 20 yr of record, it appears the curves would not be greatly different for 100-yr basin averages for Alamogordo Creek; whereas, Fig. 10 implies that the curves would be slightly steeper for the 100-yr return period at Walnut Gulch.

SUMMARY

New depth-area conversion curves for adjusting point rainfall amounts for given frequencies values to areal averages were developed from 20 years' data from densely spaced recording raingages on experimental watersheds of the USDA Southwest Rangeland Watershed Research Center in two climatic zones in the semi-arid Southwest. In southeast Arizona, at Walnut Gulch, the reductions from point-to-area were significantly greater than previously published curves, based on nationwide averages. These results offer opportunities for economy in design without relaxing frequency standards in climatologically similar areas. This is consistent with known limited area characteristics of the air-mass thunderstorms that produce most of the runoff.

New curves at Alamogordo Creek in northeastern New Mexico departed less from previous curves, but still indicate significant differences. The maximum departure of the new curves from the previous curves occurred at an area of approximately 100 km². The significant differences between Alamogordo Creek and Walnut Gulch

(Continued on page 91)

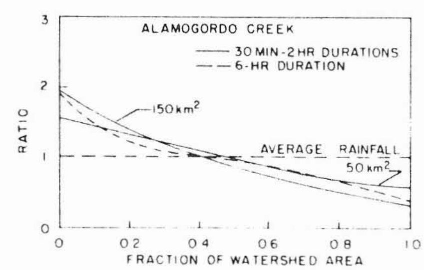

FIG. 18 Fraction of watershed equal to or exceeding average storm rainfall for Alamogordo Creek.

(Continued from page 87)

illustrate the influence of frontal storms with strong convective activity associated with cold air-mass invasions from the north and east into eastern New Mexico.

Curves were also developed indicating maximum expected rainfall and typical areal distributions of rainfall depths during major precipitation events for 50- and 150-km^2 watersheds. This is neccessary information, along with the revised point-to-area curves, to realistically predict small watershed runoff from precipitation.

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APPENDIX 1-D

PREFRE Program disk and Users' Manual (U.S. Bureau of Reclamation, 1988)

* P R E F R E *

COMPUTATION OF PRECIPITATION FREQUENCY-DURATION VALUES

IN THE WESTERN UNITED STATES

PROGRAM USER MANUAL

FLOOD SECTION
SURFACE WATER BRANCH
EARTH SCIENCES DIVISION
BUREAU OF RECLAMATION

DENVER, COLORADO

AUGUST 1988

USER MANUAL FOR PROGRAM PREFRE

--

COMPUTATION OF PRECIPITATION FREQUENCY-DURATION VALUES IN THE WESTERN UNITED STATES

1. Introduction.

The PREFRE computer program was written to compute the precipitation frequency values for each of 10 durations and for each of 7 return periods. This document describes how to prepare the input data, how to execute the program, and gives an example of the output.

The PREFRE program computes frequency values for 5-, 10-, 15-, and 30-minute and 1-, 2-, 3-, 6-, 12-, and 24-hour durations for return periods of 2, 5, 10, 25, 50, 100, and 500 years for areas in the 11 western states and presents the results in tabular form. It uses as input the precipitation frequency values taken from the NOAA Atlas 2 (11 volumes). The PREFRE program also duplicates the values in Weather Bureau Technical Paper No. 40 for the six Plains states within the Bureau's area of operations not included in the NOAA Atlas 2 volumes.

NOAA Atlas 2 reflects the effects of topography on precipitation frequencies, but it contains isohyetal maps for return periods of 2, 5, 10, 25, 50, and 100 years but only for 6- and 24-hour durations. For other durations, it is necessary to use the nomograms and equations included in the atlas.

The computer program was originally developed by Mr. Ralph Frederick, Office of Hydrology, NWS (National Weather Service). The program was extensively revised to fit Bureau of Reclamation needs in 1975 by Mr. James Mumford of what was then the Flood and Sedimentation Section, Engineering and Research Center. It was further revised in 1988 by Mr. Richard Eddy of the Flood Section to incorporate updated information for short-duration values.

The program is written in FORTRAN V for the Bureau's CYBER mainframe computer. This version has also been converted to FORTRAN 77 for use with personal computers (IBM compatible).

2. Input Data.

The following data are required for the program input file:

a. Site name.

b. Primary zone number identifying where the site is located, obtained from the map included as appendix A in this manual. The zone boundaries correspond to those found in NOAA Atlas 2, but the numbers may be different. It is advisable to identify the location of a site from the zone map in the atlas volume and refer to appendix A for the zone number used in PREFRE.

c. Zone number for short-duration values (appendix B).

d. Site latitude and longitude (required for <u>primary</u> zones 3, 9, and 11; optional for other primary zones).

e. Site elevation (required for <u>primary</u> zones 1, 2, and 6; optional for other primary zones).

f. NOAA Atlas 2 precipitation values (note that Atlas values are in tenths of inches).

(1) Standard: Enter the values of 2-year and 100-year return periods for durations of 6 hours and 24 hours.

(2) Option: The original NWS program was designed to input 12 precipitation frequency values. This format has been retained as an option. The 2-, 5-, 10-, 25-, 50-, and 100-year values for durations of 6 hours and 24 hours must be used as input for this option. The program uses the six return-period values and develops a line of best fit to the points read from the NOAA Atlas 2 maps. It then uses this line of best fit to recompute the return-period values and uses these computed values in all subsequent computations.

The input data format is presented in appendixes C1 through C3. Each field in a line must be separated from the next field by either a blank or a comma, and an entry is required for each field (i.e., enter zeroes if latitude, longitude, and elevation are omitted). Input data can be all metric, if desired.

3. <u>Output Data</u>.

The site name, zone numbers, and latitude, longitude, and elevation (if included in the input data) are printed as a heading. A table is then given showing the precipitation values for 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods for durations of 5, 10, 15, and 30 minutes and 1, 2, 3, 6, 12, and 24 hours. Output units are the same as the input units. The PC version also prints the input data for reference. Appendix D1 is a sample output from the CYBER version of PREFRE. Appendix D2 is the standard PC output. Appendix D3 is the output when the site is in primary zone 7; it prints a note regarding revised depth-area values for Arizona and New Mexico. Appendix D4 is the output when the option to input 12 precipitation values is selected.

4. <u>Program Execution</u>.

Execution of program PREFRE depends on the computer system being used. Appendix E describes the steps of execution for both the Bureau of Reclamation CYBER mainframe and the IBM PC/AT and compatibles.

Sometimes the site will be very near the boundary between two zones, a situation in which a weighting of calculated frequency values among neighboring zones may provide a more appropriate answer. In these cases, it can be helpful to make more than one run, using the neighboring zone's values. Edit the input file to change the zone number (and other data as needed) and re-run the program.

5. <u>Method of Derivation</u>.

The program follows procedures outlined in NOAA Atlas 2 to derive the precipitation frequency values. The 2-year and 100-year input figures for 6-hour and 24-hour durations are used to derive these same return frequency values for 1-, 2-, and 3-hour durations. The relationships among the 6-hour and 24-hour values and the 1-, 2-, and 3-hour values were determined by the NWS and are dependent on the zone in which the site is located. The 12-hour values are derived by taking the midpoint between the 6-hour and 24-hour input values for the 2-year and 100-year return periods. The 5-, 10-, 15-, and 30-minute duration values for 2-year and 100-year events are determined by multiplying the 1-hour values by a set of factors. These factors are dependent on the short-duration zone in which the site is located. <u>It is important to note that the short-duration zones are different from the primary (longer duration) zones</u>. The program then computes the values for the remaining return periods by fitting the precipitation values to a Gumbel distribution. The 2-year values for all durations are first adjusted from a partial duration series (input values) to an annual series. Then the 5-, 10-, 25-, 50-, and 500-year frequency values for all durations are calculated from their respective relationship to the 2-year and 100-year values in a Gumbel distribution. The 2-, 5-, and 10-year values are then converted back to a partial duration series, which correspond to the NOAA Atlas 2 map values. All output values are for point locations.

NOTE: Areal values of precipitation frequency are often needed. Because program PREFRE does not provide this information, it is necessary to follow the procedure found in the appropriate NOAA Atlas 2 volume. When areal values are required for Arizona and New Mexico, use the information found in the 1984 NOAA Technical Memorandum NWS HYDRO-40.

6. Comments.

It was decided in 1975 to change the program from the procedure originally used by the NWS to a more simplified approach using only the four key precipitation values for input. This allows for quicker setup of the input data and facilitates the use of the program. No loss of accuracy in the calculated values occurs as the 2-year 6-hour, 2-year 24-hour, 100-year 6-hour, and 100-year 24-hour maps are the key maps initially derived in the NWS studies. The maps in NOAA Atlas 2 for return periods of 5, 10, 25, and 50 years were derived from the 2- and 100-year maps in the same manner that the PREFRE program computes these values.

In the original program, only one set of national factors was used to determine 5-min to 30-min values from 1-hour values. Papers by Fredrick and Miller and Arkell and Richards presented sets of factors that depended on the location of the site. These values were used for sites west of the 105th meridian; the old factors were retained for the Plains states east of the 105th meridian.

The 1975 version of the program allowed the user to specify two zones in the event that the site was near a zonal boundary. The current version does not offer that option because two types of zones (the original long-duration zone and the new short-duration zone) are now required and major revisions to the program would be required to accommodate various combinations of multiple runs. The only way to get runs for two adjacent zones is to edit the input file after the first run (a quick and simple procedure) and execute the program again.

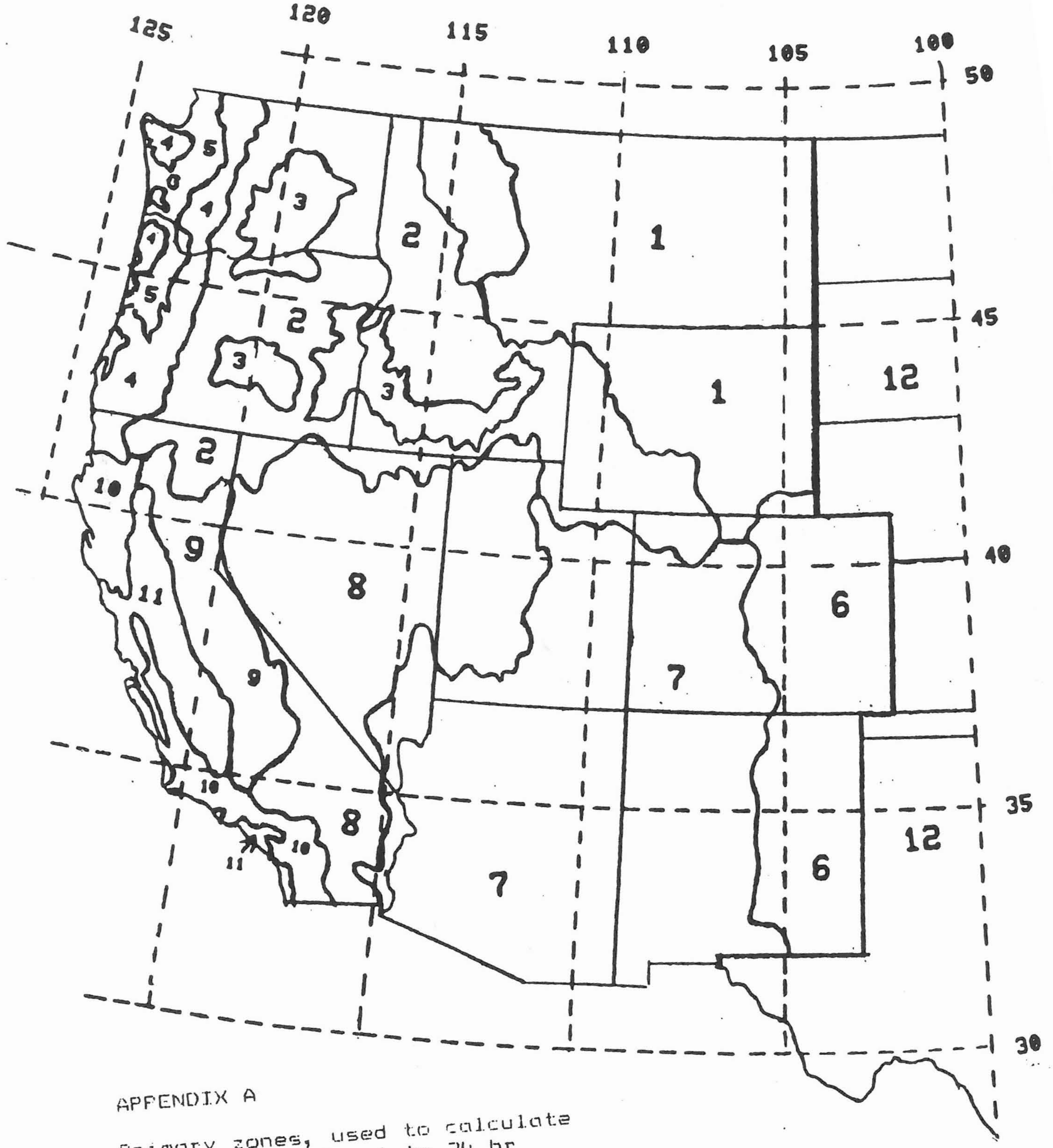
7. References.

Arkell, R. E., and F. Richards, "Short Duration Rainfall Relations for the Western United States," Preprint, Conference on Climate and Water Management-A Critical Era and Conference on the Consequences of 1985's Climate, August 4-7, 1986, Asheville, NC, Amer. Meteorol. Soc., Boston, 1986.

Frederick, R. H., and J. F. Miller, "Short Duration Rainfall Frequency Relations for California," Preprint, Third Conference on Hydrometeorology, August 20-24, 1979, Bogota, Colombia, Amer. Meteorol. Soc., Boston, 1979.

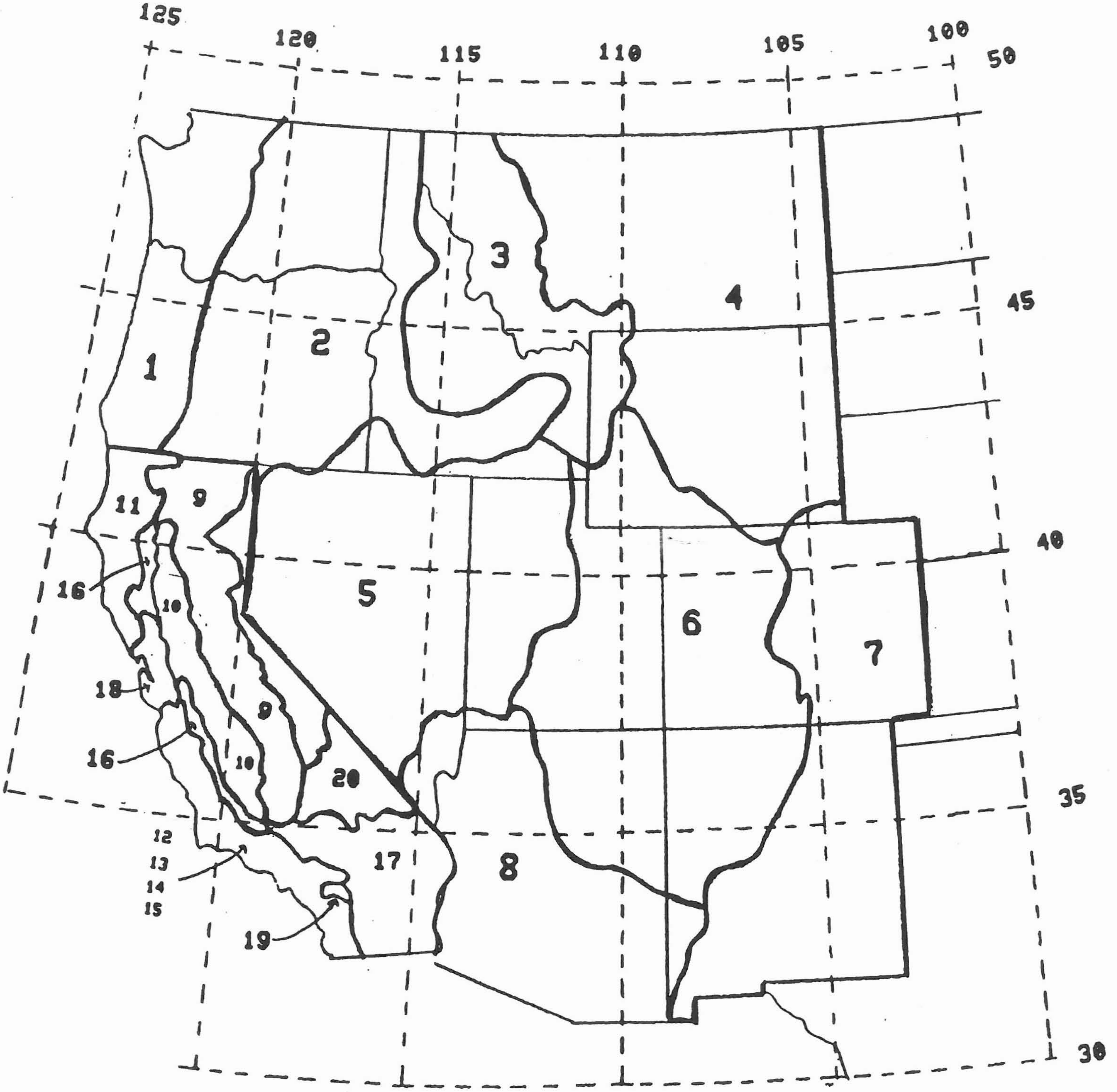
Miller, J. F., R. H. Frederick, and R. J. Tracy, "NOAA Atlas 2 - Precipitation-Frequency Atlas of the Western United State," 11 volumes, National Weather Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, Silver Spring, Maryland, 1973.

Zehr, R. M., and V. A. Myers, "Depth-Area Ratios in the Semi-Arid Southwest United States," NOAA Technical Memorandum NWS HYDRO-40, Office of Hydrology, National Weather Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, Silver Spring, Maryland, August 1984.



APPENDIX A

Primary zones, used to calculate precipitation for 1 to 24 hr durations. Zone boundaries are identical to those in NOAA Atlas 2, but zone numbers may differ.



APPENDIX B

Short-duration zones, used to calculate 5 to 30 min durations.

APPENDIX C1

INPUT FORMAT - FOUR PRECIPITATION VALUES

Line 1:
Field 1. Title of study or site name, up to 32 characters

Line 2 (fields separated by blanks or commas):
Field 1. Primary zone number (appendix A)
Field 2. Short-duration zone number (appendix B) *
Field 3. Latitude, degrees and decimals (or 0)
Field 4. Longitude, degrees and decimals (or 0)
Field 5. Elevation (or 0)
Field 6. 0 (number zero)

Line 3 (fields separated by blanks or commas):
Field 1. 2-yr 6-hr precipitation value from NOAA Atlas 2
Field 2. 100-yr 6-hr precipitation value
Field 3. 2-yr 24-hr precipitation value
Field 4. 100-yr 24-hr precipitation value

Line 4 (optional):
Field 1. ENDRUN (alpha characters)

NOTE: Actual latitude and longitude values are required for sites in primary zones 3, 9, and 11, and elevation data are required for sites in primary zones 1, 2, and 6. For other primary zones, enter either zeroes or the latitude, longitude, and elevation values. Elevation may be entered in meters, if precipitation is also metric.

* Short-duration zones 12 through 15 are all for the Southern Pacific Coast. Zone 12 is for sites with elevation greater than 700 ft. Zone 13 is for sites with elevation between 500 and 700 ft. Zone 14 is for sites with elevation less than 500 ft. Zone 15 represents an average of all elevations within the boundaries of the Southern Pacific Coast.

APPENDIX C2

INPUT FORMAT - TWELVE PRECIPITATION VALUES

Line 1: same as for four precipitation values

Line 2:
Fields 1 through 5: same as for four precipitation values
Field 6. 2

Line 3:
Field 1. 2-yr 6-hr precipitation value from NOAA Atlas 2
Field 2. 5-yr 6-hr precipitation value
Field 3. 10-yr 6-hr precipitation value
Field 4. 25-yr 6-hr precipitation value
Field 5. 50-yr 6-hr precipitation value
Field 6. 100-yr 6-hr precipitation value
Field 7. 2-yr 24-hr precipitation value
Field 8. 5-yr 24-hr precipitation value
Field 9. 10-yr 24-hr precipitation value
Field 10. 25-yr 24-hr precipitation value
Field 11. 50-yr 24-hr precipitation value
Field 12. 100-yr 24-hr precipitation value

Line 4 (optional):
Field 1. ENDRUN (alpha characters)

APPENDIX C3

SAMPLE INPUT - FOUR PRECIPITATION VALUES

Fields separated by blanks

```
QUARTZ HILL, COLORADO
6 7 39.80 105.52 8900 0
1.19 2.85 1.78 4.21
ENDRUN
```

Fields separated by commas

```
LEADVILLE, COLORADO
7,6,39.27,106.31,0,0
.79,1.85,1.00,2.79
ENDRUN
```

SAMPLE INPUT - 12 PRECIPITATION VALUES

```
KUTCH (NW), COLORADO
7 6 39.00 104.00 6100 2
1.04 1.20 2.00 2.25 2.40 2.50 1.39 1.75 1.90 2.25 2.60 3.30
ENDRUN
```

APPENDIX D1

SAMPLE OUTPUT - CYBER

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR QUARTZ HILL, COLORADO
PRIMARY ZONE NO.= 6 SHORT-DURATION ZONE NO.= 7
LATITUDE 39.80N LONGITUDE 105.52W ELEVATION 8900 FEET

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.26	.34	.39	.47	.53	.59	.73	5-MIN
10-MIN	.40	.53	.62	.74	.84	.93	1.16	10-MIN
15-MIN	.48	.66	.78	.94	1.07	1.20	1.49	15-MIN
30-MIN	.65	.90	1.06	1.29	1.47	1.65	2.05	30-MIN
1-HR	.78	1.09	1.30	1.59	1.81	2.03	2.54	1-HR
2-HR	.92	1.26	1.50	1.82	2.06	2.31	2.88	2-HR
3-HR	1.03	1.39	1.64	1.99	2.25	2.52	3.13	3-HR
6-HR	1.19	1.60	1.87	2.26	2.55	2.85	3.53	6-HR
12-HR	1.49	1.98	2.32	2.80	3.16	3.53	4.37	12-HR
24-HR	1.78	2.37	2.78	3.34	3.78	4.21	5.21	24-HR

INPUT DATA

PROJECT NAME-QUARTZ HILL, COLORADO
ZONE- 6 SHORT-DURATION ZONE- 7
LATITUDE= 39.80 LONGITUDE= 105.52 ELEVATION= 8900
2-YR, 6-HR PCPN- 1.19 100-YR, 6-HR PCPN= 2.85
2-YR, 24-HR PCPN= 1.78 100-YR, 24-HR PCPN= 4.21

```
AAAAAAAAAAAAAA
A            A
A END OF RUN A
A            A
AAAAAAAAAAAAAA
```

APPENDIX D2

SAMPLE OUTPUT - PC

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR QUARTZ HILL, COLORADO
PRIMARY ZONE NUMBER= 6
SHORT-DURATION ZONE NUMBER= 7

LATITUDE 39.80N   LONGITUDE 105.52W   ELEVATION 8900 FEET

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.26	.34	.39	.47	.53	.59	.73	5-MIN
10-MIN	.40	.53	.62	.74	.84	.93	1.16	10-MIN
15-MIN	.48	.66	.78	.94	1.07	1.20	1.49	15-MIN
30-MIN	.65	.90	1.06	1.29	1.47	1.65	2.05	30-MIN
1-HR	.78	1.09	1.30	1.59	1.81	2.03	2.54	1-HR
2-HR	.92	1.26	1.50	1.82	2.06	2.31	2.88	2-HR
3-HR	1.03	1.39	1.64	1.99	2.25	2.52	3.13	3-HR
6-HR	1.19	1.60	1.87	2.26	2.55	2.85	3.53	6-HR
12-HR	1.49	1.98	2.32	2.80	3.16	3.53	4.37	12-HR
24-HR	1.78	2.37	2.78	3.34	3.78	4.21	5.21	24-HR

INPUT DATA

PROJECT NAME=QUARTZ HILL, COLORADO
ZONE= 6   SHORT-DURATION ZONE= 7
LATITUDE= 39.80   LONGITUDE= 105.52   ELEVATION= 8900
2-YR, 6-HR PCPN= 1.19   100-YR, 6-HR PCPN= 2.85
2-YR, 24-HR PCPN= 1.78   100-YR, 24-HR PCPN= 4.21

* * * * E N D   O F   R U N * * * *

APPENDIX D3

SAMPLE OUTPUT - PC (PRIMARY ZONE 7)

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR LEADVILLE, COLORADO
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 6

LATITUDE 39.27N   LONGITUDE 106.31W   ELEVATION 10200 FEET

POINT VALUES

DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
				RETURN PERIOD				
5-MIN	.20	.26	.30	.36	.41	.45	.56	5-MIN
10-MIN	.31	.41	.47	.57	.64	.71	.88	10-MIN
15-MIN	.37	.50	.58	.70	.79	.88	1.09	15-MIN
30-MIN	.48	.64	.75	.91	1.03	1.15	1.43	30-MIN
1-HR	.58	.78	.92	1.12	1.27	1.42	1.77	1-HR
2-HR	.65	.87	1.03	1.24	1.40	1.57	1.94	2-HR
3-HR	.70	.93	1.09	1.32	1.49	1.66	2.06	3-HR
6-HR	.79	1.05	1.22	1.47	1.66	1.85	2.29	6-HR
12-HR	.89	1.25	1.49	1.81	2.07	2.32	2.90	12-HR
24-HR	1.00	1.45	1.75	2.16	2.48	2.79	3.52	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=LEADVILLE, COLORADO
ZONE= 7   SHORT-DURATION ZONE= 6
LATITUDE= 39.27   LONGITUDE= 106.31   ELEVATION=10200
2-YR, 6-HR PCPN= .79   100-YR, 6-HR PCPN= 1.85
2-YR, 24-HR PCPN= 1.00   100-YR, 24-HR PCPN= 2.79

* * * * E N D   O F   R U N * * * *

APPENDIX D4

SAMPLE OUTPUT - PC (12 PRECIP VALUES)

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR KUTCH (NW), COLORADO
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 6

OPTION NUMBER 2 --- INPUT OF 12 PRECIP VALUES
LATITUDE 39.00N   LONGITUDE 104.00W   ELEVATION 6100 FEET

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.29	.40	.47	.57	.65	.72	.90	5-MIN
10-MIN	.45	.61	.73	.89	1.01	1.13	1.41	10-MIN
15-MIN	.54	.75	.90	1.09	1.25	1.40	1.75	15-MIN
30-MIN	.68	.97	1.16	1.42	1.63	1.83	2.30	30-MIN
1-HR	.82	1.18	1.42	1.75	2.01	2.26	2.84	1-HR
2-HR	.91	1.28	1.53	1.87	2.14	2.40	3.01	2-HR
3-HR	.96	1.34	1.60	1.95	2.22	2.49	3.12	3-HR
6-HR	1.06	1.46	1.73	2.10	2.38	2.67	3.33	6-HR
12-HR	1.17	1.58	1.86	2.25	2.56	2.86	3.55	12-HR
24-HR	1.28	1.71	2.00	2.41	2.73	3.05	3.78	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=KUTCH (NW), COLORADO
ZONE= 7   SHORT-DURATION ZONE= 6
LATITUDE= 39.00   LONGITUDE= 104.00   ELEVATION= 6100
12-VALUE PRECIPITATION OPTION
PRECIPITATION VALUE:

1.04	1.20
2.00	2.25
2.40	2.50
1.39	1.75
1.90	2.25
2.60	3.30

* * * * E N D OF R U N * * * *

APPENDIX E

EXECUTION OF PROGRAM PREFRE

CYBER

The following steps are used to execute program PREFRE on the Bureau of Reclamation CYBER mainframe computer:

1. Create an input file, using any convenient name, following the format presented in appendix C. This becomes a permanent file on the CYBER. Purge it when it is no longer needed.

2. Enter OLD,PREFREB [the binary (executable) form]
   then GET,INPUT=your input file name
   then PREFREB

3. The output information is sent to the screen. It can also be printed; use the procedures appropriate for the hardware available to you.

Personal Computer

PREFRE is the executable version of the program. It may be stored on the hard disk or it may be on a floppy disk. The following steps are used to execute the program on an IBM PC/AT or compatible (a FORTRAN compiler must be available on the particular PC being used):

1. Create an input file, using any convenient name, following the format presented in appendix C. This is a permanent file on the hard disk or floppy disk.

2. For hard disk, enter PREFRE filename1 filename2
   (e.g., PREFRE PREIN1 PREOUT1)
   For floppy disk, enter A:PREFRE filename1 filename2
   (e.g., A:PREFRE A:PREIN1 A:PREOUT1)

   Filename1 (including device ID and name extension) is the name of your input file and filename2 (including device ID and name extension) is the name of the file you wish the output information written. Either or both files may be on the hard disk or they may be on a floppy disk in device A. If they are on a floppy disk, the filename must be preceded by A:. The output file will be created by the program. If you fail to enter the file names at this point, the program will prompt you to enter those names. Messages will appear on the screen, but the output data are written to the file.

3. Enter PRINT filename2

APPENDIX E (continued)

The output data will be listed at the printer. If you directed the output file to be written to the floppy disk (in device A), enter PRINT A:filename2. The output file is also a permanent file on the hard disk or floppy disk.

APPENDIX 1-E

Documentation on meeting with the U.S. Army Corps of Engineers, Los Angeles District, September 1988

GEORGE V. SABOL Ph.D., P.E.
1351 EAST 141st AVENUE
BRIGHTON, COLORADO 80601
(303) 457-0989

12 August 1988

Mr. John T. Pedersen, P.E.
U.S. Army Corps of Engineers
Los Angeles District
P.O. Box 2711
Los Angeles, California 90053-2325

Subject: Maricopa County Hydrology Manual

Dear John:

We are progressing with our efforts to develop a Maricopa County Hydrology Manual and Joe Rumann of the Flood Control District of Maricopa County and I have recently been concentrating on the design rainfall criteria. This rainfall criteria will consist of three items: 1) depth-duration-frequency information, 2) depth-area reduction factors, and 3) time distribution(s) of rainfall. The Flood Control District is planning to conduct a study to analyze regional rainfall data to update the available rainfall information, and the Arizona Department of Transporation (ADOT) is also planning a similar study for the entire state of Arizona. These two studies may be conducted independently or depending upon potential agreements for the scope of the analyses and funding the two studies could be consolidated into one project. However, whatever is the final outcome of these potential studies it will probably be at least 2 to 3 or more years before such results would be available for our use in the Hydrology Manual. Therefore, at this time we need to select design rainfall criteria for use in Maricopa County rather than rely on these future studies.

We are currently using the following guidelines in selecting rainfall criteria:

1. The criteria describes, to the best of our understanding, the actual rainfall characteristics that we believe are representative of flood producing storms in Maricopa County. For example, if 24-hour storms are not critical flood producing events then we should not select a 24-hour time distribution.
2. The selected criteria should have the consensus agreement of the regional experts in this area. Accordingly, we will coordinate with the hydrologists and hydraulic engineers of the primary agencies that deal with flooding in Arizona. This will include the Los Angeles District Corps of Engineers, Soil Conservation Service in Phoenix, Agricultural Research Service in Tucson, Arizona Department of

Transportation, Arizona Transportation Research Center, and selected individuals

3. The criteria is to be available in the literature or engineering reports and will not require extensive data analysis or original development. Some slight adjustment or modification of available information will be allowed.

We have tenatively selected NOAA Atlas 2 for the depth-duration-frequency criteria, and the depth-area reduction relations that are presented by Osborn, Lane, and Myers (1980). A copy of the depth-area reference is enclosed for your review. Incidentally, we have selected these depth-area relations over those in HYDRO-40 because the data base from Walnut Gulch that was used by Osborn is far superior than that available for the remainder of Arizona that was used in HYDRO-40 and because some of the recommendations and conclusions of HYDRO-40 are weak.

Joe Rumann and I have evaluated various rainfall distributions and have done some preliminary testing using HEC-1 and some watershed models with different methods of calculating rainfall losses and a range of loss rates. Based on these evaluations and tests we believe that the 6-hour duration storm is appropriate for the 100-year event in Maricopa County. You may recall that the Corps standard project storm for the Phoenix area is 7-hours and for Clark County is 6-hours, and therefore this appears to be consistent with the Corps' opinion for flood producing storms. Some of our thoughts and also comments of drainage engineers at the Arizona Department of Transportation are that the time distribution should have decreasing peak rainfall intensities for increasing drainage areas. In this regard we are interested in using time distribution patterns similar to those developed by the Corps for the Phoenix area and Clark County. We would need to make some modifications to these and to do that we need to have a better understanding of the analyses that were required for their development. We also have some specific questions about these.

Our needs would probably be most effectively resolved if Joe and I were to come to the LA District office. At that time I would like to review the data and analyses that were performed to develop the time distribution patterns for both the Phoenix area and Clark County. We would also like to have the opportunity to discuss these with you or others that have been involved in their development and use.

I notice that the Clark County patterns are a function of drainage area whereas the Phoenix patterns are a function of both drainage area and the 10-yr, 6-hr rainfall depth. The Phoenix patterns were developed in the early 1970s and the Clark County were only recently developed. This has prompted some questions on my part.

For Phoenix, the pattern shown in Plate 19 is selected from Plate 20 as a function of drainage area and the 10-yr, 6-hr rainfall depth. Plate 16 is used to select the 10-yr, 6-hr rainfall and this plate is taken from NOAA Atlas 2. The range of rainfall depth from Plate 16 is from 1.9 inches to 3.0 inches and this is the range for all of Maricopa County as shown in NOAA Atlas 2. Using this rainfall range with Plate 20 would mean that time distribution patterns less than number 2 would never be used. This is a little unsettling because for very small drainage areas (less than 1.0 square mile) we would like the distribution to represent the short-duration (15-minute) high-intensity rainfalls that NOAA Atlas 2 is indicating (5.68 inches/hour for 100-yr storm). Pattern 2 will not have this intensity. The limited range of application of Plate 16 is confusing to me. What is the reason for this limitation? Why is there a pattern 1 if it cannot be used?

I have some conceptual problem with the pattern number being a function of rainfall depth. For Clark County it is only a function of drainage area and this has some advantages. Is there some reason why the Phoenix and Clark County procedures for pattern selection are different?

For your convenience I have enclosed copies of the plates that I referenced and a copy of the plate for Clark County. I also enclosed copies of two handwritten tables of depth-duration-frequency and intensity-duration-frequency data for Phoenix from NOAA Atlas 2.

I will call you during the week of 15-19 August to talk to you about this. Joe and I would like to visit you in Los Angeles to review and discuss this with you and others and the week of 6-9 September would be good for us. You can advise me of an appropriate date for such a visit.

As always, your time and effort is greatly appreciated. Hopefully this will culminate in a product that will be beneficial to all of us.

Sincerely yours,

Geo V Sabol

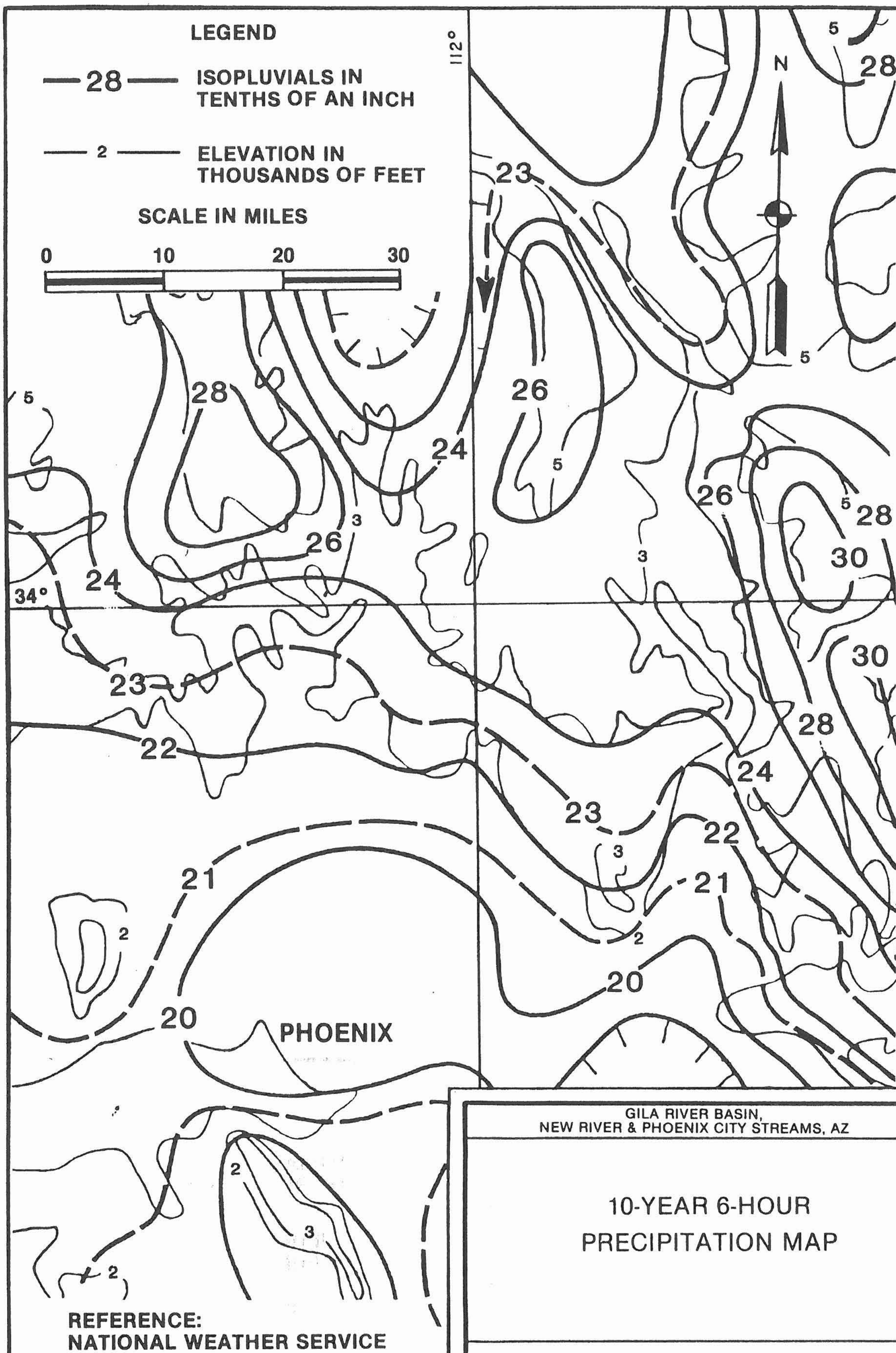
George V. Sabol

Enclosures:

1. Plates 16, 19, 20 from Phoenix Design Memorandum No. 2, Hydrology Part 2 (1982).
2. Clark County time distribution patterns.
3. Rainfall tables for Phoenix.
4. Paper by Osborn, Lane, and Myers (1980).

Copy: Mr. Joe Rumann, Hydrologist, Flood Control District of Maricopa County
w/ all enclosures except 4.

not adequate latitude, longitude to use directly



(SOURCE: REF. 2)

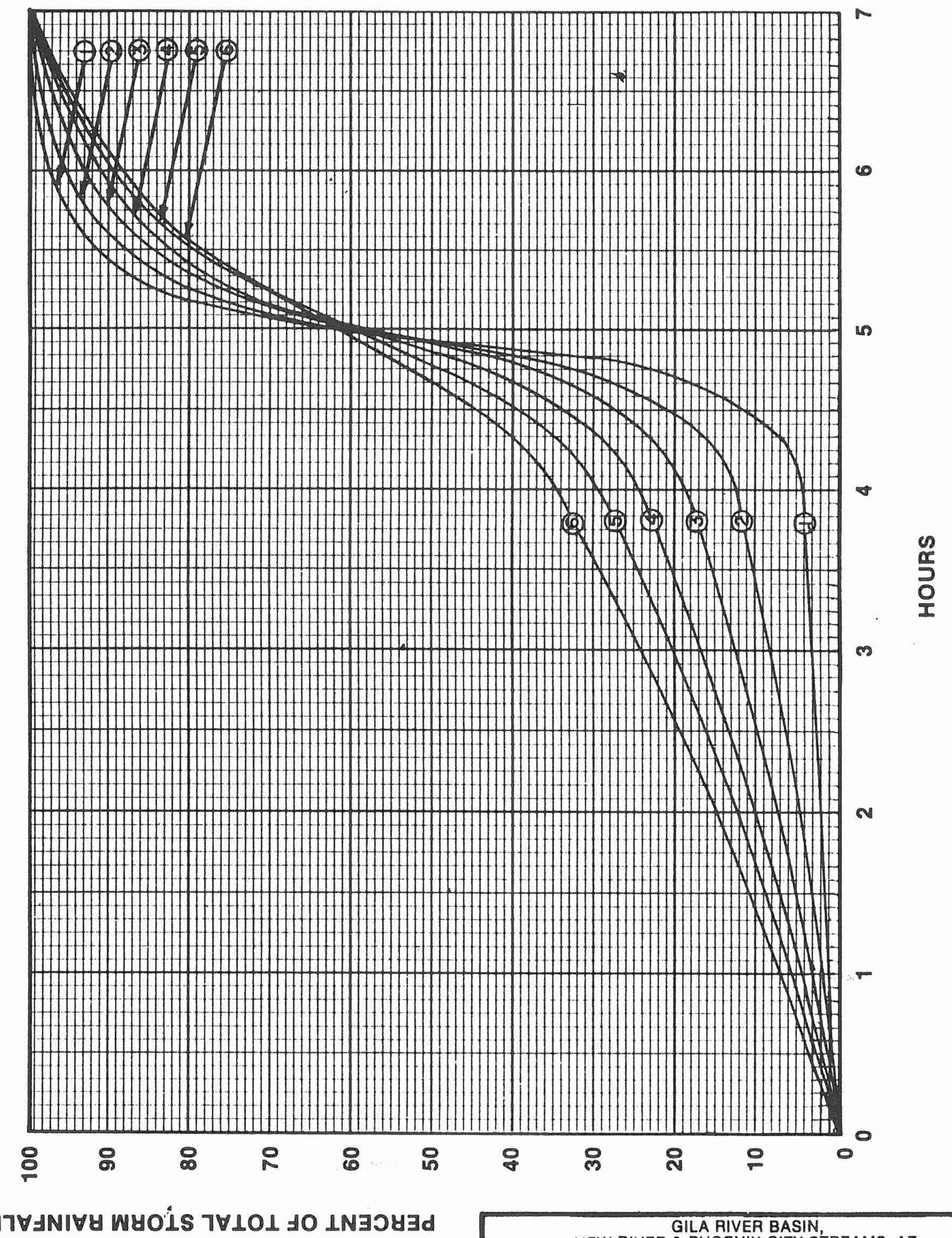
GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

10-YEAR 6-HOUR
PRECIPITATION MAP

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

(revised 2/83)

PLATE 16



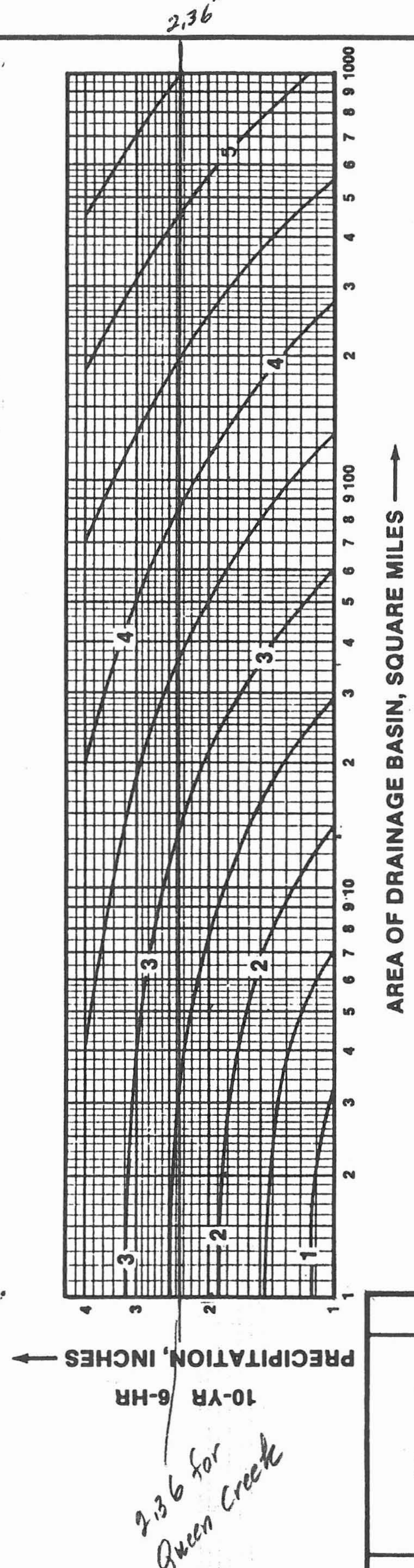
—2— PATTERN NUMBER
MAKE PATTERN NUMBER SELECTION ON PLATE 20

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ.

ARIZONA
STANDARD PROJECT LOCAL
SUMMER STORM
PRECIPITATION PATTERNS

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT



—2— PATTERN NUMBER

REFER TO PLATE 19
FOR ACTUAL PATTERN

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ.

ARIZONA STANDARD PROJECT LOCAL SUMMER STORM PRECIPITATION-AREA-PATTERN CURVES

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

(SOURCE: REF. 2)

MEMORANDUM

Subject: Meeting with Los Angeles District, U.S. Army Corps of Engineers, 8-9 September 1988
To: File
From: G.V. Sabol

Joe Rumann and George Sabol traveled to Los Angeles to meet with representatives of the Corps to discuss the rainfall criteria that the Corps used in its hydrologic studies in Maricopa County and for other regional studies. Information was obtained from John Pedersen and Dr. Charles Pyke.

Rumann and Sabol asked how the storm patterns were developed and why (using Plate 20) a Pattern No. 1 could never be selected (this would require a 10-yr, 6-hr rainfall of about 1.1 inch or less which does not occur in Arizona). The response was that although Pattern No. 1 was essentially impossible (again using Plate 20), it was necessary to define Pattern No. 1 so that Pattern Nos. between 1 and 2 could be defined. The Corps wanted the procedure to be applicable throughout Arizona for which there were locations where the 10-yr, 6-hr rainfall was less than 1.9 inches for which Pattern Nos. less than 2.0 were needed.

Similarly, Pattern No. 6 was defined so as to enable interpolation between 5 and 6.

The 10-yr, 6-hr rainfall statistic was used to select the Pattern No. so that the procedure could be used throughout Arizona and not just in the Queen Creek (Maricopa County) area.

The Corps' development of the criteria was based on the best available information, however <u>no</u> rainfall recorder data were available and therefore the analysis was highly interpretive. Dr. Pyke reanalyzed the data and he provided a copy of the basic data and reanalysis to us (Attachment A). Notice that in Dr. Pyke's 1988 reanalysis that the selection of Pattern No. is a function of drainage area only and that this is consistent with other similar analyses that the Corps has undertaken more recently (see for example the Corps' analysis for Clark County, NV). John Pedersen said that he has not used Pyke's 1988 reanalysis results for any studies, and that the reanalysis would result in higher peak discharges than the original analysis would yield.

Pedersen provided a written procedure to be used in applying the Corps' Queen Creek rainfall criteria in Arizona (Attachment B). Notice that there are 1982 and 1972 versions of that procedure. The Corps' original work used the 1972 procedure. Pedersen recommended that we look at HEC Training Document No. 15 in regard to defining rainfall criteria. That procedure is based on the concept of the hypothetical distribution.

The development of a storm pattern criteria for Maricopa County was discussed along the following general lines: First, the Corps' Pattern No. 1 would be deleted and this would be replaced by a hypothetical distribution. The new Pattern No. 1 would be applied to small drainage areas (1 sq. mi. or less). Second, a 6-hr duration would be used and the first hour of the Corps' 7-hr storm patterns would be truncated for this purpose. Third, the Pattern Nos. for 2 and above would be redrawn to correspond to the new Pattern No. 1. Fourth, a Pattern No. versus drainage area curve would be prepared based on selected Pattern No. from Plate 20 at a 10-yr, 6-hr rainfall for Queen Creek (2.36 inches). The 2-hr time distribution would be the hypothetical (same as Pattern No. 1, but only for a 2-hr duration). The Manual would describe a procedure to develop a 24-hr distribution.

Pedersen talked to us about calibrating and verifying the Maricopa County model in a manner similar to the procedure that the Corps used for the Clark County, NV study.

Attachment (A)

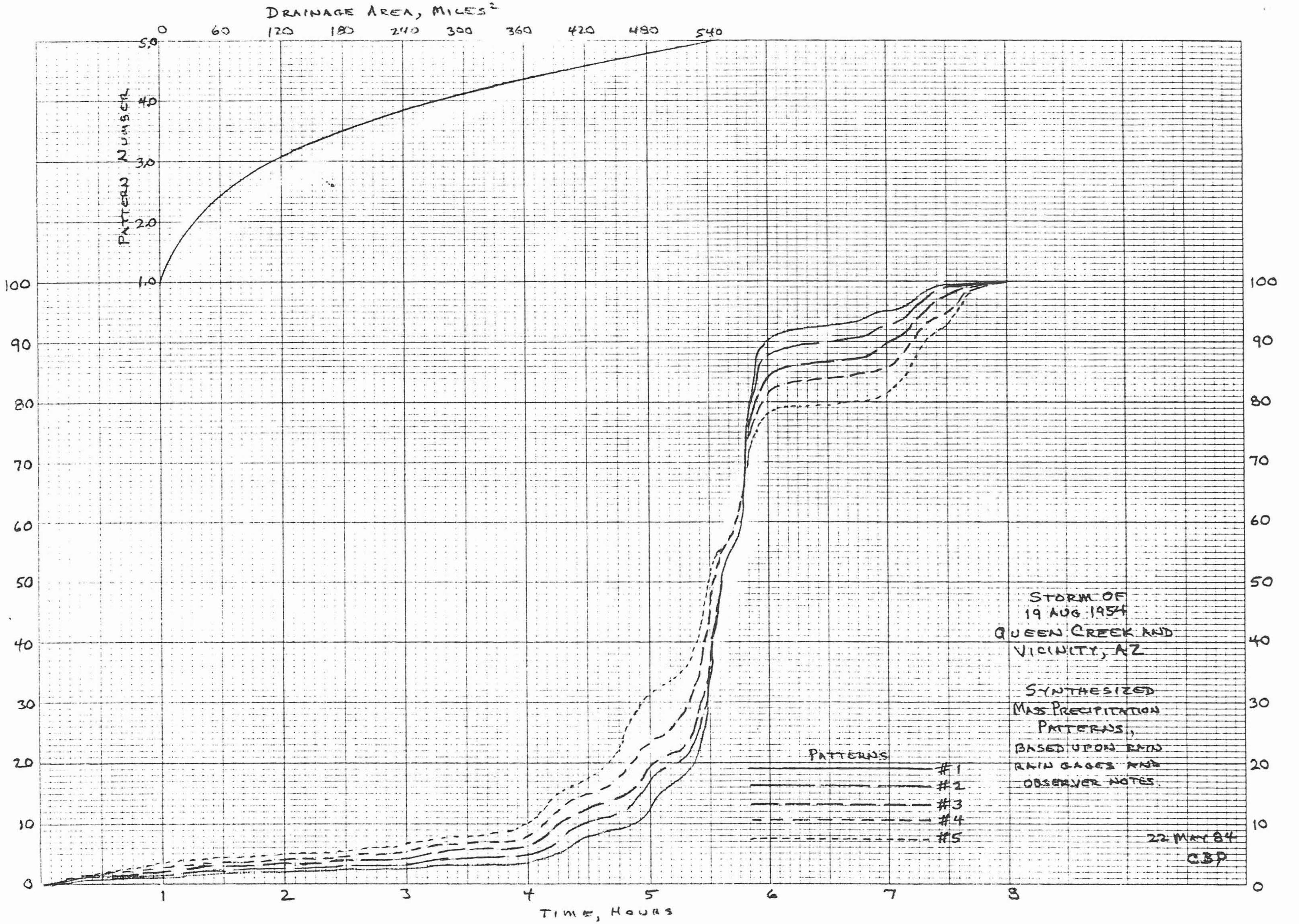
6/3/88

QUEEN CREEK, AZ STORM OF 19 AUG 1954

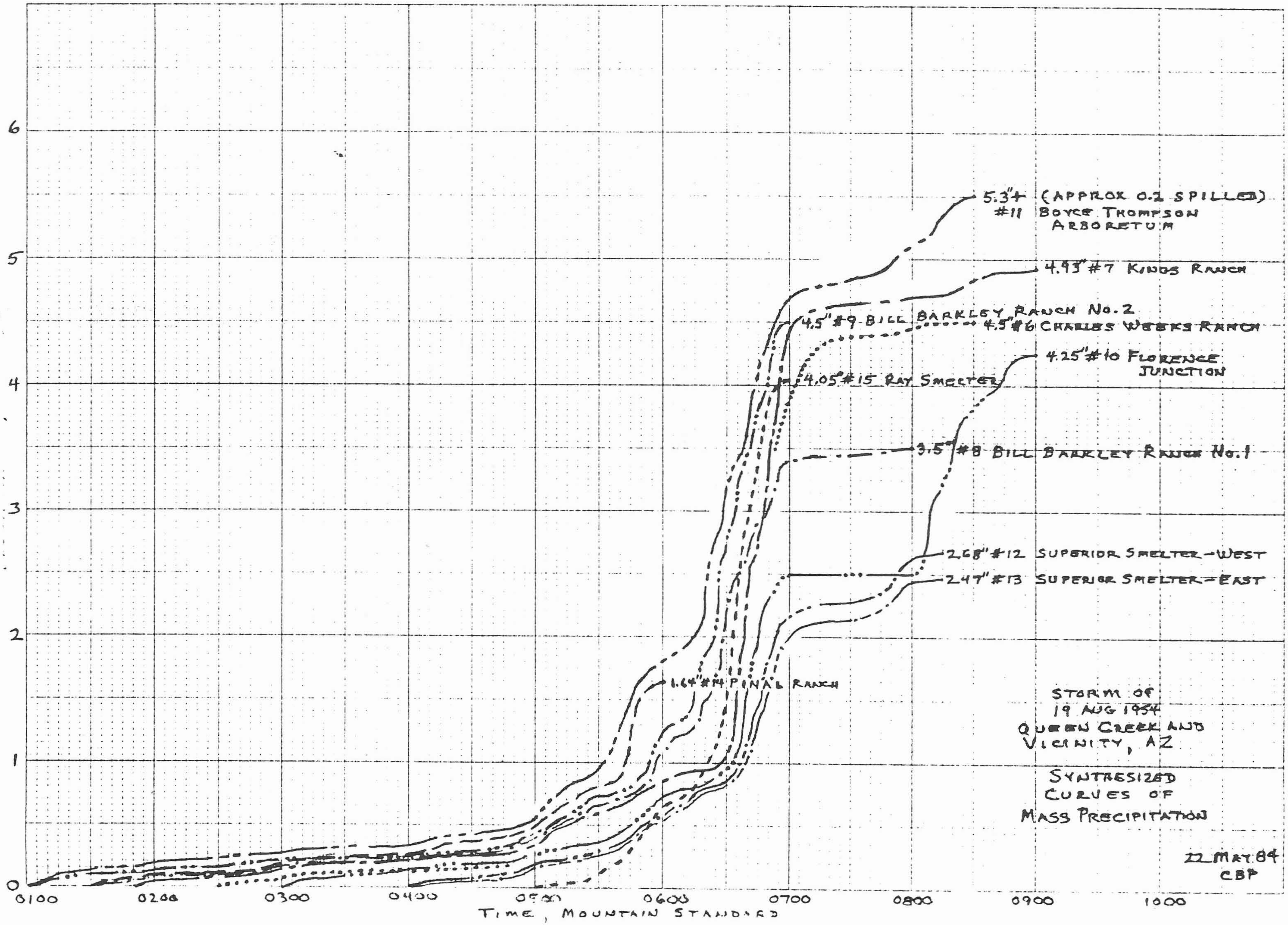
RAINFALL TIME DISTRIBUTION PATTERNS

No.	Station	Period of Rain, MST	Amount (inches)	Remarks
1.	Mesa Experiment Farm	0800-1000	.02	
2.	Falcon Field	0730-0930	.46	
3.			.00	
4.			.00	
5.			.00	
6.	Charles Weeks Ranch	0230-0830	4.5	
7.	Kings Ranch	0150-0900	4.93	0150-0630 "normal rain" 0630-0700 "rain worse [sic] he had known" One-quarter mile directly south of Kings Ranch: 5"
8.	Bill Barkley Ranch No. 1	0130-0800*	3.5	"Rain intermittent very hard"
9.	Bill Barkley Ranch No. 2	0100-0700	4.5	"Very hard rain, comes down in sheets"
10.	Florence Junction	0300-0900	4.25	0300-0700 2.50" 0800-0900 1.75"
11.	Boyce Thompson Arboretum	0100-0830*	5.3+	0100-0500 light 0500-0800 very heavy "Spilt [sic] some when measuring. Approximately .2 inch."
12.	Superior Smelter, west	0400-0815	2.68	
13.	Superior Smelter, east	0400-0815	2.47	Tipping bucket alongside: .95 inch
14.	Pinal Ranch	0130-0600	1.64	
15.	Ray Smelter	0500-0700	4.05	"Paper said it all fell in 1 and 1/2 hours"
16.	Florence		.01	
17.			.00	
18.	Williams AF Base	0156-0900	.62	0156-0347 intermittent light 0347-0508 moderate 0508-0900 light

* = approximately



K+E 12 x 20 TO THE INCH • 7 x 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1970
DRAINAGE AREA, MILES²
0 60 120 180 240 300 360 420 480 540
PATTERN NUMBER
5.0 4.0 3.0 2.0 1.0
100 90 80 70 60 50 40 30 20 10 0
1 2 3 4 5 6 7 8
TIME, HOURS
STORM OF 19 AUG 1954 QUEEN CREEK AND VICINITY, AZ
SYNTHESIZED MASS PRECIPITATION PATTERNS, BASED UPON RAIN GAGES AND OBSERVER NOTES.
PATTERNS
#1
#2
#3
#4
#5
22 MAY 84
CBP


K+E 12 x 20 TO THE INCH
KEUFFEL & ESSER CO.
6
5
4
3
2
1
0
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
TIME, MOUNTAIN STANDARD
5.3"+ (APPROX 0.2 SPILLED) #11 BOYCE THOMPSON ARBORETUM
4.93" #7 KINGS RANCH
4.5" #9 BILL BARKLEY RANCH No. 2
4.5" #6 CHARLES WEEKS RANCH
4.25" #10 FLORENCE JUNCTION
4.05" #15 RAY SMELTER
3.5" #8 BILL BARKLEY RANCH No. 1
2.68" #12 SUPERIOR SMELTER - WEST
2.47" #13 SUPERIOR SMELTER - EAST
1.64" #14 PINAL RANCH
STORM OF 19 AUG 1954
QUEEN CREEK AND VICINITY, AZ
SYNTHESIZED CURVES OF MASS PRECIPITATION
22 MAY 84
CBP

Attachment (B)

GOOD UP TO 200 mi² or more

17 Aug 7?
updated 1982

GREATER ARIZONA STANDARD PROJECT SUMMER THUNDERSTORM
(based upon Queen Creek storm of 19 August 1954)

INSTRUCTIONS FOR COMPUTATION OF RAINFALL

1. BASIC STORM: Central depth value of the 1954 Queen Creek storm equals 7.50 inches over a 7-hour period. This occurred in the mountains east of Phoenix, where the 10-year 6-hour precipitation = 2.36 inches. This storm can be transposed anywhere in central and southern Arizona and into southwestern New Mexico (west of the Continental Divide), subject to the following limitations:

   a. The maximum CENTRAL DEPTH VALUE of the transposed 7-hour storm should not exceed 7.50 inches anywhere.

   b. In areas where the 10-year 6-hour precipitation is less than 2.36 inches, the CENTRAL DEPTH VALUE of the transposed storm should be reduced according to the value of the 10-year 6-hour precipitation at the site of transposition.

2. INSTRUCTIONS FOR TRANSPOSITION of the CENTRAL DEPTH VALUE of the Standard Project Summer Thunderstorm:

   a. Obtain the 10-YEAR 6-HOUR PRECIPITATION map for Arizona from NOAA ATLAS 2 or from the set of enlarged maps of n-year t-hour precipitation. Select the average of this quantity over the drainage basin for which the transposed storm is to be applied. If this average 10-YEAR 6-HOUR PRECIPITATION should exceed 2.36 inches, the value of this quantity used in Step 2.b. should be limited to a maximum of 2.36 inches.

   b. Obtain the CENTRAL DEPTH VALUE of the transposed Standard Project Summer Thunderstorm for the drainage basin of concern by multiplying the 10-YEAR 6-HOUR PRECIPITATION (Step 2.a.) by 3.178 inches. (The value 3.178 equals 7.50 (original storm depth) divided by 2.36 (10-year 6-hour precipitation at site of original storm).). NOTE: If the 10-YEAR 6-HOUR PRECIPITATION for the transposition site (Step 2.a.) is limited to a maximum of 2.36 inches, the computed CENTRAL DEPTH VALUE of the transposed storm will be limited to a maximum of 7.50 inches.

3. DEPTH-AREA REDUCTION. The depth-area reduction used with the Greater Arizona Standard Project Summer Thunderstorm is based upon the depth-area curve of the August 1954 Queen Creek storm, modified according to the 10-year 6-hour precipitation.

   a. On the depth-area graph for the Greater Arizona Standard Project Summer Thunderstorm, select the proper DEPTH-AREA REDUCTION FACTOR (in per cent) by interpolation between curves according to Area (square miles) and 10-year 6-hour precipitation (the curves are labeled according to 10-year 6-hour precipitation, in inches and tenths).

   b. Multiply the CENTRAL DEPTH VALUE (Step 2.b.) by the DEPTH-AREA REDUCTION FACTOR (Step 3.a.) to obtain the proper AVERAGE RAINFALL DEPTH for the drainage basin considered.

(continued next page)

GREATER ARIZONA STANDARD PROJECT SUMMER THUNDERSTORM
(continued)

4. TIME DISTRIBUTION PATTERN. The Time Distribution Pattern for the Greater Arizona Standard Project Summer Thunderstorm can be obtained from the Pattern — Area — 10-year 6-hour Precipitation graph. Interpolate between curves to obtain the applicable pattern number between integer values. (Read pattern number to the nearest tenth.)

5. ENTRY INTO LADFHP. For computation of Greater Arizona Standard Project Summer Thunderstorm Flood, enter into the computer program LOS ANGELES DISTRICT FLOOD HYDROGRAPH PACKAGE (LADFHP) the Storm Number, the AVERAGE RAINFALL DEPTH, and the TIME DISTRIBUTION PATTERN:

   a. B-4 (B-card, field 4): PRECIP = 10 (Arizona summer local storm - August 1954 Queen Creek storm, 7-hour duration).

   b. F-2 (F-card, field 2): TRAIN = AVERAGE RAINFALL DEPTH (in inches and hundredths).

   c. F-5 (F-card, field 5): CN = TIME DISTRIBUTION PATTERN (curve number, in units and tenths, e.g., 2.7; note that for this storm, CN must be between 1.0 and 6.0).

$$A_1 T_1 + A_2 T_2 = A_T T_T$$

17 Aug 72

GREATER ARIZONA STANDARD PROJECT SUMMER THUNDERSTORM

INSTRUCTIONS FOR COMPUTATION OF RAINFALL

1. BASIC DEPTH of storm: total 7-hour central value = 3.178 inches times the 10-year 6-hour precipitation.

2. Obtain proper 10-YEAR 6-HOUR PRECIPITATION from U. S. Weather Bureau (National Weather Service) map of this quantity. Select average representative value of this quantity for the drainage basin concerned. If value exceeds 2.36", GO TO STEP 3.

3. Multiply 3.178 inches (Step 1) by 10-year 6-hour precipitation (Step 2) to obtain CENTRAL VALUE DEPTH of rain for drainage basin concerned. If CENTRAL VALUE DEPTH > 7.50", Limit to 7.50".

4. Select proper DEPTH-AREA FACTOR from depth-area graph. Obtain factor (in per cent) by interpolation between curves according to Area (square miles) and 10-year 6-hour precipitation (curves are labeled according to 10-year 6-hour precipitation, in inches and tenths).

5. Multiply Central Value Depth (Step 3) by Depth-Area Factor (Step 4) to obtain proper AVERAGE RAINFALL DEPTH for the drainage basin considered.

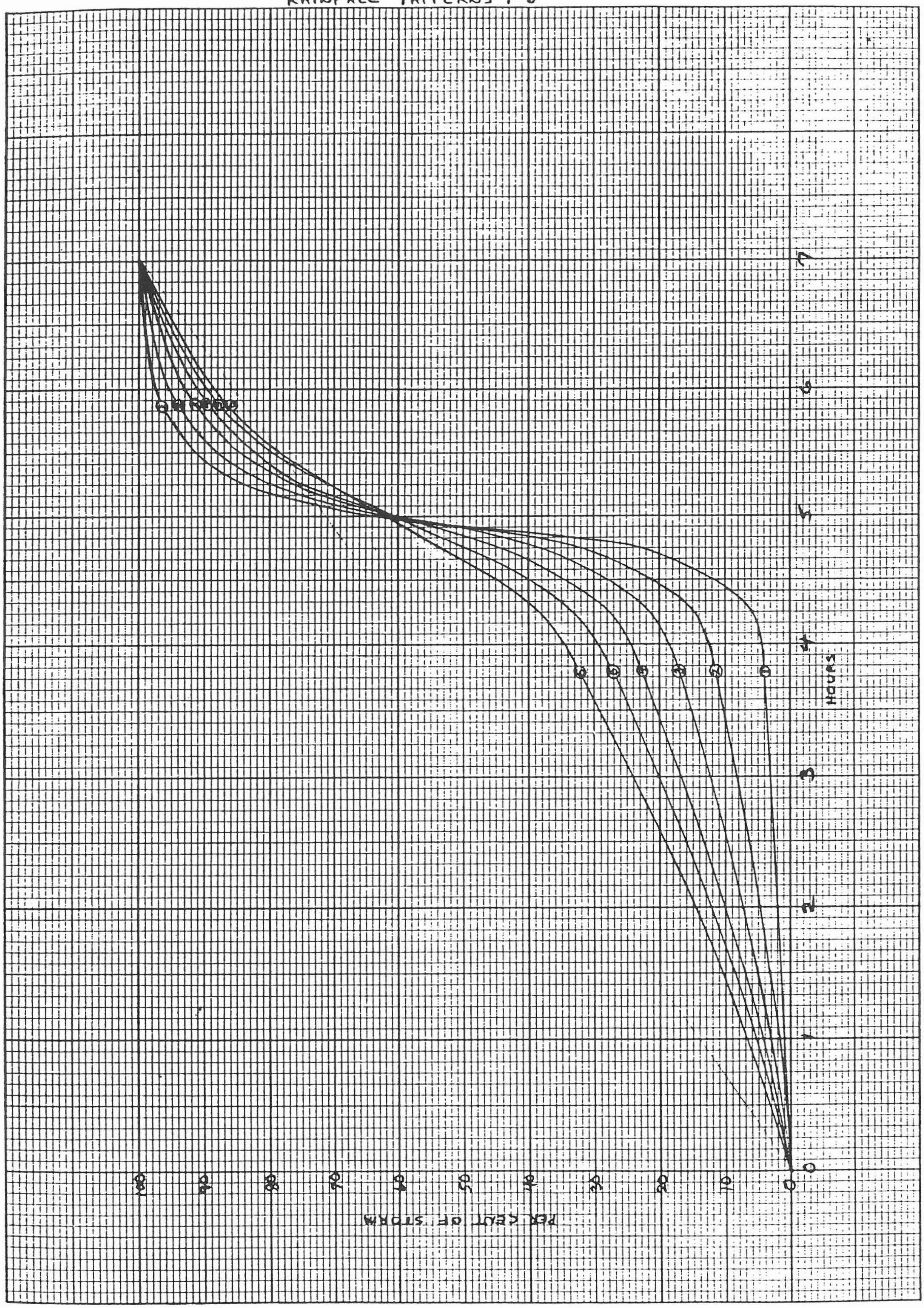
6. Select the proper STORM PATTERN from Pattern — Area — 10-yr 6-hr Precipitation graph. Interpolate between curves to obtain applicable pattern number between integer values.

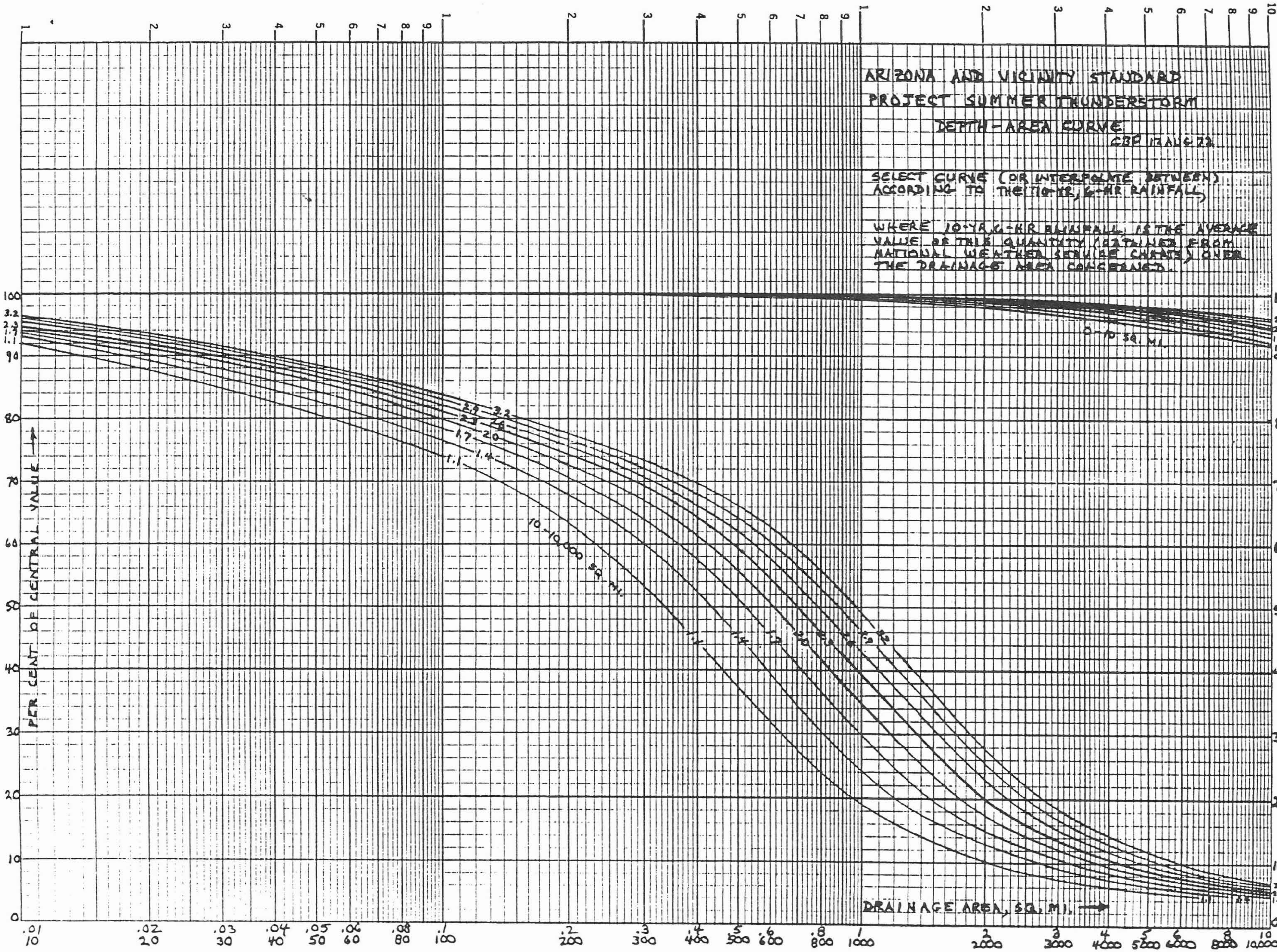
7. Submit to computer via LOS ANGELES DISTRICT FLOOD HYDROGRAPH PACKAGE program: (a) AVERAGE RAINFALL DEPTH (Step 5) in inches and decimal values, and (b) STORM PATTERN (Step 6) in integers and decimal values (computer program will generate a storm pattern interpolated between the given integer patterns).

CBP

ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM
RAINFALL PATTERNS 1-6

14 AUG 72 CBP

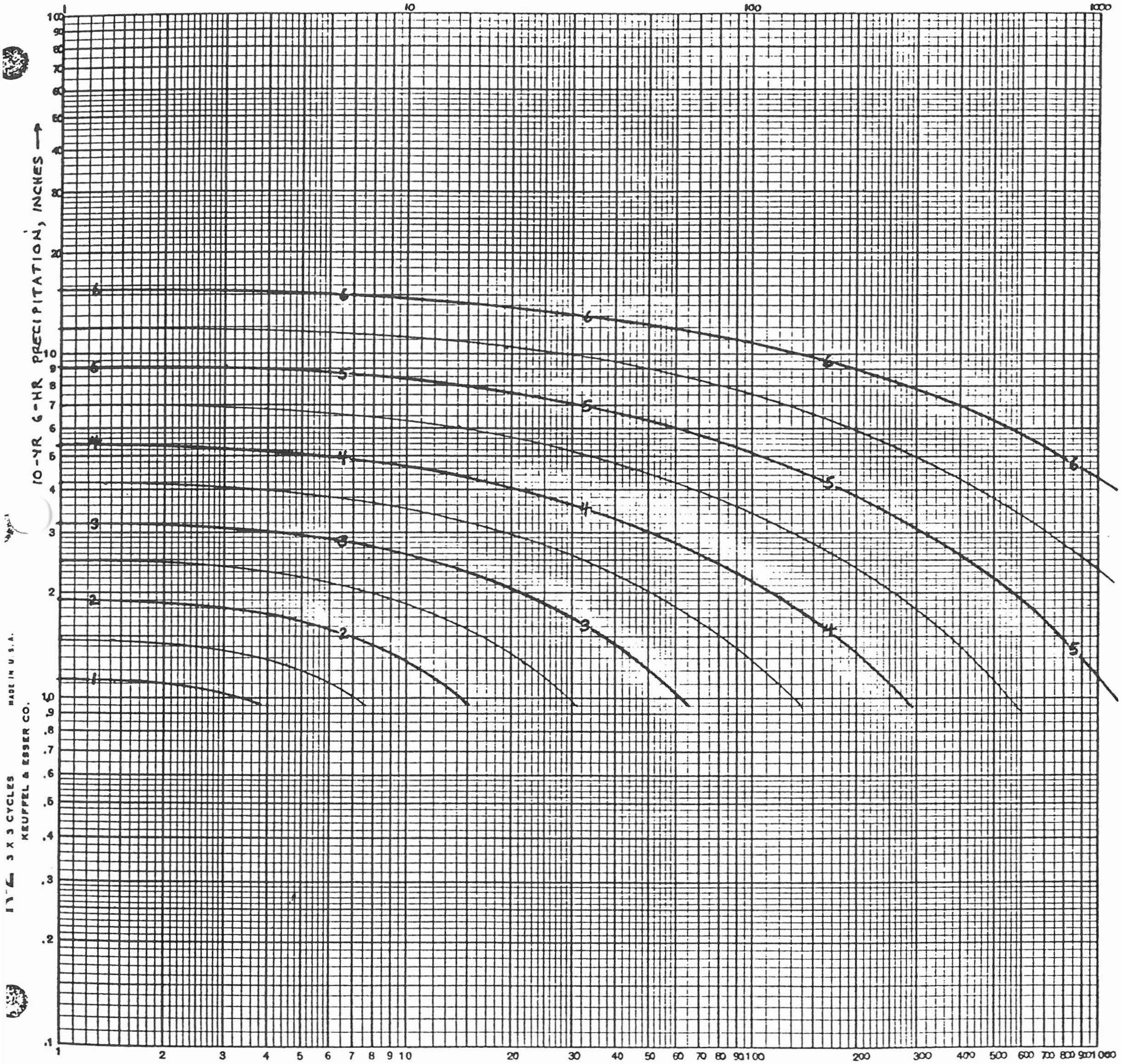



ARIZONA AND VICINITY STANDARD
PROJECT SUMMER THUNDERSTORM
DEPTH-AREA CURVE
CBP 12 AUG 72
SELECT CURVE (OR INTERPOLATE BETWEEN) ACCORDING TO THE 10-YR, 6-HR RAINFALL
WHERE 10-YR, 6-HR RAINFALL IS THE AVERAGE VALUE OF THIS QUANTITY (OBTAINED FROM NATIONAL WEATHER SERVICE CHARTS) OVER THE DRAINAGE AREA CONCERNED.
0-10 SQ. MI.
10-10,000 SQ. MI.
PER CENT OF CENTRAL VALUE →
DRAINAGE AREA, SQ. MI. →
1.1
1.4
1.7
2.0
2.3
2.6
2.9
3.2
0
10
20
30
40
50
60
70
80
90
100
.01 10
.02 20
.03 30
.04 40
.05 50
.06 60
.08 80
.1 100
.2 200
.3 300
.4 400
.5 500
.6 600
.8 800
1 1000
2 2000
3 3000
4 4000
5 5000
6 6000
8 8000
10 10,000

17 AUG '72

ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM

PATTERN — AREA — 10-YR 6-HR PRECIPITATION



P[illegible] LOS ANGELLS No.

P[illegible] M17 [illegible] VICINITY STANDARD PROJECT SUMMER THUNDERSTORM

Item [illegible] DURATION-INTENSITY AND INTENSITY PATTERN #1

Comp. by C.E.P. [illegible] Checked by [illegible] Date [illegible] 72

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
5M	[illegible]	15.13	.03		.03
10M	[illegible]	12.34	.03		.16
15M	[illegible].01	11.53	[illegible]	.24	.24
20M	47.16	9.15	[illegible]		.33
25M	56.46	7.30	[illegible]		.40
30M	61.52	5.06	[illegible]	.24	.48
35M	65.73	4.21	[illegible]		.56
40M	69.00	3.27	[illegible]		.64
45M	72.11	3.19	[illegible]	.24	.72
50M	75.28	3.07	.08		.80
55M	77.57	2.21	.08		.88
1H 00M	79.76	2.17	.08	.34	.96
5M	81.92	2.16	.08		1.04
10M	84.03	2.11	.09		1.13
15M	85.96	1.73	.09	.26	1.22
20M	87.28	1.32	.09		1.31
25M	88.33	1.05	.09		1.40
30M	89.32	.99	.09	.27	1.49
35M	90.29	.97	.09		1.58
40M	91.24	.95	.09		1.67
45M	92.13	.89	.09	.27	1.76
50M	92.64	.51	.10		1.86
55M	92.96	.32	.09		1.94
2H 00M	93.25	.29	.09	.27	2.03
5M	[illegible]	.28	.09		2.12
10M	93.81	.28	.09		2.21
15M	94.09	[illegible]	.09	.27	2.30
20M	94.34	.25	.09		2.39
25M	94.51	.17	.09		2.48
30M	94.66	.15	.10	.28	2.58
35M	94.81	.15	.10		2.68
40M	94.96	.15	.10		2.78
45M	95.10	.14	.10	.30	2.88
50M	[illegible]	.14	.10		2.98
55M	95.36	.13	.10		3.08
3H 00M	95.49	.12	.10	.30	3.18
5M	95.60	.12	.10		3.28
10M	95.72	.12	.10		3.38
15M	95.84	.12	.10	.30	3.48
20M	[illegible]	.12	.11		3.59
25M	96.08	.12	.11		3.70
30M	96.19	.11	.11	.33	3.81

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
3H35M	96.30	.11	.11		[illegible]
40M	96.41	.11	.12		[illegible]
45M	96.52	.11	.12	.35	[illegible]
50M	96.62	.10	.12		[illegible]
55M	96.72	.10	.12		[illegible]
4H00M	96.82	.10	.12	.36	[illegible]
5M	96.92	.10	.29		[illegible]
10M	97.02	.10	.32		[illegible]
15M	97.12	.10	.51	1.12	[illegible]
20M	97.22	.10	1.93		[illegible]
25M	97.32	.10	2.11		[illegible]
30M	97.42	.10	2.16	6.20	[illegible]
35M	97.52	.10	3.19		[illegible]
40M	97.61	.09	3.27		[illegible]
45M	97.70	.09	4.21	10.67	[illegible]
50M	97.79	.09	11.52		[illegible]
55M	97.88	.09	17.13		51
5H00M	97.97	.09	12.36	41.01	[illegible]
5M	[illegible]	.09	2.19		71
10M	[illegible]	.09	7.30		[illegible]
15M	[illegible]	.09	5.06	20.51	[illegible]
20M	[illegible]	.09	[illegible]		[illegible]
25M	[illegible]	.09	[illegible]		[illegible]
30M	98.51	.09	[illegible]	7.57	[illegible]
35M	98.60	.09	1.32		[illegible]
40M	98.69	.09	[illegible]		[illegible]
45M	98.78	[illegible]	[illegible]	3.36	[illegible]
50M	98.87	[illegible]	.97		[illegible]
55M	[illegible]	.09	.95		[illegible]
6H 00M	99.04	.08	.89	2.81	[illegible]
5M	99.12	.08	.73		[illegible]
10M	99.20	.08	[illegible]		[illegible]
15M	[illegible]	[illegible]	.73	.34	[illegible]
20M	99.36	.08	.25		[illegible]
25M	99.44	.08	.17		[illegible]
30M	99.52	.08	.15	.57	[illegible]
35M	99.60	.08	.15		[illegible]
40M	99.68	.08	.15		[illegible]
45M	99.76	.08	.14	.44	[illegible]
50M	[illegible]	[illegible]	[illegible]		[illegible]
55M	99.92	[illegible]	.13		[illegible]
7H 00M	100.00	[illegible]	.12	.39	[illegible]

District LOS ANGELES No. ____

Project ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM

Item STORM DURATION-INTENSITY AND INTENSITY PATTERN #2

Computed by CBP + TMC Checked by JKJ Date 14 AUG 72

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %			RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
5M	11.75	11.75	.13		.13		3H35M	90.07	.33	.33		10.59
10M	21.52	9.77	.14		.27		40M	90.40	.33	.33		10.92
15M	29.97	8.45	.14	.41	.41		45M	90.73	.33	.33	.99	11.25
20M	37.58	7.61	.14		.55		50M	91.06	.33	.33		11.58
25M	43.87	6.29	.14		.69		55M	91.39	.33	.33		11.91
30M	48.68	4.81	.14	.42	.83		4H00M	91.72	.33	.33	.99	12.2[illegible]
35M	52.32	3.64	.14		.97		5M	92.04	.32	.67		12.91
40M	55.63	3.31	.15		1.12		10M	92.35	.31	.74		13.65
45M	58.77	3.14	.16	.45	1.28		15M	92.66	.31	.90	2.31	14.55
50M	61.75	2.98	.17		1.45		20M	92.96	.30	1.85		16.4[illegible]
55M	64.40	2.65	.18		1.63		25M	93.25	.29	2.15		18.5[illegible]
1H 00M	67.05	2.65	.19	.54	1.82		30M	93.54	.29	2.46	6.46	21.01
5M	69.51	2.46	.20		2.02		35M	93.83	.29	3.14		24.15
10M	71.66	2.15	.21		2.23		40M	94.11	.28	3.31		27.46
15M	73.51	1.85	.22	.63	2.45		45M	94.39	.28	3.64	10.09	31.10
20M	75.02	1.51	.23		2.68		50M	94.67	.28	8.45		39.55
25M	76.38	1.36	.23		2.91		55M	94.95	.28	11.75		51.30
30M	77.65	1.27	.24	.70	3.15		5H00M	95.23	.28	9.77	29.97	61.0[illegible]
35M	78.87	1.22	.25		3.40		5M	95.51	.28	7.61		68.68
40M	80.05	1.18	.26		3.66		10M	95.79	.28	6.29		74.97
45M	81.13	1.08	.27	.78	3.93		15M	96.07	.28	4.81	18.71	79.7[illegible]
50M	82.03	.90	.28		4.21		20M	96.34	.27	2.98		82.7[illegible]
55M	82.77	.74	.28		4.49		25M	96.60	.26	2.65		85.41
2H 00M	83.44	.67	.28	.84	4.77		30M	96.85	.25	2.65	8.28	88.06
5M	84.00	.56	.28		5.05		35M	97.09	.24	1.51		89.57
10M	84.41	.41	.28		5.33		40M	97.32	.23	1.36		90.9[illegible]
15M	84.77	.36	.28	.84	5.61		45M	97.55	.23	1.27	4.14	92.2[illegible]
20M	85.11	.34	.28		5.89		50M	97.77	.22	1.22		93.4[illegible]
25M	85.45	.34	.28		6.17		55M	97.98	.21	1.18		94.6[illegible]
30M	85.78	.33	.29	.85	6.46		6H 00M	98.18	.20	1.08	3.48	95.68
35M	86.11	.33	.29		6.75		5M	98.37	.19	.56		96.24
40M	86.44	.33	.29		7.04		10M	98.55	.18	.41		96.65
45M	86.77	.33	.30	.88	7.34		15M	98.72	.17	.36	1.33	97.01
50M	87.10	.33	.31		7.65		20M	98.88	.16	.34		97.35
55M	87.43	.33	.31		7.96		25M	99.03	.15	.34		97.69
3H00M	87.76	.33	.32	.94	8.28		30M	99.17	.14	.33	1.01	98.0[illegible]
5M	88.09	.33	.33		8.61		35M	99.31	.14	.33		98.3[illegible]
10M	88.42	.33	.33		8.94		40M	99.45	.14	.33		98.68
15M	88.75	.33	.33	.99	9.27		45M	99.59	.14	.33	.99	99.01
20M	89.08	.33	.33		9.60		50M	99.73	.14	.33		99.34
25M	89.41	.33	.33		9.93		55M	99.87	.14	.33		99.6[illegible]
30M	89.74	.33	.33	.99	10.26		7H 00M	100.00	.13	.33	.99	100.00

District LOS ANGELES No.

Project ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM

Item STORM DURATION- INTENSITY AND INTENSITY PATTERN # 3

Computed by CBP & TMC. Checked by TMC. Date 15 Aug. 72

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
5M	8.06	8.06	.24		.24
10M	15.54	7.48	.24		.48
15M	22.42	6.88	.25	73	.73
20M	28.91	6.49	.25		98
25M	34.41	5.50	.25		123
30M	38.74	4.33	.25	.75	1.48
35M	42.28	3.54	.26		1.74
40M	45.53	3.25	.26		2.00
45M	48.57	3.04	.26	.78	2.26
50M	51.52	2.95	.26		2.52
55M	54.18	2.66	.27		2.79
1H 00M	56.74	2.56	.28	.81	3.07
5M	59.18	2.44	.30		3.37
10M	61.39	2.21	.32		3.69
15M	63.32	1.93	.34	.96	4.03
20M	65.00	1.68	.35		4.38
25M	66.51	1.51	.36		4.74
30M	67.94	1.43	.37	1.08	5.11
35M	69.32	1.38	.38		5.49
40M	70.67	1.35	.39		5.88
45M	71.98	1.31	.39	1.16	6.27
50M	73.16	1.18	.40		6.67
55M	74.08	.92	.40		7.07
2H 00M	74.83	.75	.40	1.20	7.47
5M	75.52	.68	.41		7.88
10M	76.17	.65	.41		8.29
15M	76.79	.62	.41	1.23	8.70
20M	77.37	.58	.41		9.11
25M	77.93	.56	.41		9.52
30M	78.47	.54	.41	1.23	9.93
35M	79.00	.53	.42		10.35
40M	79.52	.52	.43		10.78
45M	80.04	.52	.44	1.29	11.22
50M	80.54	.50	.45		11.67
55M	81.04	.50	.46		12.13
3H 00M	81.54	.50	.46	1.37	12.59
5M	82.04	.50	.47		13.06
10M	82.54	.50	.48		13.54
15M	83.03	.49	.49	1.44	14.03
20M	83.52	.49	.49		14.52
25M	84.01	.49	.49		15.01
30M	84.50	.49	.49	1.47	15.50

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
3H35M	84.99	.49	.49		15.
40M	85.48	.49	.49		16.4
45M	85.97	.49	.49	1.47	16.9
50M	86.46	.49	.49		17.4
55M	86.94	.48	.50		17.9
4H00M	87.41	.47	.50	1.49	18.4
5M	87.87	.46	.75		19.
10M	88.33	.46	.92		20.1
15M	88.78	.45	1.18	2.85	21.3
20M	89.22	.44	1.93		23.2
25M	89.65	.43	2.21		25.4
30M	90.07	.42	2.44	6.58	27.8
35M	90.48	.41	3.04		30.9
40M	90.89	.41	3.25		34.1
45M	91.30	.41	3.54	9.83	37.7
50M	91.71	.41	6.88		44.6
55M	92.12	.41	8.06		52.6
5H00M	92.53	.41	7.48	22.42	60.1
5M	92.93	.40	6.49		66.6
10M	93.33	.40	5.50		72.1
15M	93.73	.40	4.33	16.32	76.4
20M	94.12	.39	2.95		79.4
25M	94.51	.39	2.66		82.0
30M	94.89	.38	2.56	8.17	84.6
35M	95.26	.37	1.68		86.3
40M	95.62	.36	1.51		87.8
45M	95.97	.35	1.43	4.62	89.2
50M	96.31	.34	1.38		90.6
55M	96.63	.32	1.35		91.9
6H 00M	96.93	.30	1.31	4.04	93.2
5M	97.21	.28	.69		93.9
10M	97.48	.27	.65		94.63
15M	97.74	.26	.62	1.96	95.25
20M	98.00	.26	.58		95.83
25M	98.26	.26	.56		96.39
30M	98.52	.26	.54	1.68	96.93
35M	98.77	.25	.53		97.46
40M	99.02	.25	.52		97.98
45M	99.27	.25	.52	1.57	98.50
50M	99.52	.25	.50		99.0
55M	99.76	.24	.50		99.52
7H 00M	100.00	.24	.50	1.50	100.0

District LOS ANGELES No.

Project ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM

Item STORM DURATION-INTENSITY AND INTENSITY PATTERN #4

Computed by CBP, TMC & ZZZ Checked by TMC & CBP Date 16 AUG 72

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
5M	5.54	5.54	.37		37
10M	10.94	5.40	.37		74
15M	16.24	5.30	.37	1.11	1.11
20M	21.46	5.22	.38		1.49
25M	26.60	5.14	.38		1.87
30M	31.55	4.95	.38	1.14	2.25
35M	35.20	3.65	.38		263
40M	38.30	3.10	.38		3.01
45M	40.95	2.65	.39	1.15	3 40
50M	4334	2.39	.39		3.79
55M	45.65	2.31	.39		4.18
1H 00M	47.93	2.28	.40	1.18	4.58
5M	50.18	2.25	.40		4.98
10M	52.42	2.24	.41		5 39
15M	54.64	2.22	.42	1.23	5 81
20M	56.44	1.80	.44		6.25
25M	58.00	1.56	.46		6.71
30M	59.48	1.48	.48	1.38	7.19
35M	60.92	1.44	.49		7.68
40M	62.34	1.42	.50		8.18
45M	63.73	1.39	.51	1.50	8.69
50M	6497	1.24	.52		9.21
55M	66.05	1.08	.53		9.74
2H 00M	67.00	.95	.53	1.58	10.27
5M	67.90	.90	.53		10.80
10M	68.76	.86	54		11.34
15M	69.56	.80	.54	1.61	11.88
20M	70.30	.74	.54		1242
25M	70.99	.69	55		12.97
30M	71.66	.67	.55	1.64	13.52
35M	7232	.66	.55		14.07
40M	72.98	.66	.56		14.63
45M	73.64	.66	.57	1.68	15.20
50M	74.29	.65	.58		15.78
55M	74.93	.64	.59		16.37
3H 00M	75.57	.64	.60	1.77	16.97
5M	76.20	.63	.61		17.58
10M	76.83	.63	.61		18.19
15M	77.46	.63	.62	1.84	18.81
20M	78.09	.63	.62		19.43
25M	78.71	.62	.62		20.05
30M	79.33	.62	.62	1.86	20.67

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
3H35M	79.95	.62	.62		21.8
40M	80.57	.62	.62		21.91
45M	81.19	.62	.63	1.87	22.5
50M	81.81	.62	.63		23.1
55M	82.42	.61	.63		23.8
4H00M	83.03	.61	.63	1.89	24.4
5M	8363	.60	.95		25.3
10M	84.22	.59	1.08		26.4
15M	84.80	.58	1.24	3.27	27.7
20M	85.37	.57	2.22		29.9
25M	85.93	.56	2.24		32.16
30M	86.48	.55	2.25	6.71	34.4
35M	87.03	.55	2.65		37.0
40M	87.58	.55	3.10		40.1
45M	88.12	.54	3.65	9.40	43.8
50M	88.66	.54	5.30		49.1
55M	89.20	.54	5.54		546
5H00M	89.73	.53	5.40	16.24	60.0
5M	90.26	.53	5.22		65.2
10M	90.79	.53	5.14		70.41
15M	91.31	.52	4.95	15.31	75 3
20M	91.82	.51	2.39		77.7
25M	92.32	.50	2.31		80.06
30M	92.81	.49	2.28	6.98	82.34
35M	93.29	.48	1.80		84 19
40M	93.75	.46	1.56		85.70
45M	94.19	.44	1.48	4.84	87.18
50M	94.61	.42	1.44		[illegible]
55M	95.02	.41	1.42		90.04
6H 00M	95.42	.40	1.39	4.25	91.4
5M	95.82	.40	.90		92.3
10M	96.21	.39	.86		93.19
15M	96.60	.39	.80	2.56	93.99
20M	96.99	.39	.74		94.7
25M	97.37	.38	.69		9542
30M	97.75	.38	.67	2.10	96.0
35M	98.13	.38	.66		96.75
40M	98.51	.38	.66		97.41
45M	98.89	.38	.66	1.98	98.07
50M	99.26	.37	.65		98.72
55M	99.63	.37	.64		99.36
7H 00M	100.00	.37	.64	1.93	100.00

District LOS ANGELES No.
Project ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM
Item STORM DURATION-INTENSITY AND INTENSITY PATTERN #5
Computed by CBP & JJJ Checked by JJJ Date 16 AUG 72

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %			RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
5M	3.78	3.78	.43		.43		3H35M	76.15	.76	.76		25.
10M	7.43	3.65	.43		.86		40M	76.90	.75	.76		26.1
15M	10.98	3.55	.43	1.29	1.29		45M	77.64	.74	.76	2.28	26.8
20M	14.44	3.46	.43		1.72		50M	78.37	.73	.76		27.6
25M	17.83	3.39	.44		2.16		55M	79.09	.72	.76		28.4
30M	21.16	3.33	.44	1.31	2.60		4H00M	79.80	.71	.76	2.28	29.1
35M	24.45	3.29	.44		3.04		5M	80.50	.70	1.24		30.4
40M	27.71	3.26	.45		3.49		10M	81.20	.70	1.30		31.7
45M	30.94	3.23	.46	1.35	3.95		15M	81.89	.69	1.34	3.88	33.0
50M	34.13	3.19	.47		4.42		20M	82.58	.69	1.84		34.8
55M	37.27	3.14	.49		4.91		25M	83.26	.68	2.15		37.0
1H 00M	40.33	3.06	.51	1.47	5.42		30M	83.93	.67	2.68	6.67	39.7
5M	43.07	2.68	.53		5.95		35M	84.59	.66	3.23		42.9
10M	45.16	2.15	.54		6.49		40M	85.24	.65	3.26		46.2
15M	47.00	1.84	.54	1.61	7.03		45M	85.88	.64	3.29	9.78	49.4
20M	48.78	1.78	.55		7.58		50M	86.51	.63	3.55		53.0
25M	50.53	1.75	.56		8.14		55M	87.13	.62	3.78		56.8
30M	52.24	1.71	.57	1.68	8.71		5H00M	87.74	.61	3.65	10.98	60.4
35M	53.82	1.58	.57		9.28		5M	88.35	.61	3.46		63.9
40M	55.27	1.45	.58		9.86		10M	88.95	.60	3.39		67.3
45M	56.65	1.38	.59	1.74	10.45		15M	89.55	.60	3.33	10.18	70.6
50M	57.99	1.34	.60		11.05		20M	90.14	.59	3.19		73.84
55M	59.29	1.30	.60		11.65		25M	90.72	.58	3.14		76.9
2H 00M	60.53	1.24	.61	1.81	12.26		30M	91.29	.57	3.06	9.39	80.04
5M	61.66	1.13	.61		12.87		35M	91.86	.57	1.78		81.8
10M	62.68	1.02	.62		13.49		40M	92.42	.56	1.75		83.5
15M	63.62	.94	.63	1.86	14.12		45M	92.97	.55	1.71	5.24	85.28
20M	64.50	.88	.64		14.76		50M	93.51	.54	1.58		86.86
25M	65.34	.84	.65		15.41		55M	94.05	.54	1.45		88.31
30M	66.16	.82	.66	1.95	16.07		6H 00M	94.58	.53	1.38	4.41	89.6
35M	66.97	.81	.67		16.74		5M	95.09	.51	1.13		90.82
40M	67.77	.80	.68		17.42		10M	95.58	.49	1.02		91.84
45M	68.55	.78	.69	2.04	18.11		15M	96.05	.47	.94	3.09	92.78
50M	69.32	.77	.69		18.80		20M	96.51	.46	.88		93.66
55M	70.08	.76	.70		19.50		25M	96.96	.45	.84		94.50
3H 00M	70.84	.76	.70	2.09	20.20		30M	97.40	.44	.82	2.54	95.32
5M	71.60	.76	.71		20.91		35M	97.84	.44	.81		96.13
10M	72.36	.76	.72		21.63		40M	98.28	.44	.80		96.93
15M	73.12	.76	.73	2.16	22.36		45M	98.71	.43	.78	2.39	97.71
20M	73.88	.76	.74		23.10		50M	99.14	.43	.77		98.48
25M	74.64	.76	.75		23.85		55M	99.57	.43	.76		99.24
30M	75.40	.76	.75	2.24	24.60		7H 00M	100.00	.43	.76	2.29	100.00

District LOS ANGELES No.
Project ARIZONA AND VICINITY STANDARD PROJECT SUMMER THUNDERSTORM
Item STORM DURATION-INTENSITY AND INTENSITY PATTERN #6
Computed by CBP&JJJ Checked by JJJ Date 16 AUG 72

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
5M	2.99	2.99	.54		.54
10M	5.95	2.96	.54		1.08
15M	8.88	2.93	.55	1.63	1.63
20M	11.79	2.91	.55		2.18
25M	14.68	2.89	.55		2.73
30M	17.56	2.88	.56	1.66	3.29
35M	20.43	2.87	.56		3.85
40M	23.29	2.86	.56		4.41
45M	26.12	2.83	.57	1.69	4.98
50M	28.86	2.74	.59		5.57
55M	31.48	2.62	.61		6.18
1H 00M	33.91	2.43	.63	1.83	6.81
5M	36.17	2.26	.64		7.45
10M	38.30	2.13	.65		8.10
15M	40.29	1.99	.65	1.94	8.75
20M	42.13	1.84	.65		9.40
25M	43.84	1.71	.66		10.06
30M	45.45	1.61	.66	1.97	10.72
35M	47.01	1.56	.66		11.38
40M	48.53	1.52	.67		12.05
45M	50.00	1.47	.67	2.00	12.72
50M	51.41	1.41	.68		13.40
55M	52.76	1.35	.68		14.08
2H 00M	54.03	1.27	.69	2.05	14.77
5M	55.23	1.20	.69		15.46
10M	56.36	1.13	.70		16.16
15M	57.41	1.05	.71	2.10	16.87
20M	58.34	.93	.74		17.61
25M	52.25	.91	.78		18.39
30M	60.15	.90	.81	2.33	19.20
35M	61.05	.90	.82		20.02
40M	61.95	.90	.83		20.85
45M	62.85	.90	.83	2.48	21.68
50M	63.75	.90	.84		22.52
55M	64.64	.89	.84		23.36
3H 00M	65.52	.88	.84	2.52	24.20
5M	66.39	.87	.84		25.04
10M	67.26	.87	.85		25.89
15M	68.12	.86	.85	2.54	26.74
20M	68.98	.86	.85		27.59
25M	69.84	.86	.85		28.44
30M	70.70	.86	.86	2.56	29.30

	RANKED INTENSITY-DURATION %	5-MIN INCREMENTS OF RANKED INTENSITY-DURATION %	5-MIN INTENSITY PATTERN %	15-MIN INTENSITY PATTERN %	ACCUM INTENSITY PATTERN %
3H35M	71.56	.86	.86		30.1
40M	72.41	.85	.86		31.0
45M	73.26	.85	.86	2.58	31.8
50M	74.11	.85	.86		32.7
55M	74.96	.85	.87		33.6
4H00M	75.80	.84	.87	2.60	34.4
5M	76.64	.84	1.27		35.7
10M	77.48	.84	1.35		37.1
15M	78.32	.84	1.41	4.03	38.5
20M	79.15	.83	1.99		40.5
25M	79.98	.83	2.13		42.6
30M	80.80	.82	2.26	6.38	44.8
35M	81.61	.81	2.83		47.7
40M	82.39	.78	2.86		50.5
45M	83.13	.74	2.87	8.56	53.4
50M	83.84	.71	2.93		56.3
55M	84.54	.70	2.99		59.3
5H00M	85.23	.69	2.96	8.88	62.3
5M	85.92	.69	2.91		65.2
10M	86.60	.68	2.89		68.1
15M	87.28	.68	2.88	8.68	71.01
20M	87.95	.67	2.74		73.7
25M	88.62	.67	2.62		76.3
30M	89.28	.66	2.43	7.79	78.8
35M	89.94	.66	1.84		80.6
40M	90.60	.66	1.71		82.3
45M	91.25	.65	1.61	5.16	83.96
50M	91.90	.65	1.56		85.52
55M	92.55	.65	1.52		87.04
6H 00M	93.19	.64	1.47	4.55	88.51
5M	93.82	.63	1.20		89.71
10M	94.43	.61	1.13		90.84
15M	95.02	.59	1.05	3.38	91.89
20M	95.59	.57	.93		92.82
25M	96.15	.56	.91		93.73
30M	96.71	.56	.90	2.74	94.63
35M	97.27	.56	.90		95.53
40M	97.82	.55	.90		96.43
45M	98.37	.55	.90	2.70	97.33
50M	98.92	.55	.90		98.23
55M	99.46	.54	.89		99.12
7H 00M	100.00	.54	.88	2.67	100.00

APPENDIX 1-F

Depth-area reduction curve from NOAA Atlas 2

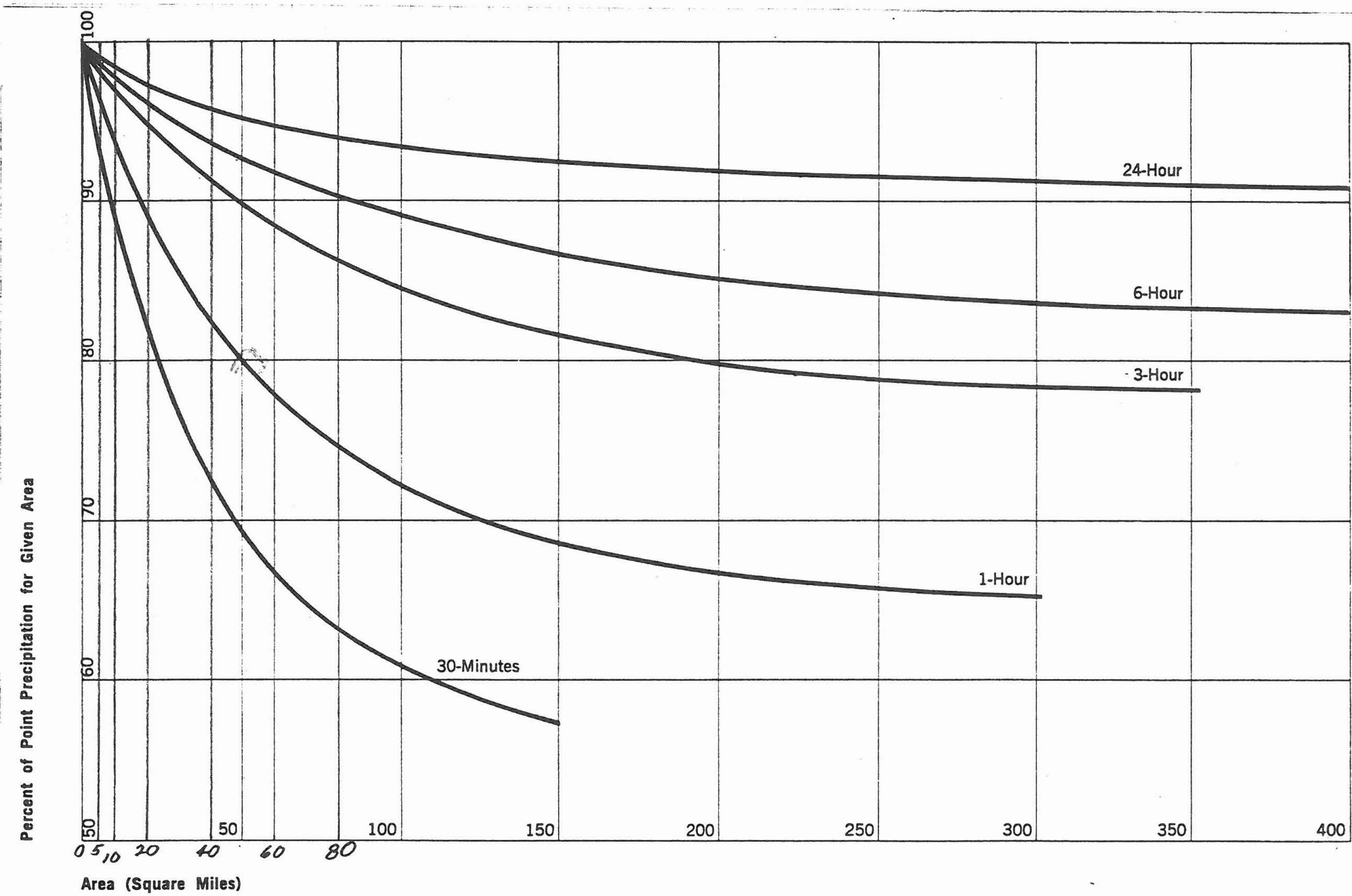


Figure 14. *Depth-Area curves.* From NOAA Atlas 2

APPENDIX 1-H

Depth-Area Ratios in the Semi-arid Southwest United States, NWS HYDRO-40 (Zehr and Myers, 1984)

Please insert a copy of NWS-HYDRO 40. My copy is badly marked-up.

APPENDIX 1-I

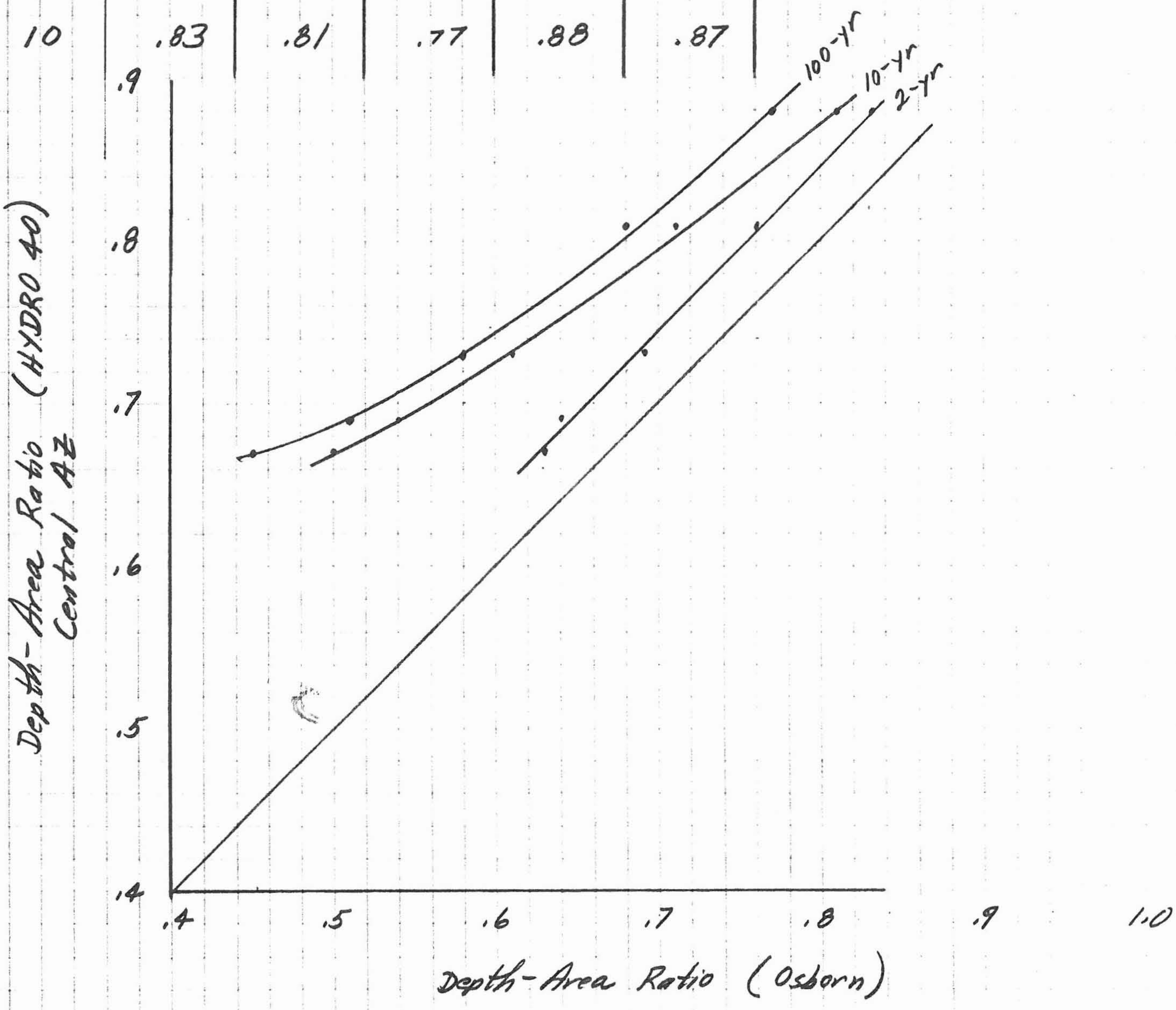
Comparisons of depth-area curves

5 Aug 88

Comparison of Depth-Area Ratios from Osborn & others (1980) and HYDRO 40 (1984)

Storm Duration = 6 hr

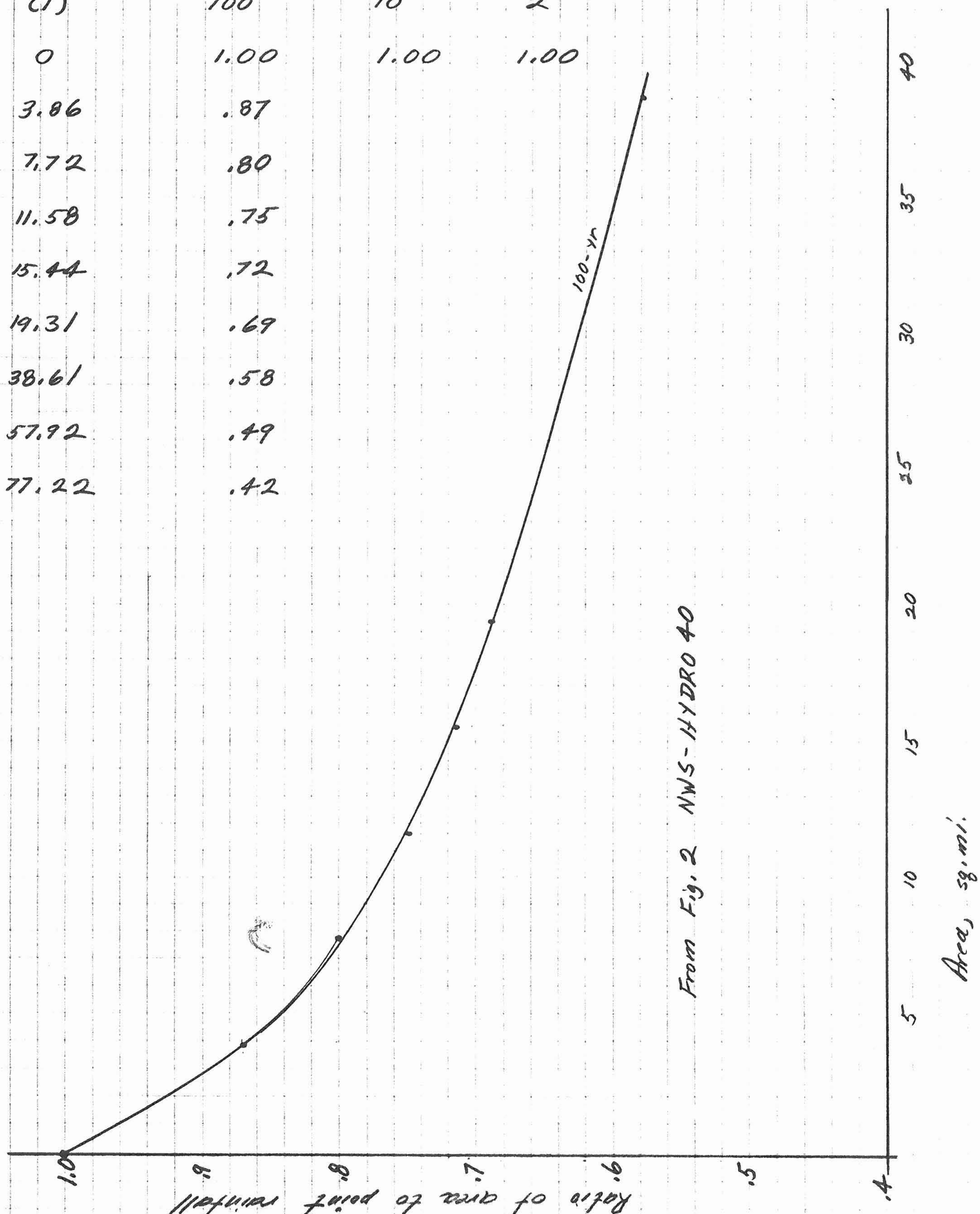
Area sq. mi.	Osborn 2-yr	Osborn 10-yr	Osborn 100-yr	HYDRO 40 Central AZ	HYDRO 40 SE AZ
80	.63	.50	.45	.67	.61
60	.64	.54	.51	.69	.63
40	.69	.61	.58	.73	.65
20	.76	.71	.68	.81	.72
10	.83	.81	.77	.88	.87



am Dg
11 July 88

2-hour Depth-Area Rainfall Reduction Ratios

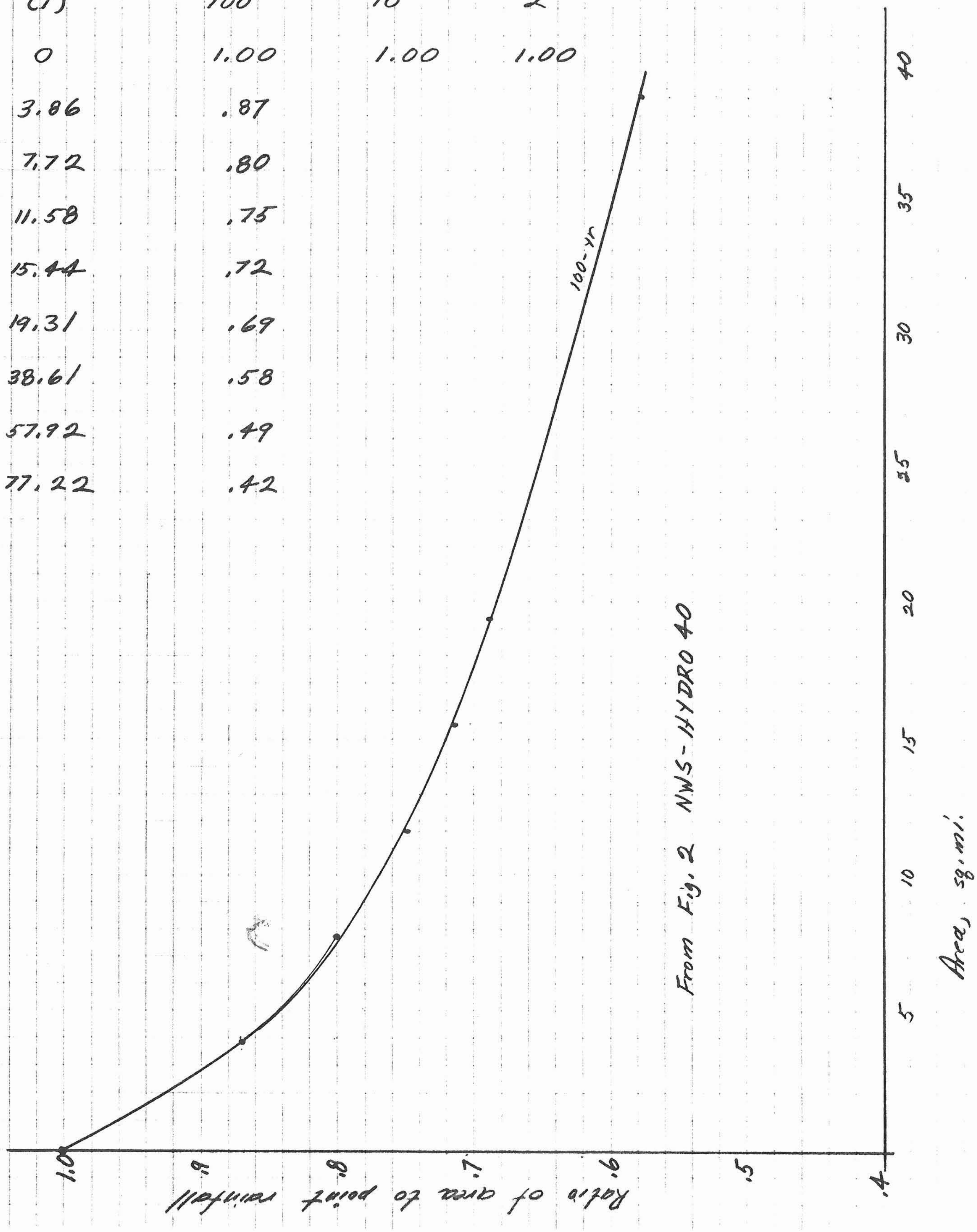
Area sq. mi. (1)	Return Period, in years 100	10	2
0	1.00	1.00	1.00
3.86	.87		
7.72	.80		
11.58	.75		
15.44	.72		
19.31	.69		
38.61	.58		
57.92	.49		
77.22	.42		



am Dg
11 July 88

2-hour Depth-Area Raintall Reduction Ratios

Area sq. mi. (1)	Return Period, in years 100	10	2
0	1.00	1.00	1.00
3.86	.87		
7.72	.80		
11.58	.75		
15.44	.72		
19.31	.69		
38.61	.58		
57.92	.49		
77.22	.42		



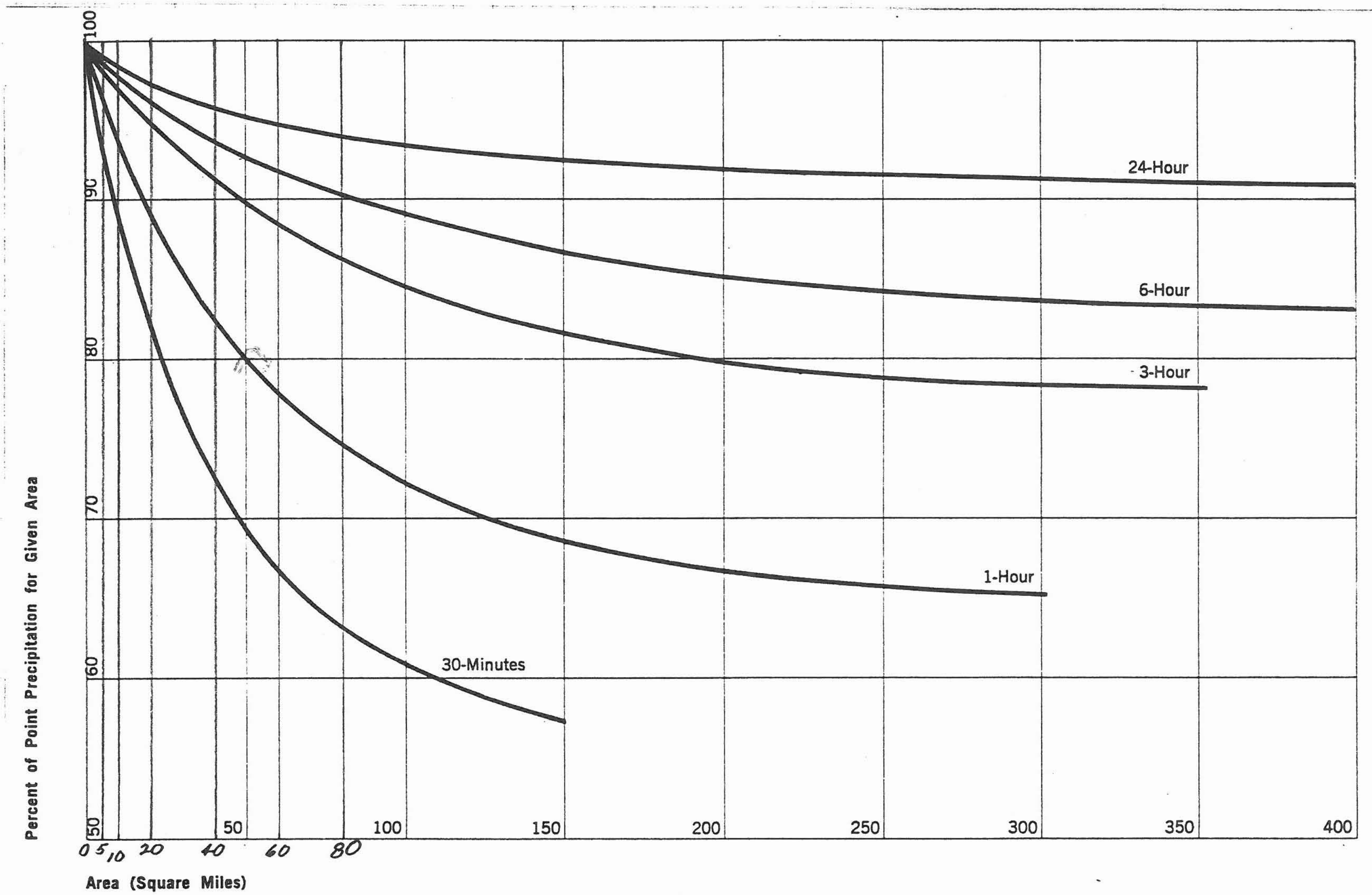


Figure 14. *Depth-Area curves.* From NOAA Atlas 2

this network are not routinely published and only recently have been available in a computer compatible form. (They were not available for the earlier atlases.) The results of this analysis for durations from 30 min to 6 hrs are reproduced in figure 2 and show significant differences from the national average curves. At Walnut Gulch, the depth-area ratios decrease more rapidly with increasing area than those published in NOAA Atlas 2 (Miller et al. 1973).

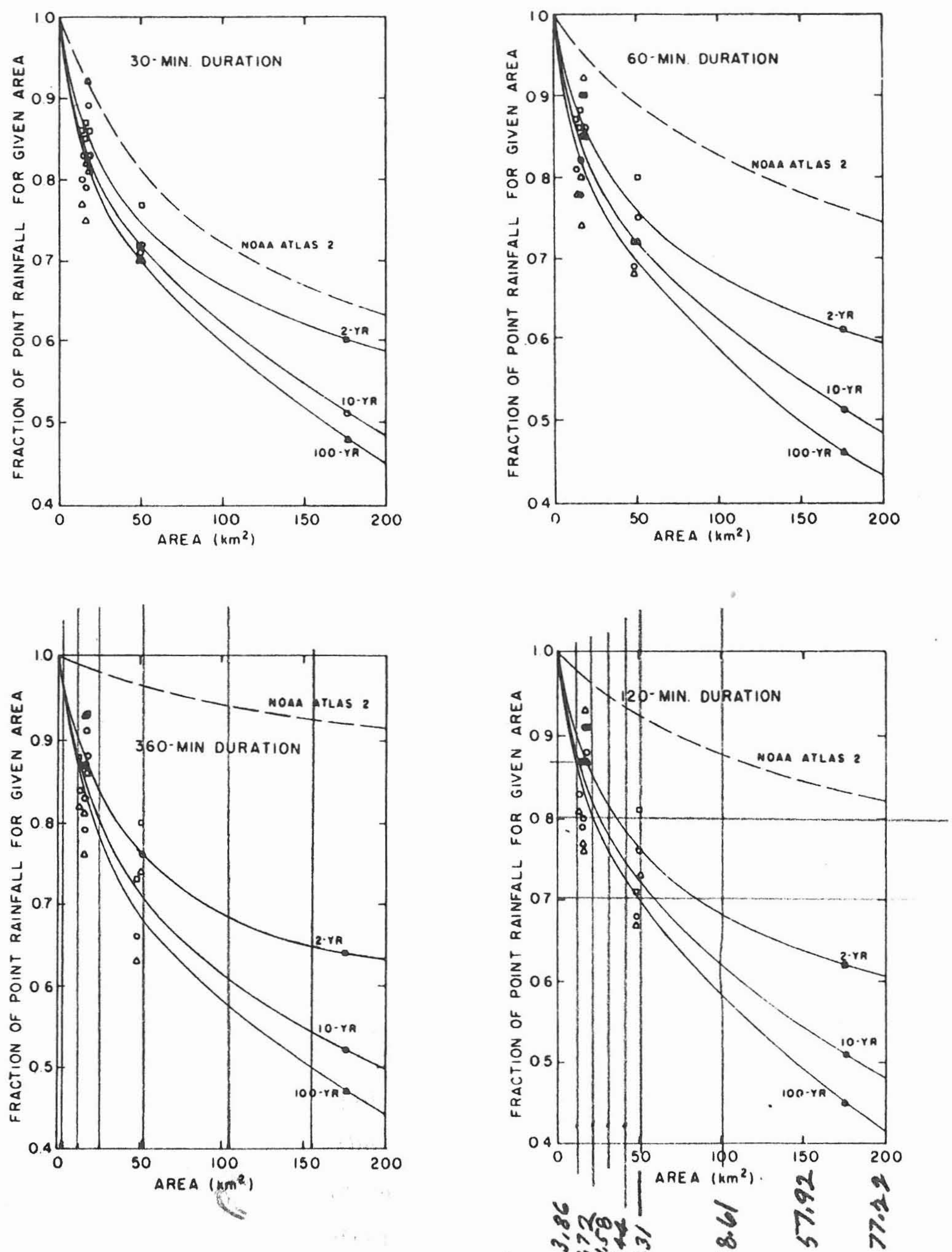


Figure 2.--Depth-area ratios at Walnut Gulch, Arizona, for durations of 30-min, 1-, 2-, and 6-hr (Osborn et al. 1980).

4.44 km²/mm   2.59 km² = 1 mi²   1.71 mi²/mm

FIG. 11 Recording raingage network and subwatersheds used in determining frequency distributions for Alamogordo Creek.

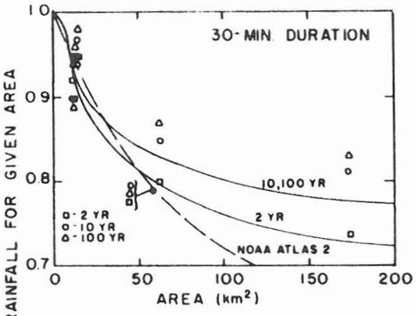
Gulch), the depth-area curves for Walnut Gulch are believed to be characteristic of much of southwestern Arizona, southwestern New Mexico, and north central Mexico.

Alamogordo Creek

The Alamogordo Creek Watershed data were analized identically to that for Walnut Gulch for 174, 59, 63, 15, 12, 13, 14 and 0 km² areas. The network is depicted in Fig. 11 along with the sub-areas. The average values were derived from all gages within the respective boundaries. Twenty-one well spaced gages with complete 20-yr records (1957-1976) were used to develop point frequencies for comparison to the 174 km² area, and all the indicated gages for the sub-area comparisons. For the latter, the same rules and procedures were used as for Walnut Gulch. In this case, the computed 100-yr depth-area curve lay above the 10-yr curve, but the difference was so slight that its reality is uncertain, and the 10-yr and 100-yr curves have been combined. The resulting depth-area curves are in Figs. 12-15.

The amounts and distributions of thunderstorm rainfall on the Alamogordo Creek Watershed are typical of the high plains in eastern New Mexico and western Texas. The extreme events can occur from either pure air-mass thunderstorms (as on Walnut Gulch) or a combination of frontal activity and convective heating (which is unusual on Walnut Gulch). The rainfalls that are largest both in area covered and depth result from the latter situation. Because of this, for similar durations and frequencies, maximum rainfall on Alamordo Creek is about 10 to 15 mm greater than that on Walnut Gulch.

The major events on Alamogordo Creek also cover larger areas than those on Walnut Gulch, and depth-area ratios were considerably higher than those on Walnut Gulch. Infact, for a 30-min duration the depth-area curve from NOAA Atlas 2 lies generally below the Alamogordo Creek curves (Fig. 12). For longer durations, Alamordo Creek curves decreased more rapidly than the NOAA Atlas 2 curves to a maximum difference at about 80 km², and then they approach the NOAA



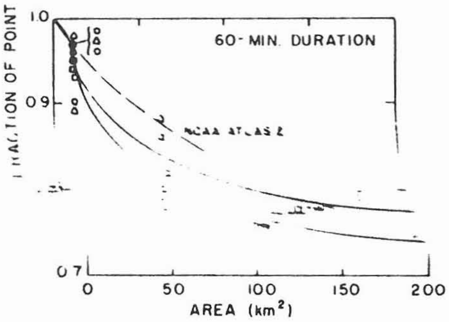
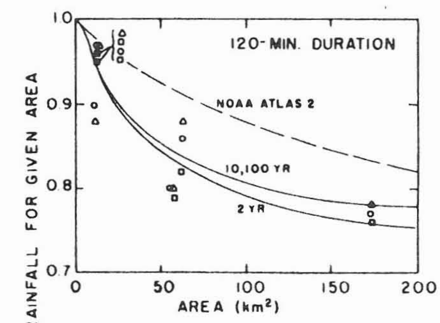


FIG. 12 (top) Point-to-area conversion ratios for 30-min duration rainfalls for selected frequencies on Alamogordo Creek.

FIG. 13 (bottom) Point-to-area conversion ratios for 60-min duration rainfalls for selected frequencies on Alamogordo Creek.

Atlas 2 curves. The range of annual average maximum watershed rainfall amounts varies much more on Alamogordo Creek than on Walnut Gulch because of the occasional massive frontal convective event. Average watershed rainfall was more variable than average point rainfall or area-to-point depth-area ratios for longer



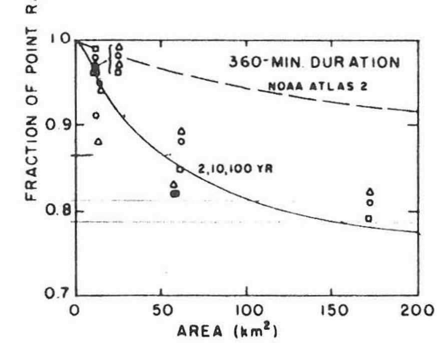


FIG. 14 (top) Point-to-area conversion ratios for 2-h duration rainfalls for selected frequencies on Alamogordo Creek.

FIG. 15 (bottom) Point-to-area conversion ratios for 6-h duration rainfalls for selected frequencies on Alamogordo Creek.

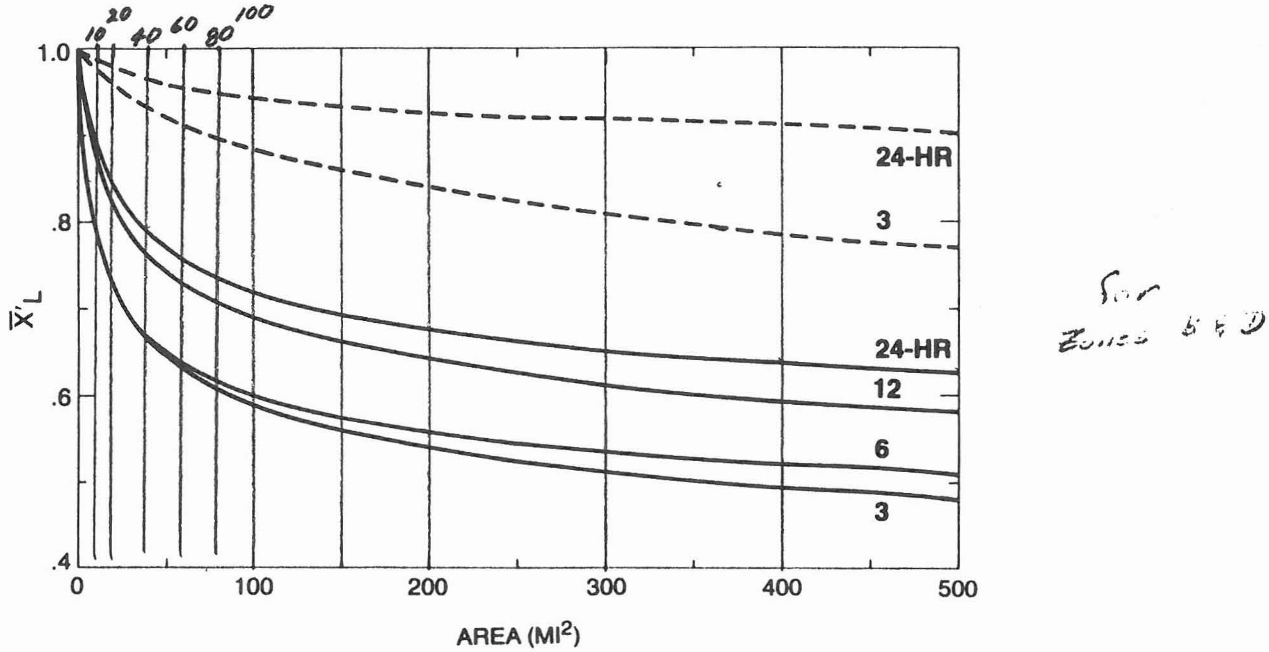


Figure 14.--$\bar{X}'_L$ (2.54-yr depth-area ratio, see sec. 4.3) for 3-, 6-, 12-, and 24-hr in southeast Arizona. Dashed lines are 3-hr and 24-hr Chicago $\bar{X}'_L$ (from TR 24)

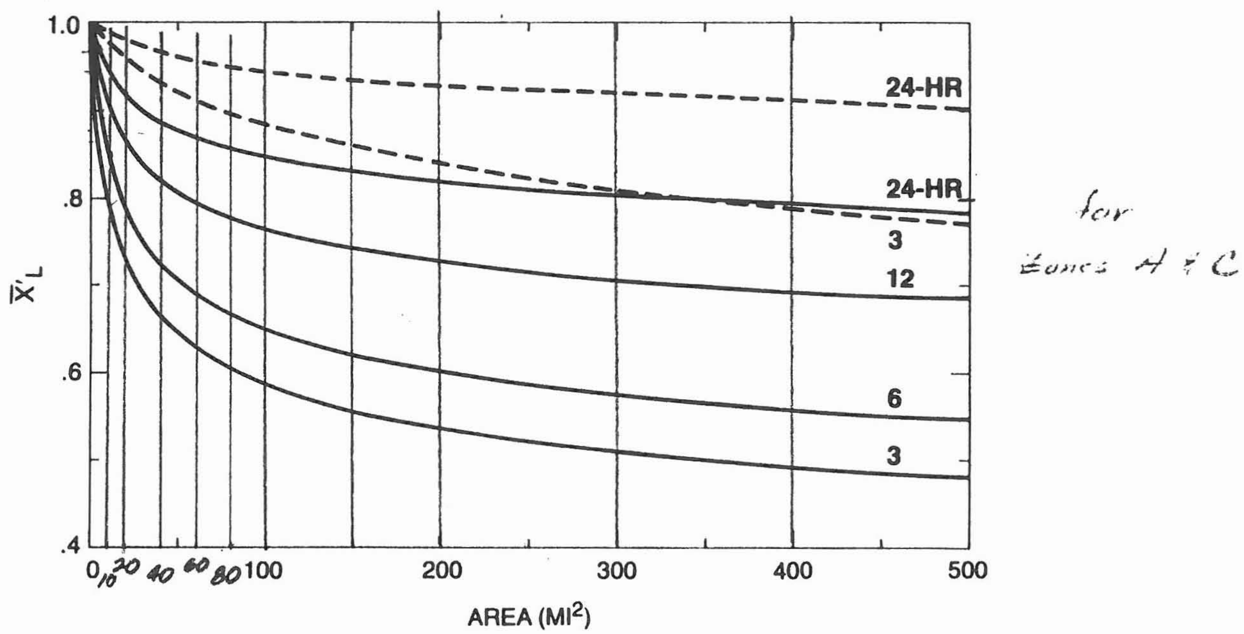


Figure 15.--Same as figure 14, but for central Arizona.

be attributed to a mixture of storm types, but still different from these found in the central Plains.

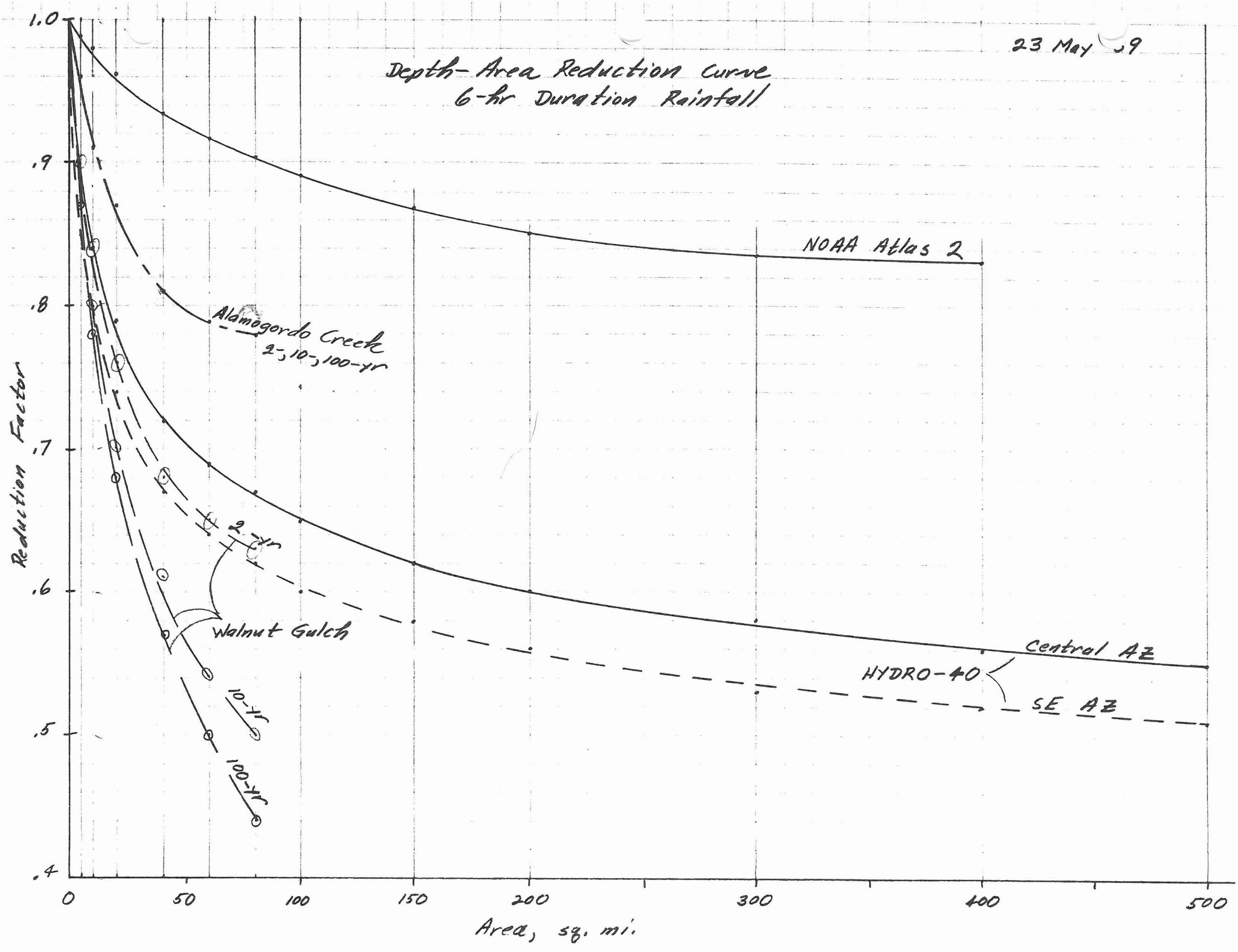
The recorder-pair data for distances greater than 15 mi contain little information on the structure of 1- and 2-hr storms. This is supported by the low

23 May 89

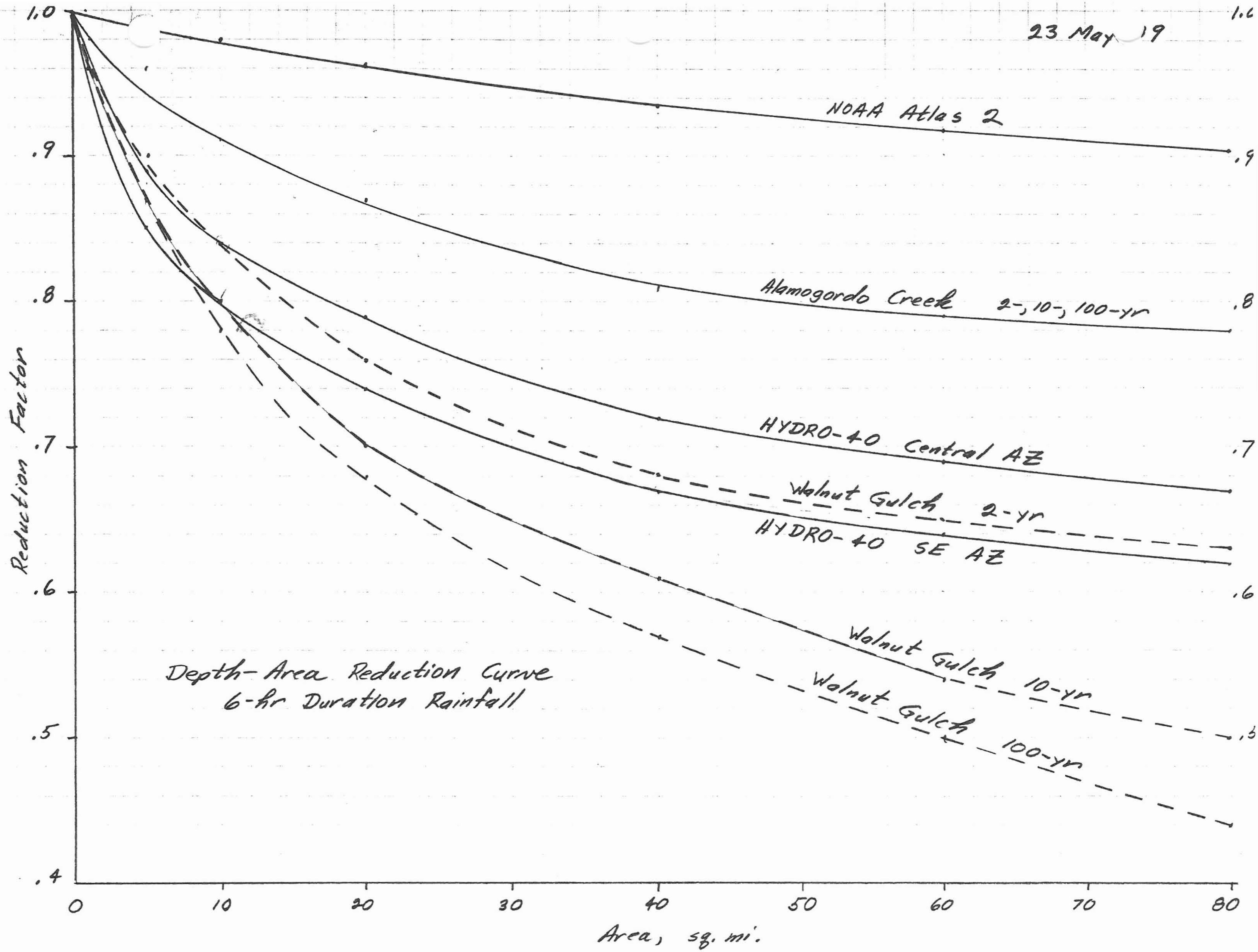
Comparison of Depth-Area Ratios for 6-hr duration rainfall

Area sq. mi.	NOAA Atlas 2 (1973)	Walnut Gulch (Osborn & others, 1980) 100-yr	10-yr	2-yr	HYDRO-40 (1984) Central AZ	SE AZ	Alamogordo Creek (Osborn & others, 1980) 100-, 10-, 2-yr
1	a	.96	.96	.96	a	a	.99
5	.987	.87	.87	.90	.89	.85	.96
10	.980	.78	.80	.84	.84	.80	.91
20	.961	.68	.70	.76	.79	.74	.87
40	.936	.57	.61	.68	.72	.67	.81
60	.918	.50	.54	.65	.69	.64	.79
80	.903	.44	.50	.63	.67	.62	.78
100	.891	c	c	c	.65	.60	c
150	.868				.62	.58	
200	.851				.60	.56	
300	.837				.58	.53	
400	.831				.56	.52	
500	b				.55	.51	

a – original graph cannot be read at 1 sq. mi.
b – graph ends at 400 sq. mi.
c – graph ends at 80 sq. mi.



23 May '69
Depth-Area Reduction Curve
6-hr Duration Rainfall
Reduction Factor
1.0
.9
.8
.7
.6
.5
.4
NOAA Atlas 2
Alamogordo Creek
2-, 10-, 100-yr
2-yr
Walnut Gulch
10-yr
100-yr
Central AZ
HYDRO-40
SE AZ
0
50
100
150
200
300
400
500
Area, sq. mi.



23 May 19
1.0
.9
.8
.7
.6
.5
.4
Reduction Factor
NOAA Atlas 2
Alamogordo Creek 2-, 10-, 100-yr
HYDRO-40 Central AZ
Walnut Gulch 2-yr
HYDRO-40 SE AZ
Walnut Gulch 10-yr
Walnut Gulch 100-yr
Depth-Area Reduction Curve
6-hr Duration Rainfall
0
10
20
30
40
50
60
70
80
Area, sq. mi.

23 May 89

Comparison of Depth-Area Ratios for 24-hour duration rainfall

Area sq. mi.	NOAA Atlas 2 (1973)	HYDRO-40				
		Central AZ	SE AZ	Walnut Gulch		
				100-yr	10-yr	2-yr
1	a	a	a	.90	.93	.99
5	.990	.96	.93	.78	.84	.95
10	.985	.93	.89	.72	.78	.90
20	.972	.92	.84	.66	.72	.85
40	.959	.89	.79	.59	.67	.80
60	.950	.87	.76	.56	.63	.77
80	.947	.85	.73	.54	.60	.75
100	.940	.83	.72	c	c	c
150	.933	.825	.69			
200	.925	.82	.68			
300	.913	.81	.65			
400	.910	.80	.64			
500	b	.79	.63			

a – original graph cannot be read at 1 sq. mi.
b – graph ends at 400 sq. mi.
c – graph ends at 80 sq. mi.

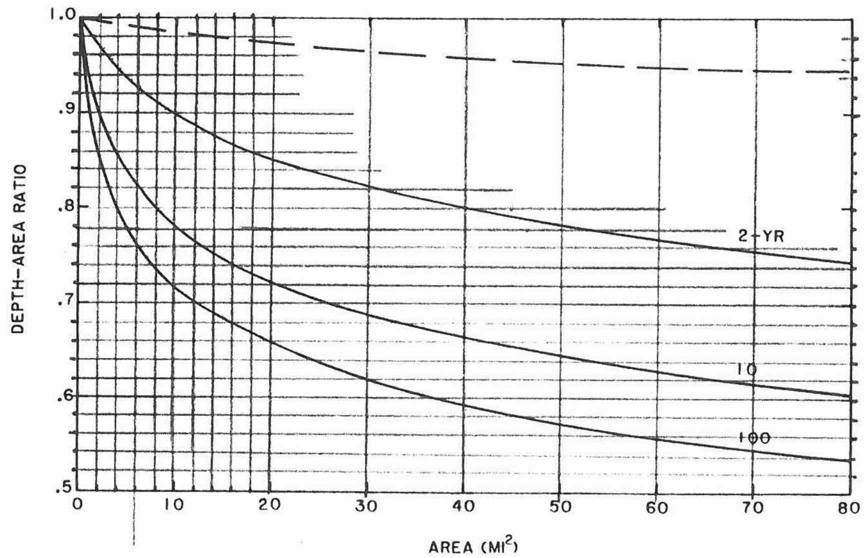


Figure 5.--24-hr depth-area ratio at Walnut Gulch for 2-, 10-, and 100-yr return periods. The dashed line is the NOAA Atlas 2 (Miller et al. 1973) 24-hr depth-area curve.

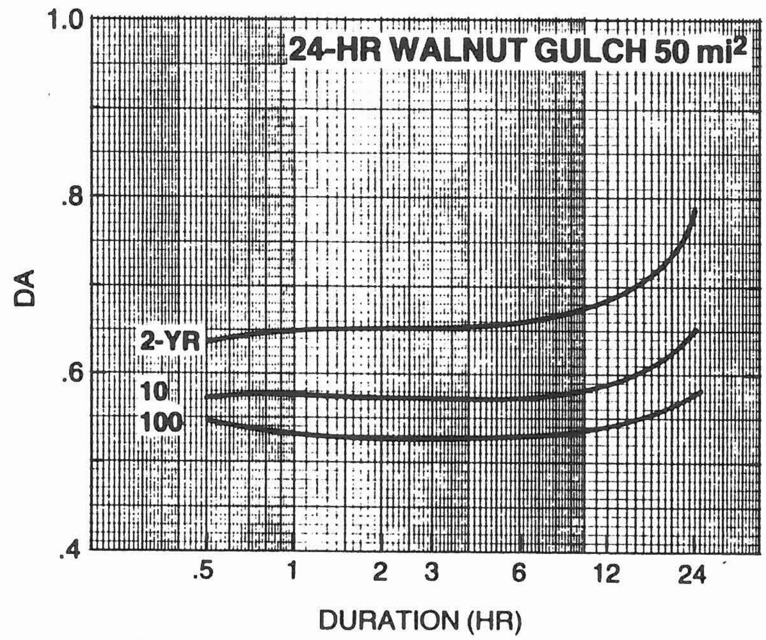


Figure 6.--Depth-area ratio vs. duration at 50 mi^2 (129.5 km^2) for 2-, 10-, and 100-yr return periods. The 24-hr Walnut Gulch results are combined with the Walnut Gulch depth-area ratios for 30 min, 1-hr, 2-hr, and 6-hr from Osborn et al. (1980).

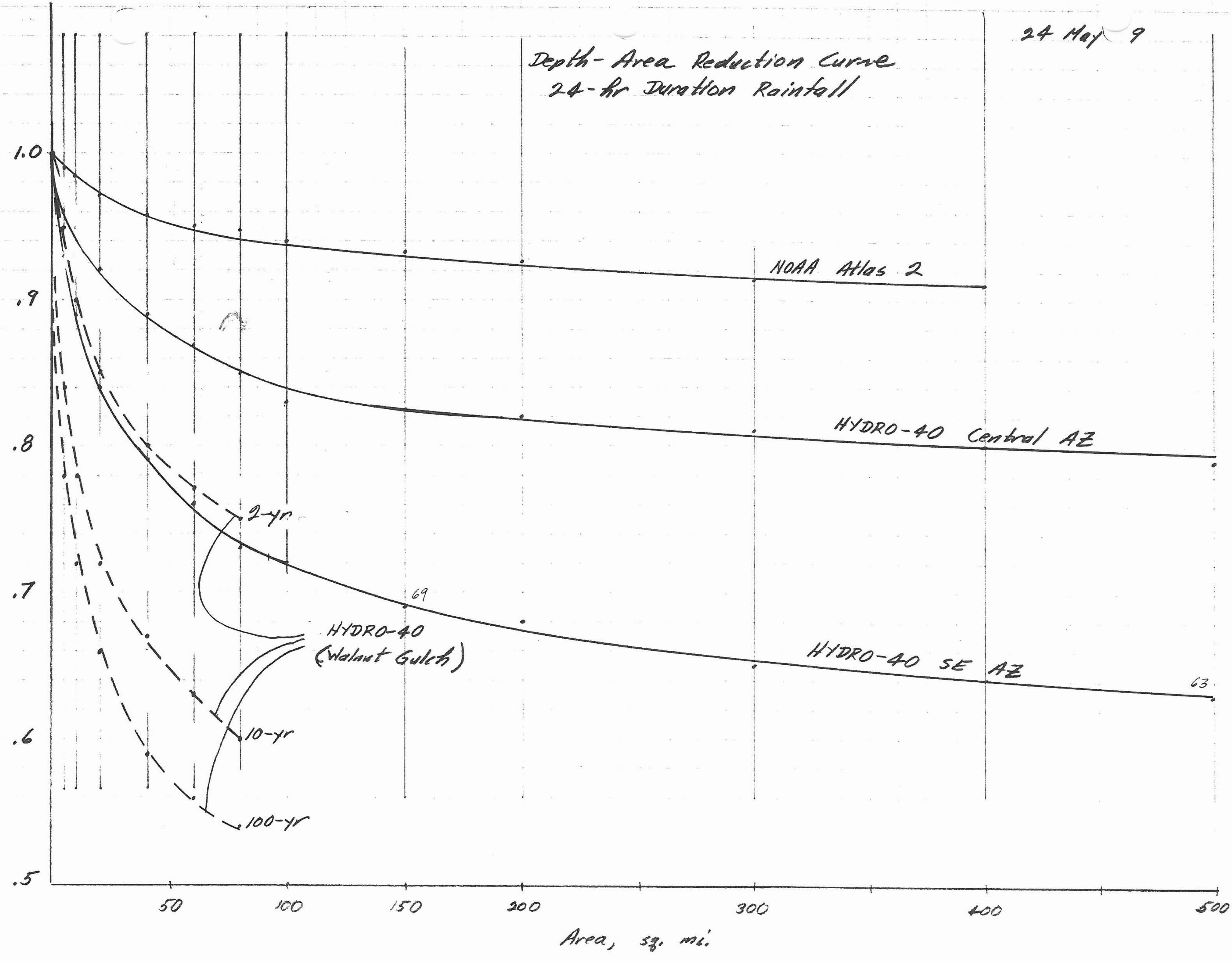
8 July 1988

Walnut Gulch

24-hour Depth-Area Rainfall Reduction Ratios

Area sq. mi (1)	Return Period, in years 100 (2)	10 (3)	2 (4)
less than 1	1.00	1.00	1.00
1	.90	.93	.99
2	.86	.90	.98
3	.82	.88	.97
4	.80	.86	.96
5	.78	.84	.95
6	.76	.82	.94
7	.75	.81	.93
8	.74	.80	.92
9	.73	.79	.91
10	.72	.78	.90
20	.66	.72	.85
30	.62	.69	.82
40	.59	.67	.80
50	.57	.65	.78
60	.56	.63	.77
70	.55	.61	.76
80	.54	.60	.75

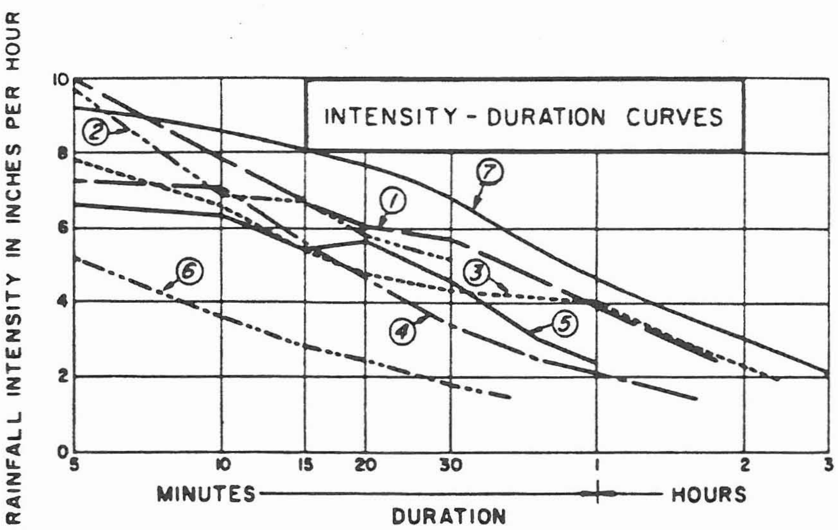
Note: Values are interpolated and in some cases smoothed from Figure 5 of NOAA Technical Memorandum NWS HYDRO-40 (1984).



24 May 9
Depth-Area Reduction Curve
24-hr Duration Rainfall
1.0
.9
.8
.7
.6
.5
NOAA Atlas 2
HYDRO-40 Central AZ
HYDRO-40 SE AZ
HYDRO-40
(Walnut Gulch)
2-yr
10-yr
100-yr
69
63
50
100
150
200
300
400
500
Area, sq. mi.

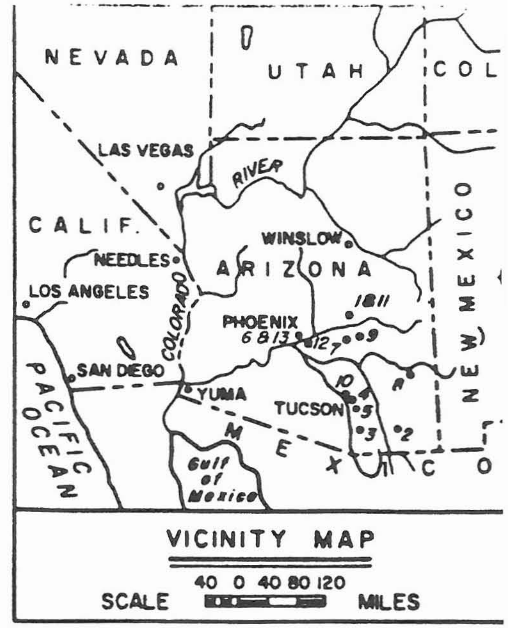
APPENDIX 1-J

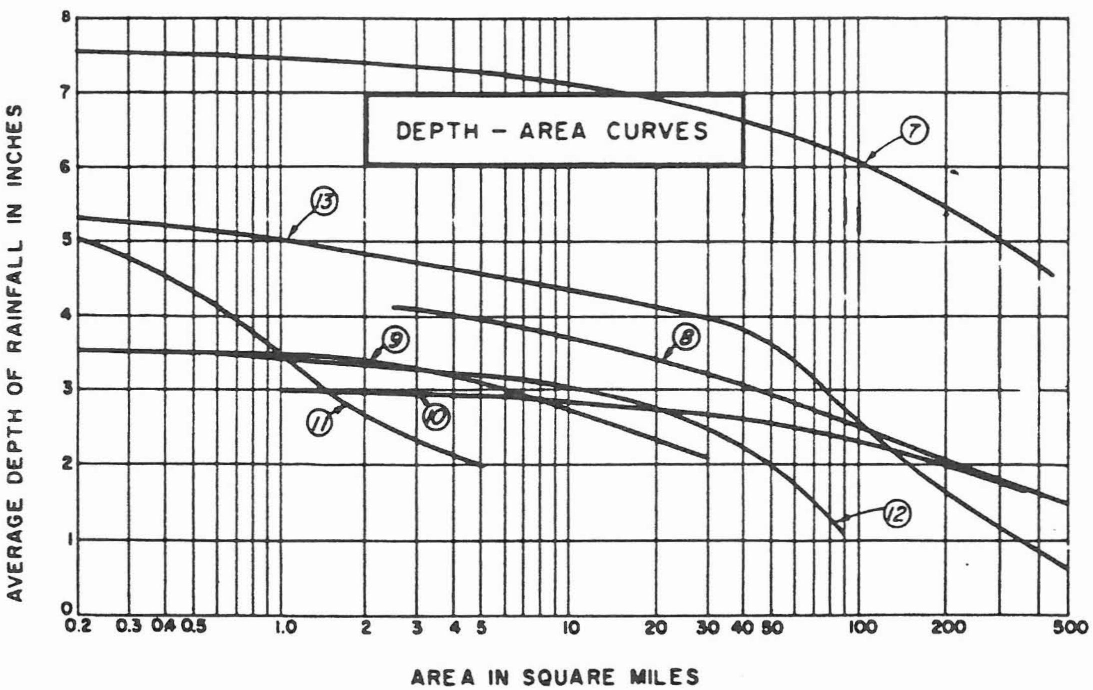
Queen Creek depth-area reduction curve
(U.S. Army Corps of Engineers, 1974)



NOTE:

INTENSITY-DURATION CURVE NO. 7 REPRESENTS APPROXIMATELY THE VALUES AT THE STORM CENTER AND IS SYNTHESIZED FROM DATA AT VARIOUS GAGES WITHIN THE STORM, SUPPLEMENTED BY INTENSITY-DURATION VALUES FROM OTHER CENTRAL ARIZONA STORMS WITH VERY SHORT DURATIONS. DATA FOR OTHER INTENSITY-DURATION CURVES ARE FOR STATIONS WITHIN THE STORM AREA BUT NOT NECESSARILY AT THE STORM CENTER.





CURVE NO.	STORM			
	LOCATION	DATE	APPROXIMATE DURATION	
			HRS.	MIN.
1	PARKER CREEK	SEPT. 10, 1933	1	45
2	WALNUT GULCH	OCT. 4-5, 1954	0	30
3	SANTA RITA	JUNE 29, 1959	2	20
4	UNIV. OF ARIZONA	AUG. 13, 1940	1	35
5	TUCSON AIRPORT	SEPT. 24, 1943	1	0
6	PHOENIX	JULY 26, 1936	0	40
7	QUEEN CREEK	AUG. 19, 1954	7	0
8	THATCHER	SEPT. 16, 1939	1	30
9	GLOBE	JULY 29, 1954	1	0
10	TUCSON	SEPT. 24, 1943	3	0
11	PARKER CREEK	AUG. 5, 1939	2	20
12	TEMPE	SEPT. 14, 1969	1	0
13	PHOENIX	JUNE 22, 1972	2	0

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

INTENSITY - DURATION AN
DEPTH - AREA CURVES

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

APPENDIX 1-K

Comparison of Design Rainfall Criteria for the Southwest

(Sabol and Stevens, 1990)

PURPOSE: DEVELOP THE FOLLOWING:

A - DEPTH - DURATION - FREQUENCY TABLE;

B - INTENSITY - DURATION - FREQUENCY TABLE;

C - DESIGN OF MASS CURVE FOR AREAS $\leq 0.5\ Mi^2$;

D - DESIGN OF MASS CURVE FOR AREAS $> 0.5\ Mi^2$.

A - DEPTH - DURATION - FREQUENCY TABLE:

LOCATION: CAREFREE AIRPORT AT T6N, R4E, SEC. 36.

(1) READ THE 6-HOUR AND 24-HOUR RAINFALL DEPTHS FOR THE 2-YEAR AND 100-YEAR FREQUENCY RETURN PERIODS, FROM THE ISOPLUVIALS IN THE HYDROLOGIC DESIGN MANUAL.

(2) USE PROGRAM PREFRE TO FIND RAINFALL DEPTHS FOR ALL OTHER FREQUENCIES AND DURATIONS (NEXT PAGE).

B - INTENSITY - DURATION - FREQUENCY TABLE:

LOCATION: CAREFREE AIRPORT AT T6N, R4E, SEC. 36.

(1) READ RAINFALL DEPTH VALUES FOR ALL DURATIONS FROM THE PREVIOUSLY DEVELOPED PREFRE TABLE AND CONVERT INTO THE INTENSITY VALUES AS FOLLOWS:

5-MIN. DURATION INTENSITY:

2-YEAR FREQUENCY: $\frac{.38\ (IN)}{5\ (MIN.)} \times \frac{60\ (MIN)}{HR} = 4.56\ IN/HR$

5-YEAR FREQUENCY: $\frac{.45\ (IN)}{5\ (MIN.)} \times \frac{60\ (MIN)}{HR} = 5.40\ IN/HR$

10-YEAR FREQUENCY: $\frac{.51\ (IN)}{5\ (MIN.)} \times \frac{60\ (MIN)}{HR} = 6.12\ IN/HR$

25-YEAR FREQUENCY: $\frac{.58\ (IN.)}{5\ (MIN.)} \times \frac{60\ (MIN)}{HR} = 6.96\ IN/HR$

50-YEAR FREQUENCY: $\frac{.64\ (IN)}{5\ (MIN.)} \times \frac{60\ (MIN)}{HR} = 7.68\ IN/HR$

100-YEAR FREQUENCY: $\frac{.71\ (IN)}{5\ (MIN.)} \times \frac{60\ (MIN)}{HR} = 8.52\ IN/HR$

*** O U T P U T   D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR CAVE CREEK AIRPORT, CAVE CREEK,
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 8

LATITUDE 33.52N   LONGITUDE 111.53W

POINT VALUES

RETURN PERIOD

DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.38	.45	.51	.58	.64	.71	.85	5-MIN
10-MIN	.57	.69	.77	.89	.99	1.08	1.30	10-MIN
15-MIN	.69	.85	.97	1.13	1.26	1.39	1.68	15-MIN
30-MIN	.92	1.14	1.30	1.53	1.70	1.88	2.29	30-MIN
1-HR	1.12	1.41	1.61	1.90	2.13	2.35	2.87	1-HR
2-HR	1.27	1.61	1.85	2.18	2.45	2.71	3.31	2-HR
3-HR	1.36	1.74	2.00	2.37	2.66	2.95	3.61	3-HR
6-HR	1.55	1.99	2.30	2.73	3.07	3.40	4.17	6-HR
12-HR	1.77	2.32	2.70	3.23	3.64	4.05	4.99	12-HR
24-HR	2.00	2.66	3.10	3.73	4.22	4.70	5.82	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE
FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=CAVE CREEK AIRPORT, CAVE CREEK,
ZONE= 7   SHORT-DURATION ZONE= 8
LATITUDE= 33.52   LONGITUDE= 111.53   ELEVATION= 0
2-YR, 6-HR PCPN= 1.55   100-YR, 6-HR PCPN= 3.40
2-YR, 24-HR PCPN= 2.00   100-YR, 24-HR PCPN= 4.70

* * * * E N D   O F   R U N * * * *

10-MIN. DURATION INTENSITY:

2-YEAR FREQUENCY: $\frac{.57(IN)}{10(MIN.)} \times \frac{60(MIN.)}{HR} = 3.42$ IN/HR

5-YEAR FREQUENCY: $\frac{.69(IN.)}{10(MIN.)} \times \frac{60(MIN.)}{HR} = 4.14$ IN/HR

10-YEAR FREQUENCY: $\frac{.77(IN.)}{10(MIN.)} \times \frac{60(MIN.)}{HR} = 4.62$ IN/HR

25-YEAR FREQUENCY: $\frac{.89(IN.)}{10(MIN.)} \times \frac{60(MIN.)}{HR} = 5.34$ IN/HR

50-YEAR FREQUENCY: $\frac{.99(IN.)}{10(MIN.)} \times \frac{60(MIN.)}{HR} = 5.94$ IN/HR

100-YEAR FREQUENCY: $\frac{1.08(IN)}{10(MIN)} \times \frac{60(MIN.)}{HR} = 6.48$ IN/HR

15-MIN. DURATION INTENSITY:

2-YEAR FREQUENCY: $\frac{.69(IN)}{15(MIN.)} \times \frac{60(MIN.)}{HR} = 2.76$ IN/HR

5-YEAR FREQUENCY: $\frac{.85(IN)}{15(MIN.)} \times \frac{60(MIN.)}{HR} = 3.40$ IN/HR

10-YEAR FREQUENCY: $\frac{.97(IN)}{15(MIN.)} \times \frac{60(MIN.)}{HR} = 3.88$ IN/HR

25-YEAR FREQUENCY: $\frac{1.13(IN)}{15(MIN.)} \times \frac{60(MIN.)}{HR} = 4.52$ IN/HR

50-YEAR FREQUENCY: $\frac{1.26(IN)}{15(MIN.)} \times \frac{60(MIN.)}{HR} = 5.04$ IN/HR

100-YEAR FREQUENCY: $\frac{1.39(IN)}{15(MIN.)} \times \frac{60(MIN.)}{HR} = 5.56$ IN/HR

THE ABOVE CALCULATIONS IS CARRIED OUT FOR ALL DURATIONS UP TO THE 24-HOUR DURATION.

THE RESULTS ARE SHOWN ON THE NEXT PAGE'S TABLE, AND THE GRAPH FOLLOWS.

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT Documentation Manual PAGE 3 OF 7

DETAIL Development of Design Rainfall Input COMPUTED ______ DATE ______

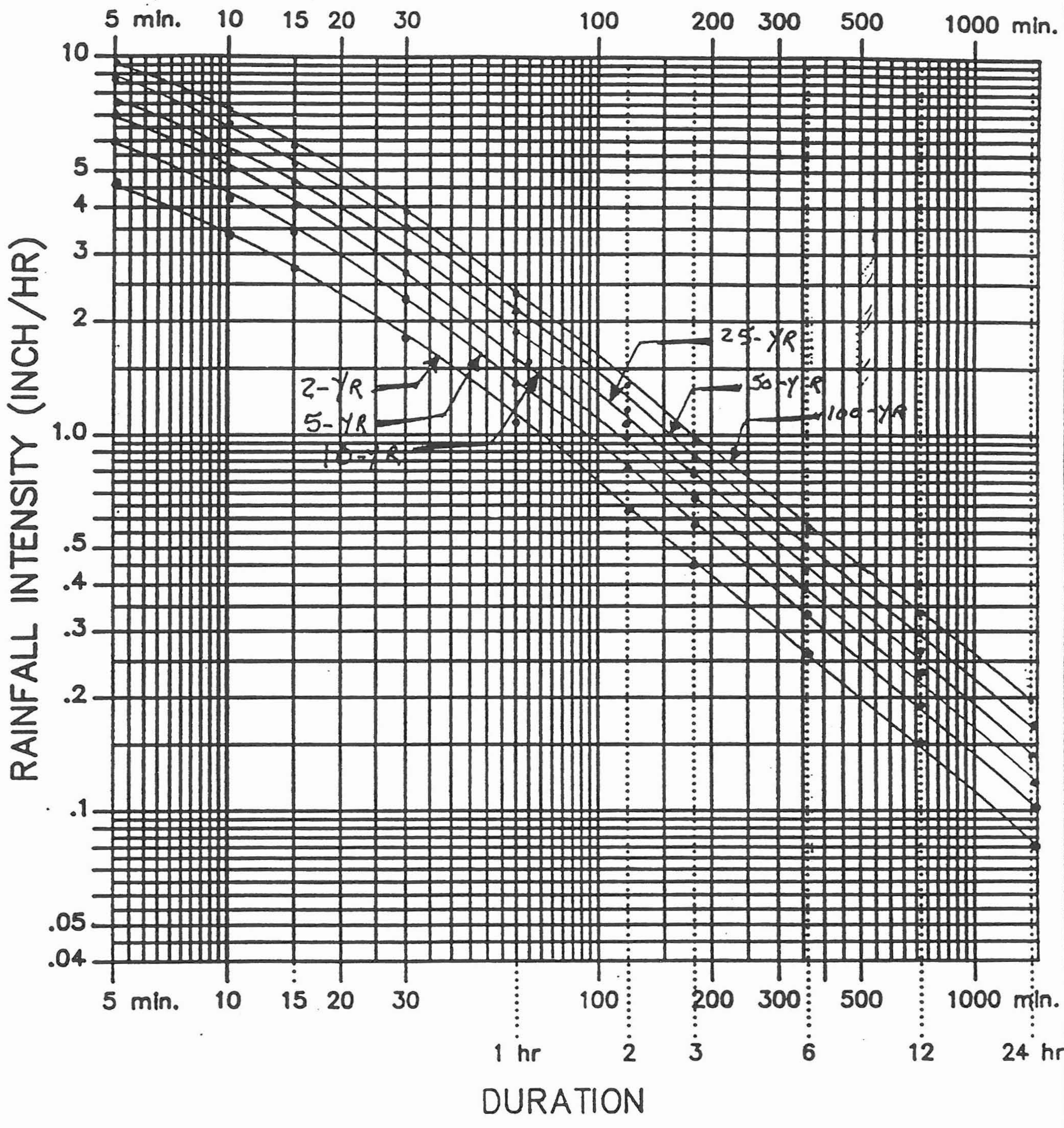
CHECKED BY ______ DATE ______

INTENSITY – DURATION – FREQUENCY TABLE

FOR CAREFREE AIRPORT

(FREQUENCY)

(DURATION)	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
5-MIN.	4.56	5.40	6.12	6.96	7.68	8.52
10-MIN.	3.42	4.14	4.62	5.34	5.94	6.48
15-MIN.	2.76	3.40	3.88	4.52	5.04	5.56
30-MIN.	1.84	2.28	2.60	3.06	3.40	3.76
1-HOUR	1.12	1.41	1.61	1.90	2.13	2.35
2-HOUR	.64	.81	.93	1.08	1.23	1.36
3-HOUR	.45	.58	.67	.79	.89	.98
6-HOUR	.26	.33	.38	.46	.51	.57
12-HOUR	.15	.19	.23	.27	.30	.34
24-HOUR	.08	.11	.13	.16	.18	.20



RAINFALL INTENSITY–DURATION–FREQUENCY RELATION

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT DOCUMENTATION MANUAL PAGE 4 OF 7

DETAIL DEVELOPMENT OF DESIGN RAINFALL INPUT COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______

C- DESIGN OF MASS CURVES FOR AREAS ≤ 0.5 Mi^2.

PROBLEM: DESIGN A 100-YEAR, 6-HOUR RAINFALL MASS CURVE FOR A 0.2 Mi^2 BASIN IN THE CAREFREE AIRPORT AREA.

PROCEDURE: SINCE THE SIZE OF DRAINAGE AREA IS SMALLER THAN 0.5Mi^2, THE DEVELOPED MASS CURVE SHOULD BE SIMILAR TO PATTERN #1.

① ASSUMING A COMPUTATIONAL INTERVAL OF 15-MIN. DURATION, DESIGN A 6-HOUR MASS CURVE;

② CALCULATE 15-MIN. RAINFALL DEPTHS USING INFORMATION FROM PART A, WHICH WAS CALCULATED TO BE 1.39 IN. OTHER VALUES CALCULATED AS FOLLOWS:

15-MIN. DEPTH = 30-MIN. DEPTH − 15-MIN. DEPTH = 1.88 − 1.39 = 0.48 IN.

THIS VALUE IS THE MOST INTENSE PORTION OF RAINFALL DISTRIBUTION AND SHOULD BE PLACED AT THE CRITICAL LOCATION OF THE MASS CURVE. GENERALLY THIS VALUE IS PLACED AT THE CENTER OF THE MASS CURVE, UNLESS IF SUPPORTED BY ADDITIONAL INFORMATION. IN THIS EXAMPLE THE CRITICAL VALUE IS PLACED AT 45-MINUTES TO THE RIGHT OF CENTER, TO BE CONSISTENT WITH PATTERN #1 IN THE HYDROLOGIC DESIGN MANUAL. THIS IS AT TIME = 4:00.

30-MIN. DEPTH = (1-HOUR DEPTH − 30-MIN. DEPTH)/2 = (2.35 − 1.88)/2 = .24 IN.
THIS VALUE IS PLACED AT TIMES 3:30 AND 4:15.

1-HOUR DEPTH = (2-HOUR DEPTH − 1-HOUR DEPTH)/4 = (2.71 − 2.35)/4 = .09 IN.
THIS VALUE IS PLACED AT TIMES 3:00, 3:15, 4:30, AND 4:45.

1-HOUR DEPTH = (3-HOUR DEPTH − 2-HOUR DEPTH)/4 = (2.95 − 2.71)/4 = .06 IN.
THIS VALUE IS PLACED AT TIMES 2:30, 2:45, 5:00, AND 5:15.

3-HOUR DEPTH = (6-HOUR DEPTH − 3-HOUR DEPTH)/12 = (3.40 − 2.95)/12 = .0375 IN.

THIS VALUE IS PLACED AT TIMES 1:00 TO 2:15, AND 5:30 TO 6:00. SINCE THE DISTRIBUTION IS TERMINATED AT 6:00, THE LAST REMAIN, 3 VALUES ARE PLACED AT 0:15 TO 0:45 AS SHOWN IN THE FOLLOWING T.

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

PROJECT DOCUMENTATION MANUAL

DETAIL DEVELOPMENT OF DESIGN RAINFALL INPUT COMPUTED ______ DATE ______

CHECKED BY ______ DATE ______

DESIGN RAINFALL DISTRIBUTION TABLE

TIME (HOURS)	RAINFALL (INCHES)	CUM. RAINFALL (INCHES)
0:00	0.00	0.00
0:15	.0375	.0375
0:30	.0375	.075
0:45	.0375	.1175
1:00	.0375	.15
1:15	.0375	.1875
1:30	.0375	.225
1:45	.0375	.2625
2:00	.0375	.30
2:15	.0375	.3375
2:30	.06	.3975
2:45	.06	.4575
3:00	.09	.5475
3:15	.09	.6375
3:30	.24	.8775
3:45	.48	1.3575
4:00	1.39	2.7475
4:15	.24	2.9875
4:30	.09	3.0775
4:45	.09	3.1675
5:00	.06	3.2275
5:15	.06	3.2875
5:30	.0375	3.325
5:45	.0375	3.3625
6:00	.0375	3.40

D- DESIGN OF MASS CURVES FOR AREAS > 0.5 Mi^2:

PROBLEM: DESIGN A 100-YEAR, 6-HOUR RAINFALL MASS CURVE FOR A 5.0 Mi^2 WATERSHED IN THE CAREFREE AIRPORT AREA.

PROCEDURE: SINCE THE SIZE OF WATERSHED IS LARGER THAN 0.5 Mi^2, AREAL REDUCTION IS REQUIRED. FROM CHAPTER 2 OF THE HYDROLOGIC DESIGN MANUAL, REDUCTION COEFFICIENT FOR A 5.0 Mi^2 AREA IS 0.965. THIS WILL REDUCE RAINFALL DEPTH BY .965 (3.40) = 3.28 IN, WHERE 3.40 IS THE 100-YEAR, 6-HOUR RAINFALL DEPTH CALCULATED IN PART A OF THIS EXAMPLE. FROM CHAPTER 2 OF THE HYDROLOGIC DESIGN MANUAL, THE PATTERN DISTRIBUTION FOR THIS AREA IS BETWEEN PATTERN #2 AND PATTERN #3, IN THIS CASE IT IS PATTERN # 2.34.

TO DEVELOP THE CORRESPONDING MASS CURVE, VALUES FROM PATTERN #2 ARE ADDED TO 34% OF THE DIFFERENCE BETWEEN THE VALUES OF PATTERN #2 AND PATTERN #3 WHICH ARE LISTED IN CHAPTER 2 OF THE HYDROLOGIC DESIGN MANUAL. ONCE PATTERN # 2.34 IS CONSTRUCTED, ITS ELEMENTS ARE MULTIPLIED BY RAINFALL DEPTH (3.28 IN), WHICH CAN BE USED AS DIRECT INPUT INTO HEC-1.

TABLE OF NEXT PAGE ILLUSTRATES THE ABOVE PROCEDURE.

DESIGN RAINFALL WITH AREAL REDUCTION

TIME	PATTERN #2	PATTERN #3	.34(#3-#2)	PATTERN # 2.34	DESIGN RAINFALL
0:00	0.0	0.0	0.0	0.0	0.0
0:15	0.9	1.5	0.2	1.1	.036
0:30	1.6	2.0	0.1	1.7	.056
0:45	2.5	3.0	0.2	2.7	.089
1:00	3.4	4.8	0.5	3.9	.128
1:15	4.2	6.3	0.7	4.9	.161
1:30	5.1	7.6	0.9	6.0	.197
1:45	5.9	9.0	1.1	7.0	.230
2:00	6.7	10.5	1.3	8.0	.262
2:15	7.6	11.9	1.5	9.1	.298
2:30	8.7	13.5	1.6	10.3	.338
2:45	10.0	15.2	1.8	11.8	.387
3:00	12.0	17.5	1.9	13.9	.456
3:15	16.3	22.2	2.0	18.3	.600
3:30	25.2	30.4	1.8	27.0	.886
3:45	45.1	47.2	0.7	45.8	1.502
4:00	69.4	67.0	-0.8	68.6	2.250
4:15	83.7	79.6	-1.4	82.3	2.699
4:30	90.0	86.8	-1.1	89.9	2.949
4:45	93.8	91.2	-.9	92.9	3.047
5:00	95.0	94.6	-.1	94.9	3.113
5:15	96.3	96.0	-.1	96.2	3.155
5:30	97.5	97.3	-.1	97.6	3.201
5:45	98.8	98.7	0.0	98.8	3.241
6:00	100.0	100.0	0.0	100.0	3.280

THE INFORMATION FROM HEREON IS ONLY BACKGROUND TO THE RAINFALL DOCUMENTATION

PART 1

DESIGN RAINFALL

Development of Procedures

The selection process for appropriate design rainfall criteria, first focuses on the adequacy of point rainfall data available in Maricopa County and supporting documents from the rainfall analyses in Clark County, Nevada (Appendices 1-A and 1-B). This information also indicates that since the longest recorded data is from the gauge at Phoenix International Airport, it is the basis of all rainfall analyses for Maricopa County.

As the next step, the commonly used temporal distributions are evaluated. The most popular method is the 24-hour, SCS Type-II distribution, developed by the Soil Conservation Service. In addition, the Soil Conservation Service 24-hour, SCS Type II-A has been used in parts of Maricopa County. Also, the City of Phoenix has developed a 24-hour distribution for their analyses (City of Phoenix, 1988, and Appendix 1-C).

A comparison of the above methods indicates that both SCS Type II and SCS Type II-A are developed from data in New Mexico. Thus, while they may generally represent the conditions in the southwest, they are not necessarily the best available information for Maricopa County. The 24-hour, City of Phoenix distribution on the other hand is based on data from the Phoenix Airport rain gauge, which utilizes the information from Technical Paper No. 40, (U.S. Department of Commerce, 1961), and (U.S. Department of Commerce, 1969). However, a more recent procedure, NOAA Atlas 2 (U.S. Department of Commerce, 1973) includes the rainfall data through 1969, thus providing a more representative distribution.

The information provided in NOAA Atlas 2 is the only available source for Maricopa County at this time. The National Weather Service (NWS) in conjunction with the local governments is in the process of updating the rainfall data for the southwestern U.S. including Arizona. The new procedures when completed, should be used to revise all current analyses.

The procedures in NOAA Atlas 2 (Appendix 1-C), are used to first develop a Depth-Duration-Frequency (D-D-F) table, from which a 24-hour, temporal rainfall distribution is put together. The NWS PREFRE program is used to develop this table (Appendix 1-D). The 24-hour distribution is referred to as the Maricopa County Flood Control District (MCFCD) point rainfall distribution (Appendix 1-E). For durations of less than 1 hour a more recent analyses by Arkell and Richards, 1986 is used (Appendix 1-F). Secondly, the D-D-F table is used to develop an Intensity-Duration-Frequency I-D-F table and graph (Appendix 1-D). A comparison of various I-D-F tables are also included in Appendix 1-D.

Following development of the 24-hour MCFCD distribution, it is recognized that all critical elements of a design rainfall should be evaluated, and compared with available data, when possible. Such elements typically include frequency, depth, duration, spacial, and temporal distribution, and depth-area relations.

The rainfall frequency is normally based on an administrative decision and in this case it is decided to be of 100-year return interval, per Uniform Drainage Policies and Standards (Appendix 1-G). A point rainfall depth is then selected for a given frequency.

Following an evaluation of historic storm events in Maricopa County, and a visit with Dr. Charlie Pyke of the Los Angeles District, U.S. Army Corps of Engineers, the Queen Creek storm of August 19, 1954 is identified as the critical peak producing event in this region. The analyses by the U.S. Army Corps of Engineers for this historic storm is used to compare the elements of the new design rainfall (Appendix 1-H). The selection process for the design rainfall criteria is also communicated with Mr. John T. Pederson of the U.S. Army Corps of Engineers (Appendix 1-K).

A 7-hour rainfall duration is assigned for the August 19, 1954 storm by the U.S. Army Corps of Engineers (Appendix 1-H). This type of high intensity rainfall is representative of the peak producing events of the monsoon season in Maricopa County. A 24-hour duration, originally selected for the MCFCD distribution is more of a general type of storm. A 6-hour duration is selected for the design rainfall rather than a 7-hour duration for ease of hydrologic computations. This process only eliminates the first hour of the rainfall which is the least intense portion, and thus will not effect the integrity of the distribution.

The 1954 Queen Creek Storm also indicates a spacial variation of rainfall, i.e., pattern distribution as a function of drainage area, Appendix 1-H). As a result the 6-hour point rainfall distribution is used on areas of up to 0.5 square mile, which is also referred to as Pattern #1 (Appendix 1-I). The pattern distributions by the U.S. Corps of Engineers are modified to arrive at 4 additional patterns as a function of area size. Also, for a design temporal distribution, the high intensity portion of the rainfall is normally placed at the center of the storm if no supporting data is available. Since for the Queen Creek storm of 1954 the high intensity portion is at the approximate 60th percentile, Patterns #1 through #5 are shifted accordingly (Appendix 1-I). A 2-hour temporal distribution is also developed which is to be used for retention design (Appendix 1-I). A comparison of different rainfall design criteria is presented in Appendix 1-J.

For depth-area reduction coefficients, NOAA Atlas 2 (US Department of Commerce 1973) is normally used. However, the data in this case is for the entire southwest, which does not provide the best available information. An other source of data is HYDRO-40, (Appendix 1-L), which is developed for application in Arizona. However, the reduction coefficients are developed for areas of up to 80 square miles, with the majority of data from the Walnut Gulch, outside of Tucson. A comparison with some of the severe thunderstorms in Maricopa County indicates that coefficients given in HYDRO-40 would be too high for Maricopa County (Appendix 1-M). Since the Queen Creek storm of August 19, 1954 is used to compare all elements of the design rainfall, and since a depth-area relation is available for this event, it is selected as the appropriate depth-area relation for Maricopa County (Appendix 1-M).

In order to facilitate the use of the methods provided by the Hydrologic Design Manual, two FORTRAN codes are developed, i.e., MUCHP1 and MCUHP2. These programs are PC compatible, easy to use, and provide the required hydrologic information for a given basin in the form of a HEC-1 input file.

MCUHP1 provides the required rainfall pattern distribution with areal reduction, time of concentration, Tc, and retention coefficient, R, for the Clark hydrograph procedure, and the associated soil loss parameters.

MCUHP2 provides the require rainfall pattern distribution with areal reduction, the unit-graph calculated from either the Phoenix Mountain S-graph, or the Phoenix Valley S-graph, and the associated soil loss parameters.

A floppy diskette of MCUHP1 and MCUHP2 is included with Volume 1, Part 1 of the Documentation Manual.

REFERENCES

City of Phoenix (1988). Storm Drain Design Manual, Subdivision Drainage Design, Development Services, Infrastructure Review, July.

U.S. Department of Commerce (1961). Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, Technical Paper No. 40, Washington D.C.

U.S. Department of Commerce (1973). Precipitation-Frequency Atlas of the Western United States, by J. F. Miller, R. H. Fredrick, and R. J. Tracey, NOAA Atlas 2, Volume VIII, Arizona.

U.S. Department of Commerce (1969). Estimated Return Periods for Short Duration Precipitation in Arizona, by Paul C. Kangieser, Technical Memorandum WBTM WR-44.

Reviews

The following individual have contributed to the technical review and/or advising for the design rainfall section:

Robin McArthur (deceased), Soil Conservation Service, U.S. Department of Agriculture, Phoenix, Arizona.

Harry Milsaps, Soil Conservation Service, U.S. Department of Agriculture, Phoenix, Arizona.

Osborn, Herbert B. (retired), Arid Lands Watershed Management Research Unit, U.S. Department of Agriculture, Tucson, Arizona.

APPENDICES

PART 1 - DESIGN RAINFALL

1-A - Rainfall criteria and sources of data for Maricopa County.

1-B - Rainfall Analyses for Clark County, Nevada.

1-C - NOAA Atlas 2 procedures and analyses of City of Phoenix rainfall distribution by Arthur Beard Engineers, Inc.

1-D - Development of Depth-Duration-Frequency table, and Intensity-Duration-Frequency table and graph.

1-E - 24-hour, Maricopa County Flood Control District (MCFCD) distribution.

1-F - Short Duration Rainfall Relations for The Western United States, Arkell, Richard E., and Frank Richards, Conference on Climate and Water Management-A Critical Era and Conference on the Human Consequences of 1985's Climate, August 4-7, 1986, Ashville, N.C. Published by the American Meteorological Society, Boston, Mass.

1-G - Uniform Drainage Policies and Standards for Maricopa County, Arizona, Resolution FCD 87-7, Flood Control District of Maricopa County, April 20, 1987.

1-H - U.S. Corps of Engineers reports on the August 19, 1954, Queen Creek Storm.

1-I - 6-hour and 2-hour storm distributions for Maricopa County.

1-J - Comparison of different design rainfall criteria.

1-K - Letter of August 12, 1988 to Mr. John T. Pederson of the U.S. Army Corps of Engineers, By George V. Sabol.

1-L - U.S. Department of Commerce, Depth-Area Ratios in the Semi-Arid Southwest United States, NOAA Technical Memorandum HYDRO-40, Silver Spring, Md., August 1984.

Osborn Herbert B., Leonard J. Lane, Vance A. Myers. Rainfall/Watershed Relationships for Southwestern Thunderstorms, Soil and Water Division, ASAE, Paper No. 77-2541, May 1979.

1-M - Comparison of depth-area ratios for selected storms in Maricopa County.

1-N - Depth-area relationship for the Queen Creek Storm of 1954. Obtained from: U.S. Army Corps of Engineers, 1974, Gila River Basin, Arizona, New Mexico, and Phoenix City Streams, Design Memorandum No.1, Hydrology Part 1, Los Angeles District, 51 p.

DOCUMENTATION OF PATTERN # VERSUS DRAINAGE AREA

There are two graphs of drainage area versus pattern # as documented in the reports by the US Army Corps of Engineers, The 1954 Queen Creek storm; and the Gila River Basin, Hydrology Part 1, (enclosed). Neither one of these graphs could readily be utilized in the Hydrologic Design Manual due to the following reasons:

A. Graph #1 can be used for areas of up to 540 square miles. A semi-log plot of this graph indicates that Pattern #1 can be used for areas of up to 3.2 square miles. This appears to be too large since Pattern #1 should be used only on small areas including those represented by point rainfall.

B. GRAPH #2 can be used for areas of up to 1000 square miles. This graph also indicates that Pattern #1 can be used for up to 3.2 square miles. Use of this graph requires the 10-year, 6-hour rainfall depth at a given location. However, this graph produces a contradiction. The lowest 10-year, 6-hour depth in Maricopa County is 1.9", indicating that Pattern #1 can not be used at all, contradicting the statement that Pattern #1 can be used for areas of up to 3.2 square miles.

C. The Corps of Engineers analysis mainly focused on the development of drainage area versus pattern # for large watersheds. Mean while, the Hydrologic Design Manual will have a good part of its application for drainage analysis of small areas thus requiring a more refined break down of pattern #1.

D. The Hydrologic Design Manual removed Patterns #1 and #6 from the Corps analysis. Pattern #6 covers a significantly large aerial extent which appears to be beyond the limits of local summer thunderstorms. Pattern #1 was replaced by a more representative source of data from NOAA, Arkell & Richards

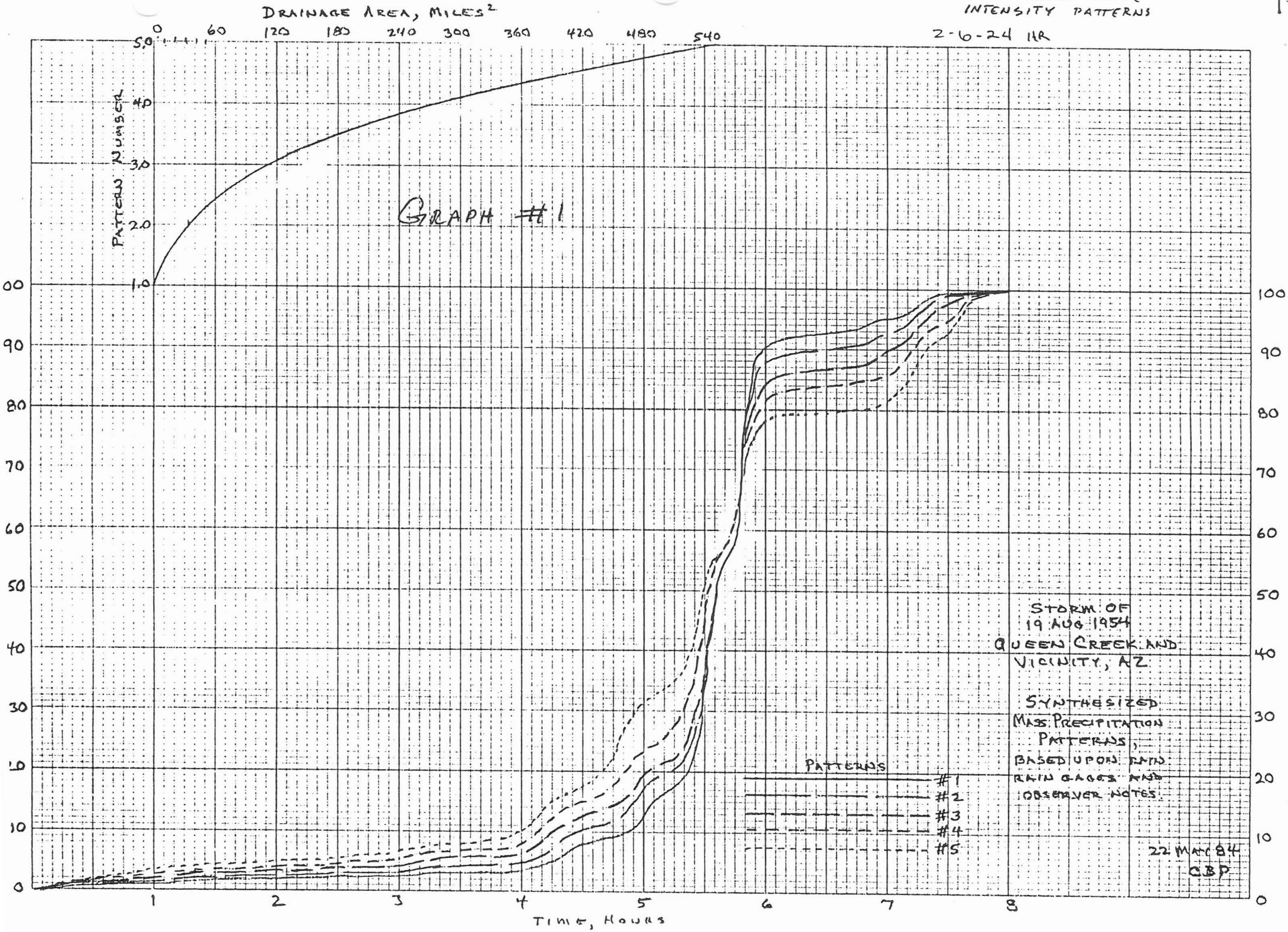
Above reasons justified the development a new graph for pattern # versus drainage area. This was accomplished by making two assumptions. First, at the upper limit, Pattern #5 should be used for a 500 square mile area. Then, at the lower limit, Pattern #1 should be used for areas of up to 0.5 square miles. It would not appear reasonable to extend Pattern #1 beyond 0.5 square miles due to the limitation on the aerial extent of point rainfall depth.

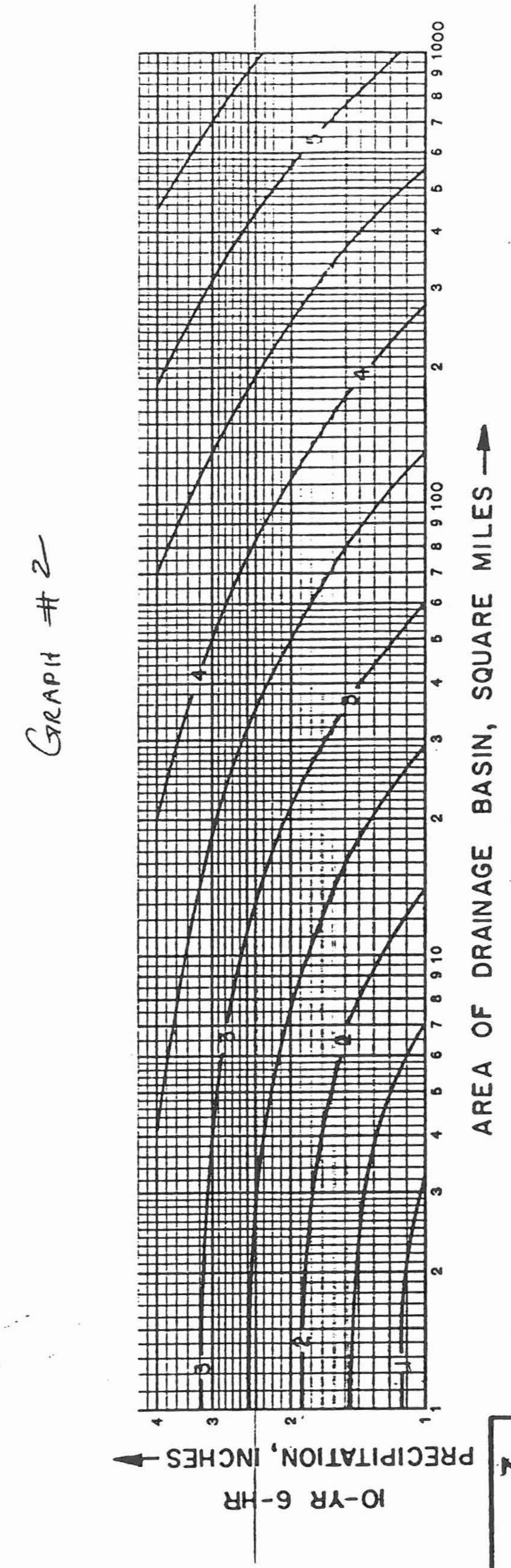
Then the data for 0.5 square miles and 500 square miles were plotted on a semi-logarithmic paper and associated drainage areas for Patterns #2 through #4 were determined, assuming a linear relationship. The assumption of linearity had to be made due to the lack of additional data points. The Corps of Engineers graph (Graph #1) is also plotted for comparison. Graph #2 is not shown since it is a function of rainfall depth at a particular location.

QUESTIONS:

1. Do we feel comfortable with the approach;
2. Do the upper and lower limits of drainage areas, i.e., 0.5 square miles and 500 square miles look reasonable;
3. Do we want to interpolate between the Corps graph and our two data points to come up with a non-linear relationship. Although, I don't seem to be able to justify that over the linear method.

STANDARD PROJECT AND
N-YEAR LOCAL STORM
INTENSITY PATTERNS
2-6-24 HR



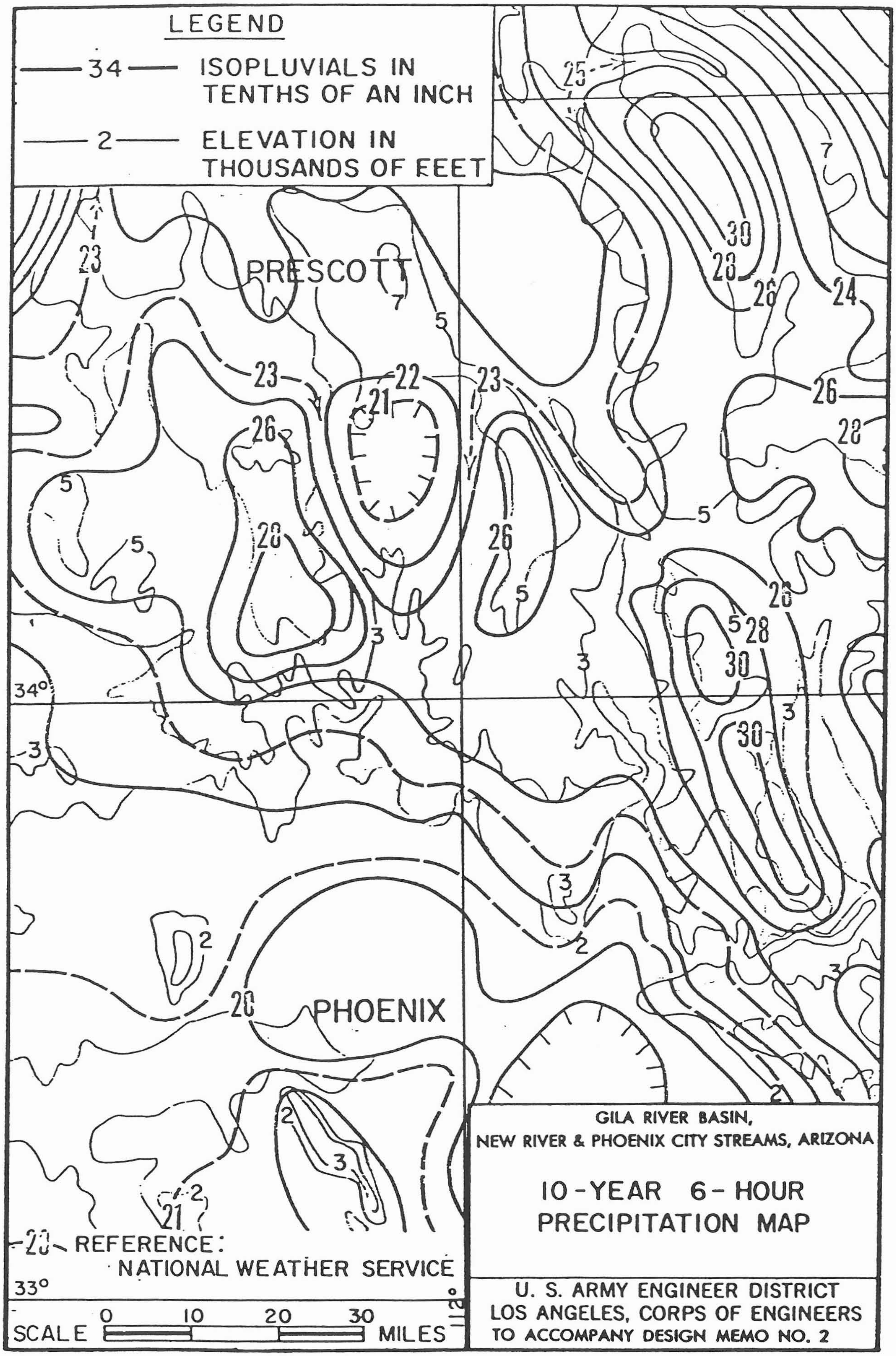


GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, ARIZONA

ARIZONA STANDARD PROJECT
LOCAL SUMMER STORM
PRECIPITATION-AREA-PATTERN
CURVES

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

PLATE 18

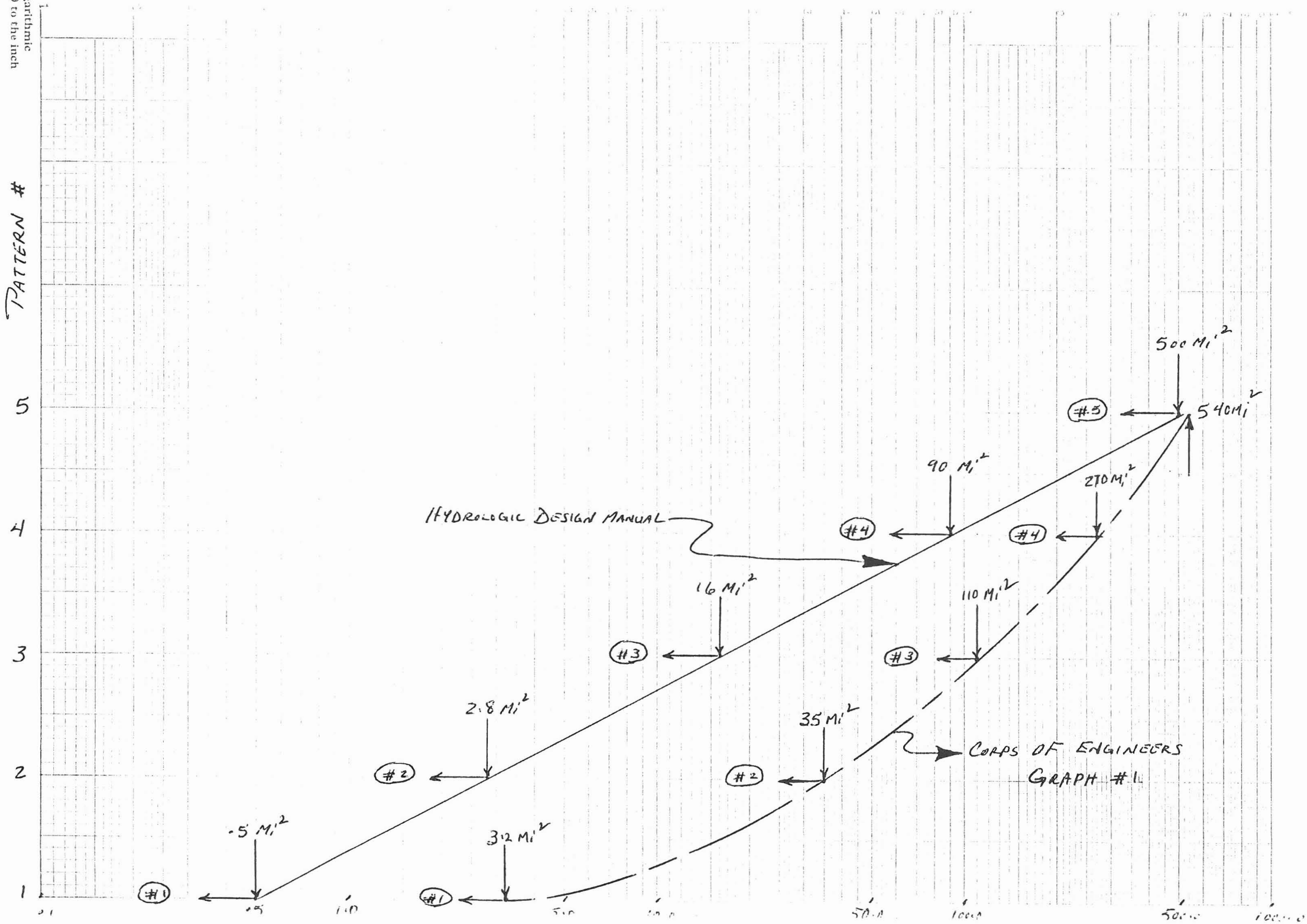


GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, ARIZONA

10-YEAR 6-HOUR PRECIPITATION MAP

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

Semi-Logarithmic
4 Cycles x 10 to the inch



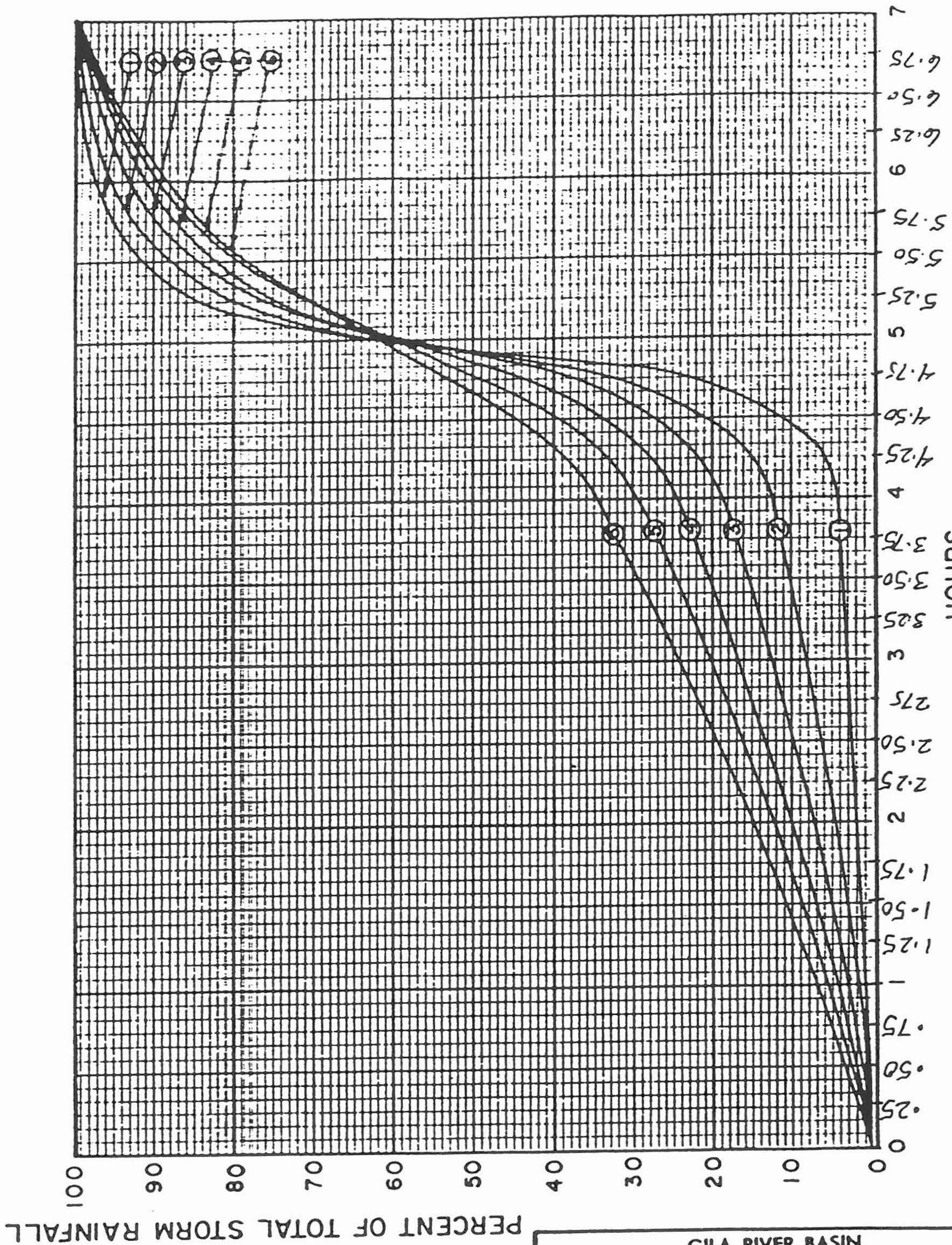
DOCUMENTATION OF 6-HOUR RAINFALL (PATTERNS #2 TO #5)

The graphs of the 7-hour distributions from the Queen Creek Storm of August 19, 1954 (Appendix 1-H) were digitized for Pattern #2 through #6 as shown by the following Table. These numbers were directly read off the graph, at 15-minute intervals. The rainfall duration was changed to 6 hours to be consistent with the previously developed Pattern #1.

Pattern #2 (columns 2,3, and 4) is used to document the procedure. First the digitized values of Pattern #2 were read off directly from the Corps of Engineer's graph (column #2). Then the first hour was removed by subtracting 1.7** from all of the remaining numbers (column #3). Since column #3 only adds up to 98.3, the numbers were divided by 98.3 and normalized to %100 (column #4). The same procedure was applied to Pattern 3 through 5.
It should be noted that the final numbers for the 6-hour patterns are the adjusted values which were modified for smoothness and consistency with the hypothetical Pattern #1. Subsequently, those numbers shown as %100 may vary from the first conversion and normalization.

6-HOUR RAINFALL MASS CURVES (PATTERN #2 TO #5)

Time (hrs)	7-hr Pat.#2	6-hr Pat.#2	6-hr Pat.#2 %100	7-hr Pat.#3	6-hr Pat.#3 %100	7-hr Pat.#4	6-hr Pat.#4 %100	7-hr Pat.#5	6-hr Pat.#5 %100
0:00	0.0			0.0		0.0		0.0	
0:15	0.3			0.5		0.8		1.1	
0:30	0.6			1.2		2.0		2.8	
0:45	1.0			2.0		3.0		4.0	
1:00	1.7**	0.0	0.0	3.0	0.0	4.2	0.0	5.5	0.0
1:15	2.3	0.6	0.9	4.0	1.5	5.6	2.1	7.0	2.4
1:30	2.9	1.2	1.6	5.0	2.0	7.0	3.5	8.8	4.3
1:45	3.7	2.0	2.5	6.0	3.0	8.5	5.1	10.4	5.9
2:00	4.8	3.1	3.4	7.0	4.8	10.0	7.1	12.0	7.8
2:15	5.3	3.6	4.2	8.5	6.3	11.8	8.7	14.2	9.8
2:30	6.6	4.9	5.1	10.0	7.6	13.4	10.5	16.0	11.9
2:45	7.0	5.3	5.9	11.0	9.0	15.0	12.5	18.0	14.1
3:00	8.0	6.3	6.7	12.5	10.5	17.0	14.3	20.0	16.2
3:15	9.0	7.3	7.6	14.0	11.9	18.5	16.0	21.0	18.6
3:30	10.0	8.3	8.7	15.2	13.5	20.2	17.9	24.5	21.2
3:45	11.0	9.3	10.0	17.0	15.2	22.5	20.1	27.0	23.9
4:00	12.2	10.5	12.0	18.8	17.5	24.5	23.2	29.5	27.1
4:15	15.0	13.3	16.3	21.8	22.2	27.8	28.1	33.0	32.1
4:30	21.0	19.3	25.2	27.5	30.4	34.0	36.4	39.5	40.8
4:45	32.5	30.8	45.1	38.0	47.2	44.0	50.0	49.0	51.5
5:00	60.0	58.3	69.4	60.0	67.0	60.0	65.8	60.0	62.7
5:15	80.0	78.3	83.7	76.0	79.6	75.0	77.3	70.0	73.5
5:30	87.5	85.8	90.0	84.5	86.8	82.0	84.1	79.5	81.4
5:45	92.5	90.8	93.8	89.5	91.2	87.5	88.8	85.2	86.4
6:00	95.5	93.8	95.0	93.0	94.6	91.0	92.7	89.5	90.7
6:15	97.0	95.3	96.3	95.0	96.0	93.5	94.5	92.5	93.0
6:30	98.5	96.8	97.5	97.0	97.3	96.0	96.4	95.5	95.4
6:45	99.0	97.3	98.8	98.5	98.7	98.0	98.2	97.5	97.7
7:00	100.	98.3	100.	100.	100.	100.	100.	100.	100.



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

STANDARD PROJECT LOCAL SUMMER STORM PRECIPITATION PATTERNS

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

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

INTEROFFICE MEMORANDUM

SUBJECT: Corp of Engineer Meeting on Hydrology Meeting **FILE:** JMR

TO: DRJ
SLS
DES

FROM: ~~JMR~~ [signature]

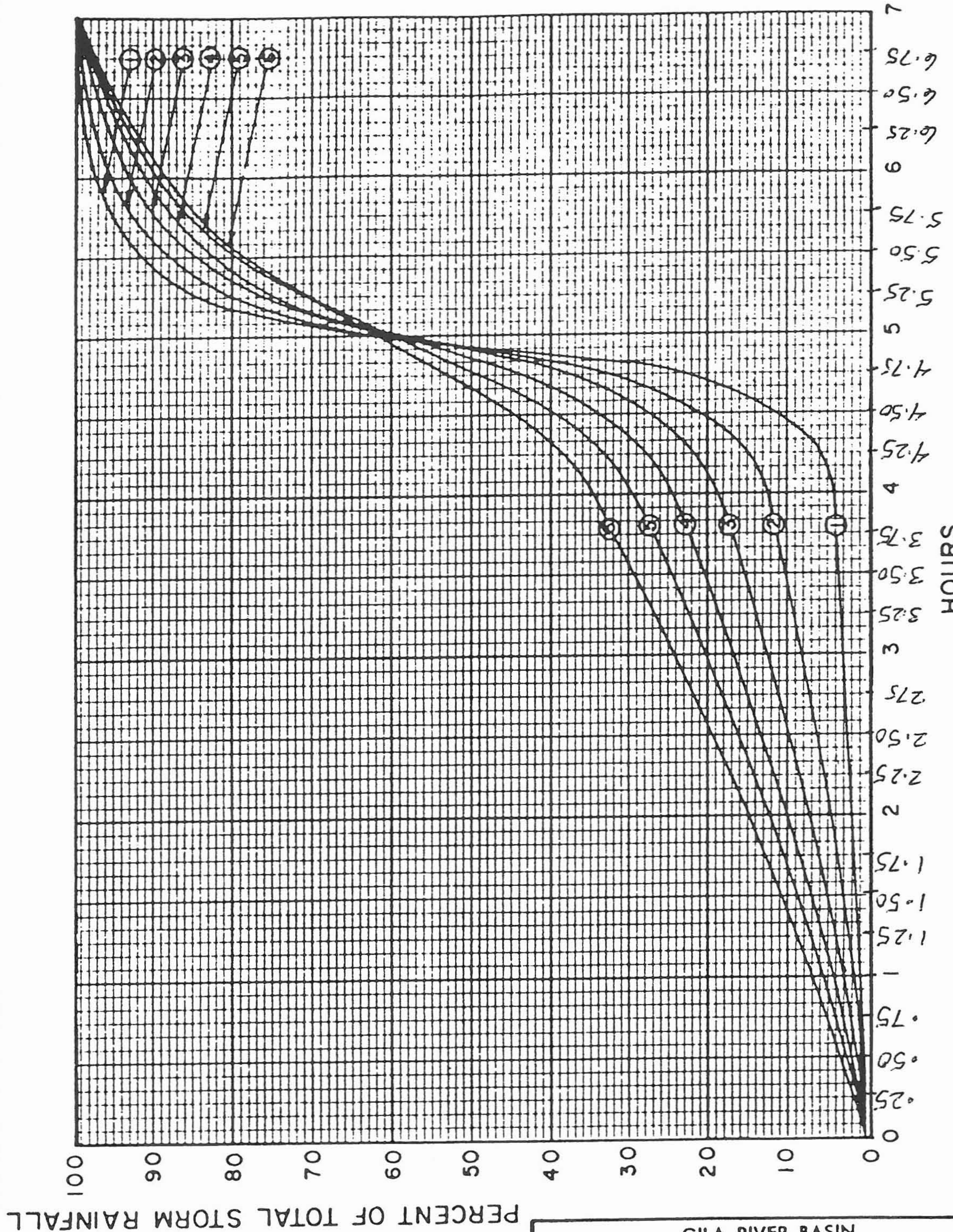
DATE: 9-13-88

On September 8th and 9th, 1988 we met with the Corp of Engineers (COE) in their Los Angeles office to discuss some technical issues concerning the Maricopa County hydrology manual. Those in attendance were John Pedersen, P.E., Supervisor Hydraulic Engineer; and Dr. Charles Pyke, meteorologist from the COE, and Dr. George Sabol P.E., consultant for the Flood Control District, and myself.

The purpose of the meeting was to evaluate the COE's data used to develop the Standard Project Storm in the Hydrology Design Memorandum for Phoenix. They indicated that using the distribution from their Design Memorandum in the FCD's hydrology manual is acceptable. The modifications we want to make to it were also acceptable. These modifications included shortening the distribution from seven to six hours, and substituting the City of Phoenix distribution for their curve one (See attached figure).

The other significant topic discussed was the necessary testing to be performed on the manual. They indicted that if the discharge values computed from this procedure are in the ballpark with expected dicharge-frequency values for the same watersheds then they would have no problems. At some point during the testing this issue will have to addressed since it is not likely that expected and computed discharge values will match.

In addition Dave asked me to met with Dennis Marfice and Nick Adelmeyer concerning their work on the flowage easements on the Agua Fria. Nick indicated that the COE will complete SPF w/ New Waddel down to the Gila by the end of the year, but the discharge-frequencies will not. He seemed to think that this question is one that has to be resolved at the administrative level before doing any more work.



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

STANDARD PROJECT LOCAL SUMMER STORM PRECIPITATION PATTERNS

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

DDK (9/30/88)

print

SUBJECT: Maricopa County Hydrology Manual (Mass Curves & More)

Pages 1 through 8 of the enclosed contain information regarding the development of 6-hour and 2-hour mass curves. The data on the 7-hour mass curves, developed by the C.O.E. for Queen Creek was used for this purpose.

First, pattern #1, and #6 were moved from the Crops' work. The remaining 4 patterns were used to develop a set of 6-hour mass curves by selecting the most intense 6 hours, i.e., hours 1 through 7. The new patterns were named #2 through #5. Then the information from the 100-year, 24-hour, 15-min mass curve, MCFCD distribution was used to provide pattern #1. Page 1 of enclosed has the data. Since the mass curves by the Corps appears to be shifted to the right, a "shifted mass curve" was needed for pattern #1. For this purpose, the most intense 8-hour distribution was selected from Page 1. Then, the last 2 hours were moved so that a 6-hour distribution, with a shifted peak similar to the new 6-hour patterns of C.O.E. can be developed, which will be referred to as pattern #1. Page 2 shows the result. However, a problem developed in that the time of peak for pattern #1 was between 4:00 and 4:15, where as the peak time for the new C.O.E. patterns was between 3:52 and 4:07. To provide a common time of peak for all of the patterns, the entire mass curve of pattern #1 was shifted in time by about 7 minutes, without violating the integrity of the distribution. Page 3 & 4 show calculations and the graph, respectively.

The next step was to develop a 2-hour mass curve for retention. First a set of 2-hour distributions were developed by selecting the most intense 2 hour part of the C.O.E. patterns #1 to #6 (7-hour distributions) as well as the MCFCD, 24-hour distribution. Then an average value of the 7 curves provided a single 2-hour distribution, which is shown on page 5.

The information on Page 7 was used to re-plot drainage area versus pattern#, as shown on Page 8.

Page 9 shows the 24-hour, 100-year, 15-min MCFCD mass curve.

Isopluvials were developed for all durations and frequencies (12 sheets). Page 10 shows a sample which is for 100-year, 24-hour period.

SCS has developed soil maps for eastern, northern, and central parts of the County (copies enclosed). A map was developed for areas with limited details (Page 11). Also a description of hydrologic soil groups was developed. This information is on Pages 12 to 16.

TABLE 2
"A" Distribution
For 24-hr, 100-yr (3.9 inch) rainfall.
From NOAA Atlas 2.

omit

Table 1-3. Worksheet for calculation of rainfall mass-curve.

Column a	Incremental Column b	Accumulated Column c	Column a	Incremental Column b	Accumulated Column c
00:15	.008	.008	12:15	1.466	2.964
00:30	.008	.016	12:30	.269	3.233
00:45	.004	.020	12:45	.039	3.272
01:00	.007	.027	13:00	.039	3.311
01:15	.008	.035	13:15	.035	3.346
01:30	.008	.043	13:30	.039	3.385
01:45	.008	.051	13:45	.028	3.413
02:00	.004	.055	14:00	.031	3.444
02:15	.007	.062	14:15	.031	3.475
02:30	.008	.070	14:30	.031	3.506
02:45	.008	.078	14:45	.031	3.537
03:00	.008	.086	15:00	.032	3.569
03:15	.004	.090	15:15	.011	3.580
03:30	.008	.098	15:30	.016	3.596
03:45	.007	.105	15:45	.012	3.608
04:00	.008	.113	16:00	.015	3.623
04:15	.008	.121	16:15	.012	3.635
04:30	.004	.125	16:30	.015	3.650
04:45	.008	.133	16:45	.012	3.662
05:00	.007	.140	17:00	.016	3.678
05:15	.008	.148	17:15	.011	3.689
05:30	.008	.156	17:30	.016	3.705
05:45	.008	.164	17:45	.012	3.717
06:00	.004	.168	18:00	.015	3.732
06:15	.015	.183	18:15	.004	3.736
06:30	.012	.195	18:30	.008	3.744
06:45	.016	.211	18:45	.008	3.752
07:00	.011	.222	19:00	.008	3.760
07:15	.016	.238	19:15	.007	3.767
07:30	.012	.250	19:30	.008	3.775
07:45	.015	.265	19:45	.004	3.779
08:00	.012	.277	20:00	.008	3.787
08:15	.016	.293	20:15	.008	3.795
08:30	.011	.304	20:30	.008	3.803
08:45	.016	.320	20:45	.007	3.810
09:00	.012	.332	21:00	.004	3.814
09:15	.031	.363	21:15	.008	3.822
09:30	.031	.394	21:30	.008	3.830
09:45	.031	.425	21:45	.008	3.838
10:00	.031	.456	22:00	.007	3.845
10:15	.032	.488	22:15	.004	3.849
10:30	.027	.515	22:30	.008	3.857
10:45	.039	.554	22:45	.008	3.865
11:00	.035	.589	23:00	.008	3.873
11:15	.039	.628	23:15	.008	3.881
11:30	.039	.667	23:30	.003	3.884
11:45	.269	.936	23:45	.008	3.892
12:00	.562	1.498	24:00	.008	3.900

Column b = incremental precipitation

Column c = running summation of Column b; can be made dimensionless by dividing each entry by the total depth.

8- HOUR DISTRIBUTION (FROM TABLE 2, "A" DIST.)

omit

"6-HOUR, SHIFTED" DISTRIBUTION (PEAKS AT 4.15) [00.15 → 6.00]

00.15	.016	7.00	3.292
00.30	.027	7.15	3.303
00.45	.043	7.30	3.283
1.00	.055	7.45	3.331
1.15	.086	8.00	3.346
1.30	.117		
1.45	.148		
2.00	.179		
2.15	.211		
2.30	.238		
2.45	.277		
3.00	.312		
3.15	.351		
3.30	.390		
3.45	.659		
4.00	1.221		
→ 4.15	2.687		
4.30	2.956		
4.45	2.995		
5.00	3.034		
5.15	3.069		
5.30	3.108		
5.45	3.136		
6.00	3.167		
6.15	3.198		
6.30	3.229		
6.45	3.260		

6- HOUR SHIFTED, CONVERTED TO PERCENTAGE

		%			%
00.15	.016	.5	5.00	3.034	95.8
00.30	.027	.8	5.15	3.069	96.9
00.45	.043	1.3	5.30	3.108	98.1
1.00	.055	1.7	5.45	3.136	99.0
1.15	.086	2.7	6.00	3.167	100.0
1.30	.117	3.7			
1.45	.148	4.7			
2.00	.179	5.6			
2.15	.211	6.7			
2.30	.238	7.5			
2.45	.277	8.7			
3.00	.312	9.9			
3.15	.351	11.1			
3.30	.39	12.3			
3.45	.654	20.8			
4.00	1.221	38.5			
4.15	2.687	84.8			
4.30	2.956	93.3			
4.45	2.995	94.6			

THIS DISTRIBUTION CONSTITUTES THE NEW PATTERN # ①.

THE ENTIRE DISTRIBUTION WILL BE SHIFTED 7 MINUTES SO THAT ITS PEAK WOULD COINCIDE WITH THOSE OF PATTERN # ② → ⑤

DEVELOPMENT OF 6-HOUR MASS CURVES.
THE 7-HOUR MASS CURVE DATA BY C.O.E. WAS USED
TO ARRIVE AT NEW PATERN #S ② → ⑤. THE 6-HOUR
MASS CURVE FOR MCFCD WAS USED AS PATERN #①.

TIME (HOURS) SHIFTED 7-MIN	①	②	③	④	⑤
0.0	0.0	0.0	0.0	0.0	0.0
.07	.5	.1	.5	.6	.7
.22	.8	.6	1.5	2.1	2.4
.37	1.3	1.2	2.0	3.5	4.3
.52	1.7	2.0	3.0	5.1	5.9
1.07	2.7	3.1	4.8	7.1	7.8
1.22	3.7	3.9	6.3	8.7	9.8
1.37	4.7	4.7	7.6	10.5	11.9
1.52	5.6	5.7	9.0	12.5	14.1
2.07	6.7	6.6	10.5	14.3	16.2
2.22	7.5	7.6	11.9	16.0	18.6
2.37	8.7	8.7	13.5	17.9	21.2
2.52	9.9	10	15.2	20.1	23.9
3.07	11.1	12	17.5	23.2	27.1
3.22	12.3	16.3	22.2	28.1	32.1
3.37	20.8	25.2	30.4	36.4	40.8
3.52	38.5	45.1	47.2	50	51.5
4.07	84.8	69.4	67	65.8	62.7
4.22	93.3	83.7	79.6	77.3	73.5
4.37	94.6	90	86.8	84.1	81.4
4.52	95.8	93.8	91.2	88.8	86.4
5.07	96.9	96.7	94.6	92.7	90.7
5.22	98.1	98.5	97.4	95.8	94.5
5.37	98.5	99	98	96.5	95.5
5.52	99	99	98.7	97.6	96.9
6.00	100	100	100	100	100

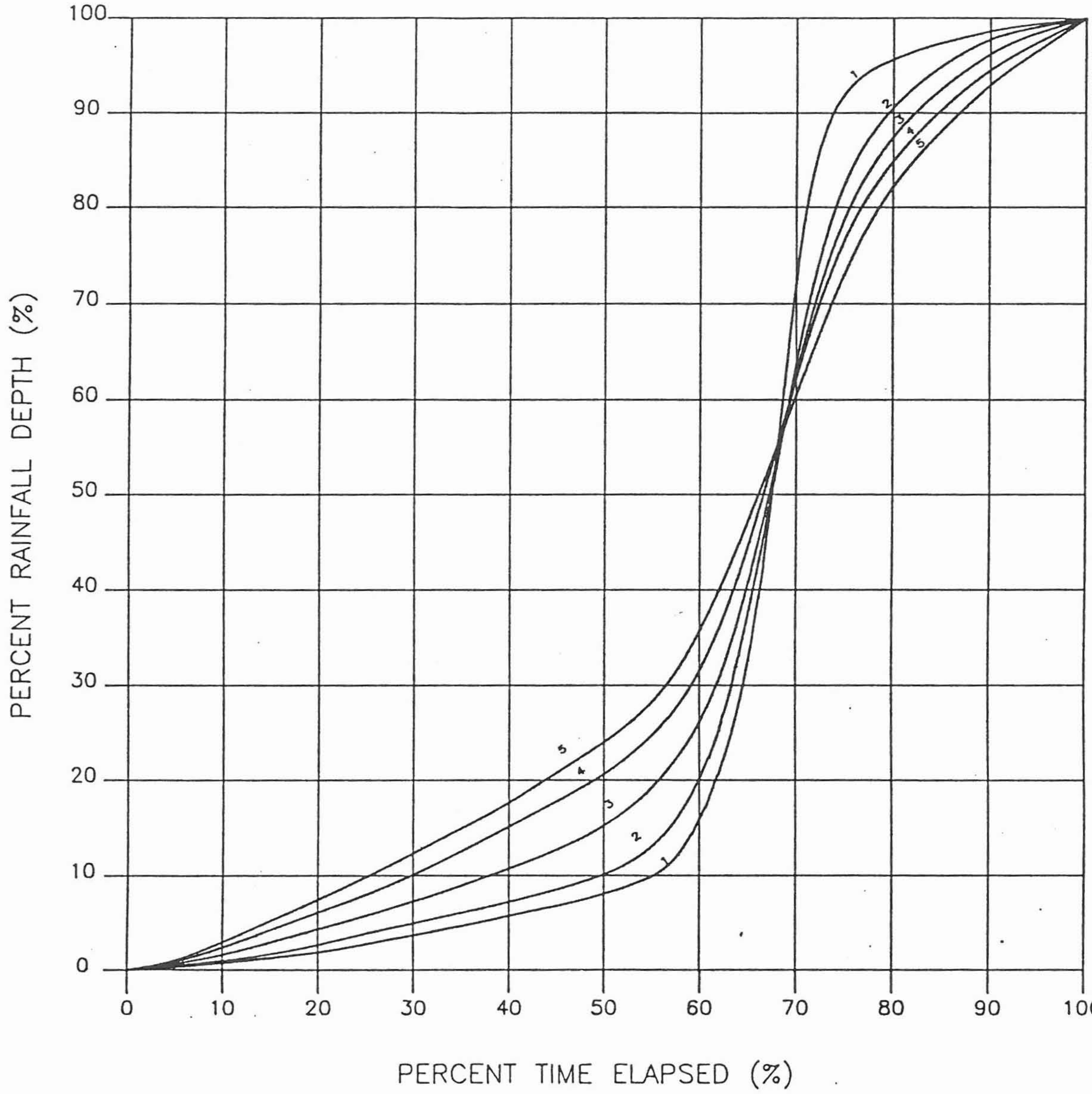


FIGURE 6-HOUR MASS CURVES FOR MARICOPA COUNTY

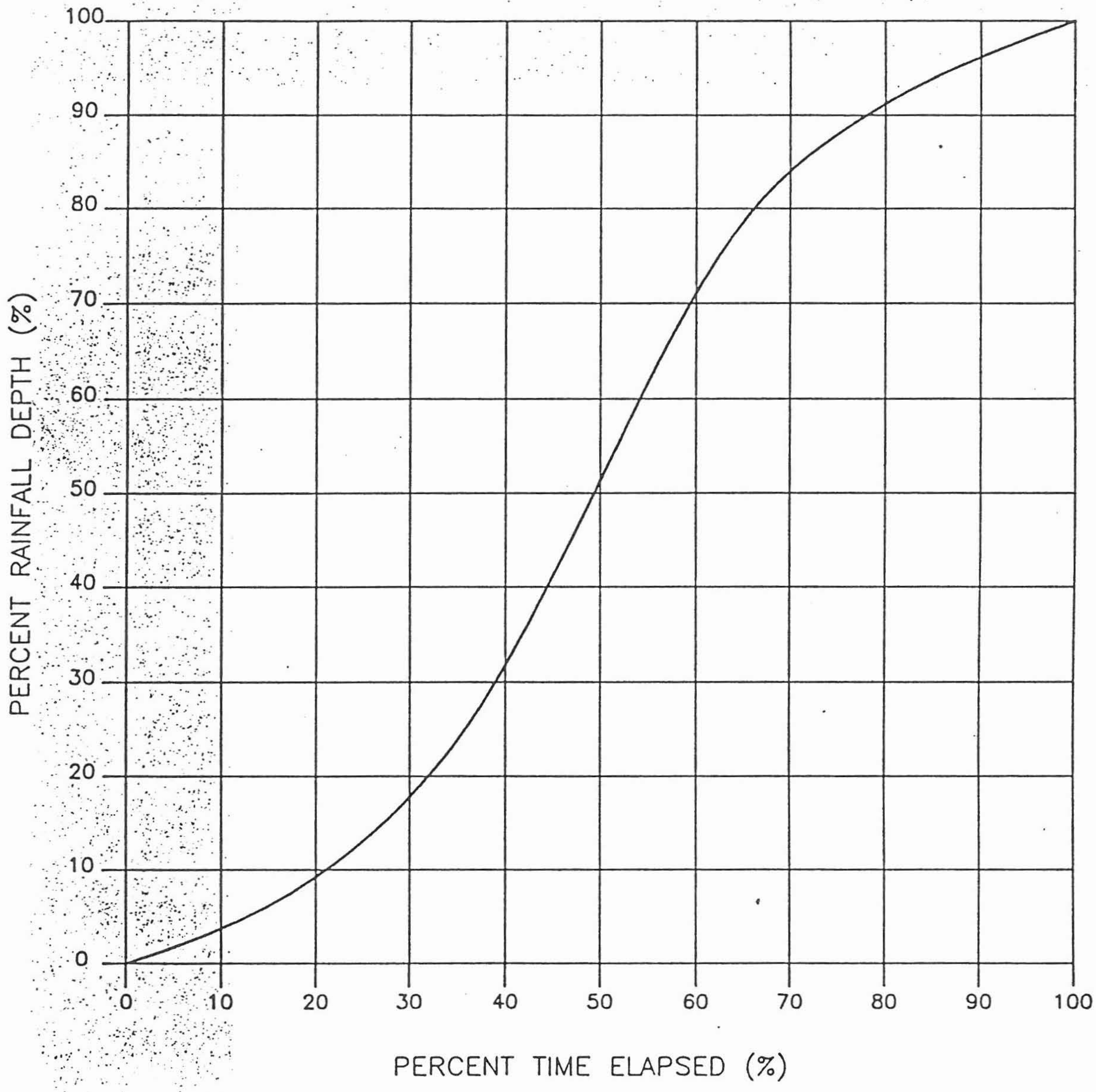


FIGURE 2–HOUR MASS CURVE
FOR RETENTION DESIGN
MARICOPA COUNTY

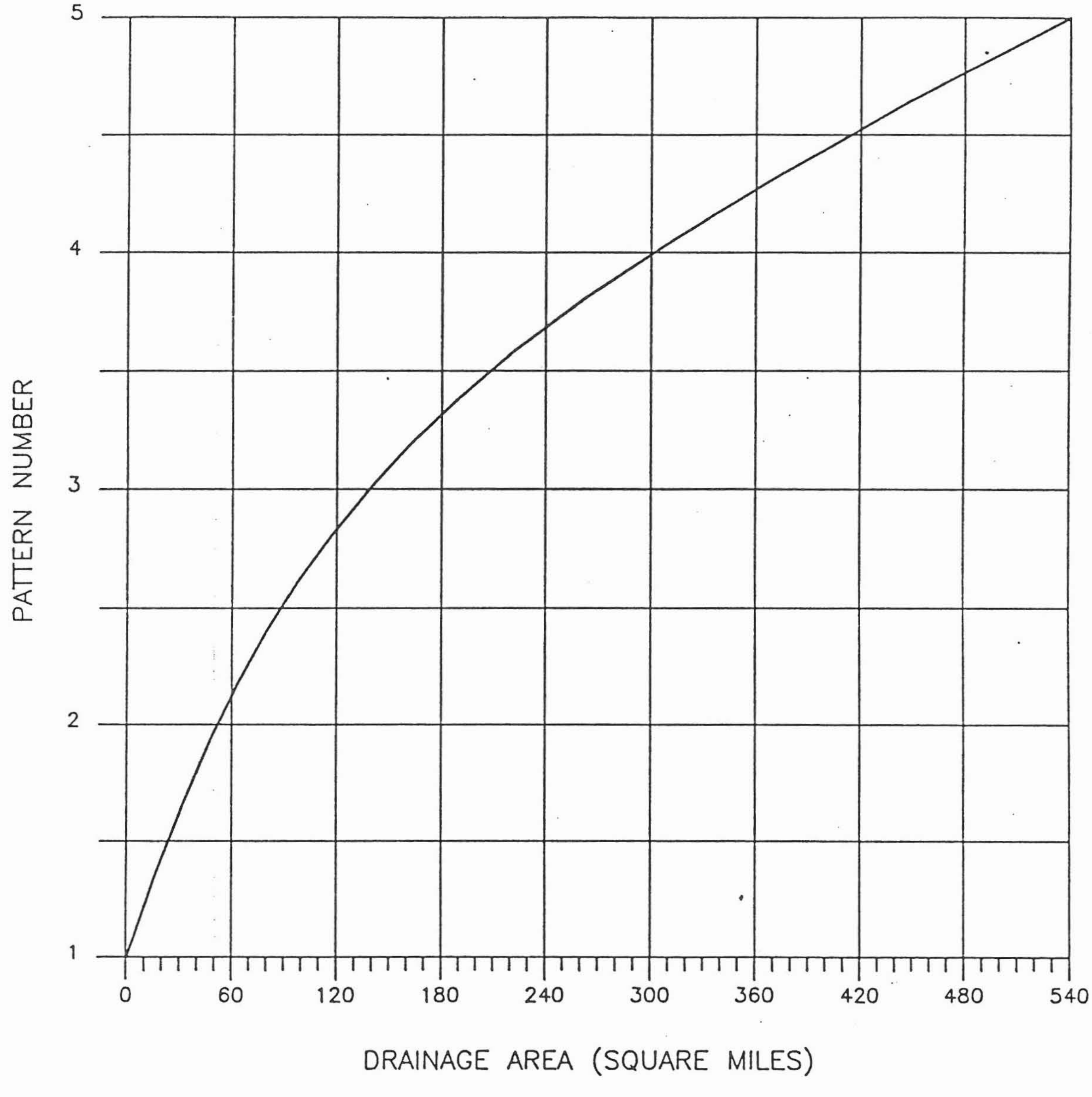
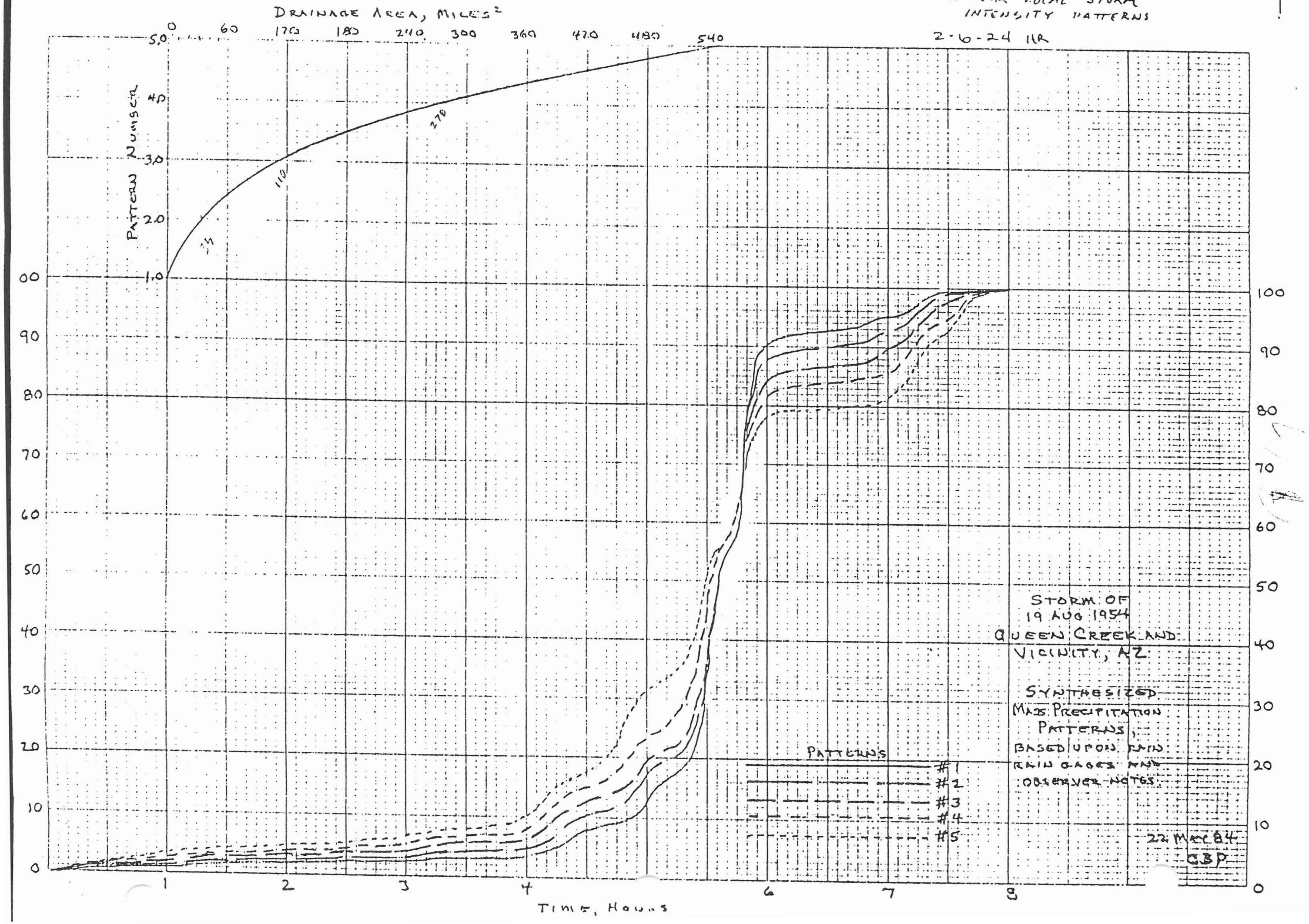


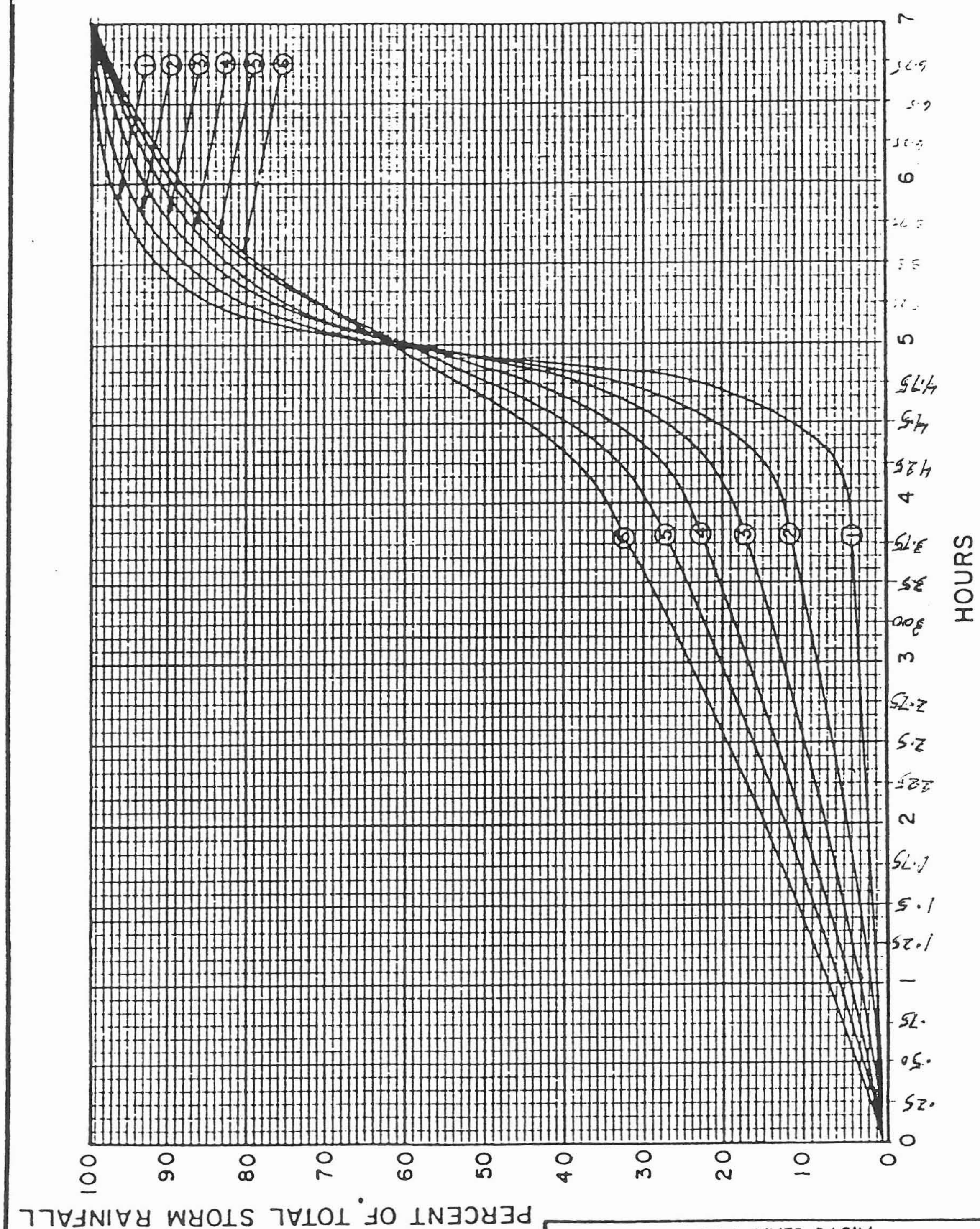
FIGURE AREA VERSUS PATTERN NUMBER FOR MARICOPA COUNTY

K&E 12 x 20 TO THE INCH
KEUFFEL & ESSER CO.

46 1970

STANDARD PROJECT AND
N-YEAR LOCAL STORM
INTENSITY PATTERNS
2-6-24 HR





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

STANDARD PROJECT LOCAL SUMMER STORM PRECIPITATION PATTERNS

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

APPENDIX 1-A

Rainfall criteria and sources of data for Maricopa County.

MARICOPA COUNTY REGIONAL RAINFALL

Preliminary Draft
9/3/85

EXECUTIVE SUMMARY

The assessment of existing isohyetal data, characterization of the Maricopa County rainfall networks, and description of procedures to update isohyetal maps and design guidelines has resulted in the following conclusions and recommendations.

Conclusions:

1. Existing data is based upon the NOAA Atlas, in which isohyetal maps and equations for producing design event guidelines were produced and formulated.

2. 33 nonrecording stations and 2 recording stations were used to produce the Maricopa County isohyetal maps for 6- and 24-hour storms. Regression equations were developed to relate precipitation from storms of shorter durations to the 6- and 24-hour precipitations.

3. The recording stations averaged 20 years of record up to 1970. The nonrecording stations had 15-70 years of data up to 1970.

4. 2-year, 6-hour and 2-year, 24-hour precipitations for individual stations are the most accurate. 100-year precipitation values are less accurate, especially for 6-hour storms.

5. Due to the large scale of the maps and few stations used, the isohyetals are not as accurate as could be possible with the data now available. This is especially true of the 6-hour isohyetal maps.

6. The regression equations for short duration storms are averages for the entire Colorado River basin. They may not adequately prepresent precipitation in Maricopa County.

7. Rainfall data collection networks are operated by Maricopa County Flood Control District, the City of Phoenix, the U.S. Geological Survey, and the National Weather Service. An approximate total of 79 telemetered gages, 23 recording gages, and 142 nonrecording gages are currently in operation.

8. The existing network is adequate for upgrading current rainfall data. Following the analysis of data the need for additional stations can be assessed.

Recommendations:

1. Existing 6-hour and 24-hour storm precipitation-frequency relations should be updated. New precipitation frequencies should be developed for stations with greater than 25 years of record (shorter records may be used in some cases).

2. The isohyetal maps should be updated using the data now available.

3. For storms up to 6 hours, revised rainfall-intensity-duration-frequency curves should be established using regression equations based on Maricopa County data.

4. In conjunction with the rainfall frequency analysis, consideration should be given to the evaluation of area rainfall reduction curves.

CONTENTS

MARICOPA COUNTY
REGIONAL RAINFALL

1. INTRODUCTION

For economical design of drainage facilities, good quality hydrologic data are required. Towards this goal the existing rainfall data of Maricopa County was evaluated and procedures for updating the data were examined. These steps included:

1. Assessing the adequacy of existing regional rainfall isohyetal data.

2. Describing and characterizing the rainfall data collection networks utilized by various jurisdictions within Maricopa County.

3. Describing the necessary steps to perform an in-depth evaluation and synthesis of isohyetal maps and design event guidelines.

The completion of these procedures provides guidance for obtaining the needed hydrologic data.

2. ADEQUACY OF EXISTING REGIONAL RAINFALL ISOHYETAL DATA

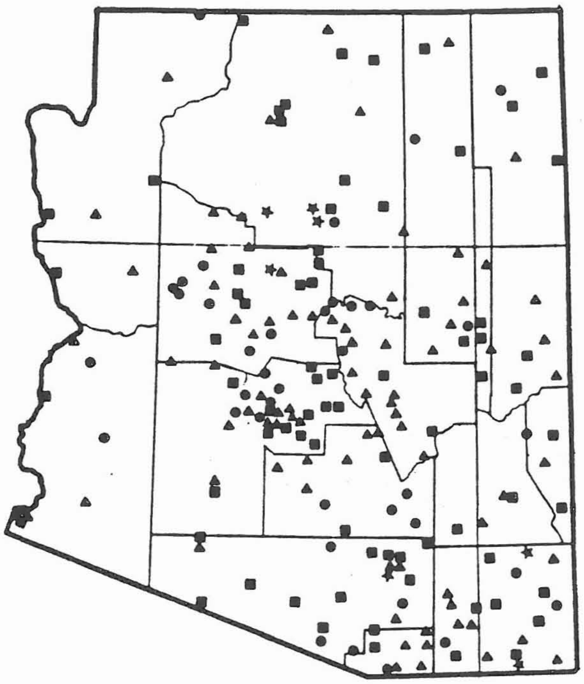
2.1 Existing Isohyetal Data

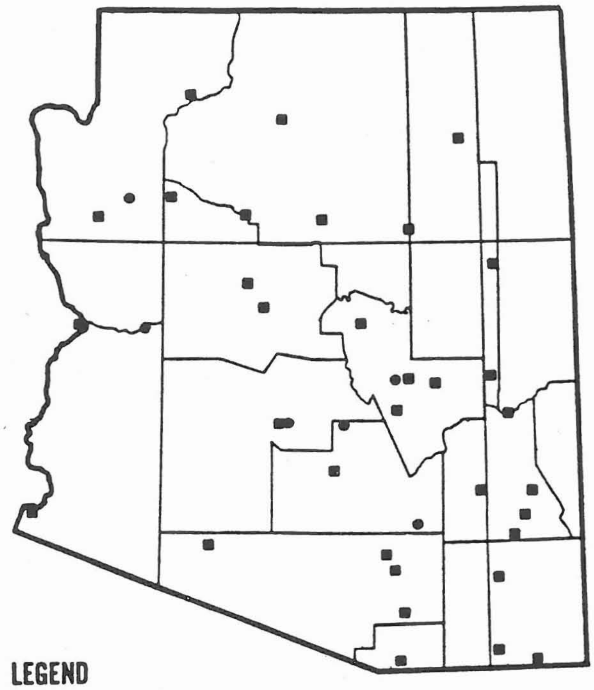
The rainfall isohyetal data used within Maricopa County are based upon the National Oceanic and Atmospheric Administration (NOAA) Atlas 2, Volume VIII - Arizona(1). The atlas updates the earlier U.S. Weather Bureau Technical Paper 40(2) and is the basis for the Arizona Department of Transportation precipitation maps(3). Figure 1 is an example isohyetal map copied from reference (3).

The NOAA Atlas contains isohyetal maps of 6-hour and 24-hour storms for return periods of 2, 5, 10, 25, 50 and 100 years. For each storm duration base maps of the 2-year and 100-year events were constructed. Maps for the intermediate frequencies were derived from the base maps. Precipitation records up to 1970 were used.

2.11 Data Used

The 24-hour precipitation values were obtained from nonrecording and recording raingages. These represented the largest available data set, and therefore, the 24-hour precipitation maps are the most accurate of the NOAA maps. The records from a total of 229 stations were used in Arizona, including 33 in Maricopa County. The nonrecording stations used are shown in Figure 2 and the recording stations are shown in Figure 3. Table 1 shows the breakdown of the lengths of record used.





LEGEND
● 10-14 YEARS
■ 15-29 YEARS
▲ 30-49 YEARS
★ 50 YEARS OR MORE

Figure 2. Nonrecording rainfall data collection stations used for the 24-hour precipitation maps.

Figure 3. Recording rainfall data collection stations used for both the 6-hour and 24-hour precipitation maps.

Years of Record (up to 1970)	Arizona Stations RGR	TR	NR
10-14	6	5	38
15-19	9	8	28
20-24	23	12	30
25-29		1	15
30-34		1	9
35-39		2	10
40-44		6	53
45-49		0	1
50-54		1	1
55-59		1	4
60-64		0	1
65-69		1	1
70-74			
75-79			
80-84			
85-89			
90-94			
Number:			
By type	38		191
Total stations		229	

Note: RGR = stations having recording-gage record.
TR = stations having recording gage for part of the record; total record includes both recording and nonrecording-gage record.
NR = stations having only nonrecording-gage record.

Table 1 Number of Stations used for the Arizona NOAA Atlas maps by length and type of record

The 6-hour precipitation values were obtained from 38 recording gages in Arizona, only 2 of which were in Maricopa County. These were the Phoenix Airport Station, which had less than 25 years of record, and the Tempe Experimental Station, which had less than 15 years of record.

2.12 Isohyetals

The isohyetal patterns were drawn based upon the precipitation frequency values calculated for the various stations and considered topographic, geographic and meteorologic features. The 2-year, 24-hour isohyetal map was drawn first and used as the basic map in construction of the other isohyetal maps. This was due to the large amount of 24-hour data available and the greater accuracy with which 2-year events can be determined.

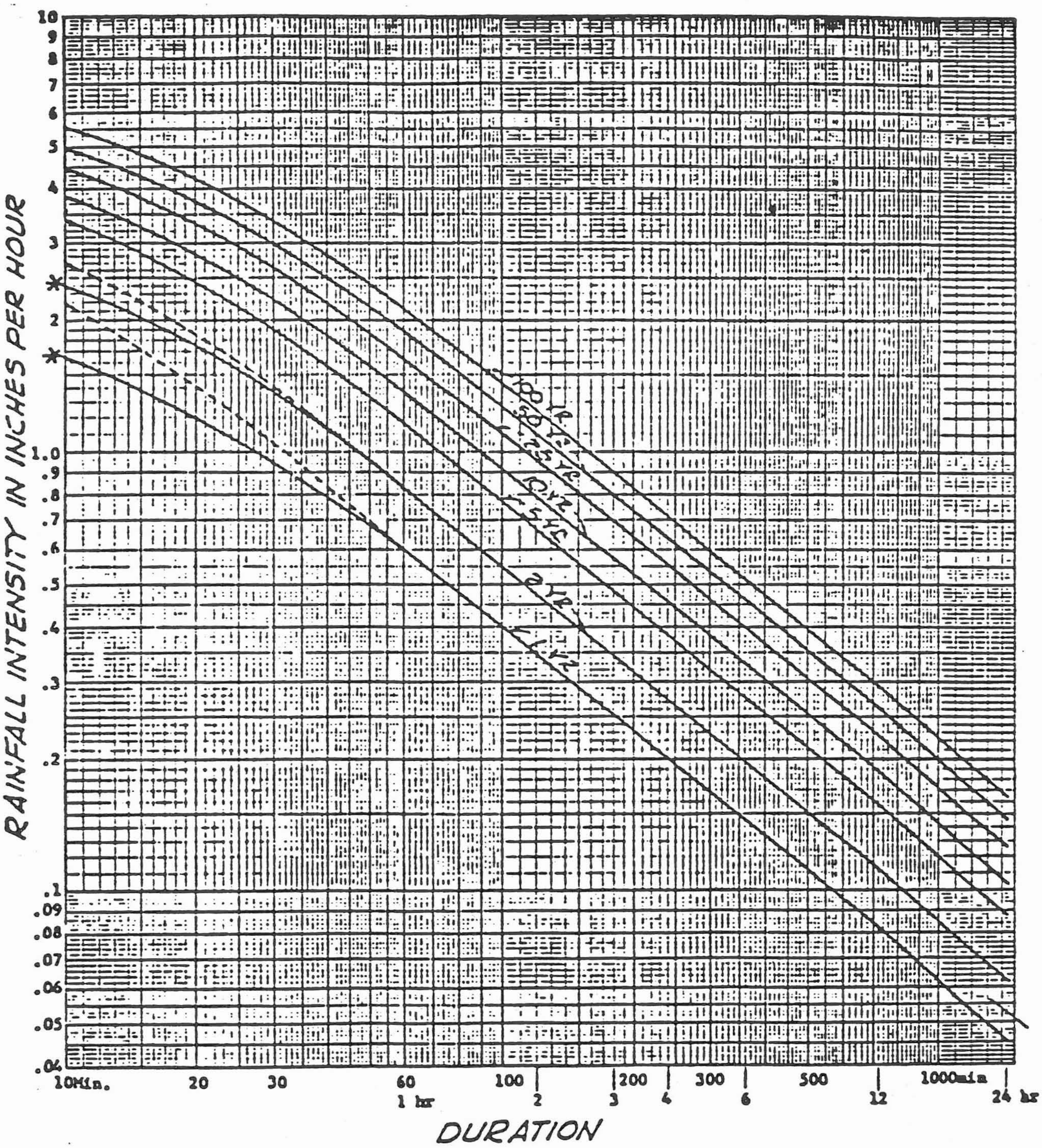
Due to the large areas covered by the maps, the amount of local detail that could be shown was limited.

2.13 Other Duration Storms

Data from storms of durations other than 6- or 24-hours are often required. To obtain this data, regression equations were developed to relate the 6- and 24-hour precipitations to storms of durations of 1, 2, 3, and 12 hours and of 5, 10, 15 and 30 minutes.

These equations were based upon precipitation records for an area roughly corresponding to the Colorado River Basin (including Arizona, as well as parts of California, Utah, Colorado and New Mexico). Because of the large area involved, the equations are fairly general.

The commonly used frequency-duration-precipitation curves are derived from the regression equations. Figure 4 shows typical curves developed for Phoenix. Frequency-duration-precipitation data developed from the equations is given in tabular form in WBTM-44(4), Figure 5.



RAINFALL INTENSITY-DURATION-FREQUENCY RELATION
FOR PHOENIX, ARIZONA
(Partial Duration Series)

Curves are based on methods of U.S. Weather Bureau Technical Papers Nos. 28 and 40 and rainfall data prepared by U.S. Weather Bureau Office of Hydrology for the Soil Conservation Service, March 1967

* **Curves revised June 1975 to reflect new information from WR-44.**

Figure 4. Rainfall Intensity-Duration-Frequency Curves (from City of Phoenix Drainge Manual).

ESTIMATED RETURN PERIODS FOR SHORT-DURATION PRECIPITATION IN ARIZONA

(Inches)

Station: Phoenix WBO

	RETURN PERIOD (YEARS)						
	1	2	5	10	25	50	100
5 min.	0.17	0.26	0.38	0.47	0.59	0.68	0.77
10 min.	0.27	0.40	0.59	0.72	0.91	1.06	1.20
15 min.	0.34	0.50	0.74	0.92	1.15	1.34	1.52
30 min.	0.47	0.70	1.03	1.27	1.60	1.86	2.10
1 hr.	0.60	0.88	1.30	1.61	2.02	2.35	2.66
2 hr.	0.65	0.94	1.39	1.72	2.15	2.49	2.82
3 hr.	0.69	1.01	1.48	1.82	2.27	2.62	2.97
6 hr.	0.81	1.16	1.70	2.07	2.57	2.96	3.35
12 hr.	0.91	1.30	1.90	2.30	2.84	3.26	3.69
24 hr.	1.02	1.44	2.10	2.53	3.12	3.57	4.04

Figure 5. Tabular display of Frequency-Duration-Precipitation Data (from Weather Bureau Technical Memorandum (WBTM) 44.

2.2 Adequacy of the Isohyetal Data

The adequacy of the NOAA Atlas maps should be assessed considering both the precipitation frequency relationships developed for the individual stations and the interpolation of isohyetal lines between stations. The individual station relationships depend primarily on the available length of record. The interpolation of isohyetal lines depends upon the distance between stations. The adequacy of the regression equations used for other duration storms must also be assessed.

2.21 Length of Record

For the individual rainfall data collection stations, records of sufficient length were required for determination of 2-year and 100-year frequency precipitations.

For determination of 2-year precipitations, the most recent 15 years of data were used. This was compared with the preceding 15 years of data, and if a significant difference was found, a longer period of record was used. Generally, the most recent 15-year time period was judged to be sufficient. As most all of the stations used had 15 years of record, the 2-year values determined for the 6-hour and 24-hour storms should be adequate.

Much longer periods of record are required for accurate determination of 100-year precipitations. Even with records of 50 years or more, considerable error can occur(5). Therefore, the entire period of record available is used.

None of the recording gages used for the 6-hour maps had greater than 25 years of record available. Therefore, the predicted 100-year precipitations are probably inaccurate.

The 24-hour, 100-year values are considered more accurate in general than the 6-hour, 100-year values, as they are based on longer periods of records.

2.22 Isohyetal Spacing

The location of the isohyetals depends upon the effects of topography and climatic factors on the movement of storms and on the type of storm that produces maximum precipitations for different areas and durations. The NOAA Atlas maps are large scale with widely spaced stations, which did not allow for much detail and accuracy in spacing the isohyetals. Also, the use of the 2-year, 24-hour isohyetals as a base map did not allow adequate consideration of the variation in storm types.

Most precipitation stations in Maricopa County are located in valley areas which generally have lower rainfall than nearby highlands. The NOAA Atlas maps attempted to show this effect, but were generally limited by the amount of detail they could show due to the scale of the maps. Prevailing wind patterns and ground slopes will also affect the isohyetal patterns. These effects were considered but, again, on a large scale.

The 24-hour maps were based upon 33 Maricopa County stations. Only 2 stations were used for the 6-hour maps, however, the 24-hour map isohyetals had to be used as a guide for the 6-hour isohyetals.

Doing this implies that the same storm patterns produce both the same 6- and 24-hour maximum precipitations. 6-hour maximum precipitations are, however, from summer convective storms (thunderstorms), while 24-hour maximums are from both convective and winter frontal storms. Topography has a significant influence on convective storms, but only a minor influence on frontal storms. Therefore, the precipitation isohyetals from each storm type should be different, and the 6- and 24-hour maps should show more differences in isohyetal patterns than assumed in the NOAA Atlas.

In summary, the isohyetal patterns are inadequate due to the scale of the maps and the need to interpolate data between stations and due to the need of using the 24-hour isohyetal patterns for the 6-hour storms.

2.23 Regression Equations

The regression equations used to estimate precipitation amounts from short duration storms were developed for a large area including Maricopa County. Therefore, they should apply to Maricopa County to some degree but not totally. There would be close agreement only if Maricopa County represented average conditions for the entire Colorado River Basin.

The regression equations are also only as good as the 6- and 24-hour precipitations which they use. The inadequacy of these precipitations will be refelected in the precipitation values obtained from using the regression equations.

3. DESCRIPTION AND CHARACTERIZATION OF EXISTING RAINFALL

Rainfall data collection networks are operated by four agencies within Maricopa County: Maricopa County Flood Control District, the City of Phoenix, the U.S. Geological Survey and the National Weather Service. Other raingage records are available (such as informal data collection by Salt River Project), but are not of the quality needed for statistical analysis.

Each of the networks are described below with regards to the number and type of gages, the length of records available, and the type of operating system used.

The location of the recording raingages operated by the above agencies are shown in Figure 6.

3.1 Maricopa County Flood Control District

The most extensive rainfall data collection network is operated by the Maricopa County Flood Control District. 188 raingages are currently in use, including 58 telemetry stations and 21 recording stations. Over 30 additional gages have been operated in the past but are now abaondoned. New gages are frequently added to the system.

Most of these gages have been installed since 1980. The breakdown of gage type and length of record is shown in Table 2.

Table 2
Type of Raingage and Length of Record
Maricopa County Flood Control District

Length of Record	Number of Gages		
	Telemetry	Recording	Nonrecording
Less than 2 years	11	--	32
2-5 years	47	16	72
5-10 years	--	--	--
Greater than 10 years	--	1	--
Greater than 20 years	--	4	5

Rainfall data is stored by computer located at Maricopa County Flood Control District offices. The telemetry stations relay rainfall quantities by radio and the data is stored at 3-minute intervals. The system has the capacity to accept data from many times the current number of stations.

A listing of the currently operated telemetry and recording gages by location and years of record is in Appendix A.

3.2 City of Phoenix

Phoenix operates 10 raingages within the city limits, as shown in Fugure 6. The first of these was installed in 1972.

The network is connected by telephone lines over which the data are sent. The location and years of record for each gage are given in Appendix A.

3.3 U.S. Geological Survey

A satellite telemetry raingage network is operated by the U.S. Geological Survey. 11 gages in or near Maricopa County are part of the system. They are shown in Fugure 6 and are described in Appendix A.

Data is currently being stored in the U.S.G.S. mini-computer system. Only data from January 1985 is available. Additional data may be available from their mainframe system. Also, Maricopa County Flood Control District has some 15 years of U.S.G.S. data on file and on computer tape, although it has not been verified for whichgages this is for.

The U.S.G.S. operates its raingages for various agencies, such as Arizona Department of Water Resources, Salt River Project, the Corps of Engineers, and the National Weather Service. All of their gages are at stream gaging locations.

3.4 National Weather Service

The National Weather Service has the oldest raingage network in Maricopa County. Most of their gages are nonrecording, though (see Figure 2 for their locations). The Phoenix and Tempe recording stations are still recording gages. Several other stations with recording gages are operated by the U.S.G.S. or others, but are reported by the National Weather Service; these are listed under the operating agency. Rainfall records of all National Weather Service recording stations in Arizona are available on computer tape at the Arizona State University Laboratory of Climatology.

3.5 Summary of Stations

The Arizona Department of Water Resources maintainsa comprehensive listing of raingage locations. This listing includes all agencies collecting rainfall data and is updated periodically.

4. DESCRIPTION OF STEPS NECESSARY TO PERFORM AN EVALUATION AND SYNTHESIS OF ISOHYETAL MAPS AND DESIGN EVENT GUIDELINES

The existing isohyetal maps and design event guidelines require evaluation to quantify their adequacy. Additional data is available to update the existing maps and design event guidelines. If required, new maps and guidelines may be synthesized.

The precipitation-frequency relationships developed for the stations used in the NOAA Atlas may be evaluated and updated using the data accumulated since 1970. Precipitation-frequency relationships may also be developed for the additional stations now available. The isohyetal maps can be revised to include the new and additional data. For short duration storms the NOAA Atlas regression equations should be revised to reflect more local data or, if enough recording gage data is available, isohyetal maps could be constructed for the desired duration storms.

4.1 Updating Precipitation-Frequency Relationships

For the NOAA Atlas maps, precipitation-frequency relationships were developed for each of the gaging stations. As these relationships were based upon pre-1970 data, and as an additional 15 years of data are now available, they can be revised to verify that the values used in constructing the maps are adequate. If they are not adequate, the maps can be updated to reflect the revised values. 100-year precipitations should show the most change.

4.11 Frequency Analysis Method

The frequency analysis of hydrologic data may be accomplished treating the data as either a partial duration series of an annual series. For the precipitation data used in the NOAA Atlas, it was required to express the results in terms of partial duration frequencies. However, the data was arranged and analyzed as an annual series and then an empirical relation was used to convert the annual series frequencies to partial duration frequencies. The use of partial duration series and their relation to annual series is discussed by Langbien (5). The frequencies were determined using a Fischer-Tippet (extreme value) Type I distribution (6). The resulting frequencies should be analyzed to assess how adequately they fit the data.

For accurate analysis of low probability events (e.g., the 100-year precipitation), a minimum of 25 years of data is recommended (7). Shorter records may be used if similar stations with longer records are available for comparison.

4.2 Updating the Isohyetal Patterns

For revising the isohyetal maps of Maricopa County, additional rainfall records would need to be analyzed as discussed above. If examination of the precipitation values show a significant difference from those shown on the NOAA Atlas maps, the isohyetals should be revised. It is likely that the 6-hour maps will need revisions and that the 24-hour maps will need at least minor revisions.

The location of isohyetals between the stations should be based upon the guidelines in the NOAA Atlas. These include how to adjust for topographic features, prevailing wind patterns and other factors influencing storm movement.

4.3 Updating the Design Event Guidelines for Short Duration Storms

As has been discussed above, the 6-hour and 24-hour precipitation maps need to be evaluated and new isohyetal maps may need to be synthesized. For hydrologic design purposes, however, the most important events in Maricopa County are the short duration storms. For the smaller basins, the short duration storms result in the highest rates of runoff and are, therefore, the basis of drainage facility design. These are also the storms for which data is the least adequate.

To evaluate the existing frequency-duration-precipitation curves, the values currently used should be compared to data obtained from stations within Maricopa County.

To update the existing data, two approaches may be taken. The first method would be to develop regression equations specifically for Maricopa County similar to those developed by NOAA for the Colorado River Basin. The second method would be to develop isohyetal maps for each of the storm durations desired based upon available precipitation data if sufficient data is now available.

To develop regression equations for desired storm durations, precipitation frequencies would need to be calculated for several representative stations for the desired durations. These precipitations would then be related to the 6- and 24-hour precipitations of the same frequencies using basic multiple regression techniques. Average equations would be found from the equations of each of the representative stations and would be adopted for all of Maricopa County. They could then be used throughout the county using the NOAA Atlas maps to obtain the local 6- and 24-hour precipitations. The use of regression equations implicitly assumes that isohyetal patterns for the short duration storms are identical to those of the 6- and 24-hour storms. This assumption is not made if isohyetal maps are made for each of the storm durations. More work and more data are required for this than for developing regression equations, but it should also result in more accuracy.

4.4 Depth-Area Curves

The NOAA Atlas also contains depth-area curves for using point precipitations to predict rainfall depths for large-area storms. These are used in various rainfall-runoff models. A more recent National Weather Service publication, Hydrometeorological Report No. 24 (1984) revises the older curves and should be used in Maricopa County.

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1. National Oceanic and Atmospheric Administration, Atlas 2, Volume VIII-Arizona Precipitation Frequency Atlas of the Western United States, Washington D.C., 1973, 41 pp.

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APPENDIX A

MARICOPA COUNTY FLOOD CONTROL DISTRICT

CITY OF PHOENIX AND U.S. GEOLOGICAL SURVEY

TELEMETRY AND RECORDING RAIN GAGES

MARICOPA COUNTY FLOOD CONTROL DISTRICT

Telemetry and Recording Rain Gages

	Gage Location	Telemetry Recording T/R	Years of Record 2	2-5	5-10	10-20	20
1.	Adobe Dam Precip.	T		(82)			
2.	Agua Fria 3	T		(81)			
3.	Agua Fria 4	T/R		(81)			
4.	Agua Fria 5	T		(81)			
5.	Agua Fria 6	T		(81)			
6.	Agua Fria 7	T		(81)			
7.	Agua Fria 8	T		(81)			
8.	Agua Fria 9	T		(81)			
9.	Agua Fria 13	T		(82)			
10.	Agua Fria 14	T	X				
11.	Buckeye FRS1 Precip.	T		(83)			
12.	Bulldog Flood-way 2	T		(82)			
13.	Cave Creek 15	T		(81)			
14.	Cave Creek 16	T		(81)			
15.	Centennial Levee 1	T		(80)			
16.	Centennial Wash 3	T		(81)			
17.	Centennial Wash 7	T		(82)			

T - Telemetry Station
R - Recording Station
(81) - Year Station Installed (if known)

	Gage Location	Telemetry Recording T/R	Years of Record 2	2-5	5-10	10-20	20
18.	Dreamy Draw Precip.	T				(74)	
19.	East Peak Whitetails	T/R		(80)			
20.	Guadalupe 2	T		(82)			
21.	Hassayampa McMicken	T		(81)			
22.	Hassayampa 3 Wilhart	T		(81)			
23.	Hassayampa 2 O'Brien	T		(81)			
24.	Hassayampa 4 Sols	T		(81)			
25.	Hassayampa 5 Sunset	T		(81)			
26.	Hassayampa 6 Mt. Union	T		(82)			
27.	Hassayampa 7 Box Precip.	T	X				
28.	Hassayampa 8 Bridge Precip.	T	X				
29.	IBW 4	T		(81)			
30.	IBW 7 Precip.	T	X				
31.	Jack Rabbit Wash 2	T		(82)			
32.	Lower Gila 1 Bend	T		(82)			

T - Telemetry Station
R - Recording Station
(81) - Year Station Installed (if known)

	Gage Location	Telemetry Recording T/R	Years of Record 2	2-5	5-10	10-20	20
33.	Lower Gila 2 Sand Tanks	T		(83)			
34.	McMicken 12 Trilby 1	T		(81)			
35.	McMicken 17 Trilby 2	T		(82)			
36.	McMicken Dam Precip.	T		(83)			
37.	Mt. Oatman	T/R		(80)			
38.	Mt. Ord	T		(82)			
39.	New River 7	T		(81)			
40.	New River 9	T	X				
41.	Rittenhouse 1	T		(82)			
42.	Rittenhouse 2	T		(81)			
43.	RWCD 4	T					
44.	Skunk Creek 7	T		(80)			
45.	Spookhill 8	T					
46.	Spookhill 10	T					
47.	Smith Peak	T/R		(80)			
48.	Thompson Peak	T		(80)			
49.	Tiger Wash 2	T		(81)			
50.	Vineyard 2	T					
51.	Vineyard 4	T	X				

T - Telemetry Station
R - Recording Station
(81) - Year Station Installed (if known)

Gage Location	Telemetry Recording T/R	Years of Record 2	2-5	5-10	10-20	20
52. Waterman Wash 10	T		(83)			
53. Yarnell Hill	T/R		(81)			
(5 additional telemetered stations are installed but their locations were not available.)						
59. Apache Junction	R		X			
60. Doggy Jones	R					(57)
61. Foothills	R					(57)
62. Gila Drain	R		(82)			
63. Gila E-W 2	R		(82)			
64. Hydroclimate	R		(80)			
65. IBW 5	R		(82)			
66. Below McMicken Dam						(57)
67. Morristown	R					(57)
68. Peoria	R		(81)			
69. Skunk Creek	R		X			
70. Waterman Wash 4	R		(80)			
71. Waterman Wash 9	R		(82)			
72. Wittman	R		(82)			
(3 additional recording tations are installed but their locations were not available)						

T - Telemetry Station
R - Recording Station
(81) - Year Station Installed (if known)

CITY OF PHOENIX

Telemetry Rain Gages

Location	Years of Record 2-5	5-10	10-15
16th St. and Thomas (Fire Station 5)			X
48th St. and Thomas (Fire Station 13)			X
16th St. and Camelback (Fire Station 17)			X
Central Ave. and Southern (Fire Station 22)			X
59th Ave. and Indian School (Fire Station 25)			X
32nd St. and Cactus (Fire Station 27)			X
27th Ave. and Northern (Fire Station 30)			X
Central Ave. and Washington (Municipal Bldg.)		X	
Deer Valley Airport		X	
35th Ave. and Greenway (Fire Station 42)	X		

V. PRECIPITATION

NORMAL TOTAL AND MAXIMUM AND MINIMUM TOTAL BY MONTHS AND YEAR OF OCCURRENCE
1896-1985

	NORMAL	MAXIMUM	YEAR	MINIMUM	YEAR
January	0.73	3.67	1897	0.00	1912 1924 1972
February	0.59	4.64	1905	0.00	1912 1967 1984
March	0.81	4.82	1941	0.00	1933 1956 1959 1984
April	0.27	3.36	1926	0.00	1904 1920 1948 1960 1962
May	0.14	1.31	1930	0.00	1899 1911 1913 1932 1939 1942 1945 1946 1952 1974 1983
June	0.17	1.70	1972	0.00	1897 1900 1901 1908 1913 1916 1917 1923 1928 1935 1939 1942 1944 1945 1946 1947 1953 1963 1964 1968 1969 1970 1971 1974 1983 1985
July	0.74	6.47	1911	0.02	1931
August	1.02	5.33	1951	trace	1973 1975
September	0.64	5.41	1939	0.00	1953 1957 1968 1973
October	0.63	4.40	1972	0.00	1898 1905 1909 1934 1950 1952 1973
November	0.54	3.61	1905	0.00	1897 1903 1904 1912 1916 1917 1932 1937 1943 1945 1948 1956 1980
December	0.83	3.98	1967	0.00	1900 1901 1917 1958 1973 1981
Annual	7.11	19.73	1905	2.82	1956

Years in Which There Were 5 (the most) Calendar Months
Without Measurable Precipitation:

1904 1938 1945 1948 1972 1973

Years in Which All Twelve Calendar Months had Measurable Precipitation:

1921 1925 1927 1949 1965 1979

Precipitation

DAILY NORMALS OF PRECIPITATION
1951-1980

	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE	
	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE
1	.03	0.03	.02	0.75	.02	1.34	.02	2.15	.00	2.40	.00	2.54
2	.03	0.06	.02	0.77	.02	1.36	.02	2.17	.00	2.40	.00	2.54
3	.03	0.09	.02	0.79	.03	1.39	.02	2.19	.01	2.41	.00	2.54
4	.03	0.12	.02	0.81	.03	1.42	.02	2.21	.01	2.42	.00	2.54
5	.03	0.15	.02	0.83	.03	1.45	.01	2.22	.01	2.43	.00	2.54
6	.03	0.18	.02	0.85	.03	1.48	.01	2.23	.01	2.44	.00	2.54
7	.03	0.21	.02	0.87	.03	1.51	.01	2.24	.01	2.45	.00	2.54
8	.03	0.24	.02	0.89	.03	1.54	.01	2.25	.01	2.46	.00	2.54
9	.03	0.27	.02	0.91	.03	1.57	.01	2.26	.01	2.47	.00	2.54
10	.03	0.30	.02	0.93	.03	1.60	.01	2.27	.01	2.48	.00	2.54
11	.03	0.33	.02	0.95	.03	1.63	.01	2.28	.01	2.49	.00	2.54
12	.02	0.35	.02	0.97	.03	1.66	.01	2.29	.01	2.50	.00	2.54
13	.02	0.37	.02	0.99	.03	1.69	.01	2.30	.01	2.51	.00	2.54
14	.02	0.39	.02	1.01	.03	1.72	.01	2.31	.01	2.52	.01	2.55
15	.02	0.41	.02	1.03	.03	1.75	.01	2.32	.01	2.53	.01	2.56
16	.02	0.43	.02	1.05	.03	1.78	.01	2.33	.01	2.54	.01	2.57
17	.02	0.45	.02	1.07	.03	1.81	.01	2.34	.00	2.54	.01	2.58
18	.02	0.47	.02	1.09	.03	1.84	.01	2.35	.00	2.54	.01	2.59
19	.02	0.49	.02	1.11	.03	1.87	.01	2.36	.00	2.54	.01	2.60
20	.02	0.51	.02	1.13	.03	1.90	.01	2.37	.00	2.54	.01	2.61
21	.02	0.53	.02	1.15	.03	1.93	.01	2.38	.00	2.54	.01	2.62
22	.02	0.55	.02	1.17	.02	1.95	.01	2.39	.00	2.54	.01	2.63
23	.02	0.57	.02	1.19	.02	1.97	.01	2.40	.00	2.54	.01	2.64
24	.02	0.59	.02	1.21	.02	1.99	.00	2.40	.00	2.54	.01	2.65
25	.02	0.61	.02	1.23	.02	2.01	.00	2.40	.00	2.54	.01	2.66
26	.02	0.63	.03	1.26	.02	2.03	.00	2.40	.00	2.54	.01	2.67
27	.02	0.65	.03	1.29	.02	2.05	.00	2.40	.00	2.54	.01	2.68
28	.02	0.67	.03	1.32	.02	2.07	.00	2.40	.00	2.54	.01	2.69
29	.02	0.69			.02	2.09	.00	2.40	.00	2.54	.01	2.70
30	.02	0.71			.02	2.11	.00	2.40	.00	2.54	.01	2.71
31	.02	0.73			.02	2.13			.00	2.54		
MONTHLY NORMAL		0.73		0.59		0.81		0.27		0.14		0.17

Precipitation

DAILY NORMALS OF PRECIPITATION
1951-1980

	JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE	NORM	TO DATE
1	.01	2.72	.03	3.48	.03	4.50	.02	5.13	.02	5.76	.02	6.30
2	.01	2.73	.03	3.51	.03	4.53	.02	5.15	.02	5.78	.02	6.32
3	.02	2.75	.03	3.54	.03	4.56	.02	5.17	.02	5.80	.02	6.34
4	.02	2.77	.03	3.57	.03	4.59	.02	5.19	.02	5.82	.02	6.36
5	.02	2.79	.03	3.60	.02	4.61	.02	5.21	.02	5.84	.02	6.38
6	.02	2.81	.03	3.63	.02	4.63	.02	5.23	.02	5.86	.02	6.40
7	.02	2.83	.03	3.66	.02	4.65	.02	5.25	.02	5.88	.02	6.42
8	.02	2.85	.04	3.70	.02	4.67	.02	5.27	.02	5.90	.02	6.44
9	.02	2.87	.04	3.74	.02	4.69	.02	5.29	.01	5.91	.02	6.46
10	.02	2.89	.04	3.78	.02	4.71	.02	5.31	.01	5.92	.02	6.48
11	.02	2.91	.04	3.82	.02	4.73	.02	5.33	.01	5.93	.03	6.51
12	.02	2.93	.04	3.86	.02	4.75	.02	5.35	.01	5.94	.03	6.54
13	.02	2.95	.04	3.90	.02	4.77	.03	5.38	.01	5.95	.03	6.57
14	.02	2.97	.04	3.94	.02	4.79	.02	5.40	.01	5.96	.03	6.60
15	.02	2.99	.04	3.98	.02	4.81	.02	5.42	.02	5.98	.03	6.63
16	.02	3.01	.04	4.02	.02	4.83	.02	5.44	.02	6.00	.03	6.66
17	.02	3.03	.03	4.05	.02	4.85	.02	5.46	.02	6.02	.03	6.69
18	.03	3.06	.03	4.08	.02	4.87	.02	5.48	.02	6.04	.03	6.72
19	.03	3.09	.03	4.11	.02	4.89	.02	5.50	.02	6.06	.03	6.75
20	.03	3.12	.03	4.14	.02	4.91	.02	5.52	.02	6.08	.03	6.78
21	.03	3.15	.03	4.17	.02	4.93	.02	5.54	.02	6.10	.03	6.81
22	.03	3.18	.03	4.20	.02	4.95	.02	5.56	.02	6.12	.03	6.84
23	.03	3.21	.03	4.23	.02	4.97	.02	5.58	.02	6.14	.03	6.87
24	.03	3.24	.03	4.26	.02	4.99	.02	5.60	.02	6.16	.03	6.90
25	.03	3.27	.03	4.29	.02	5.01	.02	5.62	.02	6.18	.03	6.93
26	.03	3.30	.03	4.32	.02	5.03	.02	5.64	.02	6.20	.03	6.96
27	.03	3.33	.03	4.35	.02	5.05	.02	5.66	.02	6.22	.03	6.99
28	.03	3.36	.03	4.38	.02	5.07	.02	5.68	.02	6.24	.03	7.02
29	.03	3.39	.03	4.41	.02	5.09	.02	5.70	.02	6.26	.03	7.05
30	.03	3.42	.03	4.44	.02	5.11	.02	5.72	.02	6.28	.03	7.08
31	.03	3.45	.03	4.47			.02	5.74			.03	7.11
MONTHLY NORMAL		0.74		1.02		0.64		0.63		0.54		0.83

Precipitation

MAXIMUM AMOUNTS FOR 5, 10, 15, AND 30 MINUTES; 1, 2, AND 24 HOURS BY MONTHS AND DAY AND YEAR OF OCCURRENCE 1896-1985

	5 Minutes	10 Minutes	15 Minutes	30 Minutes	1 Hour	2 Hours	24 Hours
January	0.35 3/1926	0.44 3/1926	0.56 3/1926	0.67 3/1926	0.75 3/1926	0.76 3/1926	1.76 9-10/1905
February	0.30 6/1935	0.41 10/1963	0.43 10/1963	0.44 10/1963	0.50 12/1936	0.67 6/1935	1.69 5-6/1935
March	0.26 4/1941	0.41 4/1941	0.43 4/1941	0.46 12/1941	0.61 12/1941	0.77 4/1941 3/1983	2.04 2-3/1983
April	0.32 19/1951	0.61 19/1951	0.75 19/1951	0.76 19/1951	0.76 19/1951	0.92 8/1926	1.66 5-6/1926
May	0.35 20/1979	0.45 20/1979	0.53 20/1979	0.59 20/1979	0.60 20/1979	0.61 20/1979	1.12 4-5/1930
June	0.30 12/1955	0.40 22/1972	0.52 22/1972	0.62 22/1972	0.92 22/1972	1.20 22/1972	1.64 21-22/1972
July	0.50 24/1978	0.70 26/1952	0.91 26/1952	1.15 17/1908	1.30 26/1917	1.47 2/1911	4.98 1-2/1911
August	0.90 16/1983	1.14 16/1983	1.17 16/1983	1.23 20/1978	1.72 18/1966	1.81 6/1918	2.27 27-28/1951
September	0.68 16/1969	1.00 16/1969	1.14 16/1969	1.27 16/1969	1.41 4/1939	2.20 4/1939	3.06 3-4/1939
October	0.68 1/1981	0.72 1/1981	0.72 1/1981	0.86 30/1928	0.93 30-31/1928	1.03 30-31/1928	2.27 18-19/1972
November	0.36 10/1931	0.38 10/1931 23/1919	0.40 23/1919	0.54 14/1918	0.67 14/1918	0.75 27/1919	2.40 9-10/1923
December	0.13 13/1975	0.22 19/1967	0.28 13/1975	0.38 19/1967	0.50 19/1967	0.68 19/1967	1.92 30-31/1915
Annual	0.90 AUG 16/1983	1.14 AUG 16/1983	1.17 AUG 16/1969	1.27 SEP 16/1969	1.72 AUG 18/1966	2.20 SEP 4/1939	4.98 JUL 1-2/1911

Precipitation

DAILY FREQUENCY OF OCCURRENCE OF TRACE OR MORE IN PERCENT
1896-1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	19	26	28	23	14	3	21	47	33	26	12	17
2	19	27	34	20	18	7	23	52	34	24	11	19
3	10	22	38	17	12	10	22	51	26	18	10	22
4	13	24	33	17	14	13	19	49	29	20	11	23
5	19	23	30	12	13	6	22	41	30	17	10	21
6	21	36	12	19	7	10	30	38	29	16	11	20
7	20	32	16	17	8	7	32	47	27	14	19	13
8	23	30	20	21	8	7	31	42	24	10	20	22
9	22	34	23	22	11	8	27	47	19	13	18	27
10	30	24	32	11	13	11	36	51	33	8	13	28
11	28	30	24	18	14	7	36	42	28	18	12	19
12	24	28	27	19	10	7	37	49	27	17	21	30
13	29	21	24	19	7	11	36	42	27	13	16	21
14	29	18	22	11	9	6	41	43	22	14	18	22
15	18	27	19	18	7	6	53	40	13	21	22	17
16	27	24	14	13	11	4	51	47	19	12	24	22
17	26	20	17	16	16	9	49	44	20	13	20	18
18	19	16	22	17	12	9	38	44	28	16	21	17
19	32	30	23	9	11	7	41	40	18	19	11	21
20	29	29	23	7	12	7	38	31	17	14	11	23
21	24	31	26	19	7	11	58	31	11	13	16	22
22	21	19	24	20	9	10	52	42	28	12	19	22
23	24	19	26	10	10	9	54	46	19	11	22	20
24	22	18	23	9	7	10	50	41	23	17	23	12
25	26	23	24	11	8	10	56	37	19	7	18	24
26	21	28	28	13	7	11	53	41	22	7	14	24
27	31	23	17	24	7	10	52	23	20	14	17	28
28	30	13	23	19	8	19	42	33	17	17	19	29
29	23	9	20	17	12	18	52	43	19	20	16	26
30	22		12	10	8	16	54	28	22	17	13	22
31	18		12		9		42	29		13		21

For Example: Precipitation has fallen on 24 percent of the Christmas Days during the 90-year period from 1896 through 1985.

Precipitation

DAILY FREQUENCY OF OCCURRENCE OF 0.01 INCHES OR MORE IN PERCENT
1896-1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	12	18	18	13	6	1	4	27	19	14	10	8
2	10	21	26	10	6	4	10	27	17	14	4	12
3	18	19	28	6	6	7	10	32	14	16	4	13
4	7	18	22	7	7	4	7	24	11	16	4	17
5	14	14	17	10	6	0	9	22	22	13	6	13
6	12	21	8	10	4	1	10	23	14	10	4	10
7	13	24	6	7	4	3	14	21	12	9	11	11
8	13	26	18	7	3	2	12	21	11	3	13	12
9	13	23	16	7	6	1	9	28	4	10	11	18
10	19	19	22	4	7	3	10	19	16	6	12	20
11	24	20	12	12	3	0	16	21	19	7	10	14
12	16	21	19	12	6	4	12	29	14	8	10	18
13	21	13	11	6	2	4	12	19	19	6	10	16
14	17	14	16	3	6	1	14	20	16	10	11	12
15	13	18	11	7	3	3	23	21	6	11	13	12
16	19	16	11	7	3	1	24	17	6	11	12	16
17	20	14	12	7	3	4	30	20	8	8	13	16
18	13	13	13	7	6	3	18	22	16	12	13	13
19	16	24	9	7	4	3	16	17	10	7	8	18
20	14	18	12	6	4	3	23	14	9	8	7	16
21	16	23	13	9	1	6	22	17	10	9	11	19
22	11	13	18	17	4	6	28	23	13	8	16	17
23	18	11	14	4	0	3	26	22	14	8	17	13
24	12	13	16	4	2	1	31	17	10	9	12	10
25	14	18	17	1	0	2	23	16	9	7	13	16
26	12	16	18	3	1	3	30	21	12	6	8	19
27	18	12	11	16	2	1	16	17	11	10	13	17
28	22	4	13	17	1	6	24	13	7	9	17	18
29	20	9	11	11	6	4	28	23	11	13	10	20
30	18		4	6	1	7	24	14	14	14	7	8
31	10		9		1		18	13		11		17

For Example: Precipitation of 0.01 inches or more has fallen on 16 percent of the Christmas Days during the 90-year period from 1896 through 1985.

Precipitation

DAILY FREQUENCY OF OCCURRENCE OF 0.10 INCHES OR MORE IN PERCENT
1896-1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	6	7	10	7	3	0	4	12	11	8	3	2
2	6	10	16	4	1	3	6	10	7	4	4	7
3	10	10	13	1	0	1	1	19	3	8	1	6
4	3	11	10	4	6	1	3	12	4	7	1	11
5	8	6	7	6	3	0	3	12	12	10	3	10
6	11	13	3	7	1	1	6	12	7	4	3	6
7	8	11	1	1	3	0	6	10	7	3	4	6
8	6	7	11	4	1	2	6	7	9	3	7	6
9	6	11	6	4	3	0	1	11	3	3	8	11
10	12	17	11	1	3	1	2	8	4	2	9	12
11	14	12	7	9	1	0	8	12	7	1	6	9
12	4	11	12	4	3	3	4	13	12	6	9	12
13	17	9	8	1	0	0	4	6	12	1	4	11
14	4	12	7	1	3	0	10	4	4	6	6	10
15	10	11	8	4	1	0	11	11	0	1	8	12
16	8	4	9	4	0	0	12	10	6	7	10	9
17	9	3	6	6	0	3	14	10	4	6	8	7
18	11	6	6	3	0	1	11	10	10	10	7	7
19	4	7	4	4	1	1	7	10	4	6	4	11
20	10	4	8	1	4	0	9	8	4	2	7	7
21	8	10	6	3	1	3	12	7	4	3	8	13
22	4	6	8	9	1	3	11	9	4	3	11	10
23	4	6	9	3	0	1	9	9	6	6	13	6
24	6	7	4	1	1	1	13	11	7	1	7	6
25	9	9	8	1	0	2	17	7	7	3	6	11
26	6	7	10	1	1	0	13	12	7	3	6	11
27	7	8	6	9	0	0	10	10	8	3	8	8
28	7	4	7	10	1	1	8	6	4	7	10	11
29	12	1	4	4	0	0	12	14	7	8	6	8
30	10		1	1	0	3	12	1	4	10	6	7
31	6		7		1		10	7		6		11

For Example: Precipitation of 0.10 inches or more has fallen on 11 percent of the Christmas Days during the 90-year period from 1896 through 1985.

Precipitation

DAILY FREQUENCY OF OCCURRENCE OF 0.25 INCHES OR MORE IN PERCENT
1896-1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	3	10	1	1	0	1	4	7	6	1	2
2	3	4	9	1	1	0	4	4	1	2	3	4
3	9	6	8	1	0	1	0	10	0	6	1	3
4	1	7	7	1	3	0	0	4	1	3	1	3
5	2	4	7	3	1	0	0	11	6	4	1	4
6	4	7	0	4	0	0	3	7	3	2	3	1
7	3	7	0	0	0	0	4	6	6	1	3	3
8	1	0	1	1	0	0	3	3	4	1	3	4
9	2	6	4	3	3	0	0	7	3	3	2	10
10	8	9	7	1	3	1	1	1	2	1	8	8
11	8	7	6	6	0	0	4	4	3	1	4	6
12	2	7	9	1	0	1	4	9	6	1	6	4
13	7	3	6	0	0	0	1	4	10	0	3	9
14	1	6	4	1	0	0	3	2	1	4	1	6
15	6	8	4	0	0	0	7	3	0	1	3	9
16	6	1	6	4	0	0	10	6	1	4	3	1
17	6	1	4	3	0	0	11	3	4	1	4	4
18	7	3	0	0	0	1	8	6	7	7	3	7
19	1	4	1	1	0	0	3	3	2	4	3	7
20	7	3	2	1	1	0	3	4	3	2	1	3
21	3	6	1	1	1	1	8	6	1	1	4	9
22	1	1	4	4	0	1	4	1	1	3	4	4
23	1	0	4	3	0	1	3	6	2	2	11	1
24	3	4	1	0	0	1	8	8	7	0	4	4
25	4	1	1	1	0	1	11	3	2	0	4	6
26	2	3	4	0	0	0	7	7	7	3	6	7
27	4	4	3	1	0	0	7	6	7	1	4	6
28	6	2	6	7	1	1	6	6	4	6	4	10
29	9	1	4	0	0	0	6	9	7	4	4	4
30	7		0	0	0	0	6	0	4	7	4	4
31	1		3		0		3	3		1		8

For Example: Precipitation of 0.25 inches or more have fallen on 6 percent of the Christmas Days during the 90-year period from 1896 through 1985.

Precipitation

DAILY FREQUENCY OF OCCURRENCE OF 0.50 INCHES OR MORE IN PERCENT
1896-1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	6	0	0	0	1	4	2	2	0	0
2	0	0	4	0	0	0	4	1	0	1	0	0
3	7	3	2	1	0	0	0	6	0	3	0	3
4	1	4	6	0	2	0	0	1	1	3	0	1
5	0	3	3	3	0	0	0	10	3	1	1	1
6	1	4	0	1	0	0	0	3	0	1	0	0
7	1	1	0	0	0	0	1	2	3	0	0	1
8	0	0	0	1	0	0	1	1	3	1	0	1
9	1	1	3	0	0	0	0	0	3	3	1	6
10	4	1	4	1	1	0	0	0	1	1	4	6
11	3	1	1	4	0	0	0	0	1	0	4	6
12	1	4	3	0	0	1	3	2	4	0	2	1
13	1	2	3	0	0	0	1	0	6	0	3	6
14	1	4	1	0	0	0	0	0	1	0	1	1
15	2	2	3	0	0	0	4	1	0	1	1	4
16	3	1	3	1	0	0	3	1	1	0	1	0
17	2	0	1	0	0	0	6	1	4	0	1	1
18	1	1	0	0	0	0	3	1	6	4	3	4
19	1	1	1	1	0	0	3	0	0	3	1	4
20	3	1	1	0	1	0	1	1	0	0	1	0
21	1	3	0	0	0	0	4	1	1	0	3	1
22	0	0	1	1	0	1	1	0	0	0	1	1
23	0	0	0	3	0	1	0	1	2	2	6	0
24	1	3	0	0	0	0	6	4	3	0	1	4
25	3	1	1	0	0	0	7	1	0	0	1	1
26	0	3	0	0	0	0	4	4	4	0	3	1
27	1	1	1	0	0	0	7	3	4	1	1	2
28	3	1	4	1	0	0	1	4	4	3	1	4
29	3	0	0	0	0	0	1	3	4	0	3	1
30	3		0	0	0	0	1	0	0	6	1	3
31	1		0		0		1	3		1		4

For Example: Precipitation of 0.50 inches or more have fallen on 1 percent of the Christmas Days during the 90-year period from 1896 through 1985.

Precipitation

DAILY FREQUENCY OF OCCURRENCE OF 1.00 INCH OR MORE IN PERCENT
1896-1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	1	3	1	0	0	0
2	0	0	0	0	0	0	1	1	0	0	0	0
3	0	1	1	0	0	0	0	1	0	1	0	0
4	0	0	1	0	0	0	0	0	1	0	0	0
5	0	0	0	1	0	0	0	3	1	0	0	0
6	0	0	0	0	0	0	0	1	0	1	0	0
7	0	0	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	3	1	0	0
9	1	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	1	0	1	1
11	1	0	0	1	0	0	0	0	1	0	1	0
12	1	0	1	0	0	0	1	0	1	0	1	0
13	0	0	0	0	0	0	0	0	3	0	0	1
14	0	0	1	0	0	0	0	0	1	0	1	1
15	0	0	0	0	0	0	0	1	0	0	0	0
16	1	0	1	0	0	0	1	1	1	0	0	0
17	1	0	0	0	0	0	3	0	3	0	0	0
18	0	0	0	0	0	0	1	1	1	0	0	1
19	0	0	0	0	0	0	0	0	0	3	0	3
20	0	0	0	0	0	0	1	1	0	0	1	0
21	0	0	0	0	0	0	1	0	0	0	0	0
22	0	0	0	0	0	1	1	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	1	1	1	0	0	0
25	0	0	0	0	0	0	4	0	0	0	0	0
26	0	0	0	0	0	0	4	0	3	0	1	0
27	0	0	0	0	0	0	3	1	1	1	1	1
28	0	0	0	0	0	0	1	0	1	0	0	0
29	1	0	0	0	0	0	1	0	1	0	0	0
30	1		0	0	0	0	1	0	0	1	0	3
31	0		0		0		0	0		1		0

For Example: Precipitation of 1.00 inch or more has fallen on 3 percent of the August 1st's during the 90-year period from 1896 through 1985.

APPENDIX 1-B

Rainfall Analyses for Clark County, Nevada.

RAINFALL FOR THE CCRFCD AREA

CONTENTS

DRAFT

TABLES

FIGURES

1. GENERAL

The United States Department of Commerce, in 1973, published a Precipitation-Frequency Atlas for Nevada[1], referred to hereafter as the NOAA Atlas. The climatological data utilized in the NOAA Atlas was that data available through 1970. A detailed set of guidelines are given on how to use the depth-duration-frequency maps, in the NOAA Atlas, to develop design rainstorms and time-intensity-frequency curves for any location within Nevada.

The NOAA Atlas, due to its publication date, did not take into account the significant major rainfall events since 1970 such as; the Eldorado Canyon storm of 1974, the Las Vegas Valley storm of 1975, the Moapa Valley storm of 1981, the Las Vegas Valley storms of 1983, and the Moapa Valley and Las Vegas Valley storms of 1984. Various studies[2,3] have been performed to examine the possibility that the NOAA Atlas does not contain "the best available information." The U.S. Corps of Engineers, Los Angeles District is also studying the impact the more recent storms have on this region's precipitation-frequency relationships.

The United States Department of Commerce, in 1984, published a report that dealt with depth-area ratios in the southwest United States[4]. This report contains a different set of depth-area curves then those published in the NOAA

Atlas. The depth-area curves in the report known as "HYDRO-40" has also been reviewed by various people and agencies. It is felt that "HYDRO-40" does contain "best available information" for this region.

As the more recent studies are being reviewed and as additional studies are being prepared it has become apparent that the information in the NOAA Atlas should be modified accordingly to reflect more realistic values for this region of Nevada. For the above stated reasons and to use rainfall information that is "the best available" at this time, it was concluded that the NOAA Atlas rainfall information should be adjusted, as the following sections depict, and that "HYDRO-40" is applicable for this region.

2. RAINFALL DEPTH-DURATION-FREQUENCY

2.1 Rainfall Depth-Duration-Frequency Maps

Using the information contained in the NOAA Atlas[1], Rainfall Depth-Duration Frequency maps were reproduced for the CCRFCD area. Maps are presented for the 6- and 24-hour durations for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence frequencies as Figures 2-1 through 2-12. The information presented on these figures consists of the following :

a. Bold numbers represents tenths of inches of rainfall (i.e. 11 = 1.1 inches).

b. Small numbers represents elevation in thousands of feet (i.e. 3 = 3000 feet).

c. 35^{o} through 37^{o} represents degrees of latitude north.

d. 114^{o} through 116^{o} represents degrees of longitude west.

The data obtained from these figures must be modified as stated in subsequent sections.

2.2 Verification Of Values Obtained From Rainfall Maps

Once the values from Figures 2-1 through 2-12 are obtained for the location rainfall data is required, verification of these values are required. NOAA Atlas[1], page 16, states "the values read ··· should be plotted on the return-period diagram ··· because (1) not all points are as easy to locate on a series of maps as are latitude-longitude intersections, (2) there may be some slight registration differences in printing, and (3) precise interpolation between isolines is difficult." The return-period diagram contained in the NOAA Atlas[1] is reproduced as Figure 2-13. The values obtained from the maps are either verified or corrected, by drawing a line of best fit, to the values read from the return-period diagram.

These values must be modified as states in subsequent sections.

2.3 Depths For Durations From One- To Six-Hours

After the verification and/or corrections are performed, as stated in Section 2.2, for the 6- and 24-hour durations for the various recurrence frequencies, the one-hour duration 2- and 100-year recurrence frequencies can be calculated with equations found in the NOAA Atlas[1] and are reproduced below:

$$Y_2 = -0.011 + 0.942 * [(X_1)(X_1/X_2)]$$

$$Y_{100} = 0.494 + 0.755 * [(X_3)(X_3/X_4)]$$

where :

Y_2 = 2-yr 1-hr estimated value (inches)
Y_{100} = 100-yr 1-hr estimated value (inches)
X_1 = 2-yr 6-hr value from Fig. 2-1 (inches)
X_2 = 2-yr 24-hr value from Fig. 2-7 (inches)
X_3 = 100-yr 6-hr value from Fig. 2-6 (inches)
X_4 = 100-yr 24-hr value from Fig. 2-12 (inches)

The one-hour duration 2- and 100-year (Y_2 & Y_{100}) recurrence frequencies are then plotted on Figure 2-13 and a straight line connecting these points is drawn. The one-hour duration 5-, 10-, 25-, and 50-year recurrence frequency values can then be read.

The 2- and 3-hour durations for the various recurrence frequencies can now be calculated using equations found in the NOAA Atlas[1]. These equations are identical for each 'X'-year recurrence frequency and are reproduced below:

$$(2\text{-hr}) = 0.341(6\text{-hr}) + 0.659(1\text{-hr})$$

$$(3\text{-hr}) = 0.569(6\text{-hr}) + 0.431(1\text{-hr})$$

where :
2-hr = 2-hr 'X'-yr estimated value (inches)
3-hr = 3-hr 'X'-yr estimated value (inches)
1-hr = 1-hr 'X'-yr previously determined (inches)
6-hr = 6-hr 'X'-yr previously determined (inches)

These values must be modified as stated in subsequent sections.

2.4 Adjustments To NOAA Atlas[1]

The NOAA Atlas[1] values are adjusted to reflect "the best available" information. Rainfall depths for durations of 6-hours and less shall to be increased by multiplying the values previously obtained by the appropriate factors presented in Table 2-1.

TABLE 2-1

RATIOS OF ADJUSTED PRECIPITATION-FREQUENCY

VALUES TO THOSE OF NOAA ATLAS[1]

Recurrence Frequency	Ratio to NOAA Atlas[1]
2-year	1.000
5-year	1.161
10-year	1.241
25-year	1.328
50-year	1.387
100-year	1.430

SOURCE : Corps of Engineers, Los Angeles District

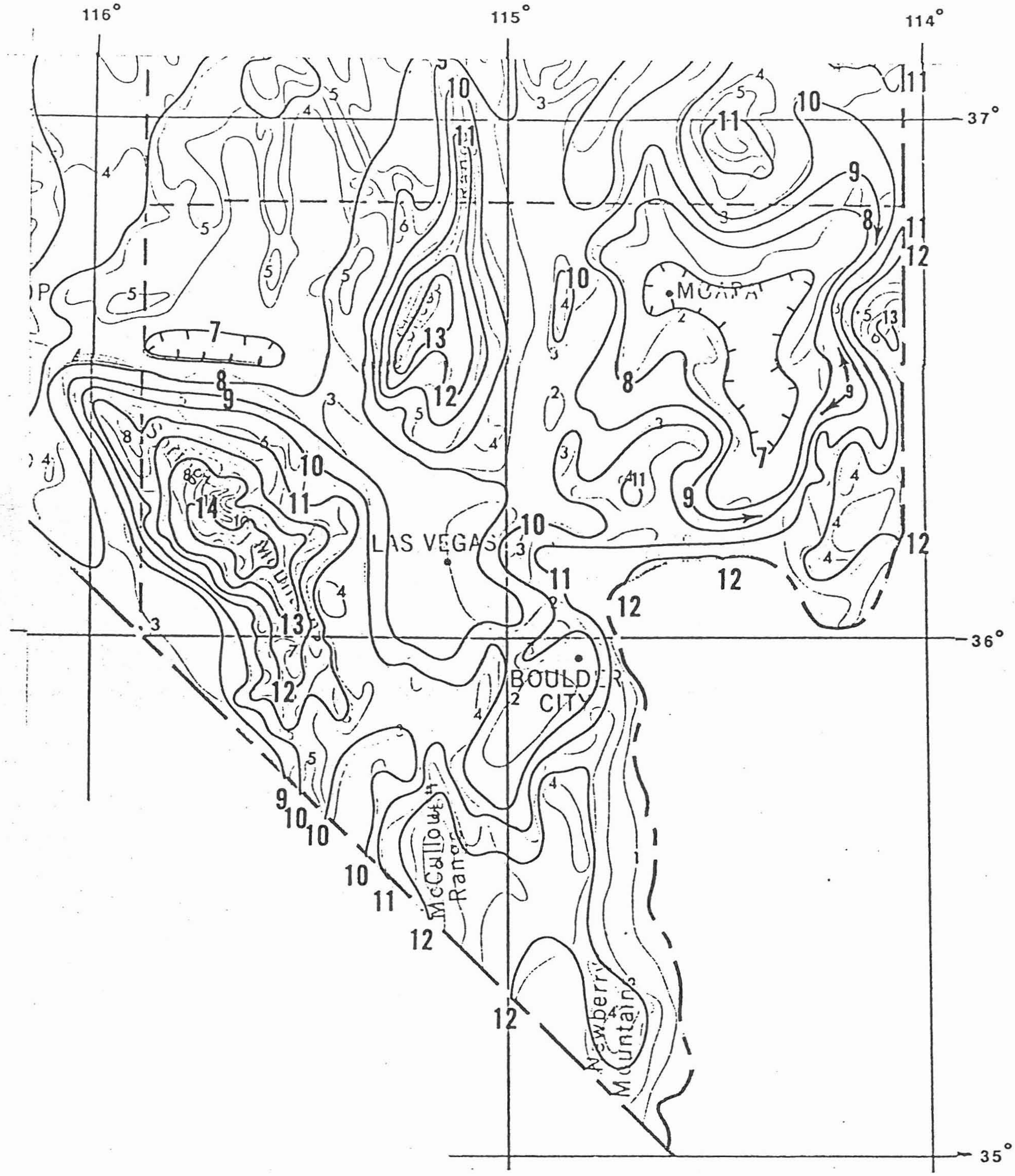


FIGURE 2-1 2-YEAR 6-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

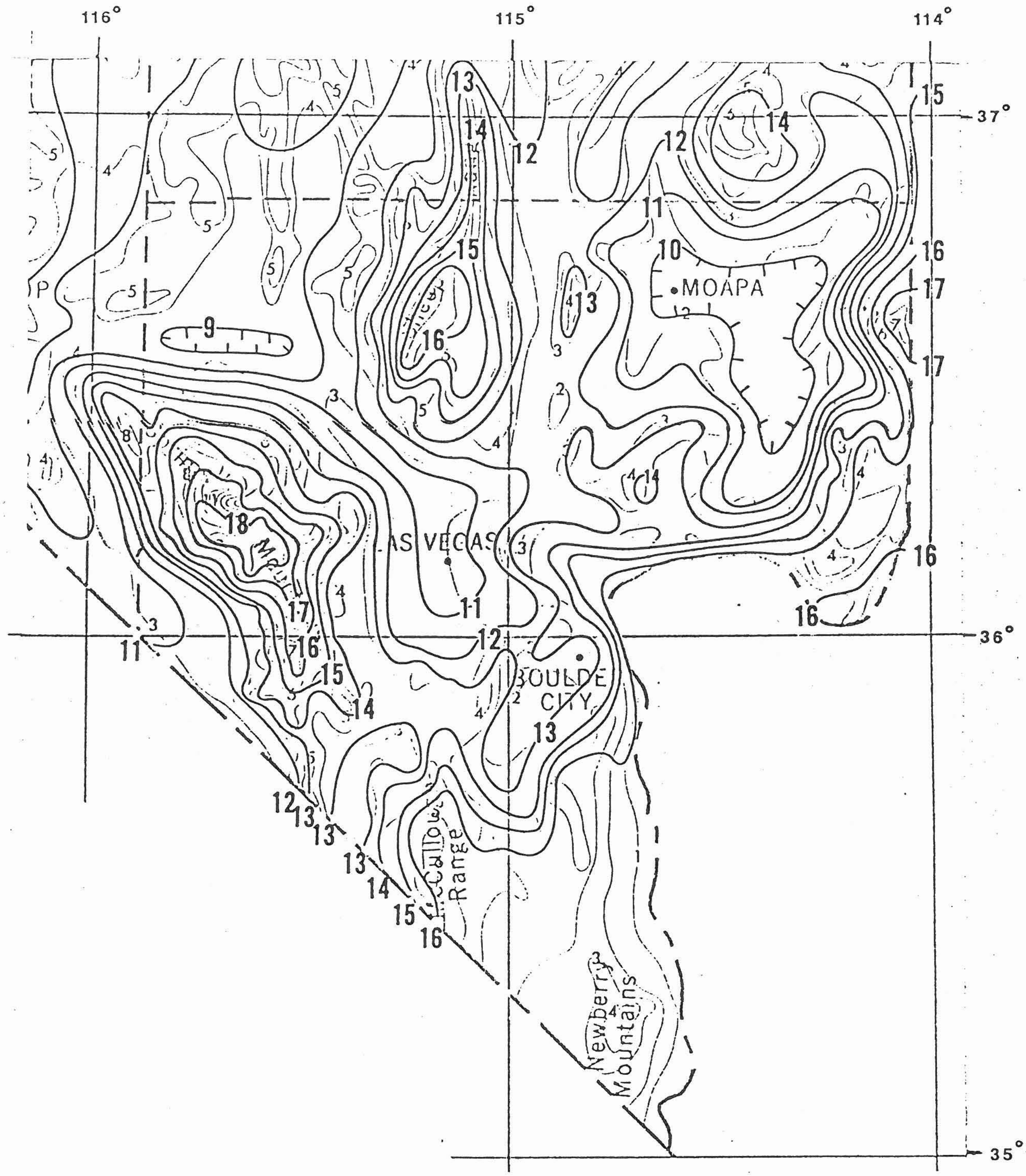


FIGURE 2-2 5-YEAR 6-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

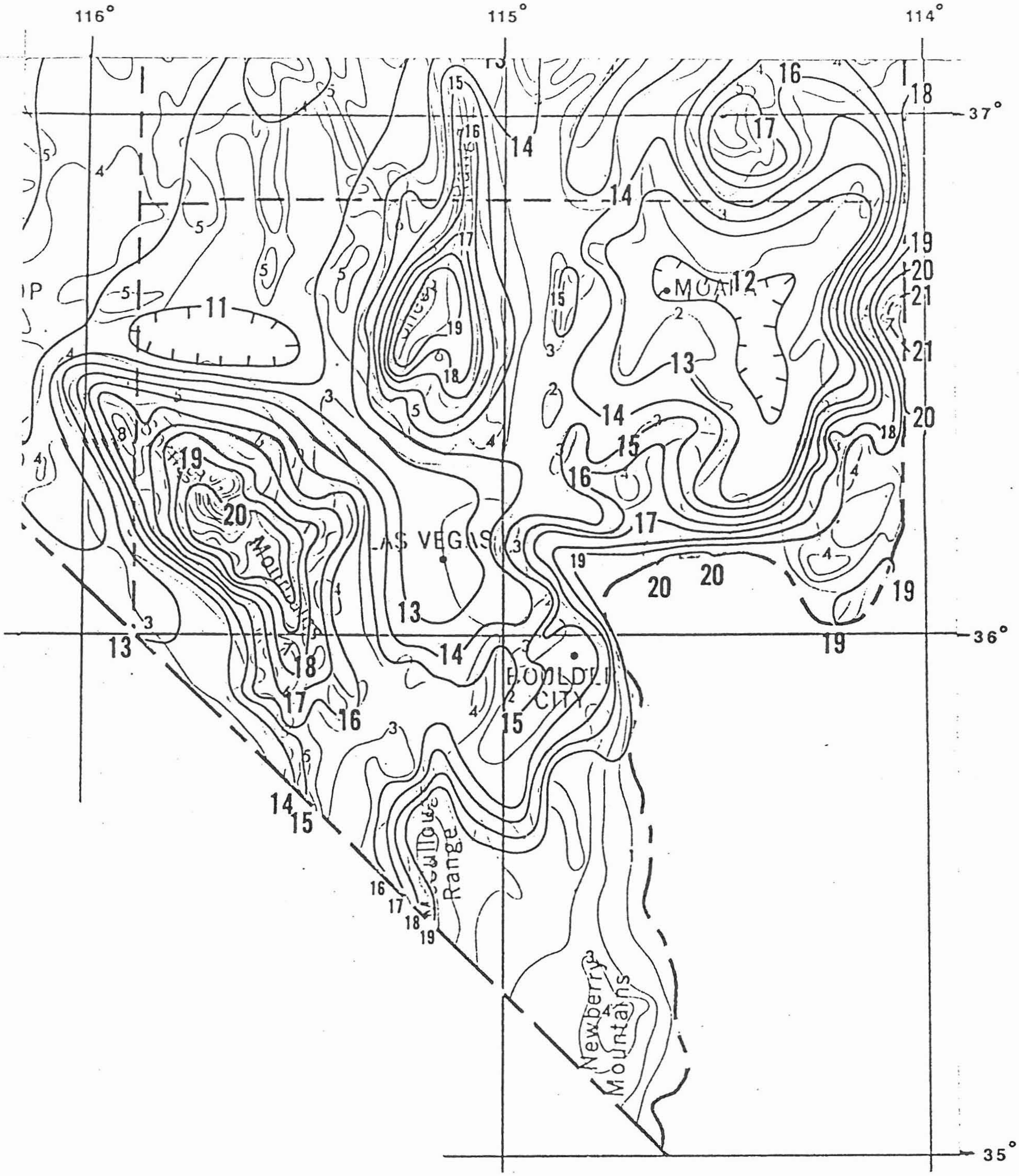


FIGURE 2-3 10-YEAR 6-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

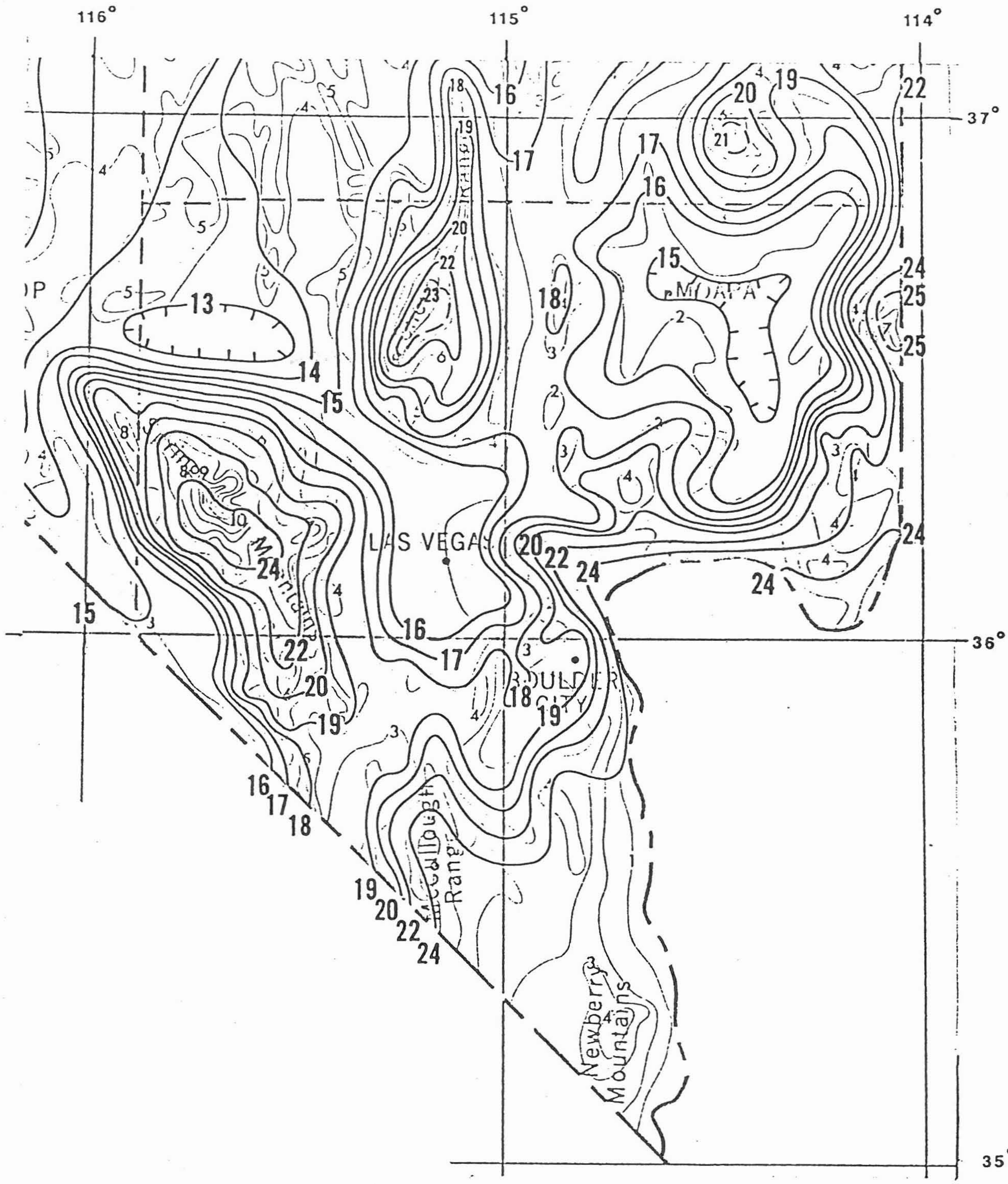


FIGURE 2-4 25-YEAR 6-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

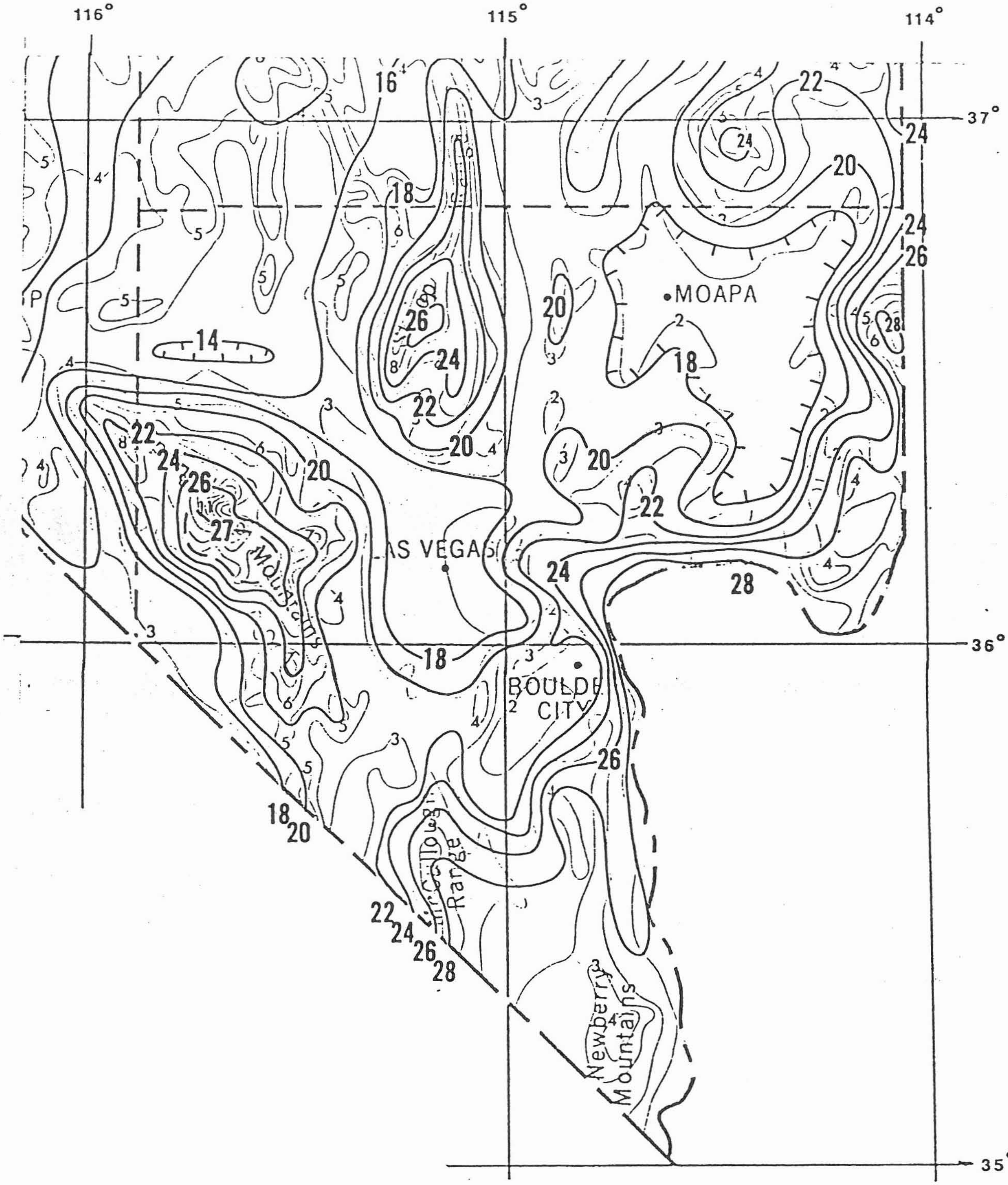


FIGURE 2-5 50-YEAR 6-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

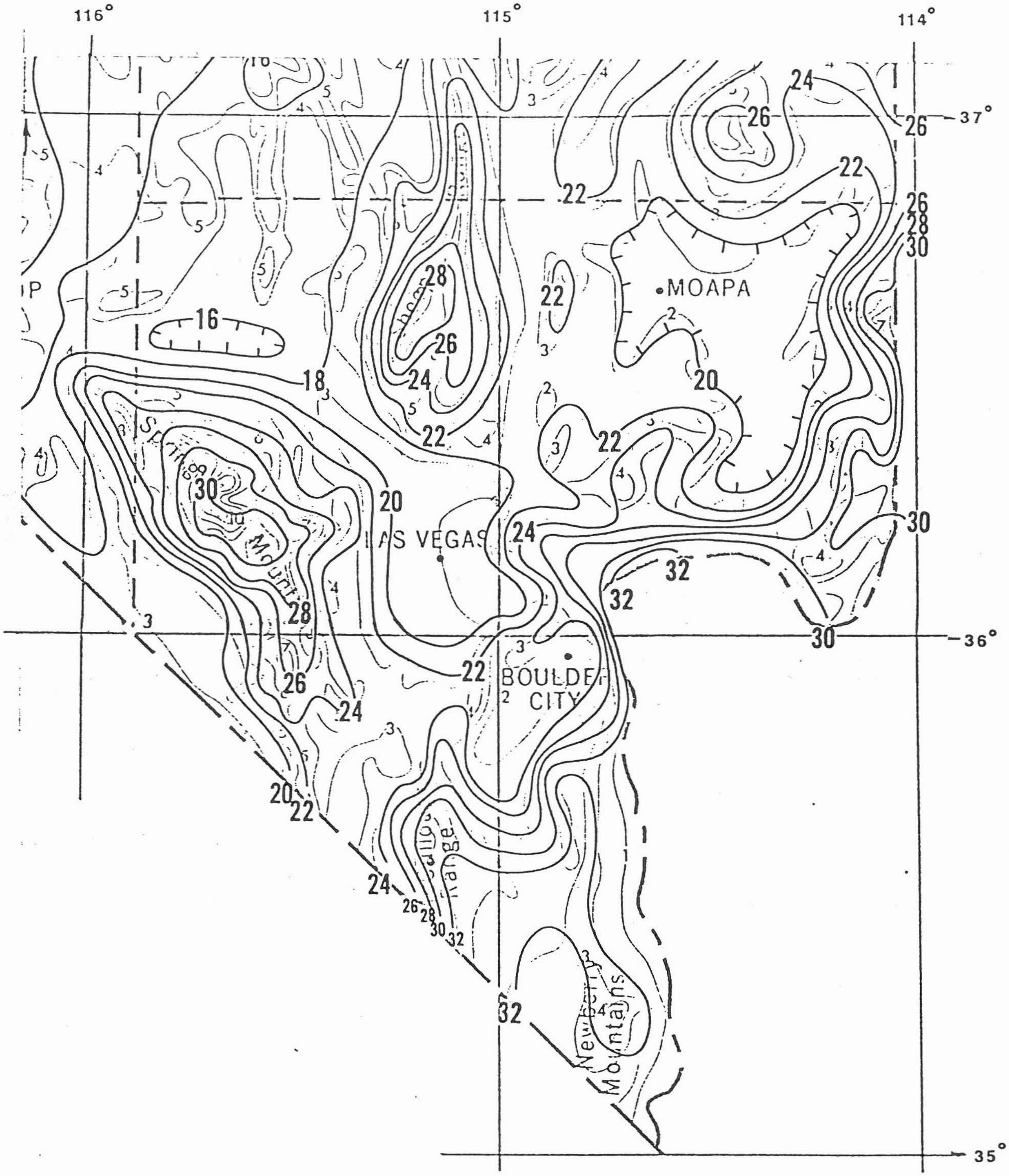


FIGURE 2-6 100-YEAR 6-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

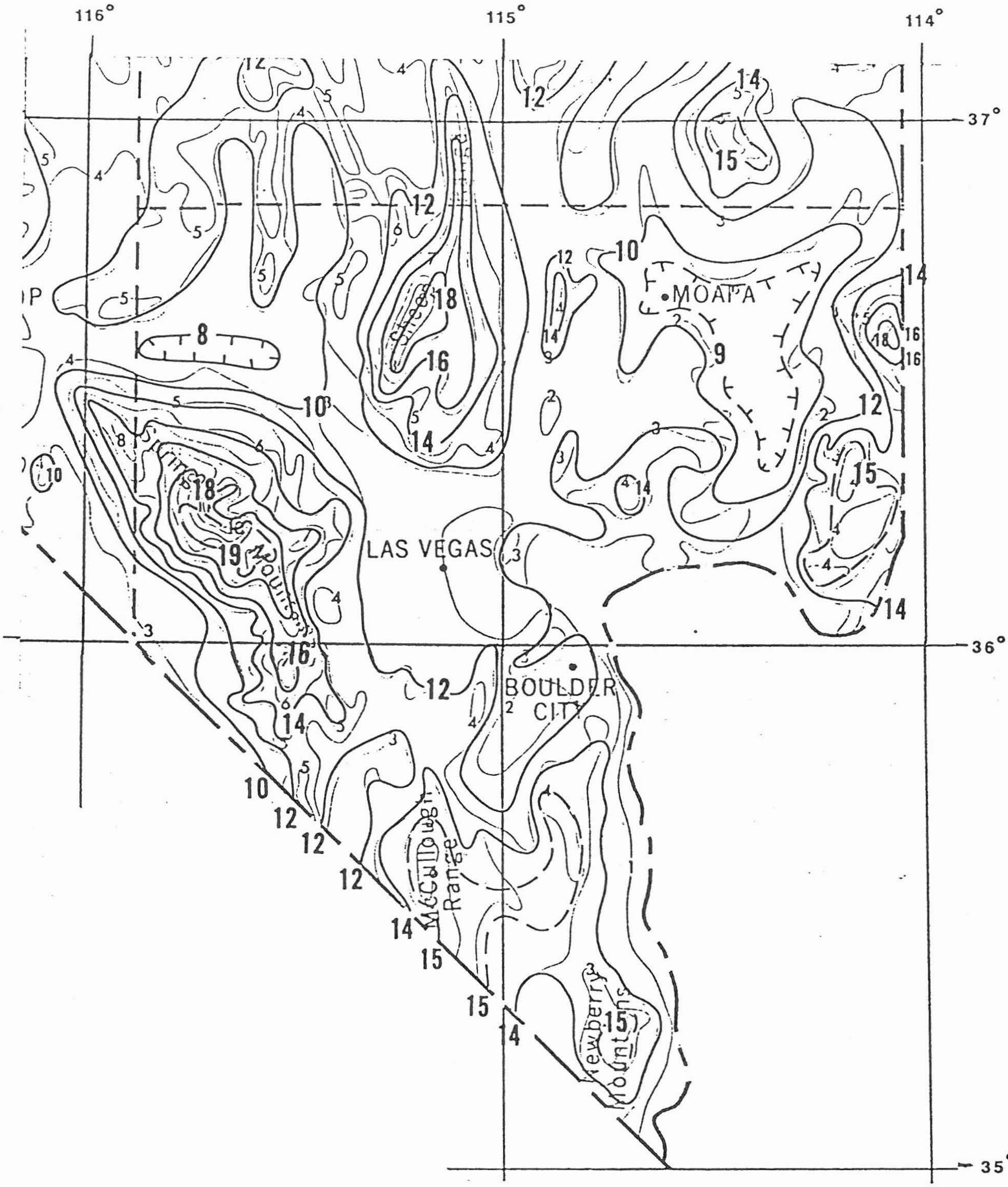


FIGURE 2-7 2-YEAR 24-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

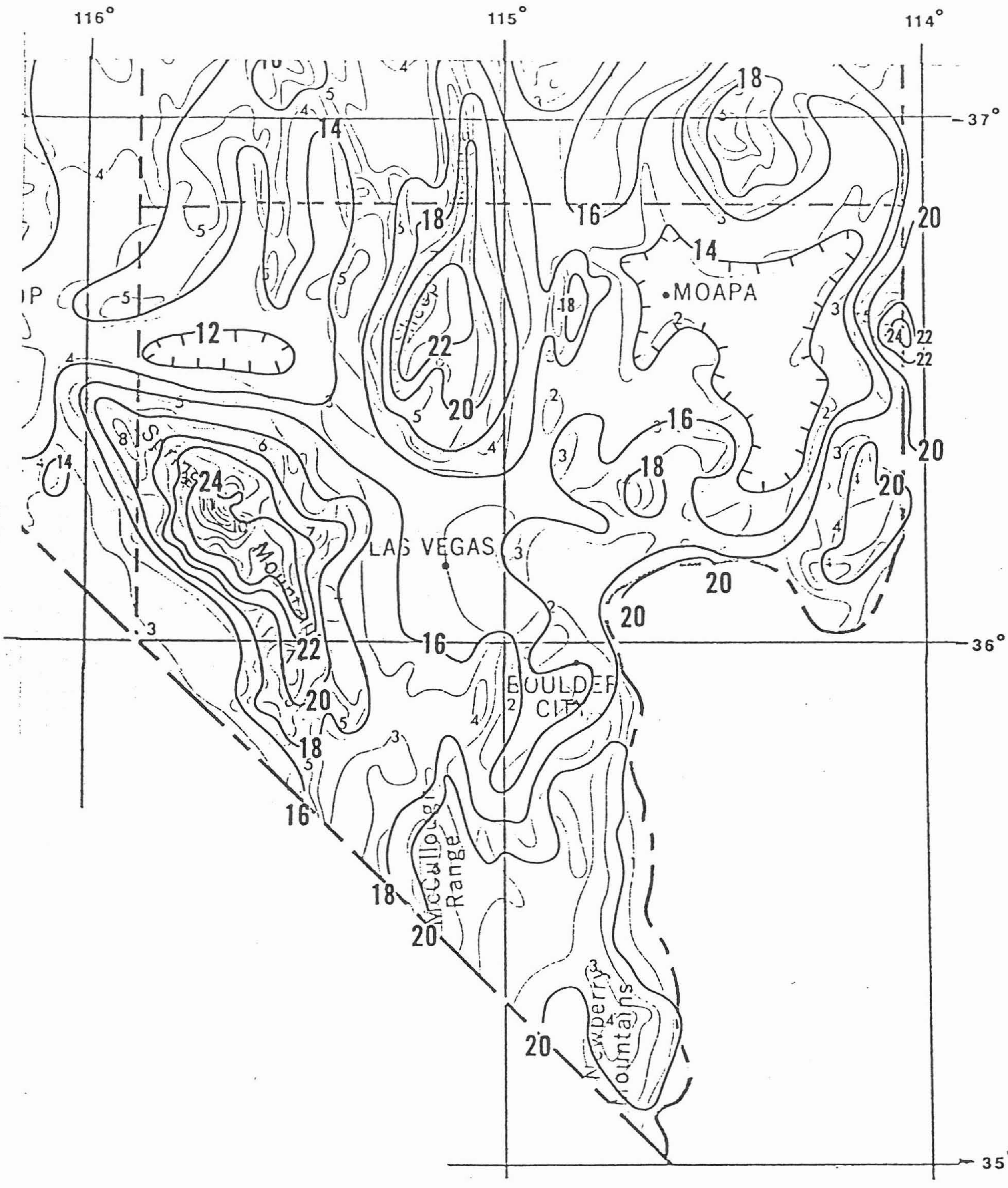


FIGURE 2-8 5-YEAR 24-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

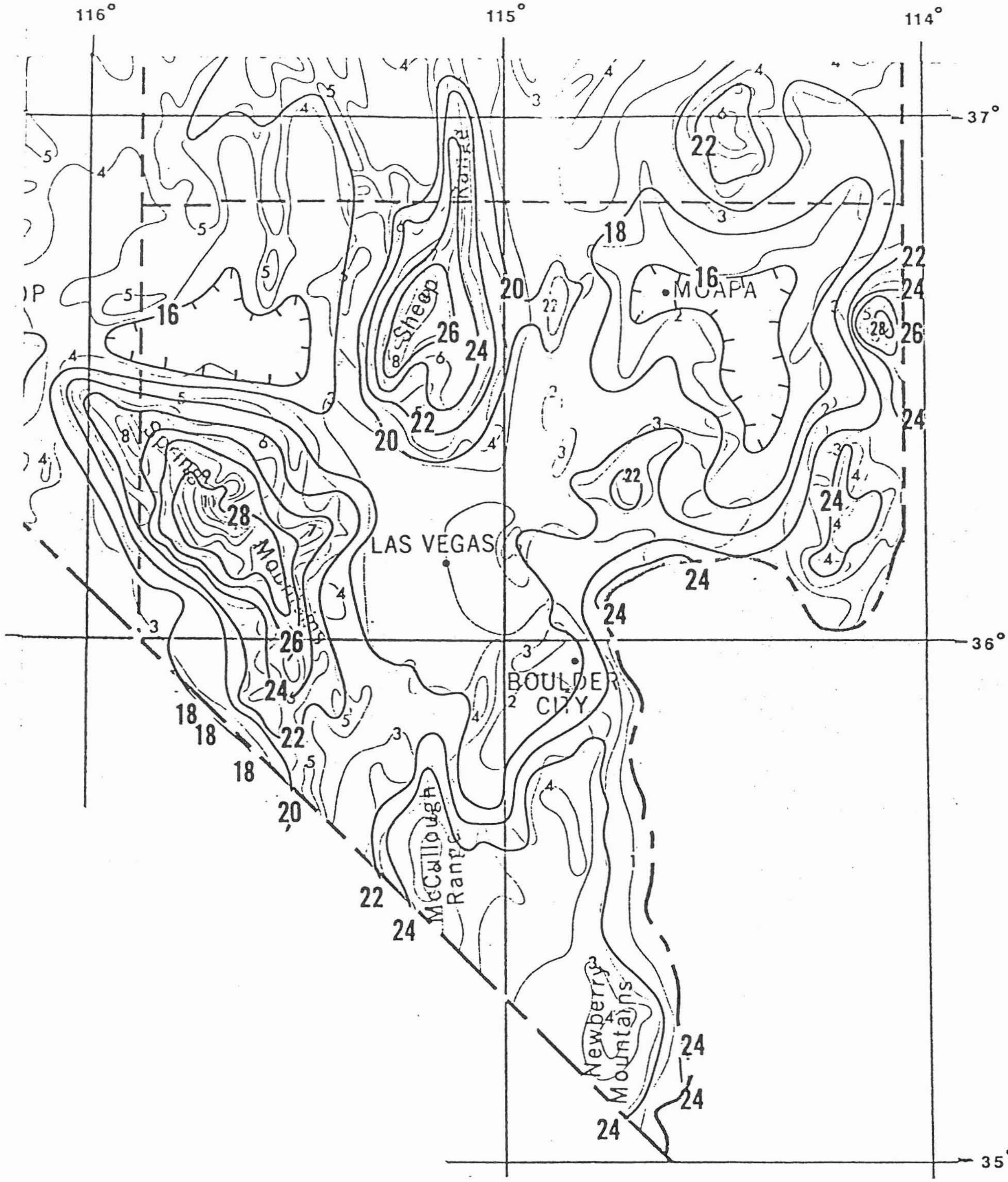


FIGURE 2-9 10-YEAR 24-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

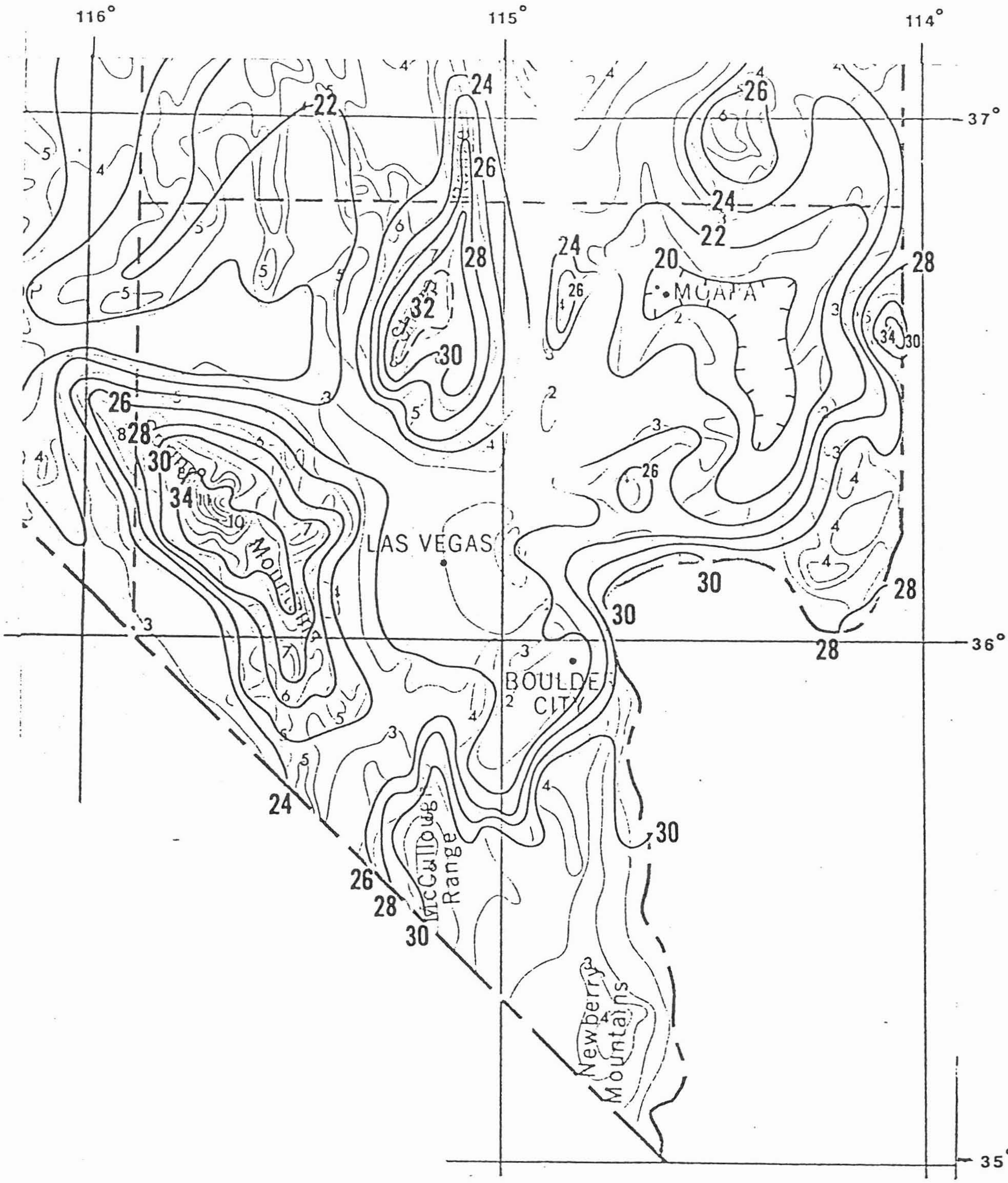


FIGURE 2-10 25-YEAR 24-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

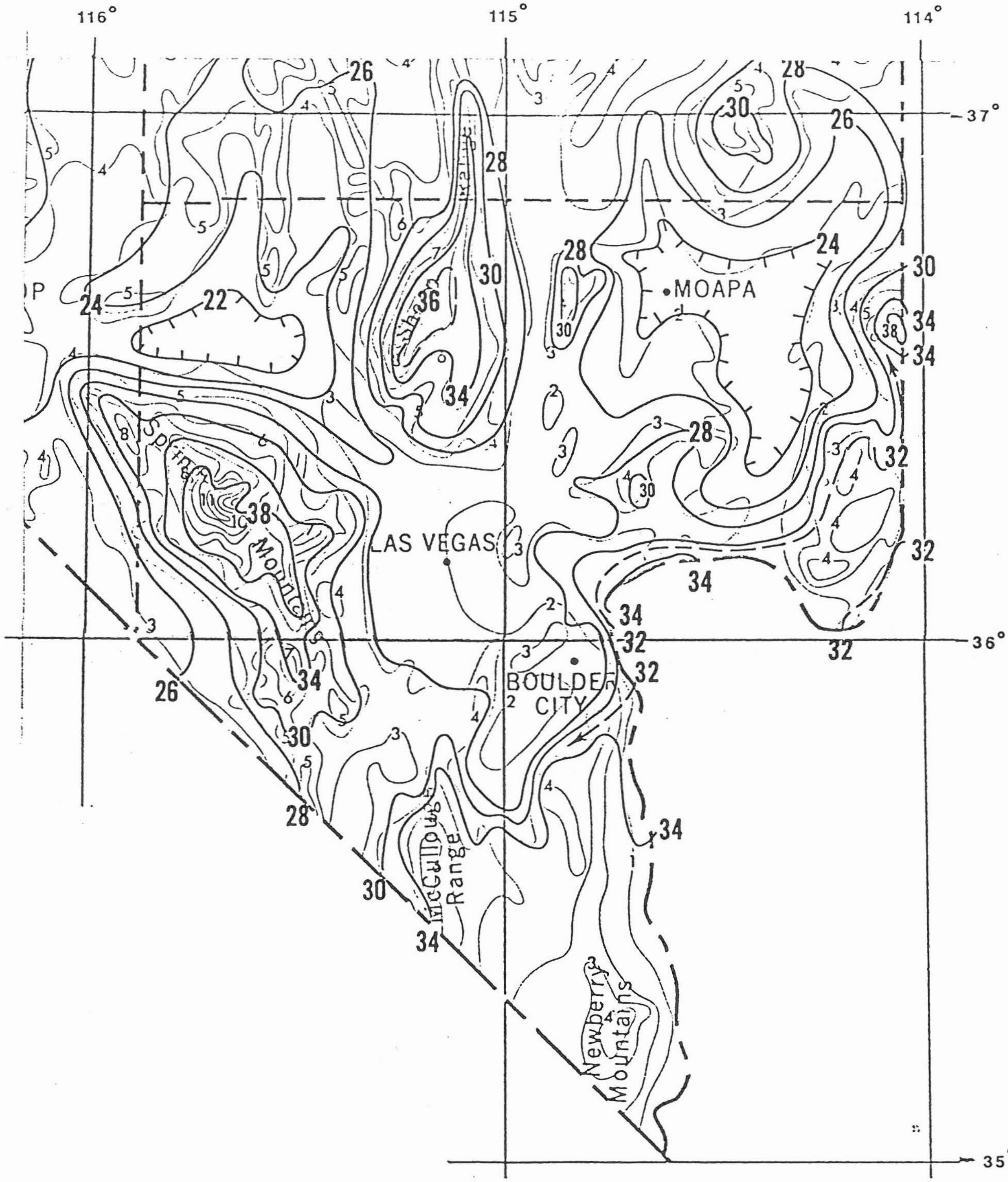


FIGURE 2-11 50-YEAR 24-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

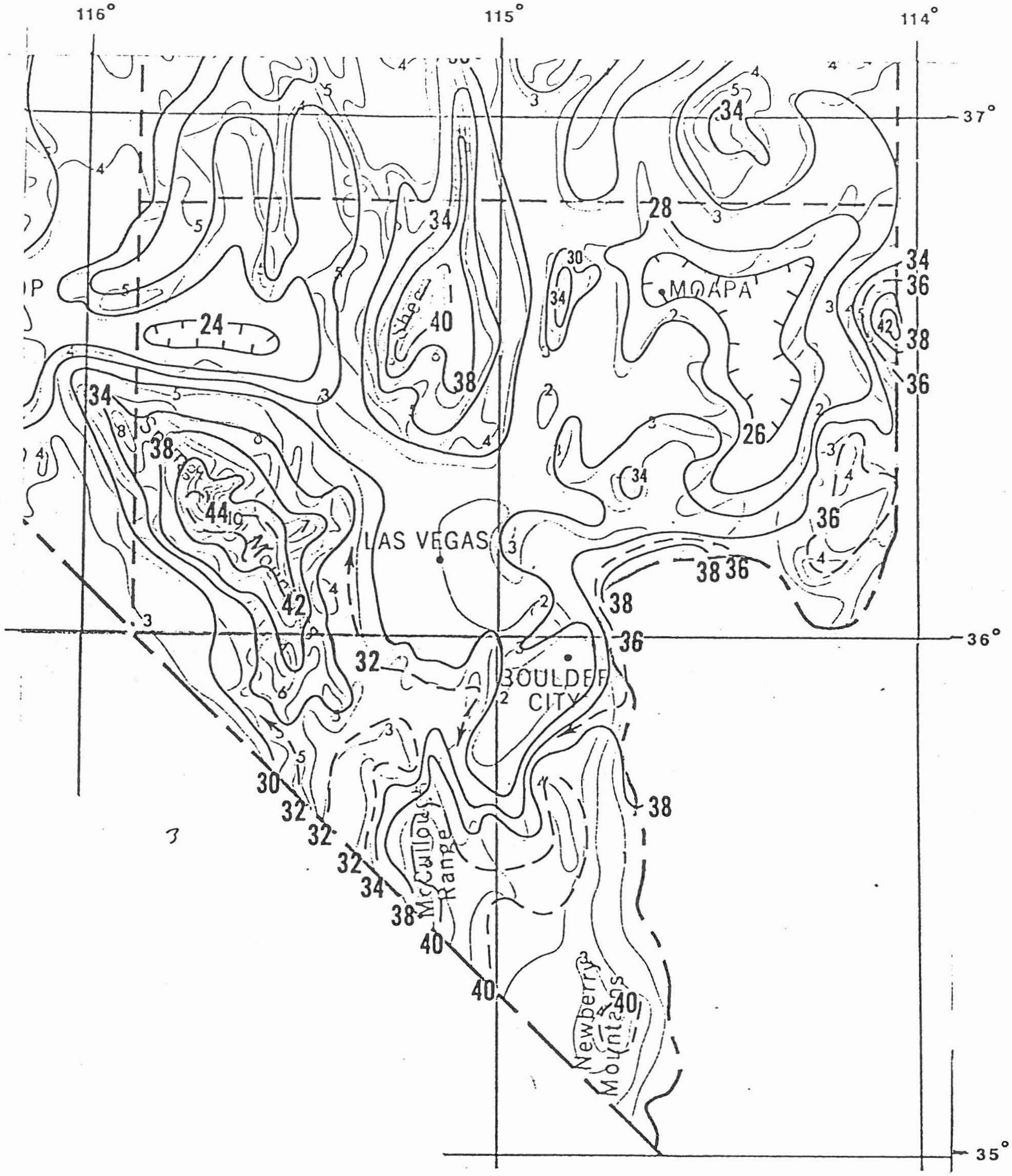


FIGURE 2-12 100-YEAR 24-HOUR RAINFALL

RAINFALL

DEPTH-DURATION-FREQUENCY

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

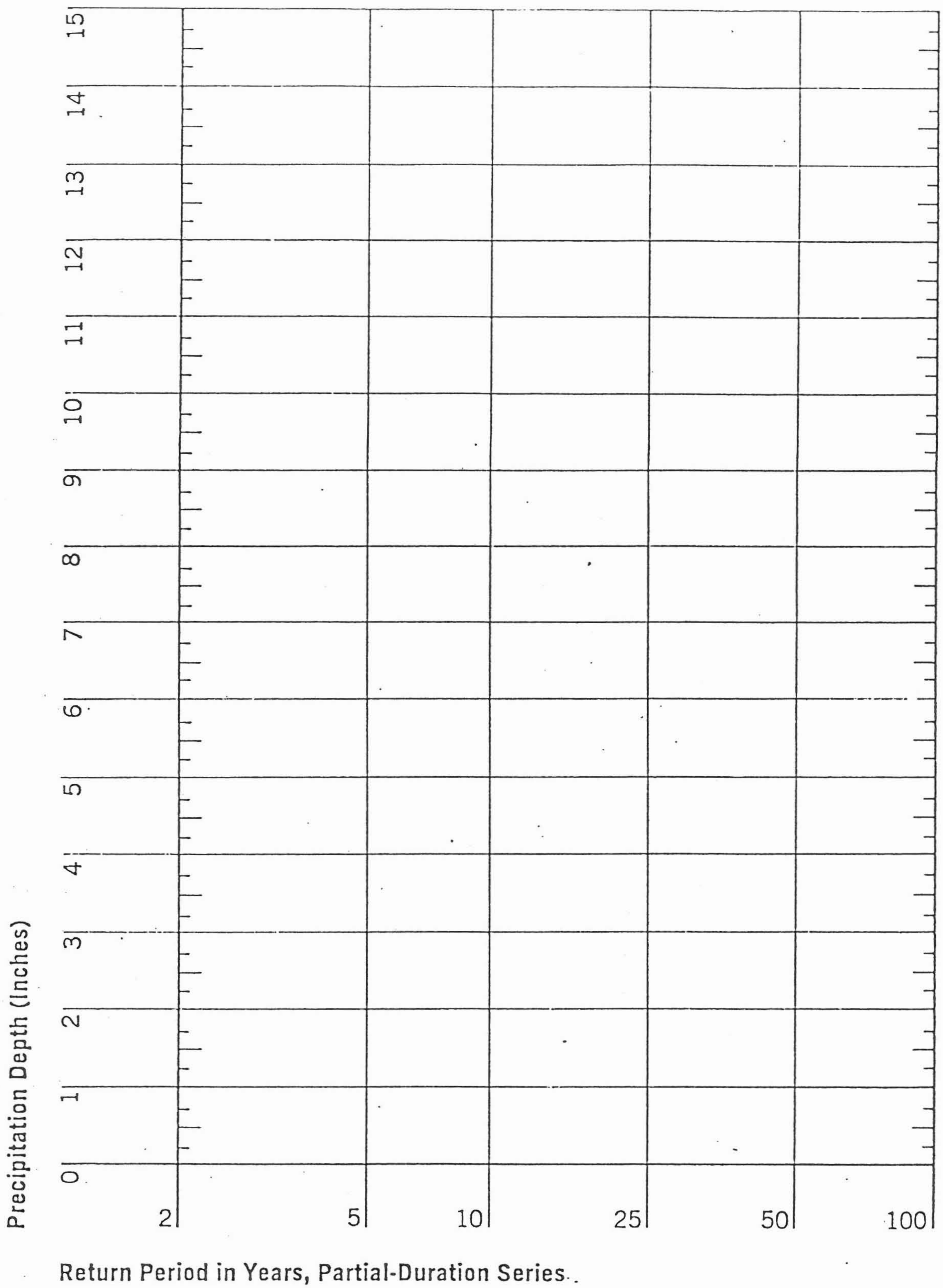


FIGURE 2-13

PRECIPITATION DEPTH VERSUS RETURN PERIOD

SOURCE: NOAA ATLAS 2, VOLUME VII NEVADA, 1973

3. DESIGN STORM DISTRIBUTIONS

3.1 General

The design storms in the CCRFCD will be for either a 3- or 6-hour duration storm. The 3-hour duration storm will be utilized when developing discharges for facilities that do not contain detention and/or retention dams. The 6-hour duration storm will be utilized when analyzing and designing detention and/or retention dams.

3.2 3-Hour Design Storm Distribution

The 3-hour design storm distribution is utilized with the 3-hour duration rainfall as stated in Section 2. The dimensionless cumulative 3-hour design storm distribution is shown on Figure 3-1, and was obtained from the CCRFCD Master Plan[3]. This 3-hour distribution is also tabulated in Table 3-1.

3.3 6-Hour Design Storm Distributions

The 6-hour design storm distributions are utilized with the 6-hour duration rainfall as determined in Section 2. The 6-hour distribution utilized is dependent upon the size of the contributing drainage area at the location design hydrographs are required.

Figure 3-2 is a graph that depicts drainage area versus design storm distribution numbers (SDN). The design SDN correspond to the 6-hour distributions shown on Figure 3-3. Table 3-2 is a tabular representation of the graphs presented on Figure 3-3.

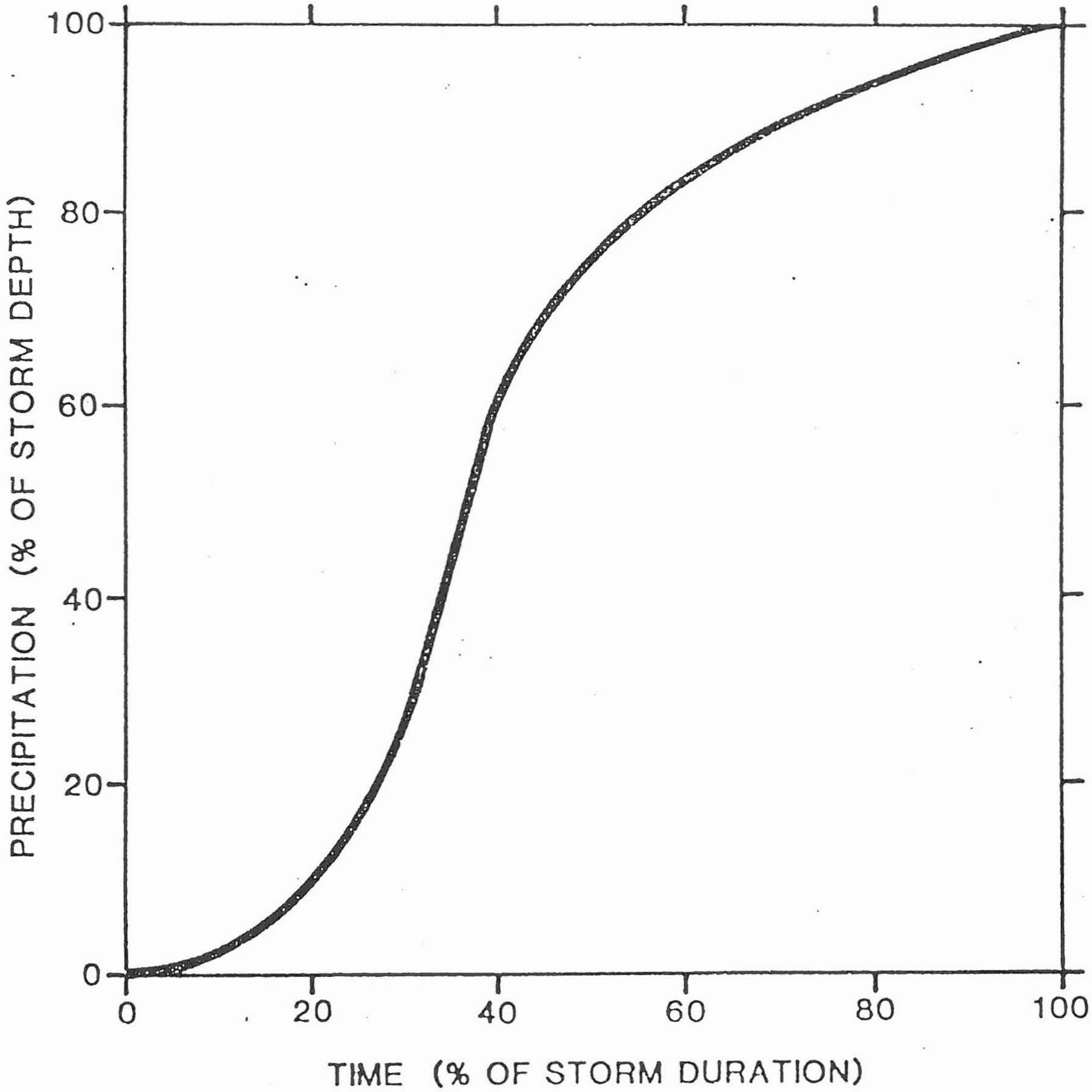
The uses of Figures 3-2, 3-3, and Table 3-2 are conditioned as follows:

a. Figure 3-2 is utilized for determination of SDN's for a 50-year recurrence interval or greater.

b. If the recurrence interval is less than 50-year use SDN 5 on Figure 3-3 or Table 3-2.

c. If the drainage area is greater than 80 square miles then use SDN 5 on Figure 3-3 or Table 3-2.

d. If the drainage area is between two of the SDN's on Figure 3-2, then round SDN to closest SDN on figure.



CUMULATIVE DISTRIBUTION FOR 3-HR DESIGN STORM

LAS VEGAS AND VICINITY

SOURCE : CCRFCD MASTER PLAN[3]

FIGURE 3-1

TABLE 3-1

DIMENSIONLESS 3-HOUR STORM DISTRIBUTION

Percent of Total Storm Duration	Percent of Total Storm Depth
0.0	0.0
4.0	0.5
8.0	1.5
12.0	2.5
16.0	5.5
20.0	9.0
24.0	14.0
28.0	22.0
32.0	34.0
36.0	50.0
40.0	63.5
44.0	70.0
48.0	74.5
52.0	78.0
56.0	81.5
60.0	84.5
64.0	86.5
68.0	89.0
72.0	91.0
76.0	93.0
80.0	95.0
84.0	96.5
88.0	97.5
92.0	98.5
96.0	99.5
100.0	100.0

SOURCE : CCRFCD Master Plan[3]

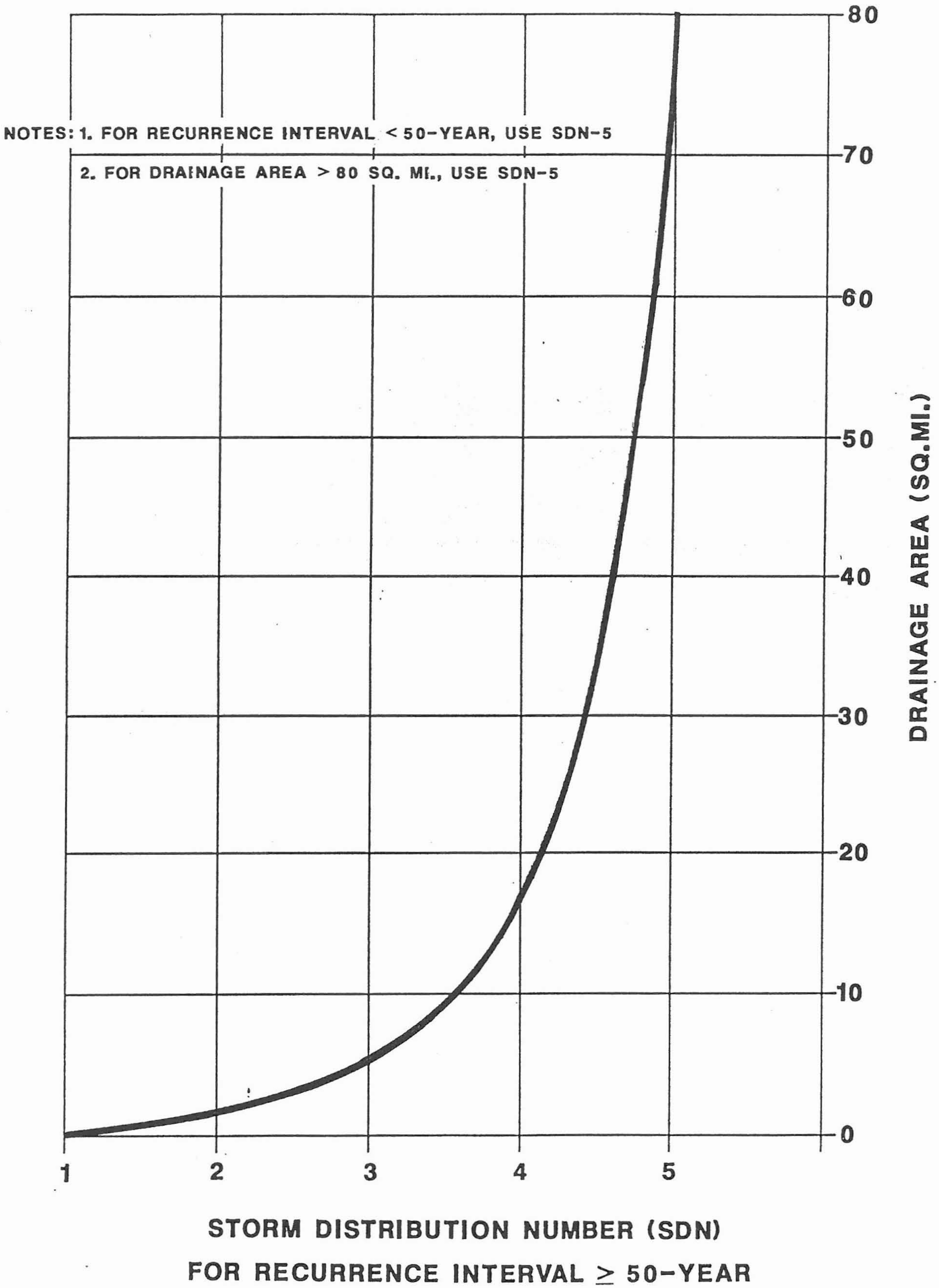
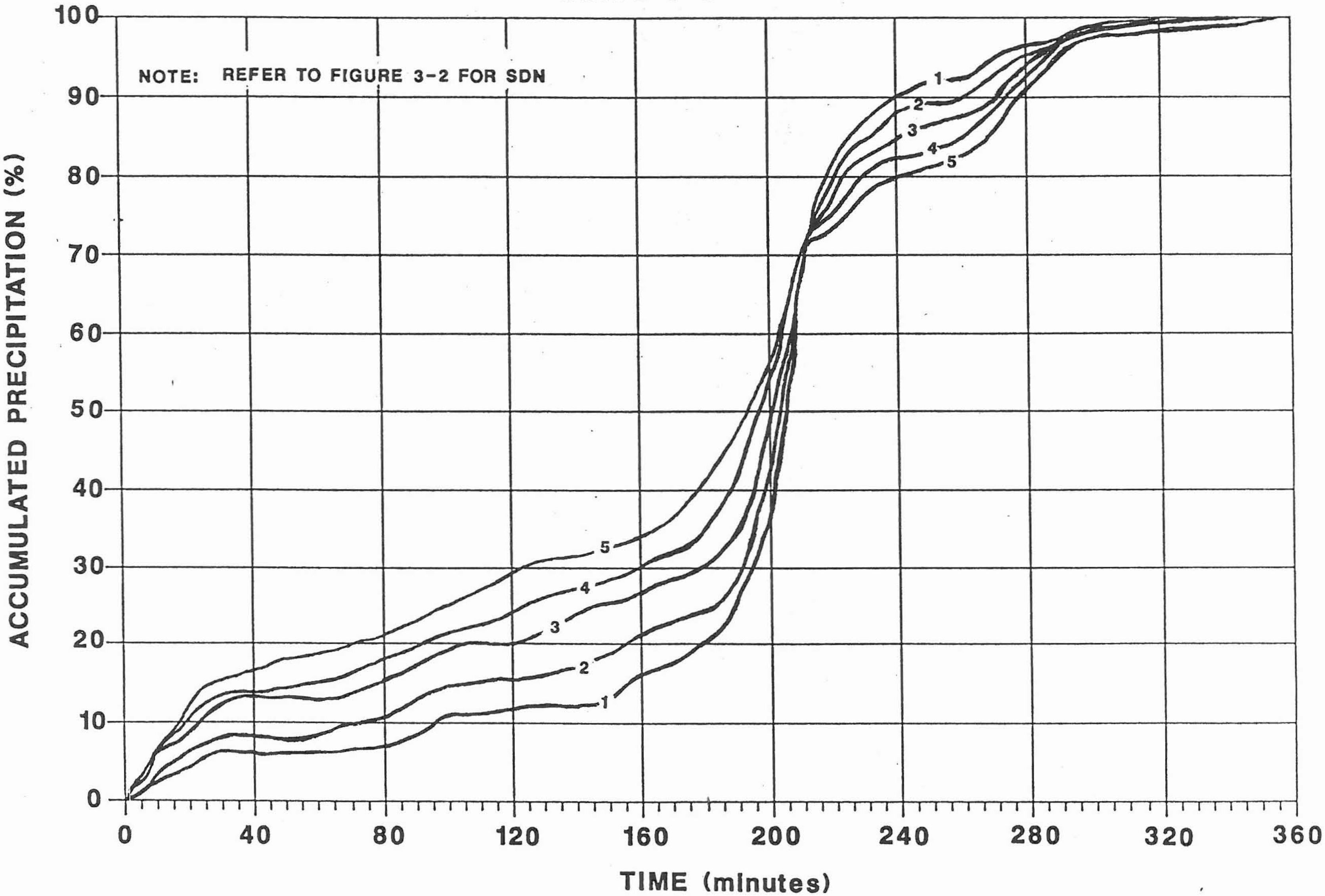


FIGURE 3-2

SOURCE : Corps of Engineers, Los Angeles District

6-HOUR DESIGN STORM DISTRIBUTIONS

SDN's 1-5



SOURCE: Corps of Engineers, Los Angeles District

FIGURE 3-3

TABLE 3-2

6-HOUR STORM DISTRIBUTIONS

(Refer to Figure 3-2)

Storm Duration (In Minutes)	Percent of Total Storm Depth SDN 1	SDN 2	SDN 3	SDN 4	SDN 5
0	0.00	0.00	0.00	0.00	0.00
5	0.40	0.70	2.00	2.00	2.00
10	2.10	3.20	5.70	5.90	5.90
15	2.90	4.70	7.00	8.00	8.00
20	3.90	6.00	8.70	10.00	11.00
25	5.40	7.60	10.80	12.30	14.40
30	6.00	8.00	12.40	13.30	15.00
35	6.00	8.00	13.00	13.90	16.00
40	6.00	8.00	13.00	14.00	16.80
45	6.00	8.00	13.00	14.10	17.10
50	6.00	8.00	13.00	14.40	18.00
55	6.00	8.10	13.00	14.70	18.20
60	6.00	8.50	13.00	15.00	18.70
65	6.00	9.00	13.30	15.40	19.00
70	6.20	9.40	14.00	16.00	19.70
75	6.40	9.90	14.20	16.90	20.20
80	6.90	10.40	14.80	17.60	21.00
85	7.30	11.20	15.80	18.40	22.00
90	8.60	12.80	17.20	19.50	23.00
95	9.90	14.00	18.10	20.60	24.10
100	10.90	14.60	19.00	21.30	25.00
105	11.00	15.00	19.70	21.70	25.90
110	11.00	15.10	19.90	22.10	26.50
115	11.10	15.20	20.00	22.60	28.00
120	11.60	15.30	20.10	23.90	29.00
125	11.90	15.40	20.40	25.00	30.00
130	12.00	15.90	21.40	26.00	30.50
135	12.00	16.80	22.90	26.60	30.90
140	12.00	17.10	24.10	26.90	31.00
145	12.40	17.50	24.90	27.70	31.70
150	13.20	19.00	25.10	28.00	32.10
155	15.00	20.10	25.60	28.40	32.70
160	16.00	21.20	27.00	30.10	33.30
165	16.80	21.90	27.80	31.20	34.60
170	17.20	22.40	28.10	31.80	36.10
175	19.00	23.00	28.30	32.40	38.10
180	20.20	24.60	29.50	35.00	40.80

Note : SDN = Storm Distribution Number

SOURCE : Corps of Engineers, Los Angeles District

TABLE 3-2 (continued)

Storm Duration (In Minutes)	Percent of Total Storm Depth				
	SDN 1	SDN 2	SDN 3	SDN 4	SDN 5
185	22.20	26.20	32.20	37.40	43.00
190	26.30	30.30	35.20	42.40	47.70
195	31.60	36.00	40.90	48.90	51.40
200	38.90	42.80	49.90	53.80	56.10
205	52.60	55.50	59.00	61.00	63.00
210	71.00	71.00	71.00	71.00	71.00
215	77.70	76.00	74.40	73.20	72.00
220	82.50	80.30	78.10	75.00	73.10
225	85.50	83.10	81.20	78.20	75.20
230	87.50	84.60	81.90	80.20	77.90
235	89.10	87.00	83.50	81.30	79.00
240	90.20	88.00	85.10	81.90	79.50
245	91.00	88.30	85.60	82.30	80.40
250	91.70	88.90	86.00	83.00	81.00
255	91.90	89.00	86.80	83.40	82.00
260	92.30	89.60	87.60	84.60	82.60
265	93.30	91.00	88.80	86.00	84.00
270	95.10	92.70	91.00	88.50	85.90
275	96.00	94.20	92.60	90.70	88.90
280	96.40	95.00	93.70	92.40	91.00
285	96.60	95.70	95.00	94.40	93.80
290	97.40	97.20	97.00	96.80	96.60
295	98.20	97.90	97.60	97.30	97.00
300	99.00	98.60	98.20	97.80	97.40
305	99.20	98.80	98.50	98.20	97.90
310	99.40	99.00	98.70	98.40	98.10
315	99.50	99.20	98.90	98.60	98.30
320	99.60	99.30	99.00	98.80	98.50
325	99.70	99.50	99.30	99.10	98.90
330	99.70	99.50	99.30	99.10	99.00
335	99.80	99.60	99.40	99.30	99.20
340	99.80	99.70	99.50	99.40	99.30
345	99.90	99.90	99.80	99.70	99.60
350	99.90	99.90	99.80	99.70	99.70
355	99.90	99.90	99.90	99.90	99.90
360	100.00	100.00	100.00	100.00	100.00

Note : SDN = Storm Distribution Number

SOURCE : Corps of Engineers, Los Angeles District

4. DEPTH-AREA ADJUSTMENTS

4.1 General

The rainfall values determined in Section 2 represents point rainfall frequency values. This section presents the method for extending the point rainfall frequency values to areal rainfall frequency values based upon HYDRO-40[4].

4.2 Adjustments for Large Watersheds

Point rainfall adjustments to large watersheds in the CCRFCD area will utilize Figure 4-1, Depth-Area Reduction Curves. Figure 4-1 is obtained from HYDRO-40[4], Figure 15, page 29.

To utilize Figure 4-1, the following must first be determined :

a. Size of contributing drainage area in square miles at the location analysis is required.

b. Storm duration in hours (3 or 6) as stated in Section 2.

Once the above data is determined enter Figure 4-1 with the drainage area and use appropriate storm duration curve to determine the depth-area reduction factor. Multiply the point rainfall value as determined in Section 2 by the depth-area reduction factor from Figure 4-1 to obtain the rainfall value to be utilized in the analysis.

4.3 Adjustments for Small Watersheds

It is difficult to interpret, from Figure 4-1, the depth-area reduction factor for drainage areas less than 10 square miles. Therefore, Table 4-1 has been prepared to aid in determining the appropriate depth-area reduction factors for smaller watersheds.

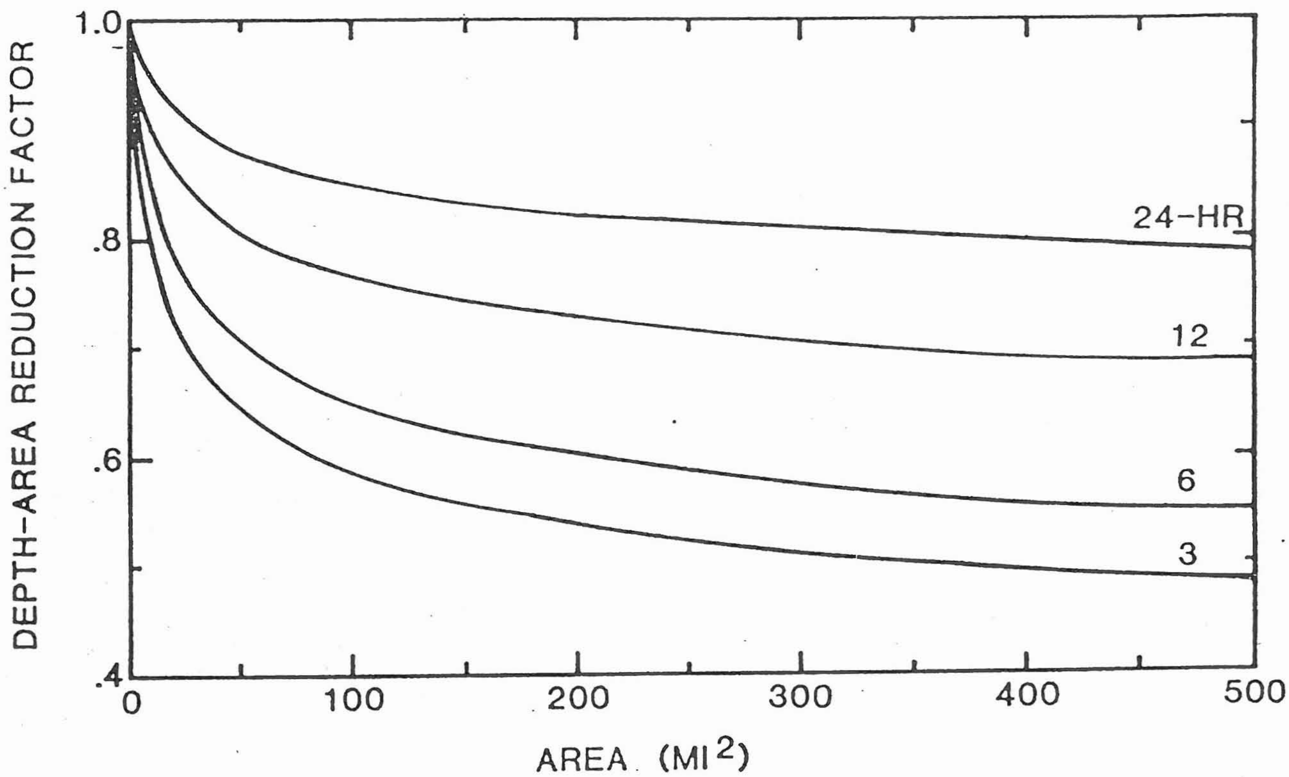
TABLE 4-1

DEPTH-AREA ADJUSTMENT FACTORS

FOR WATERSHEDS LESS THAN 10 SQ. MI.

Drainage Area Sq. Mi.	3-Hour Adjust. Factors	6-Hour Adjust. Factors
0.0	1.00	1.00
0.5	0.97	0.98
1.0	0.95	0.97
2.0	0.90	0.93
4.0	0.87	0.91
6.0	0.84	0.90
8.0	0.82	0.88
10.0	0.80	0.86

SOURCE : HYDRO-40[4]



DEPTH-AREA REDUCTION CURVES

FIGURE 4-1

SOURCE: HYDRO-40

5. INTENSITY-DURATION CURVES FOR RATIONAL FORMULA METHOD

5.1 General

Procedures stated in Section 2 to obtain and modify the NOAA Atlas[1] rainfall depths must first be done before proceeding.

5.2 Depths For Durations Less Than One-Hour

To develop Intensity-Duration curves for the Rational Formula Method of runoff analysis take the 1-hour adjusted depth(s) obtained from Section 2 and multiply by the factors in Table 5-1.

TABLE 5-1

FACTORS FOR DURATIONS OF LESS THAN ONE-HOUR

Duration(min)	5	10	15	30
Ratio to 1-hr	0.29	0.45	0.57	0.79

SOURCE: NOAA Atlas[1]

6. ACCEPTED RAINFALL DATA FOR McCARRAN AIRPORT

6.1 General

This section presents the accepted point rainfall data for McCarran Airport, Las Vegas, Nevada. The data presented is applicable to those studies that have their contributing drainage area within the following described townships and/or sections :

a. T18S, R59E, Sections 13-15, 22-26, 36

b. T18S, R60E, Sections 30-32

c. T19S, R60E, Sections 1-6, 8-16, 21-28, 33-36

d. T19S, R61E

e. T19S, R62E, Sections 2-11, 14-23, 27-34

f. T20S, R60E, Sections 1-3, 10-15, 21-28, 33-36

g. T20S, R61E

h. T20S, R62E, Sections 4-9, 16-20, 29-32

i. T21S, R60E, Sections 1-4, 9-16, 21-28, 33-36

j. T21S, R61E

k. T21S, R62E, Sections 4-9, 15-23, 25-36

l. T22S, R60E, Sections 1-4, 10-15, 24

m. T22S, R61E, Sections 1-24, 26-29

n. T22S, R62E, Sections 1-10, 17-18

6.2 Rainfall Depth-Duration-Frequency

Table 6-1 states and Figure 6-1 depicts the point rainfall depth-duration-frequency values accepted for McCarran Airport, Las Vegas, Nevada. These are also applicable to the area stated in Section 6.1.

TABLE 6-1

ACCEPTED POINT RAINFALL DEPTH-DURATION-FREQUENCY VALUES

FOR McCARRAN AIRPORT, LAS VEGAS, NEVADA

	RECURRENCE INTERVAL					
TIME	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
5 min.	0.15	0.27	0.35	0.46	0.54	0.63
10 min.	0.25	0.44	0.57	0.74	0.89	1.02
15 min.	0.33	0.57	0.74	0.97	1.15	1.32
30 min.	0.44	0.78	1.01	1.31	1.55	1.79
1 hour	0.52	0.89	1.15	1.50	1.78	2.06
2 hour	0.59	1.01	1.30	1.70	2.01	2.30
3 hour	0.64	1.08	1.39	1.82	2.15	2.48
6 hour	0.72	1.22	1.58	2.05	2.41	2.77

Note : Rainfall shown in inches

SOURCE : Corps of Engineers, Los Angeles District

6.3 Intensity-Duration Data

Table 6-2 states and Figure 6-2 depicts the point intensity-duration values accepted for McCarran Airport, Las Vegas, Nevada. These are also applicable to the area stated in Section 6.1.

TABLE 6-2

ACCEPTED POINT INTENSITY-DURATION DATA

FOR McCARRAN AIRPORT, LAS VEGAS, NEVADA

	RECURRENCE INTERVAL					
TIME (min)	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
5	1.80	3.24	4.20	5.52	6.48	7.56
10	1.50	2.64	3.42	4.44	5.34	6.12
15	1.32	2.28	2.96	3.88	4.60	5.28
30	0.88	1.56	2.02	2.62	3.10	3.58
60	0.52	0.89	1.15	1.50	1.78	2.06

Note : Rainfall values shown are in inches/hour

SOURCE : Corps of Engineers, Los Angeles District

DEPTH – DURATION – FREQUENCY CURVES
for McCARRAN AIRPORT, LAS VEGAS, NEVADA

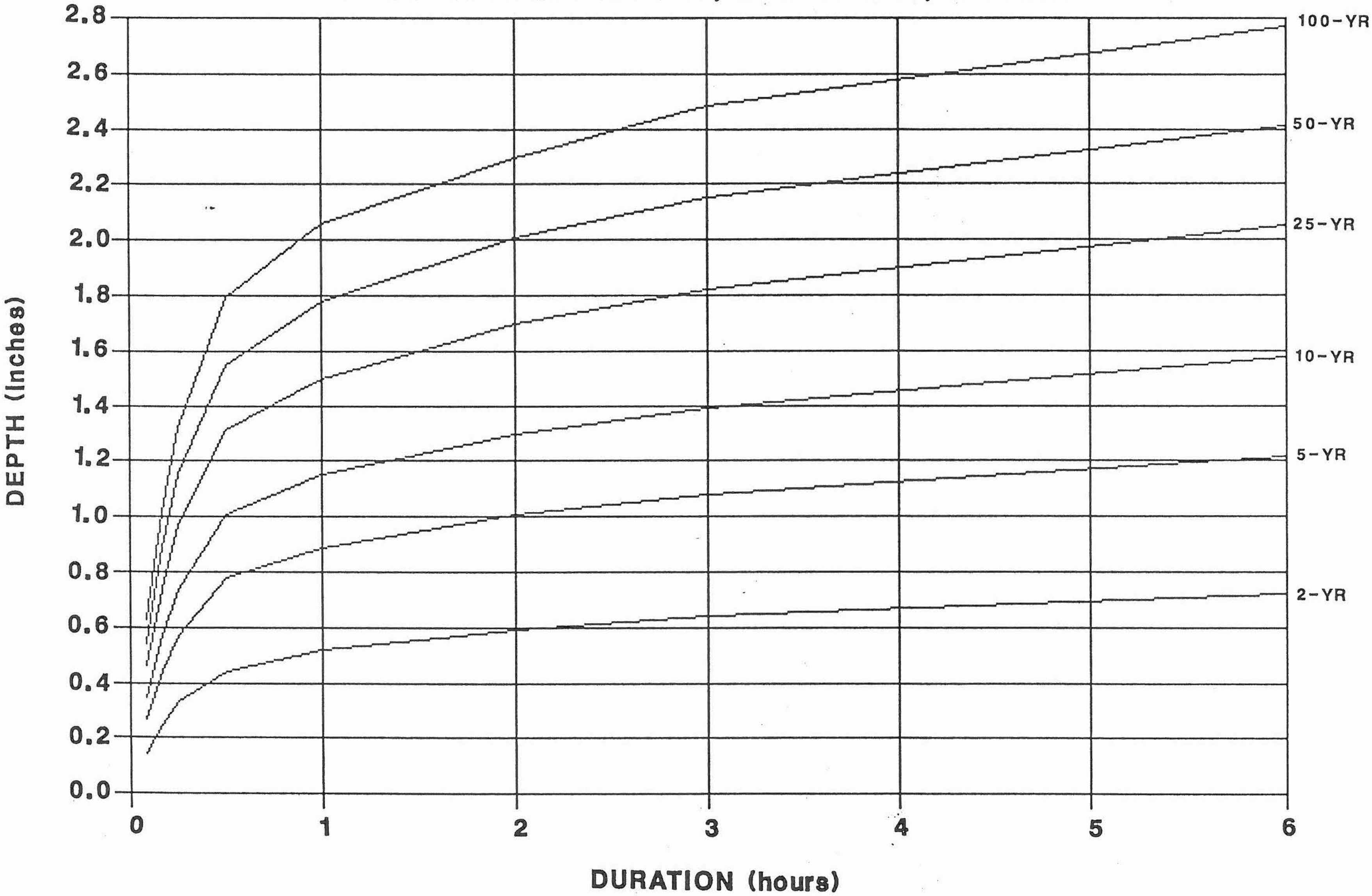
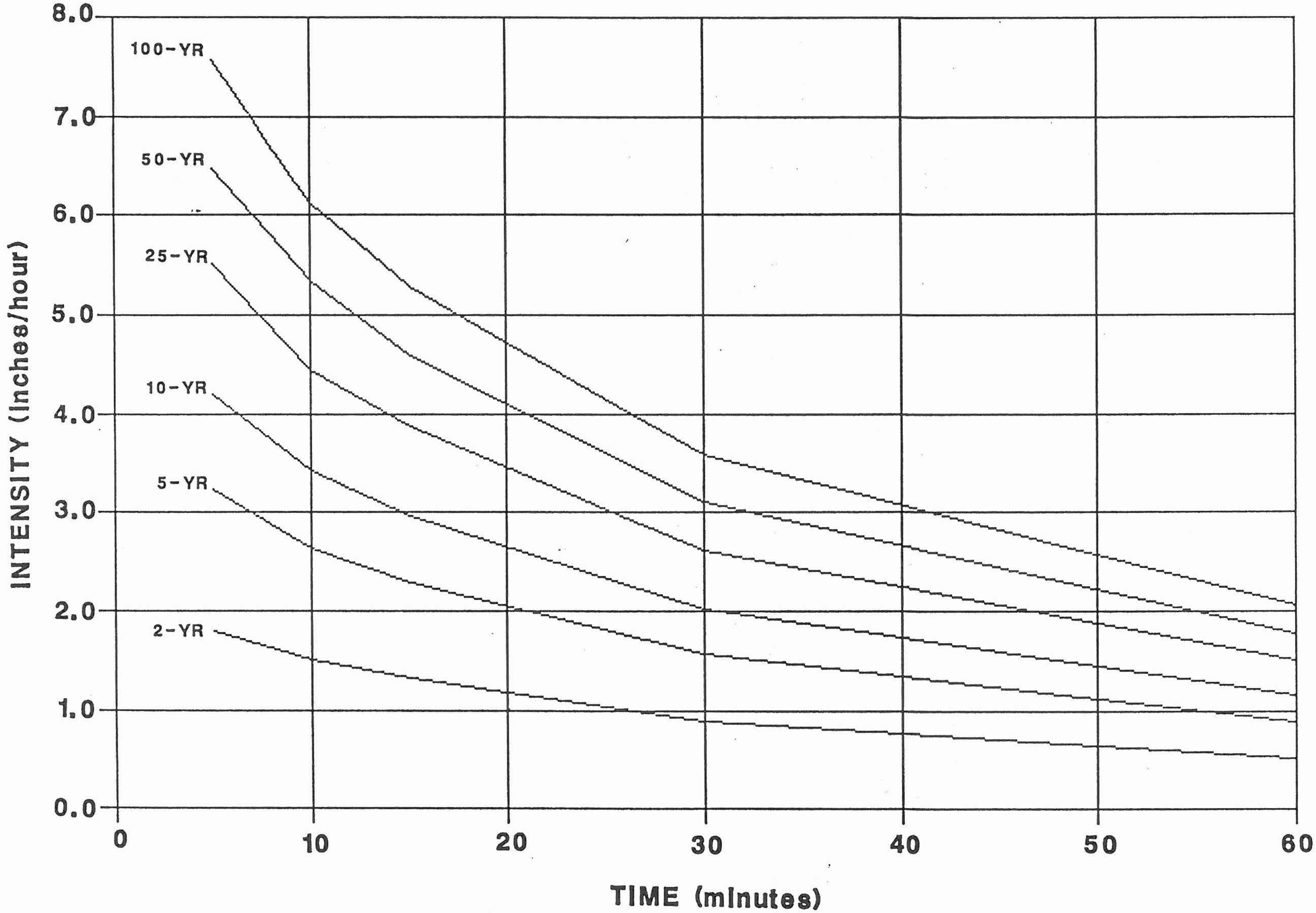


FIGURE 6-1

SOURCE: Corps of Engineers, Los Angeles District

TIME - INTENSITY - FREQUENCY CURVES
for McCARRAN AIRPORT, LAS VEGAS, NEVADA



SOURCE : Corps of Engineers, Los Angeles District

FIGURE 6-2

7. BIBLIOGRAPHY

1. NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume VII-Nevada, U.S. Department of Commerce, National Weather Service, 1973.

2. Black and Veatch, "Clark County Department of Public Works, Study of Flood Control Facilities on Flamingo Wash," 1985.

3. James M. Montgomery, Consulting Engineers, Inc., "Clark County Regional Flood Control District, Flood Control Master Plan, Volume 1," 1986.

4. NOAA Technical Memorandum NWS HYDRO-40, Depth-Area Ratios in the Semi-Arid Southwest United States, U.S. Department of Commerce, National Weather Service, August, 1984.

IV. PRECIPITATION FREQUENCY ANALYSIS

General

4-01 In order to determine n-year peak discharges (for n = 10-, 50-, and 100-year) on the various watersheds in and around Las Vegas, a determination of n-year rainfall was undertaken. Calibration studies were performed to make adjustments to model parameters to assure that the adopted n-year precipitation resulted in n-year flow rates, and are discussed in Section VII.

4-02 In the vicinity of Las Vegas, precipitation records are sparse, usually of relatively short historical duration, and mostly non-recording (observed once daily).

Thus, the construction of accurate precipitation frequencies (or return periods) in the vicinity of Las Vegas is difficult at best, especially for the short durations of rainfall, such as 6 hours or less. This is particularly true for the middle and upper portions of the watersheds west of Las Vegas, where precipitation gauges are almost non-existent.

NOAA Atlas 2

4-03 One source commonly used in the western United States for determining precipitation frequencies is Atlas 2 of the National Oceanic and Atmospheric Administration (NOAA) "Precipitation Depth-Duration-Frequency Analysis in the Western United States, Volume VII - Nevada". This atlas was published in

from the COE preliminary draft report on hydrology studies in support of Las Vegas Valley feasibility study.

1973, and is based upon various precipitation data (up to 1968) from recording and non-recording rain gauges reported to the U.S. Weather Bureau and its successor, the National Weather Service (under NOAA). NOAA Atlas 2 gives isopluvials of 6- and 24-hour maximum rainfall totals for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. These isopluvials were derived through analysis of substantial amounts of data. The analysis involved relating precipitation frequency directly to variations in topographic factors such as land slope, orographic barriers to air flow, land elevation, distance to sources of moisture, location (latitude and longitude), and surface roughness. The atlas also contains formulas (derived statistically from regression equations) for the determination of the 1-hour precipitation at 2 and 100 years, coefficients (multiplying factors) for reducing the 1-hour precipitation to durations of 5, 10, 15, and 30 minutes, and nomograms for interpolation of the precipitation depths for any duration between 1 and 24 hours and any return period between 2 and 100 years. Since the time that this reference was published, a significant number of major rainfall events have occurred in the Las Vegas area, which provide additional information for determining the rainfall intensity-frequency relationships.

Other Previous Studies

4-04 Almost all hydrology studies performed between 1973 and 1985 in the Las Vegas area that required precipitation-frequency values utilized the NOAA Atlas 2 values directly. But, in recent years, a number of intense storms (e.g., the Eldorado Canyon storm of September 1974, the Las Vegas Valley storm of July 1975, the Moapa Valley storm of August 1981, the Las Vegas storm of August 1983, and the Moapa Valley and Las Vegas Valley storms of July and

August 1984), have occurred in the area since the completion of NOAA Atlas 2, which suggested that NOAA Atlas 2 may under-estimate the actual precipitation-frequency values in the Las Vegas for the shorter durations at all return periods through at least 100 years. Because of this possible discrepancy between NOAA Atlas 2 values and the recent intense historical events in and around Las Vegas, Black and Veatch Engineers (B&V) conducted a precipitation frequency analysis in 1985 as part of a hydrologic study for Clark County. The analysis is documented in the report entitled "Study of Flood Control Facilities on Flamingo Wash" Department of Public Works, Clark County, Nevada (ref. 1).

BLACK AND VEATCH STUDY

4-05 In the B&V study, frequency analyses were performed for two recording precipitation gauges, Las Vegas (McCarran Airport) and Searchlight, and for one non-recording (observed once daily) gauge, Boulder City, all of which are in southern Nevada. The periods of record analyzed were from 1948 to 1983 for Las Vegas and Searchlight and from 1931 to 1983 for Boulder City. Annual maximum 24-hour or daily precipitation totals for the Las Vegas, Searchlight, and Boulder City gauges were compiled to determine 24-hour precipitation frequencies. Annual maximum hourly data for the Las Vegas and Searchlight gauges were compiled to determine 1-, 2-, and 3-hour precipitation frequencies. The analyses were performed by plotting the data points on Gumbel probability graph paper according to the Weibull plotting positions. Then best fit frequency curves were determined visually. Conversions were then made to account for fixed-interval versus true-interval precipitation values. A conversion factor of 1.13 was used to convert daily values to 1440 minute values and hourly values to 60 minute values, and factors of 1.08, 1.06, 1.02, and 1.01 were used to convert the 2-hour to 120 minute, 3-hour to 180 minute, 6-hour to 360 minute, and 24 hour to 1440 minute values, respectively. The factors for the 2-hour and 3-hour durations were interpolated by B&V. The results of the B&V point n-year precipitation evaluation is given in tables 1 through 3 and are shown on plates 1 and 2. The tables also give the values derived from using the NOAA Atlas 2 maps and equations. B&V concluded that the NOAA Atlas 2 point rainfall depths should be adjusted by the following factors (Las Vegas gauge analysis) for a 3-hour duration storm in the Las Vegas Valley area.

Return Period	B&V Adjustment Factor for NOAA Depths (3-hour Duration)
10-year	1.23
50-year	1.39
100-year	1.43

CLARK COUNTY REGIONAL FLOOD CONTROL DISTRICT FLOOD CONTROL MASTER PLAN STUDY (James M. Montgomery, Consulting Engineers, Inc.)

4-06 James M. Montgomery, Consulting Engineers, Inc. (JMM) developed a Flood Control Master Plan for the Clark County Regional Flood Control District (CCRFCD), Clark County, Nevada (ref. 2). JMM verified the point precipitation-frequency results presented in the B&V Study and reviewed the adjustment procedure with local meteorologists (including the Corps), then basically adopted the B&V results with a minor adjustment. The average of the results from the analyses of the Las Vegas and Searchlight gauges was adopted to adjust the NOAA Atlas 2 depths (B&V adopted the Las Vegas gauge results) and is given in the following table.

Return Period	CCRFCD (JMM) Adjustment Factor for NOAA Depths (3-hour duration)
10-year	1.23
50-year	1.41
100-year	1.44

Corps Feasibility Study

4-07 The Los Angeles District (LAD) meteorologist also investigated the point precipitation frequency analyses presented in NOAA Atlas 2, by B&V, JMM, and other information that was available in the area. Table 4 is a precipitation depth-duration-frequency tabulation, derived from NOAA Atlas 2, for the Las Vegas precipitation gauge. Table 4 lists the computed point value precipitation depths for durations from 5 minutes to ~~24~~ 6 hours, and for return periods from 2 to 100 years.

4-08 Table 5 is the equivalent of table 4, but for a precipitation frequency study conducted by the California Department of Water Resources entitled, "Rainfall Depth-Duration-Frequency for California" November 1982 (ref. 3). Data in this publication are tabulated for Las Vegas, Nevada, in addition to California stations. The study was based on regionalizing statistical parameters utilizing the Pearson Type III frequency distribution. The period of record for data used for the CDWR computations is 1941-1979.

4-09 It can be seen from tables 4 and 5 that the two sets of precipitation-frequency computations are very similar, except for durations of less than 1 hour, where the CDWR values are up to 10 per cent higher. These CDWR values are accepted over the NOAA values for durations of less than 1 hour, in that the CDWR figures are based on more localized regional precipitation frequency computations (southwest desert area), in contrast to the NOAA figures, which are obtained from the multiplication of the 1-hour precipitation values (for each return period) by constant t-minute/1-hour ratios that are used universally throughout the western United States for all return periods.

ADOPTED POINT PRECIPITATION-FREQUENCY VALUES

4-10 After lengthy consultations and discussions with local National Weather Service and private meteorologists, as well as with engineers involved with the CCRFCD/JMM and B&V studies, it was concluded that the B&V results represent perhaps the best available estimate of the true values of these precipitation frequencies in the Las Vegas area. Thus, they were adopted for use in the COE rainfall-runoff model for Las Vegas. Table 6 lists the adopted adjustment factors for return periods from 2 to 100 years. Table 7 lists the adopted precipitation frequency values to be considered in this study for the determination of n-year flood discharges. These are based upon the values from NOAA Atlas 2 (table 4), with confirmation by CDWR (table 5), adjusted by the ratios from table 6.

Analytical Point Precipitation-Frequency Analysis

4-11 After the development of the preliminary peak discharge-frequency values for Las Vegas Wash and seven of the major tributaries (Flamingo Wash, Tropicana Wash, Duck Creek, Las Vegas Creek, Pittman Wash, Range Wash, and Henderson C-1 channel), using the adopted point-precipitation amounts (adjustment to NOAA Atlas 2 depths), a copy of a letter from the Federal Emergency Management Agency (FEMA) to CCRFCD was received by LAD. The letter contained information about an updated frequency analysis for selected gauges in the Las Vegas area performed for FEMA by one of the authors of the NOAA Atlas 2. The letter stated that the updated point precipitation frequency curves developed by B&V and then adopted by the CCRFCD (JMM) and the Corps, would not have much effect on the depths given in the NOAA Atlas 2, in that the same results would be derived in NOAA Atlas 2 even if the updated B&V information were used. The letter also stated that: (1) analytical analyses (Gumbel Frequency Distribution) should have been performed (not graphical analyses) on the B&V compiled data; (2) that the differences in the FEMA (1948 to 1985) analytical analyses updating the NOAA analyses performed on the gauged data (Las Vegas, Searchlight, and Boulder City) were still within the 90 percent confidence bands on the original NOAA (1952 to 1968) analytical analysis performed on the gauged data; and (3) more surrounding gauges should have been included. It should be noted that the original (1973) analyses performed by NOAA had periods of record up to 23 years for Las Vegas and Searchlight (1- through 6-hour duration data), and the updated periods of record are about 40 years. No backup or actual computed depths were given in the letter. The backup information and computed depths for the conclusions stated in the letter to CCRFCD were requested and received by CCRFCD and the Corps.

CORPS ANALYTICAL POINT PRECIPITATION ANALYSIS

4-12 In additiona to reviewing the FEMA anlayses, the Corps conducted analytical analyses on data from five recording rainfall gauges in and around the Las Vegas area. The analytical analyses conducted by the Corps used the same approach as that used in the NOAA Atlas 2 to generate point rainfall depths, the Gumbel Frequency Distribution. Annual maximum 1-, 2-, 3-, 6-, and

24-hour precipitation depths were compiled for Las Vegas, Searchlight, Overton-Logandale, Baker (CA), and Needles (CA) gauges (see pl. 10 for location). Overton and Logandale are actually two separate gauges, but were treated as one becuase they met the NOAA Atlas 2 criterion regarding treatments of stations that are moved. That criterion states that if a station was moved (also changed names in this case), it may be treated as a single record if it did not change in elevation more than 100 feet, and the horizontal location was within 5 miles. The period of record for Overton is from 1948 to 1968 and the period of record for Logandale is from 1969 to 1986. Combining the records provided a period of record of 39 years. The periods of record for the Las Vegas, Searchlight, Baker, and Needles gauges are 38 years (1949-1986), 35 years (1952-1986), 33 years (1954-1986), and 44 years (1943-1986), respectively. The fixed-interval versus true-interval correction factors used for the 1-hour (60 min), 2-hour (120 min), 3-hour (180 min), 6-hour (360 min), and 24-hour (1440 min) durations are 1.13, 1.04, 1.03, 1.02, and 1.01, respectively. These factors differ slightly from those used by B&V in their analysis. The factors used by the Corps (as well as in the updated analysis done for FEMA) were obtained from t-minute adjustment factors recommended by the World Meteorological Organization (WMO 1981 ref. 4). The 10-year and 100-year adjusted results for durations 1 through 24 hours are tabulated in tables 8 and 9, and are compared to values derived using NOAA Atlas 2. The results are show on plates 3 through 7.

Comparison of Point-Precipitation Results

4-13 In comparing the analytical precipitation analytical analyses conducted by the Corps and that done for FEMA (updated NOAA Atlas 2 analysis for Las Vegas, Searchlight, and Boulder City gauges), the two studies produced bery similar results. Slight differences are due to the periods of record used in the analyses. A comparison of the results of the 100-year, 3-, 6-, and 24-hour values are listed in table 10. Both the Corps and updated FEMA analytically derived results were lower than the B&V graphically derived results. The B&V analysis contained records up to 1983. Even though the analytical analysis of the gauged data produced results lower than the graphical analysis (for the shorter durations 1- through 6-hour), the analytical results are still considerably higher than the values that would be derived from NOAA Atlas 2 for Las Vegas and Searchlight, particularly for 2-, 3-, and 6-hour depths. A comparison of the 10-year and 100-year adjusted results by the Corps to the values derived from NOAA Atlas 2 are given in tables 8 and 9 and are shown on plates 3 through 7. As stated previously, for the 2- through 6-hour durations there is a significant difference between the Corps results and NOAA Atlas 2 for Las Vegas and Searchlight. The differences for the 1- and 24-hour results are not as significant. For the other three gauges (Overton-Logandale, Baker, and Needles), all the results were within plus or minus 20 percent (Corps over NOAA Atlas 2) except for the 2-hour at Baker (+23.3 percent) and 1 hour Overton-Logandale (-25.2 percent).

Summary and Conclusions of Point-Precipitation Analysis

4-14 For the Las Vegas and Searchlight gauges, there are significant differences between results produced from either the FEMA or Corps analytical frequency analyses and results derived from NOAA Atlas 2. In reviewing the backup material for the analytical analysis generated for FEMA, it was noted that the analytical analysis determined for the original NOAA Atlas 2 (1973) for the Las Vegas gauge, was higher than the updated analyses for the

100-year, 3- and 6-hour durations. Table 11 gives the 100-year results of the original analytical analysis of the Las Vegas and Searchlight gauges used to generate the NOAA Atlas 2 maps and equations, the values derived using NOAA Atlas 2, and the updated FEMA analytical analysis. Note that the difference between the values derived using NOAA Atlas 2 and the original analytical analysis of the Las Vegas gauge for the 3- and 6-hour durations is plus 66.9 percent and plus 48.5 percent (original NOAA over NOAA Atlas 2), respectively, and the NOAA Atlas 2 curves plot below the 95 percent confidence limit of the original NOAA analytical curve. The updated analytical results are less than the original analytical results, but are still significantly higher than the results derived from NOAA Atlas 2; and the NOAA Atlas 2 results still are below (or just above) the 95 percent confidence limit of the updated curve. The updated FEMA 100-year, 3- and 6-hour duration results of the Searchlight gauge are significantly higher than the results derived using NOAA Atlas 2, but the NOAA Atlas 2 results are above the 95 percent confidence limit of the updated curve.

4-15 Based on the significant difference between the values developed from an analytical precipitation frequency analysis at the Las Vegas and Searchlight gauges and the values derived using NOAA Atlas 2, particularly for 2- through 6-hour durations (reasonable design storm durations), the point precipitation values in NOAA Atlas 2 should be increased for the Las Vegas Valley area. It appears that the regional smoothing done in developing the NOAA Atlas 2 isopluvials may be too gross in the Las Vegas area, particularly for the use of design storms for flood control studies. Typical design storms used in the area are 3- to 6-hours in duration. Comparing the results of the Corps frequency analysis to the results derived from NOAA Atlas 2 suggests an increase in the Las Vegas area on the order of plus 30 percent (Corps over NOAA Atlas 2) for the 100-year recurrence interval and 20 percent for the 10-year recurrence interval for the 3- and 6-hour durations, respectively. The Las Vegas gauge 100-year results of the original analytical frequency analysis used to develop NOAA Atlas 2 are plus 66.9 percent and 48.5 percent higher than the results derived from NOAA Atlas 2, for the 3- and 6-hour durations, respectively. The B&V graphical analysis adopted increases of 43 percent and 23 percent to the NOAA Atlas 2 point precipitation values for the 100-year and 10-year, 3-hour duration values. These comparisons, the number of recent intense storms in the area that did not occur directly over a recording rain gauge, and consultations with local meteorologists, suggest that the adjusted point precipitation values given in table 7 are reasonable approximations of the 10-year (23 percent increase) through 100-year (43 percent increase) values for a 6-hour duration design storm. Therefore, the values given in table 7 are adopted as the point frequency precipitation values to be used in the rainfall-runoff model developed for the Las Vegas Valley basin area.

Duration and Return Periods of Design Storms

4-16 In this study, the return periods of 10, 50, and 100 years are used for the determination of design storm precipitation. A duration of 6 hours was selected for this study's design storms. A storm of this duration will account for almost all of the volume produced by summer thunderstorms that will be contained by proposed storage type structures. These 6-hour design storms contain intense rainfall for the shorter durations as well, so that they also represent the critical storms in producing peak discharges.

Time Distributions

4-17 A detailed examination of the possible time distributions to use with the n-year design storms in Las Vegas and vicinity showed that the distributions used for the Standard Project Storm (pl. 8) are applicable to n-year design storms. The area/pattern number relationship shown in the curve at the right of plate 8 is also considered applicable for return periods of 50 and 100 years, and is so adopted. For the return period of 10 years, however, the smoother pattern no. 5 (pl. 8) is used for all areas. The design floods that are produced from these calculations are more realistic and are closer to the flood-frequency determinations that were made for streams in the greater Las Vegas area (based upon very limited data and information).

Depth-Area Relationships

4-18 The depth-area relationships derived for the Standard Project Storm (based upon the depth-area curve for the Valley of Fire center of the 10 August 1981 Moapa Valley Storm), and corraborated by the depth-area curve from NWS Hydro 40 were also considered applicable for the n-year design storms. These relationships were selected in the absence of any other, more convincing, depth-area information. It appears reasonable that such relationships should hold for storms of lesser return periods than those of the Moapa Valley storm and Standard Project Storm. The depth-area curves for design storms having return periods of 10, 50, and 100 years are shown on plate 9.

From: Study of Flood Control Facilities on Flamingo Wash
Black & Veatch Engineers

III. PRECIPITATION ANALYSES

In the determination of design storms for this study, the principal factors are point-rainfall frequency distributions and depth-area ratios for converting the point values to rainfall amounts appropriate for the entire watershed. The areal rainfall distribution also must reflect the orographic influence of the mountains, which causes rainfall intensities to be generally larger in the upper portions of the watershed than in the lower part.

A. AREA REDUCTION FACTORS

Previous evaluations of peak flows in the Las Vegas area have been based on point-rainfall distributions given in Atlas 2 of the National Oceanic and Atmospheric Administration (NOAA), "Precipitation-Frequency Atlas of the Western United States, Volume VII - Nevada". These point-rainfall values have usually been modified to areal values using either (1) the depth-area curves of Weather Bureau Technical Paper 40, "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 years", or (2) NOAA Technical Memorandum NWS HYDRO-40, "Depth-Area Ratios in the Semi-Arid Southwest United States". The depth-area curves of HYDRO-40 are based on data from Arizona and New Mexico, and the curves of Technical Paper 40 are based on data for the eastern United States. Hence, HYDRO-40 must be considered more appropriate for use in Clark County. The rain gage network in southern Nevada is not sufficiently dense to develop depth-area curves explicitly for this area.

A comparison of depth-area ratios from the two sources is given in Table 2. Inasmuch as the study area for this project is approximately 100 square miles, ratios for larger areas were not tabulated. The ratios are considered to be independent of the return period of the precipitation.

TABLE 2

DEPTH-AREA RATIOS

Drainage Area (sq. mi.)	Precipitation Duration (hours)	From Tech. Paper 40	From HYDRO-40
50	3	0.89	0.65
	6	0.93	0.71
	12	---	0.81
	24	0.95	0.88
100	3	0.85	0.59
	6	0.89	0.65
	12	---	0.77
	24	0.93	0.85

B. POINT-RAINFALL DISTRIBUTION

A thorough review of point-rainfall distribution in the Las Vegas area was also completed. NOAA Atlas 2 gives curves of 6- and 24-hour maximum rainfall totals for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. These curves were derived through analysis with substantial amounts of data and involved the use of regional relationships to factors such as land slope, normal annual precipitation, orographic barriers to air flow, land elevation, distance to sources of moisture, location (latitude or longitude), and roughness. Regression equations and nomographs are also provided in the atlas to allow determination of 1-, 2-, and 3-hour maximum precipitation amounts. This reference was published in 1973, and it was felt that significant major rainfall events since then may have shifted the rainfall intensity-frequency relationships.

Hourly rainfall data were obtained for the first-order National Weather Service stations at McCarran Airport (Las Vegas), Searchlight, and Boulder City. The periods of record for these stations were 1931 through 1983 for Boulder City and 1948 through 1983 for both Searchlight and Las Vegas. Daily data were obtained for non-recording stations at Red Rock Summit, Roberts Ranch, North Las Vegas, Kyle Canyon, and Overton. The daily records for these latter stations had considerable periods of missing data and were not analyzed. Daily precipitation totals for the Las Vegas (McCarran), Searchlight, and Boulder City gages were analyzed to determine 24-hour precipitation frequencies. Hourly data for the Las Vegas gage were analyzed to determine 1-, 2-, and 3-hour precipitation frequency distributions. The analysis was completed by plotting the data points on Gumbel probability graph paper according to the Weibull plotting position $\frac{m}{n+1}$. Lines of best fit were visually determined. The results of this analysis indicated that the 100-year daily rainfall at Boulder City was 2.97 inches, at Las Vegas the value was 2.62 inches, and at Searchlight the value was 5.09 inches. Some irregularities were noted in the data for the Searchlight gage. Therefore, the value for Searchlight is not as reliable as those for Las Vegas and Boulder City. These values were based on analysis of precipitation totals for individual calendar days and, since 24-hour precipitation events rarely fall within separate calendar days, it was necessary to convert the daily precipitation values to equivalent 1440-minute values. This was done by multiplying the values determined by analysis of the daily data by a factor of 1.13, which is the conversion factor given in NOAA Atlas 2. This results in 100-year, 24-hour precipitation totals of:

Las Vegas	2.96 inches
Boulder City	3.36 inches
Searchlight	5.75 inches

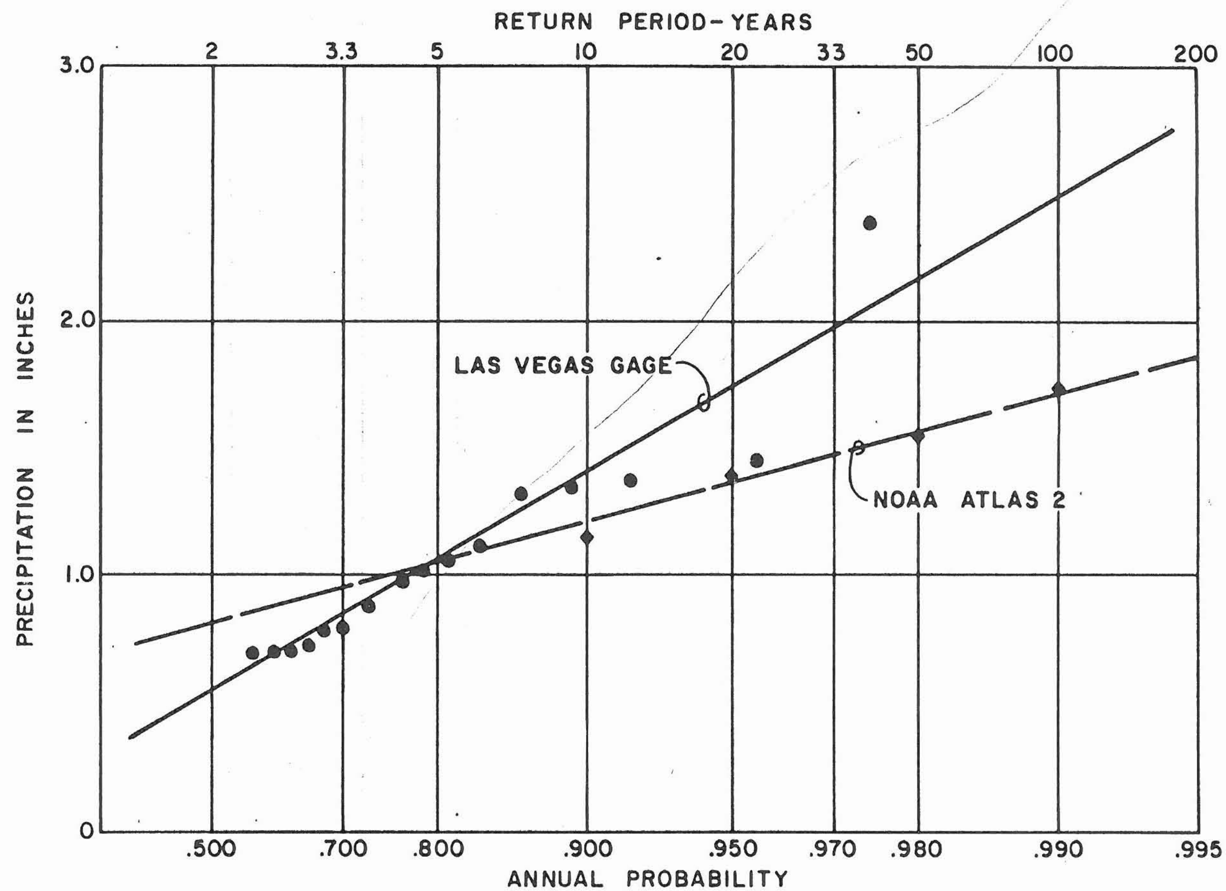
The corresponding values using only the curves of NOAA Atlas 2 are 2.96 inches for Las Vegas, 2.98 inches for Boulder City, and 3.98 inches for Searchlight. Note that even though this analysis indicated that the 100-year, 24-hour precipitation totals for Boulder City and Searchlight should be increased by 13 and 44 percent, respectively, the values for Las Vegas are identical.

Analysis of the hourly precipitation data for the Las Vegas gage was completed using the same procedure. The resultant 100-year precipitation amounts were 1.79 inches for 1 hour, 2.17 inches for 2 hours, and 2.34 inches for 3 hours. Since these values are based on clock hour precipitation totals, they had to be adjusted to reflect the fact that the maximum 60-minute rainfall probably fell in parts of two clock hours, the maximum 120-minute rainfall would occur in parts of three clock hours, and the maximum 180-minute rainfall would cover parts of four clock hours. NOAA Atlas 2 indicates that to convert a 6-hour precipitation total to a 360-minute amount, the 6-hour amount should be multiplied by 1.02. The factor to convert a 24-hour value to a 1440-minute value is 1.01. Assuming that the factor to convert the 1-hour value to a 60-minute value is 1.13

(the same as for converting daily values to 1440-minute values), the factors for 2 and 3 hours were interpolated as 1.08 and 1.06, respectively. When these factors were applied to the values mentioned previously, the resultant 100-year precipitation totals for Las Vegas are 2.02 inches for 1 hour, 2.34 inches for 2 hours, and 2.48 inches for 3 hours. The corresponding values using the procedures given in NOAA Atlas 2 are 1.44 inches for 1 hour, 1.61 inches for 2 hours, and 1.73 inches for 3 hours.

Previous investigations have indicated that the 3-hour design storm is appropriate to use for hydrologic studies in the study area. This is valid for estimating peak flows, but it is also valid for detention basin sizing only if most of the 24-hour precipitation total is contained in the 3-hour amount or if a high release rate can be maintained from detention basins during a storm. The significant discrepancy between the 100-year, 3-hour value of 1.73 inches from NOAA Atlas 2 and the value of 2.48 inches determined by analysis of gaged data warranted further investigation, so a comparison was made of the frequency distribution of the 3-hour precipitation for the two approaches. This is shown on Figure 2. The difference between the two data plots is significant, and supports the use of larger 100-year, 3-hour design storm on the basis of local data.

As a check of the calculated rainfall versus the NOAA Atlas 2 data, a comparison of 3-hour maximum precipitation frequency distributions was completed for the Searchlight gage. This comparison shown on Figure 3 also indicated additional precipitation at the 100-year recurrence interval. The 100-year, 3-hour precipitation is 2.84 inches. This is an increase of 46 percent which is similar to the increase at the Las Vegas gage of 43 percent.



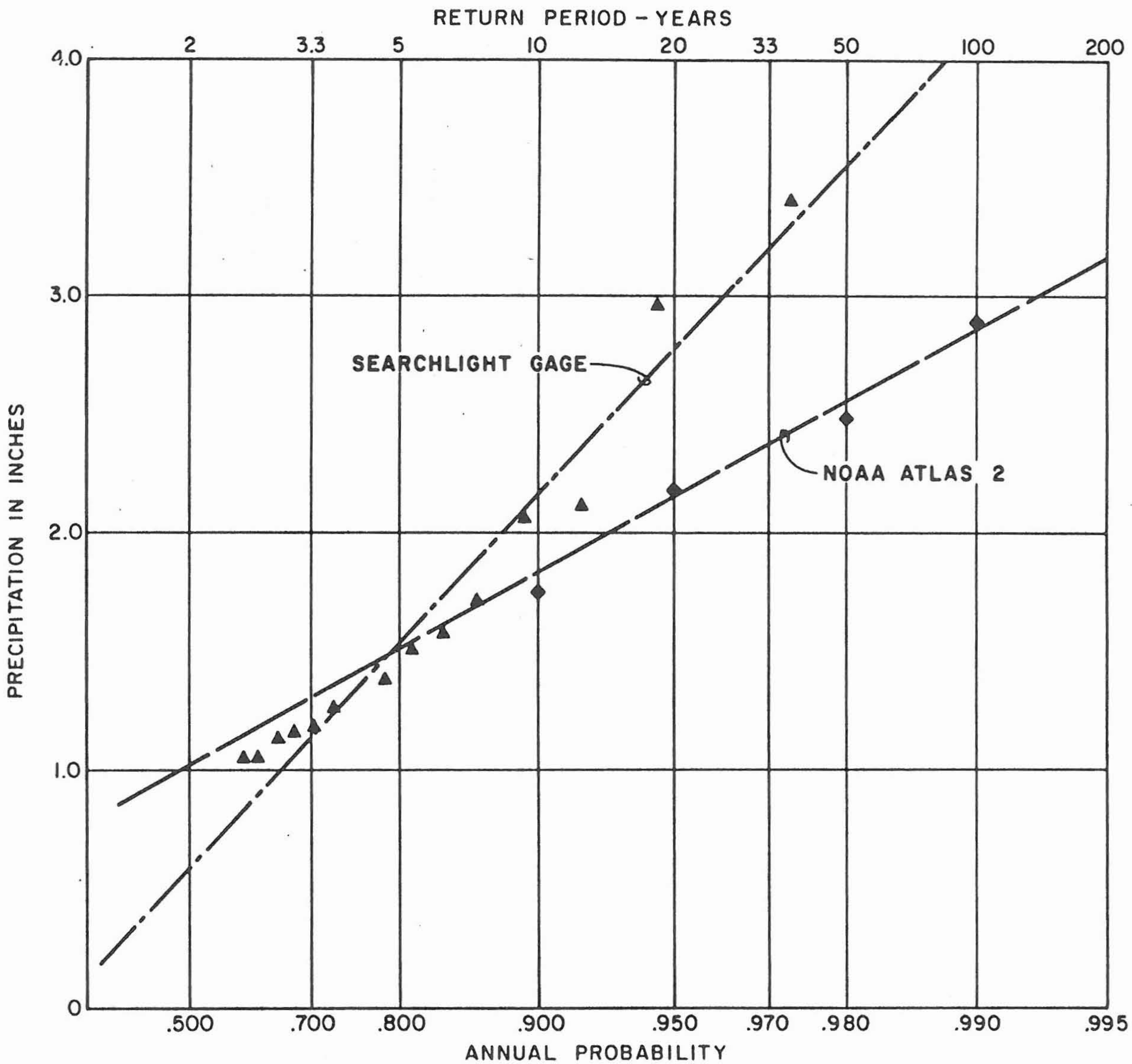
LEGEND

- ● LAS VEGAS GAGE DATA POINTS
- ◆ NOAA ATLAS 2 DATA POINTS

LAS VEGAS GAGE

ANNUAL PROBABILITY VS.
3 - HOUR PRECIPITATION

FIGURE 2



LEGEND

▲ SEARCHLIGHT GAGE DATA POINTS

◆ NOAA ATLAS 2 DATA POINTS

SEARCHLIGHT GAGE

ANNUAL PROBABILITY VS.
3-HOUR PRECIPITATION

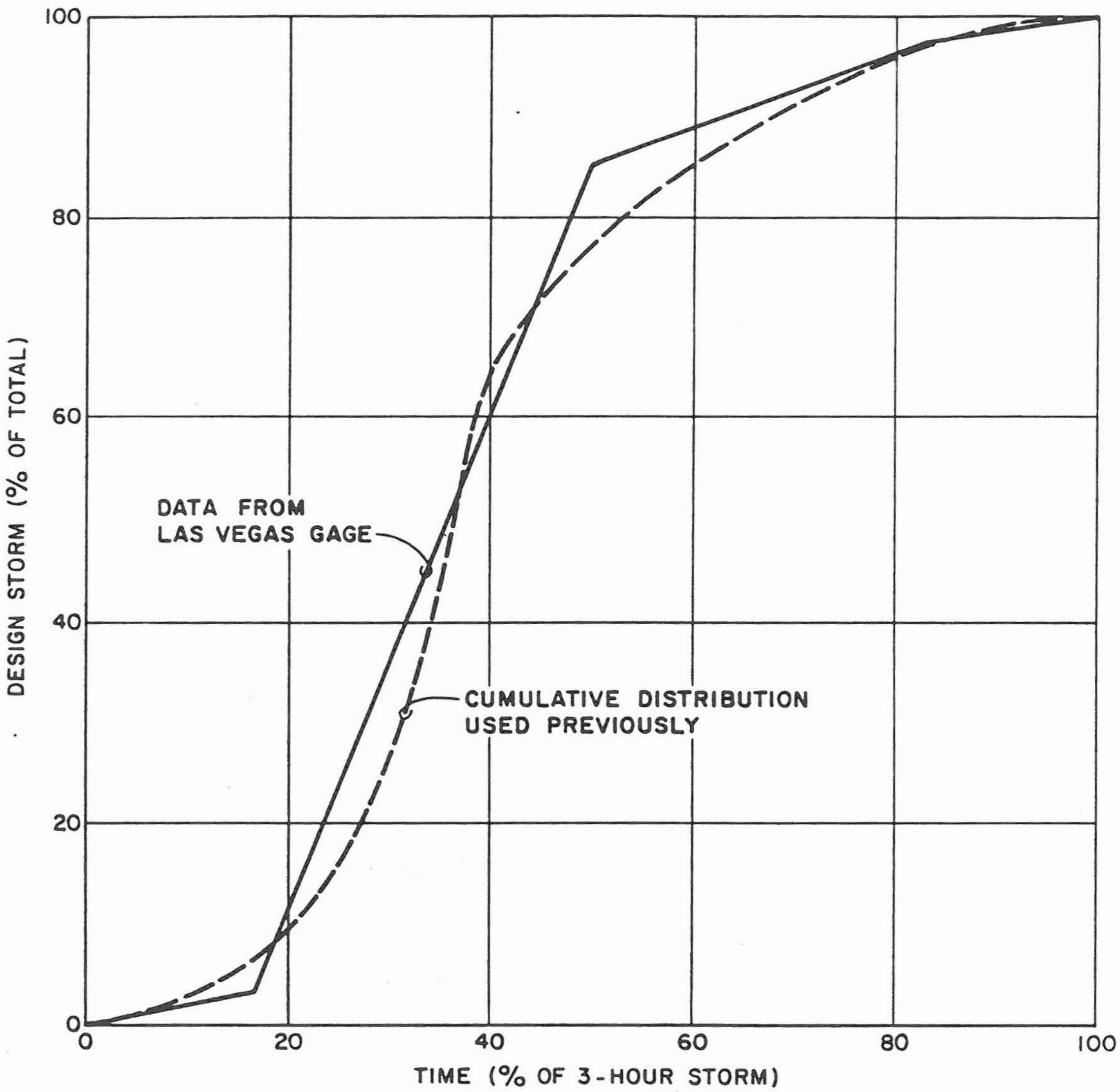
FIGURE 3

The Las Vegas data were also used to check the time distribution of precipitation within the maximum 3-hour period. The results are shown on Figure 4. The curved line is the cumulative percentage of total rainfall as a function of the percentage of the elapsed storm duration as used for previous studies. The results of analysis of the data from the Las Vegas gage are superimposed. The results generally confirmed the validity of the time distribution curve used previously, and the same distribution was used in determination of design storms for the Flamingo Wash study.

C. DESIGN STORMS

The 100-year design storm for the Flamingo Wash basin upstream from Decatur Boulevard was developed by starting with the 100-year, 3-hour precipitation value of 2.48 inches for the Las Vegas gage and increasing it from east to west across the basin in proportion to the increase in the 100-year, 6-hour point-rainfall isohyets in NOAA Atlas 2. This increase reflects the predominant increase in storm rainfall from east to west due to the orographic effects of the mountains. The resultant point rainfall values were multiplied by 0.59 in accordance with the depth-area relationship from HYDRO-40. The resultant 100-year, 3-hour isohyets are shown on Figure 5. Within the 3-hour period, precipitation was distributed using the relationship shown on Figure 4.

Design storms for the 10-, 25-, and 50-year events were also determined through the same procedure used for the 100-year storm. The isohyets of the 3-hour design storms for recurrence intervals from 10, 25, and 50 years are shown on Figures 6, 7, and 8. The 3-hour precipitation totals



CUMULATIVE PERCENTAGE OF
DESIGN STORM VS. TIME

FIGURE 4

for the Las Vegas gage are as follows (values have been corrected to 180-minute and 1440-minute totals):

Return Period	3-Hour Precipitation (inches)
10 years	1.39
25 years	1.82
50 years	2.15
100 years	2.48

The detention basins and appurtenant structures must be designed to prevent overtopping from a flood equal to one half of the Probable Maximum Flood (PME). The rainfall event which produces a PMF is the probable maximum precipitation (PMP). The PMP is defined as the reasonable maximization of meteorological factors that operate to produce a maximum storm. The PMP for each of the detention basin sites analyzed was calculated using the procedures for local storms in Hydrometeorological Report No. 49. The average 6-hour PMP for the Flamingo Wash watershed is 10.5 inches.

D. HISTORICAL STORMS

The areal distributions of major storms in 1975 and 1983 were compared to design storms to add some perspective. The isohyets of these storms are shown on Figures 9 and 10. Although NOAA Atlas 2 indicates that precipitation intensities are generally greatest at the upper end of the Flamingo Wash watershed, which also conforms to observations of experienced hydrologists in the region, both the 1975 and 1983 storms were centered over the lower part of the watershed. In both storms, very little precipitation fell at either the upper end of the watershed or at the Las Vegas gage at McCarran Airport. This demonstrates that the adequacy of detention basins must be tested against design storms over both the entire watershed and the lower portion of the watershed. A design storm centered over the lower portion of the watershed was developed using areal reduction factors larger than 0.59 because of the smaller watershed area and is shown on Figure 11.

Another observation is that, although some historical storms have caused significant amounts of precipitation over the entire watershed, others such as the 1975 and 1983 storms have been concentrated in small areas. This may indicate that the areal reduction factors appropriate for use in the Las Vegas area may actually be smaller than those indicated in HYDRO-40. The available precipitation data in the area near Las Vegas are not adequate for determining local areal reduction factors. The appropriate factors can be determined only if a network of recording precipitation gages would be installed in the region.

APPENDIX 1-C

NOAA Atlas 2 procedures and analyses of City of Phoenix rainfall distribution
by Arthur Beard Engineers, Inc.

1977

PRECIPITATION

For the past decade, Weather Bureau Technical Paper No. 40, U.S. Weather Bureau, 1961, has been accepted as the standard source for precipitation-frequency information in the United States.

With the same basic approach as Technical Paper No. 40 but utilizing currently available longer records and the maximum number of stations possible, the Precipitation-Frequency Atlas of the Western United States, Volume VIII - Arizona was prepared in 1973 by the U.S. Department of Agriculture, Soil Conservation Service, Engineering Division. Since the atlas has the most recent data available on precipitation it was used as the source for all rainfall data in this report.

Key maps developed for the atlas were the 2 and 100 year return periods for 6 and 24 hour durations. The initial map developed was the 2 year return period for the 24 hour duration. The 24 hour duration was selected because this permitted use of data from both recording and non-recording gauges. Additional records were available for the 24 hour duration because an extensive non-recording-gauge network was in existence for many years before the recording-gauge network was established in 1940. The next map developed was the 100 year return period for the 24 hour duration followed by the 6 hour duration for the 2 and 100 year return periods. After these four maps were completed, values for intermediate return periods were computed for a grid of about 47,000 points and appropriate maps prepared.

The Atlas presents the 6 and 24 hour duration precipitation-frequency maps for the return periods of 2, 5, 10, 25, 50 and 100 years. Maps for the 2, 10 and 50 year returns are found in Figures 4.1 to 4.6.

For many hydrologic purposes, other durations may be needed, such as the 1, 2 and 3 hour. Values for these durations are obtained by using data from the 6 and 24 hour maps with empirical formulas and methods developed for the atlas.

Data for the one hour duration are the first to be calculated. This is accomplished with the following equations:

$$Y_2 = -0.11 + 0.942\ (X_1^2/X_2)$$

$$Y_{100} = 0.494 + 0.755\ (X_3^2/X_4)$$

Where

Y_2 = 2 year, 1 hour estimated value

Y_{100} = 100 year, 1 hour estimated value

X_1 = 2 year, 6 hour value = 1.20 inches

X_2 = 2 year, 24 hour value = 1.40 inches

X_3 = 100 year, 6 hour value = 3.10 inches

X_4 = 100 year, 24 hour value = 3.80 inches

Solving the equations, the values obtained are:

$$Y_2 = -0.11 + 0.942 \left(\frac{1.20^2}{1.40}\right) = 0.86 \text{ inches}$$

$$Y_{100} = 0.494 + 0.755 \left(\frac{3.10^2}{3.80}\right) = 2.40 \text{ inches}$$

The 1 hour precipitation-frequency values for any return period between 2 and 100 years are found by plotting the 2 and 100 year values on a nomograph and reading values for a particular period off the straight line connecting the 2 and 100 year values. Figure 4.7 illustrates the nomograph for the 24 hour duration.

The values for the 2 and 3 hour duration are found in a similar nomograph approach. A straight line is drawn between the 1 and 6 hour values and readings taken for the 2 and 3 hour durations.

Besides the nomograph approach, the following mathematical solutions have been developed for estimating the 2 and 3 hour values in Arizona:

2 hour = 0.341 (6 hr) + 0.659 (1 hr)

3 hour = 0.569 (6 hr) + 0.431 (1 hr)

Data for the one year storm are found by using methods found in Weather Bureau Technical Memorandum No. 44 - Estimated Return Periods for Short Duration Precipitation in Arizona by the U.S. Department of Commerce, Environmental Science Services Administration.

The formula developed for finding the rainfall for the 1 year, 6 hour and 24 hour duration is:

$$P_1 = P_2 - 0.16\ (P_{100} - P_2)$$

Where

$P_1 P_2 \ldots,\ P_{100}$ are the estimated precipitation for return periods of 1, 2 and 100 years, respectively.

The remaining rainfall values for the one year durations (1hr, 2hr, and 3hr) are calculated using the equations:

$$X_1 = 2X_6 - X_{24}$$

$$X_2 = X_6 - .77(X_6 - X_1)$$

$$X_3 = X_6 - .55(X_6 - X_1)$$

Where X_1, X_2, ..., X_{24} are estimated precipitation values for durations of 1, 2, ..., 24 hours respectively.

Table 4.8 shows the precipitation data calculated for the study area.

Utilization of this precipitation data for Soil Conservation Service methods is described by K.M. Kent (retired), Chief, Hydrology Branch, Soil Conservation Service, in SCS-TP-149 entitled <u>A Method for Estimating Volume and Rate of Runoff in Small Watersheds</u>.

"Adjustment of rainfall with respect to area is not necessary in the method described because the drainage areas are small. But the distribution of storm rainfall with respect to time is an important parameter. Two major regions were identified for this purpose. Time distributions for each are tabulated in Table 1 and shown in Figure 1 (Table 4.9 of this report). Type I represents regions with a maritime climate. Type II represents regions in which the high rates of runoff from small areas are usually generated from summer thunderstorms.

"The type I and type II distributions are based on generalized rainfall depth-duration relationships obtained from Weather Bureau technical papers. The accumulative graphs in figure 2 (Figure 4.10 of this report), which are the basis for type I and type II distributions, were established by (1) plotting a ratio of rainfall amount for any duration to the 24-hour amount against duration for a number of locations and (2) selecting a curve of best fit. Selected curves are shown as dashed lines in figure 2 (only type II distributions are included in this report, see Figure 4.10). Note that the Type II distribution ...underestimates the 1-hour duration by about 0.6 inch at Lincoln, Nebr., overestimates it by about 0.5 inch at Mobile, Ala., and is within 0.1 inch on the northwest corner of Utah...These variations are within the accuracy of rainfall amounts read from the Weather Bureau references.

"Average intensity-duration values used to develop the dashed lines in figure 2 (Figure 4.10) are rearranged to form the ...type II distributions in figure 1 (Figure 4.11). The type I distribution is arranged so so that the greatest 30-minute depth occurs at about the 10-hour point of the 24-hour period, the second largest in the next 30 minutes, and the third largest in the preceeding 30 minutes. This alternation continues with each decreasing order of magnitude until the smallest increments fall at the beginning and end of the 24-hour rainfall...The type II distribution is arranged in a similar manner but the greatest 30-minute depth occurs near the middle of the 24-hour period. The selection of the period of maximum intensity for both distributions was based on design consideration rather than meterological factors.

"The effective storm period that contributes to an instantaneous peak rate of discharge varies with the time of concentration (T_c) of each small watershed. It is only a few minutes for a very short T_c and up to 24 hours for a long T_c. The effective period for most watersheds smaller than 2,000 acres is less than 6 hours. Because of the "built-in" range of 30-minute intensities, the 24-hour duration is equally appropriate for a 5-acre watershed with less than a 30-minute effective storm period as it is for a 2,000 acre watershed where the effective periods may take up the entire 24 hours."

As a check, the 24 hour duration (Figure 4.11) was compared with the 1, 2, 3 and 6 hour duration storms shown in Figures 4.12 and 4.13. Alternate I was chosen as the sample run used in the TR-20 computer program. All five durations were routed through the system for each of the four design year storms. The results verified that the 24 hour duration did develop the peak flows and therefore was the critical duration used for the Northwest Storm Drainage Study.

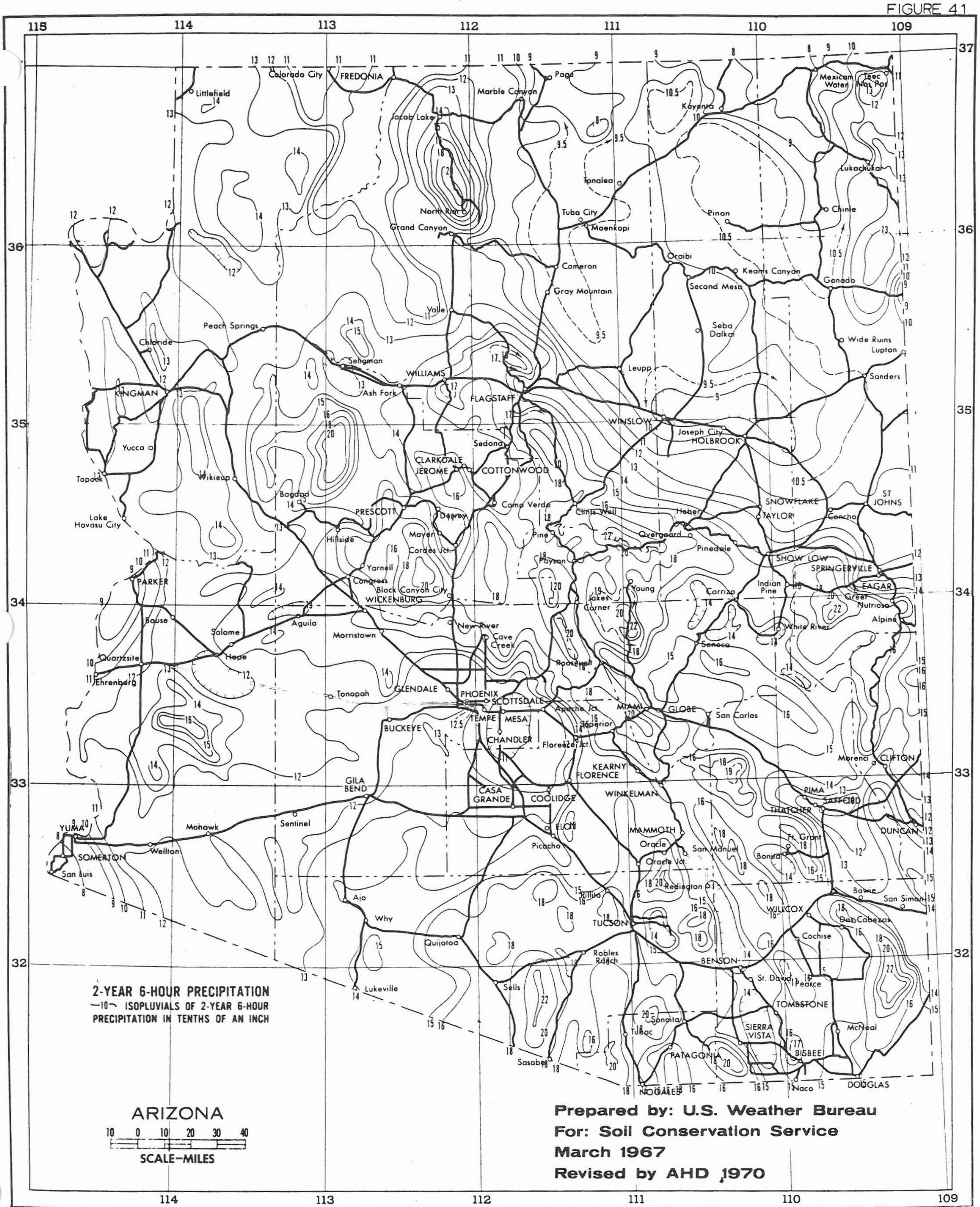
In addition, the precipitation data obtained in Table 4.8 was compared with the Soil Conservation Service Type II distribution and found to be within reasonable limits, thereby justifying the use of the standard Type II distribution. If the data had varied excessively, a new distribution curve would have had to be developed based on the collected data.

In the past, the City of Phoenix has depended upon the Rainfall Intensity-Duration-Frequency Relation Curve, Figure 4.14, for its rainfall data. The source of information for developing the curve can be found in the Weather Bureau's Technical Memorandum WR-44, Estimated Return Periods for Short Duration Precipitation in Arizona. Table 4.15 shows the data for the City of Phoenix taken at the Weather Bureau Office located at Sky Harbor Airport.

A comparison between this data and the data for the Northwest Storm Drainage Study (Table 4.8) shows that the rainfall for the 1, 2 and 5 year frequencies for all durations is generally larger. For the larger frequency storms, the opposite holds true.

Differences occur because the WR-44 source uses the one location, Sky Harbor Airport, for its Phoenix data while the report map data was obtained through interpolation of the precipitation maps for the particular study area. The point source is used only as a general representation for the Phoenix area and cannot accurately account for the rainfall differences within the many drainage basins of the valley.

FIGURE 4.1


2-YEAR 6-HOUR PRECIPITATION
—10— ISOPLUVIALS OF 2-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH
ARIZONA
10 0 10 20 30 40
SCALE—MILES
Prepared by: U.S. Weather Bureau
For: Soil Conservation Service
March 1967
Revised by AHD 1970
115
114
113
112
111
110
109
37
36
35
34
33
32
Colorado City
FREDONIA
Marble Canyon
Page
Littlefield
Jacob Lake
Kayenta
Mexican Water
Teec Nos Pos
Tonalea
North Rim
Grand Canyon
Tuba City
Moenkopi
Pinon
Chinle
Lukachukai
Cameron
Oraibi
Keams Canyon
Second Mesa
Ganado
Gray Mountain
Valle
Peach Springs
Seba Dalkai
Wide Ruins
Lupton
Chloride
Seligman
WILLIAMS
Leupp
Sanders
KINGMAN
Ash Fork
FLAGSTAFF
WINSLOW
Joseph City
HOLBROOK
Yucca
Sedona
CLARKDALE
JEROME
COTTONWOOD
Topock
Wikieup
Bagdad
PRESCOTT
Dewey
Camp Verde
SNOWFLAKE
TAYLOR
ST JOHNS
Concho
Lake Havasu City
Hillside
Mayer
Cordes Jct
Clints Well
Heber
Pine
Overgaard
Pinedale
Yarnell
Congress
Black Canyon City
Payson
SHOW LOW
SPRINGERVILLE
EAGAR
PARKER
WICKENBURG
Young
Lakes Corner
Carrizo
Indian Pine
Greer
Nutrioso
Alpine
Bouse
Aguila
New River
White River
Salome
Morristown
Cave Creek
Seneca
Quartzsite
Hope
Roosevelt
Ehrenberg
Tonopah
GLENDALE
PHOENIX
SCOTTSDALE
Apache Jct
MIAMI
GLOBE
San Carlos
BUCKEYE
TEMPE
MESA
Superior
CHANDLER
Florence Jct
KEARNY
FLORENCE
Morenci
CLIFTON
GILA BEND
CASA GRANDE
COOLIDGE
WINKELMAN
PIMA
SAFFORD
THATCHER
YUMA
Sentinel
Mohawk
ELOY
MAMMOTH
DUNCAN
SOMERTON
Wellton
Picacho
Oracle
San Manuel
Ft. Grant
Bonita
San Luis
Oracle Jct
Redington
Ajo
Rillito
Bowie
San Simon
WILLCOX
Why
TUCSON
Dos Cabezas
Cochise
Quijotoa
Robles Ranch
BENSON
St. David
Pearce
Lukeville
Sells
TOMBSTONE
Sonoita
Tubac
SIERRA VISTA
McNeal
PATAGONIA
BISBEE
Sasabe
NOGALES
Naco
DOUGLAS

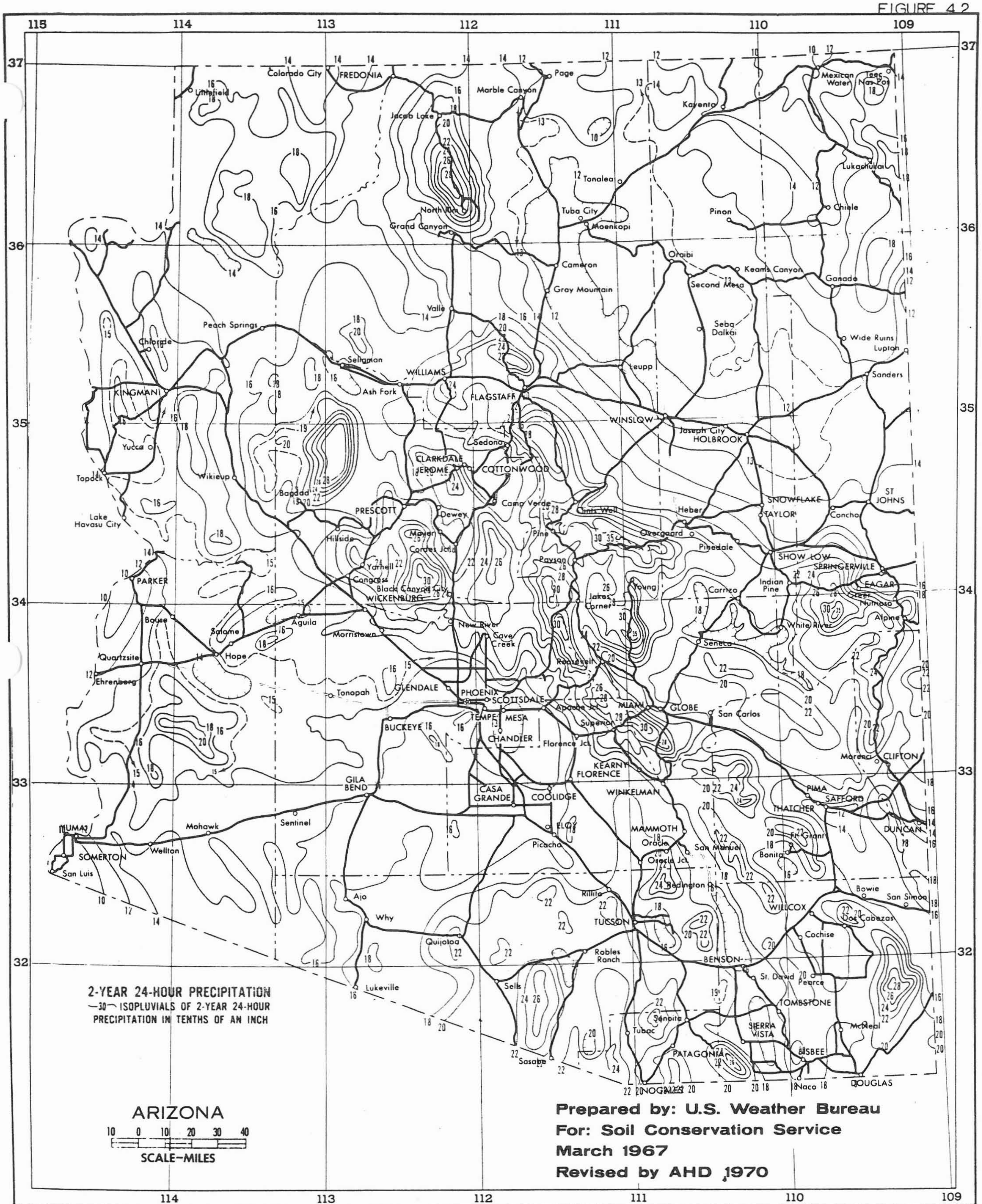

2-YEAR 24-HOUR PRECIPITATION
—30— ISOPLUVIALS OF 2-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH
ARIZONA
SCALE–MILES
Prepared by: U.S. Weather Bureau
For: Soil Conservation Service
March 1967
Revised by AHD 1970

FIGURE 4.3

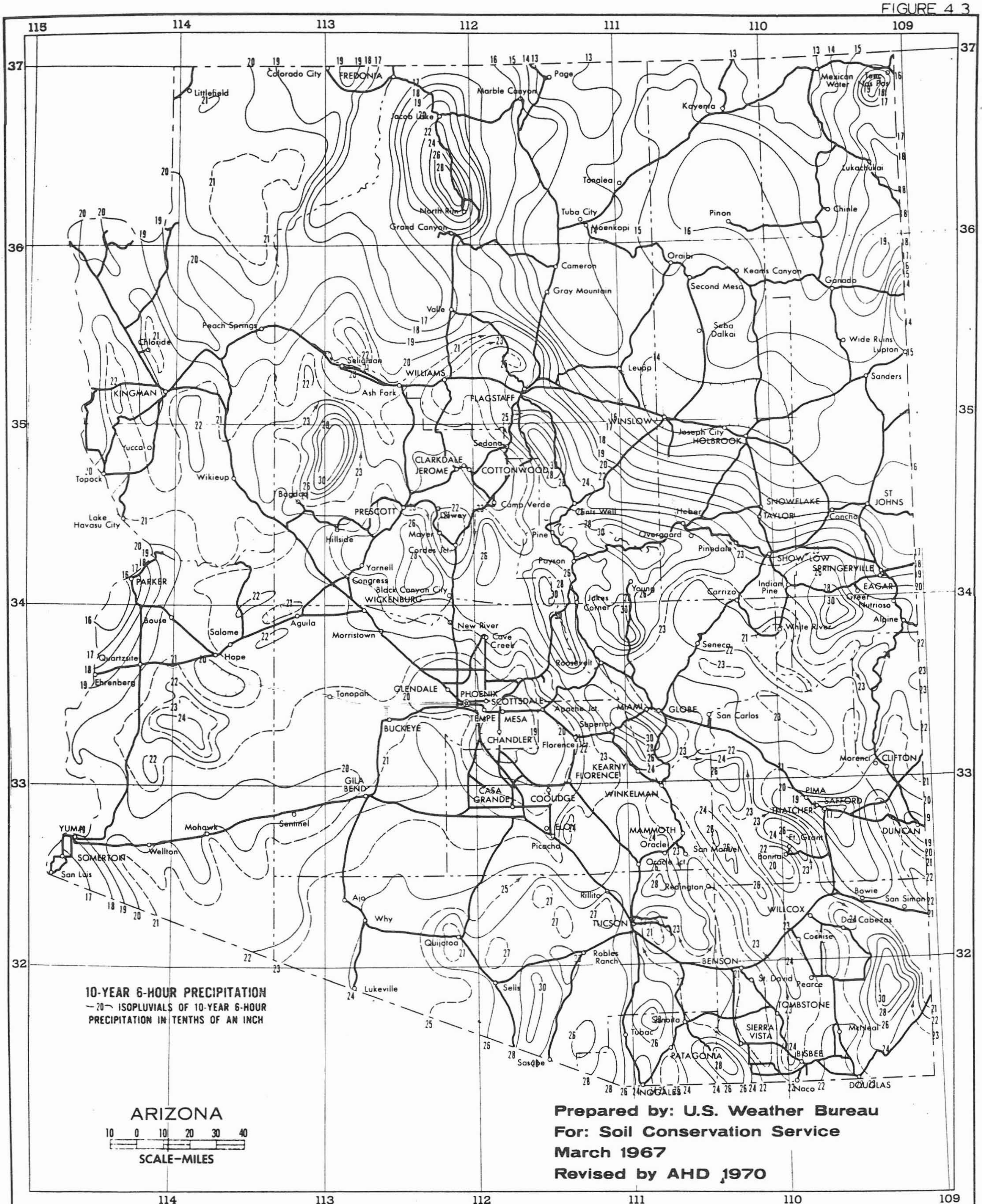


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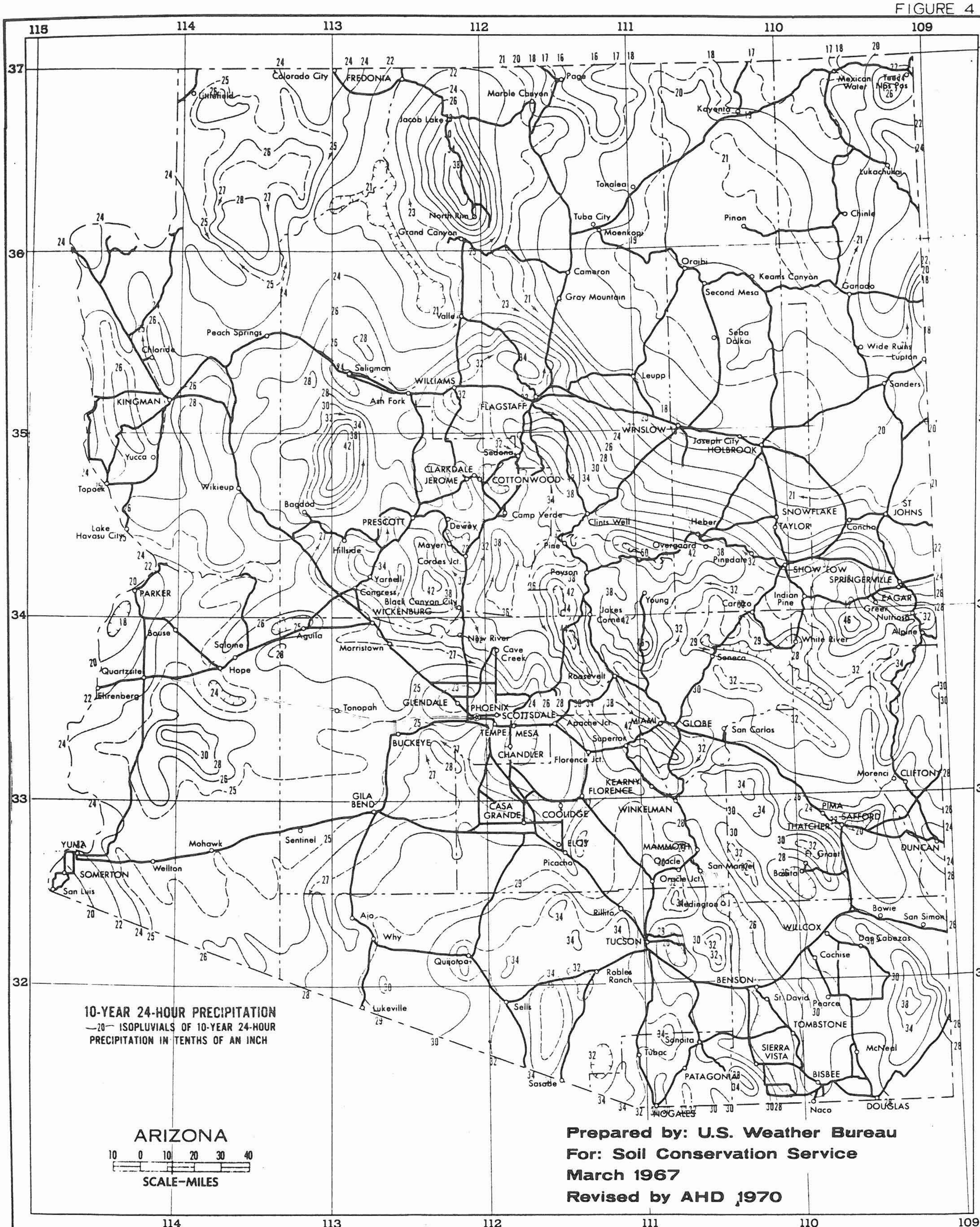
FIGURE 4.4



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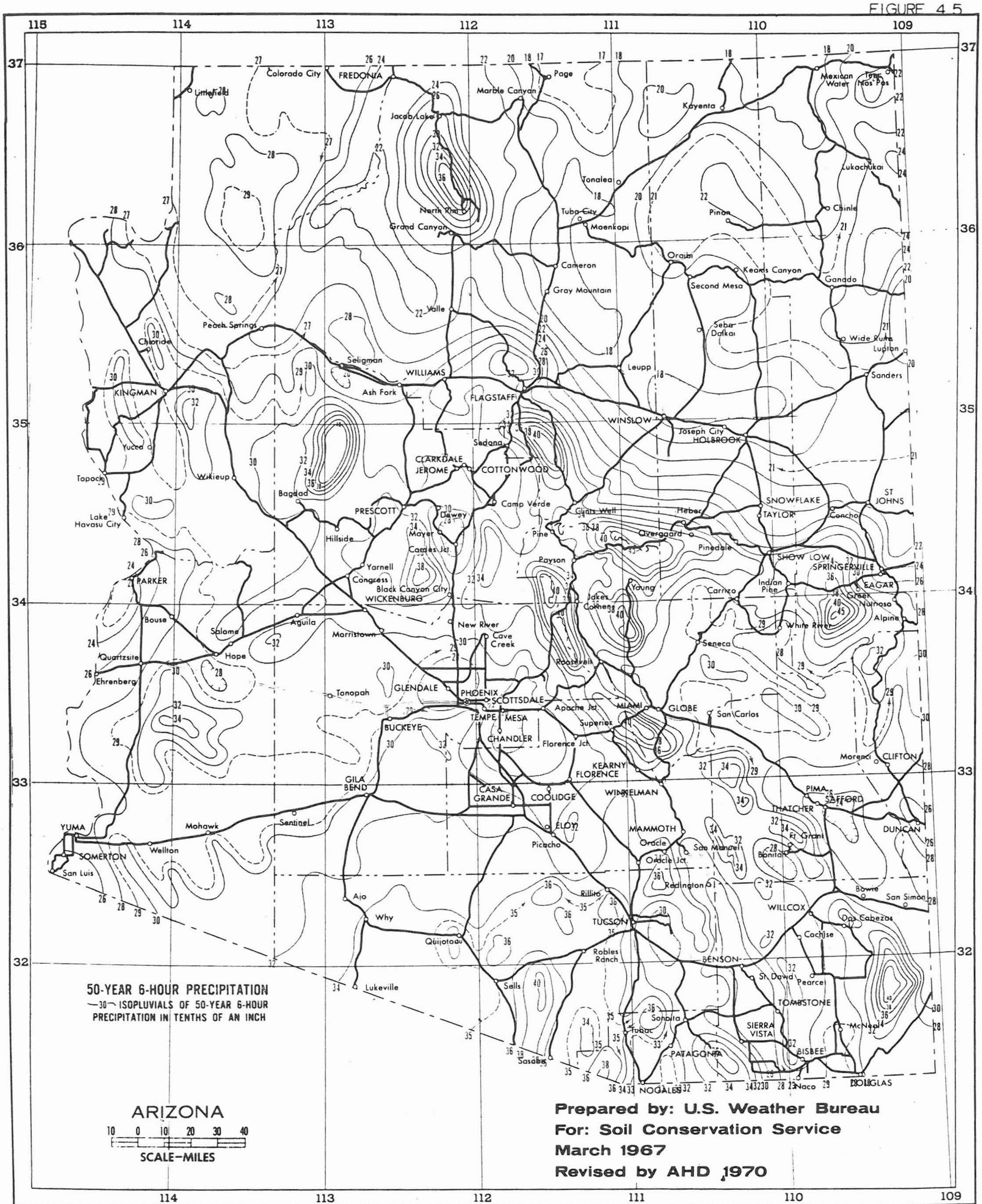
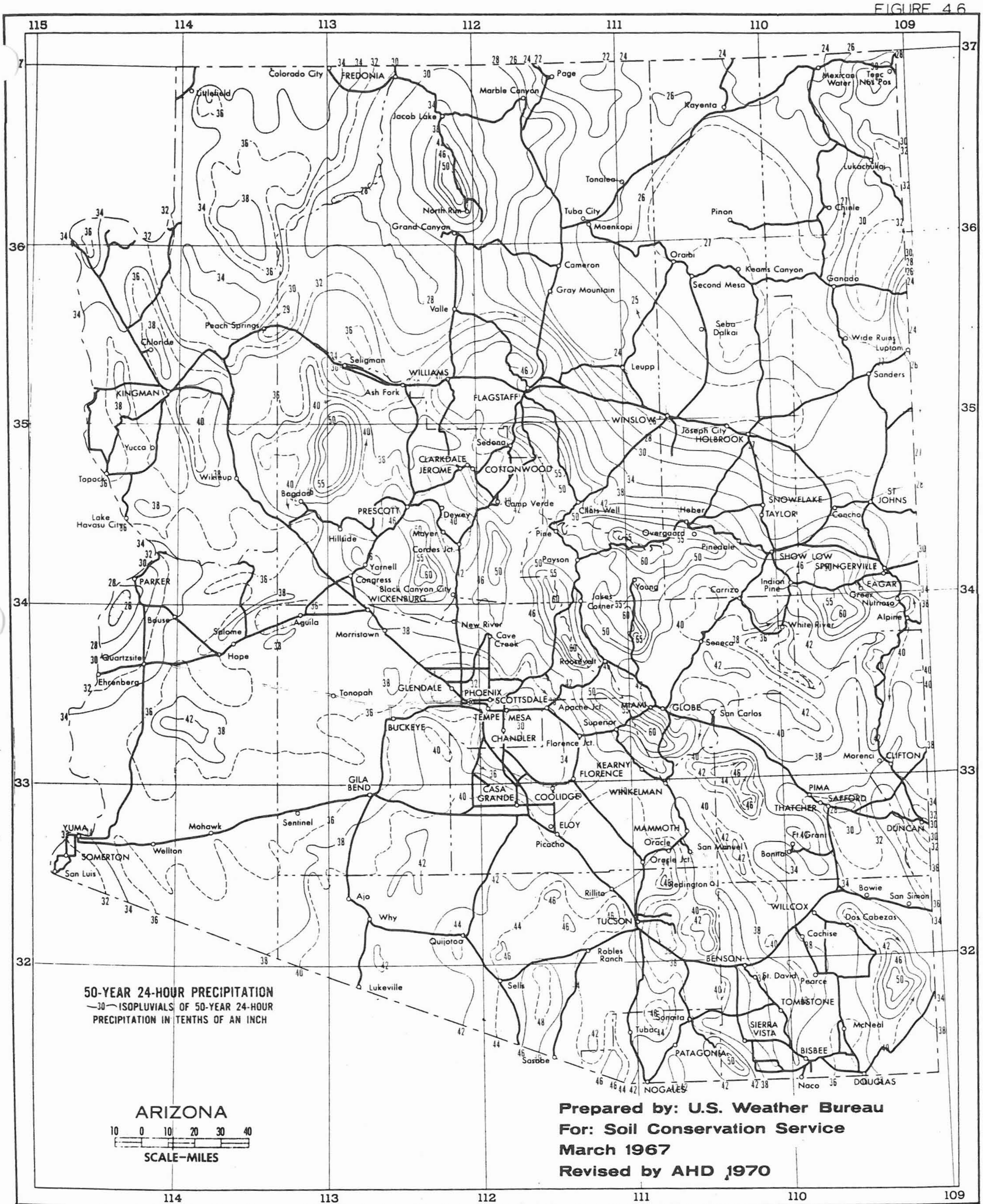

ARIZONA
10 0 10 20 30 40
SCALE-MILES
50-YEAR 6-HOUR PRECIPITATION
—30— ISOPLUVIALS OF 50-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH
Prepared by: U.S. Weather Bureau
For: Soil Conservation Service
March 1967
Revised by AHD 1970
FLAGSTAFF
PHOENIX
TUCSON
YUMA
KINGMAN
PRESCOTT
WINSLOW
HOLBROOK
GLOBE
SAFFORD
DOUGLAS
NOGALES

FIGURE 4.6



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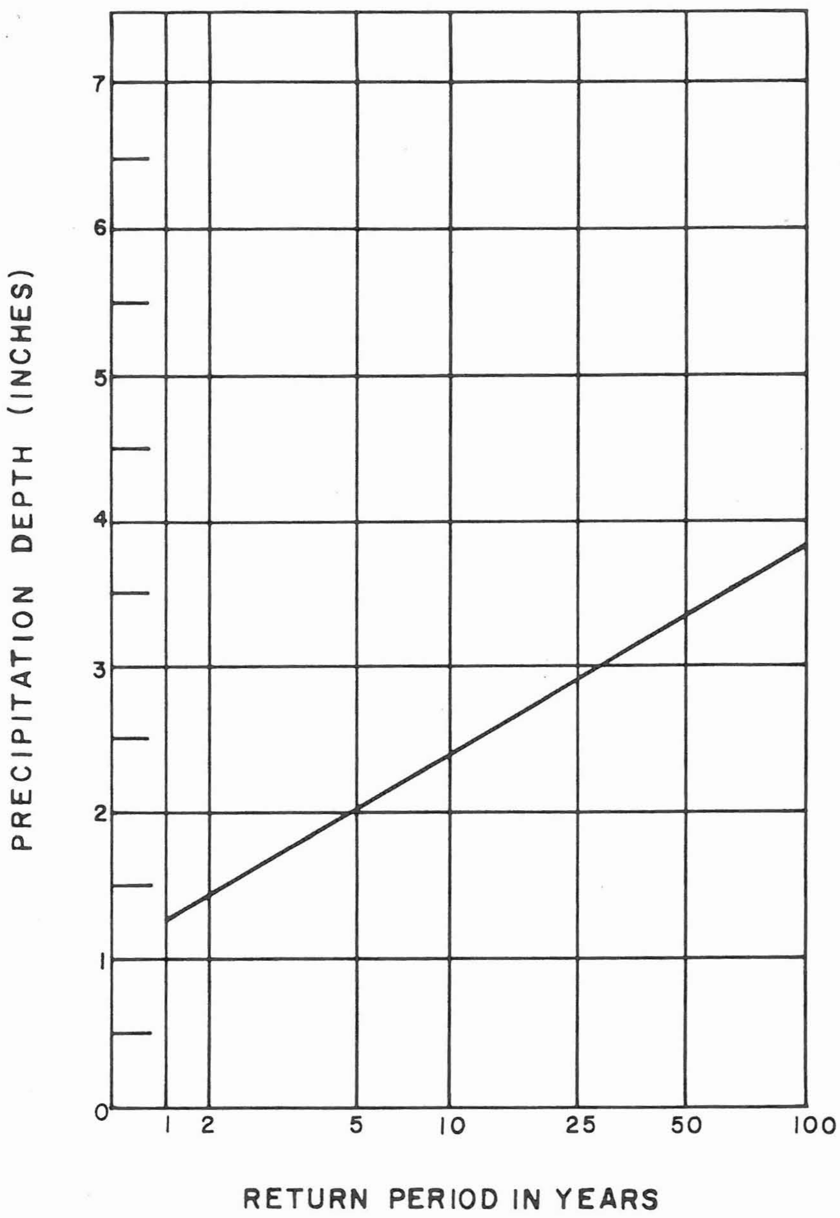


PRECIPITATION-FREQUENCY NOMOGRAPH 24-HOUR DURATION

arthur beard engineers, Inc.

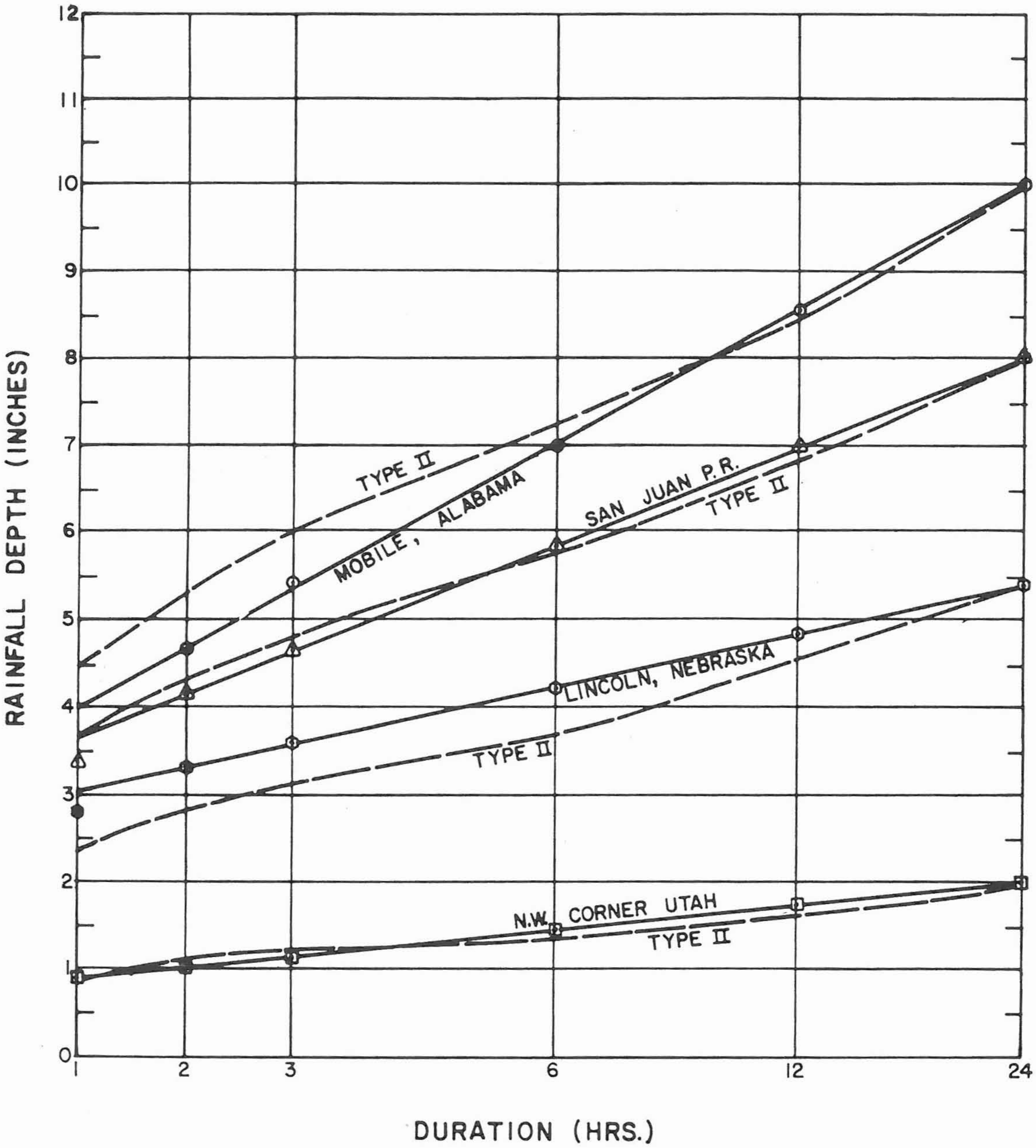
FREQUENCY (years)	DURATION (hrs)				
	1	2	3	6	24
1	0.78	0.81	0.83	0.90	1.25
2	0.86	1.10	1.15	1.20	1.40
5	1.40	1.50	1.60	1.70	2.00
10	1.55	1.70	1.80	2.00	2.35
25	1.75	1.95	2.15	2.40	2.90
50	2.00	2.30	2.50	2.80	3.30
100	2.40	2.60	2.80	3.10	3.80

NORTHWEST STORM DRAINAGE STUDY
PRECIPITATION DATA (INCHES)

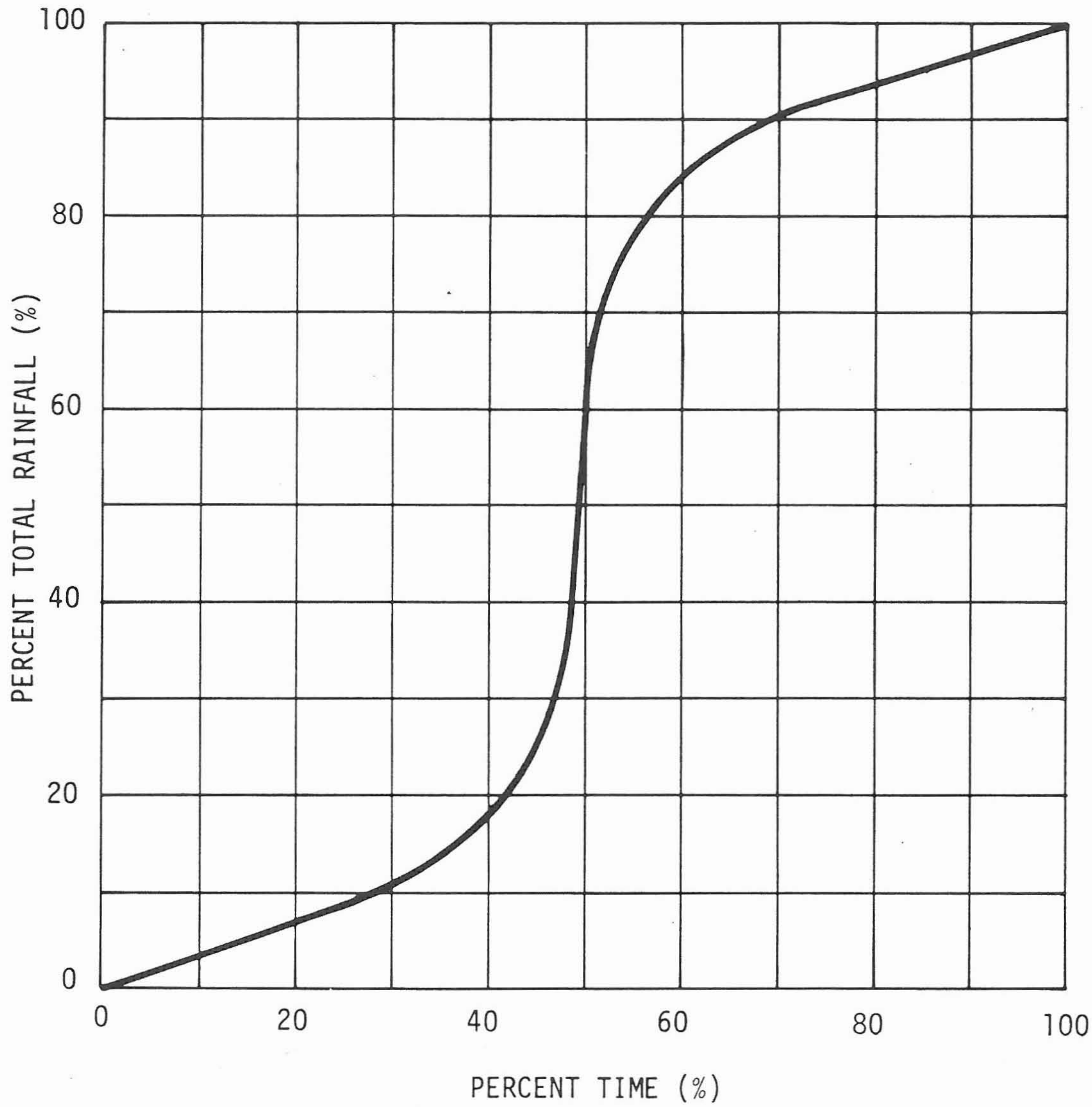
Time (hours)	Ratio of Accumulated Rainfall to Total P_X/P_{24}	
	Type I	Type II
0	0	0
2.0	.035	.022
4.0	.076	.048
6.0	.125	.080
7.0	.156	----
8.0	.194	.120
8.5	.219	----
9.0	.254	.147
9.5	.303	.163
9.75	.362	----
10.0	.515	.181
10.5	.583	.204
11.0	.624	.235
11.5	.654	.283
11.75	----	.387
12.0	.682	.663
12.5	----	.735
13.0	.727	.772
13.5	----	.799
14.0	.767	.820
16.0	.830	.880
20.0	.926	.952
24.0	1.000	1.000

From: A Method for Estimating Volume and Rate of Runoff in Small Watersheds by K.M. Kent.

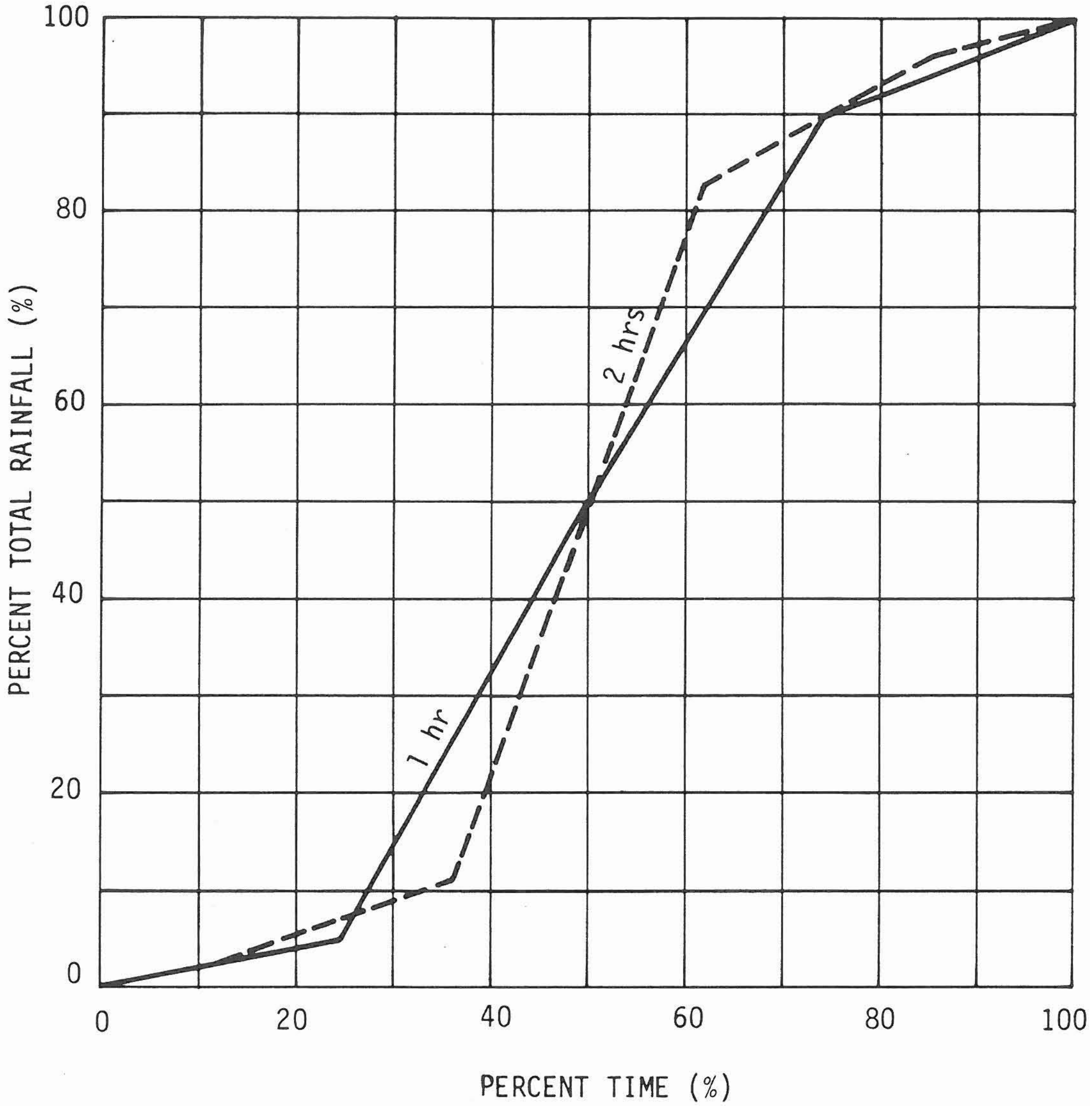
ACCUMULATION OF RAINFALL
TO 24 HOURS



GENERALIZED 25-YEAR
FREQUENCY RAINFALL
DEPTH-DURATION RELATIONSHIPS

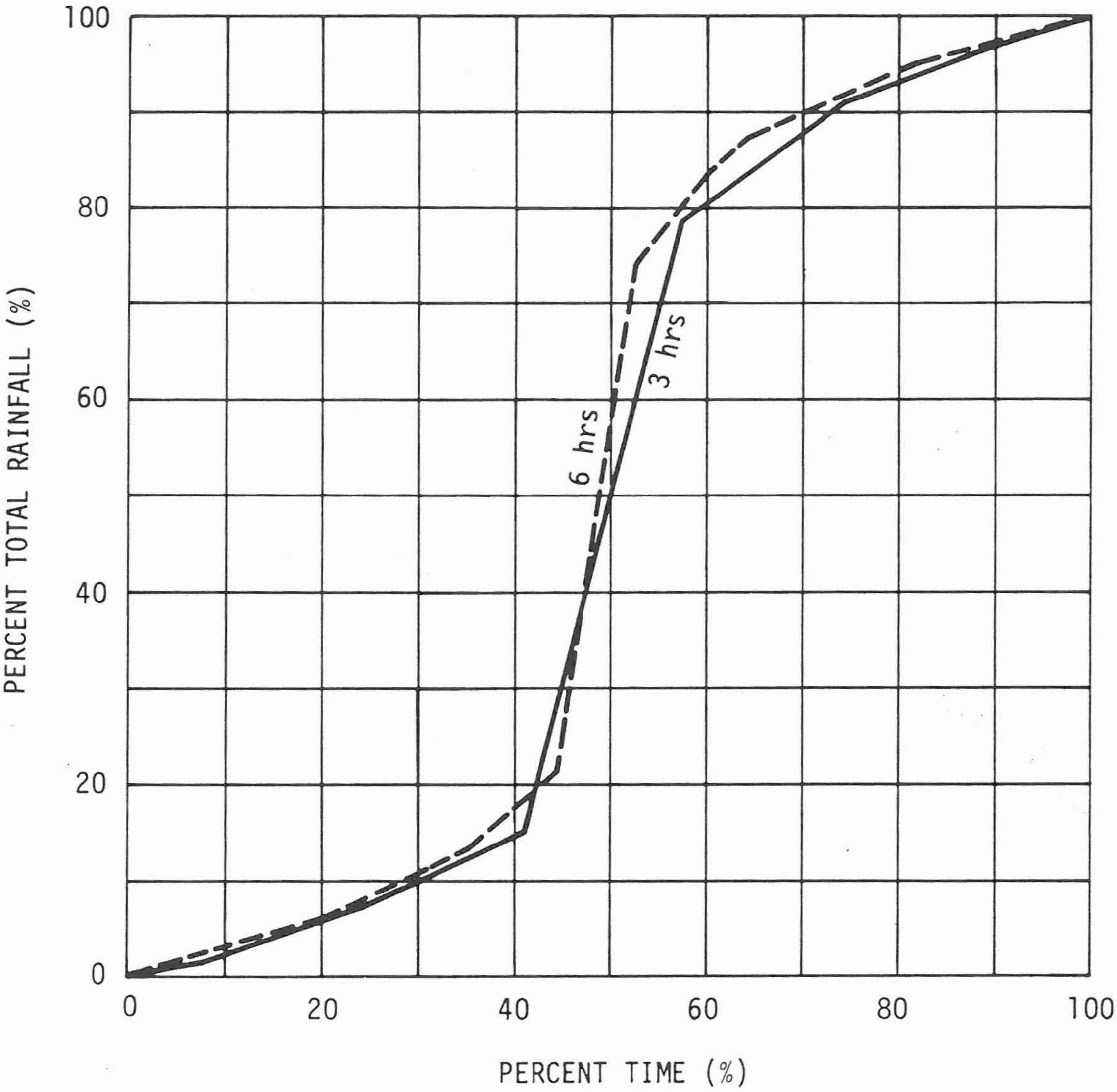


RAINFALL DISTRIBUTION
SCS TYPE II, 24 HR
SOUTHWESTERN UNITED STATES



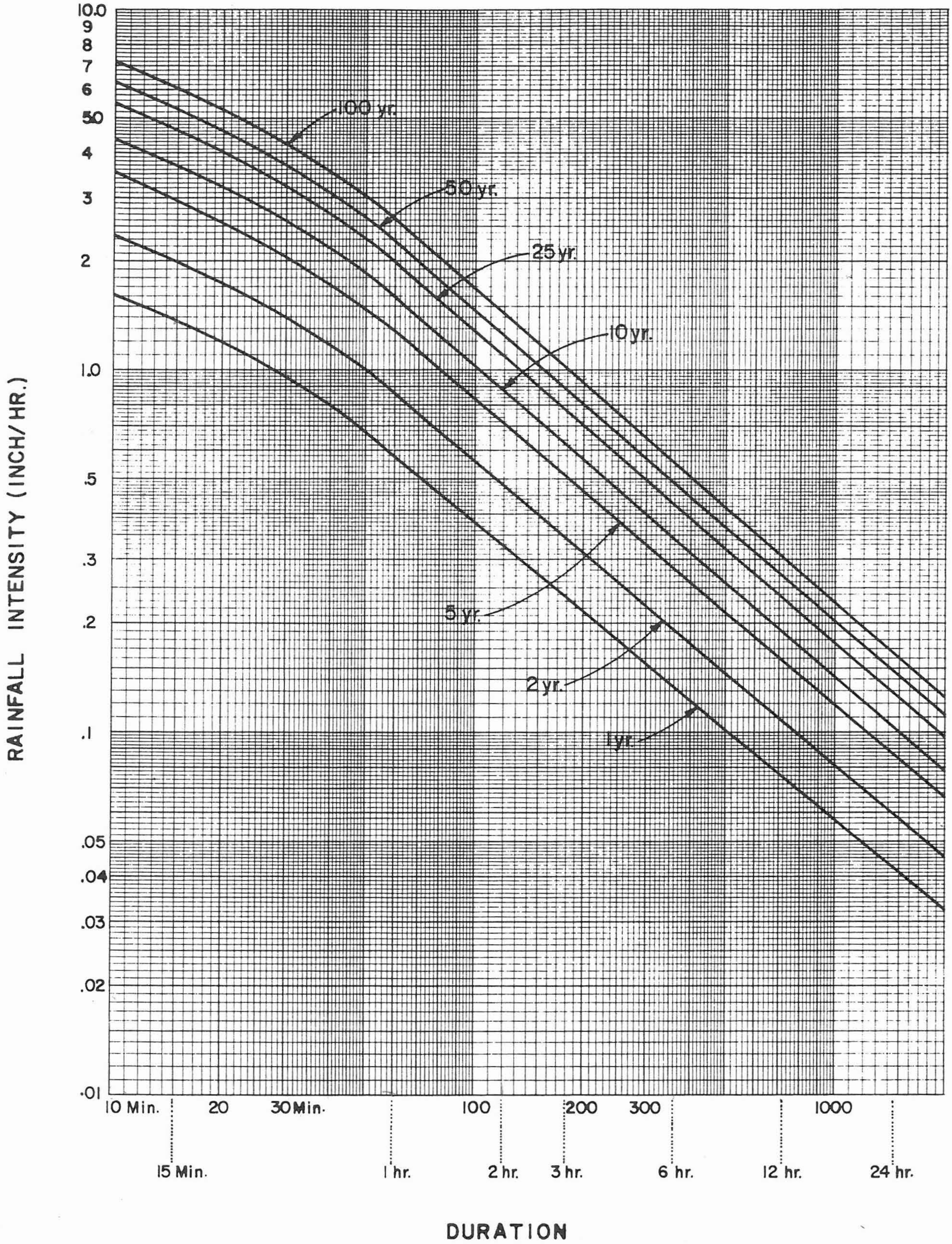
Based on estimated values as shown in Precipitation-Frequency Atlas of Western United States and discussed with H. Milsap Hydrologist SCS Phoenix Office.

RAINFALL DISTRIBUTION
1 & 2 HRS



Based on same distribution as 24 hr

RAINFALL DISTRIBUTION
3 & 6 HRS



RAINFALL INTENSITY
DURATION-FREQUENCY RELATION
FOR PHOENIX, ARIZONA

Station: Phoenix WBO

Latitude: 33° 26'

Longitude: 112° 01'

Elevation (feet): 1117

RETURN PERIOD (YRS.)

DURATION	1	2	5	10	25	50	100
5 min.	0.17	0.26	0.38	0.47	0.59	0.68	0.77
10 min.	0.27	0.40	0.59	0.72	0.91	1.06	1.20
15 min.	0.34	0.50	0.74	0.92	1.15	1.34	1.52
30 min.	0.47	0.70	1.03	1.27	1.60	1.86	2.10
1 hr.	0.60	0.88	1.30	1.61	2.02	2.35	2.66
2 hr.	0.65	0.94	1.39	1.72	2.15	2.49	2.82
3 hr.	0.69	1.01	1.48	1.82	2.27	2.62	2.97
6 hr.	0.81	1.16	1.70	2.07	2.57	2.96	3.35
12 hr.	0.91	1.30	1.90	2.30	2.84	3.26	3.69
24 hr.	1.02	1.44	2.10	2.53	3.12	3.57	4.04

ESTIMATED RETURN PERIODS
FOR
SHORT-DURATION PRECIPITATION
IN ARIZONA

APPENDIX 1-D

Development of Depth-Duration-Frequency table, and Intensity-Duration-Frequency table and graph.

Comparison of IDF Curves for
Phoenix and Recommendation for
the Selection of IDF Curves for
Maricopa County

G. Sabol, 8 May 1989

Intensity-duration-frequency (IDF) curves or a procedure to develop IDF curves are needed for the description of the Rational Method in the Maricopa County Hydrology Manual. The following sources are available for depth-duration-frequency (DDF) data for Maricopa County:

1. NOAA Atlas 2,
2. NOAA Atlas 2 with the procedure of Arkell and Richards (1986) for durations less than 1-hour, and
3. TP-40 (1961) or the data tabulations processed from TP-40 for selected locations in Maricopa County as presented by Kangieser (1969).

In addition to these basic data sources, there is also an IDF curve that is used by the City of Phoenix.

I have compared IDF curves for Phoenix that would be available from these four sources. Attached are DDF data tables, corresponding IDF data tables, and several IDF curves. The following are conclusions from the inspection of these data and curves:

1. The IDF data for Phoenix from TP-40 and Kangieser, from NOAA Atlas 2, and from NOAA Atlas 2 along with the procedure by Arkell and Richards for short duration (less than 1-hour duration) are nearly identical. For use with the Rational Method, any of these three IDF curves would yield about the same results.

2. The IDF curve for the City of Phoenix is nearly identical to the other three for a return period of 2-years. The City of Phoenix curve indicates lower intensities than the other three for return periods longer than 2-years. At a return period of 100-years, the City of Phoenix is significantly less than the other three; for example for a duration of 30-minutes the intensities are:

TP-40 and Kangieser	- 4.20 in/hr
NOAA Atlas 2	- 3.94 in/hr
NOAA Atlas 2 plus Arkell and Richards	- 3.98 in/hr
City of Phoenix	- 3.4 in/hr

   For shorter durations, the deviation is greater; and for longer durations, the deviation is less. At a duration of 6-hours and longer, the intensities are about equal.

3. The data base and/or justification for the City of Phoenix IDF curve to deviate from the three most authoritative data sources is not known to me.

4. I would not recommend using the City of Phoenix IDF curves because; 1) I don't think that there is a valid technical basis for these curves, and 2) a procedure is needed that can be used for all of Maricopa County. The same procedure should be used throughout the county.

5. I think that the best data base and procedures that are currently available to develop IDF curves is NOAA Atlas 2 with the Arkell and Richards procedure for short durations. I base this conclusion on; 1) it represents the most current data base and procedure, 2) if the NWS undertakes a restudy of precipitation data for Arizona (and Frank Richards has been involved in preliminary discussions in Arizona) then it is likely that the new short duration ratios will be incorporated in the new Arizona procedures, and 3) a NWS program (PREFRE) is available to quickly generate DDF tables based on these data and procedures.

Depth-Duration-Frequency Data for Phoenix (Kangieser, 1969)

TABLE 4.15

Station: Phoenix WBO

Latitude: 33° 26'

Longitude: 112° 01'

Elevation (feet): 1117

RETURN PERIOD (YRS.)

DURATION	1	2	5	10	25	50	100
5 min.	0.17	0.26	0.38	0.47	0.59	0.68	0.77
10 min.	0.27	0.40	0.59	0.72	0.91	1.06	1.20
15 min.	0.34	0.50	0.74	0.92	1.15	1.34	1.52
30 min.	0.47	0.70	1.03	1.27	1.60	1.86	2.10
1 hr.	0.60	0.88	1.30	1.61	2.02	2.35	2.66
2 hr.	0.65	0.94	1.39	1.72	2.15	2.49	2.82
3 hr.	0.69	1.01	1.48	1.82	2.27	2.62	2.97
6 hr.	0.81	1.16	1.70	2.07	2.57	2.96	3.35
12 hr.	0.91	1.30	1.90	2.30	2.84	3.26	3.69
24 hr.	1.02	1.44	2.10	2.53	3.12	3.57	4.04

ESTIMATED RETURN PERIODS
FOR
SHORT-DURATION PRECIPITATION
IN ARIZONA

am Dg
19 May 88
8/

Depth-Duration-Frequency Data for Phoenix, Arizona.
from NOAA Atlas 2

Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
	Depth, in inches for the indicated return periods					
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-min	.27	.38	.46	.55	.64	.72
10-min	.42	.59	.71	.86	.99	1.12
15-min	.54	.75	.89	1.08	1.25	1.42
30-min	.74	1.03	1.24	1.50	1.73	1.97
1-hr	.94	1.31	1.57	1.90	2.19	2.49
2-hr	1.03	1.44	1.73	2.09	2.41	2.74
3-hr	1.08	1.53	1.84	2.21	2.56	2.91
6-hr	1.19	1.69	2.04	2.45	2.84	3.22
12-hr	1.29	1.86	2.23	2.70	3.13	3.57
24-hr	1.40	2.03	2.42	2.96	3.44	3.93

Depth - Duration - Frequency Data
for Phoenix
from NOAA Atlas 2
and Arkell & Richards, 1986

1

PREFRE printout

*** O U T P U T D A T A ***

REVISED JUNE 1988 TO UPDATE COMPUTATION OF SHORT-DURATION VALUES

PRECIPITATION FREQUENCY VALUES FOR PHOENIX ARIZONA
PRIMARY ZONE NUMBER= 7
SHORT-DURATION ZONE NUMBER= 8

POINT VALUES

	RETURN PERIOD							
DURATION	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	500-YR	
5-MIN	.32	.42	.49	.59	.67	.75	.92	5-MIN
10-MIN	.48	.64	.75	.91	1.03	1.14	1.42	10-MIN
15-MIN	.58	.80	.95	1.15	1.31	1.47	1.83	15-MIN
30-MIN	.77	1.07	1.28	1.56	1.77	1.99	2.49	30-MIN
1-HR	.94	1.33	1.58	1.94	2.21	2.49	3.12	1-HR
2-HR	1.03	1.45	1.74	2.13	2.43	2.74	3.43	2-HR
3-HR	1.08	1.54	1.84	2.26	2.58	2.90	3.64	3-HR
6-HR	1.19	1.70	2.04	2.50	2.86	3.22	4.05	6-HR
12-HR	1.30	1.87	2.25	2.77	3.17	3.58	4.50	12-HR
24-HR	1.40	2.04	2.46	3.04	3.49	3.93	4.96	24-HR

* IF YOUR SITE IS IN ARIZONA OR NEW MEXICO, PLEASE CONSULT THE FOLLOWING PAPER FOR REVISED DEPTH-AREA VALUES:
DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES
NOAA TECHNICAL MEMORANDUM NWS HYDRO-40
ZEHR AND MYERS
AUGUST 1984

INPUT DATA

PROJECT NAME=PHOENIX ARIZONA
ZONE= 7 SHORT-DURATION ZONE= 8
LATITUDE= .00 LONGITUDE= 100.00 ELEVATION= 0
2-YR, 6-HR PCPN= 1.19 100-YR, 6-HR PCPN= 3.22
2-YR, 24-HR PCPN= 1.40 100-YR, 24-HR PCPN= 3.93

* * * * E N D O F R U N * * * *

Intensity - Duration - Frequency Data

Location: Phoenix

Source of Data: TP-40 & Kangieser

	Return Period					
Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5-min	3.12	4.56	5.64	7.08	8.16	9.24
10-min	2.40	3.54	4.32	5.46	6.36	7.20
15-min	2.00	2.96	3.68	4.60	5.36	6.08
30-min	1.40	2.06	2.54	3.20	3.72	4.20
1-hr	.88	1.30	1.61	2.02	2.35	2.66
2-hr	.47	.70	.86	1.08	1.24	1.41
3-hr	.34	.49	.61	.76	.87	.99
6-hr	.19	.28	.35	.43	.49	.56
12-hr	.11	.16	.19	.24	.27	.31
24-hr	.06	.09	.11	.13	.15	.17

Intensity - Duration - Frequency Data

Location: Phoenix

Source of Data: NOAA Atlas 2

Duration	Return Period 2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5-min	3.24	4.56	5.52	6.60	7.68	8.64
10-min	2.52	3.54	4.26	5.16	5.94	6.72
15-min	2.16	3.00	3.56	4.32	5.00	5.68
30-min	1.48	2.06	2.48	3.00	3.46	3.94
1-hr	.94	1.31	1.57	1.90	2.19	2.49
2-hr	.52	.72	.86	1.04	1.20	1.37
3-hr	.36	.51	.61	.74	.85	.97
6-hr	.20	.28	.34	.41	.47	.54
12-hr	.11	.16	.19	.23	.26	.30
24-hr	.06	.08	.10	.12	.14	.16

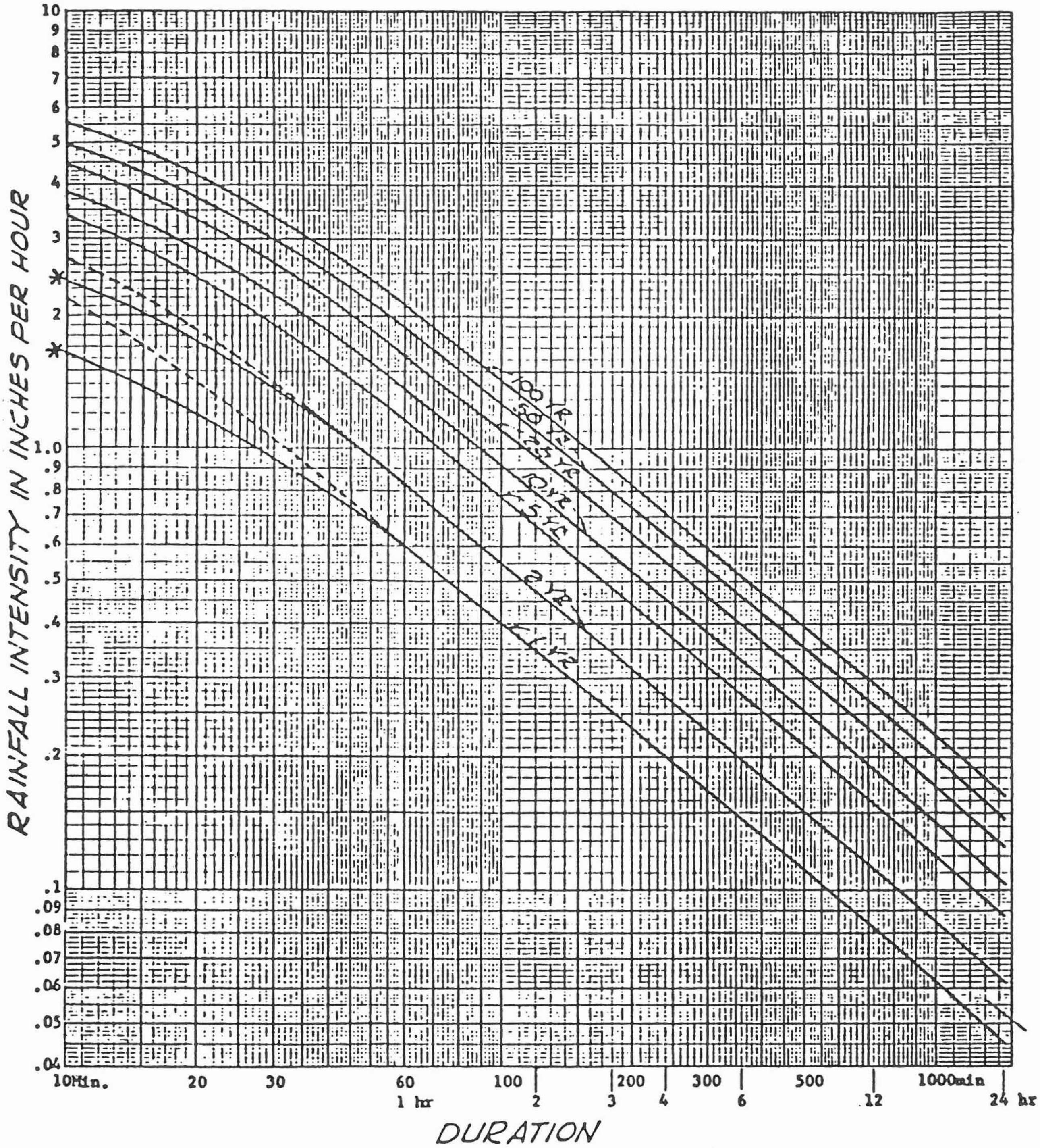
Intensity - Duration - Frequency Data

Location: Phoenix

Source of Data: NOAA Atlas and Arkell & Richards (1986) for durations less than 1-hour

	Return Period					
Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5-min	3.84	5.04	5.88	7.08	8.04	9.00
10-min	2.88	3.84	4.50	5.46	6.18	6.84
15-min	2.32	3.20	3.80	4.60	5.24	5.88
30-min	1.54	2.14	2.56	3.12	3.54	3.98
1-hr	.94	1.33	1.58	1.94	2.21	2.49
2-hr	.52	.72	.87	1.06	1.22	1.37
3-hr	.36	.51	.61	.75	.86	.97
6-hr	.20	.28	.34	.42	.48	.54
12-hr	.11	.16	.19	.23	.26	.30
24-hr	.06	.09	.10	.13	.15	.16

City of Phoenix IDF graphs



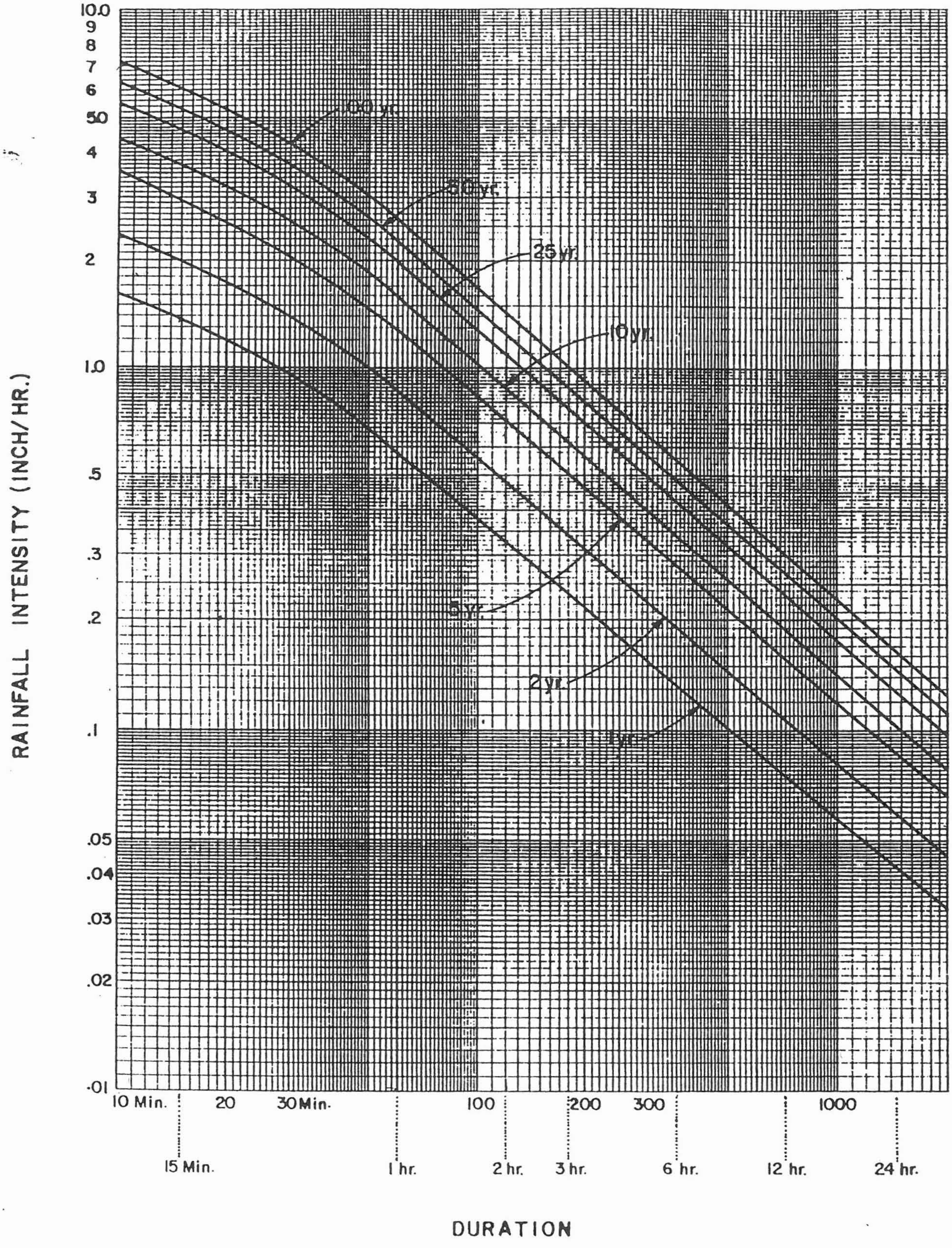
RAINFALL INTENSITY-DURATION-FREQUENCY RELATION FOR PHOENIX, ARIZONA
(Partial Duration Series)

Curves are based on methods of U.S. Weather Bureau Technical Papers Nos. 28 and 40 and rainfall data prepared by U.S. Weather Bureau Office of Hydrology for the Soil Conservation Service, March 1967

* Curves revised June 1975 to reflect new information from WR-44.

from Kangieser data

FIGURE 4.14



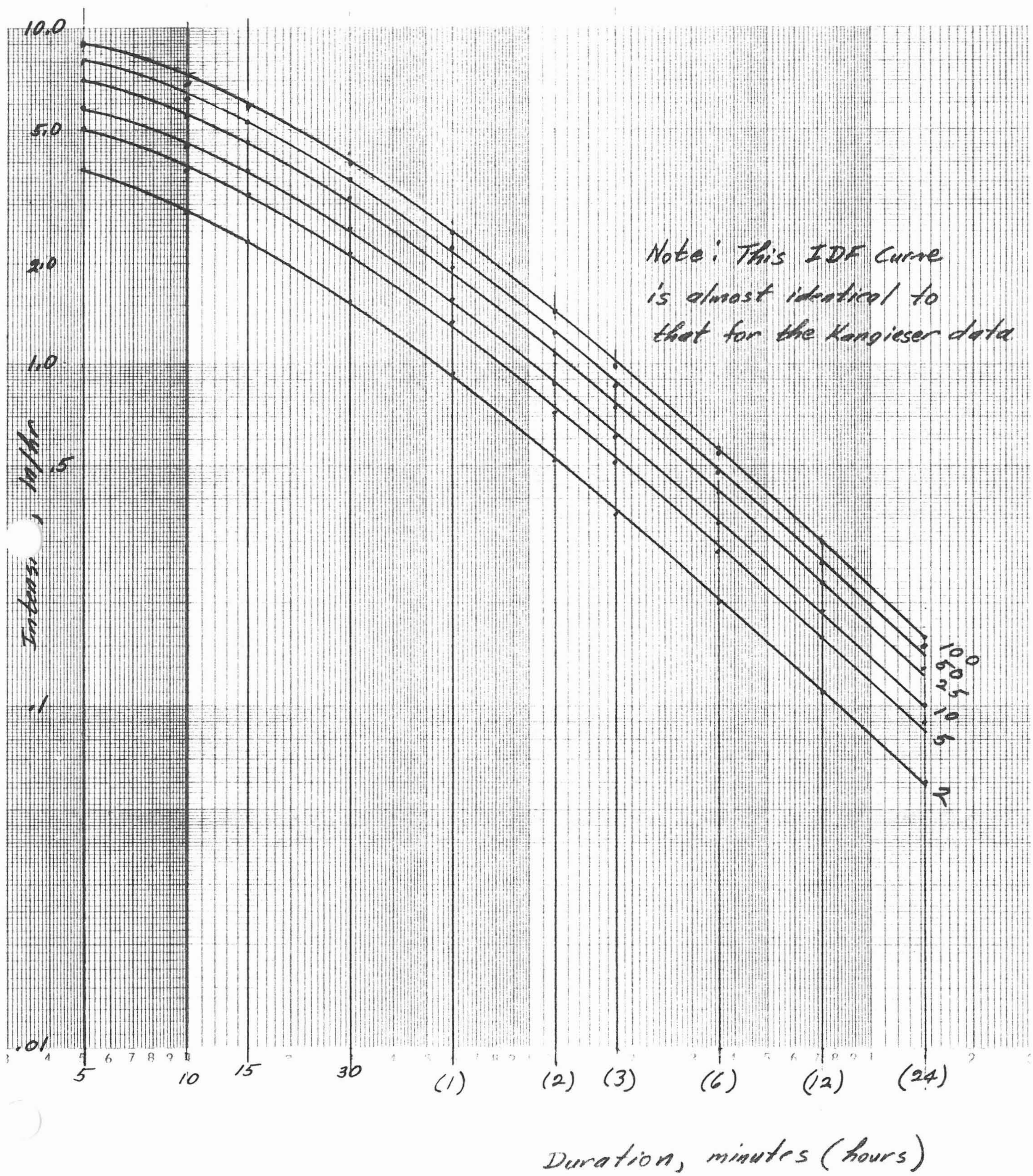
RAINFALL INTENSITY
DURATION-FREQUENCY RELATION
FOR PHOENIX, ARIZONA

GROUPS

5 May 89

IDF – Phoenix

Data from NOAA Atlas 2 with short duration procedure by Arkell and Richards (1986)



APPENDIX 1-E

24-hour, Maricopa County Flood Control District (MCFCD) distribution.

24-hour rainfall depth 3.93

time increment	increment rainfall	cumulative rainfall	time increment	increment rainfall	cumulative rainfall
00:15	.0075	.0075	12:15	1.4700	2.9600
00:30	.0075	.0150	12:30	.2500	3.2100
00:45	.0075	.0225	12:45	.0625	3.2725
01:00	.0075	.0300	13:00	.0625	3.3350
01:15	.0075	.0375	13:15	.0425	3.3775
01:30	.0075	.0450	13:30	.0425	3.4200
01:45	.0075	.0525	13:45	.0258	3.4458
02:00	.0075	.0600	14:00	.0258	3.4716
02:15	.0075	.0675	14:15	.0258	3.4974
02:30	.0075	.0750	14:30	.0258	3.5232
02:45	.0075	.0825	14:45	.0258	3.5490
03:00	.0075	.0900	15:00	.0258	3.5748
03:15	.0075	.0975	15:15	.0146	3.5894
03:30	.0075	.1050	15:30	.0146	3.6040
03:45	.0075	.1125	15:45	.0146	3.6186
04:00	.0075	.1200	16:00	.0146	3.6332
04:15	.0075	.1275	16:15	.0146	3.6478
04:30	.0075	.1350	16:30	.0146	3.6624
04:45	.0075	.1425	16:45	.0146	3.6770
05:00	.0075	.1500	17:00	.0146	3.6916
05:15	.0075	.1575	17:15	.0146	3.7062
05:30	.0075	.1650	17:30	.0146	3.7208
05:45	.0075	.1725	17:45	.0146	3.7354
06:00	.0075	.1800	18:00	.0146	3.7500
06:15	.0146	.1946	18:15	.0075	3.7575
06:30	.0146	.2092	18:30	.0075	3.7650
06:45	.0146	.2238	18:45	.0075	3.7225
07:00	.0146	.2384	19:00	.0075	3.7800
07:15	.0146	.2530	19:15	.0075	3.7875
07:30	.0146	.2676	19:30	.0075	3.7950
07:45	.0146	.2822	19:45	.0075	3.8025
08:00	.0146	.2968	20:00	.0075	3.8100
08:15	.0146	.3114	20:15	.0075	3.8175
08:30	.0146	.3260	20:30	.0075	3.8250
08:45	.0146	.3406	20:45	.0075	3.8325
09:00	.0146	.3552	21:00	.0075	3.8400
09:15	.0258	.3810	21:15	.0075	3.8475
09:30	.0258	.4068	21:30	.0075	3.8550
09:45	.0258	.4326	21:45	.0075	3.8625
10:00	.0258	.4584	22:00	.0075	3.8700
10:15	.0258	.4842	22:15	.0075	3.8775
10:30	.0258	.5100	22:30	.0075	3.8850
10:45	.0425	.5525	22:45	.0075	3.8925
11:00	.0425	.5950	23:00	.0075	3.9000
11:15	.0625	.6575	23:15	.0075	3.9075
11:30	.0625	.7200	23:30	.0075	3.9150
11:45	.2500	.9700	23:45	.0075	3.9225
12:00	.5200	1.4900	24:00	.0075	3.9300

APPENDIX 1-F

Short Duration Rainfall Relations for The Western United States, Arkell, Richard E., and Frank Richards, Conference on Climate and Water Management-A Critical Era and Conference on the Human Consequences of 1985's Climate, August 4-7, 1986, Ashville, N.C. Published by the American Meteorological Society, Boston, Mass.

Reprinted from the Preprint Volume of the Conference on Climate and Water Management—A Critical Era and Conference on the Human Consequences of 1985's Climate, August 4-7, 1986, Asheville, N.C. Published by the American Meteorological Society, Boston, Mass.

C4.4

SHORT DURATION RAINFALL RELATIONS FOR THE WESTERN UNITED STATES

Richard E. Arkell and Frank Richards

Office of Hydrology
NOAA, National Weather Service
Silver Spring, Maryland

1. INTRODUCTION

Long records of short-duration (less than 1 hr) precipitation observations necessary to estimate precipitation-frequency amounts are only available for a relatively small number of stations. This dearth of data has made the development of generalized short-duration estimates difficult, especially in the western United States where station density is particularly low and where significant meteorological variation can occur over short distances. The first short duration precipitation-frequency estimates for the western United States were based on very limited data (U.S. Weather Bureau 1953, 1954). Later, Hershfield (1961) developed precipitation-frequency maps for the entire continental United States and used uniform ratios to relate the shorter-duration amounts to longer-duration amounts. By relating the shorter durations to a longer duration that had significantly greater station density, the detailed depiction of the spatial variation of the longer duration could effectively be incorporated into the shorter duration estimates. This approach was based on the assumption that the variation of the ratio fields was smoother than was the variation of the absolute values themselves.

Miller et al. (1973), hereafter referred to as NOAA Atlas 2, developed a technique to treat spatial variations in mountainous areas and applied it in the western United States. Miller et al. chose to adopt Hershfield's nationally averaged ratios for short durations. Frederick et al. (1977) developed isoheytal maps of short-duration precipitation-frequency amounts instead of ratios for the eastern and central United States. They limited their study to the largely nonorographic portions of the United States where meteorological variation was modest and where data density was generally highest. Finally, Frederick and Miller (1979) studied short-duration precipitation-frequency amounts in the state of California. In spite of the relatively high station density, they decided to develop regional ratios rather than maps depicting the spatial variation of the short-duration estimates because of the large meteorological variability within the state.

The present study develops short duration precipitation-frequency ratios for the 10 western states not included in either Frederick et al. (1977) or Frederick and Miller (1979): Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming. The ratios relate 5-, 10-, 15-, and 30-minute precipitation-frequency amounts to 1-hour amounts from NOAA Atlas 2. We addressed a number of problems in developing these ratios. First, the station density was lower (17,000 mi^2/station) compared to the eastern and central United States (12,000 mi^2/station) and California (600 mi^2/station). Second, the rugged topography, ranging from sea level to over 14,000 ft, imposed limitations on the data's applicability, especially since most stations tended to represent lower elevations. Third, there are wide variations in climatology within the study area.

2. THE DATA

The data used in this study are the largest annual precipitation amounts for 5-, 10-, 15-, 30- and 60-minute durations. The amounts for each duration for a given year were not necessarily from the same storm, but rather were the largest amounts for that year, regardless of date of occurrence.

The locations of the 61 stations included in this study are shown in figure 1. Of these, 55 had at least 15 years of data at all durations. Six stations had less than 15 years and were used only on a limited basis; three stations were significantly above the surrounding terrain and were used only for comparative purposes. The earliest data records go back to 1896 and the most recent data were through 1984. The average number of years with data for stations with 15 years or more of data was approximately 45 years at all durations.

Each station record was examined to see if significant changes in location and elevation occurred. Fifteen stations moved during their periods of record by more than the nominal distance and elevation cutoffs of 5 miles and 200 feet. These 15 moves were further examined with

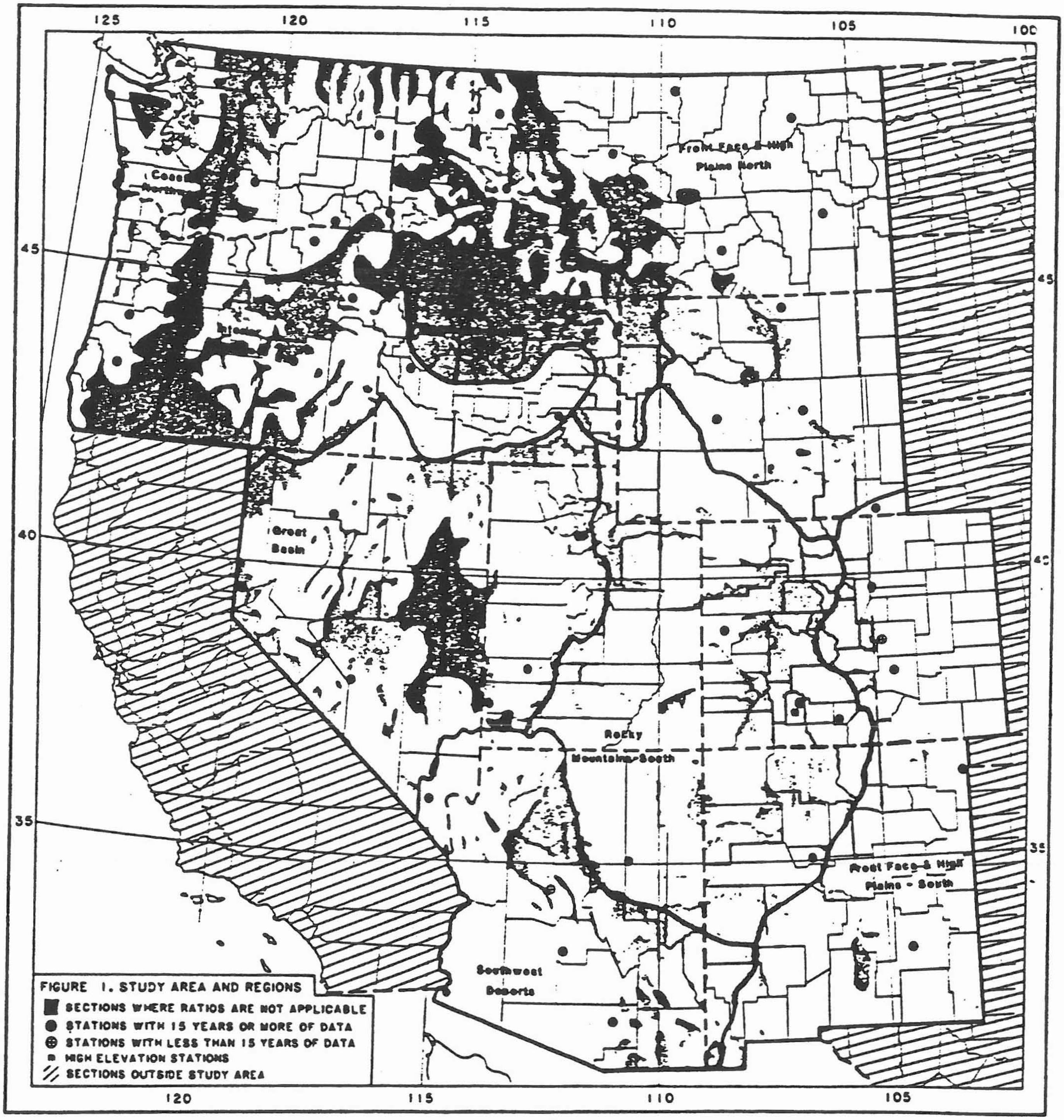


FIGURE 1. STUDY AREA AND REGIONS

respect to changes in terrain, local climatology, and urban/rural character. If, for example, a station moved 8 miles, but that move was on flat terrain with no adjacent mountains, then the relocation was probably not of climatological significance. On this basis, 7 stations made significant moves.

A detailed examination of these 7 stations revealed no consistent biases attributable to the station moves. Any possible biases were apparently smaller than the natural variability of the data themselves. Maximum short-duration amounts tended to vary more from one year to the next at most locations than did the longer duration amounts, such as 24-hour observations. In addition, no discernable biases were found that could be attributed to urban influences.

We also considered the possibility of secular trends. For example, we examined the question of whether the data from one station for the period 1900 to 1940 could be compared to the data for a second station which covered the period 1940 to 1980. Significant long-term secular trends were not evident and it was concluded that non-overlapping records were comparable.

3. PRECIPITATION-FREQUENCY STATISTICS

Frequency values were determined for all durations by fitting the data to the Fisher-Tippett Type I distribution using the Gumbel fitting technique (Gumbel 1958). Additional statistics, including skew and standard deviation, were computed for all stations. These statistics were useful as guides to understand similarities and differences in the precipitation frequencies of different stations and different regions. For example, standard deviations were larger in the southwest deserts than in the coastal northwest due to the difference between the sporadic summertime convective character of the first region and the more regular wintertime stratiform character of the second.

Ratios of 5-, 10-, 15- and 30-minute amounts to 1-hour amounts were computed for all 61 stations for the 2- and 100-year return periods. Due to the use of ratios, no correction was necessary to convert from annual to partial duration series. The next step was to average these ratios over geographic regions.

4. DETERMINATION OF REGIONS

The study area was divided into the 8 regions shown in figure 1 and listed in table 1. The determination of the number of regions involved a balance between two opposing factors. First, the regions had to be large enough to include an adequate number of stations within each to provide statistically stable results by virtue of large sample size. Second, the regions had to be small enough so that each region adequately represented a climatologically homogeneous area. The discussion below outlines how the regional boundaries were determined.

The ratios for each duration were plotted on maps for both the 2- and 100-year return periods. By plotting the ratios and finding the similarities and differences between adjoining stations, a first pass was made at determining the regions. Regional breakdowns of the western states based on climatological factors considered in previous studies were also examined. In addition, several other factors were considered. One such factor was the seasonal distribution of rainfall, ranging from the winter maximum/summer minimum in the Pacific Northwest, to the spring-summer maximum/winter minimum of the High Plains, to the less varied distribution in sections of the Intermountain Region. A second climatological factor was the seasonal distribution of thunderstorm activity, a prime producer of large short duration values. A third factor was the 6 hour and derived 1 hour patterns from NOAA Atlas 2. Other aspects of a more general nature included maximum rainfall patterns and principal paths of moisture inflow for storms producing large precipitation amounts.

We also examined the regional frequency of occurrence by month of annual maximum 1-hour amounts. For example, the maximum 3 consecutive months for 1-hour events in the Coastal Northwest is October through December, while in the Interior Northwest it is from June through August despite the fact that July and August are generally the months of lowest total rainfall. For both these regions, the proportion of the total number of annual events occurring in the most active 3-month period is lower than for other regions, being only 55 and 60 percent, respectively. This contrasts with the Rocky Mountains-South and the Southwest Deserts where upwards to 90 percent of the largest 1-hour amounts occurred during the most active 3 consecutive months, July through September.

The last significant factor in determining the regions was topography. In the general sense, topography is well correlated with the climatology discussed above and thus is not a separate factor. However, on a more detailed scale, the topography helps delineate the regional boundaries. For example, the crest of the Cascades separates the Coastal Northwest from the Interior Northwest in a well-defined fashion. Other geographic boundaries are not as well defined. There is no sharp discontinuity delineating the boundary between the northern and southern sections of the Front Face and High Plains. However, the northern boundary of the South Platte River Basin was chosen because this represents an approximate east-west division between where the Front Face of the Rocky Mountains changes from a north-south orientation in New Mexico and Colorado to a northwest-southeast orientation in Wyoming and Montana. This change in orientation influences the availability of moisture inflow to the two regions. The Front Face and High Plains could have been divided into three or more regions since the ratios gradually changed from south to north. However, the necessity of having enough stations per region to obtain stable ratios argued against this decision.

In some cases it was difficult to choose exact boundaries because a given station had statistical, climatological, and topographic similarities to two adjoining regions. Such was the case for Flagstaff, Arizona, which sits on top of a rim that separates the Southwest Deserts from the Rocky Mountains-South. Due to the greater similarity in the frequency statistics to the Southwest Deserts, it was included in that region, and the region boundary was drawn just to the north of Flagstaff.

5. REGIONAL RATIOS

Ratios were averaged over each region by weighting the individual stations by their length of record. The 2-year values were analyzed first because they were less susceptible than the 100-year values to sampling fluctuations resulting from the relatively short record lengths. The trends between regions, between durations, and between return periods were of primary interest. We attempted to minimize sampling variability by maintaining continuity and consistency in these trends.

Another consideration was comparisons with previous studies. U.S. Weather Bureau (1953, 1954) presents short-duration estimates for the western states for 3 regions: West of the Coastal Ranges, east of the Coastal Ranges and west of 115°W, and between 105° and 115°W. In both Hershfield (1961) and NOAA Atlas 2, short-duration ratios do not vary by region, but rather are based on national averages.

Table 1.—Five, 10-, 15- and 30-minute ratios for 2- and 100-year return periods

Region No.	Region	Ratios to 1 Hour: 2-Year Return Period 5 minutes	10	15	30	100-Year Return Period 5 minutes	10	15	30
1	Coastal Northwest	.30	.45	.56	.73	.36	.53	.64	.82
2	Interior Northwest	.35	.53	.64	.81	.37	.56	.67	.85
3	Rocky Mountains-North	.38	.57	.68	.84	.35	.55	.67	.84
4	Front Face and High Plains-North	.39	.58	.69	.85	.37	.56	.69	.87
5	Great Basin	.34	.51	.61	.81	.34	.52	.63	.84
6	Rocky Mountains-South	.35	.54	.65	.83	.32	.50	.62	.81
7	Front Face and High Plains-South	.33	.51	.62	.83	.29	.46	.59	.81
8	Southwest Deserts	.34	.51	.62	.82	.30	.46	.59	.80

The final consideration was comparability to information for locations adjacent to the study area. Taking such information into account accomplished two goals. First, it contributed to the degree of consistency and continuity between this study and other reports. Second, it provided additional insight into the variation of the ratios in this report, providing anchors, so to speak, at the study area boundaries. For areas east of the study region, we compared our results to Frederick et al. (1977) and for California we related our results to Frederick and Miller (1979). In addition, we developed frequency estimates for several stations with short-duration data in surrounding states. Fourteen stations were analyzed for this purpose, 10 in the Plains States and 4 in California. Most of these stations were close enough to be directly comparable to adjacent stations within the study area, while a few were chosen at greater distances from the boundaries to provide some idea of the trend in ratios leading up to the study area.

It was concluded that the ratios in this report were consistent with previous studies. The final ratios are listed in Table 1. A comparison between these ratios and those from NOAA Atlas 2 and Weather Bureau (1953, 1954) is shown in Table 2.

Table 2.—Ratios compared to other reports

Dur. (min)	Ratio to 1 Hour: This Report*	NOAA Atlas 2	Weather Bur. (1953, 1954)*
5	.34	.29	.32
10	.52	.45	.49
15	.64	.57	.59
30	.82	.79	.78

*Averaged over all regions and for all return periods

Note: Comparisons are for illustrative purposes only. Each report covers a different geographic area, and averaging is done without regard to size of region or specific return periods involved.

6. APPLICATION OF RATIOS

The ratios derived in the above analysis are based on stations whose elevations tended to be in the lower sections of each region. To extrapolate these statistics to much higher elevations would be a questionable undertaking, because of the complex effects of slope, funneling, and rain shadows that often occur in these areas. As such, the ratios are not applicable to all elevations within each region, but rather to a general range of elevations. The ranges of applicable elevation, approximately 3,000 to 3,500 ft in most areas, are summarized in table 3. In a few cases, areas are excluded that contain stations included in the analysis. The regional ratios were reviewed in light of this fact, and it was determined that no adjustments were necessary.

Areas of non-applicability, based on elevation and location considerations, are shown in figure 1 as shaded areas. These areas are based primarily on smoothed contour maps of the western states. Due to the generalized nature of the contours, there are isolated sections, primarily at the edge of shaded areas, where the ratios might be applicable. Conversely, there are isolated peaks and high elevations which are not shown as part of any shaded areas, but which may, in fact, be non-applicable areas.

Table 3.—Applicable elevations within regions

Region No.	Generally Applicable elevations (ft)
1	0-2500
2	50-3000 Columbia Basin to 2500-5500 SE
3	2000-5000 N to 4000-7000 S
4	2000-5000 N to 4000-7000 S
5	3500-7000
6	4500-8000 N to 3500-7000 S
7	4000-7500 N to 3500-7000 S
8	3000-6500 mountains to 100-3500 deserts

As discussed in section 5, ratios do not necessarily change abruptly at all regional boundaries, such as is the case along the crest of the Cascades. Probably the most gradual change is between the two halves of the Front Face and High Plains. Most other regional boundaries are better defined by local topography and climatology. Ratios for locations close to most boundaries are probably best estimated by taking into account neighboring ratios to some extent.

In many cases, it might be desirable to find values for a return periods between 2 and 100 years, or for durations different than those given in this report. To do this it is first necessary to compute the absolute values for the standard durations and return periods for the location in question. This can be done using the ratios in this report and 1-hour values determined from NOAA Atlas 2 in conjunction with the two graphs shown in figures 2 and 3. Figure 2, a probability grid based on the Fisher-Tippett distribution, is used to interpolate return periods. Figure 3, a standard semi-log scale, is used to interpolate durations.

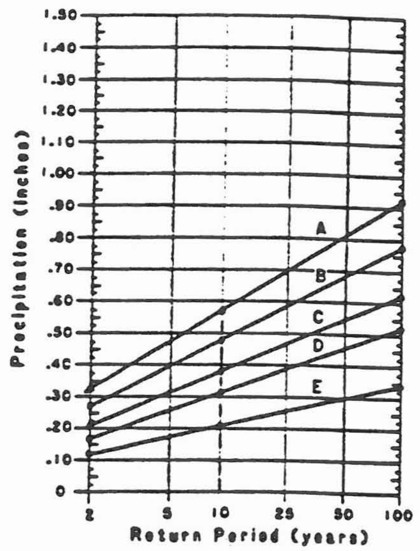


Figure 2.—Example of return period interpolation.

Three examples are given below to illustrate the interpolation procedures. The first is for return period, the second for duration, and the third for both return period and duration. The location chosen is Twin Falls, Idaho, and the source used to determine the 1-hour values is NOAA Atlas 2 (the 1-hour values were derived from the 6-hour maps using the appropriate regression equations). The 2- and 100-year 1-hour values are 0.33 and 0.92 inches. Using the ratios in this report from the Interior Northwest, the 2-year return period values for 5, 10, 15 and 30 minutes are 0.12, 0.17, 0.21. and 0.27 inches, and the 100-year return period values are 0.34, 0.52, 0.62 and 0.78 inches.

In the first example, the 10-year return period is found for the 15-minute duration. The 2- and 100-year return period values of 0.21 and 0.62 inches are plotted in figure 2 (line C), and the 10-year value of 0.38 is read off the Y-axis. In the second example, the 20-minute duration is found for the 2-year return period. The 5-, 10-, 15- and 30-minute, and 1-hour values of 0.12, 0.17, 0.21, 0.27 and 0.33 inches are plotted in figure 3 (line A) and a best fit curve, which can usually be approximated with a straight line, is drawn through these points. The 20-minute value of 0.24 inches is then read off the Y-axis. In the third example, the 20-minute duration is found for the 10-year return period. First, the 10-year values for the standard durations are found in figure 2 (lines A through E), the results being 0.21, 0.31, 0.38, 0.48 and 0.57 inches. These five durations are then plotted figure 3 (line B), to obtain a 20-minute value of 0.42 inches.

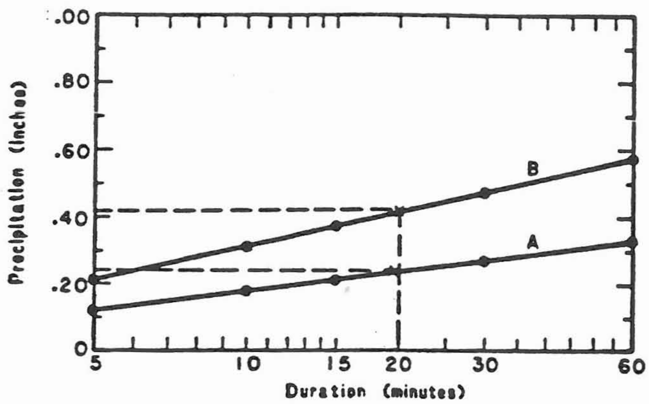


Figure 3.—Example of duration interpolation.

7. DISCUSSION OF RESULTS

The relatively high ratios encountered throughout the 10 states examined in this study, as compared to the remainder of the country, result from differences in the precipitation climatology. In all regions except the Coastal Northwest, the continental regime, including the lack of available moisture in the lee of mountain barriers, is a significant factor. The result is high short duration rainfall rates which are difficult to maintain for periods as long as 1 hour, thus causing relatively high ratios. Almost all of these events occur in late spring and summer thunderstorms that are not associated with the larger storm systems more typical of winter. Within a given region, all durations between 5 minutes and 1 hour display approximately the same seasonality.

Even the Coastal Northwest has relatively high ratios when compared to coastal California, although the mechanisms here are different. The northern coast receives considerably more rain on an annual basis than does the southern coast. Much of this rain is of a non-convective nature with steady rain over periods of several hours, as opposed to convective events on the on the order of an hour, somewhat more typical of the southern coast. Therefore, 1-hour amounts tend to be slightly lower in the north. On the other hand, maximum short-duration rates for 5- to

30-minute periods show less variation from north to south. The combination of comparable 5- to 30-minute rates with generally lower hourly rates produces somewhat higher ratios in the north. Maximum short-duration values along the northern coast occur most often in the fall and early winter at all durations, and often result from convective shower and thunderstorm activity embedded in or associated with synoptic scale storm systems. However, isolated summer thunderstorms occasionally produce significant events.

The climate of the western states is controlled primarily by two features, and these in turn affect the climatology of short-duration events. First is the semi-permanent high pressure system that sits off the California Coast, moving south in winter and north in summer. This system affects the westernmost part of the study area most directly, producing a pattern of wet winters and dry summers. This is true both to the west and east of the Cascades, although annual rainfall is considerably less to the east due to the sheltering effect of the mountains. The second feature, dominating the eastern part of the study area, is moisture from the Gulf of Mexico, which produces an almost opposite seasonal trend of wet springs and summers and relatively drier winters. In the spring, the Atlantic sub-tropical high pressure system extends westward into the Gulf and sets up a southerly flow of moist air into the high plains and eastern Rockies which is generally maintained through the summer. The climate of the southwest deserts is affected to some degree by both of these features. The Gulf of Mexico influence contributes to a summer maximum in precipitation and the Pacific influence causes a secondary winter maximum.

The eastern half of the study area tends to have the largest short-duration amounts in terms of absolute values. This is due to the inflow of Gulf moisture occurring during the warm season, which is the time of maximum convective potential, combined with the continental regime which favors short-duration convection.

Ratios in the study area tend to increase from west to east in the north, from the Coastal Northwest to the Front Face and High Plains-North. They increase from south to north in the two Front Face and High Plains regions. They also tend to increase in a southeast to northwest direction from the Front Face and High Plains-South to the Interior Northwest and Rocky Mountains-North. Looking outside the study area, ratios increase from California northward into the Coastal Northwest, and increase westward from the plains into the two Front Face and High Plains Regions. Climatically, the trends reflect the increasingly continental regime and decreasing availability of moisture moving east away from the Pacific Ocean and north and west away from the Gulf of Mexico. As a result of these trends, the highest ratios are generally found in the Front Face and High Plains-North and the lowest ratios in the Coastal Northwest and also the Front Face and High Plains-South and Southwest Deserts.

8. SUMMARY

A series of 64 ratios were developed for ten western states to be used in conjunction with 1-hour values from NOAA Atlas 2. With these ratios, precipitation-frequency estimates can be determined for 5-, 10-, 15-, and 30-minute durations for return periods of 2 and 100 years in each of eight regions. Some areas within each region were excluded due to elevation and exposure considerations.

The results show ratios that are generally higher than in most other sections of the country. These differences are well explained by climatological factors. Although these results appear meteorologically consistent, caution must be exercised when using them because of the small size of the data sample and the meteorological complexity of the study area.

9. ACKNOWLEDGEMENTS

Funding for this work was provided by the U.S. Department of Agriculture, Soil Conservation Service, as part of their watershed protection and flood prevention program. Liason with the sponsoring agency was maintained with Robert Rallison and Norman Miller.

We also want to thank Helen Rodgers for editorial work and layout of the paper, and Roxanne Johnson for preparation of the figures.

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APPENDIX 1-G

Uniform Drainage Policies and Standards for Maricopa County, Arizona, Resolution FCD 87-7, Flood Control District of Maricopa County, April 20, 1987.

UNIFORM DRAINAGE POLICIES AND STANDARDS

for

MARICOPA COUNTY, ARIZONA

February 25, 1987

Approved by the Maricopa County Board of Supervisors and
Flood Control District Board of Directors
April 20, 1987
Resolution FCD 87-7

Flood Control District of Maricopa County
3335 W. Durango St.
Phoenix, AZ 85012
602/262-1501

RESOLUTION FCD 87-7

UNIFORM DRAINAGE POLICIES AND STANDARDS FOR
MARICOPA COUNTY

WHEREAS, the incorporated municipalities and Maricopa County now have widely differing requirements for handling of stormwater drainage by developers; and

WHEREAS, many communities, agencies, and organizations recognize the need to apply uniform drainage policies, standards, and procedures throughout incorporated and unincorporated areas of Maricopa County, and a Task Force on Uniform Drainage Standards was formed consisting of the municipalities of Tempe, Phoenix, Wickenburg, Mesa, Glendale, and Scottsdale, the Maricopa Association of Governments, Homebuilders Association of Central Arizona, Salt River Project, Arizona Consulting Engineers Association, and the Flood Control District, with the municipalities of Chandler, Gilbert, Goodyear, Peoria, and Tolleson maintaining regular contact with the Task Force; and

WHEREAS, the municipalities that participated in the Task Force are prepared to adopt these policies and standards as part of their regulatory structures because they recognize that these policies and standards will result in consistency of analysis of drainage requirements, less staff time and cost in annexing County areas, and residents will be afforded equal and common protection from the hazards of stormwater drainage; and

WHEREAS, developers will find it advantageous to have only one set of drainage standards with which they must comply in developing lands within the incorporated or unincorporated areas of Maricopa County; and

WHEREAS, On September 12, 1983, the Board of Supervisors of Maricopa County and the Board of Directors of the Flood Control District entered into an Intergovernmental Agreement whereby the Flood Control District, through its Chief Engineer and General Manager, assumed all drainage administrative and enforcement responsibilities as enumerated by the Subdivision Regulations and Zoning Ordinance for the Unincorporated Area of Maricopa County, and whereby the District was to develop and recommend to the Board for adoption, a comprehensive Drainage Regulation for the Unincorporated Area of Maricopa County; and

WHEREAS, adoption of policies is a necessary step in the development and adoption of a comprehensive Drainage Regulation; and

WHEREAS, the Flood Control Advisory Board, at its February 1987 meeting, recommended adoption by the Board of Supervisors, the Board of Directors, and the communities of Maricopa County; and

NOW, THEREFORE, BE IT RESOLVED that the Board of Supervisors of Maricopa County and the Board of Directors of the Flood Control District hereby approve the Uniform Drainage Policies and Standards for Maricopa County, Arizona, as a policy framework for the preparation of a comprehensive Drainage Regulation.

Chairman, Board of Supervisors
Maricopa County

Chairman, Board of Directors
Flood Control District of Maricopa County

ATTEST:

Clerk of the Board

ACKNOWLEDGEMENTS

This document is the culmination of one and a half years of intense interagency cooperation through the Task Force on Uniform Drainage Standards. It constitutes the most complete multijurisdictional recognition to date of the need to uniformize drainage policies, standards, and procedures throughout Maricopa County.

The following individuals represented agencies and other organizations participating actively in this effort:

Kebba Buckley, Flood Control District of Maricopa County

Tom Ankeny, City of Tempe

John Baldwin, City of Phoenix

Lindy Bauer, Maricopa Association of Governments

Dave Bixler, Homebuilders Association of Central Arizona

Skip Blunt, Town of Wickenburg

Joe Kissel, Salt River Project

Collis Lovely, Arizona Consulting Engineers Association

Keith Nath, City of Mesa

Doug Plasencia, Flood Control District of Maricopa County

Ken Reedy, City of Glendale

Dick Schaner, City of Scottsdale

In addition to the regular Task Force members, several communities maintained regular contact with our efforts and contributed data and other assistance. These were Chandler, Gilbert, Goodyear, Peoria, and Tolleson.

Special recognition and thanks go to Ken Lewis of Boyle Engineering Corporation, who authored the first nine drafts of this document under contract to the Flood Control District. Mr. Lewis also played a key role in facilitating the discussions for the Task Force meetings in the first five months of the writing process. After the close of the Boyle Engineering Corporation contract, he still continued as an active and valued member of the Task Force.

Ms. Kebba Buckley, of the Flood Control District of Maricopa County, served as Project Manager for the Boyle Engineering Corporation contract and as overall facilitator for the Task Force and the Phase I process.

Table of Contents

1.0 INTRODUCTION

The governmental agencies of Maricopa County seek to establish a common basis for drainage management in all jurisdictions within Maricopa County. The Flood Control District of Maricopa County, in April 1985, invited all interested entities to a meeting to establish an agreement in principle. At that meeting, a Task Force was formed to guide the effort.

The Task Force determined that the effort should be in three phases:

Phase 1 Research, evaluate, develop and produce uniform policies and standards for drainage of new development within Maricopa County.

Phase 2 Establish a Stormwater Drainage Design Manual for use by all jurisdictional agencies within the County.

Phase 3 Prepare an in-depth evaluation of regional rainfall data and establish precipitation design rainfall guidelines and isohyetal maps for Maricopa County.

The Task Force spent two months writing a scope of work for a consultant to use as a basis for Phase 1, the establishment of a draft uniform policies and standards document. In July, 1985, the Flood Control District, on behalf of the interested agencies, contracted to Boyle Engineering Corporation for this Phase. Boyle interviewed most of the jurisdictions within the County and some in other areas of the country, wrote the first drafts of the Phase 1 document, and collated and integrated commentary from diverse sources for each draft. Boyle, specifically Mr. Ken Lewis, served as facilitator for the Task Force's discussions of the developing document during 1985.

This document is the culmination of the work of the Task Force for Phase 1. The adoption of these Drainage Policies and Standards by all agencies involved in drainage management will result in a common standard of drainage design across the County and will reduce the time and effort by both designers and government review staff for submitted drainage proposals and designs.

2.0 POLICIES

The following policies express the approach to drainage management of the jurisdictional agencies (AGENCIES) in Maricopa County.

1. The AGENCIES, through the Flood Control District of Maricopa County (DISTRICT), shall establish and publish criteria for drainage planning and design. Guidance relative to construction, operation and maintenance of drainage systems shall also be provided. The AGENCIES shall adopt criteria relevant to all public and private drainage interests. Such criteria shall be periodically reviewed and revised in the light of new knowledge, changing circumstances, and adjustments in overall comprehensive goals and objectives. Until the publication of the stormwater drainage design manual (DESIGN MANUAL), Chapter 4 of this document, "Basis of Design", sections 4.0 through 4.5.4, shall be utilized as a basis for design guidance, criteria, and standards.

2. Drainage planning shall involve concerned publics.

3. Master drainage planning for developments shall be carried out in the earliest stages of the planning process. The proposed methods of managing drainage and associated land use shall be reviewed by the AGENCY early in the process.

4. Drainage planning and design shall be based on the principle of not increasing or transferring detrimental drainage effects to other areas.

5. Basinwide master drainage planning by the AGENCIES is necessary, has started and shall be continued. The plans are being prepared on a priority basis and shall be continued subject to need and available financing.

6. Basinwide master drainage plans shall be periodically reviewed and revised in the light of new knowledge, changing circumstances, and adjustments in comprehensive planning goals and objectives. Unless otherwise determined, such reviews shall be at intervals of about 5 years.

7. The cooperation of the AGENCIES and other affected entities, including the land development industry, shall be sought to coordinate individual development and drainage schemes with the basinwide plans. To facilitate the cooperation of the AGENCIES and other affected entities, each agency shall submit to the District one copy of each draft and final drainage report it receives for any development larger than 160 acres. The DISTRICT shall catalogue and file the reports for library use by those with relevant drainage interests.

8. Drainage planning is for the purpose of minimizing inconvenience and reducing flood damage and potential loss of life. The benefits of this planning reduce overall public and private costs, including the long and short

term costs of new housing, while providing a drainage infrastructure that will account for the implementation of long-term development goals.

9. Uniform drainage policies and standards are intended to improve processing of development requests and equitable application of regulations.

10. Development and basinwide master drainage plans shall include a full range of preventive and corrective approaches, including the following:

-- Maintaining the integrity of existing drainage patterns,

-- Establishment of selected major drainage routes by the use of purchase, dedication, development rights, and easements;

-- Storage and attenuation of stormwater runoff; and

-- Construction of drainage works.

The combination of strategies shall balance engineering, economic, environmental, and social factors in relationship to stated comprehensive planning goals and objectives.

11. Multiple use of drainage works is encouraged, provided the use does not adversely impact the functional design of the system.

12. In accordance with priorities and fiscal capabilities, the AGENCIES shall develop and implement corrective drainage plans which shall mitigate existing drainage problems. Such plans shall be coordinated with comprehensive planning goals and objectives, and shall consider a combination of structural and nonstructural measures. The level of protection shall be determined on the basis of economic analyses, availability of funds and physical constraints.

13. Water conservation will be considered as an adjunct to drainage planning where feasible.

3.0 PLANNING

Drainage planning helps to achieve orderly, efficient, pleasant and diverse development of a community or group of communities. Accomplishment of the comprehensive goals and objectives can be assisted by a broad drainage planning process. Such a process should be considered within the context of the total environmental system and should be compatible with comprehensive regional plans.

The design team should think in terms of natural drainage paths and street drainage patterns and should coordinate its efforts with its drainage engineers and the drainage engineers of the AGENCIES. Drainage measures are costly when planning is poor or mediocre, whereas good planning results in lower cost drainage facilities.

It is vitally important that planning precede development for the following reasons: to ensure drainage problems are not transferred from one location to another, multiple use opportunities are not lost, and the cost for overall drainage facilities are kept to a minimum. This is best accomplished with comprehensive master drainage plans.

3.1 MASTER PLANNING

A master drainage plan describes in detail the recommended plan for drainage and the course of action for implementation in terms of priorities. It shows sizes, types and location of drainage facilities on maps in sufficient detail to allow for planning new development.

Each AGENCY in Maricopa County shall be responsible for master planning stormwater drainage facilities in its jurisdiction. Cooperation among governmental units is desirable, including joint efforts between AGENCIES and the DISTRICT. Any master planning effort shall include consultation with those entities potentially affected by such planning.

Detailed master drainage plans for various designated areas within Maricopa County are in process by both the DISTRICT and individual cities and towns. A number of these are cooperative projects of two or more AGENCIES together with the DISTRICT and one or more other sponsors. These plans are primarily focused on areas of rapid development and areas with existing stormwater problems.

3.2 TRANSFER OF ADVERSE IMPACTS

Planning and design of stormwater drainage systems shall include consideration of impacts on upstream and downstream properties and/or existing drainage systems. Adverse impacts shall be eliminated wherever possible. Any unavoidable adverse impacts shall be mitigated in coordination with affected property owners and/or AGENCIES. Specifically, the diversion of storm runoff from one drainage area to another introduces significant legal and social problems and shall be avoided unless specific reasons justify such a transfer and the affected jurisdictions agree on the transfer.

3.3 IRRIGATION FACILITIES

Irrigation facilities shall not be utilized for conveyance of stormwater drainage without the prior approval of the owner or operator of such facilities. Such approval shall be required whether or not such facilities are currently used to transport water for irrigation purposes. Any approval shall specify the discharge rate permitted, the location of facilities into which the discharge is permitted, and the length of time such a discharge shall be permitted.

3.4 DRAINAGE REPORTS

When a drainage report is required, it must be prepared in accordance with the AGENCY's requirements and sealed by a civil engineer registered as a professional engineer in the State of Arizona. Drainage reports are required for the following reasons: to analyze the effect that a proposed development would have on the runoff in the vicinity of the development; to provide data to insure that the development is protected from flooding; and to provide data supporting the design of facilities to be constructed for the management of runoff.

At this time, the AGENCIES have varying requirements for whether a drainage report is required and at what point in the planning and review process. **This will be covered in the DESIGN MANUAL by a table which will list the AGENCIES and their specific requirements.**

4.0 BASIS OF DESIGN

Until the publication of the DESIGN MANUAL, this chapter, comprised of sections 4.0 through 4.5.4, is to be utilized as a basis for design guidance and criteria.

4.1 DRAIN CLASSIFICATION

The following classification of drains into minor, major and regional drains is presented as an aid for system analysis:

Minor drains serve watershed areas up to 160 acres and are normally the drains associated with subdivision development.

Major drains include natural and man-made channels, conduits and washes, and serve watershed areas from 160 acres to about 10 square miles. .

Regional drains are the main outfalls for drainage. They serve watershed areas generally greater than 10 square miles, and include rivers and washes.

4.2 HYDROLOGIC ANALYSIS

Hydrologic procedures for general application in Maricopa County shall:

-- Provide reliable and consistent results;

-- Be capable of estimating peak discharges for various return periods and degrees of urban development;

-- Produce a hydrograph corresponding to the peak discharge;

-- Utilize input data which is readily available;

-- Be workable for main frame, microcomputer and hand calculations.

For Maricopa County two procedures shall be developed: one for areas less than 160 acres and one for areas greater than 160 acres. The primary differences between the two are ease of use and range of applicability. The specific input parameters required for each procedure shall be established and published in the Design Criteria Manual and shall be periodically updated as required.

For drainage areas less than 160 acres the Rational Method shall be used. This method is the simplest and most widely used procedure for small urban basins.

For drainage areas greater than 160 acres, the SCS dimensionless unit hydrograph procedure shall be used at this time. A new procedure, to be called the Maricopa County Urban Hydrograph Procedure (MCUHP), shall be developed for this area. The procedure shall be described in the DESIGN MANUAL. In the interim, excess rainfall shall be computed using the SCS curve number method; runoff shall be determined by the SCS dimensionless unit hydrograph method, and the resultant hydrographs routed, where necessary, by such methods as those available in SCS TR-20/TR-55 or in HEC-1.

The peak discharges determined by either of the methods are approximations. Emphasis should be placed on the design of practical and hydraulically balanced works based on sound logic and engineering, as well as on dependable hydrology.

4.3 HYDRAULIC ANALYSIS

4.3.1 Storm Sewers

Manning's formula is to be used for calculating the capacity of continous stormwater drains, with appropriate allowances for headloss at inlets, bends, junctions and manholes. Manning's "n" factors and minor energy loss coefficients shall be published in the DESIGN MANUAL. The maximum capacity for circular sections under open channel flow conditions is not to exceed full flow conditions. Uniform flow assumptions may be used in calculating the capacities of minor drains. For major drains, or where a higher degree of accuracy is required, backwater or drawdown curves should be calculated using the Standard Step method. Pressure and momentum theory may be used at bends, junctions, and manholes.

For systems flowing under pressure, the maximum pressure allowed must consider the structural limitations of both the pipe and joint. The hydraulic grade line must be maintained below ground level unless special consideration is taken to prevent water from escaping from sewers or to handle it once it does escape. Whether the system is under pressure or in open channel flow conditions, the hydraulic controls are to be clearly indicated.

4.3.2 OPEN CHANNELS

Open channels have advantages in cost, capacity, multiple use for recreational and aesthetic purposes, and potential for detention storage. However, disadvantages exist in right-of-way needs, maintenance costs and hazards to traffic and pedestrians. Careful planning and design are needed to minimize the disadvantages and to maximize the benefits.

Natural channels have velocities that are usually low, resulting in longer concentration times, increased storage and generally lower downstream peaks. If flows in natural channels are increased, consideration must be given to maintaining their stability. Channels in hillside development areas are to be be retained in their natural state unless otherwise approved by the AGENCY.

If right-of-way is limited, requiring velocities higher than allowable for the existing channel to convey the design discharges, then channel lining is required to prevent scour. The choice of lining is subject to allowable velocities, costs and aesthetics. Man made channel alignments for drains are to coincide with the natural watercourse locations, except as approved by the AGENCY. They are to discharge runoff as nearly as possible in the location and with approximately the same velocities as existed prior to construction. If diversion within a proposed development is required, sufficient work is to be done upstream and/or downstream of the diversion to provide affected properties at least the same level of flood protection as existed prior to the diversion.

Open channels adjacent to public streets are discouraged and require approval from the AGENCY. When it is necessary to locate a channel adjacent to a street, it will be placed a reasonable distance from traffic.

Open channels should maintain subcritical flow conditions wherever possible. Any channel that is not designed for subcritical conditions shall require approval from the AGENCY. Open channels should be designed to allow interception of surface flows. If it is unavoidable to construct the channel without creating a barrier to surface flow, a means of draining must be indicated. In preliminary layouts of the routing of proposed channels, it is desirable to avoid sharp curves. If this is unavoidable, design considerations are to include the reduction of superelevations and the elimination of initial and compounded wave disturbances.

Manning's formula is to be used for uniform flow computations in open channels. Water surface profile calculations are to be calculated using the Standard Step method and confluences and bridge piers are to be analyzed using pressure and momentum theory.

Unlined channels should have side slopes of 3 (horizontal) to 1 (vertical) or flatter. A minimum Manning's "n", applicable for the channel under design, is to be used for checking sections susceptible to scour, and the normal or maximum value used for determining the required cross section. Where the channel roughness changes significantly with depth, a composite Manning's "n" is to be used.

4.4 STREETS

Design standards for the collection and conveying of runoff on public streets is based on an acceptable frequency of traffic interference.

Street drainage shall be governed by Table 1, as illustrated in Figure 1.

Table 1. Design Storm Frequencies for Street Drainage (Years)**

	Frequency
A. LONGITUDINAL STREET FLOW	
No curb overtopping. *	10
Flow to be calculated assuming contained in ROW with: . 0.3 feet maximum depth over curb * . 100 cfs maximum flow . 10 fps maximum velocity	50
B. CROSS STREET FLOW (bridges, culverts, and dip sections)	
No flow across street	50
0.5 feet depth at crown or in valley gutter *	100

* Where no curb exists, maximum depth to be 0.5 feet over crown.
** No new inverted crown streets.

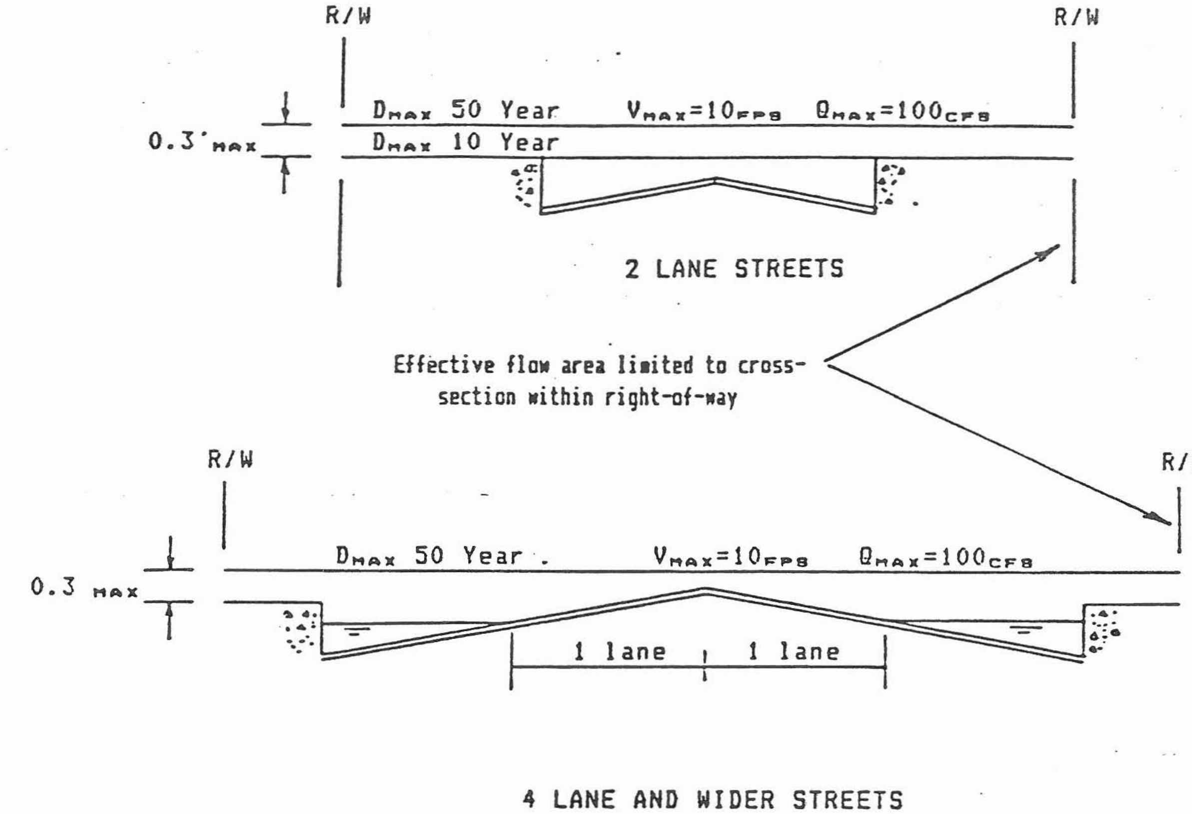

FIGURE 1A LONGITUDINAL STREET FLOW

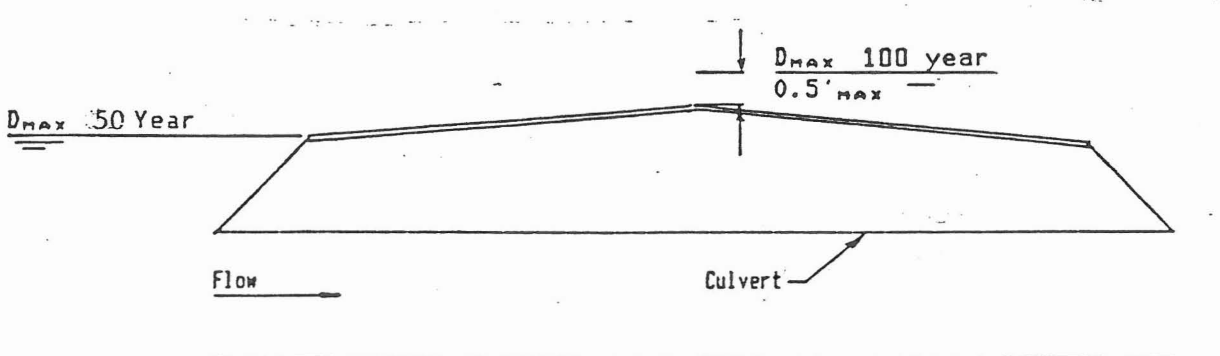

FIGURE 1B CROSS STREET FLOW

LEGEND

D -- Depth of Flow (feet)
V -- Velocity of Flow (feet per second)
Q -- Flowrate (cubic feet per second)

Regardless of the size of the culvert or bridge, street crossings are to be designed to convey the 100-year storm runoff under and/or over the road to an area downstream of the crossing to which the flow would have gone in the absence of the street crossing. In no instance shall flows up to or including 100-year frequencies cause inundation of the lowest finished floors.

For flows crossing broad shallow washes where the construction of a culvert is not practical or desirable, the road should be dipped to allow the entire flow to cross the road. The pavement through the dip section should have a one way slope and curbing and medians must not be raised. For these situations approval shall be obtained from the AGENCY.

4.5 STORAGE FACILITIES

4.5.1 Requirements for Storage

To reduce the significant cost of handling stormwater runoff and to control increased peaks and volumes from development areas, all development shall make provisions to retain the peak flow and volume of runoff from rainfall events up to and including the 100- year 2-hour duration storm falling within the boundaries of the proposed development. The 100-year 2-hour rainfall event shall be established using DISTRICT procedures.

The development shall be considered to extend to the centerline of all existing and/or future streets on the exterior boundaries, and shall include all property within the development. In some areas it may be required to retain runoff generated from adjacent arterial streets. These areas shall be designated by the AGENCY during the preliminary planning stages.

Offsite flows may not be routed through the storage facilities unless approved by the AGENCY.

Storage facilities are to be located so they can intercept the flow from the entire development area. If portions of the area cannot drain to a primary storage facility, then additional facilities are to be added for these areas as approved by the appropriate AGENCY. Wherever possible, the facilities shall be located in parks or other recreational facilities to offset the cost of open space and to encourage improved maintenance.

4.5.2 Conditions When Storage May Be Waived

If the downstream drainage system is adequate for future conditions, storage requirements may be waived by the AGENCY under the following circumstances:

1. The runoff has been included in a storage facility at another location:

2. The runoff can be directly carried to a regional drain:

3. Development of an existing parcel under one-half acre in an area where it can be demonstrated that no significant increase in the potential for flood damage shall be created by the development of that parcel.

If onsite storage is waived, the development may be required to contribute to the cost of drainage works on the basis of runoff contribution.

4.5.3 Method of Storage

Common storage facilities shall be used in preference to individual lot storage wherever possible. Common storage provided for two or more mutually adjoining properties is encouraged, subject to review by the AGENCY(IES). Such arrangements can significantly reduce maintenance costs and increase the potential for multiple uses of the facility.

Residential developments shall have no single lot storage unless approved by the AGENCY, and the design of common facilities shall not assume any individual lot onsite storage, unless approved by the AGENCY. Developments with Homeowners Associations shall locate their facilities in private drainage tracts or public sites dedicated by the developer, in accordance with requirements determined by the AGENCY. The private facilities shall be maintained by the Homeowners Association. Public tracts shall be maintained by the AGENCY. Common storage facilities from single family developments without a Homeowners Association and with public streets shall have maintenance determined by the AGENCY. The number and location of storage facilities within a development is to be approved by the AGENCY. Dedication to the public may require the inclusion of recreational facilities or other features deemed necessary by the AGENCY.

Non-Residential Developments that are not included in a public storage facility, shall provide the required storage on the lot itself without depressing the right-of-way area. Asphalt parking areas, landscape areas and underground tanks may be used for storage purposes.

4.5.4 Drainage of Storage Facilities

Storage facilities are to be drained within a period of 36 hours by either controlled bleed-off, discharge pump, infiltration or dry well.

Controlled bleed-off or pumping is the preferred method and may be required if the AGENCY considers a public nuisance would be created by surface spreading or dry wells. Responsibility for maintenance and operation of the bleed-off and/or pumping system shall be determined by the AGENCY.

Dry wells may be used with the approval of the AGENCY. The maximum disposal rate is not to exceed 0.1 cfs per well unless supported by a detailed certified soils report. Should the soils report indicate a higher rate, a conservative value of 50% of the higher rate (not to exceed 0.5 cfs) shall be used to compensate for deterioration over time. Dry wells that cease to drain a project area in a 36-hour period shall be replaced by the maintenance authority with new ones, unless an alternate method of drainage becomes available.

APPENDIX A

DEFINITIONS

AGENCY	The governmental authority in whose jurisdiction an aspect of the drainage system is regulated.
Channel	A natural or artificial watercourse with definite bed and banks for conducting flowing water.
Detention System	A system which delays runoff in a controlled manner through the combined use of temporary storage facilities and an open outlet. The duration of downstream runoff is increased and the flow peak immediately downstream is reduced.
DISTRICT	The Flood Control District of Maricopa County.
Drainage Basin	The contributing area to a single point of drainage concentration. Also called catchment area, watershed, or river basin.
Dry Well	A shaft or hole, covered and designed to allow the percolation of drainage water into the ground.
Irrigation Facilities	Channels, pipes, canals, hydraulic structures, and any other facilities through which irrigation water flows.
Outfall	The point, location or structure where drainage discharges from a channel, conduit or drain.
Retention System	A system which retains runoff in a controlled manner through the use of storage facilities. Stored water is either evacuated by percolation or released to the downstream drainage system after the storm event.
Storage Facilities	Reservoir, tank, pipes or other space for either the detention or retention of drainage.

APPENDIX B

REFERENCES

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APPENDIX 1-H

U.S. Corps of Engineers reports on the August 19, 1954, Queen Creek Storm.

CORPS OF ENGINEERS, U. S. ARMY

LOS ANGELES DISTRICT

REPORT ON FLOOD OF 19 AUGUST 1954

QUEEN CREEK AND VICINITY, ARIZONA

24 SEPTEMBER 1954

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
LOS ANGELES DISTRICT
751 SOUTH FIGUEROA STREET
LOS ANGELES 17, CALIFORNIA

24 September 1954

REPORT ON FLOOD OF 19 AUGUST 1954
QUEEN CREEK AND VICINITY, ARIZONA

AUTHORITY

1. This report is submitted pursuant to instructions in subparagraphs 4223.05 b and d, Chapter IV, Operations, Part II, Civil Works, Orders and Regulations, Corps of Engineers, U. S. Army.

GENERAL

2. This report describes the storm, flood, and flood damages that occurred 19 August 1954 in the Queen Creek Basin and the Superstition Mountain area. Also included is a description of the relatively minor storm and flood of 20 August 1954 in the same general area. Queen Creek is a tributary of the Gila River.

DESCRIPTION

3. Location and extent.--The Queen Creek drainage area and the Superstition Mountain area lie east of the confluence of the Salt and Gila Rivers and extend roughly from Superior, Arizona to Chandler, Arizona. The combined area of the drainages is approximately 880 square miles including irrigated agricultural lands in the lower portion of the basins.

4. Queen Creek Basin is composed of a drainage area of about 426 square miles. The basin is bounded on the east by the Pinal Mountains. On the south, a poorly defined ridge in the area due east of Santan Mountain separates the Queen Creek drainage area from that of the Gila River. Adjacent to and north and west of the basin is what is known locally as the Superstition Mountain area. The Superstition Mountain area, which is composed of a series of independent washes, is bounded on the north by the Superstition Mountains. These

drainages are independent of each other in the mountains and foothills, but during periods of high runoff some of the flows intermingle on the desert plain in the vicinity of the Roosevelt Water Conservation District canal.

5. Economy.--The area of principal flood damage consists of irrigated farmland in and adjacent to the Queen Creek Irrigation District, Roosevelt Water Conservation District, and the Salt River Project. Cotton is the leading crop in this area. Next in importance are alfalfa and feed grains. The towns of Gilbert, Higley, and Queen Creek and Williams Air Force Base are located in the area.

STORM AND FLOOD

6. The headwaters of Queen Creek originate in the Pinal Mountains at elevations varying from 4,000 to about 5,500 feet. The elevation of the streambed at the Whitlow Ranch dam site is about 2,050 feet. Several of the headwater streams have gradients in excess of 1,000 feet per mile. Streambeds throughout the foothills and plains generally have streambed gradients less than 100 feet per mile. The heavy rains of the storm of 19 August 1954 centered over the mountains and foothills and covered the upper Queen Creek drainage area. Heavy rains were reported in the Superstition Mountain area. Very light sprinkles to zero precipitation were reported in the plains area west and south of the Superstition and Pinal Mountains. On 20 August 1954 moderate amounts of rain were reported in the vicinity of Apache Junction in the Superstition Mountain area and at Granite Reef Dam and Mormon Flat in the Salt River area, which is adjacent to and northwest of the Superstition Mountains.

7. Rainfall.--Rain began about 1:00 a.m. on the 19th of August and continued until 8:00 or 9:00 a.m. An intensity of 2.01 inches per hour was reported at Ray (station 15, appendixes 1 and 2). Another intensity reported at Florence Junction, was 1.75 inches per hour. By applying a correction to the hourly amounts of the tipping-bucket gage located at Superior, an hourly intensity of 1.13 inches was estimated. Intensities at other stations ranged from 1/2 to 3/4 inch per hour. Another storm, more local in character and with lower precipitation intensities, began about 2:00 a.m. on the 20th and continued until 5:00 a.m. Time between the two storms ranged from 13 to 20 hours. The Queen Creek recorder at Whitlow Ranch dam site did not record properly for these storms. Table 1 shows pertinent data for 18 precipitation stations. Appendixes 1 and 2 show location of stations and isohyets for the storms of the 19th and 20th respectively.

Table 1

Pertinent data, storms of 19 and 20 August 1954, Queen Creek and vicinity, Arizona

No.	Precipitation station name and location	Precipitation		Duration	Reliability of record	Remarks
		Date	Amount			
			Inches	Hours		
1	Mesa Experiment Farm - west of Mesa.	19 20	0.02 0	2 (*)	Excellent	Light rain from 8 to 10 a.m.
2	Falcon Field 1½ miles southwest...	19 20	.46 0	2 (*)	...do.......	Located at Mr. Armstead's citrus grove.
3	Granite Reef Dam - at dam.........	19 20	0 1.35	(*) (**)	...do.......	Data obtained from U.S.W.B. at Phoenix.
4	Stewart Mountain - at dam.........	19 20	0 .41	(*) (**)	...do.......	Do.
5	Mormon Flat - at dam..............	19 20	0 1.55	(*) (**)	...do.......	Do.
6	Chas. Weeks Ranch - 4 miles east of Apache Jct.	19 20	4.5 1.5	6 4	Good	Heavy rains - 16½ hours between storms.
7	King's Ranch - 7 miles east and south of Apache Jct.	19 20	4.93 .17	7 4	Excellent	2 storms 13 hours apart.
8	Barkley Ranch #1 - 10 miles east of Apache Jct.	19 20	3.5 2.6	6½ 2	Good	2 storms 19 hours apart.
9	Barkley Ranch #2 - 12 miles east of Apache Jct.	19 20	4.5 .4	6 2	...do.......	2 storms 20 hours apart.
10	Florence Jct. - at junction of Highways 60, 70, 80, and 89.	19 20	4.25 0	6 (*)	Excellent	Heavy rains - from 3 to 7 a.m. = 2.50 in.; from 8 to 9 a.m. = 1.75 in.

See footnotes at end of table.

Table 1--Continued

Pertinent data, storms of 19 and 20 August 1954, Queen Creek and vicinity, Arizona

No.	Precipitation station name and location	Precipitation		Duration	Reliability of record	Remarks
		Date	Amount			
			Inches	Hours		
11	Boyce Thompson Arboretum..........	19 20	5.30 .07	6½ During night	Good	Very heavy rain from 5 to 8 a.m. of the 19th.
12	Superior Smelter - southwest end of town.	19 20	2.68 0	4½ (*)	Excellent	A tipping-bucket recorder at same location registered 0.95 inch of rain.
13	Superior Smelter office - east end of town.	19 20	2.47 0	4¼ (*)	...do.......	
14	Pinal Ranch - approx. 6 miles east of Superior on Highways 60-70.	19 20	1.64 1.00	4½ 2	...do.......	2 storms 16½ hours apart.
15	Ray - at smelter office...........	19 20	4.05 .42	2 During night	Good	2 storms 14 hours apart.
16	Florence - southwest side of town	19 20	.01 0	(**) (*)	Excellent	
17	Queen Creek - Town of Queen Creek.	19 20	0 0	(*) (*)	....	No record. Several residents claim there was no rain.
18	Williams Air Force Base - at headquarters on base.	19 20	.62 Trace	7 (**)	Excellent	Observations made every 6 hrs

* Not applicable.
** No data available.

8. Runoff.--The U. S. Geological Survey estimated a peak of 40,000 cubic feet per second at 10:00 a.m. on the 19th on Queen Creek at Whitlow Ranch dam site (drainage area 143 square miles). This was much greater than the previous maximum peak of record (13,200 cubic feet per second). At 9:05 a.m. a peak of 27,500 cubic feet per second was recorded at this site and at 9:45 a.m. the recording-gage station was washed out and was not recovered until a few days later. In the areas of greatest damage (Queen Creek Irrigation District, Williams Air Force Base, and Roosevelt Water Conservation District), the flood peak came at approximately 2:00 p.m. on the 19th. The flood peak continued through the irrigated area reaching the town of Gilbert between midnight and 2:00 a.m. on the 20th. The residents of Apache Junction reported two flood peaks, one between 7:00 and 10:00 a.m. on the 19th and a second, a larger peak, about 6:00 or 7:00 a.m. on the 20th. Apache Junction was the only place that reported damaging flood flow from the storm of the 20th. All floodwaters had subsided by the afternoon of the 20th.

9. Overflow area.--The runoff came down the washes from the Pinal and Superstition Mountains, crossed the desert as sheet flow and spread out over the irrigated farmland. The damaging flows from Queen Creek covered approximately 17,000 acres of farmland, from Williams Air Force Base on the north to Chandler Heights Irrigation District on the south, and from the Maricopa-Pinal county line on the east to the Roosevelt Water Conservation District canal on the west. The runoff from the Superstition Mountain area flooded irrigated agricultural land adjacent to and east of the Roosevelt Water Conservation District's dike and canal, overtopped and broke through the dike in many places, and flooded farmland from the dike to the town of Gilbert on the west. The damaging overflow inundated approximately 13,000 acres and extended from Williams Air Force Base and the Southern Pacific Railroad on the south to the vicinity of Gila and Salt River Base Line on the north. The total farmland flooded by flow from both drainage areas was about 30,000 acres.

10. The source of damaging floodwaters was easily determined except for a few areas, such as Williams Air Force Base, where runoff from both the Queen Creek drainage area and the Superstition Mountain area appeared to join and cause overflow and damage. The overflow areas of principal damage are outlined on the attached map, appendix 3. This map indicates the extent of the flood in Maricopa County where most of the damaged farmland is located. Within the outline there are areas, such as Williams Air Force Base, which were not completely inundated. To the north and east of the area shown on this map, the floodwaters were poorly defined, coming across the desert as sheet flow with occasional islands of dry land. To the south and east of the area shown on this map, severe damage from the flood occurred on a considerable acreage of cultivated farmland along Queen Creek in Pinal County.

FLOOD DAMAGE ESTIMATES

11. Field work.--Los Angeles District personnel arrived in the flooded area on Wednesday, 25 August 1954, to investigate and gather data on rainfall, runoff, and resultant flood damage. The overflow area was determined, and owners and operators of farms were interviewed. District personnel were assisted in this work by the U. S. Soil Conservation Service officials in the area. Damage reports were obtained from officials of the State of Arizona, Maricopa County, Pinal County, the town of Gilbert, and local irrigation districts. Owners of damaged business and residential property were interviewed. The field survey extended from 25 August 1954 through 30 August 1954.

12. General nature of flood damage.--All types of property were damaged by the floodwaters. As this area is principally agricultural, the highest monetary damage was to crops and irrigation facilities. Crops were completely ruined in some areas, being flattened on the ground and covered with debris. A large portion of the cotton was partially damaged as water reached the lower bolls, causing a lowering of the quality and increased harvesting costs. There was also considerable erosion, especially in fallow fields. Concrete irrigation ditches were torn out and scattered across the fields. Dikes and major irrigation canals were overtopped and breached. Residences and businesses were damaged by water and mud in the rural areas and in the towns of Apache Junction, Gilbert, and Queen Creek.

13. Roads and highways suffered heavy damage in Pinal and Maricopa Counties as floodwaters concentrated in the roads and caused considerable erosion. Major damage to public facilities was at Williams Air Force Base where a dike was overtopped and mud and debris were deposited on parts of the field. An auxiliary field was covered with mud and debris. Comparatively minor damages to railroads and utilities were noted.

14. Emergency work.--Several hundred men were at work for several hours in an attempt to protect dikes and irrigation works. Residents and businessmen in Gilbert were able to prevent considerable damage by sandbagging and moving damageable goods prior to inundation.

15. Estimates of flood damages.--Detailed estimates of damage were made on the basis of information gathered in the field. The total estimated damages amounted to $2,100,000. A summary of the estimated damages resulting from the flood of 19 August 1954 in Queen Creek and vicinity, Arizona, is given in table 2.

Table 2

Estimated damages, flood of 19 August 1954
Queen Creek and vicinity, Arizona

Type of property	Damages		
	Direct	Indirect	Total
Residential	$25,000	$2,000	$27,000
Business and industrial	90,000	15,000	105,000
Public	7,700	200	7,900
Agricultural	1,400,000	210,000	1,610,000
Irrigation works	53,500	2,000	55,500
Highways and roads	265,000	1,600	266,600
Railroads	3,000	3,000	6,000
Utilities	1,500	200	1,700
Total	1,845,700	234,000	2,079,700
			Say 2,100,000

16. Photographs.--Photographs of damaged property were taken by local photographers and by the district office representatives. Photographs selected to show the nature, extent, and severity of the flood damages are included in appendix 4 of this report.

LOSS OF LIFE

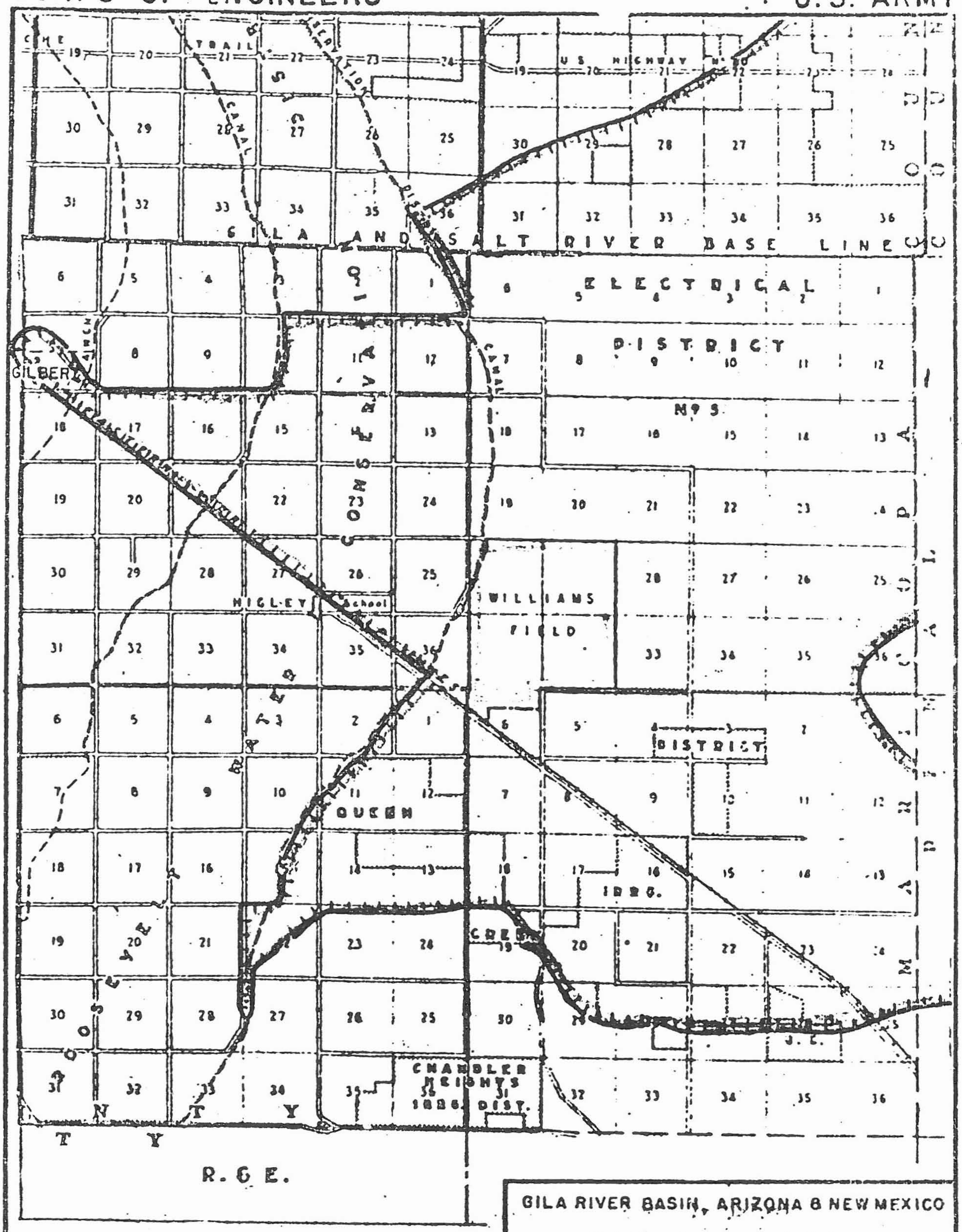
17. No loss of life occurred. Depths were not excessive in most areas and fortunately no one was caught in the washes or low spots.

DAMAGES PREVENTABLE BY AUTHORIZED CORPS OF ENGINEERS IMPROVEMENTS

18. Whitlow Ranch Reservoir.--The project for the Whitlow Ranch Reservoir was authorized by Congress in the Flood Control Act approved 24 July 1946. The recommended plan provides for a dam on Queen Creek at the Whitlow Ranch site, located 5.2 miles above the U. S. 60-70 highway bridge near Florence Junction and 2.3 miles above the mouth of Whitlow Canyon. This dam would reduce the reservoir design peak flow of 59,000 cubic feet per second to an outflow peak of 1,400 cubic feet per second. Since this dam site is above the mouth of Whitlow Canyon, floods from this canyon would not be controlled.

19. Preventable damages.--Most of the damages were easily separable into those caused by flows from Queen Creek and those caused by runoff from the Superstition Mountain area. However, in a few areas damages were caused by a combination of the Queen Creek floodwater and floodwater from other washes. In these areas, an arbitrary division of damages was made. The estimated damages from Queen Creek floodwaters below Whitlow Ranch dam site are $1,200,000. Flow from Whitlow Canyon would not be controlled and therefore it is probable that there would have been some damage even with a dam at Whitlow Ranch site. It is estimated that at least $1,000,000 in damages would have been prevented had this dam been built.

CORPS OF ENGINEERS　　　U.S. ARMY



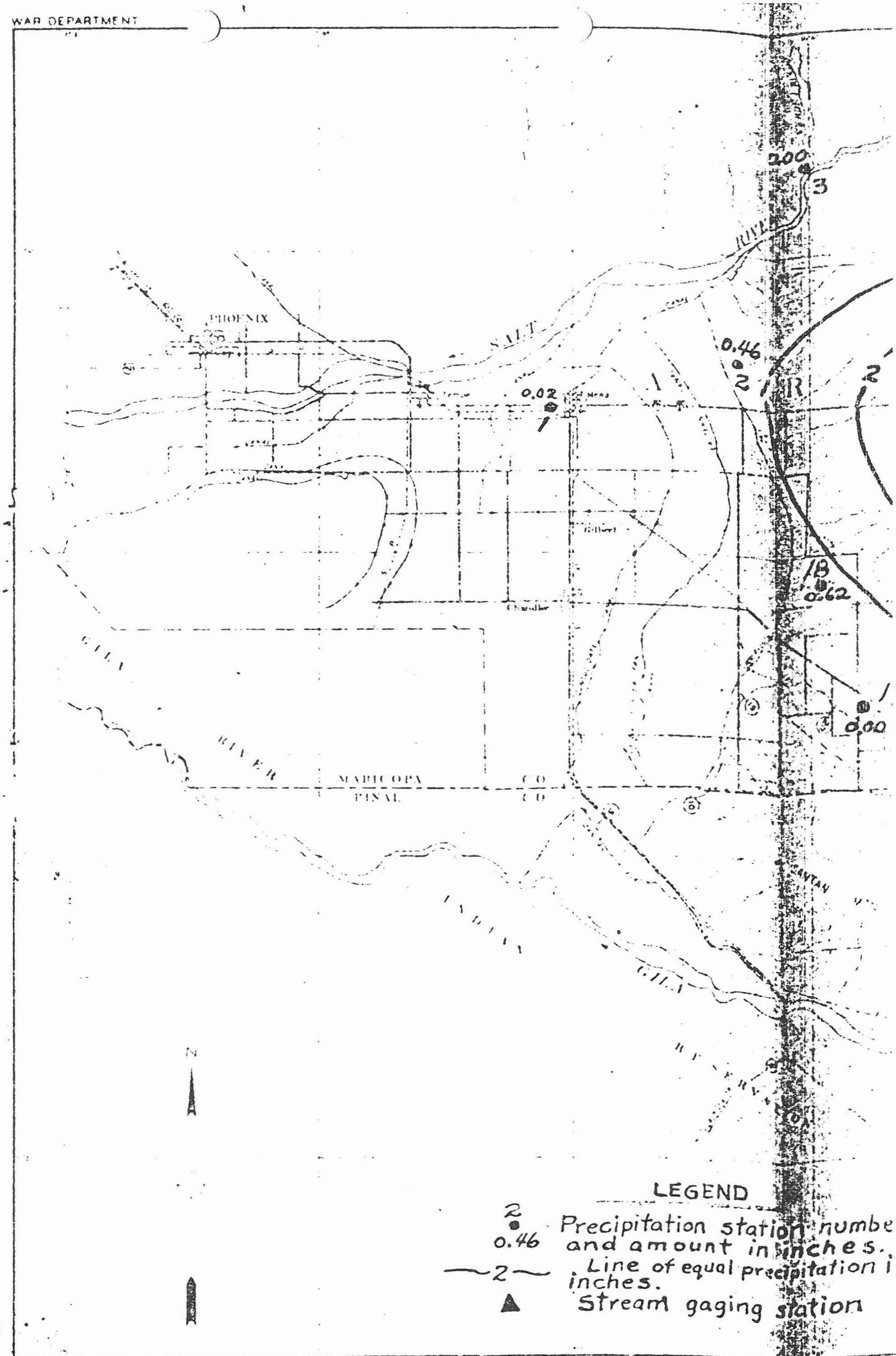
LEGEND

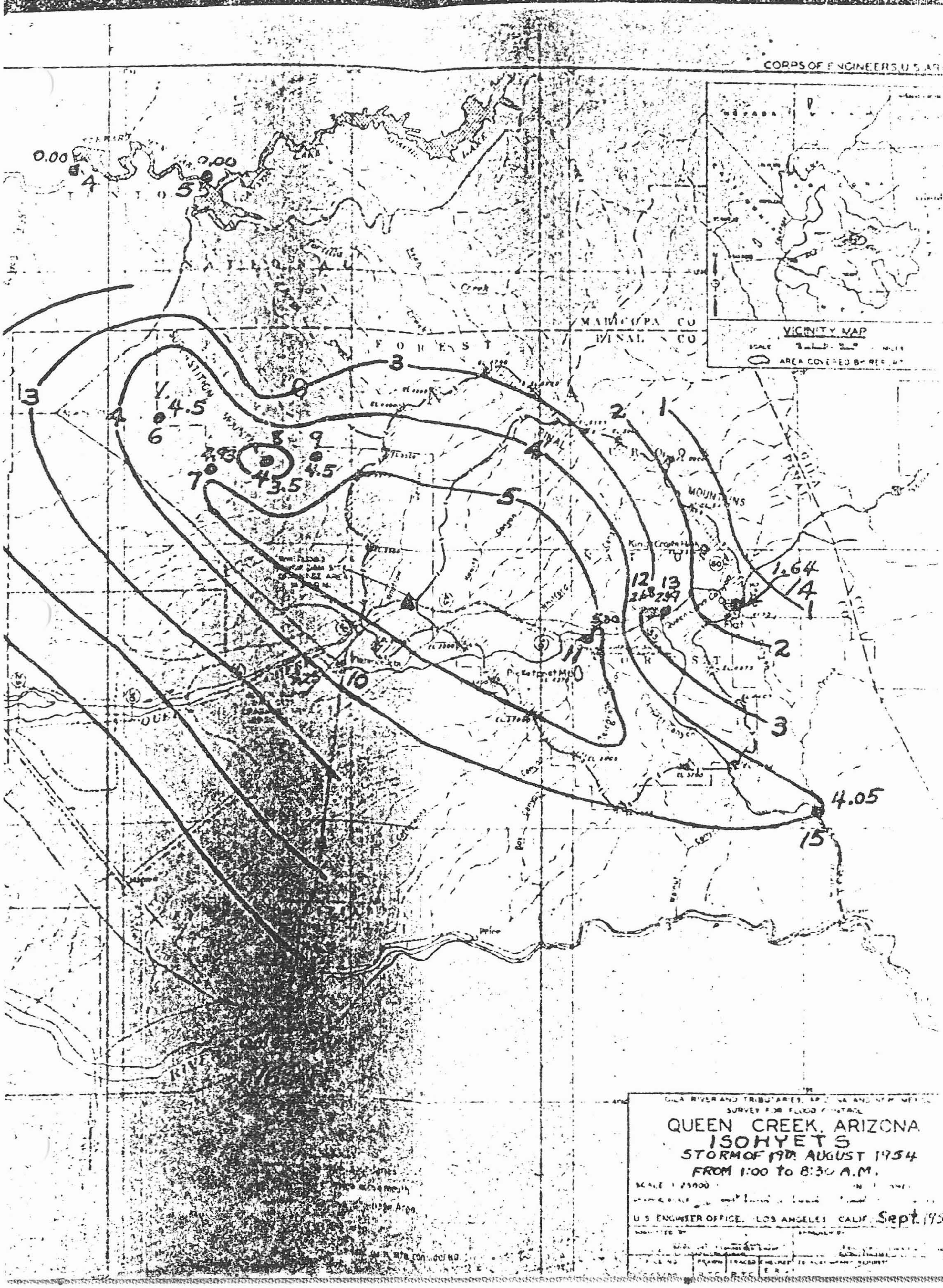
AREA DAMAGED BY FLOOD OF 19 AUGUST, 1954.

GILA RIVER BASIN, ARIZONA & NEW MEXICO

DAMAGED AREAS
FLOOD OF 19 AUGUST, 1954
QUEEN CREEK, ARIZONA AND VICINITY

OFFICE OF THE DISTRICT ENGINEER
LOS ANGELES, CALIFORNIA


WAR DEPARTMENT
PHOENIX
SALT
RIVER
R
Gilbert
Chandler
GILA
RIVER
MARICOPA CO
PINAL CO
INDIAN
GILA
N
200
3
0.46
2
0.02
1
18
0.62
0.00
2
LEGEND
2 • 0.46 Precipitation station numbe and amount in inches.
—2— Line of equal precipitation i inches.
▲ Stream gaging station



CORPS OF ENGINEERS
VICINITY MAP
AREA COVERED BY REPORT
MARICOPA CO
PINAL CO
FOREST
MOUNTAINS
GILA RIVER AND TRIBUTARIES
SURVEY FOR FLOOD CONTROL
QUEEN CREEK, ARIZONA
ISOHYETS
STORM OF 19th AUGUST 1954
FROM 1:00 to 8:30 A.M.
U.S. ENGINEER OFFICE, LOS ANGELES, CALIF.
Sept. 195

Report Of

WHITLOW RANCH DAM FLOOD CONTROL COMMITTEE

1. NAME OF PROJECT:

Whitlow Ranch Reservoir

2. LOCATION:

a. Arizona

b. First Congressional District
Second Congressional District

c. South Pacific Division, Los Angeles District Corps of Engineers, U. S. Army

3. GENERAL NATURE AND PURPOSE:

This is primarily a flood control project. The stream upon which the improvement is proposed is non-navigable. Floods in the Queen Creek basin, Arizona, cause direct and indirect damage to cultivated lands, irrigation works, urban property, highways, railroads and other utilities including an important U. S. Air Force installation at Williams Field, and constitute a menace to the lives and health of the residents.

The plan provides for the construction of a dam and basin for flood control. The dam would be of concrete, gravity type, with a maximum height of 130 feet above stream bed, and a crest length of 535 feet. An uncontrolled spillway 200 feet in length and outlet works would be an integral part of the dam. The reservoir would have a total capacity at spillway crest of 24,000 acre-feet, of which 17,000 acre-feet would be reserved for flood control, and 7,000 acre-feet for sedimentation and conservation purposes.

The operation of the reservoir would regulate the run-off from 143 square miles, reducing the maximum flow from 59,000 to 1,400 cubic feet per second. The project would provide flood protection to an area of 84,000 acres, of which 59,000 acres are highly developed irrigated lands in Queen Creek Irrigation District, the Roosevelt Water Conservation District, the Salt River Project, and the San Carlos Project.

The reservoir would be operated solely for flood control. Retardation of flood flows, however, would permit the percolation of all run-off from most floods into the underground storage basins along the channel.

4. LEGISLATIVE STATUS:

Authority from State Legislature has been obtained. (Section 75-2039 and 75-2310, Arizona Code, 1939). Survey authorized by U. S. Congress (Public Law 738, 74th Congress, H.R. 8455) approved June 22, 1936, and the Act (Public Law 761, 75th Congress, H.R. 10618) approved June 28, 1938. This project was authorized by Congress in the Flood Control Act approved July 24, 1946. It is believed that all legislative requirements have been complied with. Initiation of construction awaits only an appropriation by Congress.

5. PHYSICAL STATUS:

The project has been surveyed and transmitted by the Secretary of War, (House Document No. 220, 80th Congress, 1st Session), referred to Commitee on Public Works. No construction work has been done. Project is inactive, awaiting appropriation of funds.

6. DEPARTMENTAL STATUS:

Project has been submitted by the War Department to Congress, and received Congressional authorization, and now awaits appropriation.

7. ESTIMATED ANNUAL ECONOMIC BENEFITS:

Value of the average annual benefits estimated to accrue from the construction of a dam and basin for flood control at Whitlow Ranch site on Queen Creek amounts to $226,600.* based on 1952 price levels, compiled by the Army Engineers for this project.

8. ESTIMATED ANNUAL REVENUE:

This Project is not revenue producing.

*This figure represents annual benefits estimated by Army at 1939 price levels ($96,000.) converted to June, 1952 price levels, using factor of 2.766.

9. OTHER CREDITS TO THE PROJECT:

Other credits accruing to this project in addition to the tangible benefits reported in Item 7, are intangible benefits which are considerable but not susceptible of monetary evaluation.

a. Water released from the flood control basin at reduced rate and extended over longer period would, in large measure, recharge ground water and thus materially increase usable water supplies.

b. Soil conservation and silt control will result. These will accrue without any additional cost to the United States.

c. The protection of the tax base and the general welfare over an immediate area of 84,000 acres, some 60,000 acres of which are highly developed.

d. The protection of Williams Field Air Force Base and a substantial part of the Government's liability to other property caused by the necessity of constructing separate protecting works for the Air Base.

e. Investments and improvements within the area liable to floods are now almost at a standstill. With the hazard removed by Whitlow Dam, development can be resumed and new taxable wealth created. The annual benefits will then be correspondingly more than the $266,600. now estimated.

10. ESTIMATED COST:

Cost is estimated at $4,550,000. Note: Army estimate in House Doc. No. 220, $1,645,000. based on 1939 price levels. Army now estimates cost at $4,550,000. as at June, 1952. (See Report on Water-Resources Development by the Corps of Engineers in Arizona, dated: 1, January, 1953.)

11. ESTIMATED ANNUAL OPERATING AND MAINTENANCE EXPENSE:

Expense estimated at $21,575. Note: Army estimates of $7,800. increased by application of factor of 2.766.

12. LENGTH OF TIME ESTIMATED TO COMPLETE:

Two years, not more than three years. (Army Engineers).

13. OBJECTORS:

Hearings and publicity on this Project have developed no single objection.

14. PROPONENTS:

Queen Creek Irrigation District, Queen Creek, Arizona.
Roosevelt Water Conservation Dist., Higley, Arizona.
Salt River Valley Water Users' Assn., Phoenix, Arizona.
Maricopa County Board of Supervisors, Phoenix, Arizona.
Mesa Chamber of Commerce, Mesa, Arizona.
Gilbert Chamber of Commerce, Gilbert, Arizona.
Chandler Chamber of Commerce, Chandler, Arizona.
Sacaton Indian Tribunal Council, Sacaton, Arizona.
Maricopa Farm Bureau, Phoenix, Arizona.
Mesa Farm Bureau, Mesa, Arizona.
Chandler Farm Bureau, Chandler, Arizona.
Queen Creek Farm Bureau, Queen Creek, Arizona.

15. SPONSORS:

Maricopa County Board of Supervisors,
County Court House, Phoenix, Arizona.
Queen Creek Irrigation District,
Queen Creek, Arizona.
Roosevelt Water Conservation District,
Higley, Arizona.
Salt River Valley Water Users' Association,
Phoenix, Arizona.
Pinal County Board of Supervisors,
Florence, Arizona.

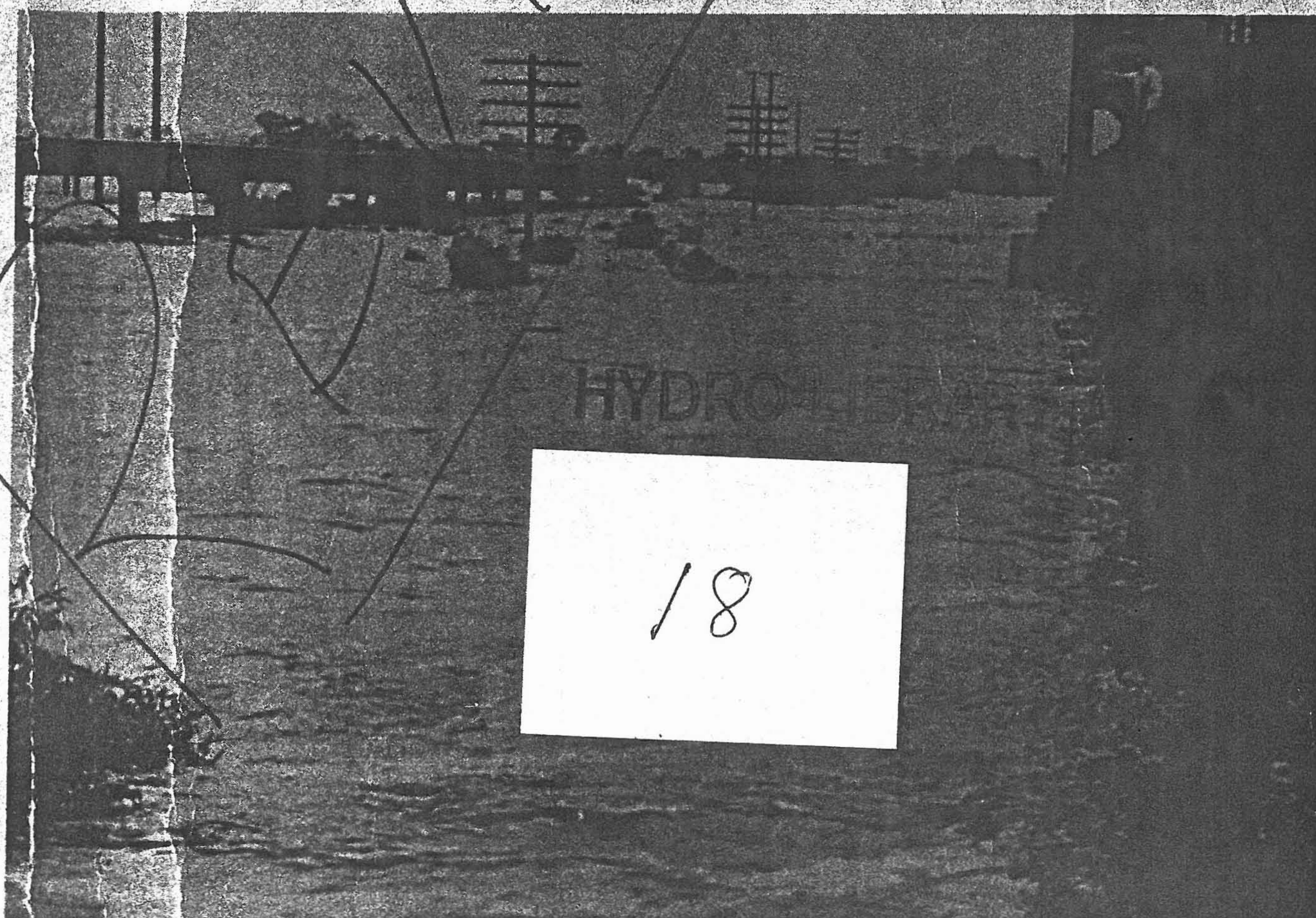
GILA RIVER BASIN

NEW RIVER AND PHOENIX CITY STREAMS
ARIZONA

DESIGN MEMORANDUM NO. 2
HYDROLOGY
PART 1

38

Preliminary



18

SEE REVISED REPORT OCT. 1974

U.S. ARMY ENGINEER DISTRICT
LOS ANGELES
CORPS OF ENGINEERS

20.2-00-1-10/73

OCTOBER 1973

fell in the desert areas to the north, but no records are available. Runoff was heavy upstream of Arizona Canal. A series of 22 breaks occurred in the south bank levee of the canal in the vicinity of Indian Bend Wash. A break in the south bank of the Arizona Canal in the Cave Creek area released water that caused nine breaks in the Grand Canal. The total peak inflow into the Arizona Canal was estimated at 30,000 cubic feet per second and Cave Creek upstream of Arizona Canal was estimated at 9,000 cubic feet per second. The maximum peak discharge in Indian Bend Wash at Arizona Canal was estimated at 15,000 cubic feet per second.

c. Storm and Flood of August 26-29, 1951. A tropical hurricane entered the mainland of Mexico from the east in the vicinity of Tampico on August 11. Moist air associated with this storm crossed Mexico to the eastern coast of the Gulf of California. This moist air augmented by moisture outflow from a tropical storm on the west side of Mexico began flowing into southwestern Arizona during the 26th, mostly in the vicinity of Organ Pipe Cactus National Monument. By the morning of the 27th, precipitation had become quite general over southern and central Arizona. Heavy precipitation spread northward and northeastward to the northern border of Arizona by the 29th. Precipitation was moderate to heavy from the 27th through the 29th. The storm was the most severe east and north of Phoenix. The total storm precipitation at Phoenix was 3.85 inches. Heaviest precipitation for the period was 13.55 inches at Crown King and 12.11 inches at Sunflower. About 65 percent of the total rainfall occurred during the maximum 24 hour period. The isohyets of the total storm precipitation are shown on plate 10. An estimate by the U.S. Soil Conservation Service, based on high water marks at numerous breaks of the Beardsley Canal in the Trilby Wash area (about 25 miles northwest of Phoenix) indicated a total peak discharge of 35,000 cubic feet per second if all the numerous flood peaks along Beardsley Canal had occurred at the same time. The total volume of runoff for this flood was estimated at 10,600 acre-feet. The peak discharge at Luke Air Force Base was estimated at 5,000 cubic feet per second by the U.S. Geological Survey. No flood estimates are available for the study area.

d. Storm and Flood of August 19, 1954. Very moist warm tropical air that originated over the Gulf of Mexico and the Gulf of California entered Arizona and New Mexico from the south during the storm period accompanied by widespread thunderstorm activity. The storm and flood of August 19, 1954, was the most severe on record within the Queen Creek drainage area approximately 50 miles east, southeast of Phoenix. Precipitation in the area occurred between 0100 and about 1000 hours on the morning of August 19, in the Superstition Mountains and Pinal Mountain areas. The precipitation intensities were very high during portions of the storm, especially between 0500 and 0900 hours. The Boyce Thompson Southwestern Arboretum, about 4 miles west of Superior reported the highest measured precipitation amount of 5.3 inches (most of it falling within 3 hours) although greater amounts are believed to have fallen in the mountains to the south. Florence Junction, about 15 miles west of Superior, reported 1 and 6 hour amounts of 1.75 and 4.25 inches respectively, while the smelter at Ray about 11 miles southeast of Superior measured 4.05 inches in less than 2 hours. An estimated 140 square miles of area had over 5 inches of precipitation, and approximately 850 square miles had over 1 inch of precipitation. The isohyets of total storm precipitation are shown on plate 11. Peak discharge at the gaging station at Queen Creek at Whitlow Ranch Dam site near Superior, Arizona (drainage area 142 square miles) was estimated at 42,900 cubic feet per second. No estimate of runoff is available for the study area.

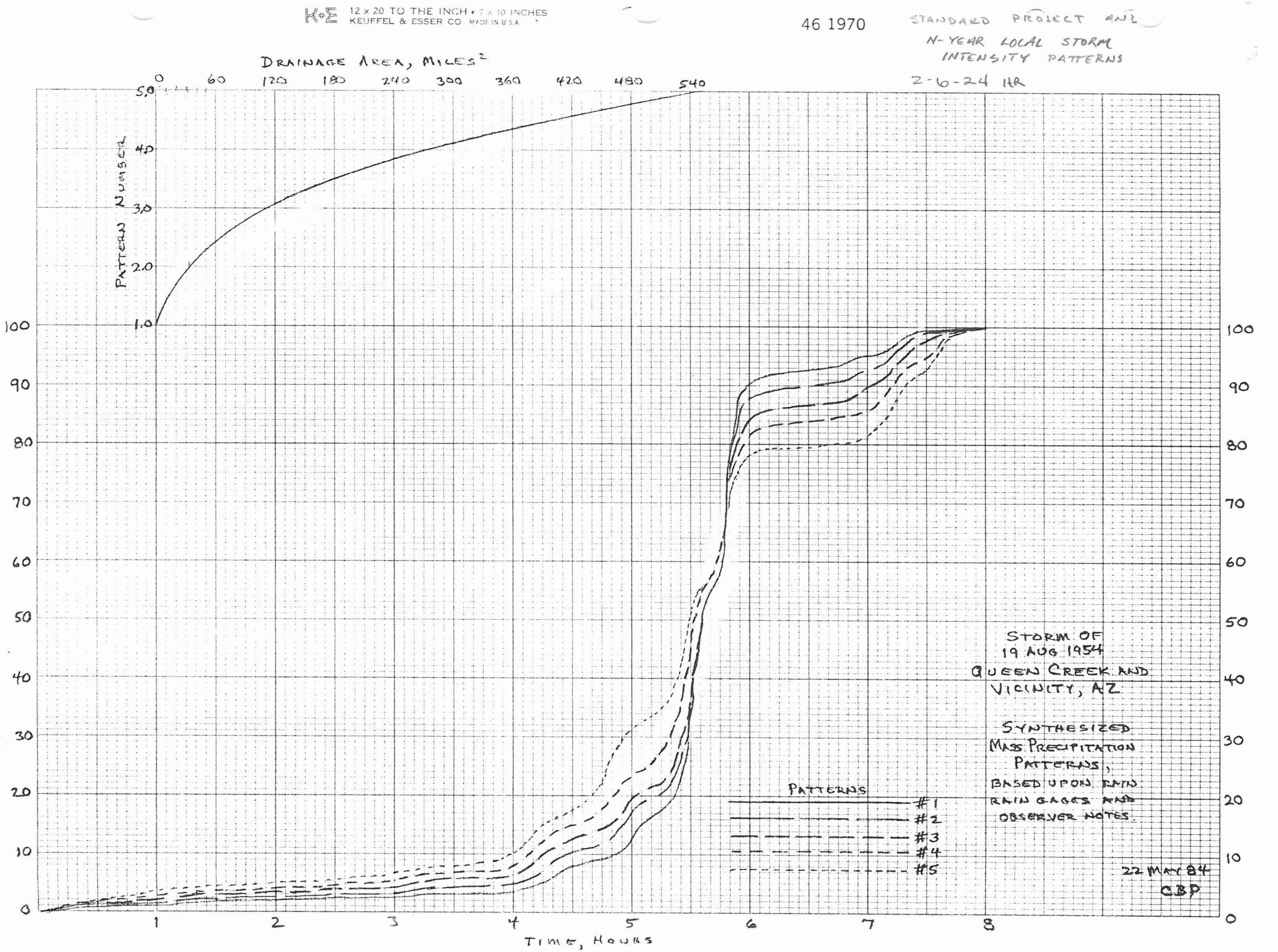
IV – SYNTHESIS OF STANDARD PROJECT FLOOD

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. It thus constitutes a standard for design that will provide a high degree of flood protection. Preparation of standard project flood estimates in this report were made in accordance with EM 1110-2-1411 (Standard Project Flood Determinations).

4-02. STANDARD PROJECT STORM (LOCAL TYPE). The August 19, 1954 thunderstorm that was centered generally in the Queen Creek drainage area was determined to be the storm with the most severe flood producing rainfall depth-area-duration relationship and isohyetal pattern that may reasonably be expected to occur over the central portion of Arizona. While the storm lasted a total of about 9 hours, local observations during the storm indicated that nearly all of the precipitation fell during a 7 hour period and that most of the rainfall occurred at many stations within 3 hours or less. Extremely intense rates of precipitation for very short durations (5 minutes to 1 hour), although not measured in the August 19, 1954 Queen Creek storm because of the complete lack of properly functioning recording rain gages in the area at the time of this storm have been measured on a number of other occasions in the vicinity of central Arizona, and are therefore considered to be reasonably characteristic of the heavier thunderstorms of this part of the state. Thus, a standard project storm of 7 hours duration, having large portions of the total precipitation occurring within 1 to 3 hours, was developed. The methods used to determine the total precipitation amounts, the intensity-duration relationships, and the precipitation-intensity patterns are explained in the following subparagraphs:

a. Total Precipitation. Total precipitation amounts for the standard project local storm were obtained from the isohyets (pl. 11) of the August 19, 1954 Queen Creek thunderstorm, transposed and centered over various drainage basins within the greater Phoenix area. Because the heaviest precipitation of this storm occurred in mountainous areas where it is felt that orographic influences were significant, the total storm depth was altered as it was transposed to the Phoenix area (as well as to other areas) by 10-year 6-hour precipitation values obtained from the National Weather Service charts. (See pl. 15.) This particular parameter was selected as the transposition factor because it is believed to be the most accurate available rainfall statistic representative of rare-event precipitation of 7 hours' duration. Transposition of the August 19, 1954 thunderstorm from the Queen Creek area to the vicinity of Phoenix by this method results in a reduction of the total storm magnitude by nearly 20 percent. Transposition of the storm to the foothill and mountain areas north of Phoenix results in smaller reductions or even slight increases in the total depth of the original storm. Plate 16 presents the depth-area reduction factor as a function of drainage area and 10-year 6-hour precipitation. Thus, the average rainfall depth over a watershed is equal to the product of 10-year 6-hour precipitation, depth-area reduction factor, and 3.178. The factor 3.178 is the ratio of maximum point rainfall to 10-year 6-hour precipitation for the observed Queen Creek storm.

b. Intensity-Duration Relationships. Intensity-duration relationships for the maximum point-value of the storm were compiled for durations from 5 minutes to 7 hours from the information available for the August 19, 1954 Queen Creek storm, with the corresponding information for other intense historical storms in the vicinity of central Arizona serving as a guide. (See pl. 14.) Each intensity-duration depth was transposed from



K+E 12 x 20 TO THE INCH • 7 x 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1970
STANDARD PROJECT AND
N-YEAR LOCAL STORM
INTENSITY PATTERNS
2-6-24 HR
DRAINAGE AREA, MILES²
0
60
120
180
240
300
360
420
480
540
PATTERN NUMBER
5.0
4.0
3.0
2.0
1.0
100
90
80
70
60
50
40
30
20
10
0
STORM OF
19 AUG 1954
QUEEN CREEK AND
VICINITY, AZ
SYNTHESIZED
MASS PRECIPITATION
PATTERNS,
BASED UPON RAIN
RAIN GAGES AND
OBSERVER NOTES.
PATTERNS
#1
#2
#3
#4
#5
22 MAY 84
CBP
1
2
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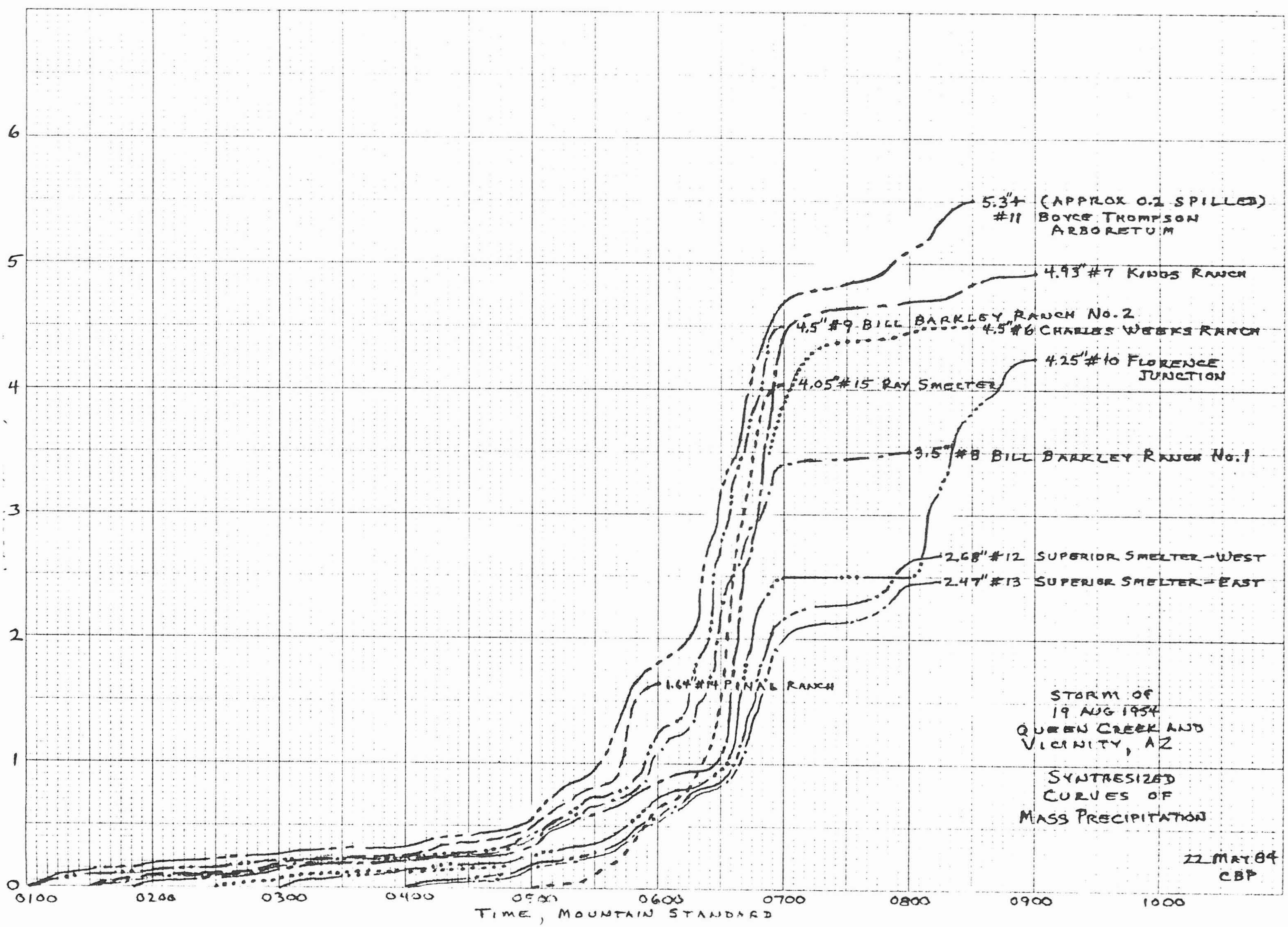
8
TIME, HOURS



6
5
4
3
2
1
0
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
TIME, MOUNTAIN STANDARD
5.3"+ (APPROX 0.2 SPILLED) #11 BOYCE THOMPSON ARBORETUM
4.93" #7 KINGS RANCH
4.5" #9 BILL BARKLEY RANCH NO. 2
4.5" #6 CHARLES WEEKS RANCH
4.25" #10 FLORENCE JUNCTION
4.05" #15 RAY SMELTER
3.5" #8 BILL BARKLEY RANCH NO. 1
2.68" #12 SUPERIOR SMELTER-WEST
2.47" #13 SUPERIOR SMELTER-EAST
1.64" #14 PINAL RANCH
STORM OF 19 AUG 1954 QUEEN CREEK AND VICINITY, AZ
SYNTHESIZED CURVES OF MASS PRECIPITATION
22 MAY 84
CBP

6/3/88

QUEEN CREEK, AZ STORM OF 19 AUG 1954

RAINFALL TIME DISTRIBUTION PATTERNS

No.	Station	Period of Rain, MST	Amount (inches)	Remarks
1.	Mesa Experiment Farm	0800-1000	.02	
2.	Falcon Field	0730-0930	.46	
3.			.00	
4.			.00	
5.			.00	
6.	Charles Weeks Ranch	0230-0830	4.5	
7.	Kings Ranch	0150-0900	4.93	0150-0630 "normal rain" 0630-0700 "rain worse [sic] he had known" One-quarter mile directly south of Kings Ranch: 5"
8.	Bill Barkley Ranch No. 1	0130-0800*	3.5	"Rain intermittent very hard"
9.	Bill Barkley Ranch No. 2	0100-0700	4.5	"Very hard rain, comes down in sheets"
10.	Florence Junction	0300-0900	4.25	0300-0700 2.50" 0800-0900 1.75"
11.	Boyce Thompson Arboretum	0100-0830*	5.3+	0100-0500 light 0500-0800 very heavy "Spilt [sic] some when measuring. Approximately .2 inch."
12.	Superior Smelter, west	0400-0815	2.68	
13.	Superior Smelter, east	0400-0815	2.47	Tipping bucket alongside: .95 inch
14.	Pinal Ranch	0130-0600	1.64	
15.	Ray Smelter	0500-0700	4.05	"Paper said it all fell in 1 and 1/2 hours"
16.	Florence		.01	
17.			.00	
18.	Williams AF Base	0156-0900	.62	0156-0347 intermittent light 0347-0508 moderate 0508-0900 light

* = approximately

APPENDIX 1-I

6-hour and 2-hour storm distributions for Maricopa County.

Development of 6-hour Point Rainfall Mass Distribution (Pattern # 1)
6-hour rainfall depth 3.22

Time increment (hours)	Incremental Rainfall Depth (inches)	Accumulated Rainfall Depth (inches)	Ratio to 6-hr Rainfall
0:00	0.0000	0.0000	0.000
0:15	0.0266	0.0266	0.008
0:30	0.0266	0.0531	0.016
0:45	0.0266	0.0797	0.025
1:00	0.0266	0.1062	0.033
1:15	0.0266	0.1328	0.041
1:30	0.0266	0.1594	0.050
1:45	0.0266	0.1859	0.058
2:00	0.0266	0.2125	0.066
2:15	0.0266	0.2390	0.074
2:30	0.0400	0.2790	0.087
2:45	0.0400	0.3190	0.099
3:00	0.0625	0.3815	0.118
3:15	0.0625	0.4440	0.138
3:30	0.2500	0.6940	0.216
3:45	0.5200	1.2140	0.377
4:00	1.4700	2.6840	0.834
4:15	0.2500	2.9340	0.911
4:30	0.0625	2.9965	0.931
4:45	0.0625	3.0590	0.950
5:00	0.0400	3.0990	0.962
5:15	0.0400	3.1390	0.975
5:30	0.0266	3.1656	0.983
5:45	0.0266	3.1922	0.991
6:00	0.0266	3.2200	1.000

DEVELOPMENT OF 6-HOUR RAINFALL MASS CURVES (PATTERNS #2 TO #5)

The 7-hour pattern distributions, developed for the Queen Creek Storm of August 19, 1954 (Appendix 1-H) is used for this purpose. Eliminating Patterns #1 and #6, a new set was developed which are being referred to as Patterns #2 to #5. The duration for these patterns were changed to 6 hours so that they can be consistent with the previously developed Pattern #1. Subsequently, the new incremental values were adjusted based on a 6-hour duration, and were normalized accordingly.

6-HOUR RAINFALL MASS CURVES (PATTERN #2 TO #5)

Time (hrs)	Pattern #2	Pattern #3	Pattern #4	Pattern #5
0:00	0.000	0.000	0.000	0.000
0:15	0.006	0.015	0.021	0.024
0:30	0.012	0.020	0.035	0.043
0:45	0.020	0.030	0.051	0.059
1:00	0.031	0.048	0.071	0.078
1:15	0.039	0.063	0.087	0.098
1:30	0.049	0.076	0.105	0.119
1:45	0.057	0.090	0.125	0.141
2:00	0.067	0.105	0.143	0.162
2:15	0.076	0.119	0.160	0.186
2:30	0.087	0.135	0.179	0.212
2:45	0.100	0.152	0.201	0.239
3:00	0.120	0.175	0.232	0.271
3:15	0.163	0.222	0.281	0.321
3:30	0.252	0.304	0.364	0.408
3:45	0.451	0.472	0.500	0.515
4:00	0.694	0.670	0.658	0.627
4:15	0.837	0.796	0.773	0.735
4:30	0.900	0.868	0.841	0.814
4:45	0.938	0.912	0.888	0.864
5:00	0.950	0.946	0.927	0.907
5:15	0.963	0.960	0.945	0.930
5:30	0.975	0.973	0.964	0.954
5:45	0.988	0.987	0.982	0.977
6:00	1.000	1.000	1.000	1.000

Development of 2-hour Point Rainfall Mass Distribution for Retention
2-hour rainfall depth 2.74

Time increment (hours)	Incremental Rainfall Depth (inches)	Accumulated Rainfall Depth (inches)	Ratio to 6-hr Rainfall
0:00	0.0000	0.0000	0.000
0:15	0.0625	0.0625	0.023
0:30	0.0625	0.1250	0.046
0:45	0.2500	0.3750	0.137
1:00	0.5200	0.8950	0.327
1:15	1.4700	2.3650	0.863
1:30	0.2500	2.6150	0.954
1:45	0.0625	2.6775	0.977
2:00	0.0625	2.7400	1.000

Interpolated 5-minute Depth Rainfall

time increment (minutes)	cumulative rainfall (inches)	percent rainfall (15-min. increment)	percent rainfall (5-min. increment)
00	.0000	0.000	0.000
05			0.011
10			0.018
15	.0625	0.023	0.023
20			0.028
25			0.032
30	.1250	0.046	0.046
35			0.071
40			0.100
45	.3750	0.137	0.137
50			0.176
55			0.232
60	.8950	0.327	0.327
65			0.601
70			0.743
75	2.3650	0.863	0.863
80			0.901
85			0.930
90	2.6150	0.954	0.954
95			0.962
100			0.970
105	2.6775	0.979	0.977
110			0.982
115			0.992
120	2.7400	1.000	1.000

APPENDIX 1-J

Comparison of different design rainfall criteria.

COMPARISON OF DESIGN RAINFALL CRITERIA

FOR USE IN ARIZONA

Three sets of different design rainfall criteria have been used with the HEC-1 program to investigate their performances over a range of watershed sizes. All three are local storm criteria and 500 sq. miles is considered the upper limit of local storm extent. Drainage areas of 0.1, 1, 10, 25,100, and 500 sq. miles were considered. These criteria should not be applied for general storms in Arizona.

The three design rainfall criteria are shown in Table A. The Green and Ampt infiltration equation was used in HEC-1 and the rainfall loss parameters are shown in Table A. The SCS Dimensionless unit hydrograph was used and the assumed basin characteristics and model input (TLAG and NMIN) are listed. Notice the NMIN = 5 minutes for A = 0.1 sq. mile with the SCS Type II distribution, and this exceeds the recommendation that NMIN $<$ .29 TLAG but is necessary for a 24-hr distribution because of the 300 computation point limit in HEC-1.

The calculation of the Maricopa County rainfall distributions are presented in Attachment A (4 sheets). Notice that Pattern No. 1 is not exactly the same as Pattern No. 1 according to the current version of the Maricopa County Hydrology Manual, but is the hypothetical distribution as developed for the ADOT Hydrology Section (copy provided).

The calculation of the SCS Type II rainfall distributions are presented in Attachment B. Notice on the work sheet that the central 6-hour part of these distributions has been calculated. This was for the purpose of graphical comparison with the other two 6-hour distributions (Figures A through F). The complete 24-hour distributions were input in the HEC-1 models.

The HMR-49 rainfall distributions were calculated by the procedures in Hydrometeorological Report No. 49, Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages (NOAA, 1984). This procedure was developed for estimating a PMP, but it may be appropriate for other severe storms of N-year frequency. The calculation of the HMR-49 distributions are presented in Attachment C (5 sheets).

The rainfall mass diagrams for each watershed area are shown in Figures A through F. Inspection of these figures results in the following observations:

1. Use of the SCS Type II distribution with the NOAA Atlas 2 depth-area reduction factors results in almost the same rainfall mass diagram for areas from 0.1 to 500 sq. miles. The 6-hour rainfall depths are low for small areas and high for large areas.
2. The rainfall mass diagrams using the Maricopa County procedure have very high intensities for small areas (0.1 to about 10 sq. miles), but the intensities and dept6hs diminish quickly for areas larger than 10 sq. miles.
3. Procedures from HMR-49 results in high intensities and rainfall depths for small areas and these are comparable to the hypothetical distribution. The intensities and rainfall depths diminish fairly systematically with increasing area. The SCS Type II and the HMR-49 rainfall mass diagrams are similar for areas from 25 to 100 sq. miles.

HEC-1 input files were prepared using each of the three design rainfall criteria and each of the six drainage areas (18 runs). A diskette is provided that contains the input and output files. Input files have an extention .DAT and output files have an extention .OUT. All file names start with RL and are followed by a code that identifies the design rainfall criteria:

MC - Maricopa County and Osborn
SCS - SCS Type II and NOAA Atlas 2
HMR - HMR-49

This is followed by a number from 1 to 6 for areas 0.1, 1, 10, 25, 100, and 500 sq. miles, respectively.

The output from the HEC-1 program are summarized in Tables B through D, and the results are presented graphically in Figures G through K.

DISCUSSION OF FIGURES G THROUGH K

Figure G

The rainfall depths with the Maricopa County procedure diminish rapidly with area. At 100 sq. miles, only 1.42 inches of rainfall is applied. This may be excessive reduction.

The rainfall depths using NOAA Atlas 2 reduction factors hardly diminish at all. This is certainly conservative, but is not realistic for areas larger than about 25 sq. miles.

The rainfall depths using HMR-49 seem reasonable and are not overly conservative nor as quickly reduced as the Maricopa County.

Figure H

For small areas (less than or equal to 1 sq. mile), the Maricopa County procedure gives the greatest runoff, and this is because the hypothetical distribution is used. The SCS Type II distribution has the least runoff for small watersheds.

For the Maricopa County procedure, the runoff depth diminishes rapidly. At 25 sq. miles the runoff is very low and at 100 sq. miles there is virtually no runoff. This does not seem reasonable.

The rainfall excess remains almost constant regardless of the size of the area when the SCS Type II distribution is used. This is contrary to observation and the physical processes that are involved.

The HMR-49 procedure results in a fairly consistent reduction in rainfall excess, except that runoff is almost 0.0 at 500 sq. miles for a uniform loam watershed with no impervious area and the center of the storm assumed to be centered about 25 miles from the outlet.

In the range 1 to 10 sq. miles, all three rainfall criteria produce about the same runoff. This is probably a fairly common drainage area size for many highway applications.

Figure I

The maximum rainfall intensities are very similar to what has been discussed for rainfall excess. That is, the Maricopa County procedure results in a dramatic (and maybe too rapid) reduction in rainfall intensity with area. There is virtually no reduction in rainfall intensity using the SCS Type II distribution. The HMR-49 procedure lies somewhere between the other two.

Figure J

The Maricopa County procedure results in very high runoff intensities for small areas, and almost no runoff at 100 sq. miles and larger. The rate of decreasing intensity with increasing area does not seem reasonable.

There is only a slight reduction in runoff intensity as drainage area increases for the SCS Type II distribution. This does not seem reasonable. The runoff intensities are low for small areas, and probably too high for large areas.

HMR-49 has much lower runoff intensity than the Maricopa County procedure for very small areas, but the runoff intensity decreases moderately up to about 100 sq. miles. Virtually no runoff is produced at 500 sq. miles.

Figure K

The Maricopa County procedure produces the highest discharges for the smallest areas, but the peak drops off dramatically, even at 25 sq. miles. Again, because the intensities are so low at 100 sq. miles and larger, the peak discharges are suspiciously low for large watersheds.

Conversely, the SCS Type II distribution gives high discharges at 100 sq. miles and larger.

The HMR-49 procedure results are similar to those using the SCS Type II up through about 10 sq. miles. At 25 sq. miles, HMR-49 gives peaks that decrease and continually diverge from those using SCS Type II.

Peak discharges are about the same for all three at about 1 sq. miles.

Note: These results are for assumed watersheds with loss rates and unit hydrograph characteristics as described. The results would change somewhat for different selections of rainfall loss methods and parameters, and different unit hydrograph procedures and parameters. However, the general results, as discussed, would be similar when comparing one set of rainfall criteria against the others.

CONCLUSIONS

1. The Maricopa County procedure (the hypothetical distribution for 6 hours) provides high peak discharges for small areas, and this may be appropriate for watersheds up to about 1 sq. mile.
2. The Maricopa County procedure results in too low rainfall depths and rainfall intensities for areas larger than about 10 sq. miles.
3. The rainfall intensities for the SCS Type II distribution are too low for areas smaller than 10 sq. miles.
4. The rainfall intensities for the SCS Type II distribution are too high for areas larger than 25 to 100 sq. miles.
5. The HMR-49 distributions seem to provide consistent results for design purposes up to about 100 sq. miles.
6. If local storms have characteristics as presented in HMR-49 and as reflected in the Maricopa County procedure, then the local storm is probably not a critical design event for watersheds much larger than about 100 sq. miles. At 500 sq. miles, local storms will produce little runoff from the watersheds. That doesn't mean that local storms don't produce floods on large watersheds. For example, a local storm could occur over only part (say the lower 100 sq. miles) of a large watershed that could produce extremely high peak discharges, and this should be analyzed.
7. The hypothetical distribution is site specific and different distributions will result for different locations in Arizona.
8. The HMR-49 procedure is site specific (function of P_6/P_1) and different distributions will result for different locations in Arizona.
9. The SCS Type II distribution cannot be tailored to local meteorologic conditions.

RECOMMENDATIONS

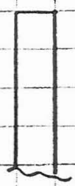
One of the following should be used for design flood hydrology in Arizona:

	Drainage Area, sq. miles	Design Rainfall Criteria
Method 1	0 to 1	Hypothetical distribution and no Depth-Area reduction
	1 to 25	SCS Type II with NOAA Atlas 2 Depth-Area reduction
	25 to 100	Procedure such as HMR-49 for local storm
	100 and larger	Both general storm and critically centered local storm
Method 2	0 to 1	Hypothetical Distribution and no Depth-Area reduction
	1 to 100	HMR-49 procedure
	100 and larger	Both HMR-49 procedure for critically centered local storm, and general storm

If the manual will be limited to watersheds of 100 sq. miles and smaller then we need not concern ourselves with the 100 and larger range in the above recommendations. Method 1 would require three sets of procedures; Method 2 only two.

SHEET .... OF ....
JOB NO. ....
BY GVS
CHK. ....
DATE 6 Nov 89

JOB ....
FEATURE TABLE A
DETAIL HEC-1 Model Input

Symbol for Figures G – K (1)	Raintall (2)	Depth-Area Reduction Factor (3)	Temporal Distribution (4)
	100-yr, 6-hr 3.22"	Maricopa County (Osborn)	Maricopa County (6-hr)
	100-yr, 24-hr 3.93"	NOAA Atlas 2	SCS Type II (24-hr)
	100-yr, 6-hr 3.22"	HMR-49	HMR-49 (6-hr)

Raintall Losses : Green and Ampt Eq'n. (loam)

RTIMP	0.0	
IA	.15 in.	
XKSAT	.25 in/hr	
PSIF	3.5 in.	(should be 4.3 in.)
DTHETA	.35	

Unit Hydrograph : SCS Dimensionless

Area sq.mi. (1)	L mi. (2)	H ft (3)	T_c hr (4)	TLAG hr (5)	NMIN min (6)
.1	.5	50	.3	.2	3 (5 for SCS Type II)
1	1.5	100	.7	.4	6
10	5	250	2.0	1.2	15
25	10	500	3.4	2.0	30
100	20	800	6.3	3.8	30
500	50	1,300	15.0	9.0	30

TABLE B

Rainfall Frequency 100 yrs.

Rainfall Depths:
6-hr 3.22 in.
24-hr 3.93 in.

Raintall Loss Alternative A
Parameters: RTIMP 0
IA .15
XKSAT .25
PSIF 3.5
DTHETA .35

Raintall Criteria		Rainfall / Rainfall Excess, inches					
Time Distribution	Depth-Area Reduction Factor	Area, in sq. mi. .1	1	10	25	100	500
HEC-1 Input File (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maricopa County	Osborn	3.22/1.76	3.15/1.59	2.51/.87	2.09/.50	1.42/.03	1.42/0.0
SCS Type II	NOAA Atlas	3.93/1.27	3.93/1.27	3.89/1.25	3.81/1.21	3.69/1.13	3.58/1.09
HMR-49		3.25/1.47	3.25/1.47	3.08/1.27	2.88/1.01	2.43/.58	1.65/0.0

TABLE C

Rainfall Frequency 100 yrs.

Rainfall Depths:
6-hr 3.22 in.
24-hr 3.93 in.

Raintall Loss Alternative A
Parameters: RTIMP 0
IA .15
XKSAT .25
PSIF 3.5
DTHETA .35

Raintall Criteria		Max Raintall Intensity / Runoff Intensity, in/hr					
Time Distribution	Depth-Area Reduction Factor	Area, in sq. mi. .1	1	10	25	100	500
HEC-1 Input File (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maricopa County	Osborn	5.8/5.2	4.7/4.1	2.1/1.5	1.44/.74	.82/.06	.62/0.0
SCS Type II	NOAA Atlas	3.0/2.5	3.0/2.5	3.0/2.4	2.9/2.4	2.8/2.2	2.7/2.2
HMR-49		3.6/3.0	3.7/2.9	3.2/2.4	2.7/1.6	1.8/.8	.8/0.0

TABLE D

Rainfall Frequency 100 yrs.

Raintall Depths:
6-hr 3.22 in.
24-hr 3.93 in.

Rainfall Loss Alternative A
Parameters:
RTIMP 0
IA .15
XKSAT .25
PSIF 3.5
DTHETA .35

Raintall Criteria		Peak Discharge, cfs					
Time Distribution	Depth-Area Reduction Factor	Area, in sq. mi. .1	1	10	25	100	500
HEC-1 Input File (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maricopa County	Osborn	254	1369	3013	2663	330	0
SCS Type II	NOAA Atlas	145	1108	4450	6388	13,699	28,477
HMR-49		165	1188	4070	4815	6401	42
MARICOPA COUNTY	NOAA	321	1823	6374	8820	15110	27845
MARICOPA COUNTY	Q.C.	321	1801	6395	8068	12553	10178

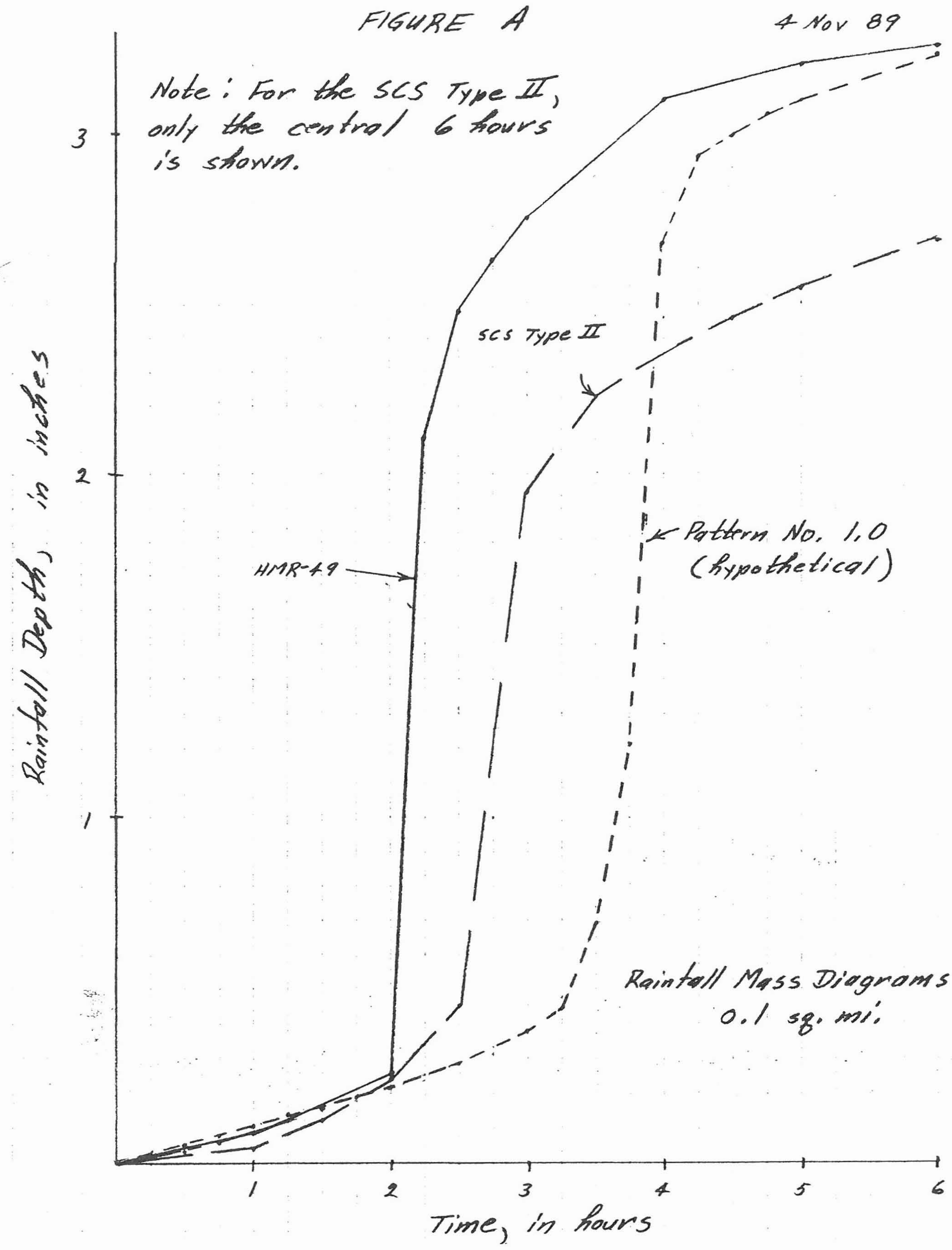


FIGURE A
4 Nov 89
Note: For the SCS Type II, only the central 6 hours is shown.
3
2
1
SCS Type II
HMR-49
Pattern No. 1.0 (hypothetical)
Raintall Mass Diagrams 0.1 sq. mi.
Raintall Depth, in inches
1
2
3
4
5
6
Time, in hours

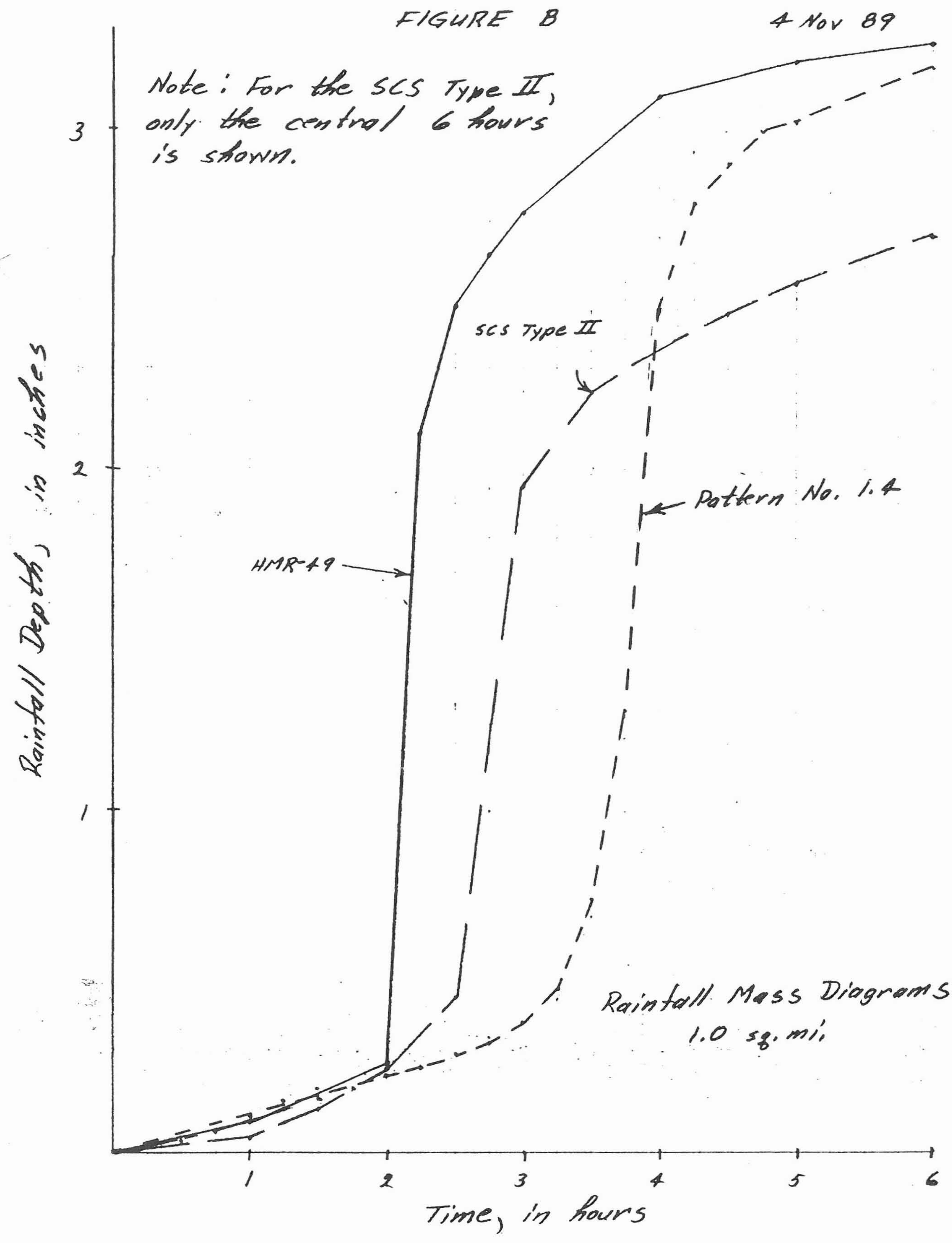
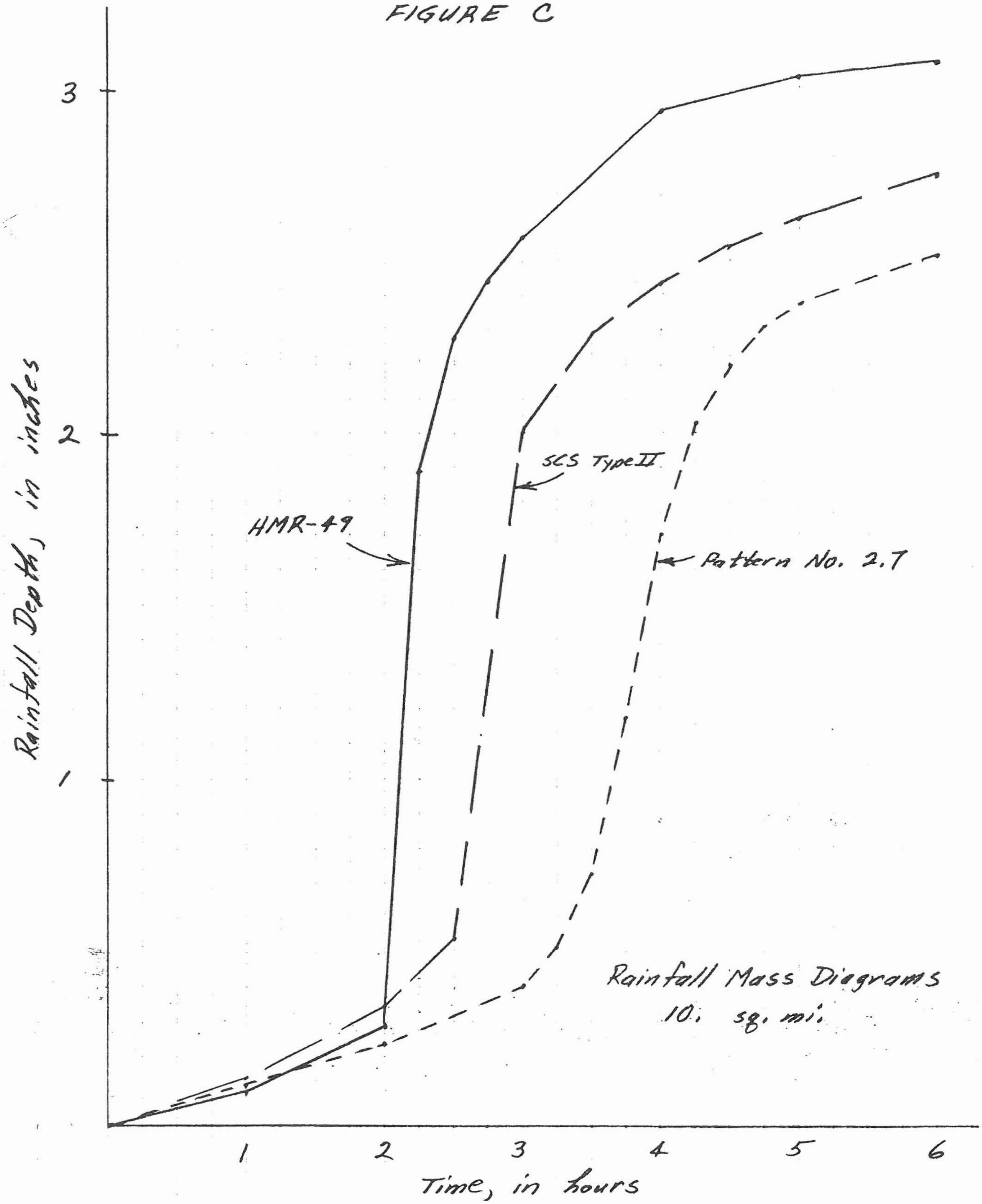


FIGURE B
4 Nov 89
Note: For the SCS Type II, only the central 6 hours is shown.
Raintall Depth, in inches
3
2
1
SCS Type II
Pattern No. 1.4
HMR-49
Raintall Mass Diagrams
1.0 sq. mi.
1
2
3
4
5
6
Time, in hours

4 Nov 89

FIGURE C



4 Nov 89

FIGURE D

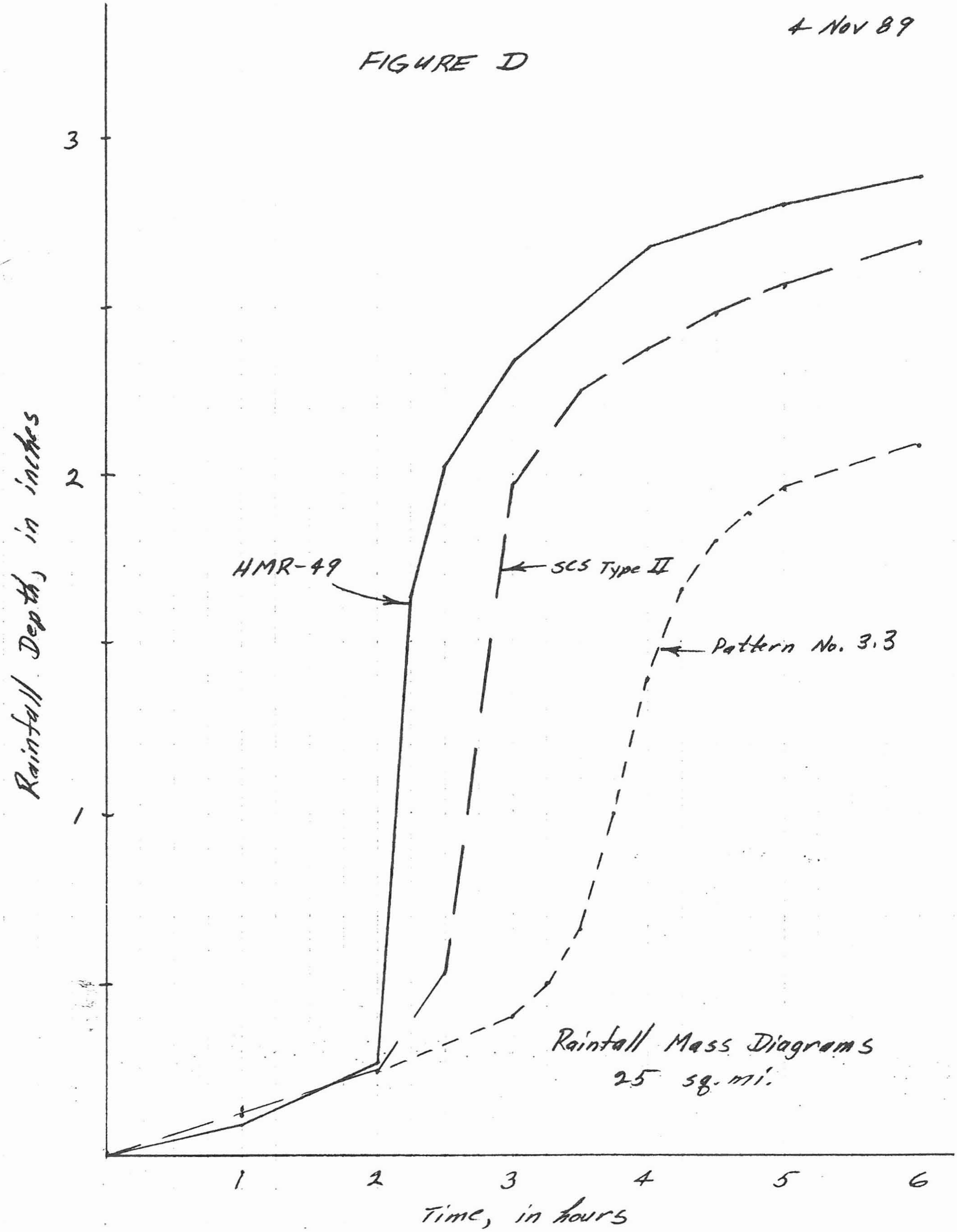
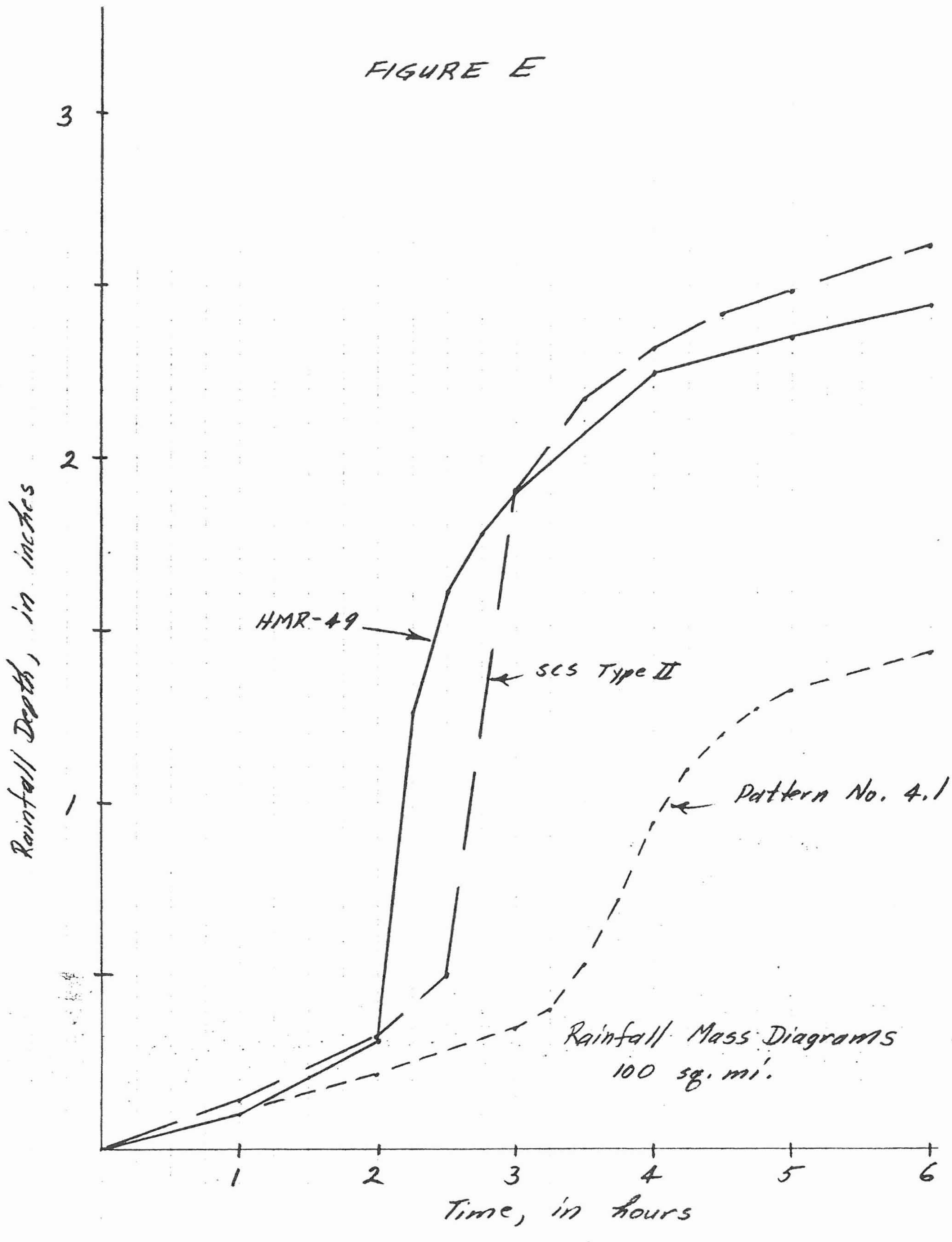
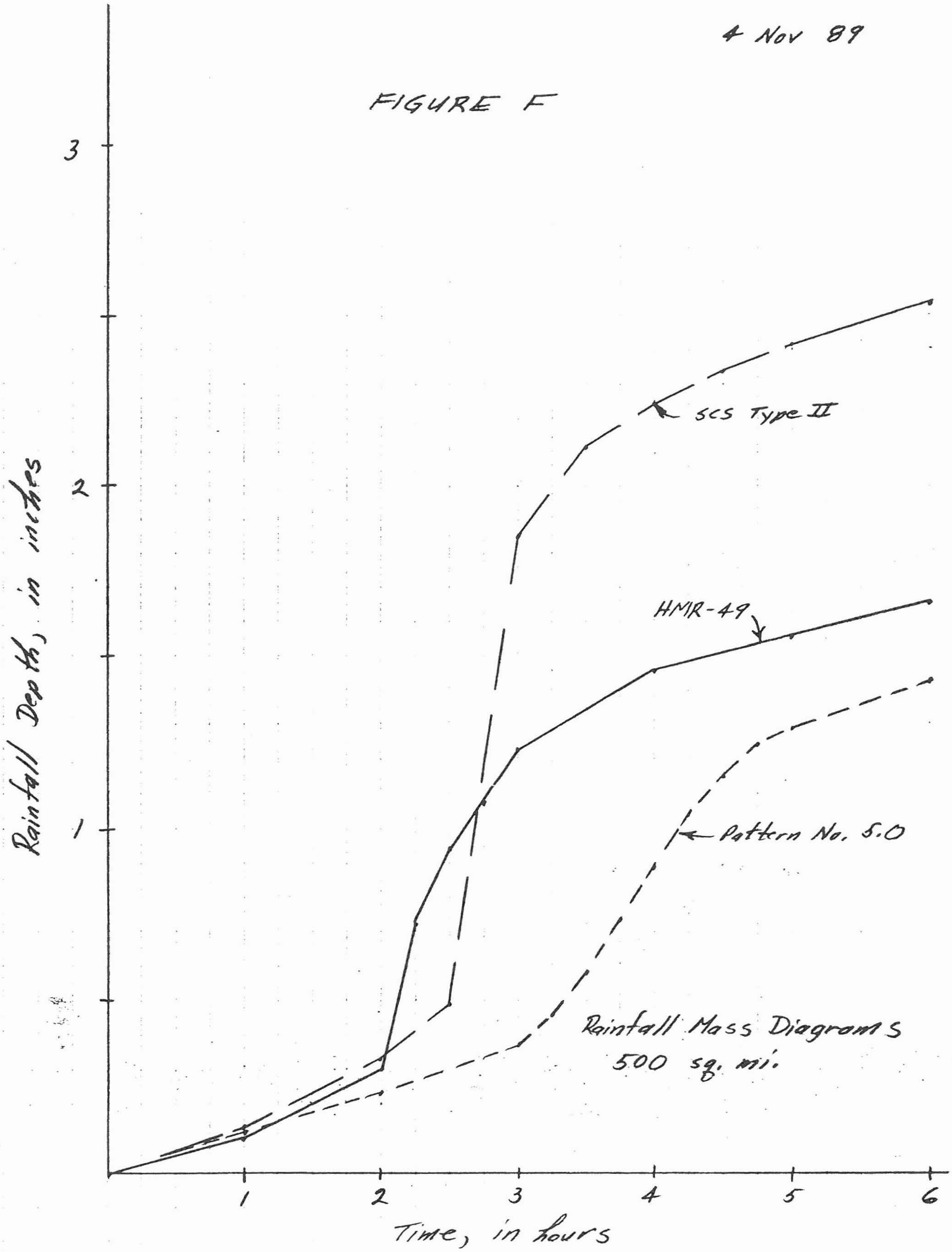


FIGURE E

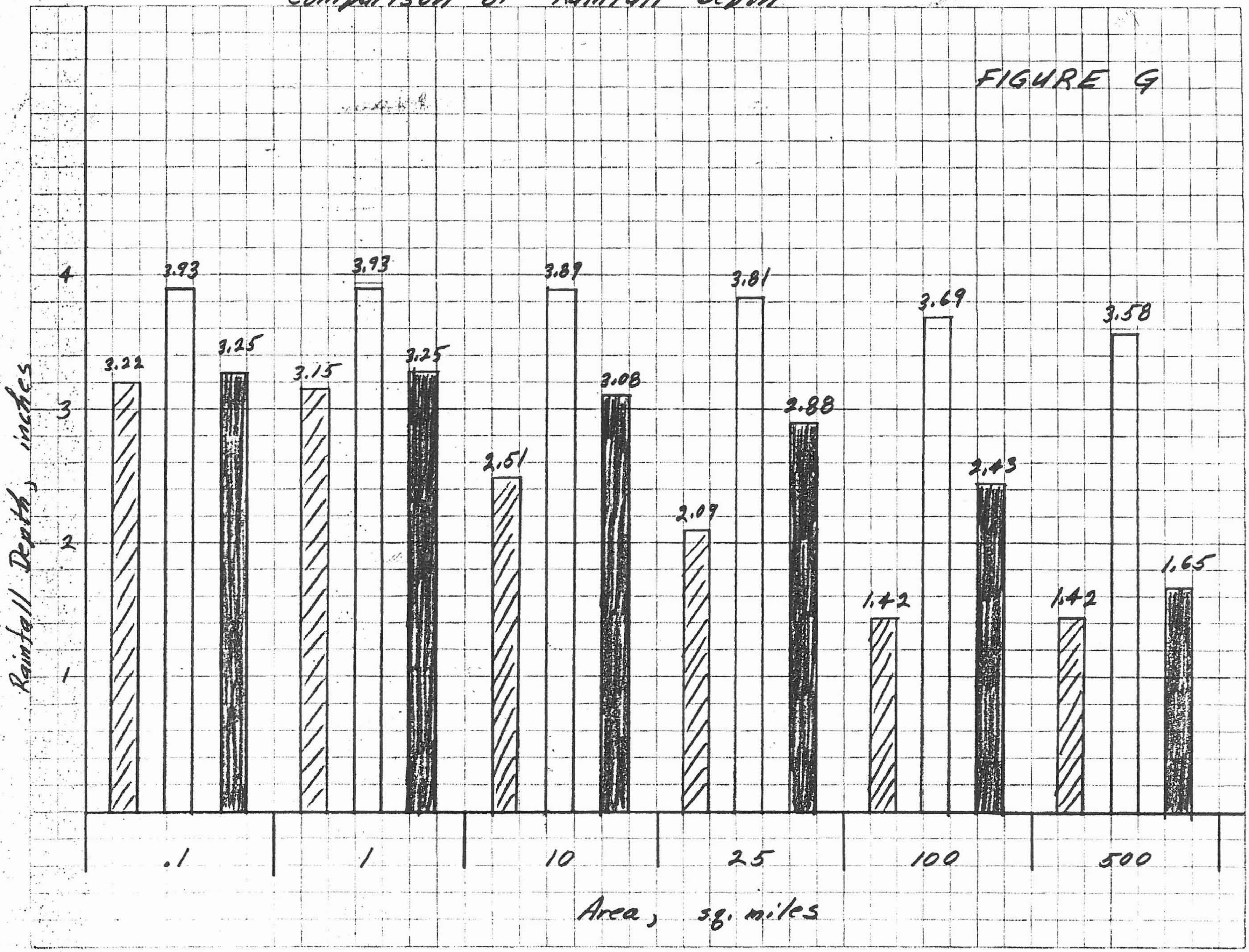

3
2
1
Rainfall Depth, in inches
HMR-49
SCS Type II
Pattern No. 4.1
Rainfall Mass Diagrams
100 sq. mi.
1
2
3
4
5
6
Time, in hours

4 Nov 89

FIGURE F



Comparison of Rainfall Depth



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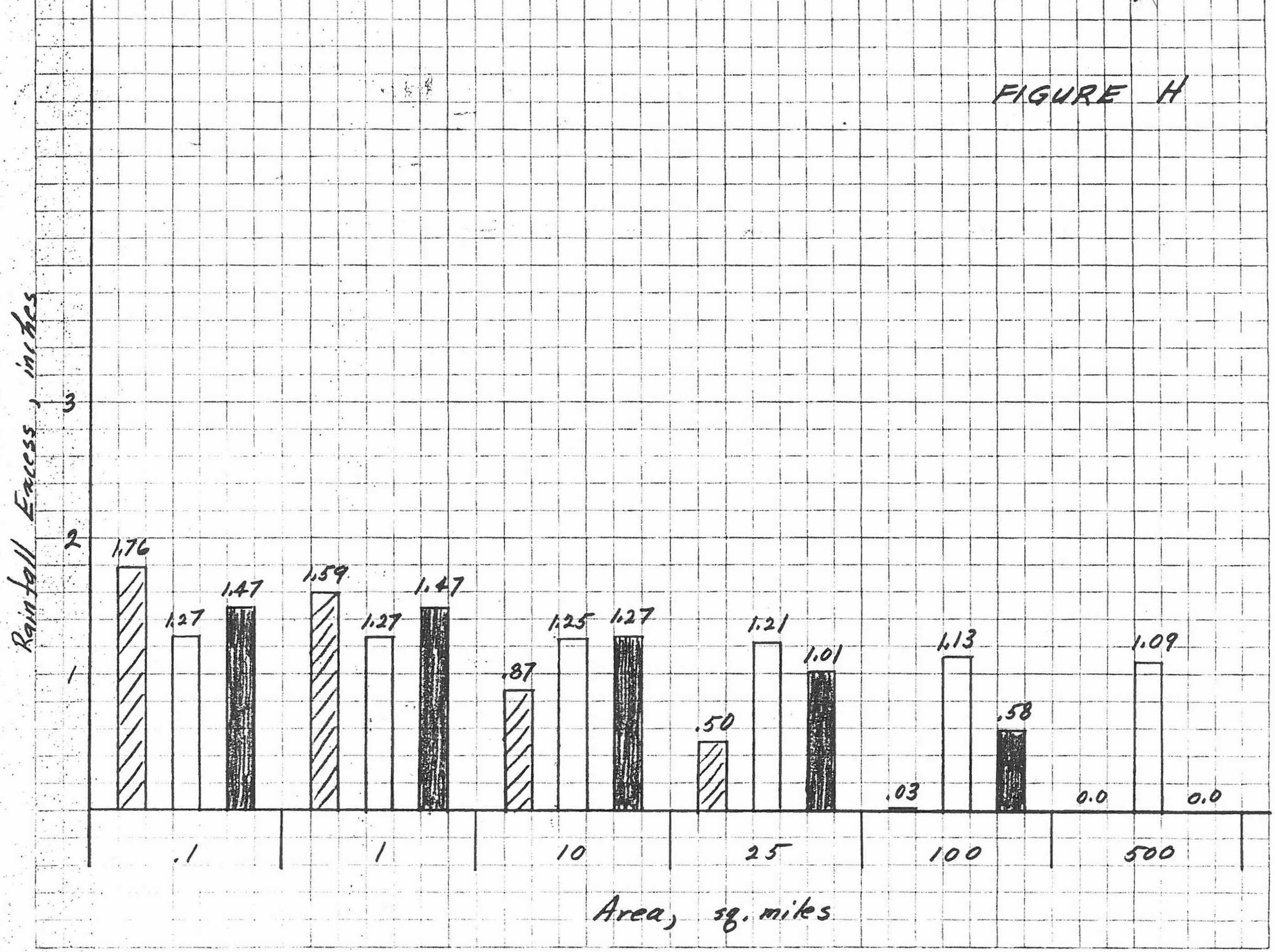
JOB NO.
BY
CHK.
DATE 6 Nov 89

Comparison of Rainfall Excess (Runoff)

FIGURE H



JOB
FEATURE
DETAIL

SHEET OF
JOB NO.
BY
CHK.
DATE 6 Nov 89

APPENDIX 1-K

Letter of August 12, 1988 to Mr. John T. Pederson of the U.S. Army Corps of Engineers, By George V. Sabol.

GEORGE V. SABOL Ph.D., P.E.
1351 EAST 141st AVENUE
BRIGHTON, COLORADO 80601
(303) 457-0989

FLOOD CONTROL DISTRICT
RECEIVED
AUG 15 88

	CH ENG		P & PM
	DEP		HYDRO
	ADMIN		LMGT
	FINANCE		FILE
	C & O		
	ENGR		

REMARKS

12 August 1988

Mr. John T. Pedersen, P.E.
U.S. Army Corps of Engineers
Los Angeles District
P.O. Box 2711
Los Angeles, California 90053-2325

Subject: Maricopa County Hydrology Manual

Dear John:

We are progressing with our efforts to develop a Maricopa County Hydrology Manual and Joe Rumann of the Flood Control District of Maricopa County and I have recently been concentrating on the design rainfall criteria. This rainfall criteria will consist of three items: 1) depth-duration-frequency information, 2) depth-area reduction factors, and 3) time distribution(s) of rainfall. The Flood Control District is planning to conduct a study to analyze regional rainfall data to update the available rainfall information, and the Arizona Department of Transporation (ADOT) is also planning a similar study for the entire state of Arizona. These two studies may be conducted independently or depending upon potential agreements for the scope of the analyses and funding the two studies could be consolidated into one project. However, whatever is the final outcome of these potential studies it will probably be at least 2 to 3 or more years before such results would be available for our use in the Hydrology Manual. Therefore, at this time we need to select design rainfall criteria for use in Maricopa County rather than rely on these future studies.

We are currently using the following guidelines in selecting rainfall criteria:

1. The criteria describes, to the best of our understanding, the actual rainfall characteristics that we believe are representative of flood producing storms in Maricopa County. For example, if 24-hour storms are not critical flood producing events then we should not select a 24-hour time distribution.
2. The selected criteria should have the consensus agreement of the regional experts in this area. Accordingly, we will coordinate with the hydrologists and hydraulic engineers of the primary agencies that deal with flooding in Arizona. This will include the Los Angeles District Corps of Engineers, Soil Conservation Service in Phoenix, Agricultural Research Service in Tucson, Arizona Department of

Transportation, Arizona Transportation Research Center, and selected individuals

3. The criteria is to be available in the literature or engineering reports and will not require extensive data analysis or original development. Some slight adjustment or modification of available information will be allowed.

We have tenatively selected NOAA Atlas 2 for the depth-duration-frequency criteria, and the depth-area reduction relations that are presented by Osborn, Lane, and Myers (1980). A copy of the depth-area reference is enclosed for your review. Incidentally, we have selected these depth-area relations over those in HYDRO-40 because the data base from Walnut Gulch that was used by Osborn is far superior than that available for the remainder of Arizona that was used in HYDRO-40 and because some of the recommendations and conclusions of HYDRO-40 are weak.

Joe Rumann and I have evaluated various rainfall distributions and have done some preliminary testing using HEC-1 and some watershed models with different methods of calculating rainfall losses and a range of loss rates. Based on these evaluations and tests we believe that the 6-hour duration storm is appropriate for the 100-year event in Maricopa County. You may recall that the Corps standard project storm for the Phoenix area is 7-hours and for Clark County is 6-hours, and therefore this appears to be consistent with the Corps' opinion for flood producing storms. Some of our thoughts and also comments of drainage engineers at the Arizona Department of Transportation are that the time distribution should have decreasing peak rainfall intensities for increasing drainage areas. In this regard we are interested in using time distribution patterns similar to those developed by the Corps for the Phoenix area and Clark County. We would need to make some modifications to these and to do that we need to have a better understanding of the analyses that were required for their development. We also have some specific questions about these.

Our needs would probably be most effectively resolved if Joe and I were to come to the LA District office. At that time I would like to review the data and analyses that were performed to develop the time distribution patterns for both the Phoenix area and Clark County. We would also like to have the opportunity to discuss these with you or others that have been involved in their development and use.

I notice that the Clark County patterns are a function of drainage area whereas the Phoenix patterns are a function of both drainage area and the 10-yr, 6-hr rainfall depth. The Phoenix patterns were developed in the early 1970s and the Clark County were only recently developed. This has prompted some questions on my part.

For Phoenix, the pattern shown in Plate 19 is selected from Plate 20 as a function of drainage area and the 10-yr, 6-hr rainfall depth. Plate 16 is used to select the 10-yr, 6-hr rainfall and this plate is taken from NOAA Atlas 2. The range of rainfall depth from Plate 16 is from 1.9 inches to 3.0 inches and this is the range for all of Maricopa County as shown in NOAA Atlas 2. Using this rainfall range with Plate 20 would mean that time distribution patterns less than number 2 would never be used. This is a little unsettling because for very small drainage areas (less than 1.0 square mile) we would like the distribution to represent the short-duration (15-minute) high-intensity rainfalls that NOAA Atlas 2 is indicating (5.68 inches/hour for 100-yr storm). Pattern 2 will not have this intensity. The limited range of application of Plate 16 is confusing to me. What is the reason for this limitation? Why is there a pattern 1 if it cannot be used?

I have some conceptual problem with the pattern number being a function of rainfall depth. For Clark County it is only a function of drainage area and this has some advantages. Is there some reason why the Phoenix and Clark County procedures for pattern selection are different?

For your convenience I have enclosed copies of the plates that I referenced and a copy of the plate for Clark County. I also enclosed copies of two handwritten tables of depth-duration-frequency and intensity-duration-frequency data for Phoenix from NOAA Atlas 2.

I will call you during the week of 15-19 August to talk to you about this. Joe and I would like to visit you in Los Angeles to review and discuss this with you and others and the week of 6-9 September would be good for us. You can advise me of an appropriate date for such a visit.

As always, your time and effort is greatly appreciated. Hopefully this will culminate in a product that will be beneficial to all of us.

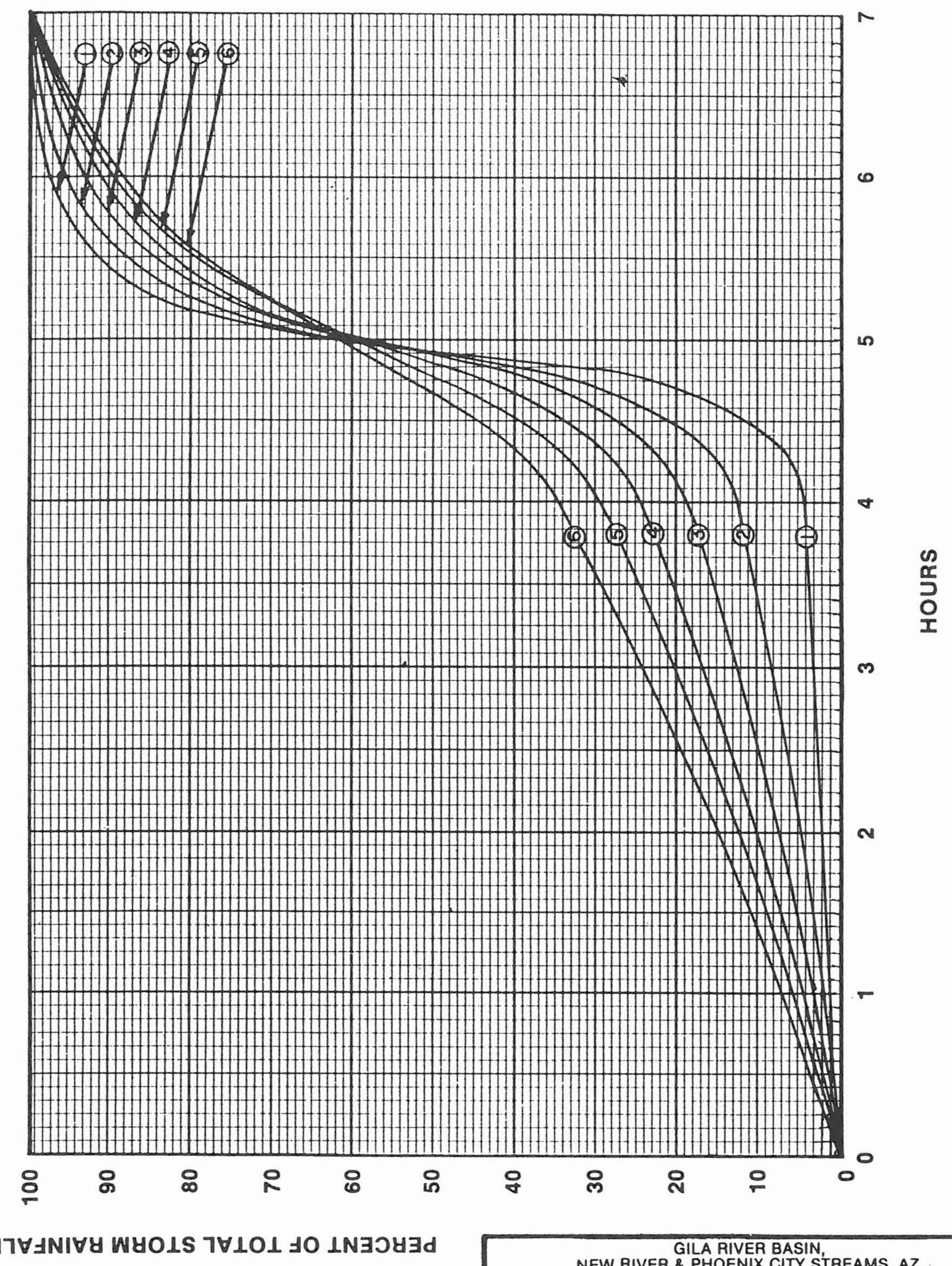
Sincerely yours,

George V. Sabol

Enclosures:

1. Plates 16, 19, 20 from Phoenix Design Memorandum No. 2, Hydrology Part 2 (1982).
2. Clark County time distribution patterns.
3. Rainfall tables for Phoenix.
4. Paper by Osborn, Lane, and Myers (1980).

Copy: Mr. Joe Rumann, Hydrologist, Flood Control District of Maricopa County
w/ all enclosures except 4.



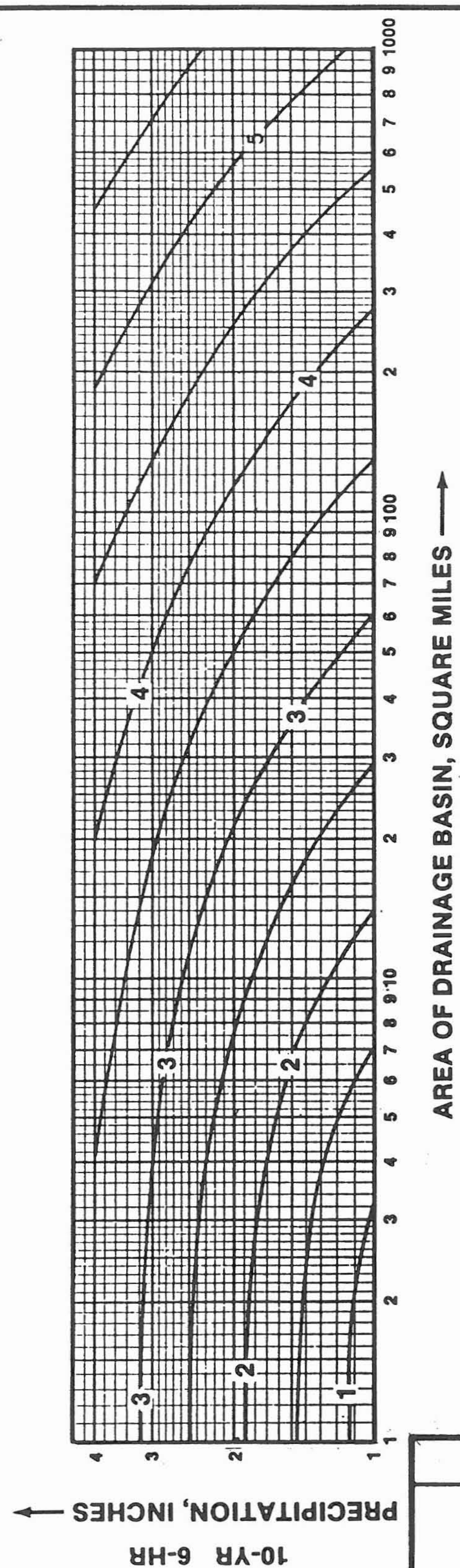
—2— PATTERN NUMBER
MAKE PATTERN NUMBER
SELECTION ON PLATE 20

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ.

ARIZONA
STANDARD PROJECT LOCAL
SUMMER STORM
PRECIPITATION PATTERNS

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT



—2— PATTERN NUMBER

REFER TO PLATE 19
FOR ACTUAL PATTERN

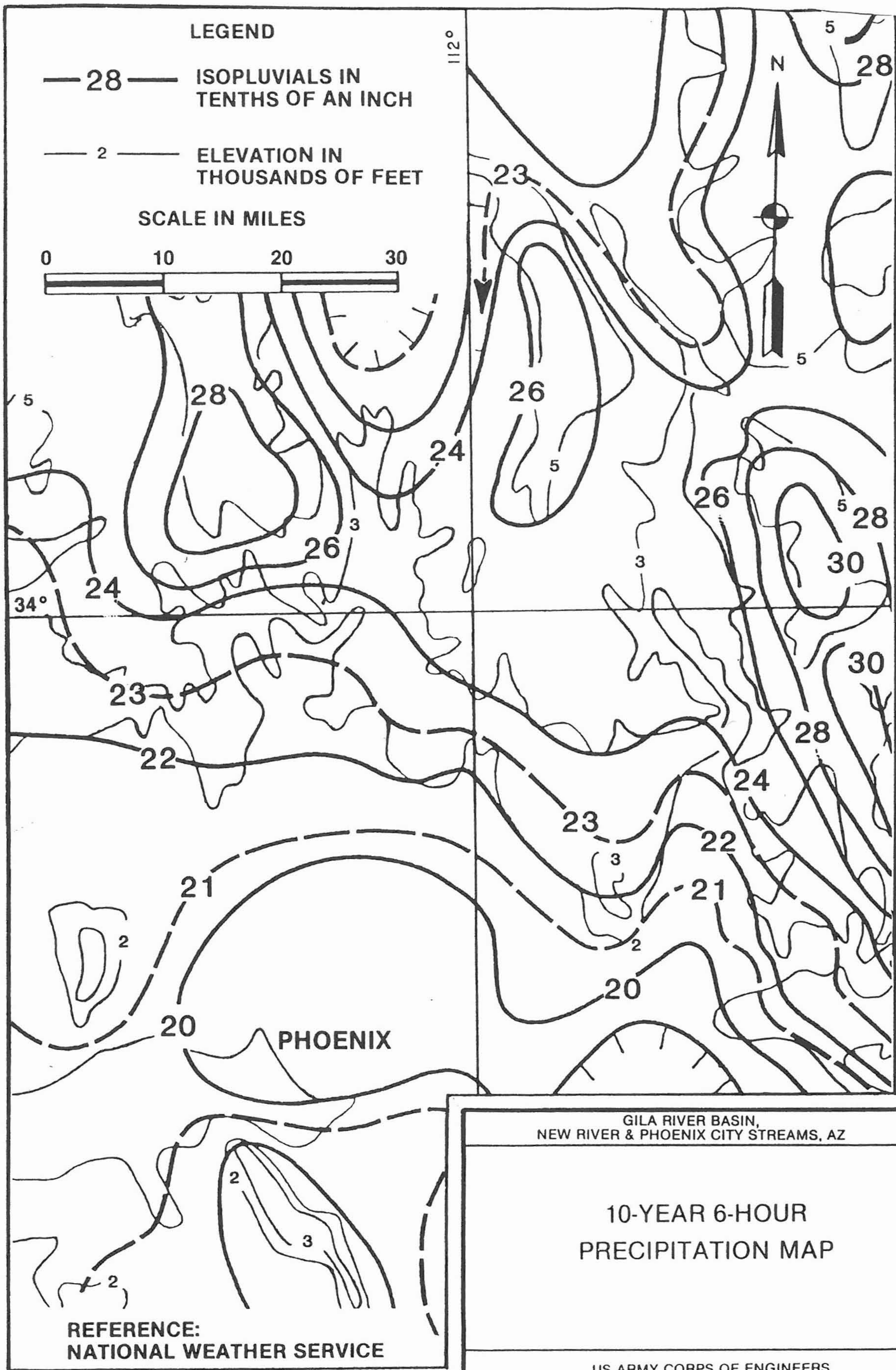
GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ.

ARIZONA STANDARD PROJECT LOCAL SUMMER STORM PRECIPITATION-AREA-PATTERN CURVES

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

(SOURCE: REF. 2)

to use directly



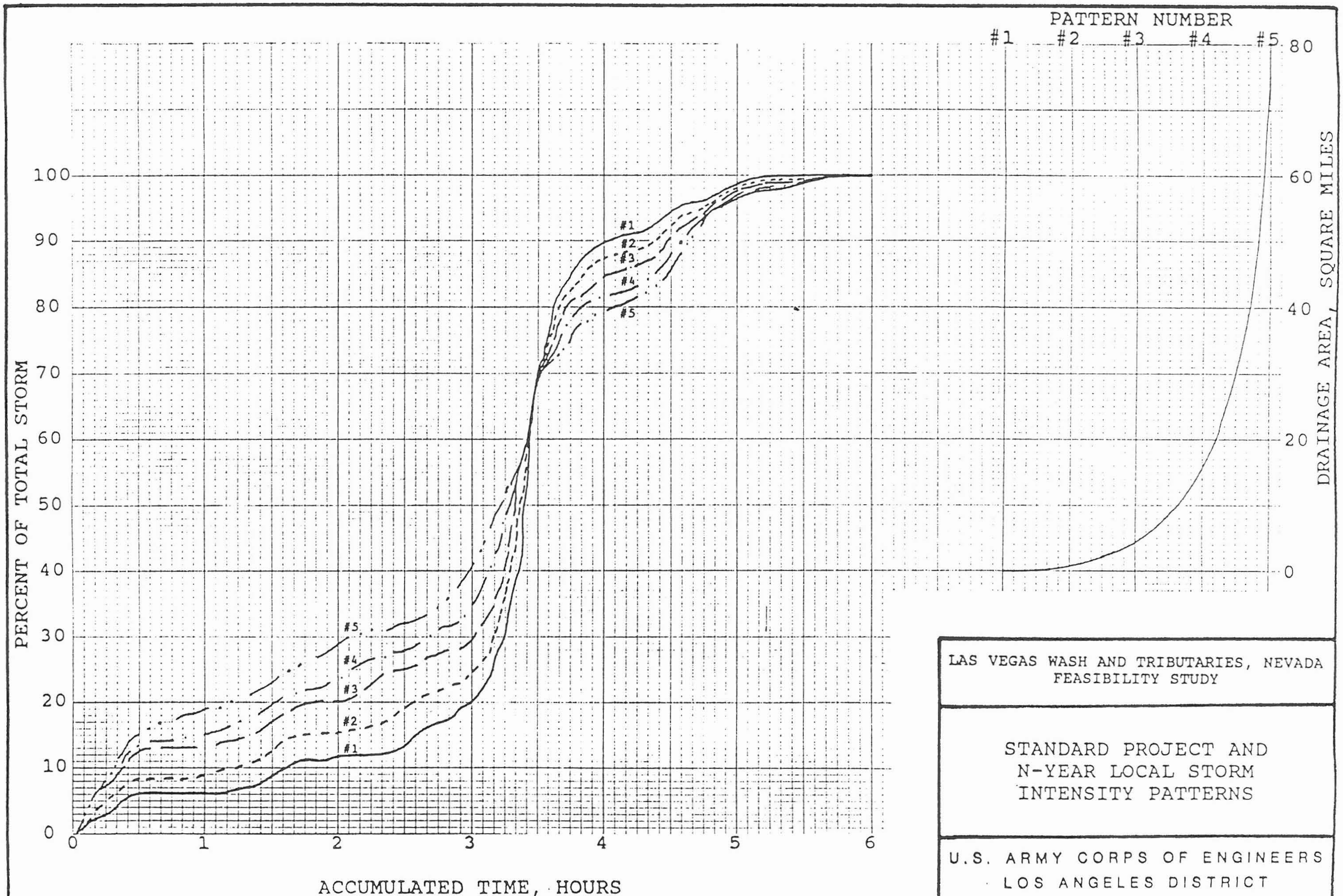
(SOURCE: REF. 2)

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

10-YEAR 6-HOUR PRECIPITATION MAP

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

(revised 2/83)



LAS VEGAS WASH AND TRIBUTARIES, NEVADA
FEASIBILITY STUDY

STANDARD PROJECT AND
N-YEAR LOCAL STORM
INTENSITY PATTERNS

U.S. ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

am Dg
19 May 88
81

TABLE P-3

Depth-Duration-Frequency Data for Phoenix, Arizona.

Duration	Depth, in inches for the indicated return periods					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-min	.27	.38	.46	.55	.64	.72
10-min	.42	.59	.71	.86	.99	1.12
15-min	.54	.75	.89	1.08	1.25	1.42
30-min	.74	1.03	1.24	1.50	1.73	1.97
1-hr	.94	1.31	1.57	1.90	2.19	2.49
2-hr	1.03	1.44	1.73	2.09	2.41	2.74
3-hr	1.08	1.53	1.84	2.21	2.56	2.91
6-hr	1.19	1.69	2.04	2.45	2.84	3.22
12-hr	1.29	1.86	2.23	2.70	3.13	3.57
24-hr	1.40	2.03	2.42	2.96	3.44	3.93

am Dg
19 May 88
10/

TABLE P-4

Intensity-Duration-Frequency Data for Phoenix, Arizona.

Duration (1)	Intensity, in inches per hour for the indicated return period					
	2-yr (2)	5-yr (3)	10-yr (4)	25-yr (5)	50-yr (6)	100-yr (7)
5-min	3.24	4.56	5.52	6.60	7.68	8.64
10-min	2.52	3.54	4.26	5.16	5.94	6.72
15-min	2.16	3.00	3.56	4.32	5.00	5.68
30-min	1.48	2.06	2.48	3.00	3.46	3.94
1-hr	.94	1.31	1.57	1.90	2.19	2.49
2-hr	.52	.72	.86	1.04	1.20	1.37
3-hr	.36	.51	.61	.74	.85	.97
6-hr	.20	.28	.34	.41	.47	.54
12-hr	.11	.16	.19	.23	.26	.30
24-hr	.06	.08	.10	.12	.14	.16

APPENDIX 1-L

U.S. Department of Commerce, Depth-Area Ratios in the Semi-Arid Southwest United States, NOAA Technical Memorandum HYDRO-40, Silver Spring, Md., August 1984.

Osborn Herbert B., Leonard J. Lane, Vance A. Myers. Rainfall/ Watershed Relationships for Southwestern Thunderstorms, Soil and Water Division, ASAE, Paper No. 77-2541, May 1979.

NOAA Technical Memorandum NWS HYDRO-40

DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES

Silver Spring, Md.
August 1984

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

NOAA TECHNICAL MEMORANDUMS

National Weather Service, Office of Hydrology Series

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Publications listed below are available from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161. Prices on request. Order by accession number (given in parentheses). Information on memorandums not listed below can be obtained from Environmental Science Information Center (OA/D812), NOAA, Rockville, MD 20852.

Weather Bureau Technical Notes

TN 44 HYDRO 1 Infrared Radiation From Air to Underlying Surface. Vance A. Myers, May 1966, 35 pp. (PB-170-664)

ESSA Technical Memorandums

WBTM HYDRO 2 Annotated Bibliography of ESSA Publications of Hydrometeorological Interest. J. L. H. Paulhus, February 1967, 20 pp. (Superseded by WBTM HYDRO 8)

WBTM HYDRO 3 The Role of Persistence, Instability, and Moisture in the Intense Rainstorms in Eastern Colorado, June 14-17, 1965. F. K. Schwarz, February 1967, 21 pp. (PB-174-609)

WBTM HYDRO 4 Elements of River Forecasting. Marshall M. Richards and Joseph A. Strahl, October 1967, 61 pp. (Superseded by WBTM HYDRO 9)

WBTM HYDRO 5 Meteorological Estimation of Extreme Precipitation for Spillway Design Floods. Vance A. Myers, October 1967, 29 pp. (PB-177-687)

WBTM HYDRO 6 Annotated Bibliography of ESSA Publications of Hydrometeorological Interest. J. L. H. Paulhus, November 1967, 27 pp. (Superseded by WBTM HYDRO 8)

WBTM HYDRO 7 Meteorology of Major Storms in Western Colorado and Eastern Utah. Robert L. Weaver, January 1968, 75 pp. (PB-177-491)

WBTM HYDRO 8 Annotated Bibliography of ESSA Publications of Hydrometeorological Interest. J. L. H. Paulhus, August 1968, 25 pp. (Superseded by NWS HYDRO 22)

WBTM HYDRO 9 Elements of River Forecasting (Revised). Marshall M. Richards and Joseph A. Strahl, March 1969, 57 pp. (PB-185-969)

WBTM HYDRO 10 Flood Warning Benefit Evaluation--Susquehanna River Basin (Urban Residences). Harold J. Day, March 1970, 42 pp. (PB-190-984)

WBTM HYDRO 11 Joint Probability Method of Tide Frequency Analysis Applied to Atlantic City and Long Beach Island, N.J. Vance A. Myers, April 1970, 109 pp. (PB-192-745)

NOAA Technical Memorandums

NWS HYDRO 12 Direct Search Optimization in Mathematical Modeling and a Watershed Model Application. John C. Monro, April 1971, 52 pp. (COM-71-00616)

NWS HYDRO 13 Time Distribution of Precipitation in 4- to 10-Day Storms--Ohio River Basin. John F. Miller and Ralph H. Frederick, July 1972, 41 pp. (COM-72-11139)

NWS HYDRO 14 National Weather Service River Forecast System Forecast Procedures. Staff, Hydrologic Research Laboratory, December 1972, 7 chapters plus appendixes A through I. (COM-73-10517)

NWS HYDRO 15 Time Distribution of Precipitation in 4- to 10-Day Storms--Arkansas-Canadian River Basins. Ralph H. Frederick, June 1973, 45 pp. (COM-73-11169)

(Continued on inside back cover)

NOAA Technical Memorandum NWS HYDRO-40

DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES

Raymond M. Zehr and Vance A. Myers

Office of Hydrology
Silver Spring, Md.
August 1984

UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and
Atmospheric Administration
John V. Byrne, Administrator

National Weather Service
Richard E. Hallgren,
Assistant Administrator

TABLE OF CONTENTS

LIST OF FIGURES

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List of Symbols

A — area

b — coefficient used in equations that model the data (see Appendixes II and III)

C_x — calibration factor used to place final curves between bounds

cv — coefficient of variation (see Appendix I)

cov — covariance between precipitation amounts at two stations (see Appendix I)

DA — depth-area ratio

d — distance

d_s — distance separating exponential model (inner) from linear model (outer)

f — frequency (reciprocal of return period)

K_t — coefficient in Chow's equation, depends on return period

M — coefficient used in equations that model the data (see Appendixes II and III)

N — number of observations

P_5 — 5-station average precipitation

s — standard deviation of precipitation amounts

$\overline{X}$ — average of precipitation amounts

y — fitted value of model statistic

Subscripts

A, B — designate annual maxima at particular stations associated with station-pair statistics

a, b — designate precipitation amount at second station that is concurrent with the annual maximum at the first station
b is also used to designate the statistic for station-pair totals made up of the annual maximum at one station and the concurrent amount at the second station

L — designates "final" statistic fit between bounding values with the aid of the calibration constant (C_x)

m — designates annual maximum of station-pair total

in — designates smaller distances where exponential model is used

out	designates larger distances where linear model is used
t	designates specific return period, i.e., "t" years

Superscripts

The prime (') is used to designate relative values, that is individual values normalized by maxima. Any primed quantity has a value ranging from 0 to 1.

DEPTH-AREA RATIOS IN THE SEMI-ARID SOUTHWEST UNITED STATES

Raymond M. Zehr* and Vance A. Myers+
Office of Hydrology
National Weather Service, NOAA, Silver Spring, MD 20910

ABSTRACT Geographically fixed depth-area ratios are estimated for Arizona and western New Mexico. While the study relies on a methodology for computing depth-area ratios from dense network data, modification of the approach was necessary to extend the results to data sparse regions. Available data indicate that reductions of point rainfalls for area size in the semi-arid Southwest are greater than previously published nationwide average depth-area curves.

1. INTRODUCTION

1.1 Purpose and Definition of Depth-Area Ratios

A knowledge of rainfall frequencies is basic to the design of many runoff carrying structures and to decisions on flood plain occupancy. Rainfall frequencies for these purposes are published as maps of point rainfalls for specified durations. For many problems the design engineer or investigator needs the corresponding frequency values for depth of rainfall averaged over a basin. To meet this need, nomograms are published giving the conversion factor necessary to estimate areal average depths at a particular location based on published point rainfall-frequency values. These adjustment factors are geographically fixed depth-area ratios. They are defined as ratios of two rainfalls, point values and areal average values with the same return periods. They are not

*Current affiliation Regional and Mesoscale Meteorology Branch, National Environmental Satellite, Data, and Information Service, and Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Ft. Collins, CO.

+Currently, Consulting Meteorologist, Fairfax, VA

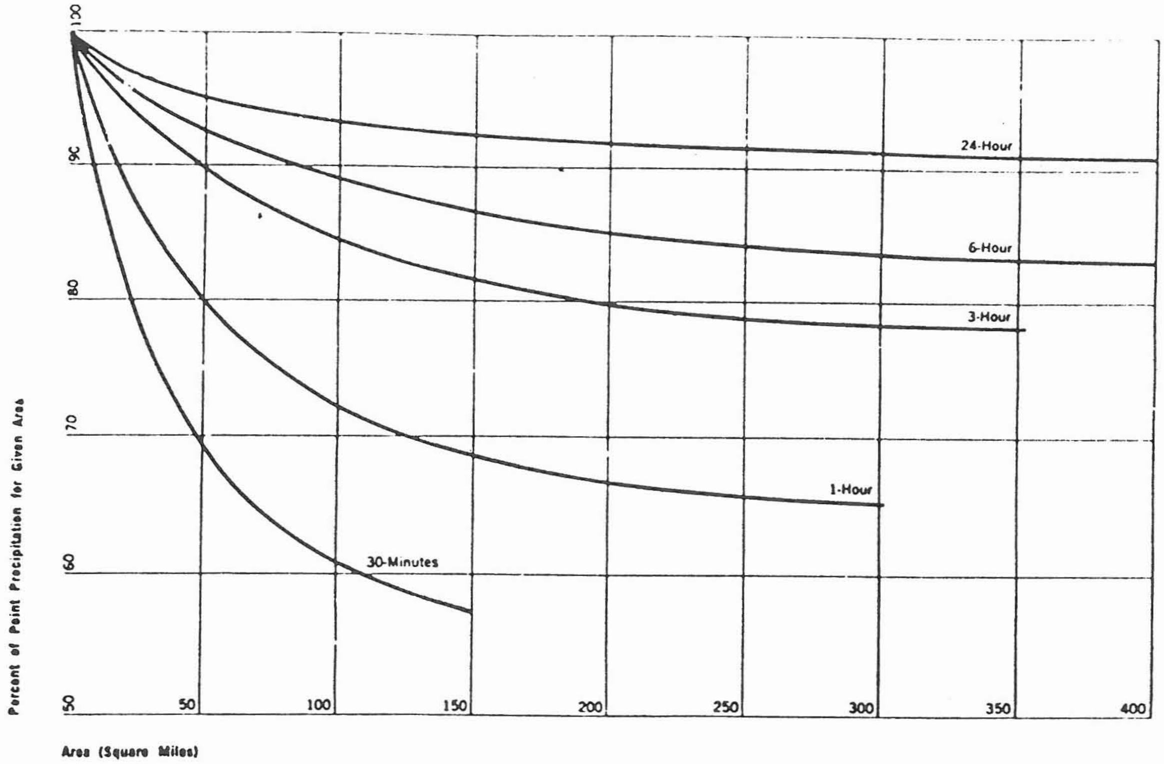

Figure 1.--Depth-area ratios from NOAA Atlas 2 (Miller et al. 1973).

necessarily dependent on the same set of storms, i.e., specific values in both the numerator and denominator may come from different precipitation events. Similar ratios based on the morphology of individual storms are termed storm-centered depth-area ratios.

1.2 Previous Work

A nomogram of geographically fixed depth-area ratios was first published by the U.S. Weather Bureau (now the National Weather Service, NWS) in the late 1950's in U.S. Weather Bureau Technical Paper No. 29 (U.S. Weather Bureau 1957-60). Such nomograms were based on data from dense networks of recording gages. Only a limited amount of such data is available. All data was pooled to produce a national-average depth-area nomogram (fig. 1). Reanalysis of basic data for various subsequent atlases indicated no evidence that would warrant changes in the nationwide average nomogram.

Osborn et al. (1980) analyzed 20 years of dense network recording raingage data from the Agricultural Research Service experimental watershed at Walnut Gulch in southeast Arizona to develop geographically fixed depth-area ratios. Data from this network are not routinely published and only recently have been available in a computer compatible form. (They were not available for the earlier atlases.) The results of this analysis for durations from 30 min to 6 hrs are reproduced in figure 2 and show significant differences from the national average curves. At Walnut Gulch, the depth-area ratios decrease more rapidly with increasing area than those published in NOAA Atlas 2 (Miller et al. 1973).

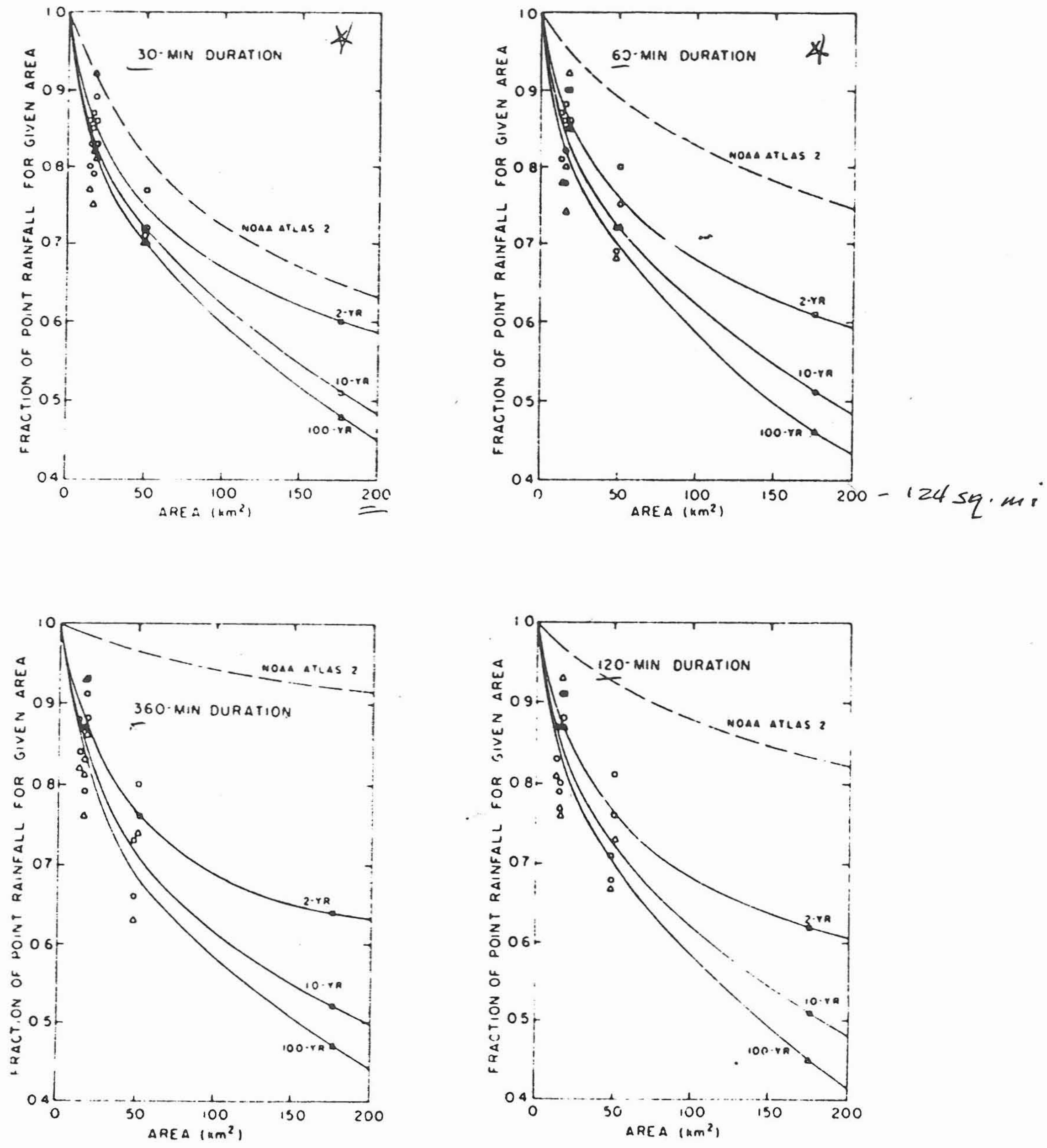

Figure 2.--Depth-area ratios at Walnut Gulch, Arizona, for durations of 30-min, 1-, 2-, and 6-hr (Osborn et al. 1980).

In NOAA Technical Report No. 24 (Myers and Zehr 1980), the methodology for computing geographically fixed depth-area ratios was extended and a model developed that permitted the estimation of upper and lower bounds on depth-area ratios from simultaneous rainfall records at station pairs, with calibration of the specific curve within these bounds using a few 5-station groups. There is considerable reliance in the present work on that study, hereafter referred to as TR 24. Some familiarity with that report will be assumed and the references to it will be concise.

1.3 Objective of Present Study

The objective of this study is to derive depth-area ratios in a form suitable for engineering use for a substantial portion of Arizona and New Mexico. This involves, a) developing depth-area ratios for Walnut Gulch for 24 hr, a duration not included in the study by Osborn et al. (1980), b) extending the Walnut Gulch ratios to areas larger than the original 79.5 mi^2 (200 km^2), and c) defining a region over which the Walnut Gulch curves apply and additional regions over which they apply with modification.

The 24-hr duration is necessary for maximum utility in hydrologic procedures of the Soil Conservation Service which uses 24 hr as a basic duration, and as the vehicle for exploring within-region and inter-region depth-area ratio variations. For reasons related to storm characteristics to be discussed later, the geographic variation of depth-area ratios is greater at 24 hr than at shorter durations.

2. WALNUT GULCH, ARIZONA, 24-HR DEPTH-AREA RATIOS

2.1 Data

Precipitation data are archived at the Agricultural Research Service experimental watersheds by accumulations at break points, i.e., precipitation accumulation and time and date at selected points on a recorder trace. Connecting these points by straight lines approximates the recorder trace (precipitation mass curve). These data cannot be processed directly for frequency analysis. Amounts for successive standard durations, such as an hour or a day must be abstracted by interpolation for an entire period of record.

Annual maxima, used for depth-area ratio evaluation, can then be abstracted for the standard durations or combinations of them.

In the analyses for the various National Weather Service atlases, the 24-hr annual maxima depict the greatest precipitation amounts for any consecutive 1440-min interval. When using either hourly or daily observations, at least a few annual maxima will be less than those for 1440 consecutive minutes because the fixed observation time can cause the 1440-min amount to be partitioned. An empirical factor, applied to the precipitation-frequency values, is used to adjust for this effect in NWS atlases. The Walnut Gulch 24-hr depth-area ratios derived here are based on a fixed clock time without adjustment. The Southwest Watershed Research Center abstracted 15 yr of 24-hr 2 a.m. to 2 a.m. MST rainfall data at twenty Walnut Gulch gages (fig. 3) and furnished these data to this project. The 2 a.m. time was chosen as most often falling between, rather than during storms. In comparison to other uncertainties, it seems unlikely that dimensionless ratios of areal-to-point values for these 24-hr periods would differ significantly from 1440-min data.

2.2 Station Groups

The TR 24 method of depth-area ratio analysis was followed with these Walnut Gulch data. The approach involves deriving basic statistics from pairs of stations distributed over available interstation distances, and statistics from five-station sets. The selected pairs are listed in table 1 and the five-station groups in table 2. The latter are chosen as being most like the desired configuration of a single center station and four outer stations with uniform spacing. Two examples are depicted in figure 4.

2.3 Depth-Area Ratios

The first step in determining depth-area ratios, using the TR 24 method, required the determination of $\overline{X}'_m$, s'_m, $\overline{X}'_b$, s'_b, and cov'_{Ab} using the station pairs. Formal mathematical definitions of these statistics are found in Appendix I. The notation here is identical with that in TR 24. $\overline{X}'_m$ and s'_m are the relative mean and standard deviation of the annual maximum series of two-station total precipitation. They are expressed as ratios of the station-pair statistics to the individual station statistics, and thus, are termed relative. $\overline{X}'_b$, s'_b and cov'_{Ab} are the relative mean, standard deviation and

Table 1.--Walnut Gulch station pairs for 24-hr analysis

Pair no.	Stations		Distance (mi)	Pair no.	Stations		Distance (mi)
41	1	3	0.9	51	1	30	7.7
42	56	54	1.1	59	33	70	8.3
43	66	68	1.3	57	23	68	8.8
44	29	30	1.6	53	8	56	9.1
45	3	8	1.9	54	9	60	9.6
32	3	9	2.1	40	11	66	10.1
31	1	9	2.4	64	3	56	10.7
39	30	33	2.8	69	18	68	10.7
46	44	60	3.0	66	8	66	11.4
47	30	44	4.1	60	18	70	11.7
48	33	56	5.0	61	1	60	12.3
50	47	54	5.1	68	9	70	12.8
56	18	44	5.6	67	8	70	13.0
55	11	47	6.3	65	3	68	13.8
52	3	29	6.7	62	1	68	14.5
58	30	66	7.4	63	1	70	15.3
49	1	29	7.5				

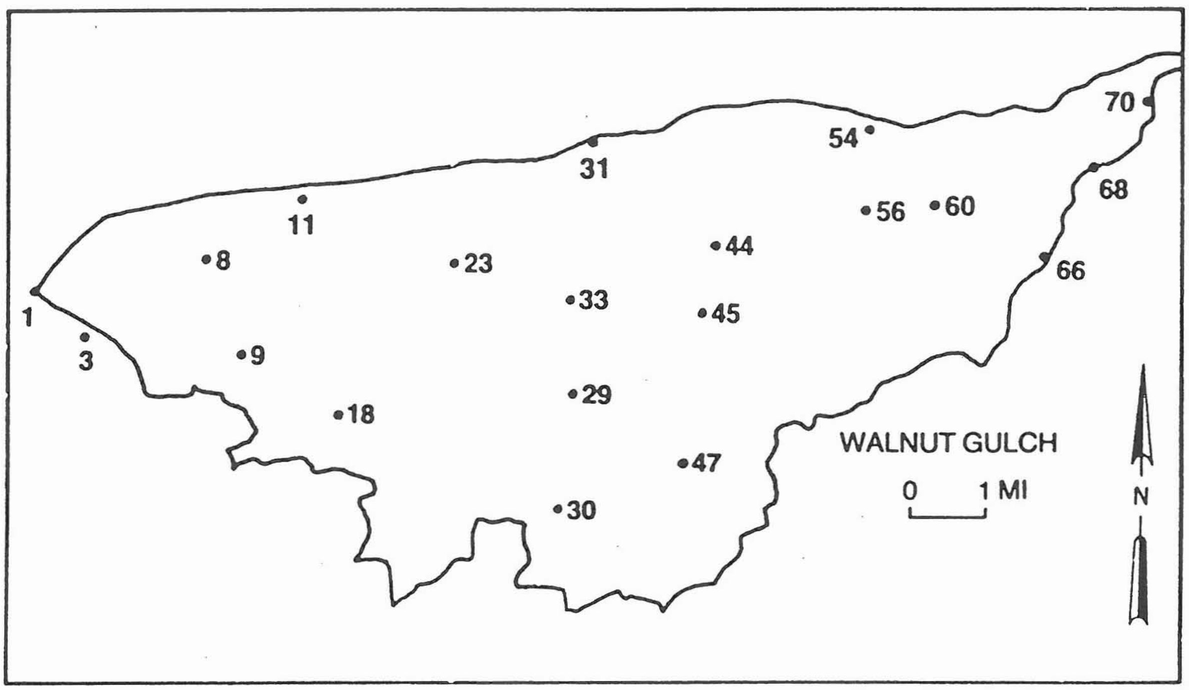

Figure 3.--Walnut Gulch, Arizona, basin and rain gages used for 24-hr analysis. Numbers are station identifiers.

Table 2.--Walnut Gulch 5-station groups for 24-hr analysis

Group no.	Center station	Surrounding stations				$\bar{d}$(mi)
13	33	23	29	31	45	1.70
11	29	18	30	33	45	2.03
16	60	44	54	66	68	2.03
14	33	18	30	31	44	2.15
19	8	1	3	11	18	2.15
12	29	18	23	45	47	2.33
15	45	29	31	47	56	2.35
10	23	11	18	29	31	2.40
17	33	11	18	47	56	3.78
18	45	18	30	54	66	4.10

$\bar{d}$ = average of the four distances from the center station to the surrounding stations.

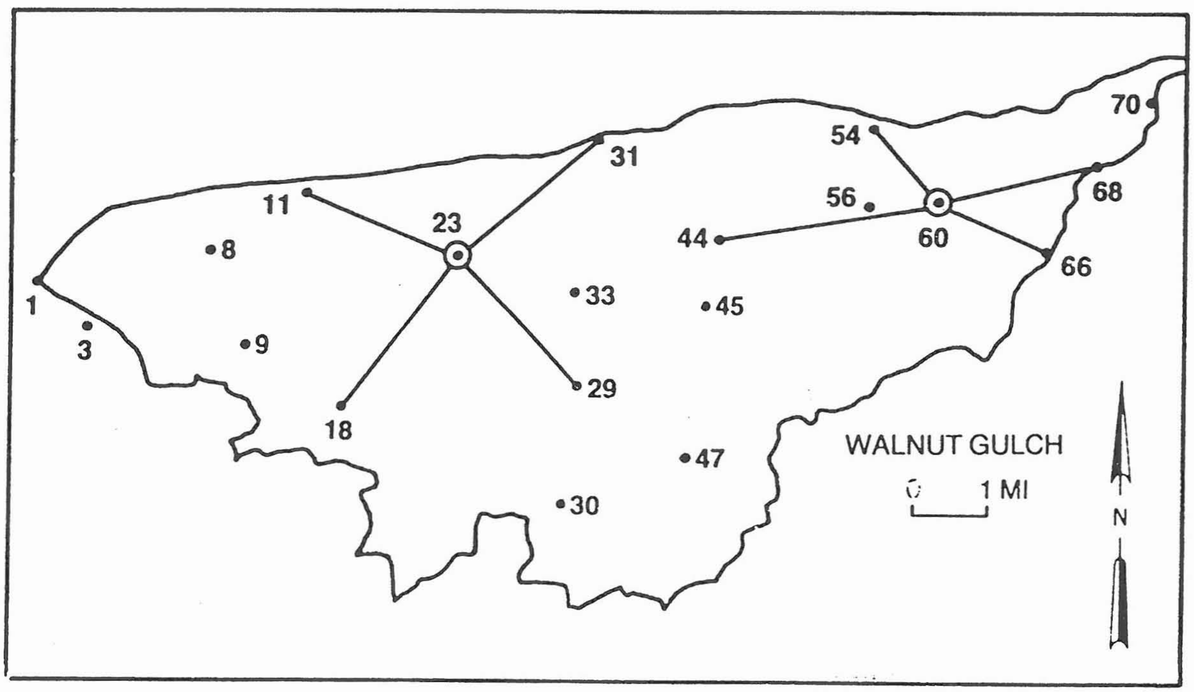

Figure 4.--Typical examples of two of the ten five-station groups listed in table 2.

covariance of rain falling at one member of a station pair simultaneous with annual maximum rainfall at the other member of the pair. These statistics were fit to analytic curves in a manner similar to that used in TR 24. The fitting coefficients and formula are included in Appendix II.

The TR 24 method combines curves fit to station-pair statistics vs. interstation distance and theoretical considerations to estimate bounds for the relative mean, $\overline{X}'_L$, and the relative standard deviation, s'_L, of the annual series of areal average rainfall. Five-station statistics are then used as a calibration to place $\overline{X}'_L$ and s'_L curves vs. area between the bounds. Values from these curves are used to compute depth-area ratios as functions of area and return period.

The results of this methodology applied to 24-hr Walnut Gulch data are shown in figures 5 and 6. The 24-hr depth-area curves for 2-, 10-, and 100-yr return periods calculated from the adopted $\overline{X}'_L$ and s'_L appear in figure 5. Combining 24-hr results with the 30-min to 6-hr depth-area ratios from Osborn et al. (1980) produced the depth area ratio vs. duration curves in figure 6. It is noted that the 24-hr Walnut Gulch results are a reasonable complement to the curves of Osborn et al., which were derived by an independent method. A limited comparison of these two methods for developing depth-area curves revealed small differences in results. The technique of Osborn et al., produced curves with a somewhat greater reduction for area than those developed by the TR 24 method. The differences were not considered significant and were well within the range of differences expected from analyzing the data by different methods.

3. EXTENSION BEYOND WALNUT GULCH

More widely spaced precipitation data and other clues were used in an attempt to define the area for which the Walnut Gulch depth-area ratios are valid, and other areas where they may be applicable with some modification. The intent was to delineate zones with climate sufficiently homogeneous to justify using a common set of depth-area ratios in engineering applications. Zone definition was necessarily based on inferences from limited information.

3.1 Data Types

Ideally, data would be available at closely spaced intervals throughout the study area and would be suitable for direct calculation of depth-area ratios.

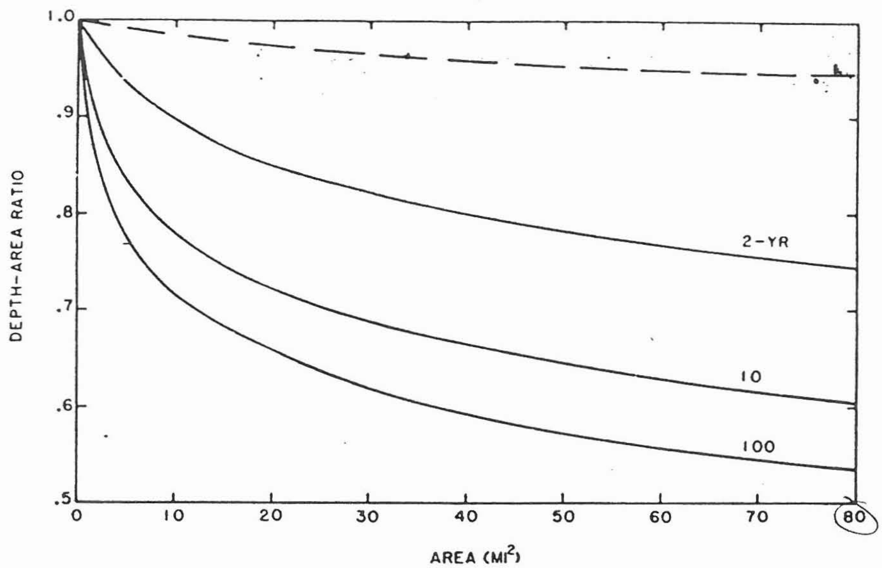

Figure 5.--24-hr depth-area ratio at Walnut Gulch for 2-, 10-, and 100-yr return periods. The dashed line is the NOAA Atlas 2 (Miller et al. 1973) 24-hr depth-area curve.

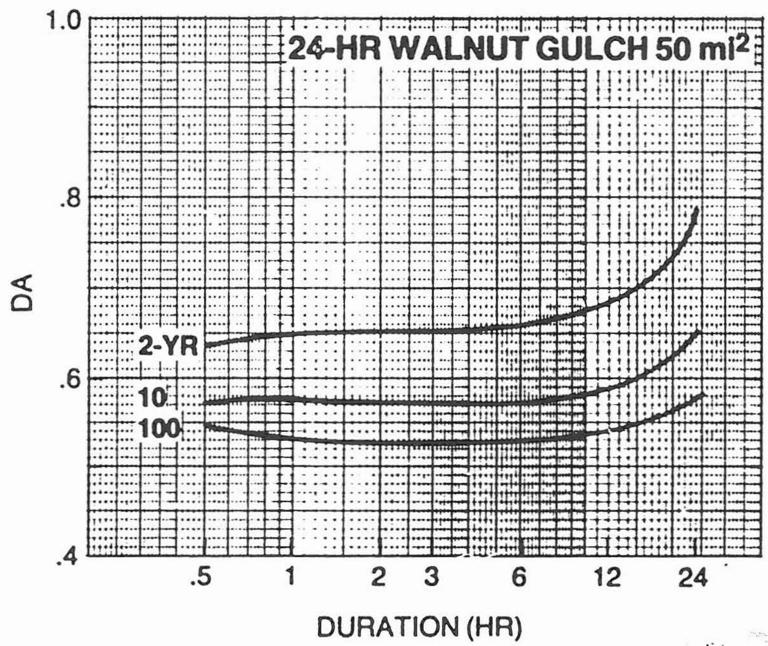

Figure 6.--Depth-area ratio vs. duration at 50 mi^2 (129.5 km^2) for 2-, 10-, and 100-yr return periods. The 24-hr Walnut Gulch results are combined with the Walnut Gulch depth-area ratios for 30 min, 1-hr, 2-hr, and 6-hr from Osborn et al. (1980).

Such data do not exist. Inferences are made from each of the following data sources or types. They progress in sequence from data of greatest to least direct applicability, and from least to greatest coverage of the study area.

3.1.1 Dense Networks

The dense network at Walnut Gulch has been described. Osborn et al. (1980) also published depth-area ratios for the Alamogordo Creek, NM, Experimental Watershed. The location in eastern New Mexico is shown as "AC" in figure 7b. Statistics from recorder pairs (section 3.1.2 below) indicate that depth-area ratios in the upper Rio Grande basin near Albuquerque are similar to those for Walnut Gulch and different from those at Alamogordo Creek, though the distance between Albuquerque and Alamogordo Creek is much less than that between Albuquerque and Walnut Gulch. Storms in eastern New Mexico depend heavily on moisture flow from the Gulf of Mexico that is not disrupted by orographic barriers. Cold fronts that approach from the northeast and lodge against the mountains and minimally modified tropical storms are often associated with heavy rainfall on the Alamogordo Creek Watershed (Osborn et al. 1980). Both situations differ from conditions that usually accompany heavy rainfalls in the Walnut Gulch area. Alamogordo Creek data are not used further in this study because of these meteorological differences. The eastern boundary to the present investigation (dashed line in figure 7b) is placed at the crest of the Sangre de Cristo in northern New Mexico and along the major easternmost ridges to the south near 105° 45'W. The mountains along the eastern boundary in central and southern New Mexico have lower elevations and are less continuous than the Sangre de Cristo. Therefore, the previously mentioned characteristic storm differences are less applicable in southern New Mexico than along the Sangre de Cristo crest.

3.1.2 Recorder Pairs

Simultaneous rainfall at a pair of gages allows the estimation of the covariance of point rainfall at the interstation distance, and thus is related to depth-area ratios over corresponding area sizes. Recording gage pairs with 12 or more years of simultaneous record during 1948-75 and with interstation distances of 50 mi or less were identified in Arizona and western New Mexico. The pairs are listed in table 3 and the locations of midpoints between paired stations are depicted in figure 7. The pair numbers in the tables and on the map are

Table 3.--Arizona and New Mexico station pairs

Pair no.	Stations*		Dist (mi)	Yr of record	Pair no.	Stations*		Dist. (mi)	Yr of record
	Arizona					New Mexico			
710+	8940	9534	2.2	18	810	0903	4366	4.7	20
711	6481	6486	3.1	14	815	4719	7827	4.7	18
712+	0966	8409	13.6	17	817	1286	4009	15.7	25
713+	8810	8820	14.4	14	818	3374	8518	16.1	15
714+	8409	9279	15.0	17	820	1138	7423	18.3	15
715	6676	6801	16.7	19	821	0234	0903	18.8	26
716	8264	8940	17.2	18	824	1138	8387	21.8	16
717	8264	8348	18.2	15	826	4426	8535	23.0	16
718	8264	9534	18.5	19	828	0234	4366	23.4	21
720+	0768	2659	23.7	21	835	6435	9686	28.0	24
721	7741	8940	24.0	15	836	7423	8387	29.9	22
722+	7593	8820	24.6	24	838	3374	4366	32.9	17
723	0808	9271	26.7	22	839	0640	7423	33.1	18
724+	6546	8409	27.6	16	840	1286	3225	33.9	25
725+	0966	1870	27.8	15	841	4426	9686	34.0	21
727+	9066	9279	28.5	17	842	0903	3374	34.4	17
728	7741	8264	28.9	12	844	0903	8518	34.6	17
729+	5921	7593	29.0	22	845	3225	4009	34.8	23
730+	6546	9279	29.1	17	846	4366	8518	35.3	17
731	1314	8348	34.8	13	847	0818	5800	35.7	17
733+	6119	8820	35.3	24	853	0234	8518	37.7	18
734+	0966	6546	36.4	16	856	1286	4426	38.3	23
735	8348	9534	36.4	13	858	6435	8535	38.6	16
736	6323	8940	37.1	20	862	4426	6435	40.3	22
737	6323	9534	37.3	19	863	4436	8072	41.2	15
738+	7593	8810	38.6	12	868	2024	3225	42.5	21
740	0487	6801	39.2	18	870	3225	8535	44.1	16
741	1314	6481	40.9	20	873	0234	4719	44.4	21
742+	1870	8409	41.4	14	875	0903	8072	44.5	20
743+	0768	1870	42.5	18	876	0234	3374	44.8	18
744	1314	6486	43.8	19	879	3225	4426	45.6	20
745+	6119	6546	44.7	13	881	0640	8387	46.0	22
746	0487	3010	46.6	23	884	8535	9686	47.7	16
747+	0808	6546	47.1	17	885	0818	4009	48.2	19
748+	0808	9279	48.1	18					
749	0808	7741	48.7	16					
750	6468	9439	49.6	25					

* Station index numbers are published in "Hourly Precipitation Data," Environmental Data Service, 1951-1975.
+ "Southeast Arizona" station pairs

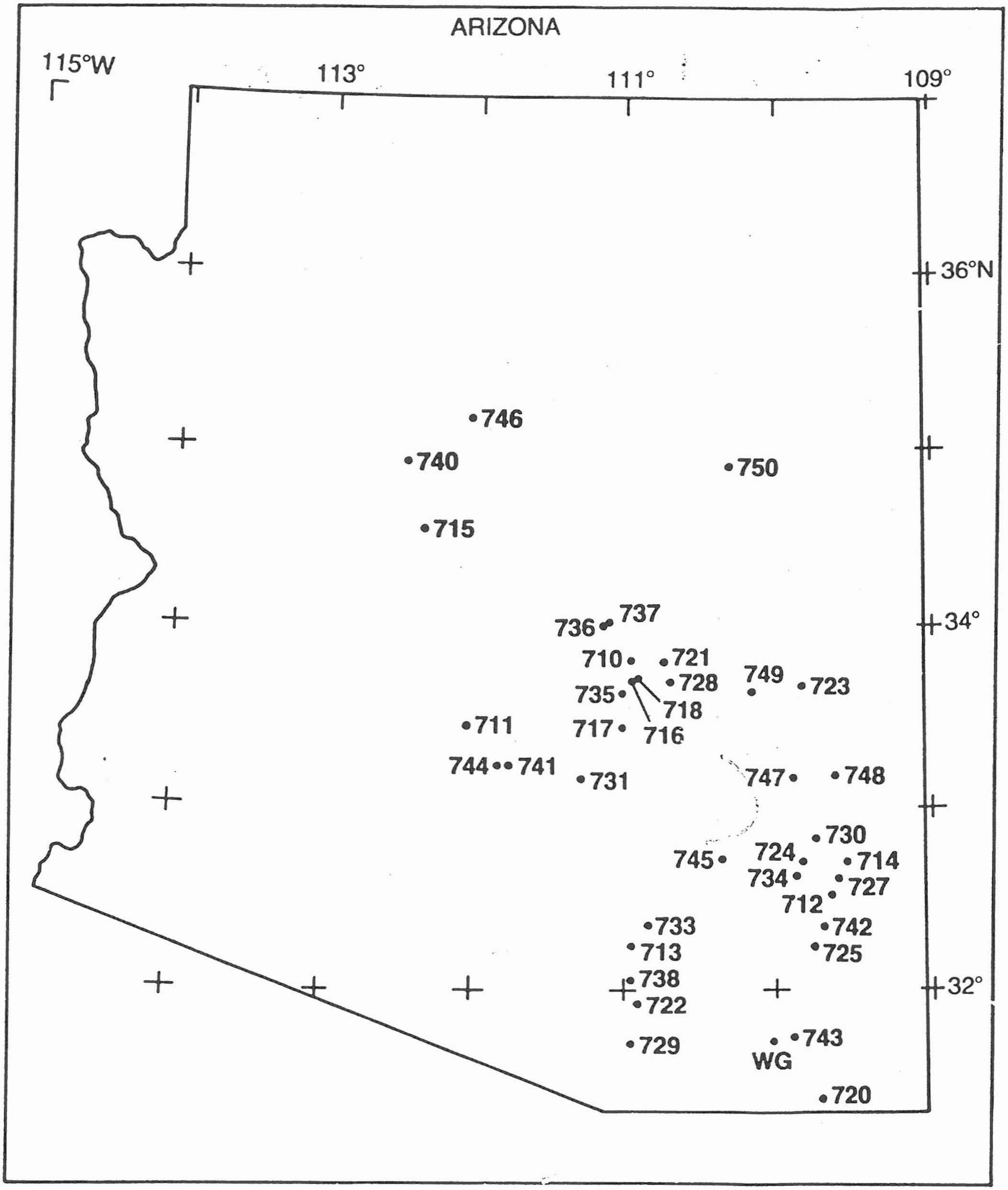

Figure 7a.--Locations of midpoints between Arizona recorder pairs. Identification numbers are from table 3. Point labeled WG is Walnut Gulch.

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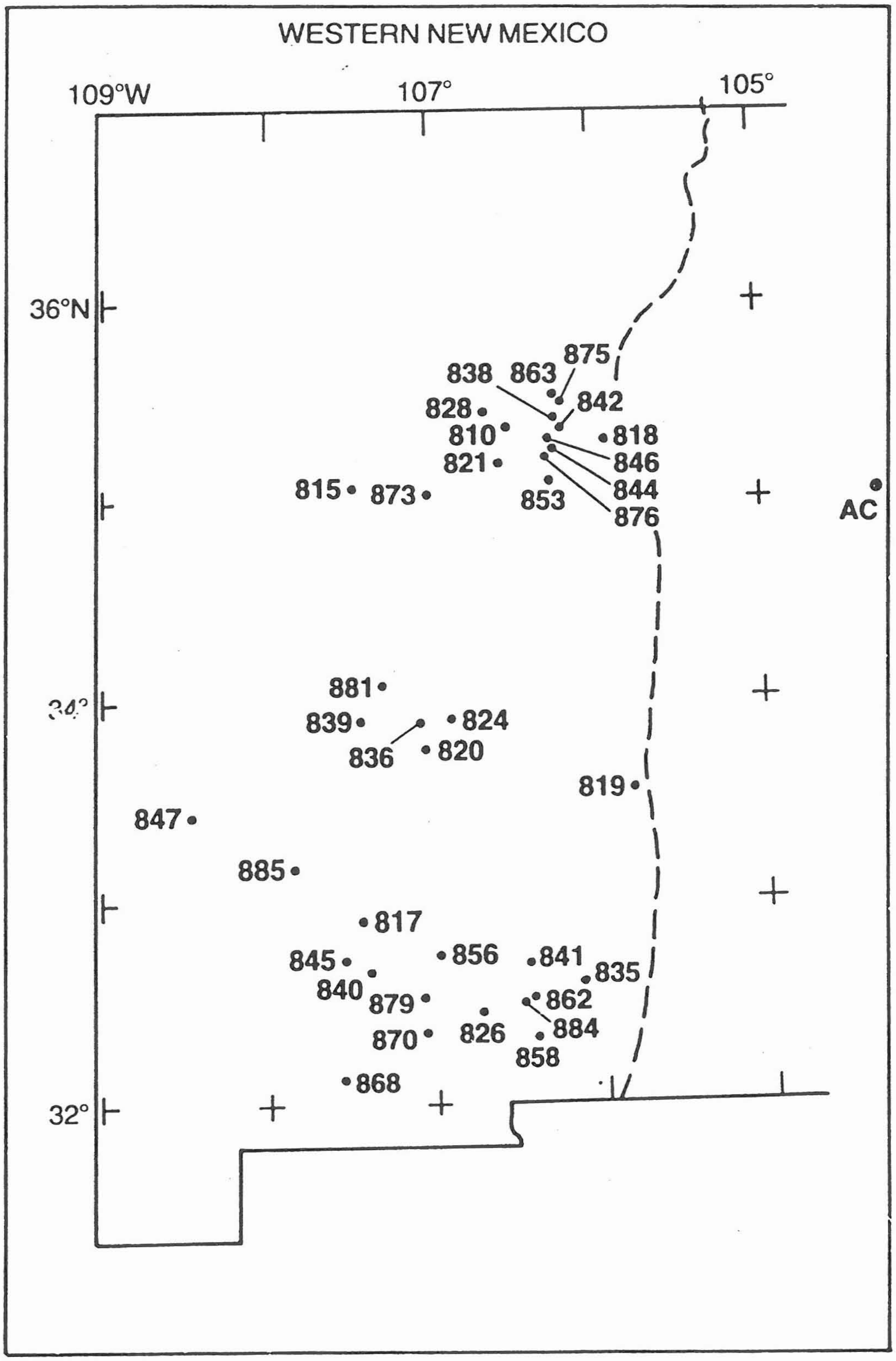

Figure 7b.--Locations of midpoints between New Mexico recorder pairs. Identification numbers are from table 3. Point labeled AC is Alamogordo Creek.

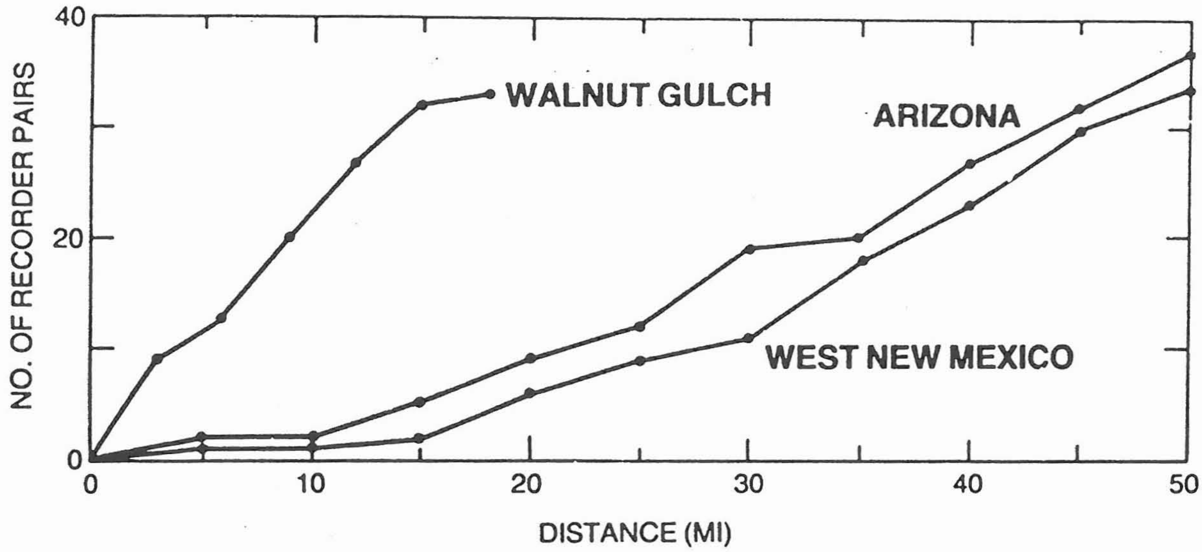

Figure 8.--Distribution of recorder-pair interstation distances for Arizona, western New Mexico, and Walnut Gulch 24-hr data. Points denote total number of pairs with interstation distance less than or equal to the plotted distance.

arbitrary identifiers. Figure 8 depicts the distribution of interstation distances. Most distances exceed 15 mi and are large for optimum relevance to area sizes of 500 mi^2 and less, our greatest interest. For the area sizes of greatest interest, the recorder-pair statistics are most useful as indices of regional and interdurational variations of depth-area ratios.

3.1.3 Daily Precipitation Stations

The study area is covered more densely and uniformly by daily reporting precipitation stations (Environmental Data Service 1951-76) than with recorder stations (see figs. 9 and 10). The percentage of annual maximum daily rainfalls at each station that occur in the cool season was used as an indicator of the contribution of general vs. local storms to the 24-hr annual series. A zone with more cool-season storm influence on the annual series could be expected to have larger depth-area ratios than a zone with less cool-season influence.

An attempt was made to use daily reporting station pairs in the same manner as recorder pairs to evaluate station-pair statistics for the 24-hr duration. The effect of varying observation times could not be overcome and this attempt was not successful.

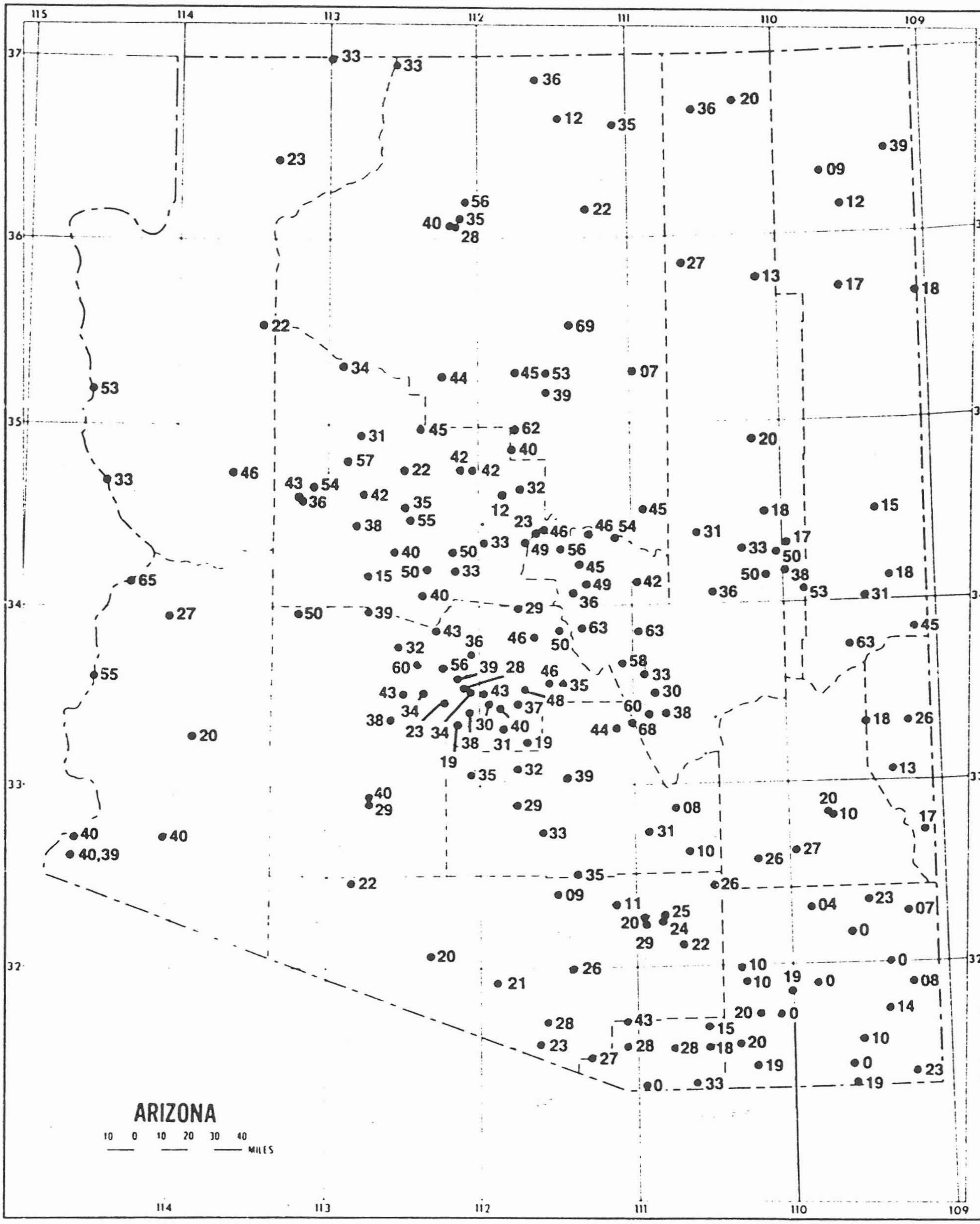

Figure 9.--Percentages of daily annual maxima in the "cool-season" (November through April) for Arizona.

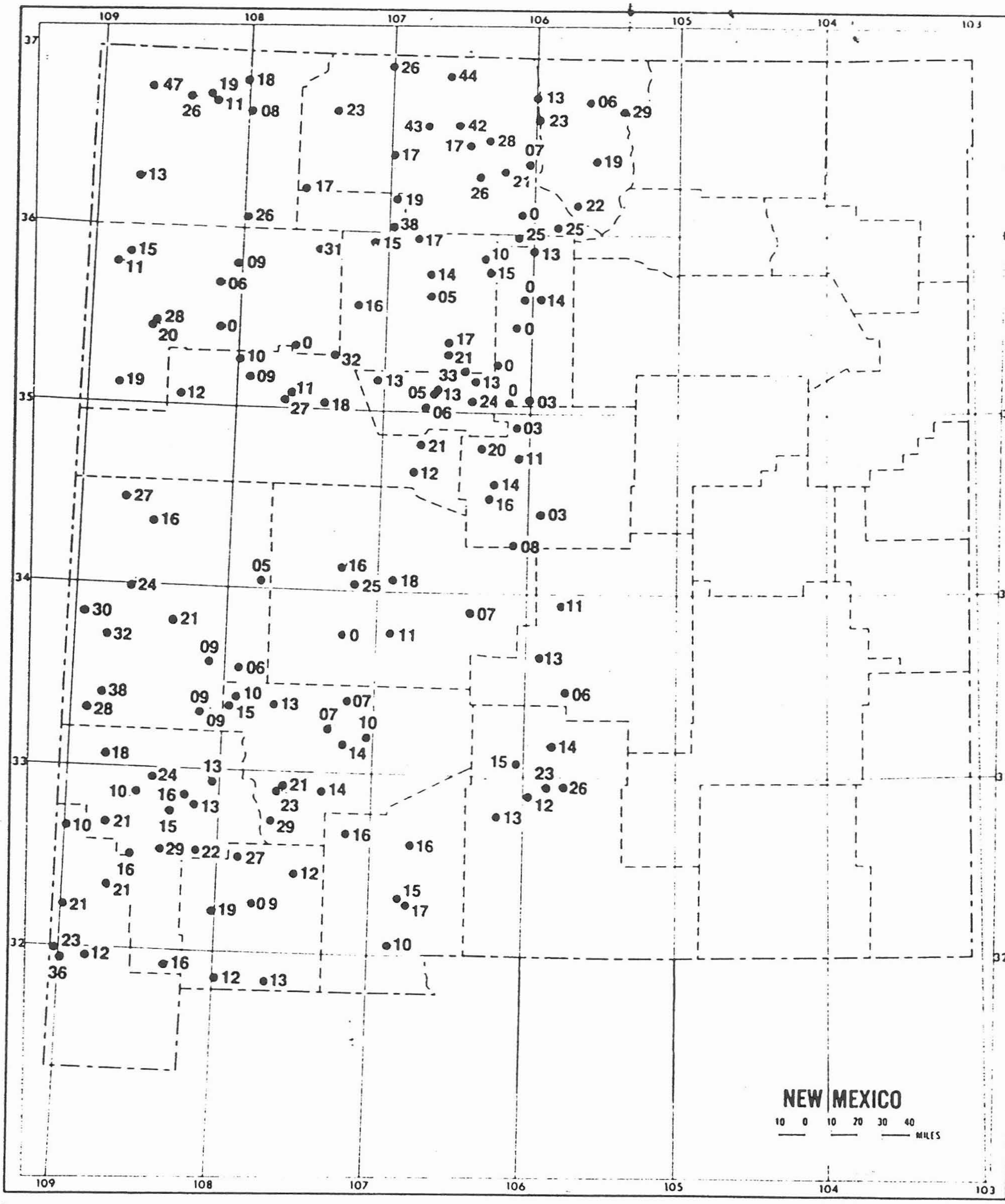

Figure 10.--Same as figure 9, except for western New Mexico.

3.1.4 Topography and Synoptic Factors

Landforms and elevations are defined everywhere on topographic maps at all scales of variation relevant to present purposes. Topographic information is the least direct of the data used. However, judicious use of topographic information in combination with knowledge of meteorological factors can provide useful insights into the spatial variation of generally "noisy" quantitative data, such as that discussed above.

3.1.5 Rainfall-Frequency Values

Rainfall-frequency values are also defined everywhere in map form in NOAA Atlas 2. It would be of great utility if station-pair statistics, measured at a limited number of points, could be predicted from parameters that are more universally available, such as these rainfall-frequency values. As outlined in Appendix II, the TR 24 approach was used to fit the station-pair data to analytic equations. The deviations at each station pair midpoint from this curve of best fit were used in a regression with the 2-yr 24-hr rainfall (determined from NOAA Atlas 2) as a predictor. The results yielded a low correlation with large scatter. A possible explanation for the poor relationship is that there are insufficient data to compensate for the relatively large amount of "noise" in the $\bar{X}_m'$ deviations. No further attempt was made to use the rainfall-frequency values.

3.2 Station-Pair Statistics

The data used for the paired recorder phase of the project are hourly precipitation values on Office of Hydrology, National Weather Service, magnetic tapes (Peck et al. 1977). These contain the data published in Hourly Precipitation Data (Environmental Data Service 1951-75). For quality control, it was possible to take advantage of work from another project (Frederick et al. 1981) which tabulated periods of missing data and accumulated data. Years of record with data of poor quality were eliminated, with criteria similar to those used in TR 24.

The quantities $\bar{X}_m'$, and $\bar{X}_b'$ (defined in Appendix I) were calculated for all station pairs and normalized to a 20-yr record by the TR 24 method. At each pair, values at 1, 2, 3, 6, 12 and 24 hr were first smoothed over duration, fitting the data to eq. (3-5) of TR 24. These duration-smoothed values were then fit over interstation distance, again using the TR 24 approach. Arizona and New Mexico data were fit separately.

3.3 $\overline{X}'_b$ Statistic vs Interstation Distance

With increasing distance between recorder-pair stations, a distance is approached at which there is practically no relationship between simultaneous rainfalls at the stations and no information applicable to depth-area ratios is obtainable. This distance is determined by the space and time scale of the meteorological systems which produce the annual maximum rainfalls, and varies with duration, storm type, and topography. The statistic $\overline{X}'_b$ becomes quite small at large interstation distance. However, by definition it cannot be negative. Thus, when curves are fit to $\overline{X}'_b$ with interstation distances distributed from zero to very large values, a theoretical curve will be asymptotic to a small positive value.

Table 4 lists the number of recorder pairs with $\overline{X}'_b < 0.1$ within intervals of interstation distance for each duration (0.1 is an arbitrary value and has no explicit physical significance). Based on table 4 and careful inspection of $\overline{X}'_b$ plots (not shown), the following decisions were made with regard to the applicability of these recorder-pair statistics to depth-area evaluation:

1. 1-hr and 2-hr recorder-pair data may produce unrepresentative results and are not used.

2. 3-hr pairs are limited to those with interstation distances less than 35 mi.

3. Pair statistics with interstation distances up to 50 mi are applicable for durations of 6 hr and greater.

3.4 Search for Geographical Variations

To search for meteorologically homogeneous zones, for each station-pair, deviations of each statistic at each duration from the corresponding curve fit using all station pairs were plotted on maps. The clearest geographical pattern of deviations was for $\overline{X}'_m$ at 24 hr in Arizona (fig. 11a). There is a preponderance of negative values southeast of the dashed line, while positive

Table 4.--Number of recorder pairs with $\bar{X}_b'$ < 0.1

Distance (mi)	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr	Total no. of pairs
				Arizona			
0-5	0	0	0	0	0	0	2
5-10	0	0	0	0	0	0	0
10-15	2	1	0	0	0	0	3
15-20	3	0	0	0	0	0	3
20-25	3	2	0	0	0	0	3
25-30	6	4	2	0	0	0	7
30-35	1	0	0	0	0	0	1
35-40	5	4	4	0	0	0	6
40-45	4	3	2	0	0	0	4
45-50	5	4	4	0	0	0	5
0-50	29	18	12	0	0	0	34
% of total	85	53	35	0	0	0	
				New Mexico			
0-5	0	0	0	0	0	0	1
5-10	0	0	0	0	0	0	0
10-15	0	0	0	0	0	0	1
15-20	3	0	0	0	0	0	4
20-25	3	1	1	0	0	0	3
25-30	2	1	0	0	0	0	2
30-35	7	5	1	0	0	0	7
35-40	5	4	2	0	0	0	5
40-45	7	6	5	0	0	0	7
45-50	4	3	3	2	0	0	4
0-50	31	20	12	2	0	0	34
% of total	91	59	35	6	0	0	

values are dominant northwest of this line. There is less suggestion of this difference at 6 hr and it virtually disappears at 3 hr (figures not shown). Inspection of the New Mexico deviations (fig. 11b) suggests no consistent variation over the region.

On the basis of this tentative separation, the station pairs in Arizona were divided into two sets, "southeast Arizona," southeast of the line of figure 11a and "central Arizona," the remaining pairs. Curves were fit again to each statistic in these two sets: the curves for 3, 6 and 24-hr for $\bar{X}_m'$ appear in figure 12 along with the New Mexico curve. Due to the paucity of data at

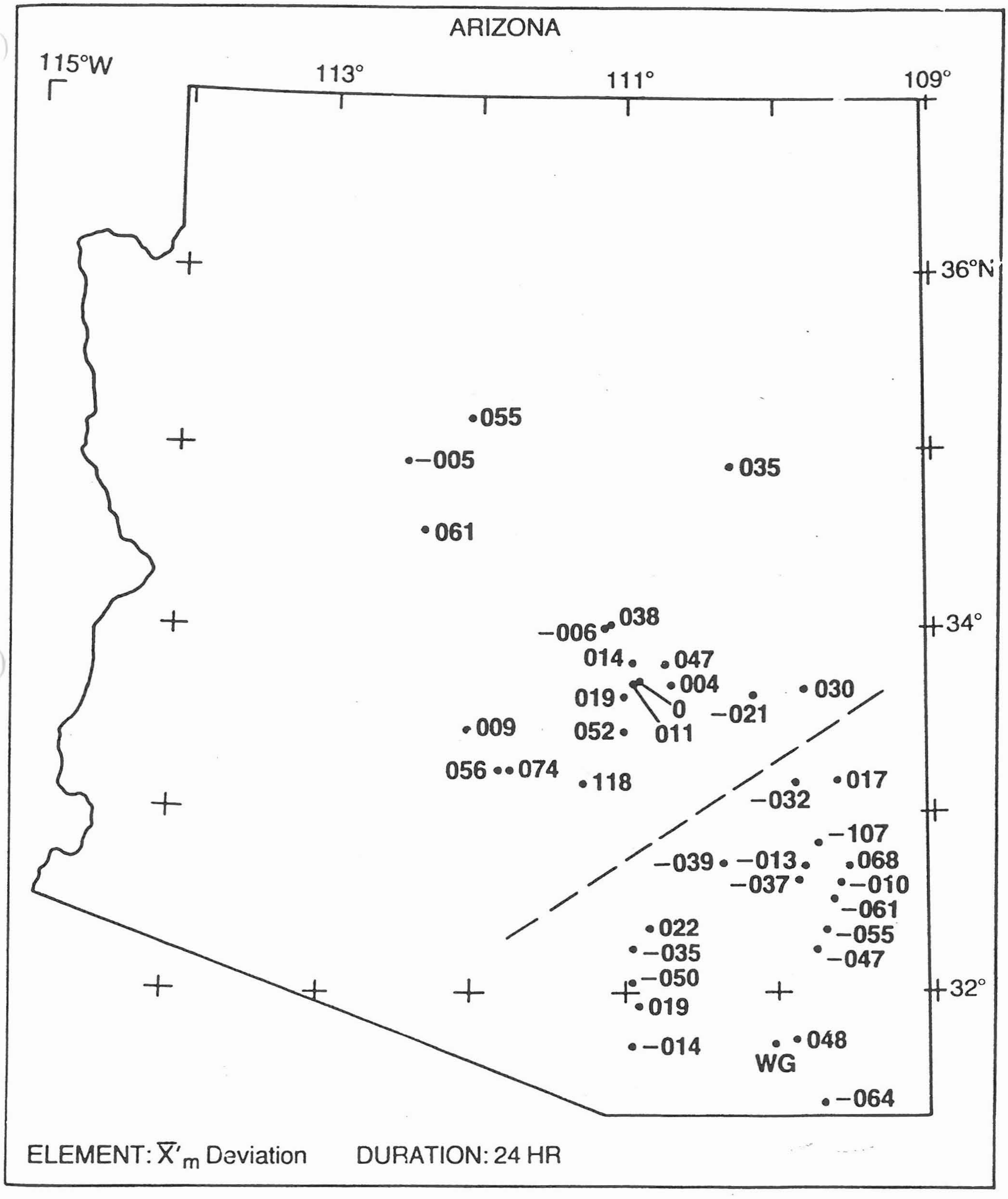

Figure 11a.--Deviation ($X10^{-3}$) of $\bar{X}'_m$ from the fitted curve for the 24-hr duration in Arizona.

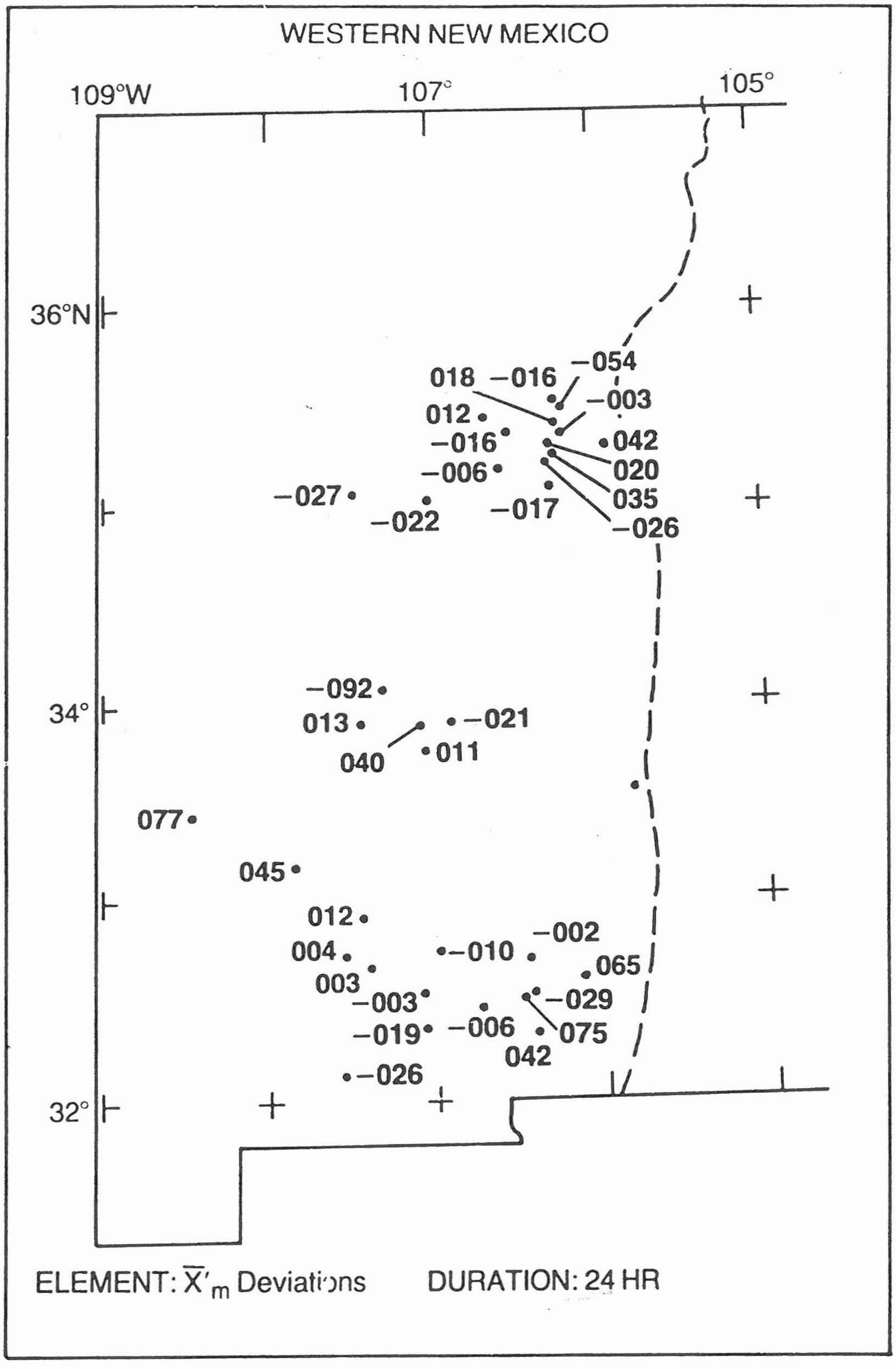

Figure 11b.--Deviation ($X10^{-3}$) of $\overline{X}'_m$ from the fitted curve for the 24-hr duration in New Mexico.

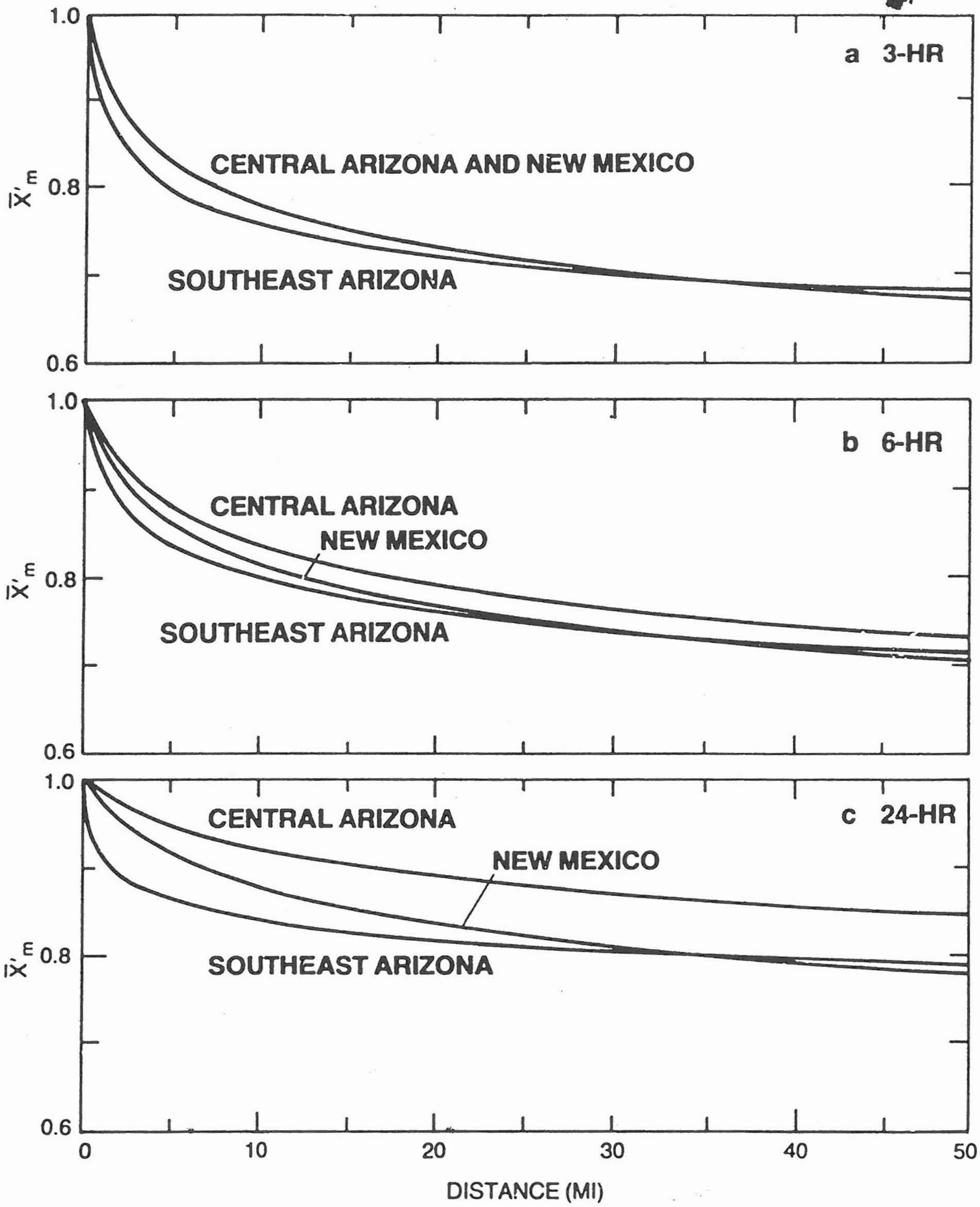

Figure 12.-- $\bar{X}'_m$ curves for southeast Arizona, central Arizona, and western New Mexico. a) 3-hr, b) 6-hr, c) 24-hr.

distances less than 15 mi (see table 3 and fig. 8), a valid comparison among regions should be restricted to the 15-50 mile range. Essentially no difference appears at 3 hr, small differences at 6 hr, and marked differences at 24 hr. $\overline{X}'_m$ in central Arizona is larger than in southeast Arizona and western New Mexico where the values are quite similar. To a lesser degree, the other station-pair statistics exhibited similar differences among regions and durations.

A depth-length ratio defined in TR 24, chapter 3, can be derived from data at a pair of stations. With the Gumbel fitting of Fisher-Tippett Type I Distribution as the frequency distribution model, $\overline{X}'_m$ is identical with the depth-length ratio for the 2.54-yr return period (see sec. 4.2). Thus, basic decisions on zonal variation of depth-area ratios were made from $\overline{X}'_m$ statistics, with the other statistics used as supporting information.

3.5 Seasonal Variation as an Indicator

Inspection of the tabulated dates of 24-hr annual maxima revealed that central Arizona experienced more winter occurrences than southeast Arizona. This is taken as another clue that general storms have more influence on rainfall-frequency values in central Arizona than in southeast Arizona, and that at least at the 24-hr duration, depth-area ratios could be expected to be higher in central Arizona. The seasonal variation of 24-hr annual maxima at individual precipitation stations, both daily and recorder, was used to refine the boundary between these regions and to compare other regions not covered by station pairs (recorders) within these regions.

With some experimentation, the year was divided into two seasons, May-October and November-April, hereafter termed the warm and cool seasons. The percentage of 24-hr annual maxima that occur in the cool season are plotted on maps of Arizona and New Mexico in figures 9 and 10. Thirty percent appears to be about the break point on figure 9 between the southeast Arizona type of climate and the central Arizona type. These data do not suggest any substantial zones of climate different from both of these.

3.6 Topographic and Synoptic Indications

Topographic features and known synoptic meteorological characteristics of storms suggest some explanations for the detected regional differences in $\overline{X}'_m$ and the other statistics. Locations along and west of the Mogollon Rim in central Arizona are exposed to a relatively unimpeded flow of air from the Gulf of California and the Pacific Ocean. Moisture inflow into southeast Arizona and most of New Mexico is reduced by both distance and the sheltering effect of the Sierra Madre in Mexico. The importance of the flow of air from the south and west lies in its warm moist character which affects areal coverage as well as intensity of precipitation. Topographic features that tend to favor storm occurrence in particular locations increase both the temporal persistence and the areal coherence, thus, a positive correlation between these two features is expected. Similarly, storm types that persist for 24 hr tend to yield more uniform areal coverage of precipitation than short duration local storms. Short duration storms tend to be due to small scale convective cells that vary little from one location to another. Hence, greater regional variation for 24-hr than for shorter durations is expected.

3.7 Definition of Zones

Compositing all of the clues and information suggests dividing Arizona and western New Mexico into the four depth-area ratio zones in figure 13. Zone A is the portion southwest of a generalized 3,000-ft elevation contour, readily exposed to moist inflow from the Gulf of California and the Pacific Ocean, but with rather smooth terrain. B is the portion northeast of a generalized drainage divide from the Kaibab Plateau to Humphrey's Peak, and along the highest elevations of the Mogollon Mesa to Baldy Peak. C is along the Mogollon Rim and lies between zones A and B. Zone D includes the higher elevation region of southeastern Arizona that is at least somewhat shielded from the Gulf of California by the Sierra Madre in Mexico, and is the southeast Arizona zone that has been referred to previously. The northern part of the study portion of New Mexico is an extension of zone B, and the southern part is an extension of zone D. While the available data provide no conclusive support for this extension, it was nevertheless made because it was felt that the shielding influence indicated in southeastern Arizona would extend into New Mexico in a fashion related to the prevailing moisture inflow.

Using the 30-percent break point on figure 9 between the southeast Arizona type of climate and the central Arizona type and additional insight from the above analysis, it was concluded that zones D and B are best represented by the Walnut

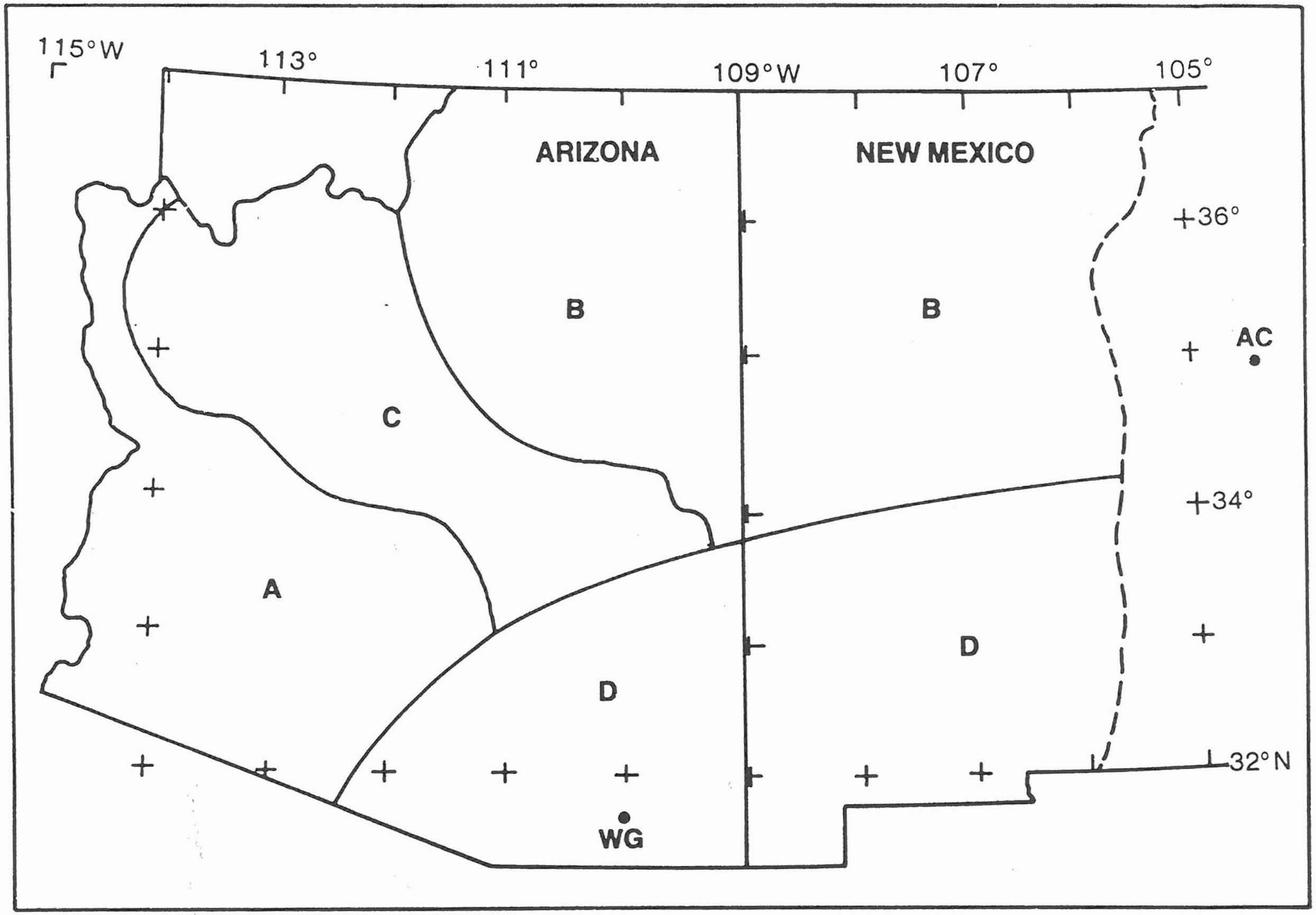

Figure 13.--Map of study area and depth-area zones.

Gulch depth-area ratios, while adjusted values should be applied to zones C and A, for durations of 6, 12, and 24 hr. The higher percentages of cool-season maxima are a principal reason for associating lower elevation, less rugged zone A with Zone C. (Very few recorder pairs are available in zone A.) The shorter distance from the Gulf of California and Pacific Ocean moisture sources may have a similar effect as the topography and elevation of zone C in favoring cool-season storms.

4. DEPTH-AREA RATIOS

The Arizona recorder pairs (table 3), the Walnut Gulch pairs (table 1), and the 5-station groups (table 2), were used to derive two separate sets of depth-area curves for 6-, 12-, and 24-hr durations. Pair statistics for locations southeast of the dashed line on the map in figure 11a comprised the southeast Arizona data set (these pairs are noted in table 3), while the group of remaining pair statistics were termed central Arizona.

In view of the lack of clear geographical pattern of $\overline{X}'_m$ deviation from a fitted curve for 3 hr (see sec. 3.4) and the convergence of depth-area curves going from 24 hr to 6 hr (see fig. 12), a single 3-hr depth-area curve was derived from all Arizona recorder pairs with interstation distances less than 35 mi.

Southeast Arizona depth-area curves are presented as representative of zones B and D and the central Arizona curves as representative of zones A and C (fig. 13), as discussed in chapter 3. It should be emphasized that these are best estimates based on limited data and information. The only dense network data available to this study are from Walnut Gulch. If additional dense networks were available in the study area, it is likely that both the definition of zones and depth-area ratio curves could be refined. However, in spite of uncertainties, we believe that a valid step toward regionalization has been accomplished with the depth-area curves presented.

4.1 Curve Fitting

The problem of the lack of recorder pairs at interstation distances of less than 15 mi was mentioned previously. The problem was minimized for the 24-hr southeast Arizona data set by including the 24-hr Walnut Gulch data. The resulting data set contains 50 recorder pairs with a reasonable distribution over interstation distance for this duration.

With the available data, the fitting procedure of TR 24 was found to be inadequate for $\overline{X}'_m$ and $\overline{X}'_b$ statistics for other durations, because of the paucity of data at distances of less than 15 mi. An alternative procedure was devised. The data points beyond a distance d_s (10-20 mi), were fit to a straight line. The data points at distances less than d_s were fit using the TR 24 approach, imposing the slope and intercept of the straight line at (d_s, y_s). The details of this curve splicing procedure are outlined in Appendix III. Comparisons of the results of the unmodified TR 24 curve fitting procedure and the curve splicing technique are shown in figure III-1. The complete sets of coefficients for the 2-station statistics curves used in developing the depth-area curves are listed in Appendix IV.

4.2 2.54-Year Depth-Area Ratios

Chow's generalized frequency equation (Chow 1951) relates a return value of (X_t) to the mean ($\overline{X}$) and standard deviation (s_x) of the annual series: $X_t = \overline{X} + K_t\ s_x$. The standard deviation is multiplied in the equation by a frequency factor, K_t, dependent on frequency (return period) and the statistical distribution assumed. For the Gumbel fitting of the Fisher-Tippett Type I Distribution used in this study, $K_t = 0$ occurs at a return period of 2.54 yr. (Equations for deriving K_t for this distribution are found in Appendix I of TR 24.) Thus, the frequency value at this particular return period is independent of the standard deviation and is equal to the mean of the annual series. The 2.54-yr depth-area ratios for Walnut Gulch may be immediately equated to the relative mean of the annual series of areal average annual maximum rainfalls, $\overline{X}'_L$. This fact is used in the following sections.

4.3 Relative Mean of Areal Average Annual Maximum Rainfall, $\overline{X}'_L$

The TR 24 method applies theoretical considerations and areal integration to obtain estimates of upper and lower bounds of $\overline{X}'_L$ from curves fit to $\overline{X}'_m$ and $\overline{X}'_b$. $\overline{X}'_L$ values between the bounds are obtained by interpolation based on calibration with a mean data point obtained from 5-station relative areal means. This procedure was followed for the 24-hr duration for southeast Arizona

Table 5.—Calibration constant, C_x.

Duration (hr)	Radius (mi)	Calibration point Type	X_L'	Bounds Upper	Lower	C_x
3	4.65	Areal	0.62	.716	.356	0.73
6	4.65	Areal	0.63	.760	.406	0.63
12	-	-	-	-	-	0.64
24	2.50	5-point	0.825	.873	.736	0.65

with the ten Walnut Gulch 24-hr 5-station groups providing the calibration. The calibration constant, C_x is defined as:

$$C_x = \frac{(\bar{X}_L') \text{ calibration} - (\bar{X}_L') \text{ lower}}{(\bar{X}_L') \text{ upper} - (\bar{X}_L') \text{ lower}}$$

At 3 and 6 hr the 2.54-yr Walnut Gulch depth-area ratios from Osborn et al. (1980) at 176 km^2 (68 mi^2) are equated to $\bar{X}_L'$ and are used for calibration. The resulting C_x values are listed in table 5. The 12-hr calibration value was set at 0.64, intermediate between the 6- and 24-hr calibration constants.

Areal or five-point data for calibration are only available at Walnut Gulch. The southeast Arizona Walnut Gulch calibration values were applied in central Arizona to the bounds for that zone.

Figures 14 and 15 depict the 3-, 6-, 12-, and 24-hr $\bar{X}_L'$ or 2.54-yr depth-area ratio curves for southeast Arizona (zones B and D) and central Arizona (zones A and C), respectively. 3-hr and 24-hr $\bar{X}_L'$ curves for Chicago from TR 24 are shown for comparison. With respect to 24-hr depth-area ratios, the climate in southeast Arizona is different from that in Chicago. The central Arizona curves lie between the Chicago and southeast Arizona curves. A possible explanation is that the typical storm types that predominate at Chicago are different from those prevalent in Arizona for 24 hr. The annual maxima in southeast Arizona are primarily limited area thunderstorms, while in central Arizona annual maxima can

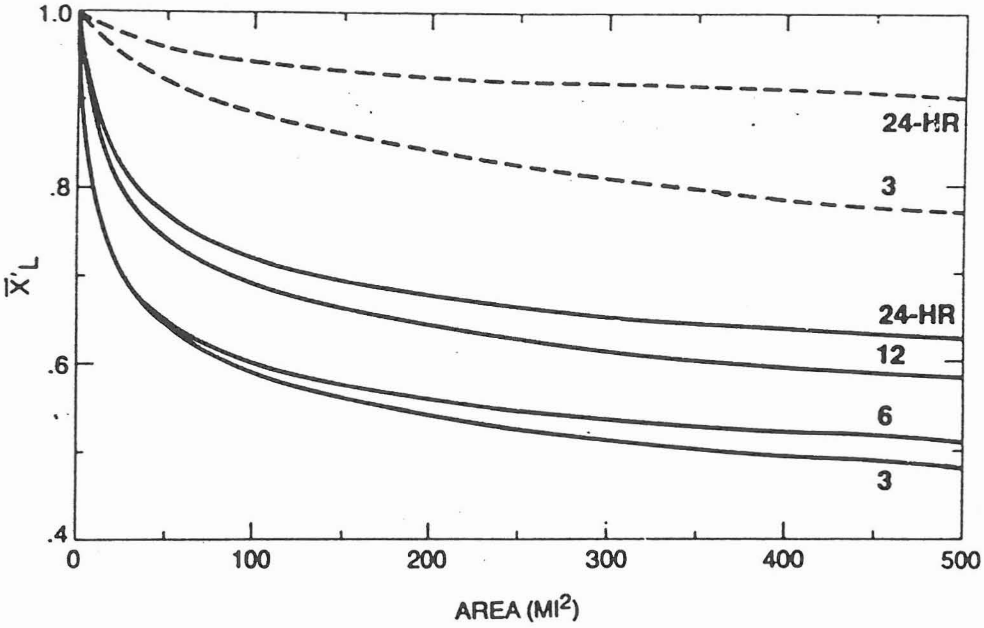

Figure 14.—$\bar{X}'_L$ (2.54-yr depth-area ratio, see sec. 4.3) for 3-, 6-, 12-, and 24-hr in southeast Arizona. Dashed lines are 3-hr and 24-hr Chicago $\bar{X}'_L$ (from TR 24)

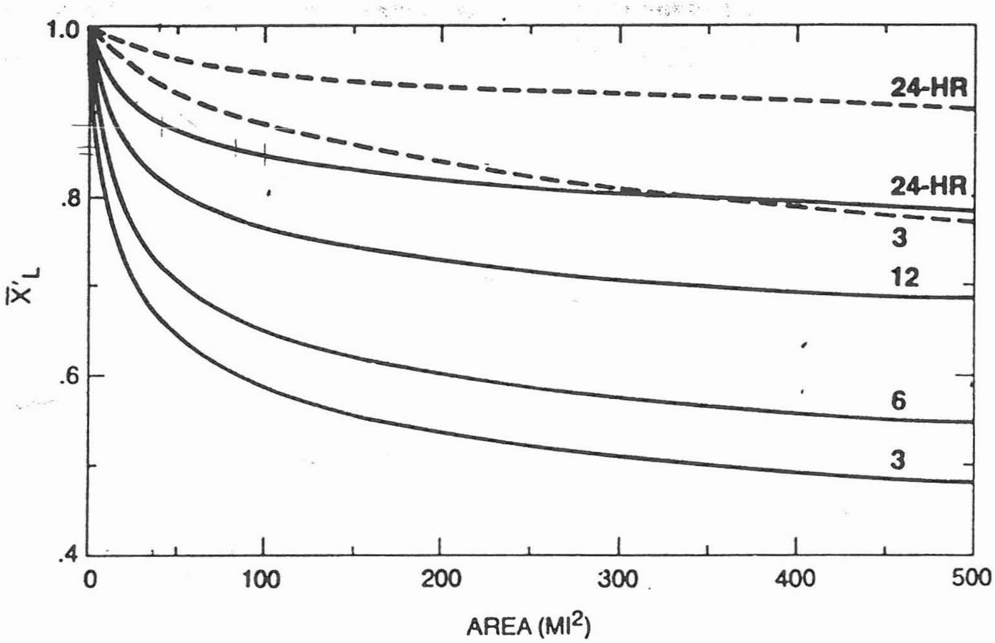

Figure 15.—Same as figure 14, but for central Arizona.

be attributed to a mixture of storm types, but still different from these found in the central Plains.

The recorder-pair data for distances greater than 15 mi contain little information on the structure of 1- and 2-hr storms. This is supported by the low values of $\bar{X}_b'$ at this range for these durations (see table 4). Our attempts to extract guidance from these widely spaced locations proved fruitless. $\bar{X}_L'$ is not defined at these durations in this study. Rather, Walnut Gulch depth-area ratios from Osborn et al. (1980) may be used for these durations up to the area size of the Walnut Gulch network, about 76 mi^2. We were unable to define 1- and 2-hr depth-area ratios for area sizes greater than 76 mi^2.

4.4 Depth-Area Ratios

The two-station variance statistics s_m', s_b' and cov_{Ab}' (defined in Appendix I), exhibited considerably greater scatter than $\bar{X}_m'$ and $\bar{X}_b'$. To a lesser degree, this was also true for Chicago data in TR 24. Considering the extreme scatter and the previously discussed data limitations, the decision was made to estimate depth-area ratios based only on statistics of the mean. This meant that the possibility of specifying the depth-area variation with return period was lost. Both physical reasoning and the data indicated that any return-period variation would produce lower depth-area ratios for rarer events. It was felt that the limited amount of data and the large amount of scatter precluded quantifying the variation with return period. As discussed in sections 3.4 and 4.2, use of mean quantities is equivalent to determining the depth-area ratios for the 2.54-yr return period. Use of a mean curve for all return periods will lead to conservative estimates for all return periods greater than 2.54 yr. The difference at the 2-yr return period is small, and considering the degree of uncertainty associated with the entire analysis, can be considered negligible.

5. DISCUSSION

5.1 Recommended Depth-Area Ratios

In the Walnut Gulch basin the 24-hr depth-area ratios of figure 5 should be used. For durations of 6 hr and less, the results of Osborn et al. (1980) are appropriate. There are no basin-specific curves for 12-hr amounts. If a 12-hr depth-area ratio is necessary, the curves in figure 14 for southeast Arizona should be used as guidance for interpolation between the 6-hr values found by Osborn et al. and the 24-hr depth-area ratios of figure 5. Use of the depth-area ratios in figure 5 for locations other than Walnut Gulch would depend on the similarity of the meteorological conditions between the other locations and those in the Walnut Gulch basin.

Outside the Walnut Gulch basin, the depth-area ratios in figures 14 and 15 should be used. The curves in figure 14 are most appropriate for use in the zones indicated as B and D in figure 13. The recommended depth-area curves for zones A and C of figure 13 are presented in figure 15. Figure 16, from Osborn et al. (1980), shows depth-area ratios for durations of 30 to 360 min for return periods of 2 and 100 yr. For a given return period, there is little systematic difference among the durations of 3 hr or less. It is likely that the differences are due in large part to sampling variations. For this reason, we recommend that the 3-hr depth-area ratio be used for all durations less than 3 hr. Any error introduced will likely produce slightly conservative estimates of areal rainfall amounts for the shorter durations.

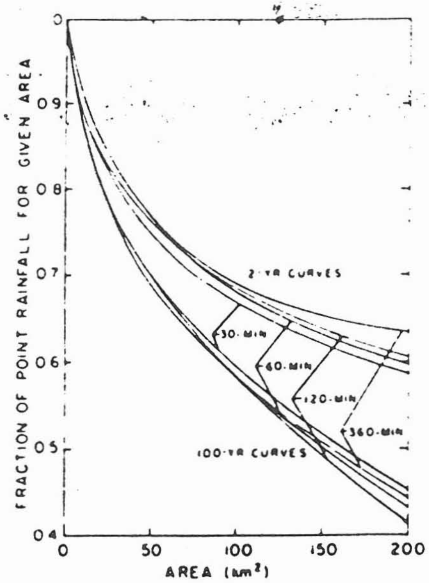

Figure 16.--Point to area rainfall ratios from Osborn et al. (1980).

5.2 Uncertainty of the Depth-Area Ratios

The depth-area ratios shown in figures 14 and 15 are to be applied over the zones shown in figure 13. Examination of figure 7 reveals that there are practically no station-pair data available in zone A, and little data available in the northern portion of zone C. While there does appear to be a definite difference in the deviations from the fitted curves in Arizona that was used to define the separation of zone D from zone C (fig. 11a), no such cleavage was apparent in New Mexico (fig. 11b). In fact, the station-pair data from New Mexico were not used when calculating the depth-area ratios in figures 14 and 15. The conclusion that must be drawn from these observations is that the uncertainty of the depth-area ratios in figures 14 and 15 may vary considerably over the zones shown in figure 13.

The depth-area ratios shown in figure 14 are most accurate for zone D in Arizona. There is a higher degree of uncertainty associated with their use in zone D in New Mexico, as well as in all of zone B. The use of the depth-area curves of figure 15 is most appropriate in the southernmost portion of zone C where almost all of the station-pair data is located. The uncertainty of the curves in figure 15 in the northern portion of zone C is greater than the south simply because of the dearth of data. While the discussion in sec. 3.5 suggests that zone A may be similar to zone C, there is little station-pair data available to support this conclusion. Therefore, there is a higher degree of uncertainty associated with the use of the depth-area values in figure 15 for locations in zone A.

5.3 Comparison of Results

Osborn et al. (1980) have shown that NOAA Atlas 2 (Miller et al. 1973) depth-area curves are conservative for the Walnut Gulch, AZ, watershed. This study confirms and expands on their results. For example, for a 300-mi^2 basin with a 24-hr point rainfall of 2.0 in., one obtains areal rainfalls of 1.32 in. (0.66 X 2.0) if the basin is located in zones B or D and 1.60 in. (0.80 X 2.0) for locations in zones A or C. In contrast, using NOAA Atlas 2, the assigned areal rainfall is about 1.82 in., based on a depth-area ratio of 0.91, regardless of location.

5.4 Determination of Depth-Area Ratios in Data-Sparse Regions

The results of this study demonstrate that the conceptual approach presented in TR 24 can be adopted in data-sparse regions. But data limitations and significant departures from meteorological homogeneity can necessitate modifications to the specific implementation of the approach described in TR 24. The underlying approach is to fit the various statistics, using an exponential model such as in TR 24, using a mixed model such as in the present study, or some other appropriate model which is both consistent with the data and depicts the underlying meteorological situation. In data-sparse areas, the selection of an appropriate model will always require a certain amount of meteorological judgment. The final depth-area curves will be dependent on the suitability of the model selected.

The results of this study highlight two problem areas in data-sparse regions: (1) the requirement of a dense network of raingages or other information to allow the calibration between the theoretical bounds, and (2) the sensitivity of the variance statistics with small data samples. The use of station-pair statistics offers the promise of extracting useful information from previously underutilized data. While these data allow the definition of bounds on the depth-area ratios, the final results require calibration between these bounds. Direct calibration requires a dense raingage network. Indirect calibration, such as using calibration constants from what appear to be meteorologically similar locations, depends on the validity of the assumptions made and introduces an additional level of uncertainty.

Precipitation data is generally characterized by a higher degree of variability than most other meteorological quantities. Higher order moments such as the variance (and, therefore, the standard deviation) and covariance are more sensitive than the mean to noise in the data. As in this study, when there is a limited amount of data, the natural variability can be so large that it may be impossible to adequately quantify the standard deviation or covariance, no matter what model is selected to fit the data. In data-sparse regions, the absence of sufficient amounts of data to compensate for large sampling variability may preclude the quantitative determination of the variation of the depth-area ratios with a return period (or even estimation of the depth-area ratio itself). Both theoretical considerations and other studies where adequate data were available indicate that use of mean values instead of the complete Chow equation (see sec. 4.2) in the TR 24 approach produce conservative depth-area ratios for rarer events (longer return periods).

Finally, in data-sparse areas, the delineation of zones where different depth-area ratios apply will be heavily dependent on the judgment of the individual analyst. This judgment will typically be based on an understanding of the interaction of both synoptic and mesoscale meteorological processes with topographic and other geographic features. The available data can be used to critically assess definition of zones based on the meteorologist's judgment, but definitive evaluation will often be difficult, if not impossible, in data-sparse areas. The final specification of zones will usually require use of auxiliary information, such as use of daily values in this study, to identify areas where cool-season precipitation was most significant. Once zones have been specified, the problem of determining appropriate depth-area ratios for each of the zones remains (see discussion above).

6. SUMMARY

This study develops geographically fixed depth-area ratios for Arizona and western New Mexico. These ratios are required to reduce published point precipitation-frequency values to areal values as part of the basis for design of hydrologic structures. These depth-area ratios, developed specifically for this semi-arid region, are smaller than the national average ratios previously published by the National Weather Service. The new ratios will lead to more economical designs for pre-determined risk levels.

Variation of depth-area ratios over the study region is inferred primarily from various statistics from simultaneous rainfalls at pairs of recording gages. This is done by heavy reliance on the concepts in a previous report of the authors (Myers and Zehr 1980) that develops procedures for fitting surfaces in interstation distance-precipitation duration space to station-pair rainfall statistics and for adjusting the pair statistics to areal average statistics. The previous report treats a dense network of gages, all in the same climate. The present report includes regard for climatological variation that may exist within the overall study area.

Depth-area ratios at the Walnut Gulch Experimental Watershed of the Agricultural Research Service in southeastern Arizona are an essential anchor point for the present study. Walnut Gulch depth-area ratios for durations up to 6 hr are from Osborn et al. (1980). Walnut Gulch ratios for 24 hr are newly calculated and are presented in a chapter 2 of the present report.

There are very few recorder pairs in the study area with interstation distances of less than 15 mi, other than those at Walnut Gulch. Special procedures were applied to extrapolate Walnut Gulch values throughout the study area, with zone adjustments, to cover the corresponding basin sizes of several hundred square miles and less.

Depth-area ratios are presented separately by zones. An original four zones were reduced to two because the data were inadequate to either quantify differences or to determine additional depth-area ratios. Zone to zone variation in depth-area ratios is considered negligible for all durations less than 3 hr and is most pronounced at the longest duration analyzed (24 hr). Zones are defined by a combination of indicators from recorder-pair data, topography, seasonal variation of 24-hr single station annual maxima, and presumed storm types.

The importance of dense networks for anchor points should not be minimized. This report carries out the engineering necessity of extracting practical ratios of importance to design of structures that in the aggregate cost very substantial sums. In regions where expenditures for hydrologic structures are expected, early attention should be given to providing the anchor point dense network depth-area data, either conventionally or by remote sensing techniques, in order to secure a sufficiently long record to average out sampling variation. Such data cannot be secured within the time frames of individual projects.

Refinement and improvement of results and methodologies are always desirable. The procedure for calibrating between bounds detailed in TR 24 is a critical step in the methodology which has not been thoroughly investigated. The variation of the calibration constant, C_x, with duration and with area remains uncertain. Thus far, lack of data has prevented extensive evaluation.

The concept of climatic homogeneity and determination of the maximum interstation distance at which pair statistics are pertinent with regard to depth-area ratios, have been discussed in this report. Additional investigation of these problems is needed. This is especially true for mountainous regions where the effect of elevation and slope on rainfall and depth-area characteristics of storms is greater than in flat terrain regions, such as Chicago.

ACKNOWLEDGMENTS

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APPENDIX I. DEFINITIONS

Variables and statistics discussed previously are explicitly defined here. Additional information is available in TR 24.

Pair statistics

$$\bar{X}'_m = \bar{X}_m/[0.5\ (\bar{X}_A + \bar{X}_B)]$$

$$s'_m = s_m/[0.5\ (s_A + s_B)]$$

X and s are the mean and standard deviation of the annual maximum series. Subscript m refers to the series of pair averages, and A and B refer to the individual stations.

$$\bar{X}'_b = 0.5[(\bar{X}_b/\bar{X}_A) + (\bar{X}_a/\bar{X}_B)]$$

$$s'_b = [(s_b/s_A)(s_a/s_B)]^{1/2}$$

$\bar{X}'_b$ and s'_b denote mean and standard deviation of series "simultaneous with annual maximum." The subscripts on the right signify stations A and B explicitly, with upper case designating annual maximum and lower case, simultaneous with annual maximum.

$$cv'_b = s'_b/\bar{X}'_b$$

This definition is derived from the definition of the coefficient of variation, cv.

$$cov'_{Ab} = 0.5\ [(cov_{Ab}/s^2_A) + (cov_{aB}/s^2_B)],$$

where cov is covariance, and the subscripts on the right refer to specific stations as before.

Five-station statistics

$\bar{X}'_{5m}$ and s'_{5m} are the relative mean and standard deviation of the annual maxima of the 5-station group averages, which are weighted averages.

$$P_5 = .244P_A + .188(P_b + P_c + P_d + P_e)$$

where P_5 is the rainfall of the 5-station group, subscript A refers to the center station, and b, c, d, and e, the outer stations. The stations are normalized to relative form by dividing by the corresponding statistic at the center station, A.

APPENDIX II. CURVE FITTING USING THE TR 24 METHOD

$\bar{X}'_m$ and $\bar{X}'_b$ statistics at durations 1, 2, 3, 6, 12 and 24 hr, for Arizona and New Mexico recorder pairs (table 3) were fit to:

$$y = 1 - M e^{-[ad^b]^{-1}},$$

where y is the statistic and d the interstation distance. Coefficients a, b, and M, for various durations are listed in table II-1. Table II-2 contains coefficients for the Walnut Gulch curves.

Table II-1.--Coefficients for Arizona and New Mexico station-pair data

	t(hr)	a	b	M
$\bar{X}'_m$				
Arizona	1	.9726	.3407	.5
	2	.6148	.3883	.5
	3	.5158	.3891	.5
	6	.4145	.3658	.5
	12	.3532	.3363	.5
	24	.3066	.3162	.5
New Mexico	1	.7613	.3951	.5
	2	.5666	.4005	.5
	3	.4969	.3981	.5
	6	.4187	.3836	.5
	12	.3683	.3619	.5
	24	.3315	.3394	.5
$\bar{X}'_b$				
Arizona	1	.8337	.9829	1.0
	2	.6684	.7905	1.0
	3	.5927	.7113	1.0
	6	.5053	.5887	1.0
	12	.4376	.4975	1.0
	24	.3795	.4381	1.0
New Mexico	1	.0635	2.4464	1.0
	2	.3405	1.0120	1.0
	3	.2826	.9368	1.0
	6	.2421	.8281	1.0
	12	.2397	.7161	1.0
	24	.2502	.6126	1.0

Table II-2.--Coefficients for 24-hr Walnut Gulch pair statistics

Statistic	a	b	M
X'_m	.3649	.4278	0.50
s'_m	.7546	.4990	0.50
$\bar{X}'_b$	.5014	.6024	1.00
cov'_{Ab}	.8131	.6255	1.24

APPENDIX III. CURVE SPLICING

A curve splicing procedure was devised to obtain a better fit of pair statistics for 24 hr in southeast Arizona. This data set includes the Walnut Gulch pairs (table 1) and southeast Arizona pairs (table 3). The TR 24 curve fitting equations over estimated the data points in the 5-15 mile distance range and underestimated at 0-5 miles for both the $\bar{X}'_m$ and $\bar{X}'_b$ statistics. When the curve splicing procedure was applied, much of this bias was removed. The curves derived from the two fitting procedures and data points are depicted in figures III-1 and III-2 for $\bar{X}'_m$ and $\bar{X}'_b$, respectively.

Implementing the splicing procedure requires that a distance, d_s, be imposed for a splice point, (d_s,y_s). On figures III-1 and III-2 d_s = 15 miles. At distances greater then d_s, designated by subscript "out," data are fit to a straight line. At distances less than d_s, designated by subscript "in," data are fit using the TR 24 procedure.

$$d > d_s: \quad y_{out} = a_{out} + b_{out}\, d \qquad \text{(III-1)}$$

$$d < d_s: \quad y_{in} = 1 - M e^{-[a_{in} d^{b_{in}}]^{-1}} \qquad \text{(III-2)}$$

Here, y is the statistic, d is distance, and a_{out}, b_{out}, a_{in}, b_{in}, and M are the coefficients which must be determined. a_{out} and b_{out} are evaluated by linear regression for data points, (d, y), $d > d_s$. It is required that the inner and outer portions of the curve join and have equal slopes at (d_s, y_s), as stated by equations (III-3) and (III-4), at d_s,

$$(y_{in})_s = (y_{out})_s \qquad \text{(III-3)}$$

$$\left[\frac{\partial y_{in}}{\partial d}\right]_s = \left[\frac{\partial y_{out}}{\partial d}\right]_s \qquad \text{(III-4)}$$

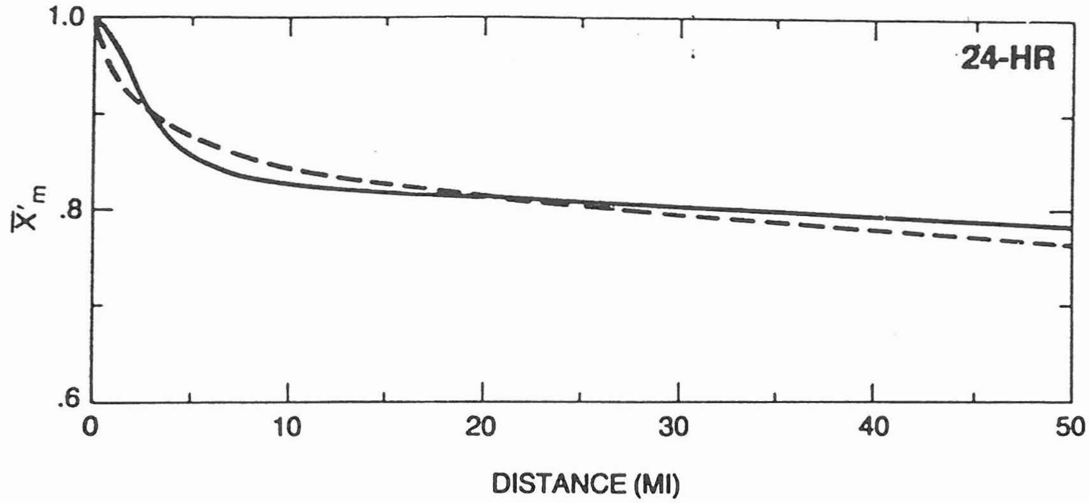

Figure III-1.--24-hr Walnut Gulch and southeast Arizona $\bar{X}'_m$. Solid curve is derived by the curve splicing procedure. Dashed curve is derived by the TR 24 fitting method.

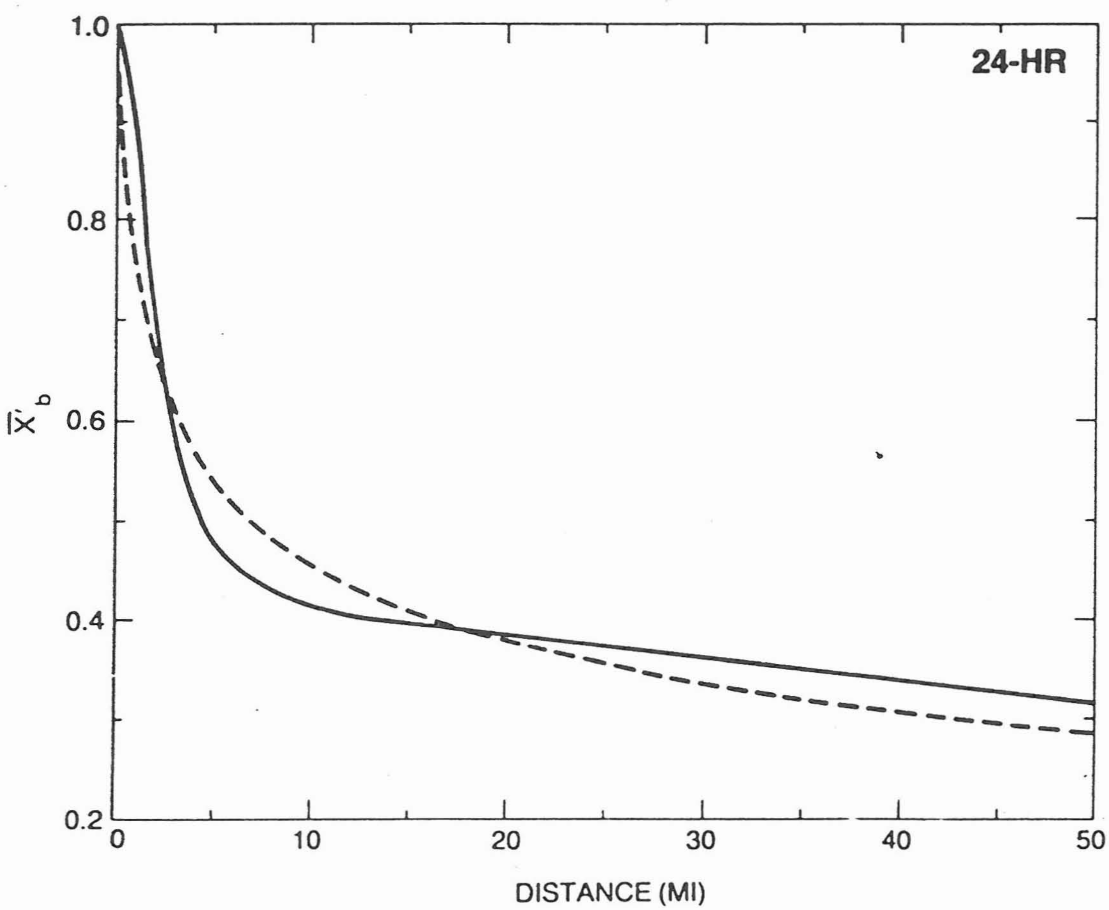

Figure III-2.--Same as figure III-1, except for $\bar{X}'_b$.

Substituting (III-1) and (III-2) into (III-3),

$$1 - M\, e^{-[a_{in}\, d_s^{\,b_{in}}]^{-1}} = a_{out} + b_{out}\, d_{out} \qquad \text{(III-5)}$$

Substituting (III-1) and (III-2) into (III-4),

$$a_{in}^{-1}\, b_{in}\, d_s^{\,-b_{in}+1}\, (y_s - 1) = b_{out} \qquad \text{(III-6)}$$

Solving (III-5) and (III-6) simultaneously for b_{in},

$$b_{in} = \frac{-\, d_s\, b_{out}}{(y_s - 1)\, \ln\left[\dfrac{1 - a_{out} - b_{out}\, d_s}{M}\right]} \qquad \text{(III-7)}$$

Rewriting (III-2),

$$a_{in} = \frac{-1}{d_s^{\,b_{in}}\, \ln\left[\dfrac{1 - y_s}{M}\right]} \qquad \text{(III-8)}$$

After a_{out} and b_{out} are determined by linear regression, y_s is determined and all quantities on the right side of (III-7) are known except M. To solve for a_{in} and b_{in}, M is initialized to $(1-y_s)$. b_{in} and a_{in} are evaluated with equations (III-7) and (III-8). The sum of squares of deviations of data points at $d < d_s$ from the fitted curve are computed. M is then incremented and iterations performed until the sum of squares of deviations is a minimum. These values of a_{in}, b_{in}, and M, are the "best fit" to the data points at $d < d_s$, with the restriction that the curve pass through (d_s, y_s) with slope, b_{out}, at the splice point. This approach was also used for durations of less than 24 hr.

APPENDIX IV. COEFFICIENTS USED IN CHAPTER 4 DEPTH-AREA RATIO ANALYSES

Coefficients a_{out}, b_{out}, a_{in}, b_{in} and M for the curves of the pair statistics used to derive $\bar{X}'_L$ depicted in figures 14 and 15 are listed in table IV-1.

Table IV-1.--Coefficients for $\bar{X}'_m$, and $\bar{X}'_b$ used in determination of chapter 4 depth-area ratios ($\bar{X}'_L$)

	t(hr)	a_{out}	b_{out}	a_{in}	b_{in}	M	d_s(mi)
$\bar{X}'_m$							
Southeast Arizona							
	3	.7974	-.00287	.7004	.5606	.336	15
	6	.8070	-.00211	.5486	.6090	.316	20
	12	.8323	-.00185	.5479	.6040	.276	20
	24	.8471	-.00141	.5241	.7320	.224	20
Central Arizona							
	3	.7974	-.00287	.7004	.5606	.336	15
	6	.8056	-.00165	.4541	.8570	.269	20
	12	.8815	-.00199	.3581	.6690	.231	20
	24	.9319	-.00196	.2393	.6900	.182	20
$\bar{X}'_b$							
Southeast Arizona							
	3	.2590	-.00373	1.3232	1.3183	.807	10
	6	.3165	-.00326	1.3262	1.3500	.741	10
	12	.3878	-.00315	.4868	1.3500	.695	15
	24	.4442	-.00268	.4914	1.3753	.626	15
Central Arizona							
	3	.2590	-.00373	1.3232	1.3183	.807	10
	6	.4050	-.00429	.8965	1.3500	.671	10
	12	.5336	-.00399	.7661	1.3500	.537	10
	24	.6407	-.00321	.7344	1.3500	.416	10

Rainfall/Watershed Relationships for Southwestern Thunderstorms

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ABSTRACT

DEPTH-AREA relationships for thunderstorm rainfall were developed from 20 years of record from dense raingage networks in Arizona and New Mexico, using the National Weather Service method described in NOAA Atlas 2. The relationships are compared with similar previously published ones. Relationships also were developed to indicate the distribution of storm rainfall over a watershed. This information could be valuable to agencies, groups, and individuals involved in water resources design and evaluation for climatologically similar areas.

INTRODUCTION

The National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), published a precipitation frequency atlas, NOAA Atlas 2 (Miller et al., 1973) for the Western United States, which consisted of a series of volumes, one for each Western state. Volumes 4 (New Mexico) and 8 (Arizona) are of particular interest in this study. A value read from the isopluvial maps in each of these volumes "is the value for that point and the amount for that particular duration which will be equalled or exceeded, on the average, once during the period of time indicated on the individual map." Also, there is a depth-area monogram in each volume to be used to estimate average rainfall over watersheds of up to 1000 km², given the average point value over the basin.

The depth-area curves in NOAA Atlas 2 were developed, by necessity, from groupings of closely spaced recording raingages available in the published data of the regular cooperative network of the NWS. No groupings sufficiently closely spaced for this purpose were available in the Southwest. Significant regional and frequency variations were not detected in the available data from the remainder of the United States. Fig. 1 shows the curve published for Arizona and New Mexico, but derived from regions outside the Southwest. These are based on 2-yr data, but are meant to be applied to all return periods up to 100 years (Miller et al., 1973).

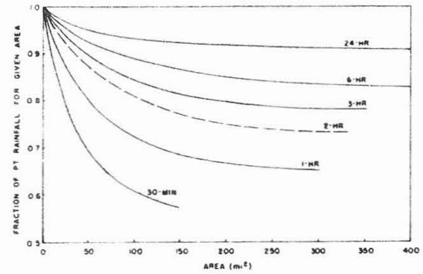

FIG. 1 Point-to-area conversion ratios for selected durations (Fig. 14, NOAA Atlas 2), 2-h interpolated.

In this paper we use records from dense recording raingage networks, operated by the USDA, Southwest Rangeland Watershed Research Center at the Walnut Gulch Experimantal Watershed near Tombstone, AZ, and the Alamogordo Creek Experimental Watershed near Santa Rosa, New Mexico (Fig. 2), to develop new depth-area curves. We believe the new curves are applicable to southwestern watersheds of similar climates for rainfall durations from 30 min to 6 h over areas up to 200 km². We compared these new curves with the NOAA Atlas 2 curves. Complete descriptions of the experimental watersheds and their instrumentation have been given by Renard (1970) and the Agricultural Research Service (1971). Gage density in each basin is about 1 per 3 km².

For many design problems on Southwestern watersheds, information is needed to supplement the type of information provided in NOAA Atlas 2. Most rain-produced runoff from small Southwest rangeland watersheds results from intense, short-lived thunderstorms of limited areal extent (Osborn and Laursen, 1973). Also, in many cases, an estimate of the distribution of the storm rainfall over the area is important in estimating the runoff from the storm. In a final section of this paper, distribution curves are developed from selected Walnut Gulch and Alamogordo Creek data.

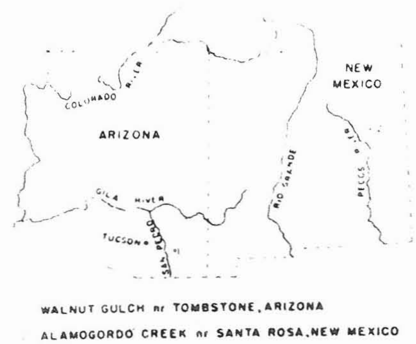

FIG. 2 Location of USDA-SEA-AR experimental watersheds.

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Contribution of the Southwest Watershed Research Center, USDA-SEA-AR, Tucson, AX, and National Weather Service, NOAA, Commerce Dept., Silver Spring, MD.

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TABLE 1. MAXIMUM ANNUAL RAINFALL FREQUENCIES (mm) ESTIMATED BY FITTING SEVERAL FREQUENCY DISTRIBUTIONS TO 20 YEARS (1957-76) OF DATA FOR WALNUT GULCH

	Log normal			Pearson Type III			Log-Pearson Type III			Gumbel		
	30-min	1-h	2-h	30-min	1-h	2-h	30-min	1-h	2-h	30-min	1-h	2-h
2-yr												
Basin average	14.0	17.0	18.4	15.0	17.9	19.2	14.8	18.0	19.3	14.1	16.9	18.3
RG #3	21.1	25.0	27.2	22.0	24.7	27.1	21.6	24.8	27.3	21.2	25.2	27.3
RG #33	25.8	29.9	31.2	25.0	29.2	30.6	24.6	28.3	29.8	26.2	30.2	31.5
RG #66	22.7	26.1	28.6	24.0	27.6	29.5	22.8	26.4	28.4	23.1	26.4	28.9
10-yr												
Basin average	20.9	24.7	25.8	19.5	23.1	24.5	19.9	23.3	24.5	21.1	24.9	26.2
RG #3	32.9	40.0	43.2	31.8	40.3	43.2	32.3	40.2	43.1	34.1	43.4	46.3
RG #33	43.1	49.2	50.8	45.0	51.4	52.7	44.0	50.2	51.8	49.0	55.7	56.9
RG #66	38.4	43.0	47.0	37.3	41.5	46.6	38.2	42.7	47.2	40.3	44.8	50.1
100-yr												
Basin average	28.9	33.5	34.1	22.4	26.8	28.2	23.0	26.1	27.2	29.8	34.8	36.0
RG #3	47.4	58.6	63.1	40.4	59.2	61.9	42.3	60.9	62.1	50.2	66.0	70.0
RG #33	65.5	50.8	75.5	71.3	79.5	80.1	81.5	93.4	92.8	77.5	87.5	88.7
RG #66	58.9	64.7	70.5	49.5	53.7	63.8	57.1	61.7	72.1	61.7	67.8	76.5

POINT-TO-AREA CURVES

Basic Method

The method used by NWS for developing the point-to-area curves, shown in Fig. 1, was described in detail in U.S. Weather Bureau Technical Paper No. 29 (1958). Briefly, the technique for developing point-to-area curves for a particular duration consisted of the following steps.

1 Annual maximum rainfall amounts were listed by duration for each station in the groups of closely spaced, recording raingages.

2 Similarly, annual maximum rainfall amounts for various durations over areas of several sizes were determined. Areal depths are the average of the gages within the area. These annual maximum areal values did not necessarily occur on the same day as the maximums at individual stations.

3 The same type of frequency distribution was fitted to the annual maximums at each gage and for each area.

4 For a given frequency, the point values within each area were averaged (assuming negligible climatological gradients within the network).

5 The ratios of areal to averaged point values at equal frequencies or return periods defined the point-to-area curve.

Frequency Distribution

The NWS uses the Gunbel extreme value procedure (Gumbel, 1958) for fitting of the Fisher-Tippett Type I distribution for developing rainfall frequency maps and depth-area curves. The choice of this frequency distribution is partly based on work that showed that for the continental United States, this distribution fitted maximum annual point rainfalls fairly well (Hershfield and Kohler, 1960) and was slightly better than some other standard methods used in predicting frequencies for independent samples not used in deriving the curves (Hershfield, 1962). For a limited check on frequency distributions applicable to the data of this study, we fitted Walnut Gulch and Alamogordo Creek basin average and selected station maximum annual storm rainfall with log normal, Pearson Type-III, log Pearson Type-III, and the Gumbel fitting of the Fisher-Tippett Type I frequency distributions, by the method of moments. An illustrative portion of these values for Walnut Gulch are listed in Table 1.

By visually comparing plotted points with computed curves for the several distributions, we concluded that for the data as a whole, the Gumbel distribution seemed to fit best. For this reason and for continuity with previous NWS work, it was selected for this study.

The Gumbel fitting is based on the concept that a series of values, all of which are maximums from independent samples of equal and sufficient size, drawn from the same population (e.g., annual maximum rainfalls), conforms to the probabillity distribution of a dimensionless "reduced variate", y, if suitably scaled. The term y is defined by its probability distribution as:

$$y_{Pr} = -\ln(-\ln Pr) \qquad [1]$$

where Pr is the probability that a reduced variate, y, chosen at random, will be less than or equal to the particular value, y_{Pr}. Following an example given by the National Bureau of Standards (1953), this distribution is fitted to a sample of size N of a real variable, X, by assuming the common plotting position formula

$$Pr = \frac{m}{N+1} \qquad [2]$$

applies to both y and X, where m is rank from lowest to highest. In principle, a linear regression fit is made to the N pairs, X_m, y_m, where X_m's are from the sample and the y_m's are found by substituting equation [2] into equation [1]. This may be simplified by using precomputed tables, which require only the mean and standard deviation of the X's and the sample size N as input. The steps and tables for the simplified procedure are listed by the World Meteorological Orgainzation (1974).

The relatively small values of some of the annual maximums lead to one additional empirical test. At the same stations in Table 1, we applied the Gumbel fitting of the extreme value distribution to the 20 highest rains, regardless of year of occurence (partical duration series), with the thought in mind that "partial duration" storms in an arid climate might be regarded as extremes for this distribution. However, by visual inspection, use of the partial duration series did not improve the fit compared

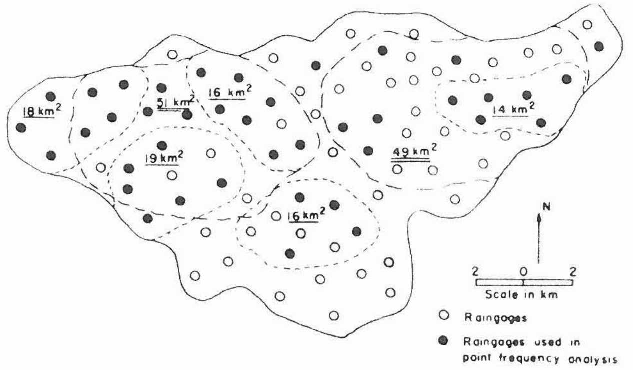

FIG. 3 Recording raingage network and subwatersheds used in determining frequency distributions for Walnut Gulch.

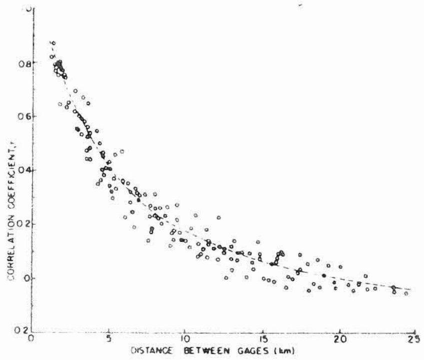

FIG. 4 Correlation coefficients for rainfall amounts for selected pairs of gages on Walnut Gulch.

to the annual series, at least in this case. For this reason, and because the original work was based on annual series, the partial duration series was not used.

Walnut Gulch Curves

Recording raingage records for the period 1957-1976 on and immediately adjacent to the Walnut Gulch Experimental Watershed were used in this study. Gages were added as funds became available through 1965, when the network of 80 gages was completed, as shown in Fig. 3. The 26 gages with a full period of record, are more concentrated on the lower (western) end of the watershed. Therefore, subareas for analysis were chosen mostly on the lower half of the watershed where the records are longest and the gages closest together.

In constructing representative areas (second step of "basic method"), raingages were assumed to represent rainfall within an 0.8 km (one-half-mile) radius. Area outlines were drawn by connecting the imaginary circular areas around each station, tangentially. Areal average rainfalls were obtained by averaging amounts from all existing gages within each area. As gages were added to each area, they were included in the areal average. The raingages were fairly well spaced in most years, so all were given equal weight in averaging areal rainfall. Obviously, the averages are more uncertain in the early years of fewer gages, particularly before 1960. Annual maximum rains were determined for each of 20 years (1957-1976), and the frequency distribution fitted separately for areas of 176, 51, 49, 18, 19, 16, 15, 14 and zero (point) km² (fig. 3), for durations of 30, 60, 120 and 360 min.

Gages used for point frequency comparison to areal values are indicated in Fig. 3. Only gages with no more than 2 yr of missing record were used for this. The few missing years (at 14 of the 40 gages) were filled in by interpolation of annual maximums from adjacent stations. As it turned out, using 20 gages with complete records gives almost the same result as using 40 gages with some estimated record. As stated, there was an uneven distribution of raingages on Walnut Gulch during the early years of record. For better distribution, six of the gages on the lower end of the watershed were omitted in the point analysis comparison with 176 km² area.

The variability of estimating based on point records is illustrated in Table 2. Estimated rainfall amounts for annual series for varying durations and frequencies based on records from 6 raingages were compared. For example, the 100-yr, 1-h rainfall estimate at raingage 33 is about double that of raingage 31. The two gages are only 2 miles apart, and both records are excellent.

As an indicator of the scale of the phenomenon being investigated, correlation coefficients were compared at Walnut Gulch between rains at selected pairs of gages with varying distance between them (Fig. 4). The correlation is for storm depths during 1961-72, when at least one of the two storm gage totals equalled or exceeded 5 mm. No storm had a duration longer tha 2 h. The curve is fitted by eye.

As a check on possible non-random distribution of rainfall on Walnut Gulch, estimated 100-yr, 1-h rainfall amounts were plotted against gage elevation (Fig. 5). The range of values is greater on the lower end of the watershed where there were more gages, but there is certainly no clear evidence of higher or lower average values within the 450 m elevation range on the watershed.

Depth-area curves were constructed through the plotted points (1.0 for zero) for 2-, 10- and 100-yr return periods for durations of 30, 60, 120 and 360 min (Figs. 6-9) by using a method suggested by one of the authors (Myers) for a least squares fit to:

$$r = 1 - M \exp\left[-a\left(\frac{A}{A_o}\right)^{b-1}\right] \qquad [3]$$

TABLE 2. COMPARISON BETWEEN PREDICTED RAINFALL AMOUNTS (mm) FOR ANNUAL SERIES FOR VARYING DURATIONS AND FREQUENCIES USING SIX DIFFERENT STATION RECORDS ON WALNUT GULCH

	2-yr			10-yr			100-yr		
	30-min	1-h	2-h	30-min	1-h	2-h	30-min	1-h	2-h
RG #1	21.8	25.4	26.8	37.3	50.1	55.0	56.5	80.9	90.2
RG #33	26.2	30.2	31.5	49.0	55.7	56.9	77.5	87.5	88.7
RG #66	23.1	26.4	28.9	40.3	44.8	50.1	61.7	67.8	76.5
RG #3	21.2	25.2	27.3	34.1	43.4	46.3	50.2	66.0	70.0
RG #31	19.9	22.1	23.2	30.5	33.5	34.8	43.8	47.6	48.7
RG #70	23.2	28.6	32.3	39.6	49.2	57.6	59.8	74.9	89.4

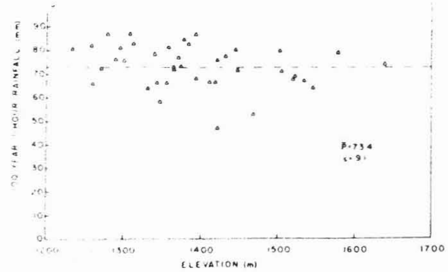

FIG. 5 Comparison of estimates of 100-yr, 1-h rainfall amounts with elevation for selected raingages on Walnut Gulch.

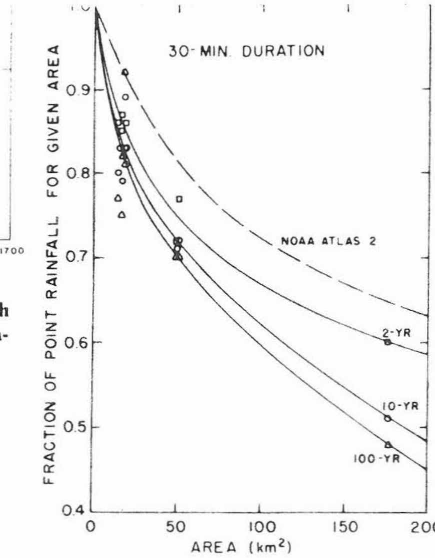

FIG. 6 Point-to-area conversion ratios for 30-min duration rainfalls for selected frequencies on Walnut Gulch.

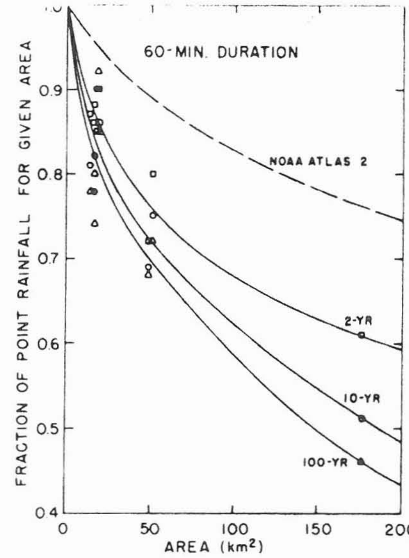

FIG. 7 Point-to-area conversion ratios for 60-min duration rainfalls for selected frequencies on Walnut Gulch.

where r is depth-area ratio for area A in km², A_o is a unit area of 1 km², and M, a, and b are fitting constants. The curves were extrapolated to 200 km², reasonable limit based on available data. The curves lie well below the NOAA Atlas 2 curves, show more change with frequency, and show less change with duration.

To highlight the change with the duration, the 2- and 100-yr event curves from Figs. 6-9 are replotted together on Fig. 10. The difference between the 30-, 60- and 120-min curves for a given frequency are small, and could be due to sampling variation. However, there are real differences between the families of curves of the 2-yr and 100-yr events. Clearly, the curves are consistent with features of summer thunderstorm rain in southwestern Arizona with the following characteristics: (a) the airmass thunderstorms are of short duration and limited areal extent, and (b) the extreme events tend to be confined to about the same areal extent as lesser events. Thus, up to about 2 h, depth-area ratios do not increase with duration. When storms move and deposit their heaviest precipitation some distance apart in succeeding h, area-point differences necessarily are reduced with increasing duration. The NOAA Atlas 2 depth-area curves reflect this characteristic. Many storms move fairly rapidly across the Walnut Gulch watershed, but these fast-moving events do not produce the maximum annual events. In the case of Walnut Gulch, the curves for respectively longer return periods plot below shorter return periods, because the standard deviation, which is most influential on the longer return periods in the Gumbel method, is less for the watershed averages than for point values.

Based on topography, the similarity of point rainfall frequencies, subjective experiences in observing thunderstorms, and qualitative confirmation from a few small watershed networks (with less record than Walnut

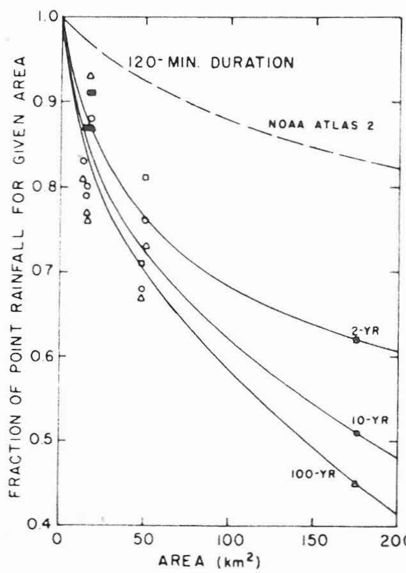

FIG. 8 Point-to-area conversion ratios for 2-h duration rainfalls for selected frequencies on Walnut Gulch.

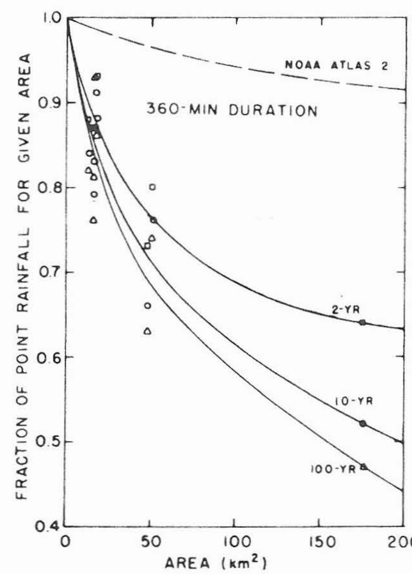

FIG. 9 Point-to-area conversion ratios for 6-h duration rainfalls for selected frequencies on Walnut Gulch.

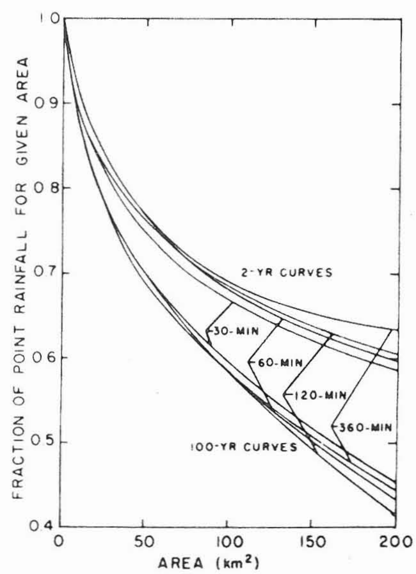

FIG. 10 Comparison of point-to-area rainfall ratios for 2-yr and 100-yr events for Walnut Gulch.

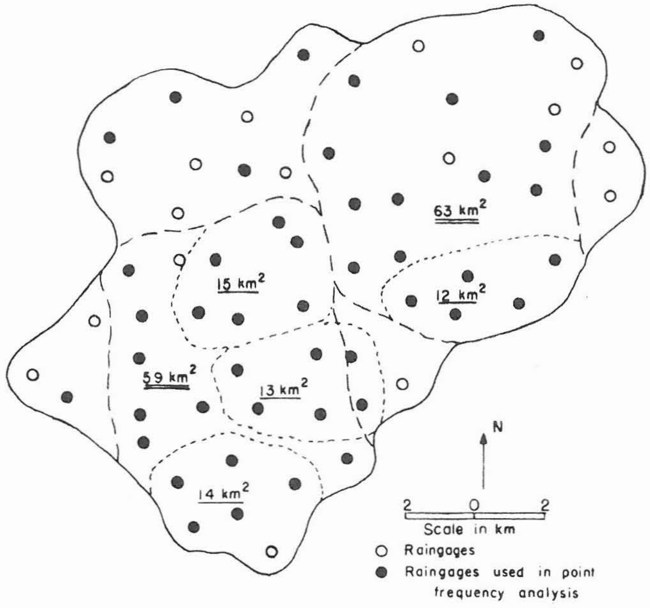

FIG. 11 Recording raingage network and subwatersheds used in determining frequency distributions for Alamogordo Creek.

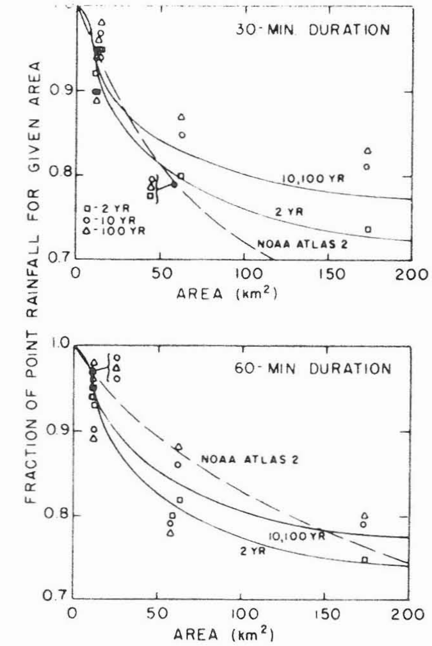

FIG. 12 (top) Point-to-area conversion ratios for 30-min duration rainfalls for selected frequencies on Alamogordo Creek.

FIG. 13 (bottom) Point-to-area conversion ratios for 60-min duration rainfalls for selected frequencies on Alamogordo Creek.

Gulch), the depth-area curves for Walnut Gulch are believed to be characteristic of much of southwestern Arizona, southwestern New Mexico, and north central Mexico.

Alamogordo Creek

The Alamogordo Creek Watershed data were analized identically to that for Walnut Gulch for 174, 59, 63, 15, 12, 13, 14 and 0 km² areas. The network is depicted in Fig. 11 along with the sub-areas. The average values were derived from all gages within the respective boundaries. Twenty-one well spaced gages with complete 20-yr records (1957-1976) were used to develop point frequencies for comparison to the 174 km² area, and all the indicated gages for the sub-area comparisons. For the latter, the same rules and procedures were used as for Walnut Gulch. In this case, the computed 100-yr depth-area curve lay above the 10-yr curve, but the difference was so slight that its reality is uncertain, and the 10-yr and 100-yr curves have been combined. The resulting depth-area curves are in Figs. 12-15.

The amounts and distributions of thunderstorm rainfall on the Alamogordo Creek Watershed are typical of the high plains in eastern New Mexico and western Texas. The extreme events can occur from either pure air-mass thunderstorms (as on Walnut Gulch) or a combination of frontal activity and convective heating (which is unusual on Walnut Gulch). The rainfalls that are largest both in area covered and depth result from the latter situation. Because of this, for similar durations and frequencies, maximum rainfall on Alamordo Creek is about 10 to 15 mm greater than that on Walnut Gulch.

The major events on Alamogordo Creek also cover larger areas than those on Walnut Gulch, and depth-area ratios were considerably higher than those on Walnut Gulch. Infact, for a 30-min duration the depth-area curve from NOAA Atlas 2 lies generally below the Alamogordo Creek curves (Fig. 12). For longer durations, Alamordo Creek curves decreased more rapidly than the NOAA Atlas 2 curves to a maximum difference at about 80 km², and then they approach the NOAA Atlas 2 curves. The range of annual average maximum watershed rainfall amounts varies much more on Alamogordo Creek than on Walnut Gulch because of the occasional massive frontal convective event. Average watershed rainfall was more variable than average point rainfall or area-to-point depth-area ratios for longer

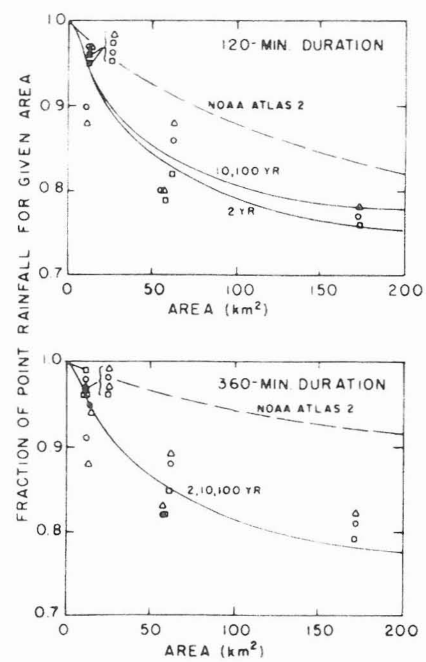

FIG. 14 (top) Point-to-area conversion ratios for 2-h duration rainfalls for selected frequencies on Alamogordo Creek.

FIG. 15 (bottom) Point-to-area conversion ratios for 6-h duration rainfalls for selected frequencies on Alamogordo Creek.

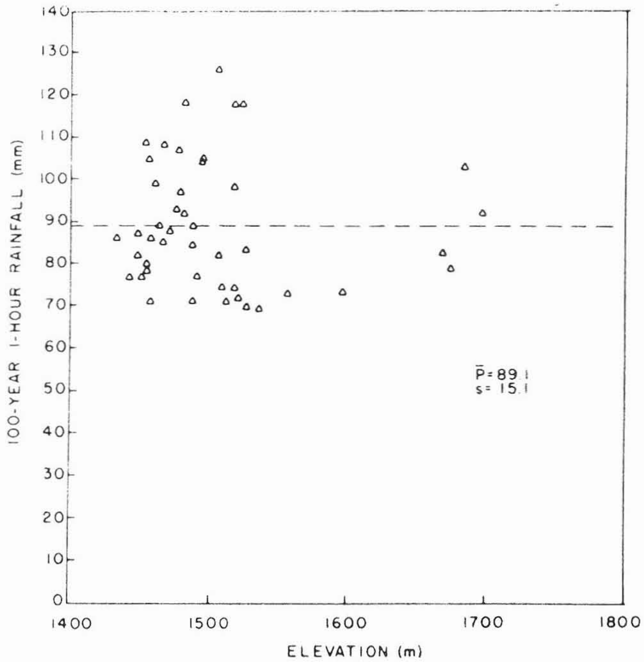

FIG. 16 Comparison of estimates of 100-yr, 1-h rainfall amounts with elevation for selected raingages on Alamogordo Creek.

return periods were greater than for shorter return periods.

Estimated 100-yr, 1-h rainfall amounts were plotted against gage elevation as a check on the assumption of random rainfall distribution on Alamogordo Creek (Fig. 16). Again, the range of values is greater at the lower elevations where there were more gages, but there is certainly no clear evidence of higher or lower values within the 300 m elevation range on the watershed.

DISTRIBUTION OF STORM RAINFALL

Once the engineer or hydrologist has determined the average watershed rainfall from the point frequency value and depth-area curve, there is still the question of the distribution of rainfall within the watershed during the storm. This is needed for runoff prediction based on the precipitation. For example, the 100-yr, 1-h rainfall at a fixed point within a watershed is significantly less than the largest 1-h rainfall expected once in 100 years somewhere within that watershed. Curves were developed from the Walnut Gulch and Alamogordo Creek raingage records for 50- and 150-km^2 watersheds to indicate this maximum as well as the watershed rainfall distribution in terms of the fraction of the watershed covered by percentages of the basic average (Figs. 17 and 18). The curves are averaged from the five storms on each basin with the largest total storm average basin rainfall in 20 yr. The curves do not necessarily apply to lesser storms expected on the average more often than once in about 5 yr.

As examples of the application of the curves for Walnut Gulch, the 100-yr, 1-h point rainfall averaged over the 40 stations in Fig. 3 is 75 mm (from tabulation not shown). From Fig. 7, the corresponding depth-area ratio for 150 km^2 is 0.50—average watershed rainfall would be about 38 mm. From Fig. 17, the maximum rainfall at some point within the watershed would be about 110 mm, and only 40 percent of the watershed would be covered by 38 mm or more of rainfall. Similarly, the 100-yr, 1-h point rainfall for Alamogordo Creek is about 90 mm. From Fig. 13, the depth-area ratio is 0.78—the average watershed rainfall is 70 mm. From Fig. 18, the maximum point rainfall at some point within the watershed would be about 140 mm, and about 40 percent of the watershed would be covered by 70 mm of rainfall or more. Similar curves were developed for rainfall distributions with 50 km^2 basins and are shown on Figs. 17 and 18.

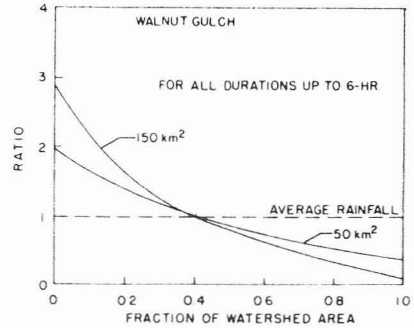

FIG. 17 Fraction of watershed equal to or exceeding average storm rainfall for Walnut Gulch.

The storms, from which Figs. 17 and 18 are derived, are in the 5- to 25-yr return period range. Based on 20 yr of record, it appears the curves would not be greatly different for 100-yr basin averages for Alamogordo Creek; whereas, Fig. 10 implies that the curves would be slightly steeper for the 100-yr return period at Walnut Gulch.

SUMMARY

New depth-area conversion curves for adjusting point rainfall amounts for given frequencies values to areal averages were developed from 20 years' data from densely spaced recording raingages on experimental watersheds of the USDA Southwest Rangeland Watershed Research Center in two climatic zones in the semi-arid Southwest. In southeast Arizona, at Walnut Gulch, the reductions from point-to-area were significantly greater than previously published curves, based on nationwide averages. These results offer opportunities for economy in design without relaxing frequency standards in climatologically similar areas. This is consistent with known limited area characteristics of the air-mass thunderstorms that produce most of the runoff.

New curves at Alamogordo Creek in northeastern New Mexico departed less from previous curves, but still indicate significant differences. The maximum departure of the new curves from the previous curves occurred at an area of approximately 100 km^2. The significant differences between Alamogordo Creek and Walnut Gulch

(Continued on page 91)

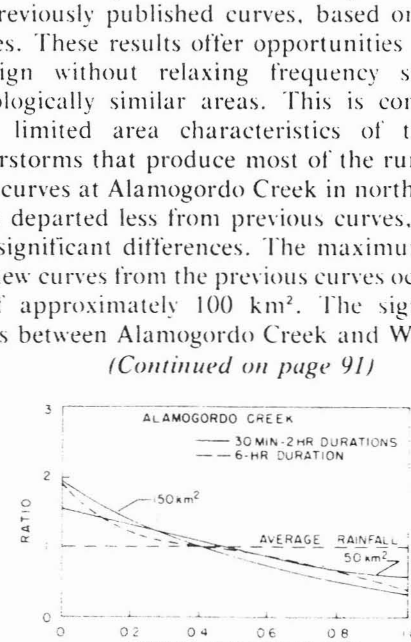

FIG. 18 Fraction of watershed equal to or exceeding average storm rainfall for Alamogordo Creek.

(Continued from page 87)

illustrate the influence of frontal storms with strong convective activity associated with cold air-mass invasions from the north and east into eastern New Mexico.

Curves were also developed indicating maximum expected rainfall and typical areal distributions of rainfall depths during major precipitation events for 50- and 150-km² watersheds. This is neccessary information, along with the revised point-to-area curves, to realistically predict small watershed runoff from precipitation.

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5 Miller, J. F., R. H. Frederick and R. J. Tracey. 1973. Precipitation—Frequency Atlas of the western United States, IV: New Mexico and VIII: AZ, NOAA Atlas 2, National Weather Service, NOAA, Silver Spring, MD.

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APPENDIX 1-M

Comparison of depth-area ratios for selected storms in Maricopa County.

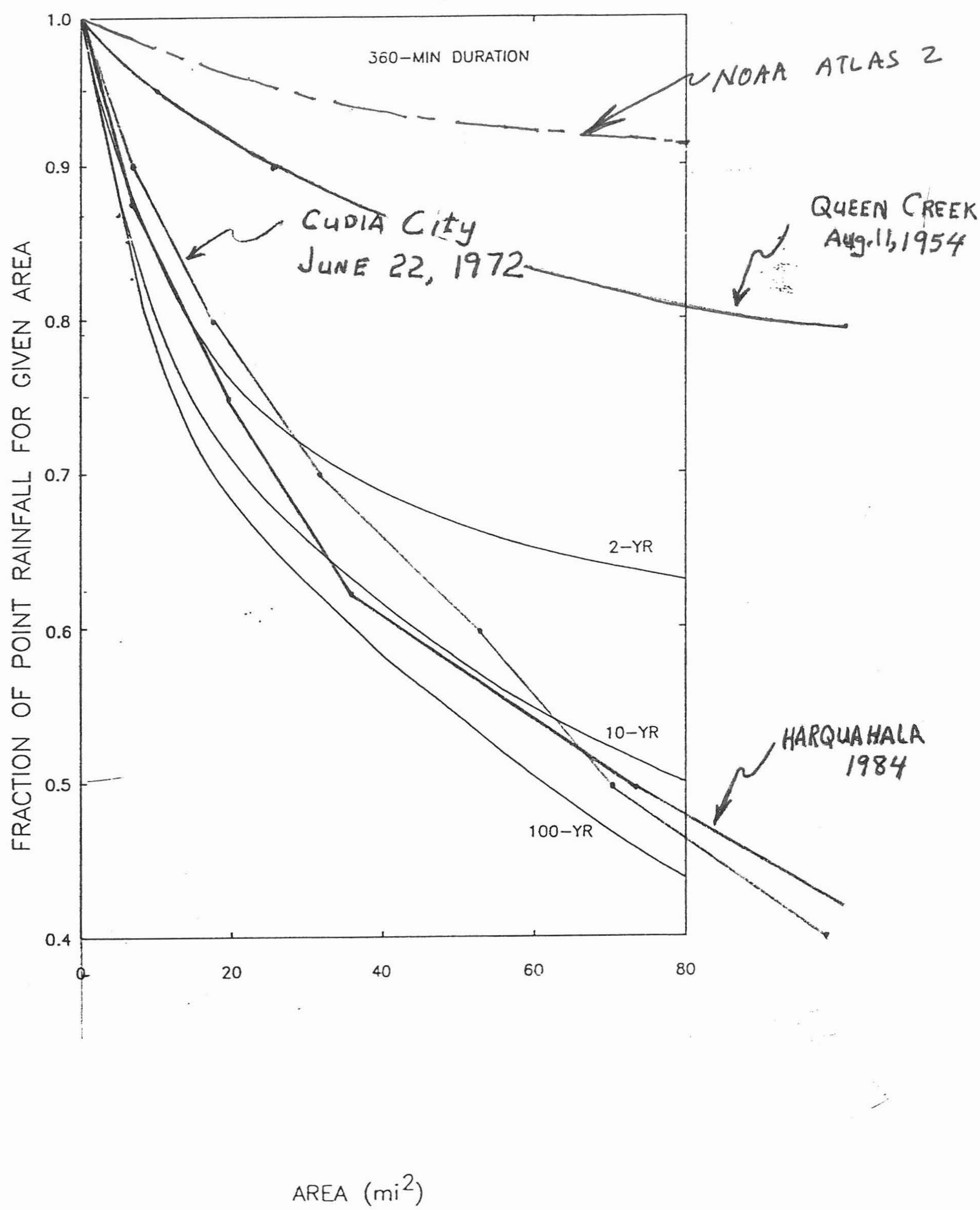
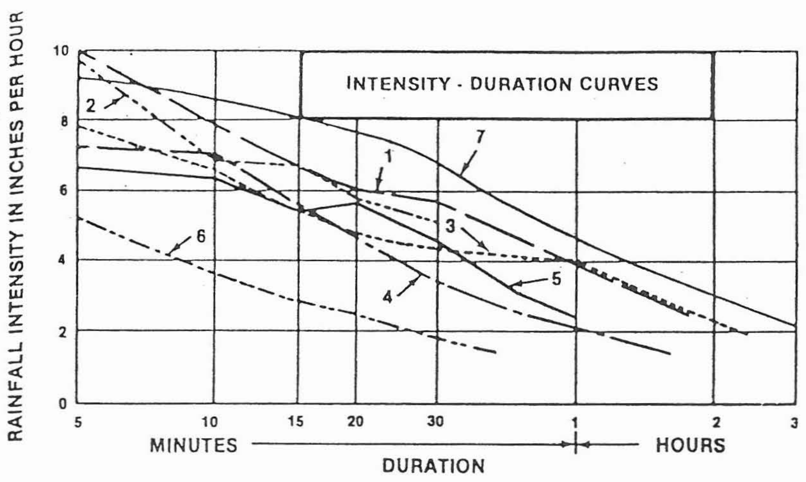
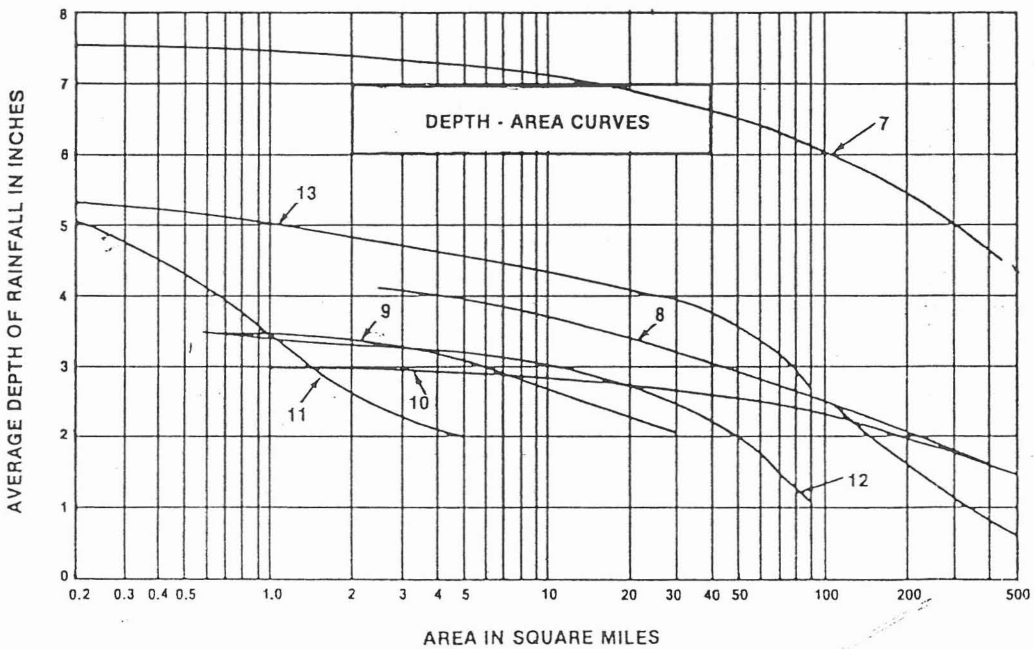


FIGURE 24. Point-to-area conversion ratios for 6-h duration rainfalls for selected frequencies.

APPENDIX 1-N

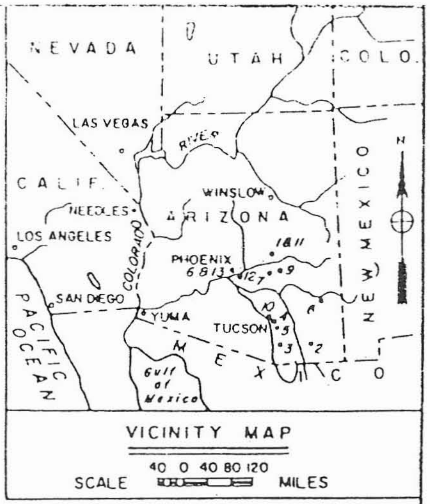
Depth-area relationship for the Queen Creek Storm of 1954. Obtained from: U.S. Army Corps of Engineers, 1974, Gila River Basin, Arizona, New Mexico, and Phoenix City Streams, Design Memorandum No.1, Hydrology Part 1, Los Angeles District, 51 p.





NOTE:
INTENSITY-DURATION CURVE NO. 7 REPRESENTS APPROXIMATE VALUES AT THE STORM CENTER. THE CURVE IS SYNTHESIZED FROM DATA AT GAGES WITHIN THE STORM, AND IS SUPPLEMENTED BY INTENSITY-DURATION VALUES FROM OTHER SHORT DURATION STORMS IN CENTRAL ARIZONA. DATA FOR OTHER INTENSITY-DURATION CURVES ARE FOR STATIONS WITHIN THE STORM AREA BUT NOT NECESSARILY AT THE STORM CENTER.

USED IN THE ANALYSIS



CURVE NO.	STORM LOCATION	DATE	APPROXIMATE DURATION HRS	MIN
1	PARKER CREEK	SEPT. 10, 1933	1	45
2	WALNUT GULCH	OCT. 4-5, 1954	0	30
3	SANTA RITA	JUNE 29, 1959	2	20
4	UNIV. OF ARIZONA	AUG. 13, 1940	1	35
5	TUCSON AIRPORT	SEPT. 24, 1943	1	0
6	PHOENIX	JULY 26, 1936	0	40
7	QUEEN CREEK	AUG. 19, 1954	7	0
8	THATCHER	SEPT. 16, 1939	1	30
9	GLOBE	JULY 29, 1954	1	0
10	TUCSON	SEPT. 24, 1943	3	0
11	PARKER CREEK	AUG. 5, 1939	2	20
12	TEMPE	SEPT. 14, 1969	1	0
13	PHOENIX	JUNE 22, 1972	2	0

REDUCTION COEFFICIENTS

	NOAA	QUEEN CREEK
1 mi^2	1.00	.99
10 mi^2	.980	.95
100 mi^2	.865	.795
200 mi^2	.852	.728
400 mi^2	.830	.622

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

INTENSITY-DURATION AND DEPTH-AREA CURVES

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

OURCE: REF. 2)