THE LITTLE USED THIRD DIMENSION

By

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ABSTRACT

The papers presented during the past ten years at Western Snow Conferences on statistical approaches for solving problems in snow hydrology, improving water-supply forecasts and on meteorological aspects of snow hydrology, are briefly reviewed. Seasonal and long-term variations in high elevation - low elevation ratios or winter precipitation amounts for selected stations in the western states are analyzed. The possible effects of such fluctuations on the indices commonly used in snow hydrology studies are discussed.

Those who work in the field of snow hydrology are well aware of the limitations of the statistical procedures commonly in use. Most methods provide fairly realistic answers for the average or near normal cases but are least reliable under abnormal conditions. This is especially true for the field of water supply forecasting.

The purpose of this paper is to point out some evidences why it might be advantageous to introduce additional meteorological data, especially analyzed synoptic or current weather information, rather than continual re-evaluation of the same basic data as has been used in the past.

A review of the proceedings of the Western Snow Conference for the past ten years shows that there have been at least ten papers dealing with different statistical approaches for solving problems in snow hydrology. About half that number advocated the use of additional surface data to improve water supply forecasting. Ten other papers have dealt with the meteorological aspects of snow hydrology.

Max Kohler (1957) reviewed the development of procedures for water-supply forecasting as covered in published literature up to the time of our meeting in 1957. At the same meeting, Burns and Strauss (1957) reported on graphical forecast errors. Hannaford, Wolfe and Miller (1958) showed a graphical method for determination of area-elevation weighting of snow course data; Work, Beaumont and Davis (1962) on using snowpack ratios in runoff forecasting; Kuehl (1962) on improving water supply forecasts by limiting techniques.

Several papers have reported on the use of additional data for improvement of the standard water supply forecast procedures: Peck (1954) on the use of low winter streamflow as an index to ground-water carryover effects; Stockwell (1959) on the use of soil moisture data; several on the effect of changes in vegetation on streamflow; Anderson and Gleason (1959), Anderson (1960), Hoover (1960), Lull and Pierce (1960), and Packer (1960); and Peak (1962-1963) on the use of wind data to improve forecasts in Wyoming.

With the exception of the use of wind data by Peak, most of the additional data could be termed two-dimensional. All the records (precipitation, snow survey data, runoff, etc.) were collected at the surface of the earth.

While these new techniques have improved our procedures, there remain many problems still to be solved. One of these is time trends in the basic precipitation-runoff relations; that is, changes in the amount of runoff for the same precipitation during different periods of time. Other problems which have been only partially solved are those associated with determining the optimum value of our statistical indices derived from basic data.

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Several studies on weather factors related to snow hydrology have also been covered during the past ten years by papers at the Western Snow Conference. Garstka (1954) reported on the heat exchange and melt of late season snow patches in heavy forest; Mondrillo (1956) on the thermodynamics of transpiration during active snow melt; Walsh (1957) on the meteorological and snow studies in the Central Sierra; West (1959) on snow evaporation and condensation; Sellers (1960) on precipitation trends in Arizona and Western New Mexico; Grant and Schleusener (1961) on snow fall and snow fall accumulation near Climax, Colorado; Schermerhorn (1961) on short-range snow melt forecasts; Miller (1962) on the interception loss of snow; and Elliott and Walser (1963) on changes in seasonal runoff relationships as related to cloud seeding activity.

This list does not include all papers which have been presented on the various subjects at the Western Snow Conference but it does show the range of information which has been reported.

The paper by Sellers (1960) demonstrated that precipitation has not decreased materially over the last fifty years. There have been numerous reports of trends in the relations of precipitation and runoff and they are evident in most of such relations for the western United States for data covering long periods of time.

The trends are evident whether you use precipitation or snow survey data. Causes for the apparent changes in the precipitation-runoff relations are difficult to completely explain. The use of ground-water carry-over factors have helped, as have corrections for man-made or ecological changes in basin characteristics. However, in most cases, all of the time trends are not removed by such methods.

Recent studies by Williams and Peck (1962) on terrain influences on precipitation as related to synoptic situations demonstrated that there is a relation between storm type and the precipitation ratio from high to low elevations along the Wasatch Front of northern Utah. This report showed that the ratio of high level to low level precipitation varied during the season. A graph from the paper (Fig. 1) shows the variation (dashed curve) in averaged high-low level precipitation ratios for the winter months of October-April (Silver Lake Brighton, 8,700 feet MSL, over Salt Lake City, 4,248 feet MSL). The ratio changes from about 2.5 during October to near 4.0 for the winter months of December-February and back to near 2.0 during April. The solid black curve represents the average number of days by month for the period 1945-1960 when an upper-air cold low was present over the Great Basin area. A storm was classified as a "cold low" type if during the precipitation period a closed 200-ft contour appeared on the 500 mb chart with a center located between the Continental Divide on the east and the Sierra-Cascades on the west, and between 35^{o} and 45^{o}N. The number of cold-low days is inversely related to high-low level precipitation ratio. Fig. 2 further shows that the ratio varied for other types of storms; near 2.0 for cold lows; slightly over 5.0 for warm front over-running; near 7.0 for cold fronts; and near 9.0 for miscellaneous types without cold lows aloft or frontal activity present. This analysis was made for the winter season alone for the period October 1953 through April 1959. Only precipitation occurring during storms of at least 0.40 inch at Silver Lake Brighton or Salt Lake City, Utah, in a 48-hour period was included.

One conclusion which can be drawn from the information in Fig. 1 and Fig. 2, is that identical indices of the same parameter for two seasons may not represent the same areal distribution. For example, the April 1 water equivalent of snow or the total October-April precipitation for two different years may be the same but if the storm types during the two seasons were not essentially the same, the areal distribution of the precipitation might be substantially different. This could happen if precipitation occurred primarily during the winter months during one season, but in the fall or early spring during the second season.

Methods to account for yearly variation in distribution were introduced in some of the cited papers. However, the techniques proposed did not completely account for the variations experienced. In addition, the available data on snow cover and snow water equivalent at the lower elevations limits the usefulness of most statistical approaches. Areal weighting has also been tried. This is good but is also limited by available data in many areas.

Table 1 is a tabulation of the high-low level October-April precipitation ratios

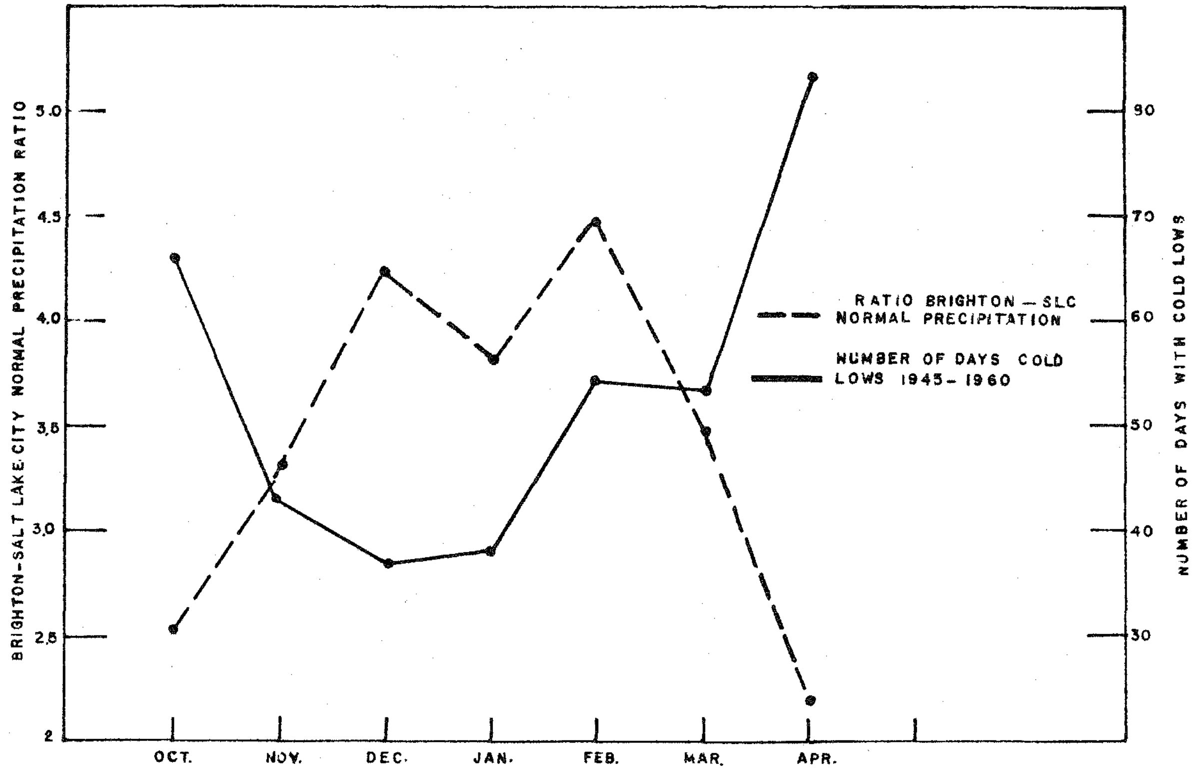

Fig. 1. Ratio of monthly normal precipitation, Silver Lake Brighton to Salt Lake City, and number of days with cold lows over plateau.

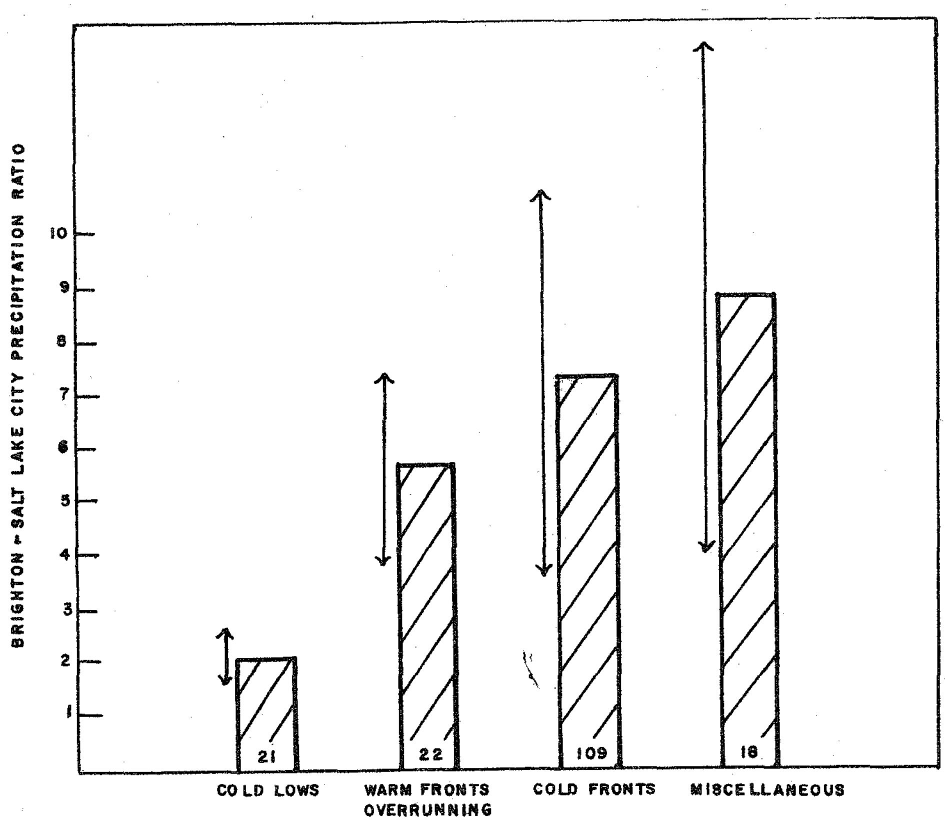

Fig. 2. Ratio of Silver Lake Brighton To Salt Lake City, precipitation for different storm types. The number of cases for each type is shown at the bottom of the respective bars. Arrows to left of the bars show standard deviation.

TABLE I

HIGH-LOW LEVEL ELEVATION PRECIPITATION
RATIOS OCTOBER-APRIL PERIOD

Silver Lake Brighton (8,700 ft. MSL) (SLB) / Salt Lake City, Utah (4,248 ft. MSL) (SLC)
Silver Lake Brighton (8,700 ft. MSL) (SLB) / Midvale, Utah (4,250 ft. MSL) (MID)

Water Year	Ratio SLB/SLC	10-Yr. Mean 1/	Ratio SLB/MID	10-Yr. Mean 1/	Water Year	Ratio SLB/SLC	10-Yr. Mean 1/	Ratio SLB/MID	10-Yr. Mean 1/
1916	3.48		3.71		1940	2.05	2.87	2.76	3.39
1917	2.30		2.67		1941	2.08	2.83	2.21	3.30
1918	3.00		2.84		1942	2.58	2.72	3.03	3.15
1919	3.40		3.38		1943	3.88	2.79	4.52	3.23
1920	2.60		2.46		1944	2.44	2.73	2.66	3.10
1921	3.05		2.85		1945	3.84	2.86	3.59	3.17
1922	3.09		3.19		1946	3.76	2.87	3.70	3.14
1923	2.51		3.00		1947	2.79	2.86	2.91	3.13
1924	2.90		3.20		1948	3.13	2.90	3.39	3.16
1925	2.28	2.86	2.28	2.96	1949	2.89	2.94	2.81	3.16
1926	2.36	2.75	2.65	2.85	1950	3.87	3.13	4.18	3.30
1927	3.22	2.84	3.09	2.89	1951	4.03	3.32	4.53	3.53
1928	2.42	2.78	2.63	2.87	1952	2.61	3.32	2.72	3.50
1929	2.54	2.70	2.75	2.81	1953	2.48	3.18	3.23	3.37
1930	3.00	2.74	3.53	2.92	1954	4.31	3.37	4.54	3.56
1931	2.47	2.68	3.18	2.95	1955	4.04	3.39	3.60	3.56
1932	3.66	2.74	4.50	3.08	1956	4.29	3.44	4.16	3.61
1933	3.20	2.81	3.73	3.15	1957	2.90	3.46	3.00	3.62
1934	3.11	2.83	3.91	3.23	1958	3.17	3.46	3.39	3.62
1935	2.54	2.85	2.90	3.29	1959	2.91	3.46	3.54	3.69
1936	3.61	2.98	4.04	3.43	1960	2.83	3.36	4.44	3.72
1937	2.86	2.94	2.94	3.41	1961	3.41	3.30	3.37	3.60
1938	2.75	2.97	3.16	3.46	1962	3.99	3.43	4.02	3.73
1939	2.46	2.97	2.80	3.47					

1/ Moving mean entered at end of 10-year period.

computed for Silver Lake Brighton (8,700 ft. MSL) and the valley stations of Salt Lake City (4,248 ft. MSL) and Midvale (4,250 ft. MSL) in northern Utah. All of these stations are known to have long consistent records. The ten-year moving means for the high-low precipitation ratios are also listed in Table 1. The ten-year average for the period 1920-1929 is 2.70 for the Silver Lake Brighton-Salt Lake City ratio while for a later ten-year period (1950-1959) it is 3.46; a significant change in the ratio. Precipitation during the 1920-1929 period during October-April at Silver Lake Brighton averaged 32.5 inches or nearly the same as observed for the 1950-1959 period (33.8 inches). However, at the Salt Lake City station, the average amounts were 12.0 inches for the 1920-1929 period and 10.2 inches during 1950-1959. How much of the apparent time trend in precipitation-runoff relations can be attributed to the change in the precipitation ratio is a matter of conjecture. It is not suggested that all of the difference in the precipitation-runoff relations is due to a change in storm type. Attempting to assign all or most of the variation to one factor is a fallacy that has been too often used. Certainly, differences in groundwater carryover, variations in weather conditions outside the period covered by winter precipitation, ecological or man-made changes in the basin as well as climatic trends affecting evapo-transpiration, could influence the precipitation-runoff relations. Relative causes for the time trends probably vary from basin to basin. Perhaps too little attention has been given to the possibility of variation in storm types accounting for at least part of the shifts observed in precipitation-runoff relations in the western United States.

Detailed daily upper-air maps are available since about 1943. These maps were studied to determine if there was a change in the type of storms for the years when the high-low level precipitation ratios were great as compared with the years when they were small. For this purpose, eight years having high ratios and eight with low ratios during the 1943-1961 period were selected from the Silver Lake Brighton-Salt Lake City October-April precipitation ratios in Table 1. For the 8 years with high ratios, there was an average of 14.4 days with cold lows aloft while for the eight years with low ratios, there were 18.1 days with cold lows aloft. Precipitation observed at Salt Lake City, Utah, associated with cold lows aloft storms only (Oct-April period) averaged 4.00 inches for the years with the low ratios and only 2.80 inches for those with the high ratios. Total precipitation observed at Silver Lake Brighton during the two eight-year groupings were approximately the same (32.8 inches for the low ratio years and 33.9 inches for the high ratio years). These variations tend to verify the fact that more cold low aloft storms are associated with the low ratio years.

Since reliable upper-air maps are not available prior to 1943, a count was made to determine the number of surface lows which moved through Utah during each of the eight-year periods to see if these might be correlated with the cold-low type of storms. During the eight years with the high ratios, there was an average of 10.0 from Oct. to April while for the years with low ratios the average was 12.2 days. It is interesting to note that for the ten year period 1950-1959, there was an average of twelve surface lows each year and in the 1920-1929 period, an average of twenty-two surface lows. It is possible that the general upper-air circulation patterns were different during the two decades. More cold lows aloft may have been experienced during the 1920 decade which would have accounted for the small high-low elevation ratios. During the ten years ending in 1959, there were a relatively small number of cold lows aloft. The use of upper-air data may hold promise as a means for improving water supply forecasts and could open up new avenues of research. The value of observed precipitation as indices for areal distribution of precipitation may be enhanced by correlating storm or even shorter period amounts with measured upper air parameters, thereby eliminating the need for storm typing. Many storms are not clear cut cases but have characteristics of several types.

The question arises if this technique would work in other areas of the west. Plots of high-low ratios of monthly precipitation normals for stations covering the west bring out some interesting facts.

It is well known that precipitation amounts vary over the west. High-low elevation precipitation ratios also vary as may be seen in the plotted graphs of monthly mean ratios for pairs of stations in each western state (Fig. 3). The ratio at any location for any months is primarily dependent upon the predominate storm type causing the precipitation. The variations in the high-low elevation precipitation ratios reflect the great variance of storm types which occur in the West.

The Leadville-Cheesman, Colorado, plotted ratios have the same general characteristics observed for northern Utah. For the State of Washington, the variation in the ratios for the October-April period is very small; for the Oregon plotting, the highest ratios are found for the months of October and April with lower ratios during the winter months. In California very little seasonal variation is noted. This lack of variation during the season probably accounts for the excellent correlations found between precipitation or snow survey data and runoff in this area.

Moving inland we find little variation during the season for Idaho and Arizona but an extremely high range in ratio values in Nevada. Here the ratio for October is over 2.5 decreasing in December and January to near 2.0 and rising until it is near 4.0 for March and April. This pattern is in direct contrast to that observed in northern Utah. The curve selected for Montana shows a gradual increase from October to April in the ratios while that for Wyoming has a peak ratio value in February. In New Mexico the ratio values for Cloudcroft RS-Alamogordo increase rapidly from October to March with a sharp decrease to April. It should be noted that precipitation during March is an important factor in determining the water supply outlook for the Rio Grande Basin.

No attempt has been made to type the storms associated with the variations in ratios for the different sections of the west. Studies relating upper-air parameters to precipitation distribution should produce results of more general application than simple storm typing. From the variations found in the changes in the high-low ratios for the Utah area, it is evident that the seasonal ratios do not always follow the same pattern. Changes in the overall weather pattern which cause departures from the mean pattern of high-low ratios may cause deviations in the effects of computed seasonal indices. Such deviations have been noted in California where the normal pattern of high-low ratios is very consistent. Corrections applied to the seasonal indices for such years, based on a knowledge of the changes in the weather patterns, may improve the value of the indices.

Robert Elliott (1962), has done considerable research on the relation of orographic precipitation to orographic lift and upper air parameters. Myers (1962) of the Hydrometeorological Section, U. S. Weather Bureau, has shown good predictability of rainfall distribution for the Sierras west of Reno, Nevada, from upper airflow patterns. Results of such studies as these have not yet found their way into operational use for hydrologic purposes.

The title of the paper, "The Little Used Third Dimension," implies that weather data should be used to a greater extent in snow hydrology problems. The non-use is not all due to a need for research but to some extent to the difficulty of obtaining daily weather data, especially for humidity, wind, radiation, etc. Part of this problem has been solved by the fact that most Weather Bureau data are now available on punch cards. However, this does not preclude the fact that for many areas of the west, daily measurements of weather observations of the kind and type required for detailed studies are not available. This is especially true for wind and humidity records. With the future requirements indicated for our water supplies, adequate data of all kinds will be required for proper use, conservation and planning of the available resources. Research which will determine the extent and kinds of basic data which will be required should be accomplished and means taken to obtain such information.

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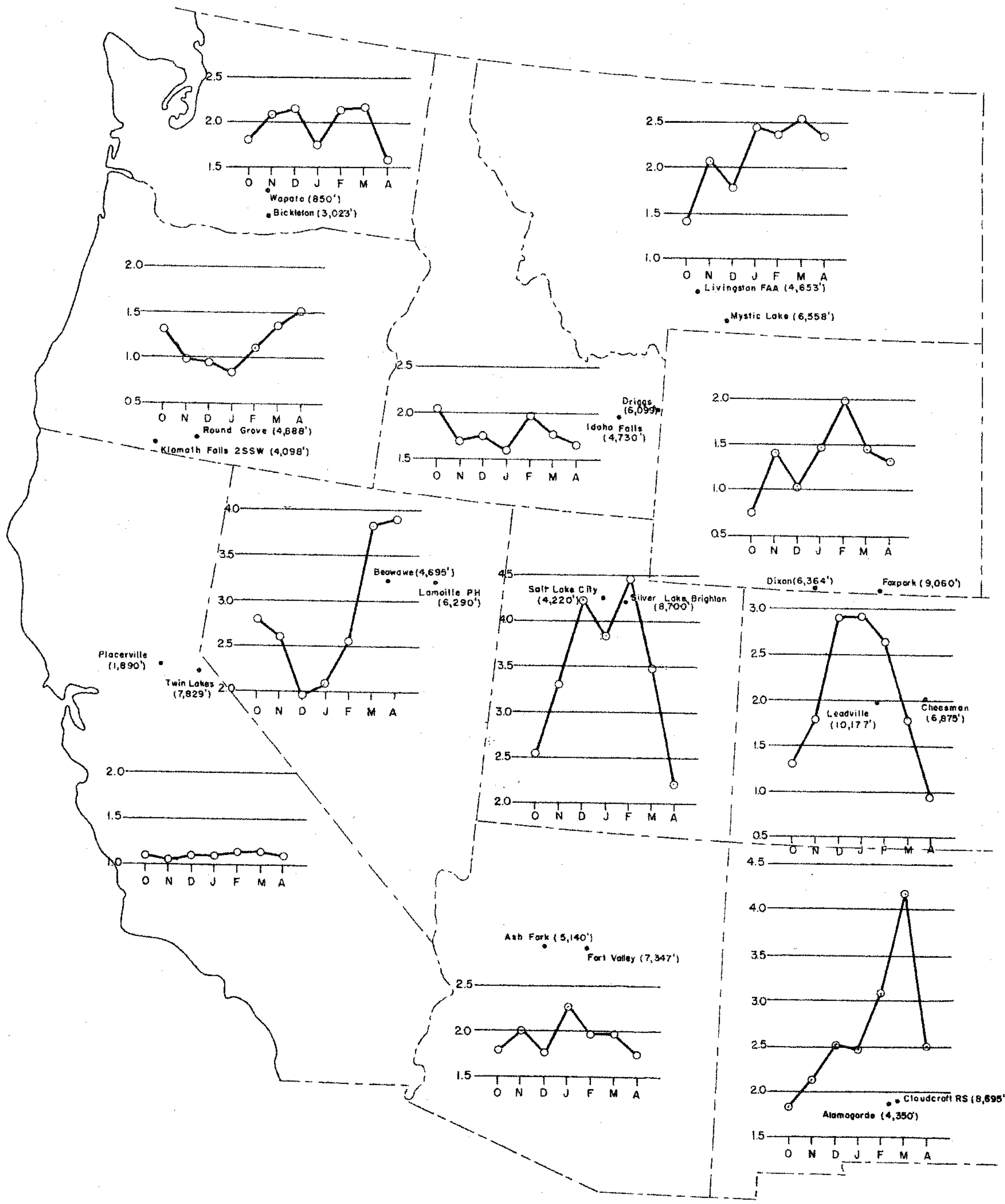

Fig. 3 Diagrams, showing variations in the ratios of monthly precipitation (Oct-April) for pairs of selected high-low elevation stations in the eleven western states.