TECHNICAL PAPER NO. 24

Rainfall Intensities for Local Drainage Design in the United States

For Durations of 5 to 240 Minutes and 2, 5, and 10-Year Return Periods

Part I: West of the 115th Meridian

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Rainfall Intensities for Local Drainage Design
in the United States

PREFACE

This report has been prepared for the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers, to provide rainfall intensity-frequency data for design criteria in estimating required capacities of drainage systems for various types of military installations. These data consist of the 5 to 240-minute rainfall intensities expected to be equalled or exceeded on an average of once in 2, 5, and 10 years.

While a new rainfall intensity-frequency study for the entire United States is greatly needed, financial limitations precluded an undertaking of such magnitude at this time. Consideration of available funds, adequacy of previous studies, and priorities of military construction projects led to the conclusion that this report should deal with that portion of the United States lying west of the 115th meridian. The study area may be extended eastward, in which case the results will be published as another part of this report.

At meetings between representatives of the two cooperating agencies during the planning stage of this investigation, the following decisions were made: (1) Because of time and cost limitations, the study was to be based on readily available data, most of which was in published form. This eliminated the tremendous cost involved in evaluating high, short-duration intensities for thousands of station-years of raingage charts, with, it is believed, very little sacrifice of accuracy in the final results. (2) For convenience in design use, the results were to be presented in the form of 1-hour rainfall maps and intensity-duration curves suitable for use with current Engineering Manuals of the Corps of Engineers.

The general plan of the study was to determine first the 2-year clock-hour rainfall amounts for the hundreds of stations for which clock-hour data are readily available. These 2-year clock-hour amounts were then converted to 2-year maximum hourly amounts for the maps of item (2) above by the use of relations based on 13 stations for which maximum hourly data were available. Other relations based on 34 long-record stations provide a means for converting the 2-year to 5 and 10-year amounts. Finally, intensity-duration curves were constructed so that intensities for any duration from 5 to 240 minutes could be readily obtained if the hourly amount were known. These intensity-duration curves were based on 33 long-record stations for which annual maximum rainfall amounts for durations of 5 minutes to 24 hours were available.

The investigation was conducted under the direct supervision of J.L.H. Paulhus, Chief of the Cooperative Studies Section, coordination with the Corps of Engineers being effected through Kenneth S. Eff of the Airfields Branch. W. E. Hiatt, Chief of Hydrologic Service's Division, and his assistants, M. A. Kohler, A. L. Shands, and W. T. Wilson, served as consultants. Others contributing were D. M. Hershfield, project leader; C. W. Cochrane and M. A. Bilello, technical assistants; G. M. Foster, R. J. Haley, Mrs. B. A. Littler, Mrs. R. A. McCrory, and W. G. McMillan, clerical aids. Drafting was by I. A. Santiago; typing by Mrs. B. R. True.

In this new edition a few revisions have been made and a few small errors have been corrected. However, the final results are exactly the same as those in the original edition.

BASIC DATA

SOURCES

1. Sources of published hourly and daily precipitation data were the Hydrologic Bulletin and the Climatological Data, together covering the period 1940-1951. The hourly data contained in these two publications are clock-hour amounts, i.e., amounts for 60-minute periods beginning and ending on the hour such as 1 to 2, 2 to 3, etc. The term "clock-hour" is used with the same meaning in the entire report to distinguish these amounts from maximum hourly amounts, which are the maximum amounts for any continuous 60-minute period.

2. There were about 650 recording gages in the study area for which published clock-hour data were readily available for the period 1940-1951 or portion thereof. Published daily rainfall amounts were available for the same period for some 1300 nonrecording gages. However, data for many stations had to be discarded for the following reasons: (1) The period of record was less than five years, making it unreliable for determination of rainfall amounts having the required recurrence intervals. (2) There were significant changes in the location of the gage during the period of record. (3) Large rainfall amounts in the published data could not be verified from original records. (4) In the case of the nonrecording gages, their data were not used if there was a recording gage at or near the same station; and neither were they all used when located close together in areas having homogeneous rainfall characteristics. After these discards had been effected, there remained about 500 recording gages with an average record of slightly less than 10 years and about 400 nonrecording gages with an average record of about 10 years on which to base the study.

3. The data for the long-record stations used to derive relations for converting (a) clock-hour data to maximum hourly, (b) 2-year values to 5 and 10-year, and (c) 1-hour intensities to those for 5 to 240 minutes were obtained from unpublished sources. These sources, available for Weather Bureau first-order stations only, were the Local Climatological Record and Weather Bureau Forms 1001 and 1017. The Local Climatological Record and Form 1001 contained the maximum 5, 10, 15, 30-minute and 1, 2, and 24-hour rainfall amounts for each month of record. Forms 1001 and 1017 and some old WPA tabulations yielded clock-hour rainfall amounts for the period prior to 1940, which was not covered by either the Hydrologic Bulletin or Climatological Data.

4. Since the data of paragraph 3 were to be used to develop relations having a fairly high degree of reliability, it was important that only stations having relatively long records be used. Weighing the advantages of very long records from a few stations against those of shorter records from a larger number of stations, it was decided that a minimum record of 15 years would provide the required degree of reliability and a satisfactory network of stations. There were 33 stations west of the Continental Divide with the required minimum record, 27 being in the study area proper. The average record for the 33 stations was about 40 years. Because of their use in the study, the 33 stations will be referred to in the remainder of this report as control stations.

SURVEY OF DATA FOR FREQUENCY ANALYSIS

5. In surveying the basic clock-hour data for frequency analysis, only amounts equal to or above a selected base value for a particular station were considered. The magnitude of the base value was set so that the number of clock-hour amounts obtained would at least equal the years of record, i.e., for a station having a 10-year record, the survey had to yield at least the 10 highest values[1]. The only restriction affecting this rule was that there should be no more than one clock-hour amount in any 4-hour period. In other words, a minimum interval of 3 hours was required between any two successive selected values. This particular minimum interval was selected because it yields results suitable for the required drainage-design criteria and because it is consistent with the current instructions[2] concerning the definition of excessive precipitation.

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[1] Tabulations of these highest values for individual stations are available for inspection in the Hydrologic Services Division, U.S. Weather Bureau, Washington, D.C. The material is not now in suitable form for photographic reproduction, but future publication is being considered.

[2] WBAN Manual of Surface Observations, Circular N, U.S. Weather Bureau, June 1951.

6. For an example of how the survey was conducted, consider the following observed sequence of tabulated clock-hour amounts:

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                         A. M. Hour Ending
     1     2     3     4     5     6     7     8     9    10    11    12
          .01   .02   .08   .24   .43   .36   .35   .42   .61   .72

                         P. M. Hour Ending
     1     2     3     4     5     6     7     8     9    10    11    12
    .61   .43   .44   .52   .72   .68   .89   .71   .63   .75   .32
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Assuming that the base value for the station which recorded the above precipitation was .50, it is immediately obvious that several amounts should be considered in selecting data for the frequency analysis. Examining the above sequence, the .89-inch amount ending at 7 p.m. was selected because it is the highest amount. Its selection automatically excluded the amounts for three hours on each side because of the minimum interval of three hours specified above. Re-examination of the sequence reveals that the .72-inch amount ending at noon is also eligible for selection, eliminating the amounts for the preceding and following 3-hour periods. Since there are no other amounts meeting the base value and 3-hour restrictions, this particular sequence contributed only two amounts for frequency analysis.

7. Realizing that the length of the minimum interval between amounts selected for frequency analysis would have some effect on the results, a comparison was made between 2-year clock-hour amounts obtained using a 3-hour interval and those obtained using a 24-hour interval. The comparative tests were based on data for 15 stations, the method of frequency analysis used being the same as described in paragraphs 8-9. The results are shown in Table 1. As might be expected, there is a slight tendency for the data selected on the basis of the 3-hour limitation to yield slightly higher values for the same frequency than do the data selected on the basis of the 24-hour limitation. However, the differences are small, the largest being .06 inch at Opid's Camp. Of the stations with at least 40 years of record, only Tatoosh Island shows any difference whatever.

Table 1

COMPARISON OF 2-YEAR CLOCK-HOUR AMOUNTS
FOR 3 AND 24-HOUR INTERVALS

Station	Record (years)	2-Yr Clock-Hour Amounts (in.)	
		3-hr interval	24-hr interval
Baker, Ore.	45	.36	.36
Big Bear Lake Dam, Calif.	11	.79	.74
Boise, Idaho	53	.31	.31
Cajon West Summit, Calif.	11	.38	.35
Hetch Hetchy, Calif.	11	.50	.50
Kalispell, Mont.	52	.37	.37
Mt. Wilson, Calif.	11	.87	.83
North Head, Wash.	50	.45	.45
Opid's Camp, Calif.	11	1.14	1.08
Portland, Ore.	62	.40	.40
Reno, Nev.	46	.36	.36
Tacoma, Wash.	44	.37	.37
Tatoosh Island, Wash.	49	.55	.53
Walla Walla, Wash.	47	.30	.30
Winnemucca, Nev.	46	.29	.29

TWO, FIVE, AND TEN-YEAR ONE-HOUR RAINFALL DATA

FREQUENCY ANALYSIS OF CLOCK-HOUR RAINFALL

8. The first step in preparing the data selected as described in paragraphs 5-6 for the frequency analysis was to tabulate the amounts in decreasing order of magnitude for each station. The highest clock-hour amount for a station was assigned the serial number 1; the second highest,

number 2, etc. The so-called "California" method was then used to compute the plotting position of each amount. The plotting formula is $T_r = t/m$, where T_r is the return period in years of the item having serial number m in a series arranged in decreasing order when t is the period of record in years. The percentage frequency may then be computed as 100 divided by T_r.

9. After the plotting positions of tabulated clock-hour amounts for a station had been computed, the amounts were plotted against return-period or frequency on logarithmic paper. Lines of best fit were then drawn by inspection. Figure 1 shows examples of the tabulations, plotted data, and curves. In the majority of cases, the curves were practically straight lines, as for Kneeland. However, there were also many cases where appreciable curvature, as for Del Monte, was indicated. It was from curves such as those of Figure 1 that the 2-year clock-hour amounts were obtained for each station.

FREQUENCY CURVES OF CLOCK-HOUR RAINFALL

	HIGHEST CLOCK-HOUR RAINFALL AMOUNTS AND RETURN PERIODS*			
	DEL MONTE (10-Yr. Rec.)		KNEELAND (8-Yr. Rec.)	
	Amt. (in.)	Ret. Per. (yrs.)	Amt. (in.)	Ret. Per. (yrs.)
	1.00	10.0	.57	8.0
	.71	5.0	.50	4.0
	.54	3.3	.48	2.7
	.51	2.5	.43	2.0
	.48	2.0	.42	1.6
	.48	1.7	.41	1.3
	.43	1.4	.39	1.1
	.43	1.2		
	.41	1.1		

*Return periods computed by dividing the period of record by the serial number of the amounts arranged in decreasing order.
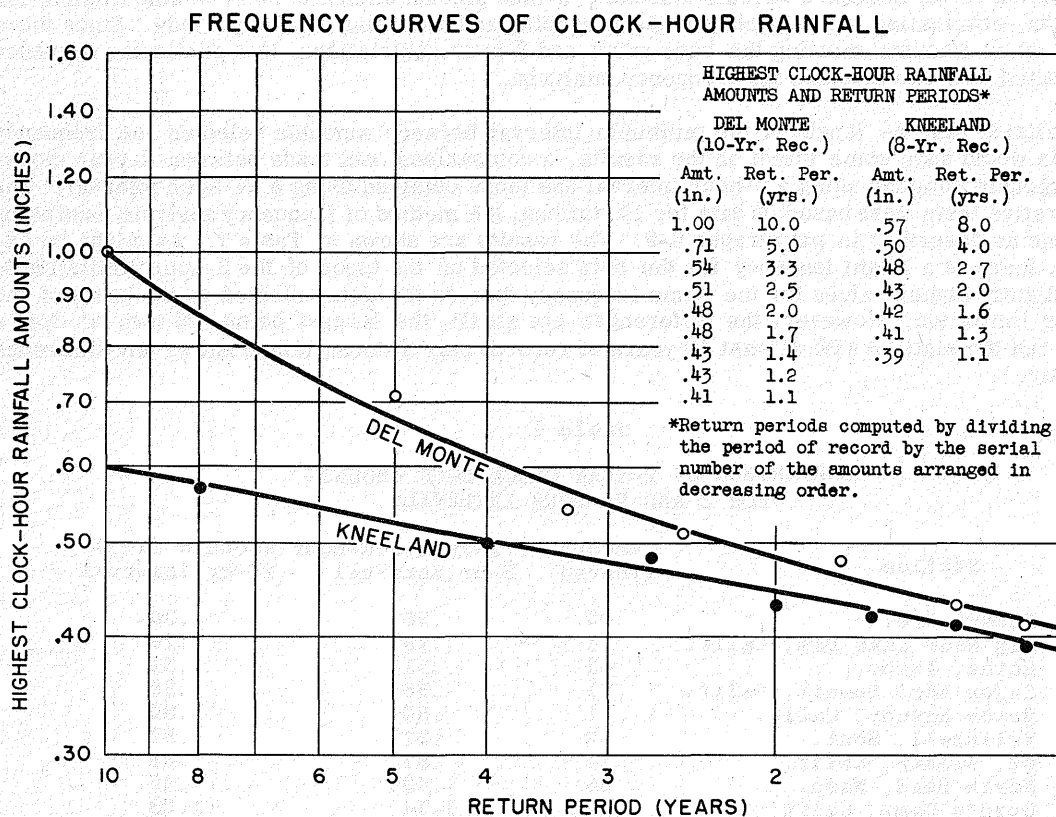
Figure 1

10. It is now in order to explain why 5 and 10-year clock-hour amounts, although required, were not obtained from these curves. Tests based on several long-record stations indicated that 5 and 10-year values obtained from records of not more than about 10-years could be extremely unreliable. Figure 2 shows the results of the test based on rainfall for Salt Lake City, Utah. The curves shown were constructed exactly as described in paragraphs 8-9, one being based on the record for the period 1940-1951, and the other on that for the period 1894-1951. For the 2, 5, and 10-year return periods the short-record curve yields clock-hour amounts of .55, .69, and .82 inches, while the long-record curve yields .42, .56, and .68 inch, respectively. It is impossible to explain these differences as resulting from changes in gage site during the record period. The station history makes no mention of any significant change in gage location, and a double-mass analysis[1] revealed no signs of such a change. The differences exist only because

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[1] Kohler, M. A., On the Use of Double-Mass Analysis for Testing the Consistency of Meteorological Records and for Making Required Adjustment, Bull. Am. Met. Soc., vol. 30, p 188, 1949.

COMPARISON OF RAINFALL FREQUENCY CURVES
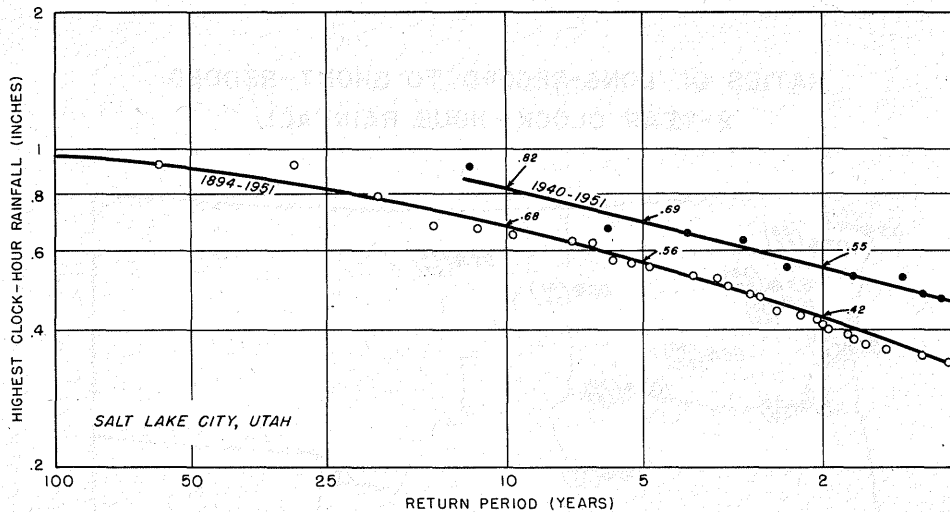BASED ON SHORT AND LONG RECORDS

Figure 2

several of the highest clock-hour amounts of record at Salt Lake City just happened to occur during the period 1940-1951.

11. There were sufficient discrepancies like those for Salt Lake City to determine that the 5 and 10-year rainfall amounts read from the frequency curves for stations with about 10 years or less of record were generally unreliable. In fact, the Salt Lake City data, showing a difference of .13 inch, or about 31 percent of the value indicated by the long-record curve, suggest that the reliability of 2-year rainfall amounts obtained from a record of only about 10 years should be investigated also.

LONG-RECORD VS SHORT-RECORD 2-YEAR CLOCK-HOUR RAINFALL

12. The percentage ratios of long-record 2-year clock-hour amounts to short-record values for 30 long-record stations are plotted on the map of Figure 3. The two 2-year clock-hour amounts, in hundredths of an inch, for each station are shown in parentheses. Ratios below 100 indicate that the 1940-1951 period yielded higher 2-year values than did the total period of record, and vice versa. It should be noted that small differences between the 2-year amounts may have a large effect on the ratio. For example, at Port Angeles, Wash., the 2-year values of .29 and .27 inch have a ratio of 107 percent. While there is some evidence of specific areas showing either high or low ratios, there are enough cases of high and low ratios at adjacent stations to suggest that there may be local variations in the ratios that may be as great as any large-scale variations apparent from this map. It was therefore decided that reliable adjustments could not be made from the limited data available. This decision appears even more justifiable when it is considered that differences in fitting the frequency curves to the plotted data could account for a few hundredths of an inch, which could affect the computed ratios by as much as 10 to 15 percent.

MAXIMUM HOURLY VS CLOCK-HOUR RAINFALL

13. Thus far, only clock-hour amounts have been considered. In order to convert these clock-hour values to the required maximum hourly intensities, a relation was developed between the two types of data. This was done by first obtaining the maximum hourly amounts and times of occurrence for each month for about 10 years of record at 13 control stations. The individual amounts at each station were then plotted against the higher of the two clock-hour amounts into which the 60-minute period of maximum intensity extended. Class intervals were selected so as to yield groups of approximately equal size, and the mean for each group was then computed. Straight lines fitted to the group means by inspection and passing through the origin very closely approximated the lines of best fit (Figure 4). The inset map of Figure 4 shows that there is no

RATIOS OF LONG-RECORD TO SHORT-RECORD
2-YEAR CLOCK-HOUR RAINFALL
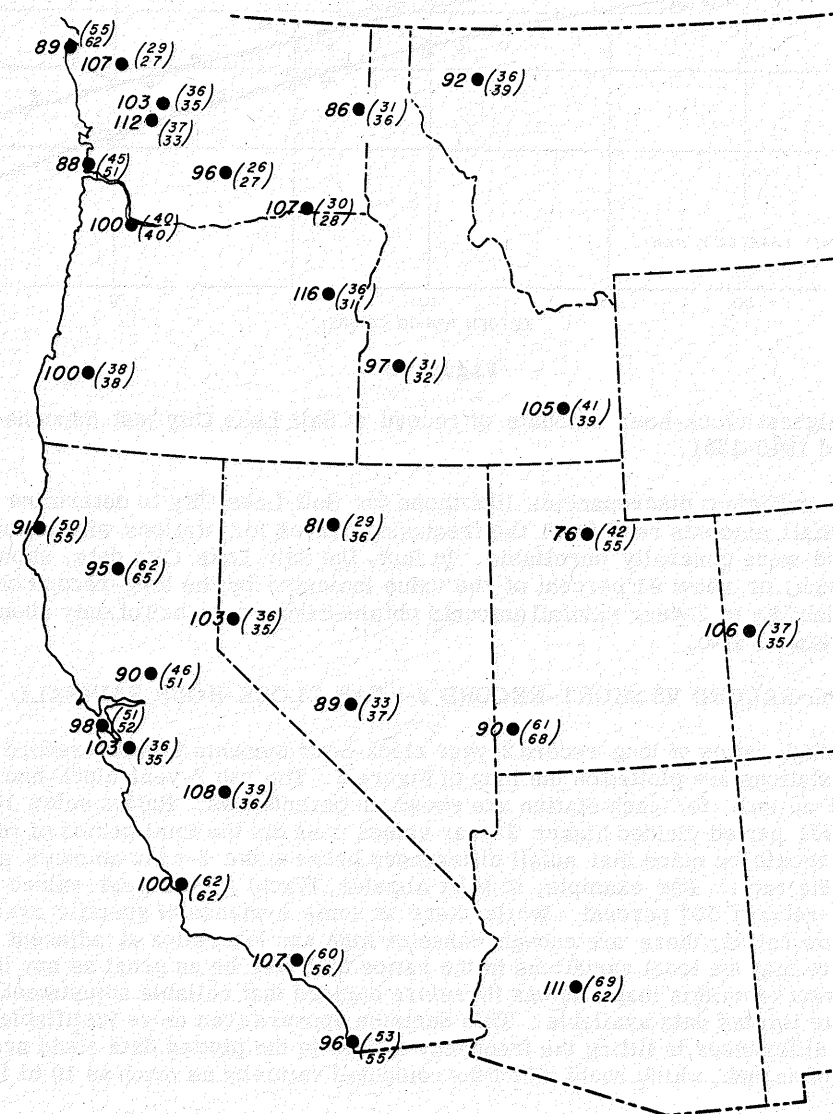
-NOTE-

UPPER NUMBERS IN ( ) ARE 2-YEAR CLOCK-HOUR RAINFALL AMOUNTS
(IN HUNDREDTHS OF AN INCH) BASED ON TOTAL PERIOD OF RECORD
(APPROX. 40 YEARS). LOWER NUMBERS ARE 2-YEAR CLOCK-HOUR
AMOUNTS BASED ON PERIOD 1940-1951. LARGE FIGURES ARE RATIOS
(IN PERCENT) OF THE TWO CLOCK-HOUR AMOUNTS.

Figure 3

RELATION OF MAXIMUM HOURLY PRECIPITATION
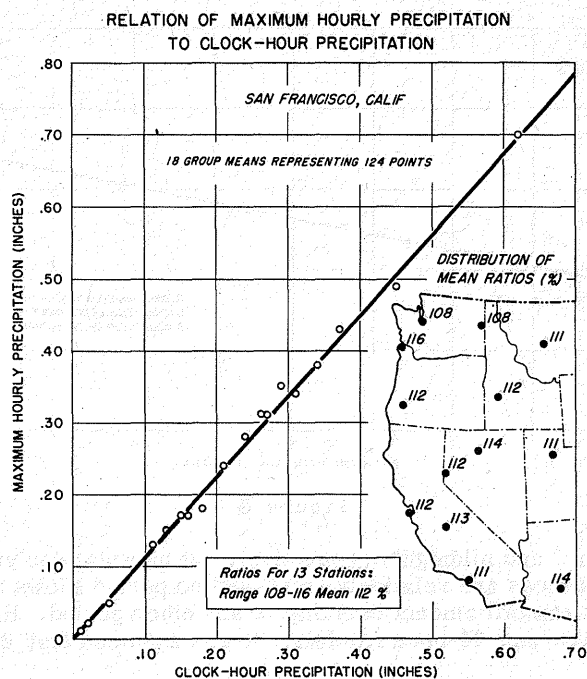TO CLOCK-HOUR PRECIPITATION

Figure 4

orderly geographic variation in the slopes obtained for the 13 stations. The mean slope for the 13 stations was 112 percent.

14. In deriving relations like those of Figure 4, hourly amounts for a wide range of magnitude were used. This was done to determine as reliably as possible if the relationship was linear or curvilinear. After the relationship had been determined to be linear, the relations were recomputed using only hourly rainfall amounts in the range of interest for this study, that is, above about the 2-year values. Straight lines through the means and origin yielded a mean slope of 113 percent for the 13 stations. This was the value selected to adjust all clock-hour data to maximum hourly intensities. It should be noted that a factor of 1.14 was obtained in an independent study[1] based on six Florida stations.

TWO-YEAR 1-HOUR RAINFALL DATA FOR FINAL MAPS

15. After all 2-year clock-hour rainfall amounts had been converted to 2-year 1-hour intensities by applying the 113-percent factor, the adjusted values were plotted on maps for the approximately 500 stations for which they were available. These stations, but not the plotted data, are shown on the maps of Figures 7-9 at the end of the report.

RELATION OF 2-YEAR 1-HOUR TO 2-YEAR DAILY RAINFALL

16. In order to supplement the plotted hourly precipitation data of the preceding paragraph, data from nonrecording gages were utilized. This was accomplished by developing relations between the 2-year 1-hour and 2-year daily rainfall data from recording gages. In order to limit the effects of possible geographic variations, separate relations were derived for each of the maps in Figures 7-9. Figure 5 shows the relation for the area shown in Figure 7. A least-squares line fits the data well, although the true relation should be depicted by a curve through the origin. The three relations yielded standard errors of estimate of .08, .10, and .11 inch.

17. Tests were made to determine whether relations of the type shown in Figure 5 are affected by the time of observation. Computations of 2-year 24-hour rainfalls based on 24-hour periods

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[1] Maximum Station Precipitation for 1, 2, 3, 6, 12, and 24 Hours, W. B. Tech. Paper 15, Part III: Florida, pp 2-3, 1952.
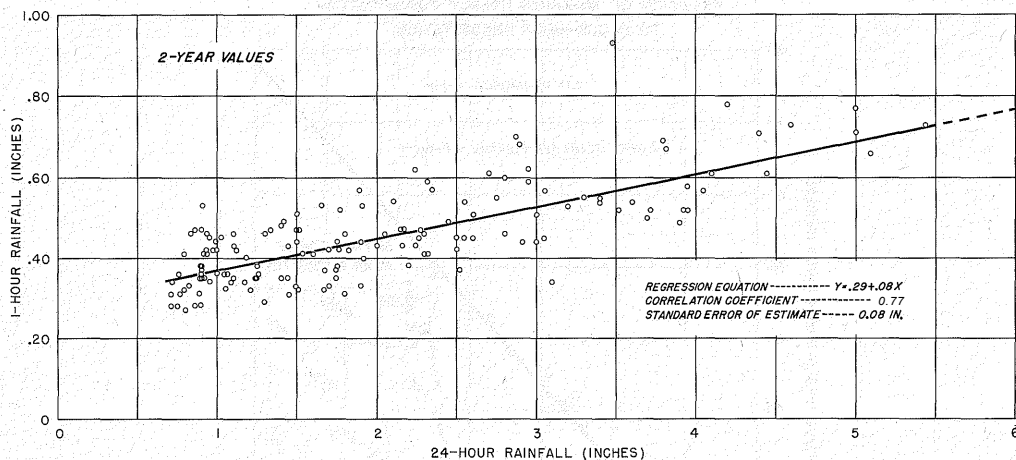
RELATION BETWEEN 1-HOUR AND 24-HOUR RAINFALL

Figure 5

ending at 8 a.m., 6 p.m., and midnight, respectively, at nine stations yielded the results shown in Table 2. These differences are relatively small and no period shows a consistently larger or smaller 2-year 24-hour rainfall amount than that of any other period. Hence, in developing relations between the 1-hour and 24-hour rainfalls, it was assumed that there was no difference.

Table 2

COMPARISON OF 2-YEAR 24-HOUR AMOUNTS
FOR THREE OBSERVATION TIMES

Station	24-Hour Period Ending:		
	8 a.m.	6 p.m.	mid.
Boise, Ida.	.80	.80	.88
Greenwater, Wash.	2.55	2.30	2.45
Los Angeles, Calif.	2.27	2.20	2.35
North Head, Wash.	2.04	2.18	2.32
Pullman, Wash.	1.28	1.20	1.30
Tacoma, Wash.	1.80	1.79	1.74
Walla Walla, Wash.	1.20	1.12	1.21
Winnemucca, Nev.	1.03	.98	.92
Yakima, Wash.	.77	.75	.77
Totals	13.74	13.32	13.94
Means	1.53	1.48	1.55

TWO-YEAR 1-HOUR RAINFALL MAPS

18. The isopluvials of Figures 7-9 were fitted to the recording-gage data, using the data from the nonrecording gages for interpolation purposes. In other words, data from nonrecording gages were discounted when in apparent disagreement with the recording-gage data. Although no detailed investigation of topographic influences on rainfall intensity-frequency data was made, some of the influences were recognized from examination of the plotted data and were utilized subjectively in constructing the isopluvials.

19. As might be expected, the reliability of the maps decreases as the ruggedness of the terrain increases. This is due to two factors: (1) the areal representativeness of the data for a station in rugged terrain is extremely limited, and (2) there are usually fewer stations in the more rugged areas. Item (2) is exemplified by the relatively flat centers of high rainfall intensity along most of the western slopes of the coastal ranges as compared to the several small sharp centers along the divide near Los Angeles where the gage network is much denser.

8

20. Thus far, only the hourly intensities for a 2-year return period have been discussed. The reason why the 5 and 10-year 1-hour intensities were not obtained in the same manner as the 2-year was given in paragraphs 10-11. Briefly, the records were, in general, too short to permit reliable estimates of the 5 and 10-year values. It was therefore necessary to determine how the 5 and 10-year amounts were related to the 2-year from long-record stations. There were 34 such stations west of the Continental Divide with an average record of about 40 years, no record being less than 17 years. Frequency curves of the clock-hour amounts for these stations had already been constructed, as described in paragraphs 8-9. It was a simple matter, therefore, to obtain the 2, 5, and 10-year clock-hour amounts.

21. In order to determine the relations between 5-year and 2-year and between 10-year and 2-year 1-hour rainfall, the clock-hour data for the 34 stations were plotted on the charts of Figures 10-11. Examination of the plotted data revealed evidence of a geographic factor. While the data are too sparse to delineate accurately the zones of influence, the division of the plotted data suggested two zones and an approximate location of their common boundary. However, it appears logical to assume that the geographic factor is probably mostly of orographic origin. Consequently, the divide of the coastal ranges is used, in general, as the common boundary of the two zones, namely Zone I to the west and Zone II to the east (see Figures 7-9).

22. As can be seen from Figures 10-11, straight lines through the origin and the means of the groups fit the data very well. While these relations are based on clock-hour amounts, they are considered applicable to maximum hourly amounts because they and the relations between the two types of data (pars. 13-14) are linear and through the origin. This means that the slopes of the lines of Figures 10-11 can be used as adjustment factors for obtaining the 5 and 10-year 1-hour rainfalls from the 2-year values. Consequently, the 5 and 10-year 1-hour rainfall for any point on the maps of Figures 7-9 can be quickly obtained by reading the 2-year value from the map and multiplying it by 1.24 and 1.48, respectively, if in Zone I or by 1.40 and 1.76, respectively, if in Zone II.

23. It should not be inferred that the relations of Figures 10-11 account for all topographic influences. Actually, there may be areas within the delineated zones where the true relation would be much different from those shown. This is probably true for those areas at high elevations which experience frequent and heavy rainfall. There is reason to suspect that the slopes of the relation would be less than shown for such regions because of the higher expectancy of consistently heavy rainfalls.

INTENSITY-DURATION RELATIONS

24. While the objective of this study was to determine the rainfall intensities for durations of 5 to 240 minutes expected to be equalled or exceeded on an average of once in 2, 5, and 10 years, the only duration considered thus far is the 1-hour. The original plan of the study called for the construction of isopluvial maps for the 1-hour duration and intensity-duration charts for obtaining the intensities for other durations. This chapter deals with the preparation and presentation of these intensity-duration data.

FIVE TO 240-MINUTE INTENSITIES FOR RETURN PERIODS OF 2, 5, AND 10 YEARS

25. As may be recalled from paragraph 3, tabulations of the maximum 5, 10, 15, 30, 60, and 120-minute rainfall amounts for each year of record were readily available for 33 long-record stations west of the Continental Divide. Similar tabulations of 24-hour amounts were also available. The 2, 5, and 10-year rainfall amounts for all these durations were determined by the Gumbel method[1] and then plotted on logarithmic paper. For each station smooth curves were

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[1] Evaluation of Climatic Extremes, Environmental Protection Section Report No. 175, Research and Development Branch, Military Planning Division, Office of the Quartermaster General, March 1951.
Gumbel, E. J., On the Frequency Distribution of Extreme Values in Meteorological Data, Bull. Am. Met. Soc., vol. 23, pp 95-105, 1942.

fitted by inspection to the data for each of the three return periods. The 2, 5, and 10-year rainfall amounts for durations of 5, 10, 15, 30, 60, 90, 120, 150, 180, and 240 minutes at each station were then read from these curves and converted into intensities in terms of inches per hour.

ONE-HOUR INTENSITIES VS INTENSITIES FOR OTHER DURATIONS

26. The 1-hour intensities for all 33 stations and for all three return periods were then plotted against the intensities for each of the other durations. Figure 6 shows one of these plots -- that for 10-minute intensities vs the 1-hour. Here again, there is definite evidence of a geographic factor. In general, the data appear to separate quite naturally into the same two zones delineated in paragraph 21, and shown on the maps of Figures 7-9. Straight lines through the origin and the group means appear to fit the data well. The separation of the data into two distinct groups or zones and the good fit of straight lines through the origin and group means were evident on the intensity charts for all durations. It had been intended at first to derive separate relations for each of the three return periods. However, the means for each return period were found to lie close to the line through the mean of the three return periods and the origin, and it was decided that one slope for each zone would suffice for all three periods. The relations (slopes) obtained between the 1-hour intensities and those for various other durations are listed in Table 3.

Table 3

RELATIONS BETWEEN INTENSITIES FOR 1-HOUR AND FOR OTHER DURATIONS

Duration (min.)	ZONE I	ZONE II
5	3.57	4.37
10	2.54	3.20
15	2.06	2.55
30	1.44	1.64
90	.80	.73
120	.68	.58
150	.60	.49
180	.54	.42
240	.46	.34

27. The relations between the 1-hour intensities and those for other durations, obtained as described in paragraph 26, were used to construct the two sets of curves of Figures 12-13. The reliability of these curves is, of course, subject to the limitations of the representativeness of the relations on which they are based.

28. The curves are labeled with the 1-hour rainfall intensities, which would be obtained, for any particular point, from the maps of Figures 7-9. If concerned with the 2-year return period only, the user would then proceed directly to either of Figures 12 or 13, depending on whether the point was located in Zone I or Zone II. The curve labeled with the 1-hour intensity obtained from the map would then reliably depict the 2-year intensities for other durations. If 5 or 10-year intensities were also required, the 2-year intensities should be multiplied by the proper factors indicated on either Figure 10 or 11, whichever is applicable. A specific example follows.

EXAMPLE OF OBTAINING INTENSITY-FREQUENCY DATA FROM FIGURES 7-13

29. Assume that the 2, 5, and 10-year rainfall intensities for durations of 10, 20, 30, 45, and 60 minutes are required for the point at 36°N and 119°W. From the map of Figure 9, the approximate value of .40 inch is obtained for the 2-year 1-hour rainfall. Since this site is in Zone II, Figure 13 is used to obtain the intensities for the other required durations. Using the curve labeled 0.4, the following intensities, in inches per hour, are obtained:

	10 min.	20 min.	30 min.	45 min.	60 min.
2-year	1.2	0.8	0.6	0.5	0.4

Since the 1-hour value was for a 2-year return period, the above intensities are also for a 2-year return period. However, the 5-year and 10-year intensities are quickly obtained by multiplying

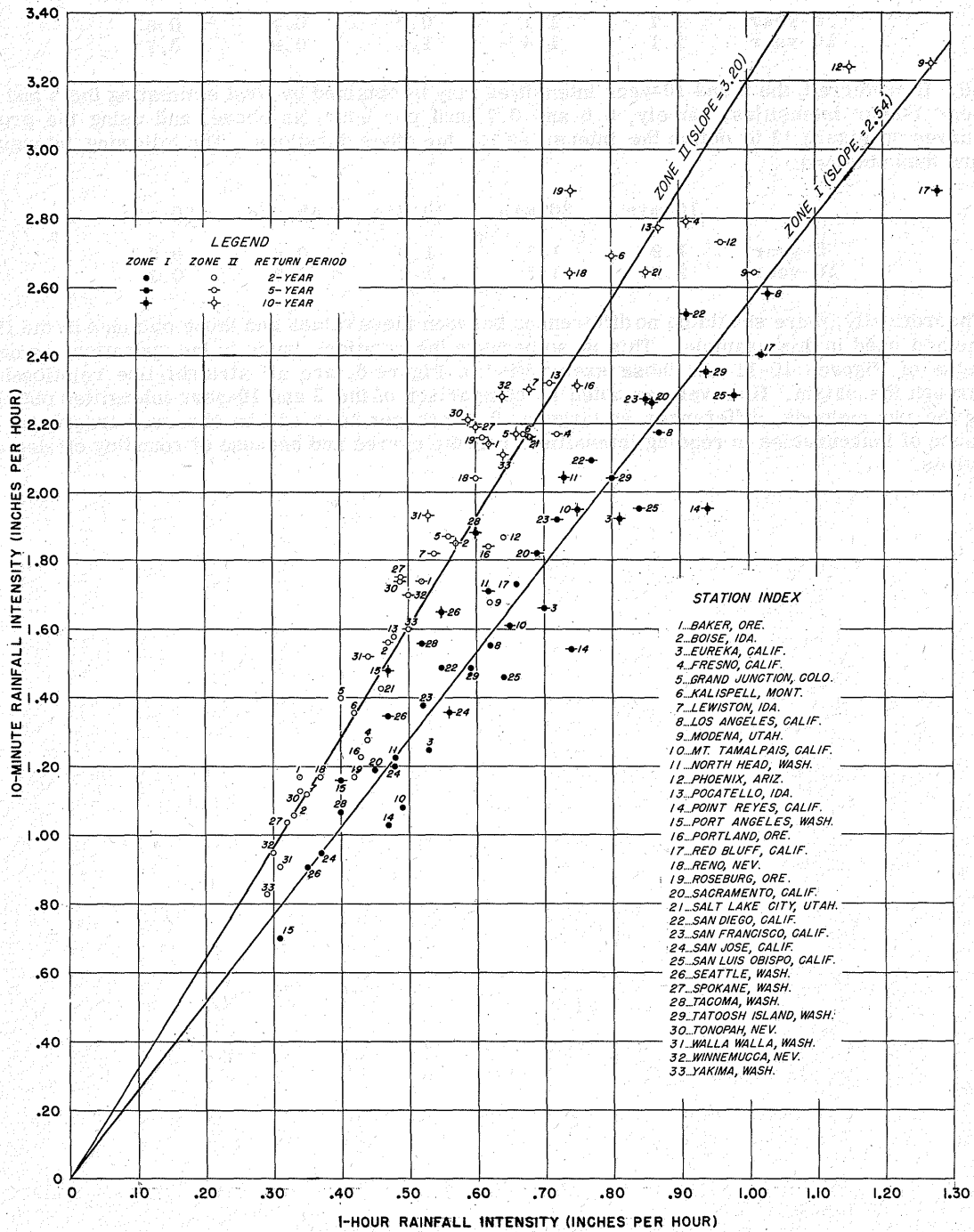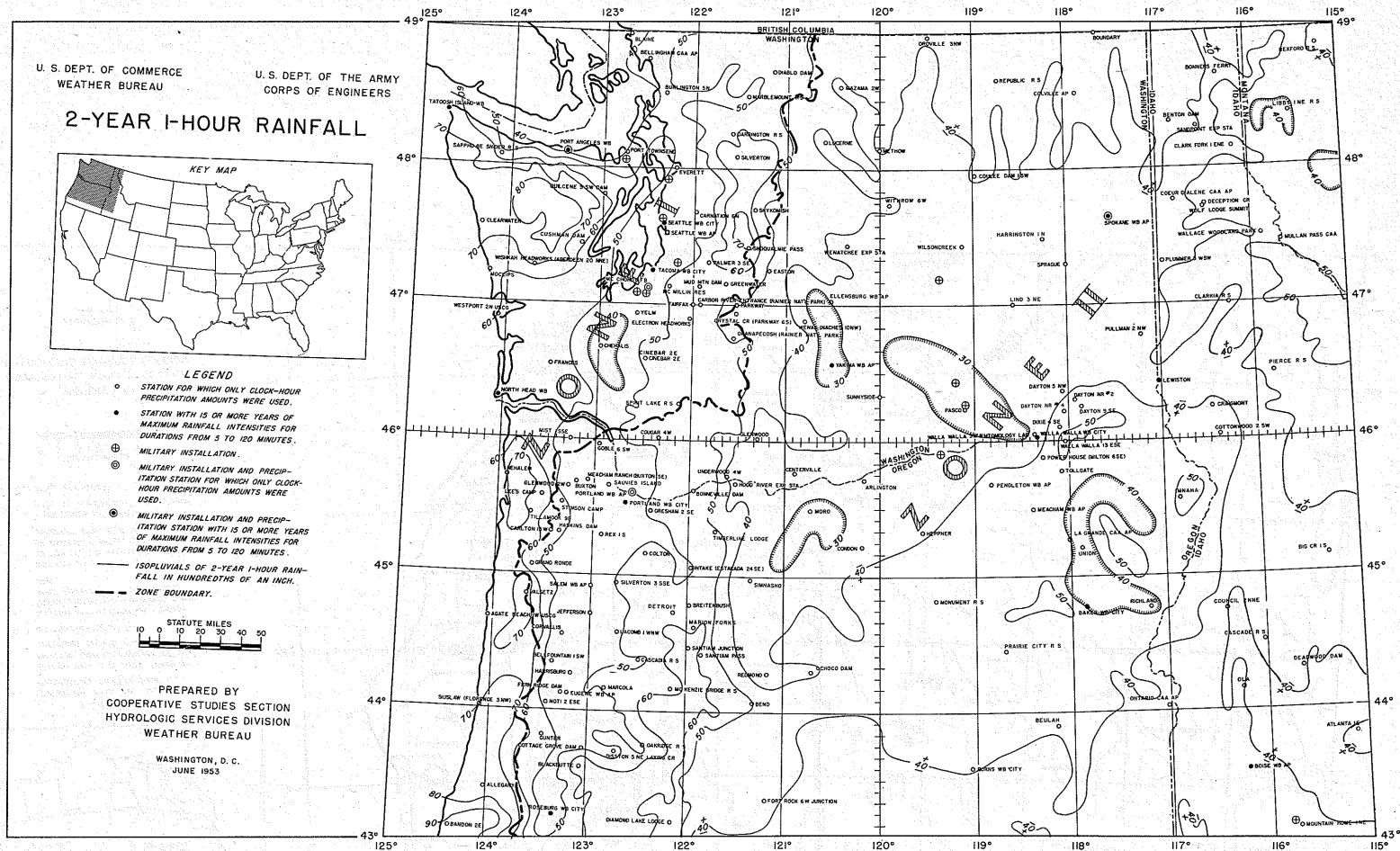## RELATION BETWEEN 10-MINUTE AND 1-HOUR RAINFALL INTENSITIES

Figure 6

11

the 2-year amounts by the factors indicated for Zone II in Figures 10-11, namely, 1.40 and 1.76. This adjustment yields the following intensities:

	10 min.	20 min.	30 min.	45 min.	60 min.
5-year	1.7	1.1	0.8	0.7	0.6
10-year	2.1	1.4	1.1	0.9	0.7

30. If preferred, the 5 and 10-year intensities may be obtained by first estimating the 5 and 10-year 1-hour intensities, namely, 0.6 and 0.7 inch per hour, as above, and using the proper curves of Figure 13 to obtain the intensities for the other durations. The following intensities are thus obtained:

	10 min.	20 min.	30 min.	45 min.	60 min.
5-year	1.9	1.3	1.0	0.8	0.6
10-year	2.2	1.5	1.2	0.9	0.7

Theoretically, there should be no differences between these values and those obtained by the first method used in this example. This is so because the relations basic to the operation, namely, those of Figures 10-11 and those exemplified in Figure 6, are all straight-line relationships through the origin. However, as noted by comparison of the 5 and 10-year intensities obtained by the two methods, differences as large as 0.2 inch per hour will be observed frequently because of inaccuracies in reading intensities from the curves and because of rounding off decimal values.
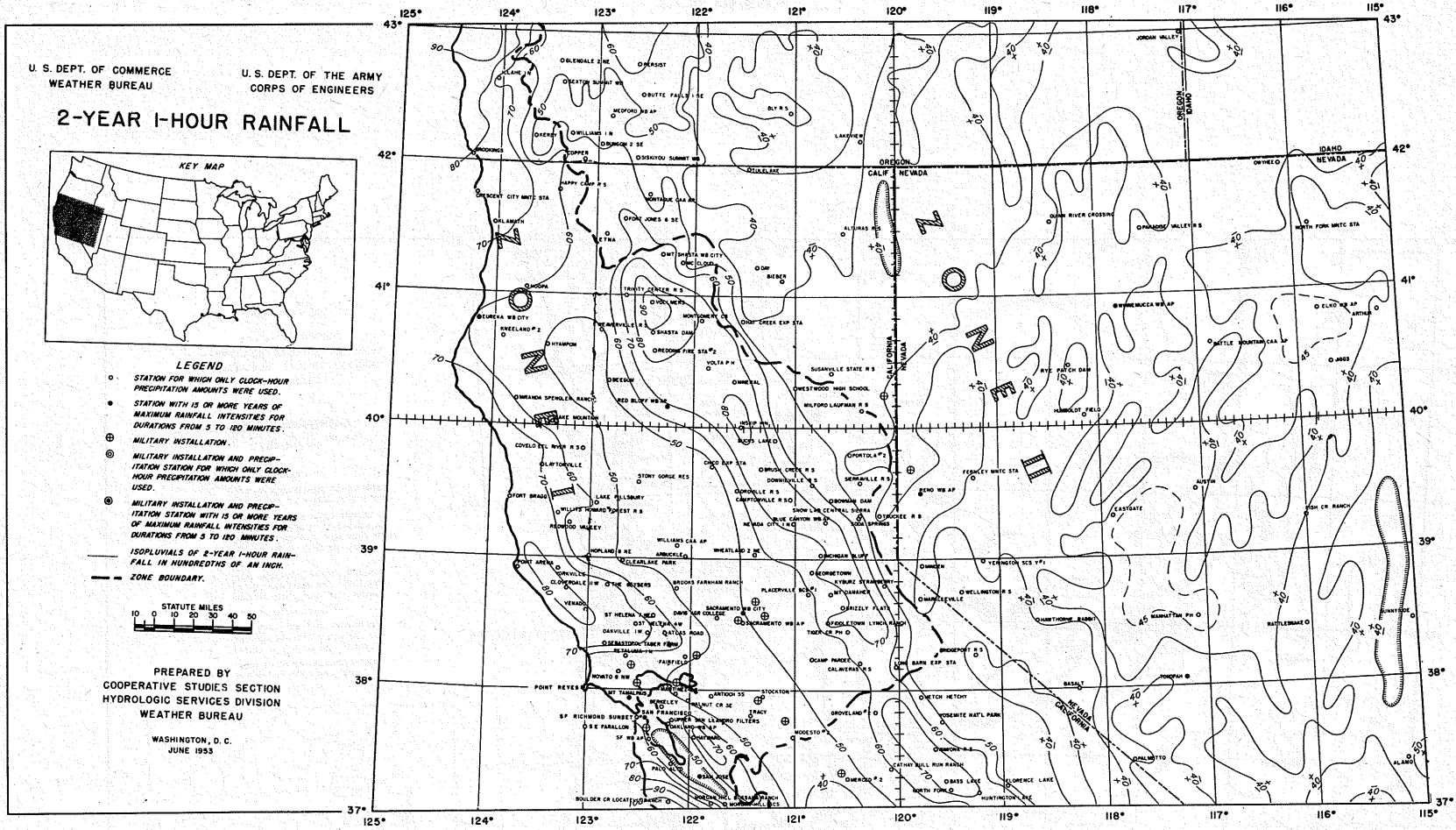
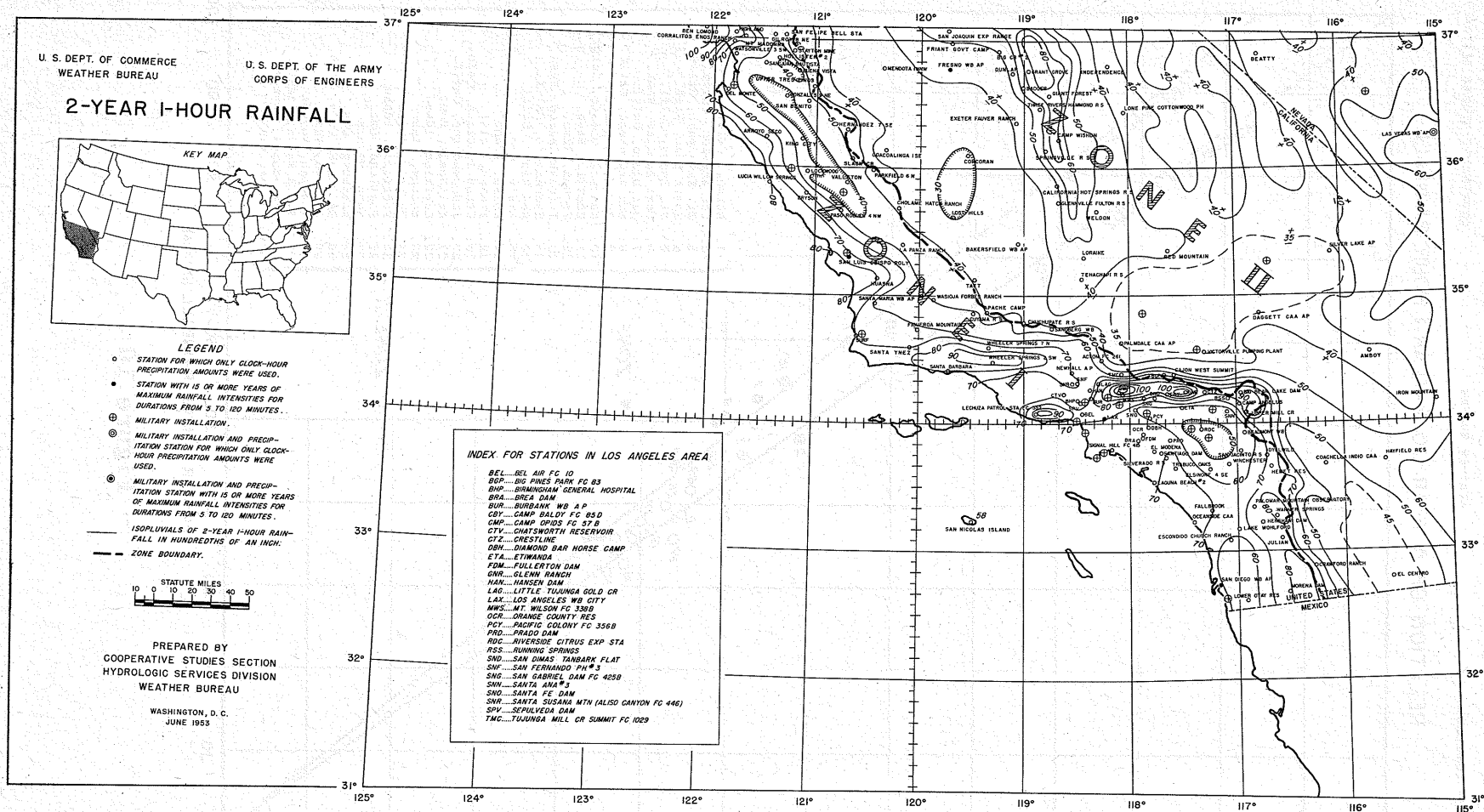2-YEAR 1-HOUR RAINFALL

13

Figure 7

Figure 8

U. S. DEPT. OF COMMERCE
WEATHER BUREAU

U. S. DEPT. OF THE ARMY
CORPS OF ENGINEERS

2-YEAR 1-HOUR RAINFALL

KEY MAP

LEGEND

○ STATION FOR WHICH ONLY CLOCK-HOUR PRECIPITATION AMOUNTS WERE USED.

● STATION WITH 15 OR MORE YEARS OF MAXIMUM RAINFALL INTENSITIES FOR DURATIONS FROM 5 TO 120 MINUTES.

⊕ MILITARY INSTALLATION.

⊕ MILITARY INSTALLATION AND PRECIPITATION STATION FOR WHICH ONLY CLOCK-HOUR PRECIPITATION AMOUNTS WERE USED.

◉ MILITARY INSTALLATION AND PRECIPITATION STATION WITH 15 OR MORE YEARS OF MAXIMUM RAINFALL INTENSITIES FOR DURATIONS FROM 5 TO 120 MINUTES.

—— ISOPLUVIALS OF 2-YEAR 1-HOUR RAINFALL IN HUNDREDTHS OF AN INCH.

– – ZONE BOUNDARY.

STATUTE MILES
10 0 10 20 30 40 50

PREPARED BY
COOPERATIVE STUDIES SECTION
HYDROLOGIC SERVICES DIVISION
WEATHER BUREAU

WASHINGTON, D. C.
JUNE 1953

INDEX FOR STATIONS IN LOS ANGELES AREA

BEL.....BEL AIR FC 10
BGP.....BIG PINES PARK FC 83
BHP.....BIRMINGHAM GENERAL HOSPITAL
BRA.....BREA DAM
BUR.....BURBANK WB A P
CBY.....CAMP BALDY FC 85D
CMP.....CAMP OPIDS FC 57 D
CTV.....CHATSWORTH RESERVOIR
CTZ.....CRESTLINE
DBH.....DIAMOND BAR HORSE CAMP
ETA.....ETIWANDA
FDM.....FULLERTON DAM
GNR.....GLENN RANCH
HAN.....HANSEN DAM
LAG.....LITTLE TUJUNGA GOLD CR
LAX.....LOS ANGELES WB CITY
MWS.....MT. WILSON FC 338B
OCR.....ORANGE COUNTY RES
PCY.....PACIFIC COLONY FC 356B
PRD.....PRADO DAM
RDC.....RIVERSIDE CITRUS EXP STA
RSS.....RUNNING SPRINGS
SND.....SAN DIMAS TANBARK FLAT
SNF.....SAN FERNANDO PH # 3
SNG.....SAN GABRIEL DAM FC 425B
SNN.....SANTA ANA # 3
SNT.....SANTA FE DAM
SNR.....SANTA SUSANA MTN (ALISO CANYON FC 446)
SPV.....SEPULVEDA DAM
TMC.....TUJUNGA MILL CR SUMMIT FC 1029

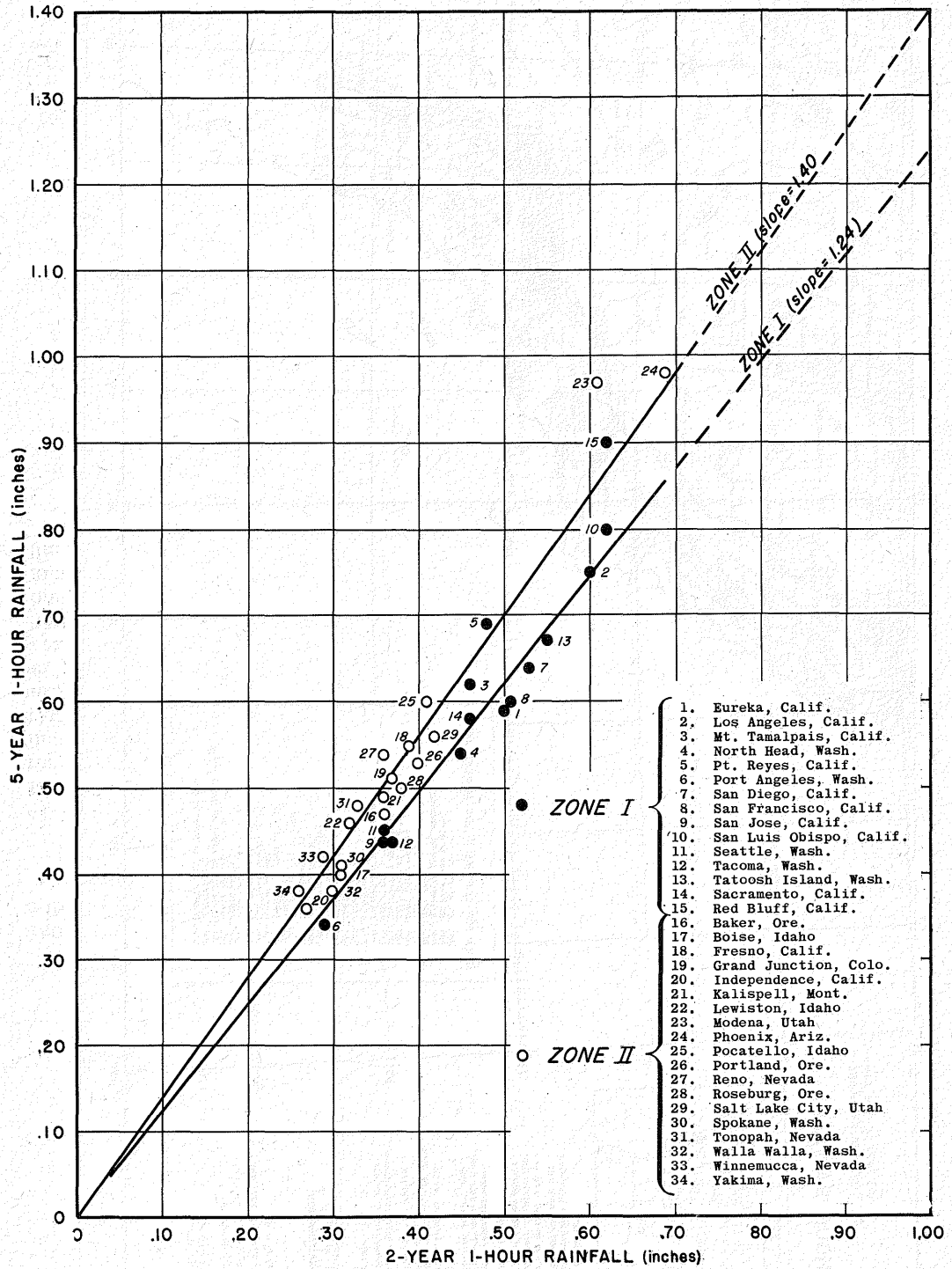**Figure 9**

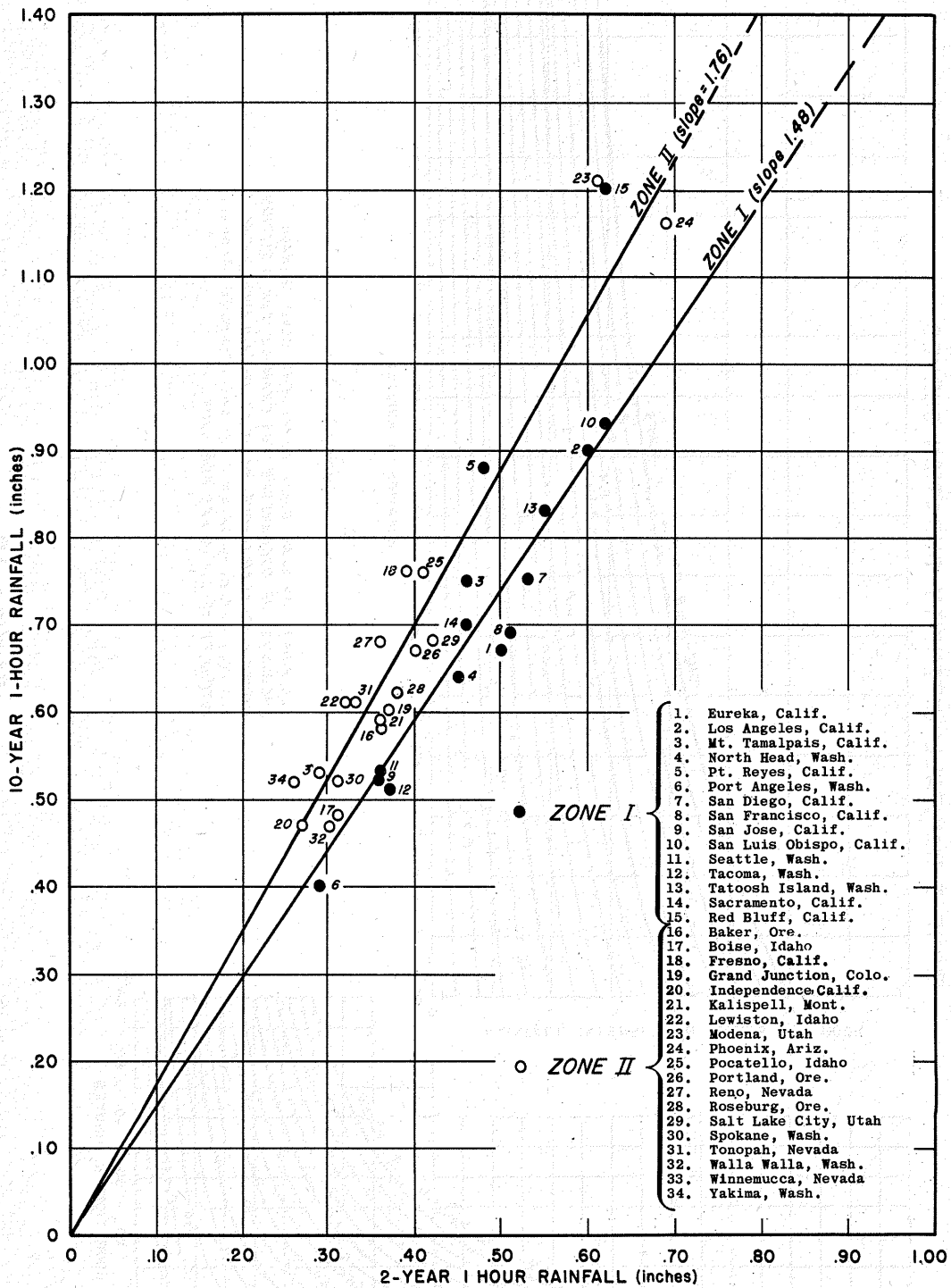## RELATION OF 5-YEAR TO 2-YEAR I HOUR RAINFALL

Figure 10

RELATION OF 10-YEAR TO 2-YEAR 1 HOUR RAINFALL

Figure 11

1. Eureka, Calif.
2. Los Angeles, Calif.
3. Mt. Tamalpais, Calif.
4. North Head, Wash.
5. Pt. Reyes, Calif.
6. Port Angeles, Wash.
7. San Diego, Calif.
8. San Francisco, Calif.
9. San Jose, Calif.
10. San Luis Obispo, Calif.
11. Seattle, Wash.
12. Tacoma, Wash.
13. Tatoosh Island, Wash.
14. Sacramento, Calif.
15. Red Bluff, Calif.
16. Baker, Ore.
17. Boise, Idaho
18. Fresno, Calif.
19. Grand Junction, Colo.
20. Independence, Calif.
21. Kalispell, Mont.
22. Lewiston, Idaho
23. Modena, Utah
24. Phoenix, Ariz.
25. Pocatello, Idaho
26. Portland, Ore.
27. Reno, Nevada
28. Roseburg, Ore.
29. Salt Lake City, Utah
30. Spokane, Wash.
31. Tonopah, Nevada
32. Walla Walla, Wash.
33. Winnemucca, Nevada
34. Yakima, Wash.

● ZONE I

○ ZONE II
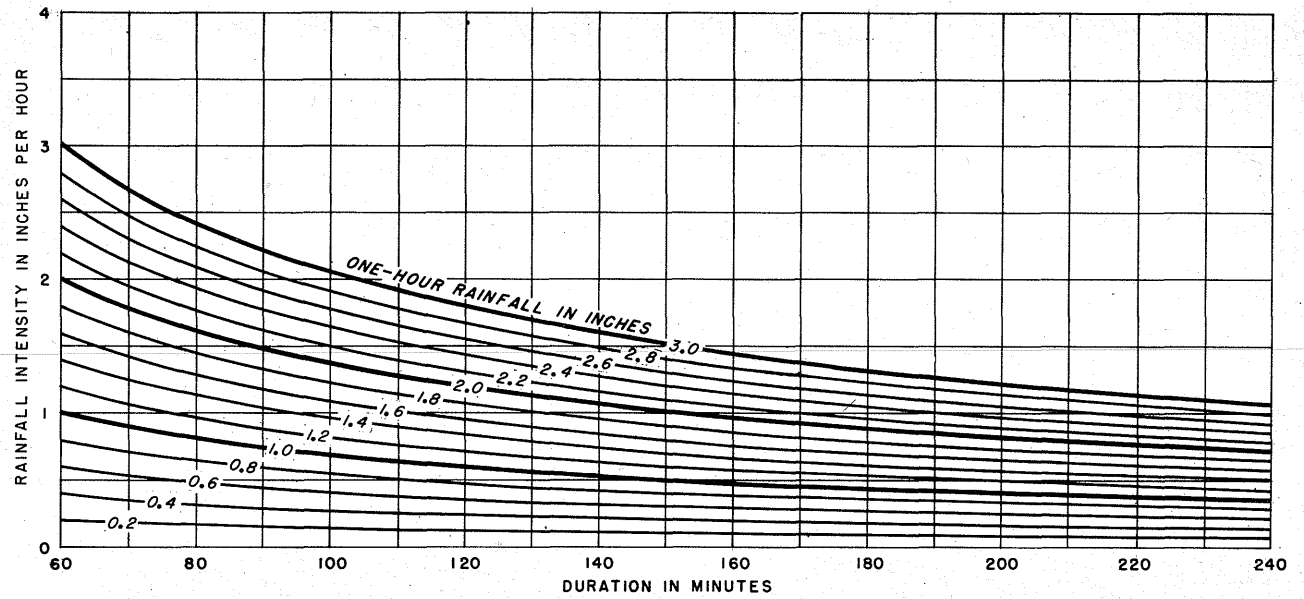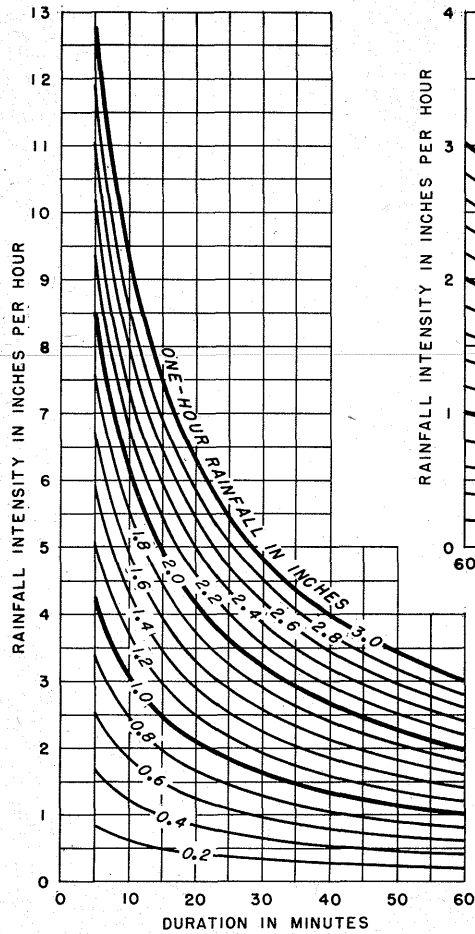
ZONE I RAINFALL INTENSITY-DURATION CURVES
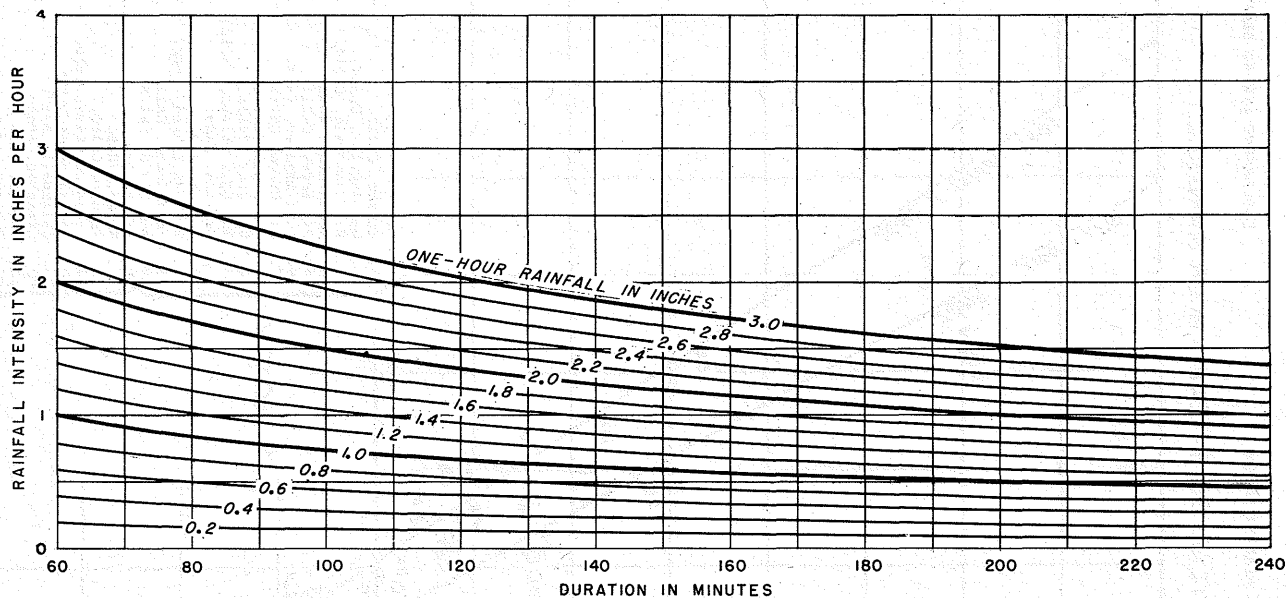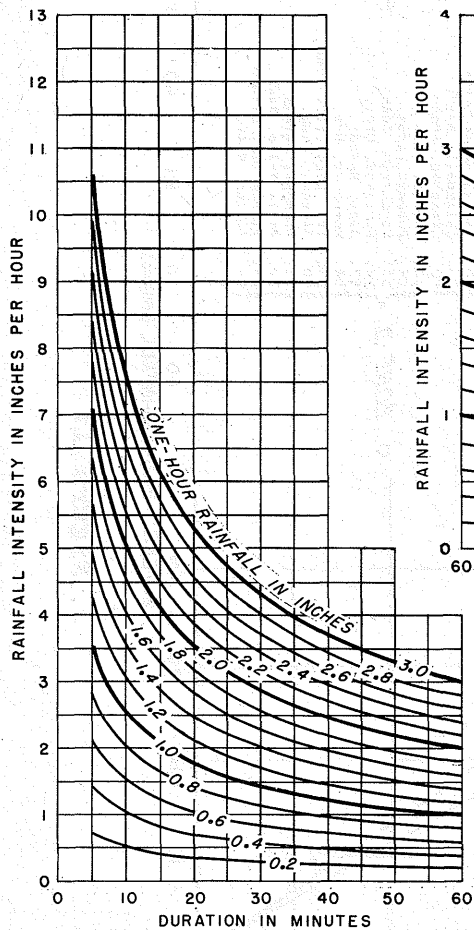
— NOTE —

ALL POINTS ON SAME CURVE REPRESENT SAME AVERAGE
FREQUENCY OF OCCURRENCE. FOR EXAMPLE, FOR A STATION
HAVING A 10-YEAR 1-HOUR RAINFALL OF 2.0 INCHES, THE
2.0-INCH CURVE INDICATES A 10-YEAR 10-MINUTE RAINFALL
INTENSITY OF 5.1 INCHES PER HOUR.

Figure 12

ZONE II RAINFALL INTENSITY-DURATION CURVES

— NOTE —

ALL POINTS ON SAME CURVE REPRESENT SAME AVERAGE
FREQUENCY OF OCCURRENCE. FOR EXAMPLE, FOR A STATION
HAVING A 5-YEAR 1-HOUR RAINFALL OF 1.4 INCHES, THE
1.4-INCH CURVE INDICATES A 5-YEAR 15-MINUTE RAINFALL
INTENSITY OF 3.5 INCHES PER HOUR.

Figure 13