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SHORT DURATION RAINFALL FREQUENCY RELATIONS FOR CALIFORNIA

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The need for precipitation-frequency values for durations under 1 hour has increased greatly during the recent past. Drainage design for shopping center parking lots, cattle feed lots, storm sewer systems for urban developments, and other small drainage areas with their short periods of concentration require precipitation-frequency values for these durations. To partially meet this need NOAA Technical Memorandum NWS HYDRO-35, "Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States," [Frederick et al. 1977] was published. This publication, unlike its predecessors, defines the geographic and frequency variation in short-duration rainfall over the relatively uncomplicated terrain of the Eastern and Central United States. Another common procedure is to develop ratios of the short-duration value to 1-hr (60-min) value derived from more abundant data. This procedure is used in the 11 Western conterminous United States where short-duration rainfall frequency values are still obtainable only as fixed ratios of the 1-hr values from NOAA Atlas 2 [Miller et al. 1973]. These ratios are based upon a nationwide average relationship developed from data for 200 National Weather Service stations and do not vary with region nor with return period.

For durations from 1 to 24 hours, NOAA Atlas 2 incorporates elevational, geographical and frequency differences in relations between the various durations. For durations less than 1 hour, there are few stations having N-min data extracted from their records. This has made a study of such relations difficult. There is, however, one data set that can be used to investigate such relations. The Resources Agency, Department of Water Resources of California, has abstracted annual maximum values for short (less than 1 hour) duration rainfall from recording raingages distributed throughout that State. These raingages are operated by a variety of federal, state, and local organizations and private utility companies. The data have been published in "Rainfall Analysis for Drainage Design, Volume 1, Short-Duration Precipitation Frequency Data," Bulletin 195, Department of Water Resources State of California [Goodridge 1976]. The data are also available on magnetic tape.

The annual maximum amount for 5-, 10-, 15-, 30-, and 60-min durations were extracted for each station in the data set which had at least 15 years of record. Only those years were used where data were available for each of the 5 durations. The data were used to form N-min (N=5, 10, 15, 30) to 60-min ratios.

There were 250 such stations distributed throughout the State. Elevations of these stations range from 30 feet below sea level to over 8,000 ft mean sea level. Figure 1 shows the geographical distribution of these stations. Stations at elevations above 4,000 ft are indicated by an X. Although the stations are reasonably evenly distributed, there is more concentration in the San Francisco and Los Angeles metropolitan areas, and a lack of data for the lee slopes of the Sierra Nevada, Death Valley, and Northeastern Desert areas of eastern California.

California is a State with a wide diversity of topographical and climatological regimes. Thus, state-wide averaging was not considered to be the best method. We, therefore, divided the State into 14 reasonably meteorologically and topographically homogeneous regions, figure 2. One of the defined regions, Death Valley and the northern part of the Desert, could not be analyzed since there were no recording raingage stations with data for durations of less than 1 hour for 15 or more years of record. The region east of the crest of the Sierra Nevada was analyzed in less detail than the remaining regions since there were a total of only seven stations in this region and the northern stations showed distinct differences from those south of approximately 39°N. These two regions are indicated in figure 2 as regions of no data and limited data, respectively. During the investigation comparison of station ratios indicated the three regions along the Sierras could be combined into one region, and those of the coastal mountains south of San Francisco Bay could be combined into another region. The preliminary boundaries are shown as dashed lines on figure 2 and the final regional boundaries by solid lines. Table 1 shows the number of stations (grouped by length of record) within each of the final regions. The average record length for the stations used was slightly over 25 years. The longest average record lengths were in the Central Valley, slightly over 30 years, North Pacific Coast, nearly 30 years, and the Sierra Nevada, slightly over 25 years. The shortest average record lengths, just over 20 years, were in the San Jacinto Basin and Southeast Desert.

The three regions with the most topographic variations are the Sierra Nevada, North Pacific Coast, and South Pacific Coast. Figure 3 shows by 1,000-ft elevation bands the percentage of stations for these three regions and for the entire state. Although a majority of the stations within these orographic regions are at the lower elevation, there is a reasonable percentage of

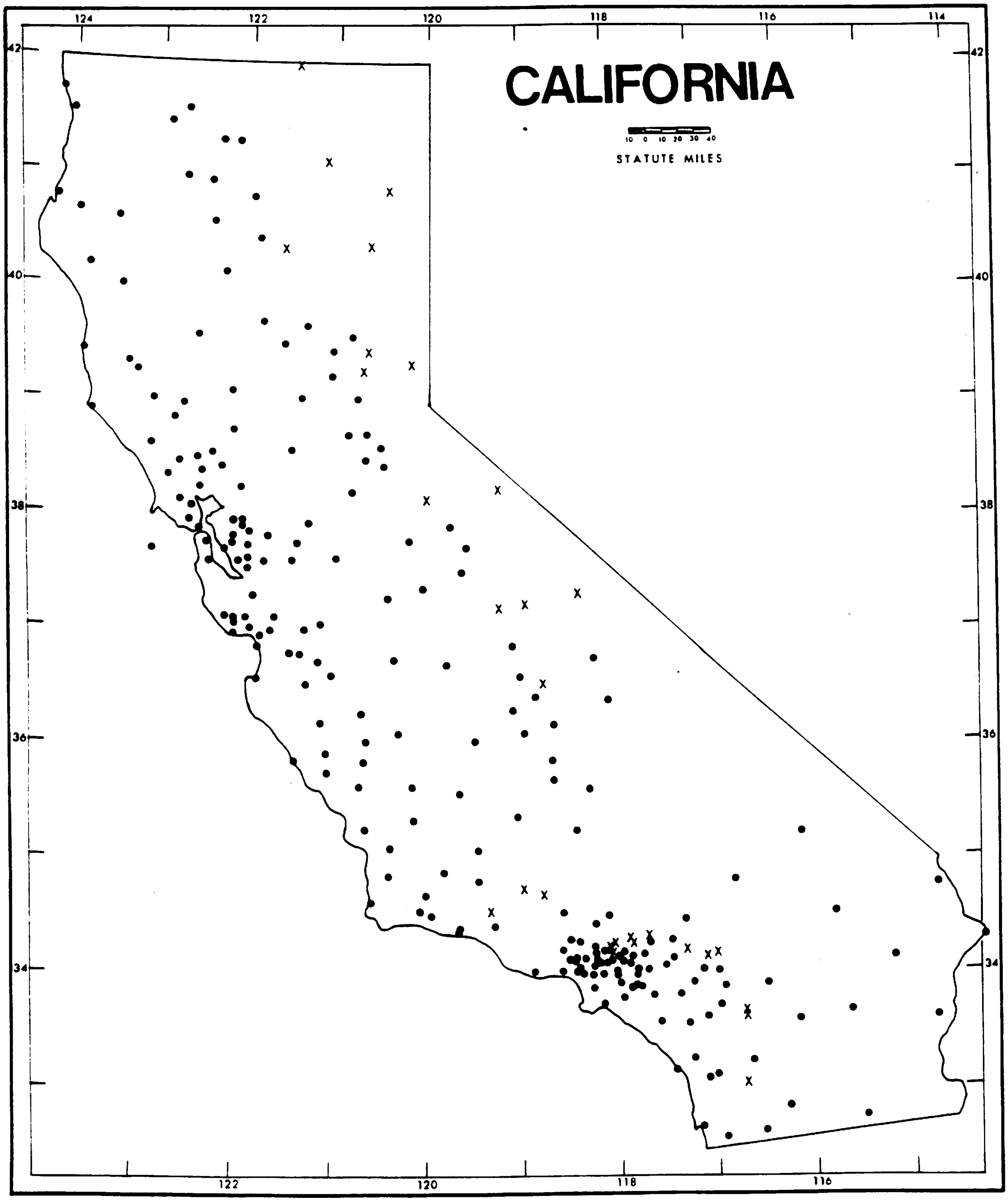

Figure 1.--Geographic distributions of stations used in this study.

Table 1.—Distribution of stations within each of the major geographic regions grouped by length of record.

Region \ Length of Record (yrs)	15-19	20-24	25-29	30-34	35-39	40-44	45-49	>50	Total No. of Stations
Sierra Nevada	3	12	8	16	1				40
Central Valley	2	1	2	9	2			3	19
North Pacific Coast	3	1	4	7				1	16
South Pacific Coast	26	15	20	14	13	13	3	2	106
Lee of Coastal Ranges	4	1	1	3					9
Southeast Desert	1	7	2						10
San Francisco Bay	13	9	5	3	1			2	33
San Jacinto Basin	2	2	1	1					6
Other	1	3	3	4					11
Total	55	51	46	57	17	13	3	8	250

stations at the higher elevations. For example, within the Sierra Nevada over 20% of the stations are above 4,000 feet.

For each of the 250 stations having at least 15 years of annual maximum 5- to 60-min amounts, frequency values were determined by fitting the Fisher-Tippett Type I Distribution to the series of annual maxima. The fitting method used was that developed by the late E. J. Gumbel [1958]. All subsequent analysis was done using ratios of 5-, 10-, 15-, and 30-min values to the 60-min value determined by the station-frequency analysis for return periods of 2, 5, 10, 25, 50, and 100 years. No attempt has been made to draw isopluvials of the N-min frequency values. We are instead seeking dimensionless relations between the N-min and 60-min values which can then be used in conjunction with the 1-hr (actually 60-min) values in NOAA Atlas 2, Volume XI: California.

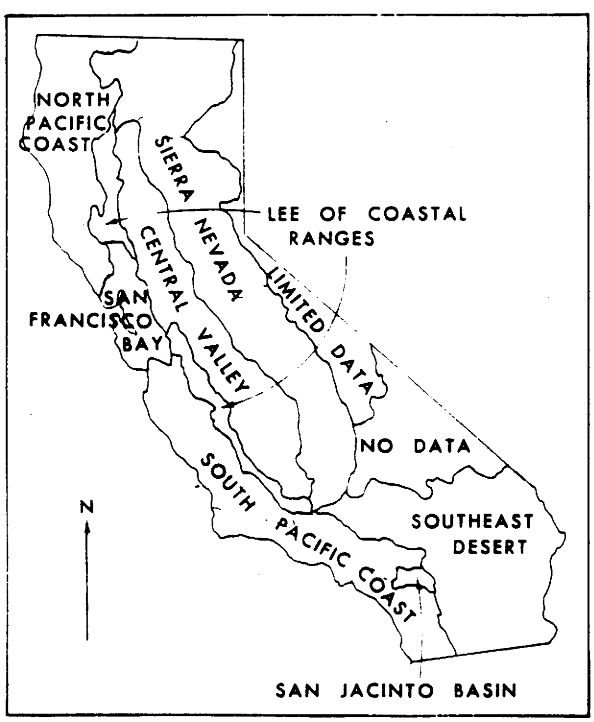

Figure 2.--Major geographic regions in California used to study short duration precipitation-frequency ratios.

For each of the physiographic regions originally outlined, an average of the station N-min to 60-min ratios for each duration for each return period was computed. At the same time a standard deviation (not shown) was computed to have a check on the internal consistency of the ratios within each region. This was done not only with equal weight for each station, but also with stations weighted by length of record. Results were so close between the weighted and unweighted values that it was concluded that no differences were involved. The results presented are for unweighted averages. Weighted standard deviations are, of course, smaller because of the apparently larger sample size.

The unweighted average ratios and standard deviations were compared for each of the 12 regions originally selected for which values could be determined. These comparisons showed that the three preliminary regions within the Sierra Nevada and the three preliminary regions of the South Pacific Coast had only negligible differences for the four ratios and six recurrence intervals considered. For this reason, the three regions of the Sierra Nevada and the three parts of the South Pacific Coast were each combined. Figure 4 is a plot of the average 5-

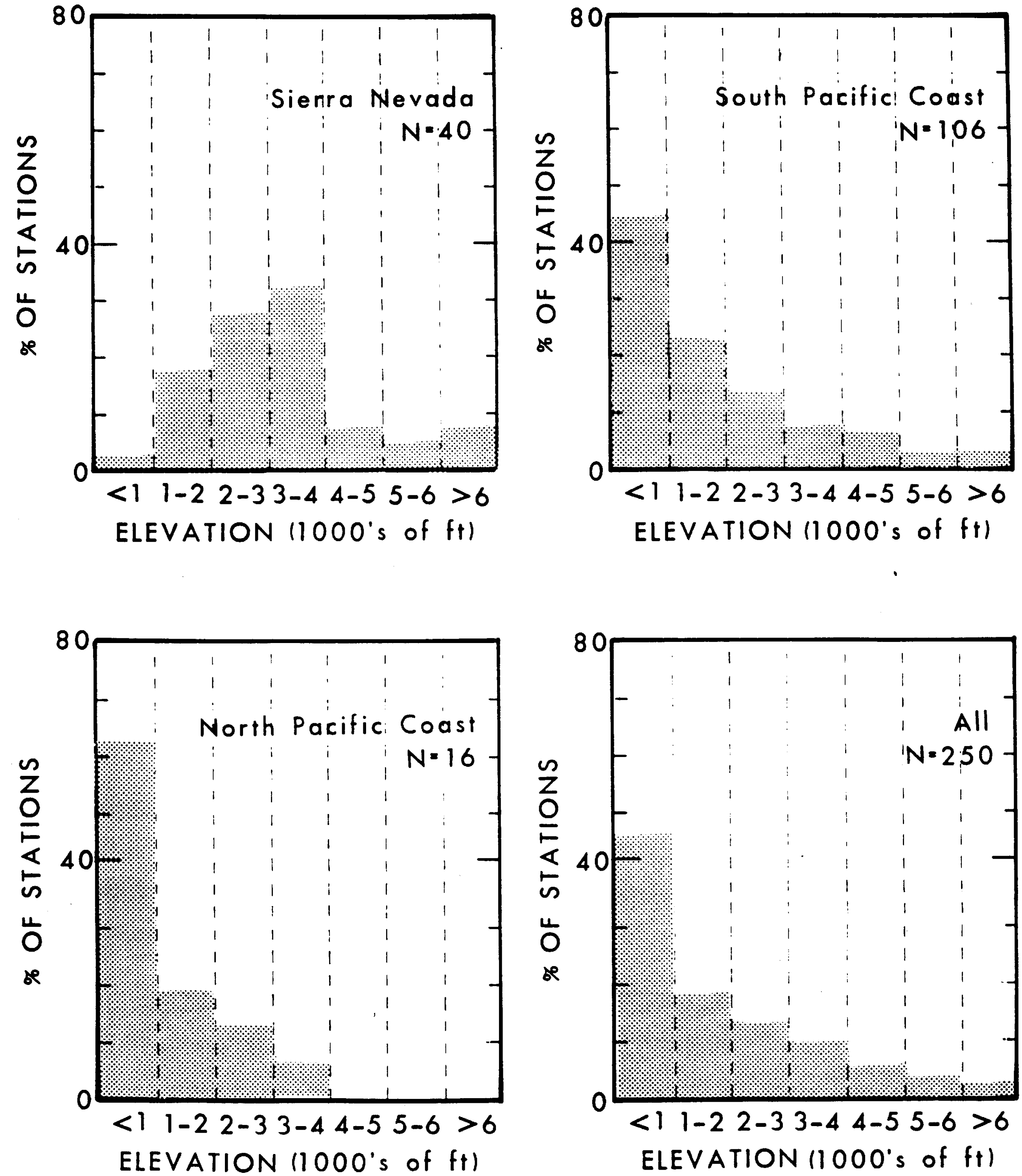

Figure 3.--Distribution of station elevation by 1,000-ft bands in major orographic regions of California and for all stations.

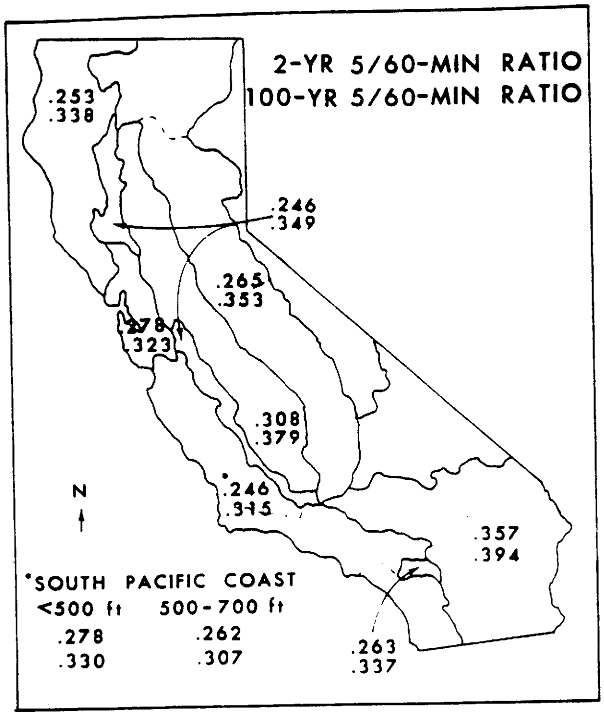

Figure 4.-- 5- to 60-min ratios for the 2- and 100-yr return periods for major geographic regions of California. Values for South Pacific Coast Region are for stations at elevations >700 ft.

to 60-min ratio for the 2- and 100-yr recurrence interval for the various regions. The lowest ratios are in the orographic and coastal areas. The highest ratios are in the Central Valley and the Southeastern Desert. These higher ratios are indicative of the more convective and short lived nature of the precipitation in these latter two regions.

In orographic and coastal regions, there is a continued vertical air motion resulting from topographic features that is relatively independent of atmospheric process. In mountainous regions during storm situations the prevailing winds blow against the mountains causing a forced ascent and vertical motion. In coastal regions, the prevailing winds move from a relatively frictionless surface to one with greater friction. This results in a horizontal convergence and some vertical motion. This is combined, even in the San Francisco Bay region, with ascent over coastal hills. These continued vertical motions in the atmosphere tend to prolong the precipitation and thus reduce the ratios between values for short durations. In addition, in the coastal regions and the Sierra Nevada the 5- and 60-min values nearly always come from general cyclonic storms during the colder portion of the year. In the Desert and Central Valley, in addition to having precipitation values from the general cyclonic storms during the cooler season, there are convective showers and thunderstorms that occur during the warmer months.

In precipitation-frequency studies it has been hypothesized that as the duration decreases, the N- to 60-min ratios are less dependent on elevation. The relation of N- to 60-min ratios to elevation was examined by correlating the station ratios with elevation within each region. The result confirms this hypothesis. In a few areas and for some return periods, the correlation coefficients did reach values in the 0.30 to 0.50 range and in most cases there was a negative correlation. However, it was not stable and not persistent. For example, in the preliminary north Sierra Region at the 2-yr return period correlations were -0.50 to -0.60. Correlation fell off rapidly as the return period increased, and at the 25-, 50-, and 100-yr return periods the coefficients were small with two positive and two negative ones. In the South Pacific Coastal Region, the correlations for the 5- to 60-min ratio with elevation varied between -0.31 for the 2-yr return period to 0.04 at the 100-yr return period.

Another method of examining the variation of ratios by elevation is to group stations by elevation bands. Figure 4 shows average 5- to 60-min ratios for the South Pacific Coastal Region by such elevation bands. Examination of these ratios shows a progression up the coastal ranges. For the area below 500 feet the ratio is 0.278. It decreases as one goes into the mountains and is 0.262 for 500-700 ft and 0.246 for the region above 700 ft. The ratio for all stations within the South Pacific Coastal Region for the 2-yr return period is 0.254 (not shown on fig. 4). When the data for the 100-yr recurrence interval is examined, however, one sees an interruption in the progression of the 5- to 60-min ratios the values being 0.330 (<500 ft) lowering to 0.307 (500-700 ft), then rising to 0.315 (>700 ft), and 0.394 (Desert), respectively, and for the region as a whole it is 0.317. The lowest ratio is now in the 500-700 ft elevation band. Scatter plots and plotting of the ratios on maps failed to reveal any factor which could produce a significant improvement over the average ratio shown.

Figure 5 shows the 30- to 60-min ratios for the 2- and 100-yr recurrence intervals. The geographic pattern is similar to that shown for the 5- to 60-min ratios. The lowest ratios again are in the coastal and orographic regions with the highest ratios in the Central Valley and Desert areas. If one again examines the ratios preceding eastward across the southern California coastal mountains, we see a decrease in ratios from the lowest elevation band, stations near the coast, into the lower foothills, elevation band 500 to 700 feet, and onto the slopes of the San Gabriel and San Bernardino Mountains and then an increase into the desert areas. Although the changes are consistent in both the 2- and 100-yr recurrence interval, the differences between the ratios are small. The 30- to 60-min ratio for the entire South Pacific Coastal Region is 0.679 for the 2-yr return period and 0.731 for the 100-yr return period. None of the differences between similar regions, e.g., the North Pacific Coastal and the South Pacific Coastal Regions, are meaningful at the 2-yr recurrence intervals. However, the differences between regions are larger and are greater than one standard deviation at the 100-yr return period.

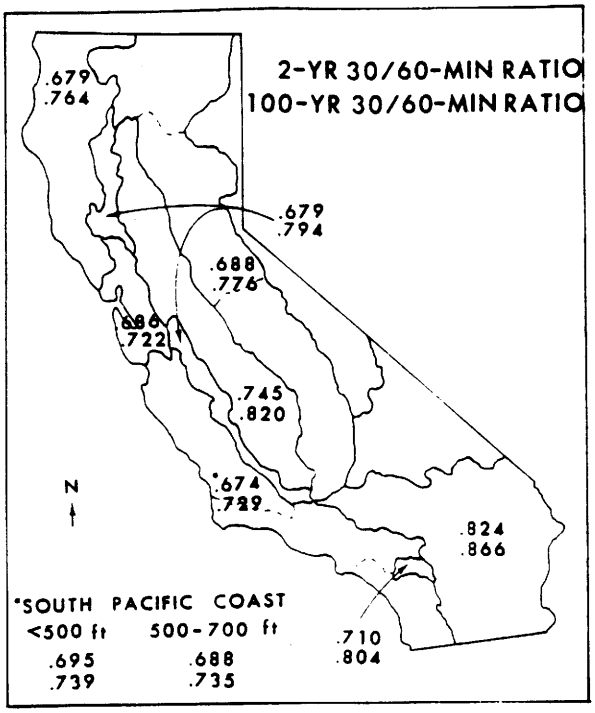

Figure 5.-- 30- to 60-min ratios for the 2- and 100-yr return periods for major geographic regions in California. Values for South Pacific Coast Region are for stations at elevations >700 ft.

The San Jacinto Basin in southern California is a relatively arid region. Moisture bearing winds must enter from the south-southwest or south across the Coastal Plain or across the barrier of the Santa Ana Mountains on the west that averages approximately 3,000 feet in elevation. These sheltering effects are evident when a comparison is made of ratios for stations in this basin with ratios from stations on nearby exposed coastal mountains. As expected, ratios for the sheltered valley stations are higher. They are slightly lower than the ratios for stations in the Central Valley. Ratios for this basin are probably indicative of those that would be found in other reasonably large sheltered valleys along mountain ranges. Valleys of more limited extent and those with a direct flow of moisture bearing winds would not show this difference in 30- to 60-min or 5- to 60-min ratios.

In the Eastern and Central United States, the N-min to 60-min ratios decrease with increasing return periods, i.e., 5- to 60-min ratio at the 100-yr return period was smaller than at the 2-yr return period. In the California sample, the reverse is true. For example, in the San Francisco area the 5- to 60-min ratio at the 100-yr return period is 116% of the same ratio at the 2-yr return period. Figure 6 shows the variation of ratio of 10- to 60-min values with return period for four of the regions of California. The variation for the other regions and durations is similar: the ratio increases as the recurrence interval increases. The increase is not linear and has some tendency to become asymptotic at some point. The short record does not permit any conclusions on when this point is reached. The important thing is that the ratio increases for all regions. Of the 250 stations, only 18 had each of the 5-, 10-, 15-, and 30-min to 60-min ratios that decreased with increasing return period. Forty other stations had one or more N-min ratio that decreased with increasing return period. The other 192 stations had N-min to 60-min ratios that all increased as the return period increased for all durations.

Another duration investigated in this study was the 15-min period. Table 2 shows the 15- to 60-min ratios for the eight geographic regions investigated. The same feature evident in the data for the other durations is evident here. The highest ratios are in the Central Valley and the Southeast Desert with the San Jacinto Basin being somewhat intermediate between those and the orographic and coastal regions. The lowest ratios are in the coastal areas with the Sierra Nevada being just slightly higher. The ratios increase with increasing return period.

There are seven stations in the region to the lee of the Sierra Nevada crest between 36° 30'N and nearly 41°N, a distance of about 350 miles. The stations range in elevation from approximately 3,800 feet to slightly over 6,500 feet. The four southern stations, which include the lowest and highest elevations, have ratios

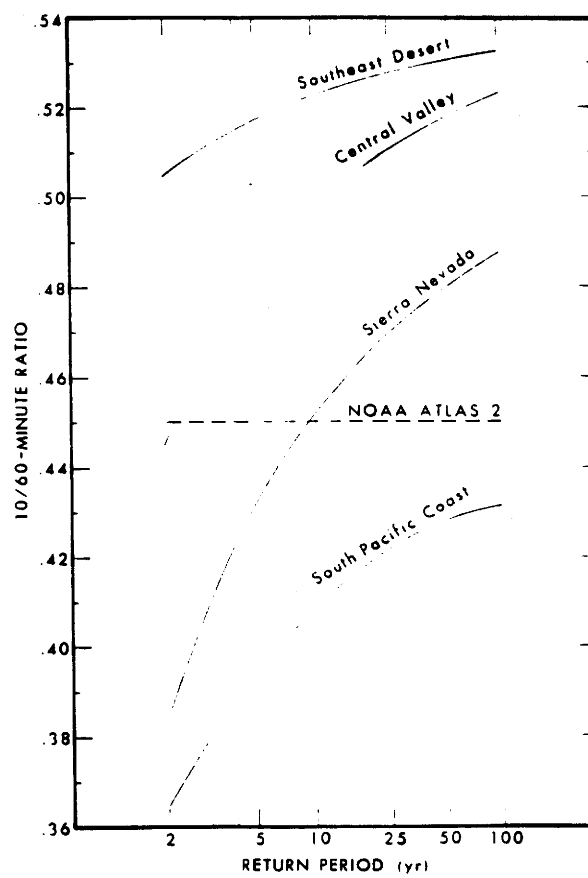

Figure 6.--Variation of 10- to 60-min ratio with return period for the South Pacific Coastal, Sierra Nevada, Central Valley and Southeast Desert Regions of California.

Table 2.-- 15- to 60-min ratios for major geographic regions of California

Region \ Return Period (yrs)	2	5	10	25	50	100	Number of Stations
Sierra Nevada	.485	.534	.554	.571	.581	.589	40
Central Valley	.551	.598	.616	.632	.641	.648	19
North Pacific Coast	.467	.514	.534	.554	.565	.574	16
South Pacific Coast - >700 ft	.461	.492	.505	.516	.522	.527	77
South Pacific Coast - 500-700 ft	.481	.499	.507	.514	.518	.521	9
South Pacific Coast - <500 ft	.495	.521	.531	.541	.546	.550	20
South Pacific Coast - Entire Reg.	.469	.498	.510	.521	.526	.531	106
Lee of Coastal Range	.470	.529	.552	.572	.583	.592	9
Southeast Desert	.633	.653	.661	.668	.671	.674	10
San Francisco Bay	.481	.502	.512	.520	.525	.529	33
San Jacinto Basin	.504	.555	.575	.593	.603	.611	6

which are similar to those in the lee of the coastal mountains. The three northern stations, all north of 39°N, have ratios that are approximately the same as those in the Southeastern Desert. It is impossible, therefore, to draw any conclusions. It will require considerably more data or the ability to relate these variations to some other physiographical factor before reliable ratios can be used in the lee of the Sierra Nevada.

It was the initial aim of this investigation to develop meaningful relations that could be extended by use of index relations to other parts of the west. We have been able to define variations between geographical regions in California. The Central Valley, a wide flat agricultural valley, is different from the Southeastern Desert Region of California. These two regions have different 5- to 60-min, 10- to 60-min, etc., ratios than the slopes of the Sierra Nevada or the coastal mountains. It would be misleading to take a limited sample of stations with short-duration precipitation that are located primarily on valley floors and to extend these ratios into the surrounding mountainous regions. If the (primary) interest, however, is in peak rates of runoff use of valley ratios and thus concentrating precipitation into shorter time increments would produce a higher peak. This use of ratios determined from valley floor stations would then tend to be conservative. Investigations are continuing with the intent of developing a methodology which would permit the use of a limited sample of stations to develop meaningful geographic variations in the relations of extreme short duration precipitation to 1-hr values.

REFERENCES

Frederick, R. H., V. A. Myers and E. P. Auciello, 1977: Five- to 60-min precipitation frequency for the eastern and central United States. *NOAA Technical Memorandum* NWS HYDRO 35, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, Md., 36 pp.

Goodridge, J. D., 1976: Rainfall analysis for drainage design, Vol. I - Short duration precipitation frequency data; Vol. II - Long duration precipitation frequency data; Vol. III - Intensity-duration frequency curves. *DWR Bulletin* 195, California Department of Water Resources.

Gumbel, E. J., 1958: *Statistics of Extremes*. Columbia University Press, New York, 375 pp.

Miller, J. F., R. H. Frederick and R. J. Tracey, 1973: Precipitation-frequency atlas of the western United States, Vol. I: Montana; Vol. II: Wyoming; Vol. III: Colorado; Vol. IV: New Mexico; Vol. V: Idaho; Vol. VI: Utah; Vol. VII: Nevada; Vol. VIII: Arizona, Vol. IX: Washington; Vol. X: Oregon; Vol. XI: California. *NOAA Atlas* 2, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, Md.