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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

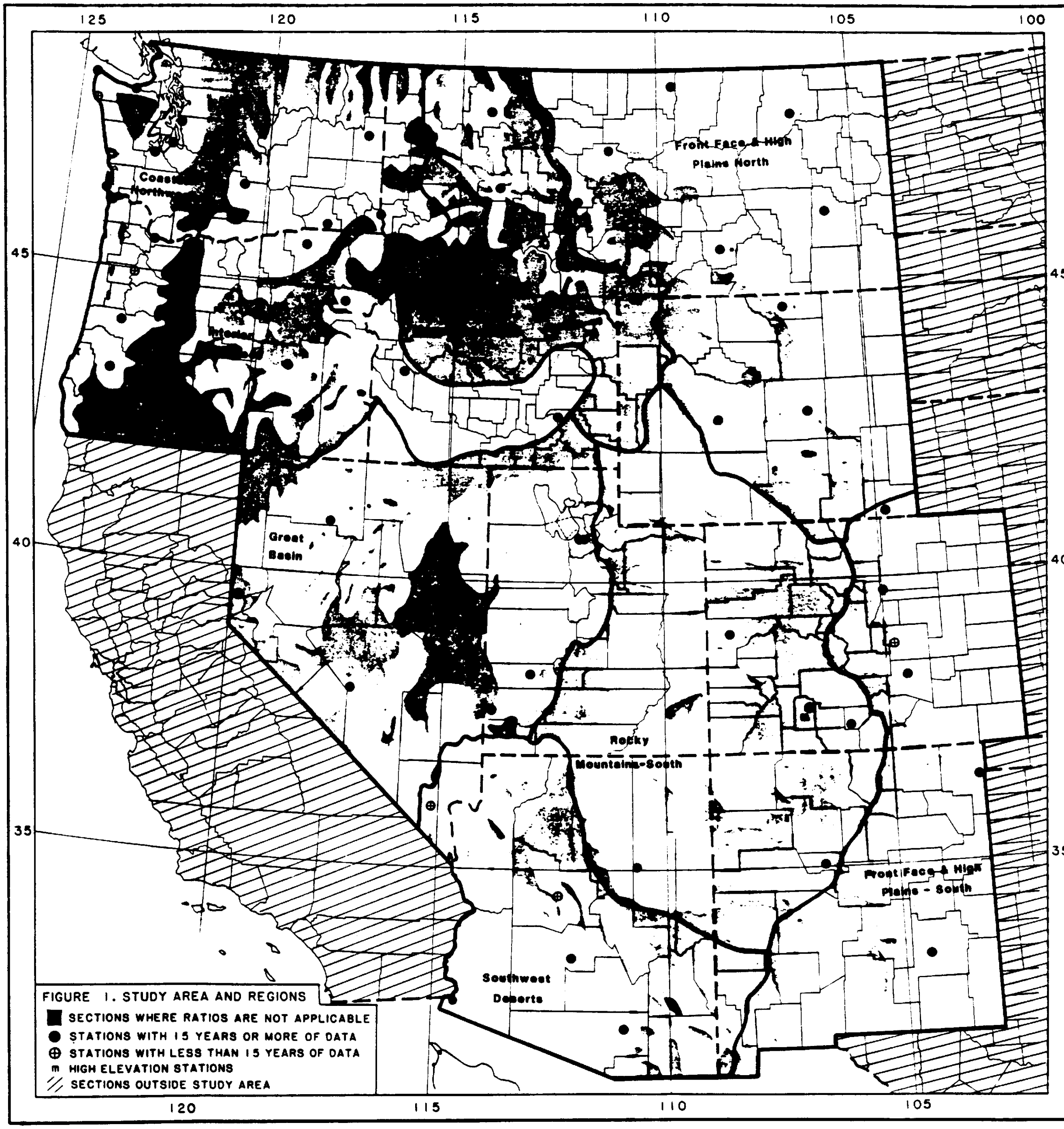

FIGURE 1. STUDY AREA AND REGIONS

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	10	15	30	100-Year Return Period 5	10	15	30
		minutes				minutes			
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.

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

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.

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.

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

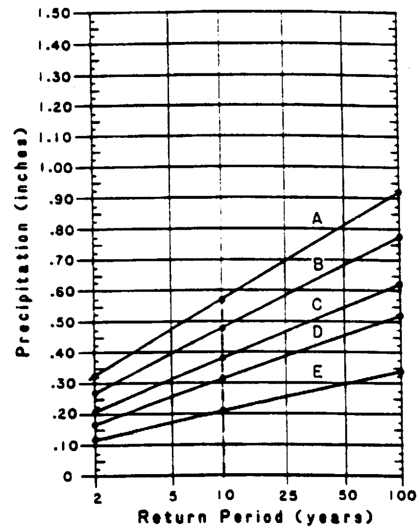

Figure 2.—Example of return period interpolation.

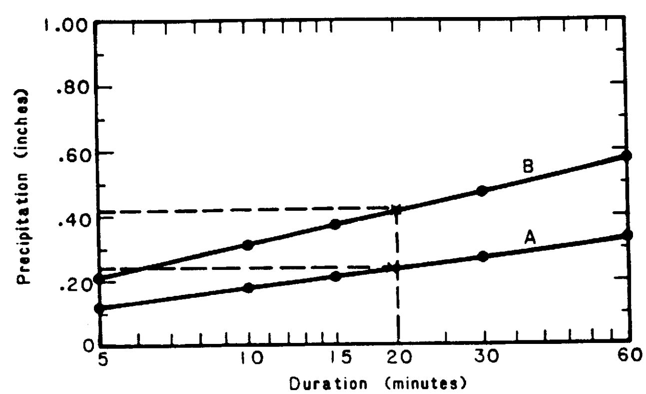

Figure 3.—Example of duration interpolation.

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

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