Analysis of Colorado Average Annual Precipitation for the 1951–1980 Period

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I. Introduction

Isohyetal maps of average annual precipitation have long been and continue to be a backbone and starting point for many climatic, hydrologic and basic water resource and land use studies. In Colorado there have only been a few satisfactory attempts during the past several decades to complete such a map. The most recent and most complete attempt to date was the "Normal Annual (and Summer and Winter Season) Precipitation Map of Colorado, 1931-1960" completed during the 1960s by the U. S. Weather Bureau. This two map set has proven credible in depicting, with local accuracy, the great diversity of the precipitation climate of Colorado.

The 1931-60 map set, which was printed by the U. S. Geological Survey and distributed by the Colorado Water Conservation Board, has been out of print since the early 1970s. Although still considered relatively accurate, the years have gradually taken a toll on the credibility of this product. Research results and computer simulations, such as the orographic precipitation model of Rhea (1978), have presented justification for challenging the accuracy of the original analysis in portions of the Colorado Rockies. Also, considerably more precipitation data have been collected since 1960 improving the data base for the analysis.

In 1982, the Colorado Climate Center, with funding from the National Oceanic and Atmospheric Administration National Climate Program Office and the Colorado State University Agricultural Experiment Station, initiated the effort to update the Colorado precipitation map. The interagency Colorado Hydrometeorological Committee provided peer review throughout the project. Drafting and printing services were donated by the U. S. Geological Survey.

II. Methodology

The method used in deriving the 1931-60 Colorado precipitation maps was first developed for the state of Utah by the Water Supply Forecast Center of the U. S. Weather Bureau in Salt Lake City, Utah. The method, described in a paper by Peck and Brown (1962), was a valid and creative approach to analyzing precipitation patterns in areas of complex terrain with sparse data Following summarization and adjustment of precipitation means from available station records (5 to 30 year records for the period 1931-60), regression relationships of precipitation and elevation were developed for various climatic divisions for winter and summer seasons. Anomalies from these regression equations were defined as the variation of each station mean from the regression line, in inches. These anomalies, found to be related to physiographic features, were plotted on a base map and anomaly isolines were constructed. These were then combined with the precipitation-elevation relationships for each area and for each season to compute mean precipitation values for a grid of points on the map leading to the final isohyetal contouring.

Rather than starting over with a new method or developing new precipitation-elevation relationships and new anomaly contours (which would have been costly and time consuming), the decision was made to accept the original precipitation map as the starting point for the new analysis, changing contours only in areas where substantive evidence now exists to justify modification. Therefore, the emphasis was placed on finding and incorporating as much new data as possible into this analysis. In particular, great effort was made to include high elevation data ($\geq$ 9,000 feet) to assure accuracy in the highest precipitation zones in Colorado. A study by Loren Crow (1982), which was a precursor to this map analysis, showed that extrapolation of precipitation-elevation relationships to high elevations was simply not appropriate without the existence of good high-elevation data.

The actual method used to develop the new precipitation map therefore consisted of these few steps: 1) Assemble all available precipitation data. 2) Calculate and verify monthly, seasonal, and annual precipitation totals. 3) Adjust shorter records and seasonal data to a consistent base period. 4) Plot data points on overlay over original 1931-1960 precipitation map. 5) Adjust isohyets to be consistent with the new data. This procedure, while outwardly simple, required extensive careful data processing. Improvement over the original map is a result of more and better data, not of a more sophisticated method.

III. Data

A 30-year averaging period, 1951-1980, was chosen for the new analysis to coincide with the most recent standard period for computing "normals" used by the National Climatic Data Center. Water years (October 1-September 30) were used for calculation of annual precipitation totals. In Colorado, this is more practical than the calendar year since it is well correlated with the state's water storage/water usage cycle. Mountain snows begin accumulating in October and this snowpack normally continues to build until sometime in April and May. Peak water usage is associated with the May-September growing season since agriculture accounts for the vast majority of water used in Colorado. Demand peaks during early and mid summer and then tapers off in September as temperatures cool and crops mature. Over a 30-year period, the choice of which 12-month period is used to calculate annual precipitation totals and averages has very little effect on the final results.

The first step towards the completion of a new Colorado precipitation map was thorough investigation of available data sources. Major emphasis was placed on obtaining data from networks consisting of several stations employing consistent instrumentation and observing techniques. In Colorado, this implied that the vast majority of the precipitation data meeting the requirements of this map analysis came from Federal sources.

A minimum of 15 years of consistent data (data from one site or a compatible nearby location(s)) from the 1951-1980 period was a requirement for a station in order to be included in the analysis. Adjustment techniques described in Section IV were used to fill in missing data for those stations with less than 30 complete years of data. An additional requirement was that the gages used to collect precipitation needed to be of comparable accuracy to the NWS standard 8" non-recording raingage.

The National Weather Service (NWS) cooperative network of more than 200 climatological stations ended up being the backbone for this analysis. NWS data are typically limited to populated areas and mountain valleys. Therefore, other data sources were required to help describe mountain precipitation patterns. Snowpack measurements from 151 U. S. Department of Agriculture Soil Conservation Service (SCS) snow courses were the primary high elevation data sources. Since snowpack data are only seasonal, a procedure was developed to produce estimates of average annual precipitation from spring snowpack readings. This will be described in section IV.

Other data sets which were examined included U. S. Forest Service storage gage data, limited standard raingage and storage gage data from the U. S. Bureau of Land Management and the Bureau of Reclamation, and miscellaneous precipitation records from a small number of university, private, and local sources around the state. National Weather Service cooperative weather stations with between 5 and 15 years of data were included for supplemental information.

Several potential data sources were investigated but found to be inadequate for inclusion in this analysis. Recording raingage data from the NWS hourly precipitation network included too much missing data. It underestimated actual precipitation by significant but inconsistent amounts. A similar problem was noted with the U. S. Forest Service Fire Weather network which is a summer-only network.

Many other data sets were not included directly in this analysis because data records were too short. However some of these data sets contained useful high spatial resolution data in mountainous areas. Sources such as the U. S. Bureau of Reclamation San Juan Mountain research data set and data from the Climax weather modification experiment were examined and used to check and confirm the placement of isopleths.

The appendix contains index information and seasonal and annual precipitation averages for the primary data points used in generating the precipitation map.

IV. Analysis

Data from all stations were assembled into a uniform data set consisting of monthly precipitation values October 1950 through September 1980. Seasonal data sets such as storage gage data and the SCS snow course data were processed separately since they did not contain monthly readings throughout the year. All monthly data were checked for accuracy and, when necessary, compared with their original hand-written daily observation form. For all complete years, annual totals along with October-April and May-September seasonal totals were calculated. All missing or incomplete months and years were flagged for later consideration during the adjustment procedures.

An important aspect of this precipitation analysis was "adjusting" all precipitation to be consistent with the complete 1951-1980 period. Separate procedures were used depending on the type of gage used (standard raingage, storage gage, etc.) and the priority assigned to the station. Each procedure for adjustment is outlined separately.

Priorities were assigned to each station based on the length of record and the quality of the data collected. Table 1 shows the priority definitions that were were used and the implication that had for the analysis. Stations which were used in this analysis are listed in the appendix according to their priority rating. The approximate locations for these stations are shown in Figure 1 and 2. The first 3 categories contained mostly NWS weather stations. SCS snow course data and some USFS and BLM storage gage data were given a priority rating of 4. Data from priorities 2-4 all needed some adjustment before being used. No adjustment was performed on priority 5 data which was composed of miscellaneous short record stations (5-14 years) and much of the old

Table 1.

Priority Rating System Used in Processing Precipitation Data for the 1951-1980 Colorado Average Annual Precipitation Map.

Priority Rating	Data Require-ments	Examples	Length of Record (years)	Data Adjustments	Implications for Isohyetal Analysis
1	complete monthly data	NWS cooperative station	30	None	Isohyets must be drawn to fit these data.
2	complete monthly data	NWS cooperative station	25-29	normal ratio method used to fill in missing months to to make a complete 30-year data set.	Isohyets must be drawn to fit these data.
3	complete monthly data	NWS cooperative station	15-25	ratio adjustment used to adjust annual mean to be consistent with complete 30-year data sets.	Isohyets usually drawn to fit these data.
4	seasonal or annual data	SCS snow course	14-30	adjust seasonal data to annual. No adjustments for record length.	Used to reposition isohyets where two or more data points suggest change.
5	miscellaneous data sources not a part of standard station networks or short record length data set	USFS storage gage data Short NWS data	5-30	None	Used in data sparse areas to check positioning of contours.

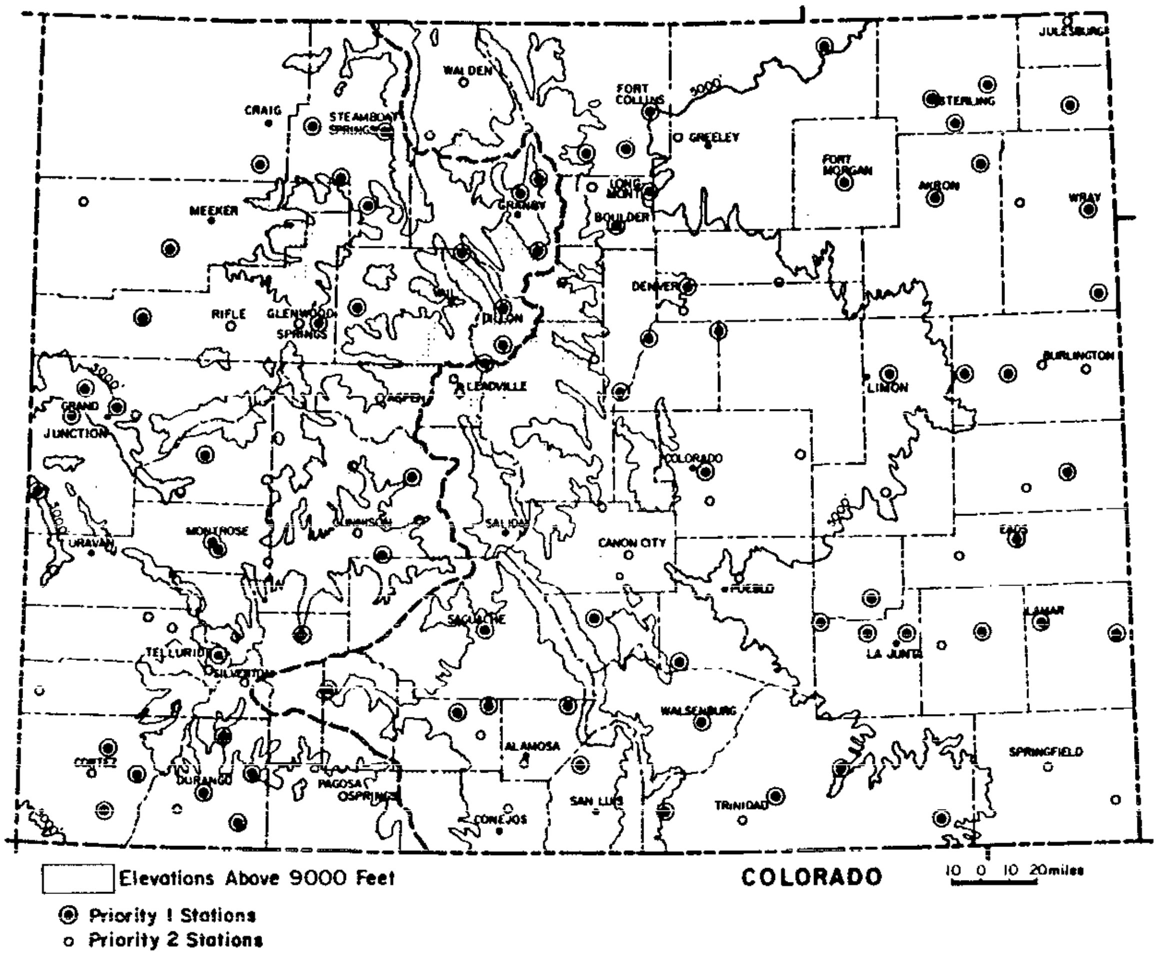

Figure 1. Locations of primary precipitation measurement sites used to generate the 1951-1980 Colorado average annual precipitation map.

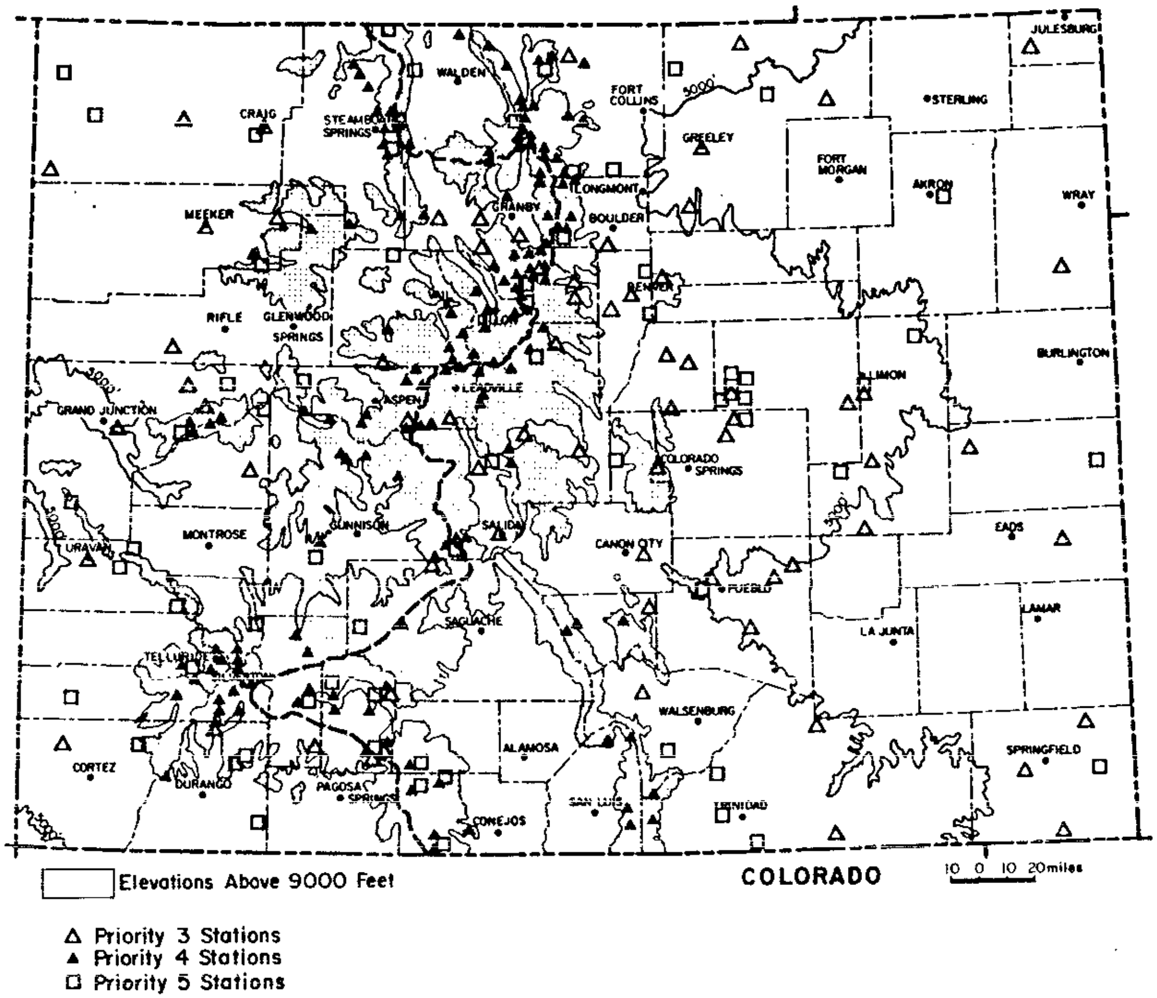

Figure 2. Locations of secondary precipitation measurement sites used to generate the 1951-1980 Colorado average annual precipitation map.

storage gage data. Priority 5 data generally were not used directly in positioning the isohyets. Priority 1 stations were used "as is" with no adjustments needed.

Figure 1 shows clearly the low number of high priority (complete and near complete 30-year data sets) data points in Colorado. Using priority 1 and 2 stations only, it would have been nearly impossible to produce a map of the scale and resolution we desired. Adding short record length and seasonal data to the analyses (Figure 2), was imperative to achieve reasonable data density particularly in the mountains.

A. "Normal-ratio" adjustment procedure

Priority 2 stations (25-29 years of complete data) ranged from stations with just one missing month to as much as 5 consecutive years of missing data. For these stations, the "normal-ratio" procedure was used to estimate monthly precipitation for each missing month. The "normal-ratio" procedure (Linsley et al., 1982) for estimating missing monthly precipitation totals is described by the following equation:

$$EST_j = \frac{\sum PMON_i}{\sum PAVG_i} \times PAVG_j ,$$

where

EST_j = estimated precipitation value for a specific month at station j.

$PMON_i$ = recorded precipitation values for the specific month at each of the i 30-year stations within the same climatic region as station j.

$PAVG_i$ = 30-year normals for the specific month at each of the i stations in the same climatic region.

$PAVG_j$ = the average precipitation for the available record at the station for which the specific monthly value is being estimated.

For the purpose of making these estimates, 25 state climatic divisions were used (Doesken et al., 1983). These divisions are shown in Figure 3.

B. Ratio adjustment procedure

Priority 3 stations (only 15-24 complete years of data) had far too much missing data to justify estimating values for each missing month. For these stations, annual averages were calculated based on only the available complete years of data. Then annual averages were adjusted to the 1951-1980 period using the ratio adjustment method defined below.

$$LTAVG_j = \frac{STAVG_j}{STAVG_k} \times LTAVG_k ,$$

where

$LTAVG_j$ = adjusted 1951-80 annual mean precipitation for station j.

$STAVG_j$ = short term annual mean precipitation calculated from available complete years of data for station j.

$STAVG_k$ = annual mean precipitation for station k (priority 1 station) computed for those years station j had complete data.

$LTAVG_k$ = 1951-80 mean annual precipitation for station k.

In order to determine which "long-term" 30-year priority 1 station might provide the best comparison with any particular short term priority 3 station, the state was divided into 7 regions (Figure 4). Correlation coefficients were then computed for all possible combinations of short-term and 30-year stations in each region based on precipitation totals

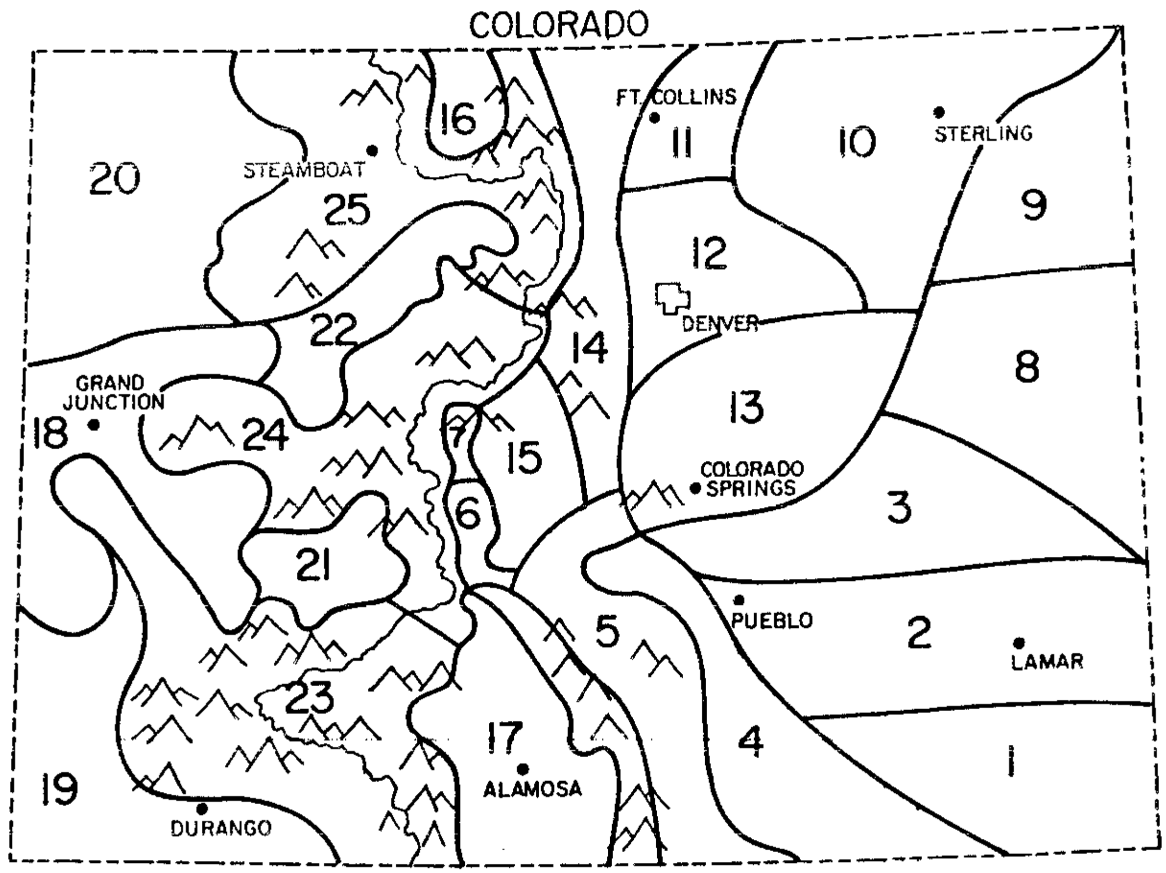

Figure 3. Twenty-five state climatic divisions (Doesken et al., 1983) used for grouping climatically similar stations when performing "normal-ratio" adjustments to estimate missing monthly precipitation.

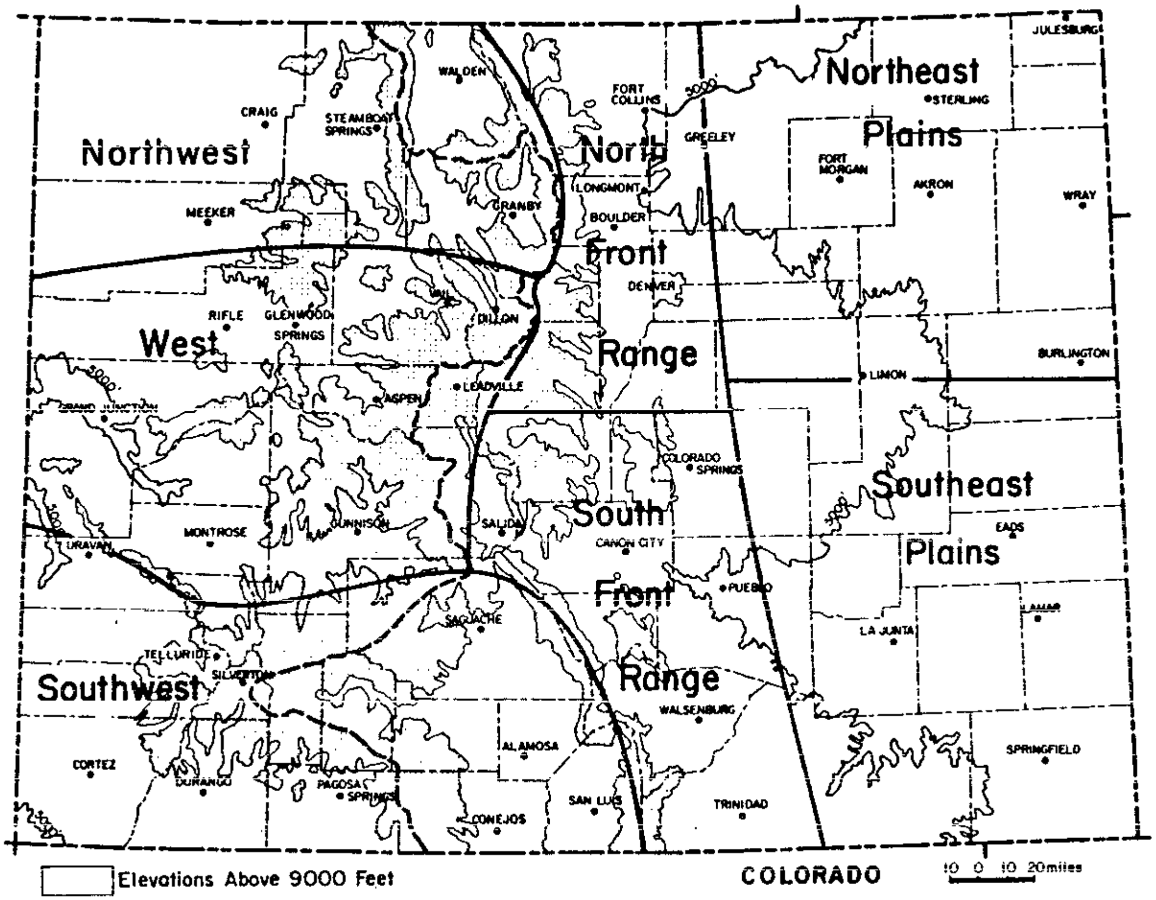

Figure 4. Seven regions used for grouping stations when performing "ratio adjustment" to adjust short record stations (15-24 years) to the 1951-1980 base period.

for common years. The stations with the highest correlation coefficient were paired. Correlation coefficients for the best matched pairs averaged 0.81 and ranged from a low of 0.60 to a high of 0.93. The actual adjustments which were made ranged from -2.02" to +1.29". Of the 71 stations adjusted, 70% were adjusted by less than 0.50". Only annual precipitation averages were adjusted. No estimates of monthly or seasonal averages were made for this set of stations.

C. Mean annual precipitation estimates from snow course data

In the Colorado high country, where a large portion of the state's precipitation falls, year-round measurements are sparse. Of the NWS stations with complete 30-year records, only 5 of them are above 9,000' of which only one is located above 10,000'. The priority 2 and 3 stations add 12 more sites above 9,000' elevation of which 6 are at least 10,000' above sea level. This is certainly inadequate station density to support the type of detailed isohyetal analysis which is attempted here. For this reason a considerable effort was made to make use of all other high elevation data sources such as winter snowpack data collected by the SCS (priority 4 stations).

Historical snow course data gathered in Colorado dates back to the mid 1930s. The data collected by the SCS consist of once a month readings, February 1 to May 1 of snowdepth and water content. At a few stations, some earlier and later measurements are also taken. In no way do these measurements determine the annual precipitation at those sites. Neither do they give an exact measurement of winter season precipitation since they obviously do not take melting or evaporation/sublimation into account. They simply give an indication of the amount of water on the ground at a specific time in the form of snow and/or ice which will eventually melt and contribute to the spring runoff.

Estimates of annual precipitation have been made using snow course data. A paper by Farnes (1971) outlined a procedure used to obtain estimates in Montana. He began by developing a simple regression relationship between annual precipitation and April 1 snowpack for locations where year-round raingages and snow courses were co-located. Modifications were then made based on the density of forest canopy in the immediate vicinity of each snow course. A less elegant method was developed as a part of this project using only Colorado precipitation and snowpack data. A two step approach was taken making independent estimates of winter and summer precipitation and combining them to get annual precipitation.

The first step is based on precipitation-snowpack relationships. Snow courses and year-round precipitation gages have been co-located for more than 15 years (within 1 mile horizontal distance and within 200 vertical feet of each other) at 11 locations in the Colorado mountains. From these 11 sites, admittedly a meager sample, a regression relationship was developed between elevation and the ratio of October-April gage precipitation to average April 1 snowpack water content. April 1 measurements were used even though it is prior to the end of the October-April winter season because melting often occurs during April at all but the highest snow courses.

The resulting relationship is shown graphically in Figure 5.

$$R = \frac{16{,}450 - z}{5{,}600} ,$$

where

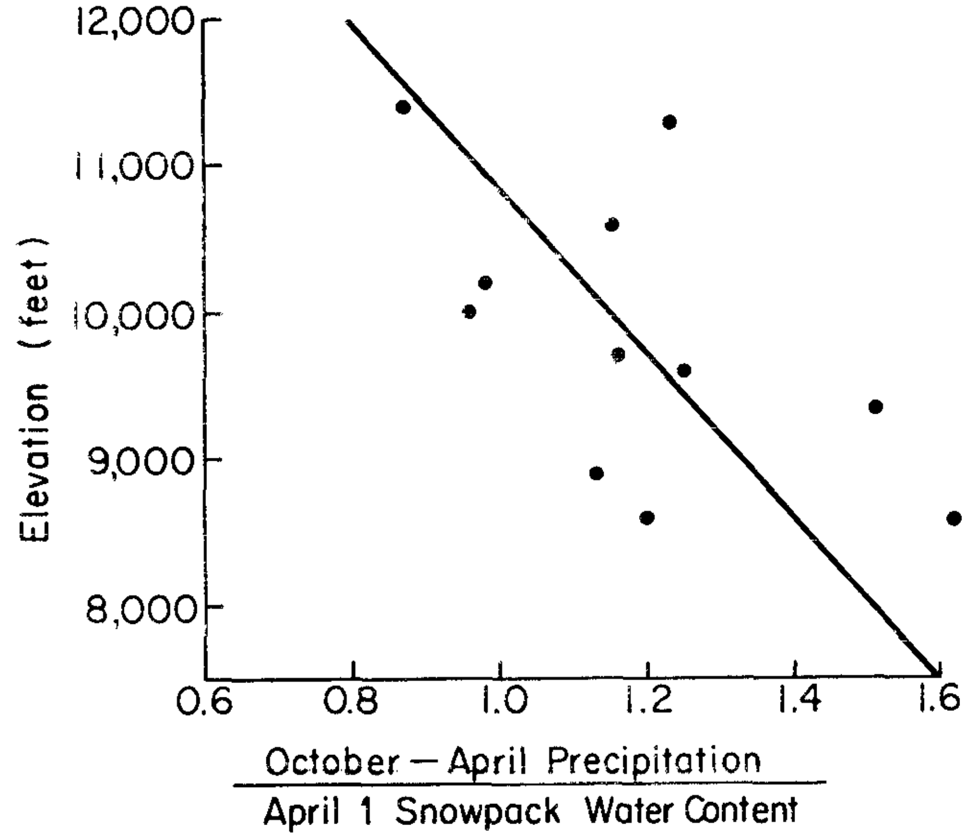

Figure 5. The relationship with elevation of the ratio of winter (October-April) precipitation to April 1 snowpack water content in the Colorado Rockies.

$$R = \frac{\text{October-April average precipitation (inches)}}{\text{April 1 average snowpack water content (inches)}} ,$$

z = elevation (feet) applicable from 8,000' to 10,300' ,

r^2 = 0.32 .

With a correlation coefficient (r^2) of 0.32 the accuracy of this relationship is far from perfect. It does, however, supply a framework for making an objective and reasonable first approximation of winter season precipitation at locations where the elevation and the average April 1 snowpack water content are known. According to this expression, as elevations approach 10,850 feet the ratio approaches 1. This means that April 1 snowpack water content becomes equal to (or greater than for elevations above 10,850 feet) the October-April precipitation. This is not an acceptable conclusion since the April 1 snowpack as defined by its time of observation does not include any of the precipitation that falls during the month of April. For this reason, the regression relationship was only used for elevations up to 10,300 feet. At higher elevations, where melting during the month of April is often not significant, May 1 average snowpack was used as a direct estimate of October through April average precipitation. May 1 snowpack is logically a slight underestimate of actual precipitation because some melting and sublimation/evaporation occurs during the 7-month winter season. However it is conceivably a better estimate of precipitation than actual gage measurements. This is possible because of inefficient gage catch which often occurs in windy, exposed locations.

Part of the reason for the 0.32 correlation coefficient is that factors other than elevation affect the precipitation/snowpack ratio. From the Colorado data it is apparent that factors such as latitude, temperature, and even the magnitude of the snowpack water content itself affect the ratio. Further error was introduced by the fact that most precipitation stations were not precisely co-located with the nearby snow course. Insufficient data were available to justify performing multiple regression analysis using these and other variables. Instead, subjective modifications were permitted to improve the estimates of winter season precipitation. In many areas excellent improvements on the first approximation could be made by using other known climatic information for a given site. For example, the regression equation applied to the Blue Mesa snow course predicts 11.21 inches of October-April precipitation. Because this area is known for being unusually cold for its elevation (resulting in less reduction of the April 1 snowpack by melting than at other sites) and because April precipitation is normally light in that area (less than 1 inch), the estimate was subjectively lowered to 10.00 inches. Please note that in the appendix all October-April precipitation estimates that were subjectively modified from their regression-determined values are appropriately noted.

The second step in determining estimates of annual average precipitation at snow courses was to estimate summer (May-September) precipitation. Summer season estimates were based on available measured data in the vicinity of snow courses and on the 1931-1960 map analysis of May-September average precipitation. The distribution of summer precipitation in Colorado is much more uniform than winter precipitation. With few exceptions most of the mountainous areas of Colorado receive from 8 to 14 inches of May-September precipitation.

Therefore, summer estimates accurate to within ± 3 inches can be made with considerable confidence.

Final estimates of average annual precipitation were then generated by simply summing the two seasonal estimates. The results for 151 snow courses are shown in the appendix. The method for deriving these values may be somewhat crude and subjective, but based on familiarity with Colorado precipitation characteristics we are confident that the results are both reasonable and consistent. If error was made, it was made on the conservative side--underestimating actual precipitation.

D. Research data sets

Data from several major research activities were examined for possible use in this mapping project. For example, precipitation measurements taken in support of the Climax weather modification experiment (Grant, 1984), project Skywater (U.S. Bureau of Reclamation, 1976) in the San Juan Mountains, and the Little South hydrology studies on the Poudre River (Meiman and Leavesly, 1974) were examined. Data from these and other similar projects were not used directly in the final analysis. However, precipitation gradients suggested by these higher density mountain networks were examined to improve the subjective "feel" for precipitation patterns in the mountains. These data sets would have been used more rigorously were it not for the excellent accuracy of the original 1931-1960 precipitation analysis.

E. Orographic precipitation model results

A simple operationally-oriented orographic precipitation model was developed for western Colorado (Rhea, 1978) to diagnose the effect of topography on winter precipitation. The goal was to develop a tool for objectively predicting 12-hour snowfall amounts to aid in avalanche warning and prediction. Model results were summed over the October 15-April 30 period for several years to test its ability to reproduce climatological precipitation patterns. Rhea tested his results versus the October-April precipitation analysis on the 1931-1960 maps. Results of this test showed a very good comparison at higher elevations--good enough to justify the operational use of the model.

The model-generated winter precipitation pattern was carefully examined during the process of generating the new 1951-1980 map. While model results were not used directly in the mapping process, they were used to give an indication of precipitation in data sparse areas. For example, model results were used to help justify small increases of annual average precipitation on portions of the Uncompahgre Plateau where data are nearly nonexistent. The model also suggested that portions of the Grand Mesa, the Flat Top mountains, and the Park Range east of Steamboat Springs may receive more winter precipitation than previously thought.

V. Results

A. Mapping procedure

Annual precipitation values were plotted on a mylar overlay over the original 1931-1960 isohyetal map. A color coding scheme was used to easily identify the priority ranking of each station. During this first mapping step priority 1, 2 and 3 data were plotted. The map was then systematically examined, and all locations were identified where new data points were in conflict with the original analysis. Reconstruction of the isohyets was then begun using the guidelines shown in Table 1 changing the map to conform to the 1951-1980 data. Where there was no new data and where no other new information was available, the original isohyets were assumed to be correct.

The contour intervals used on the original map were retained: 1 inch up to 8.00 inches, 2 inches 8.00 to 12.00 inches, 4 inches 12.00 to 20.00 inches, 5 inches 20.00 to 30.00 inches and 10 inches where annual precipitation exceeds 30.00 inches. These intervals were consistent with data density and with the magnitude of precipitation gradients.

After this first contouring step, estimates of average annual precipitation based on snow course measurements were added to the overlay. Isohyets were adjusted in the high elevation areas only where 2 or more data points were in conflict with the analysis.

The final step involved general verification of the analysis based on other information sources such as priority 5 stations, the Rhea orographic precipitation model, research data sets and analyses, and the expert knowledge of individuals very familiar with the hydrometeorology of Colorado. The Colorado Hydrometeorological Committee provided group review of the project. This review and verification phase took place over a 6-month period and resulted in a few minor modifications to the overall precipitation pattern. This phase also included verification of suspect data sets where station locations and measurement techniques were questioned. An effort was begun to use vegetation analysis and satellite imagery from LANDSAT to confirm contour placements in parts of western Colorado. The time, effort and cost of undertaking this approach was found to exceed the project resources.

In September 1983 the completed 1951-80 isohyetal analysis was delivered to the U. S. Department of the Interior Geological Survey Colorado District Offices at the Denver Federal Center. All of the final drafting and color work in preparation for publication was done in their facilities. The printing itself was done by the U. S. Geological Survey National Mapping Division in Reston, Virginia.

B. Comparison with the 1931-1960 map

There are a number of differences between the old 1931-1960 isohyetal map and the new 1951-1980 analysis. For the most part, the differences are small both in area and magnitude. Many small changes were made in local areas where single contours were moved short distances. There were only a handful of systematic changes that affected areas greater than a few square miles. Changes from the original map resulted mostly from having recent data in areas where little or no measured data were available 20 years ago. Changes were also a result of differences in the measured averages from one period to the next or differences in the interpretation and analysis of the data.

Areas where changes were made from the 1931-1960 averages that affect sizeable areas are shown in Figure 6. The largest single change

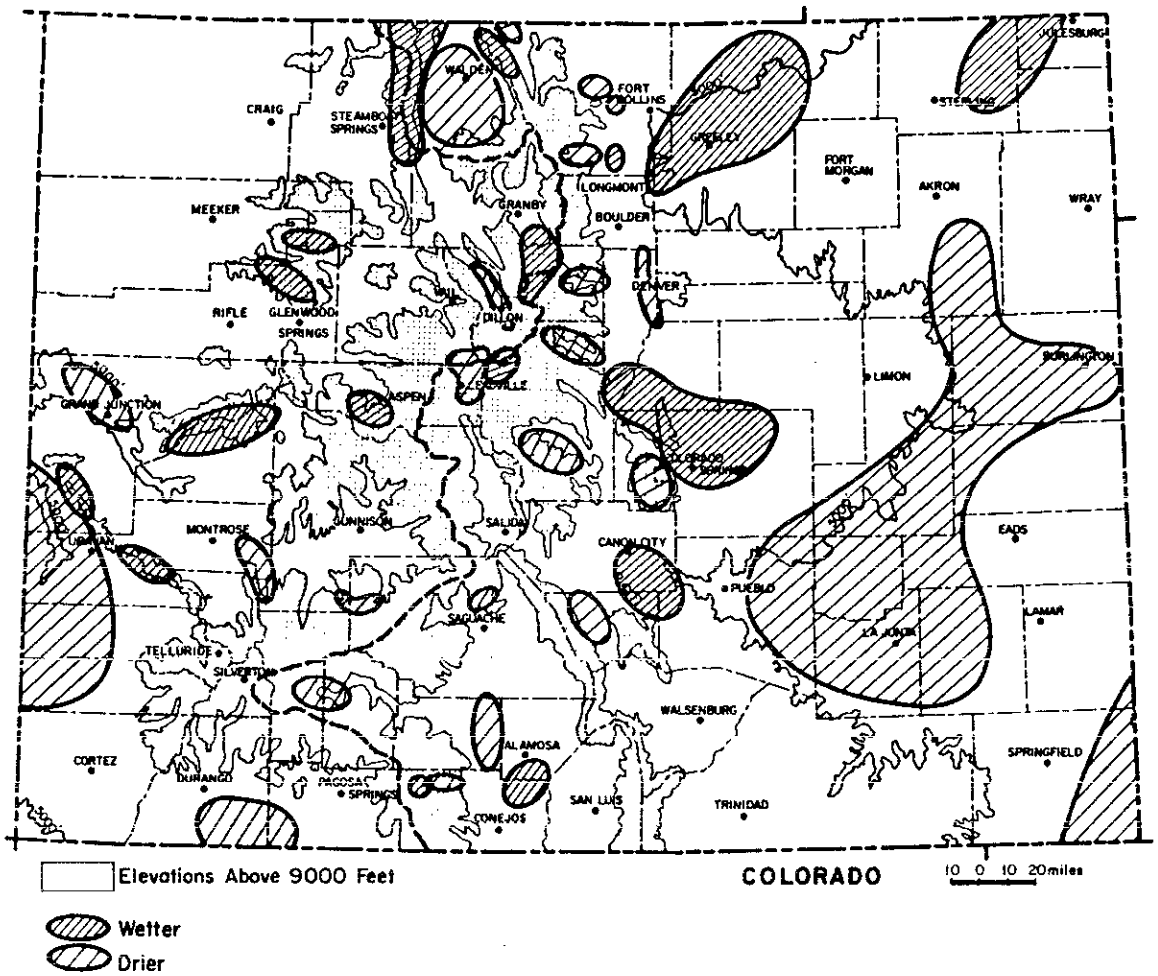

Figure 6. Areas where the new 1951-1980 isohyetal map differs from the original 1931-1960 analysis.

in magnitude was in the Park Range east of Steamboat Springs where recent snow course data indicate that sizeable areas receive more than 50 inches and some areas more than 60 inches of precipitation annually. At the same time, North Park, the area just east of the Park Range, is now analyzed to be drier than before. As a result, there is an incredible precipitation gradient along the east slope of the Park Range--10 inches or more per mile in some areas. Other areas where significant changes have occurred are listed below in Table 2.

A direct station by station comparison was performed to see the exact changes in average annual precipitation at locations where data were collected during both 30-year periods. The 1941-1970 averages (National Climatic Data Center, 1973) were also included to determine if any noticeable continuing trends are occurring. Table 3 shows the results of this comparison. Less than 70 stations had sufficient data in the 1931-1980 period to have averages calculated for both 30-year periods. Only about half of these had complete records within 1 mile of the same location. Only 8 stations had continuous records with no station moves of more than a few yards during the 50-year period. Eleven stations were moved less than 1/3 mile with little change of elevation.

From 1931-1960 to 1941-1970 precipitation averages increased over most of the state. The increase was most noticeable along the eastern border of the state where the drought of the 1930s was most severe. Changes in excess of one inch were common in the eastern counties. The only area where there seemed to be a systematic lowering of precipitation was at lower elevations in extreme southwestern Colorado.

Table 2.

The Ten Most Significant Differences Between the 1951-1980 Precipitation Map and the 1931-1960 Map (not necessarily in order of significance).

Location	Change	Reason for Change
Park Range east of Steamboat Springs	Wetter locally 0 to 10"	New data available and interpretation of orographic precipitation characteristic
North Park area around Walden	Drier 1-3"	New data available.
Berthoud Pass area	Wetter 2-10"	New data available.
Gateway, Uravan Dove Creek area	Drier 1-3"	Change in precipitation and new data available.
Leadville, Fremont Pass, Tennessee Pass	Drier 0-5"	New data available.
South side of Grand Mesa	Wetter 1-4"	Interpretation of orographic precipitation characteristic
Estes Park, Idaho Springs, Bailey	Drier 1-3"	New data available and new interpretation of precipitation/ elevation relationship on eastern slope
Colorado Springs, Palmer Ridge	Wetter 0-3"	New data indicates that the Palmer Ridge precipitation maximum extends farther south than originally analyzed
Longmont, Greeley, Briggsdale areas	Wetter 1-2"	Change in precipitation
Arkansas Valley Pueblo to Las Animas	Drier 1"	Change in precipitation

Table 3.

Comparison of 30-Year Annual Precipitation Averages
for 1931-1960, 1941-1970 and 1951-1980
for Specific Colorado Stations.

Station Name	Annual Average Precipitation (inches) 1931-60*	1941-70*	1951-80**	Large Station Moves(s) and/or Data Gap(s)	No Station Moves(s) or Data Gap(s)
Akron	16.17	16.30	15.65		
Alamosa	6.56	6.94	7.15		
Ames	25.41	26.84	24.71	X	
Boulder	18.57	18.91	18.14		
Buena Vista	9.69	10.71	10.03		
Burlington	16.35	16.85	15.33		
Byers 5ENE	14.05	15.40	14.77		
Canon City	12.66	12.99	12.54		
Cedaredge	11.51	11.92	11.47		
Cheesman	14.48	15.48	15.97		(X)
Cheyenne Wells	14.97	16.26	15.01		
Colorado Springs	13.19	15.73	15.41	X	
Cortez	13.20	12.90	12.56		
Crested Butte	23.00	25.11	24.67	X	
Del Norte	8.65	9.41	9.63		
Delta	7.75	7.89	7.15		
Denver WSFO	14.81	15.51	15.33		
Dillon	18.42	16.76	14.77	X	
Durango	18.04	18.59	18.59		
Eads	13.78	15.09	14.09		
Estes Park	16.07	15.87	13.80	X	
Fort Collins	14.19	14.94	14.47		(X)
Fort Lewis	18.78	18.12	17.61		(X)
Fort Morgan	12.86	13.20	12.45		(X)
Fraser	17.43	18.52	19.27	X	
Fruita	8.31	8.30	8.18		
Glenwood Springs	18.03	16.53	16.26	X	
Grand Junction WSO	8.29	8.41	7.95		
Greeley	11.12	12.20	11.93		
Gunnison	11.00	11.24	10.75		
Haswell	12.24	13.31	12.32		
Hayden	15.45	16.11	16.00		
Hermit 7ESE	15.07	15.80	15.37		
Holyoke	17.81	18.40	17.62		(X)
Idaho Springs	15.00	15.92	14.47		
Ignacio 1N	14.45	14.17	14.17		X
Julesburg	16.32	17.44	17.16		(X)
Kassler	17.41	17.82	17.19		X
Lakewood	15.14	14.95	15.64	X	

Table 3 continued.
(Comparison of 30-Year Annual Precipitation Averages)

Station Name	Annual Average Precipitation (inches) 1931-60*	1941-70*	1951-80**	Large Station Moves(s) and/or Data Gap(s)	No Station Moves(s) or Data Gap(s)
Lamar	14.20	15.33	14.52		
Las Animas	12.25	12.87	12.21		
Leadville	18.48	16.82	15.44	X	
Leroy 5WSW	17.97	18.99	17.38		
Longmont 2ESE	12.03	12.74	12.98		X
Mesa Verde	18.28	17.82	17.50		(X)
Montrose #2	9.11	9.67	9.00		X
Northdale	13.42	12.67	11.88		(X)
North Lake	20.34	20.79	20.15		X
Norwood	15.73	14.96	13.89		
Ordway	11.28	11.84	10.77		(X)
Palisade	8.76	9.11	8.94		
Parker 9E	13.41	13.39	13.03		
Pitkin	15.68	17.75	17.65	X	
Pueblo WSO	11.84	11.91	11.02		
Rico	26.49	26.85	26.22		
Rifle	10.93	11.24	11.26		
Rocky Ford 2SE	12.31	12.53	11.04		X
Rush 2NNE	13.22	13.41	12.82		
Saguache	8.10	8.49	8.55		(X)
Shoshone	18.79	19.68	19.83		X
Silverton	22.26	22.53	22.33		
Spicer	14.06	14.34	13.89		
Springfield	14.73	15.36	14.64		
Steamboat Springs	23.47	23.87	23.44		(X)
Sterling	14.10	14.96	15.01		
Telluride	23.79	23.41	21.61	X	
Waterdale	15.14	15.82	15.80		X
Wray	17.49	18.51	17.02		
Yuma	16.73	17.98	16.65		

* averages computed by the National Climatic Data Center.

** averages computed by the Colorado Climate Center.

(X) station moves less than 1/3 mile and 25 feet elevation.

From the 1941-1970 to the 1951-1980 averaging period, average annual precipitation dropped at almost all weather stations. Again, the change was most dramatic and consistent on the Eastern Plains where the 1970s brought a number of dry years. The trends were less consistent in the mountains and were difficult to confirm since most of the stations were relocated at least once during the past few decades. The effect of these station moves, even minor ones, can be very dramatic in the mountains. On the plains small changes in station location may have little effect.

The resulting pattern of change of annual average precipitation from the 1931-1960 period to the 1951-1980 period was much less systematic than either of the 10 year changes. The pattern indicated that most of the Eastern Plains were drier than they had been in the 1931-1960 period. However the only areas where these changes were significant (more than 0.50 inch) was in the vicinity of Burlington and along the Arkansas River from LaJunta to Pueblo. The most dramatic change toward drier conditions occurred in the extreme southwest portion of the state where a decrease in precipitation was noted in both 10-year periods. Slightly greater precipitation was observed at stations east of the mountains from Colorado Springs north to Fort Collins and throughout the Rio Grande Valley. In the mountains changes were difficult to decipher. Station moves seemed to have a much greater impact on the averages at the few high elevation stations than did any actual changes in precipitation. There are only 11 stations at elevations above 8,000 feet that were operated throughout most of the 1931-1980 period. Of these only 4 earned a priority 1 ranking and only 1 station, North Lake, was operated continuously and was never relocated during that period. It has since been closed. Obviously, Colorado's high elevation precipitation measurements have left something to be desired. For future research and analysis, we must work hard now to establish and preserve high quality, year round precipitation stations at fixed locations in the Colorado mountains.

C. Variability of Colorado precipitation

The 1951-80 precipitation map is a graphic visual demonstration of the variation of annual precipitation in complex terrain. It shows only the average precipitation and gives no information about how variable precipitation is from one year to the next. Fortunately, some measures of the year to year variability of precipitation are not nearly so dependent on the terrain as precipitation itself. If precipitation was normally distributed, then the preferred measure of variability would be the ratio of the standard deviation to the mean. Since precipitation is not normally distributed, the cumulative distribution of the probability of nonexceedance is a better indicator of variability.

Cumulative distributions can be developed to obtain nonexceedance probabilities both empirically and mathematically. The Gamma function is well known for its ability to produce an accurate fit to an actual distribution of precipitation data. The advantage of using the Gamma function is that it smooths some of the inherant noise from a distribution of real data and makes it easy to calculate the probability of nonexceedance as a function of precipitation. Because of the smoothing process, comparisons among a number of stations are less affected by natural "noise" in the precipitation data.

An example of the cumulative distribution produced both empirically and mathematically (employing the Gamma function fit) for Fort Collins, Colorado, for the period 1951-1970 is shown in Figure 7. The average annual precipitation for this period was 14.66". Based on the Gamma fit, there is a probability of 0.50 (the median) that the annual precipitation will not exceed 14.10". Similarly there is a probability of 0.20 (a 20% chance) that precipitation will not exceed 10.36", and a probability of 0.80 (an 80% chance) that precipitation will not exceed 18.64". The magnitude of the difference between precipitation amounts at the 0.20, 0.50 and 0.80 probability levels gives a good indication of the precipitation variability at a particular site.

At the time the 1951-80 precipitation map was prepared, the Gamma function had been fitted to monthly and annual precipitation for 162 stations in Colorado for the period 1951-70 (Benci and McKee, 1977). The assumption made here is that the probability distribution of the 1951-70 data is very similar to the probability distribution for 1951-1980. Precipitation amounts related to nonexceedance probabilities of 0.20, 0.50 and 0.80 were obtained from these distributions. The following paragraphs describe how these data were used in the construction of three maps showing the variability of Colorado precipitation. When used in conjunction with the 1951-1980 map, these maps estimate precipitation amounts associated with probability levels of 0.20, 0.50 and 0.80.

1) Median precipitation. Figure 8 combines the ratio of the median precipitation (i.e. the precipitation value with a nonexceedance probability of 0.50) to the average annual precipitation. The median (0.50) precipitation can be determined for any location in Colorado by multiplying an appropriate value from Fig. 8 for any specified location times a value from the average precipitation map for that same location.

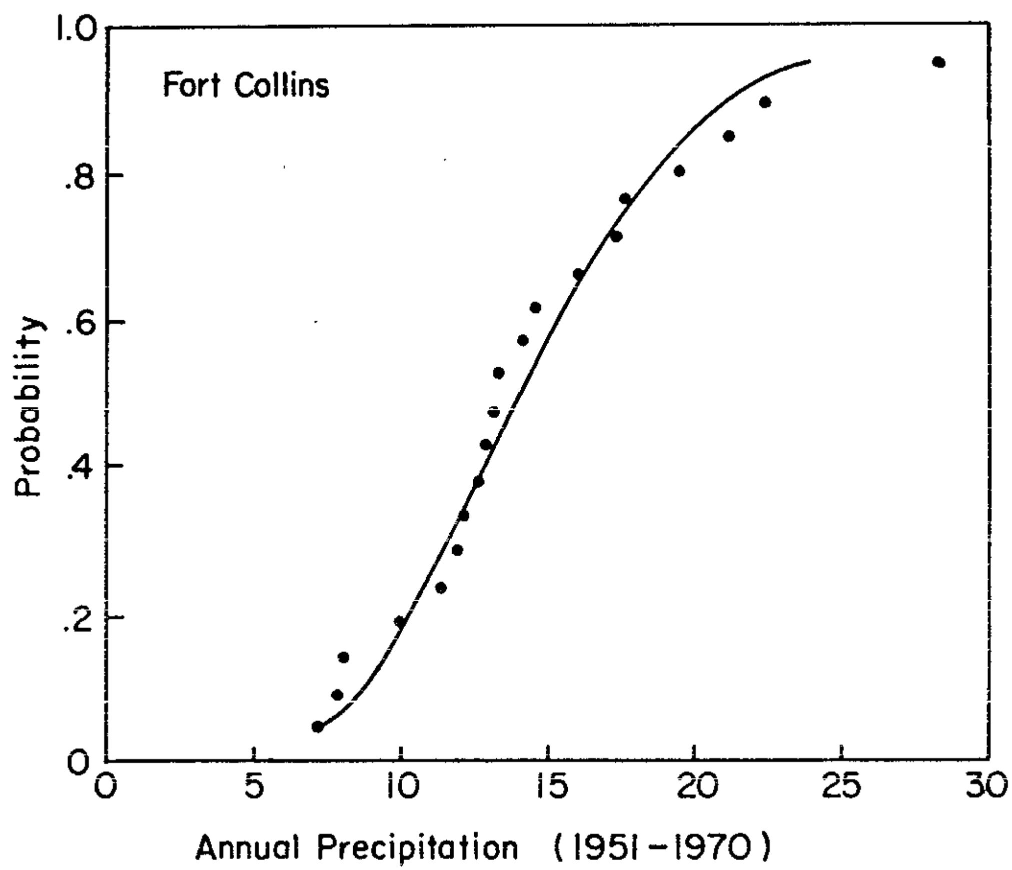

Figure 7. Cumulative distribution function of annual precipitation for Fort Collins, Colorado, for the period 1951-1970. The dots represent the empirical distribution while the smoothed curve is derived form the Gamma function fit to the data points.

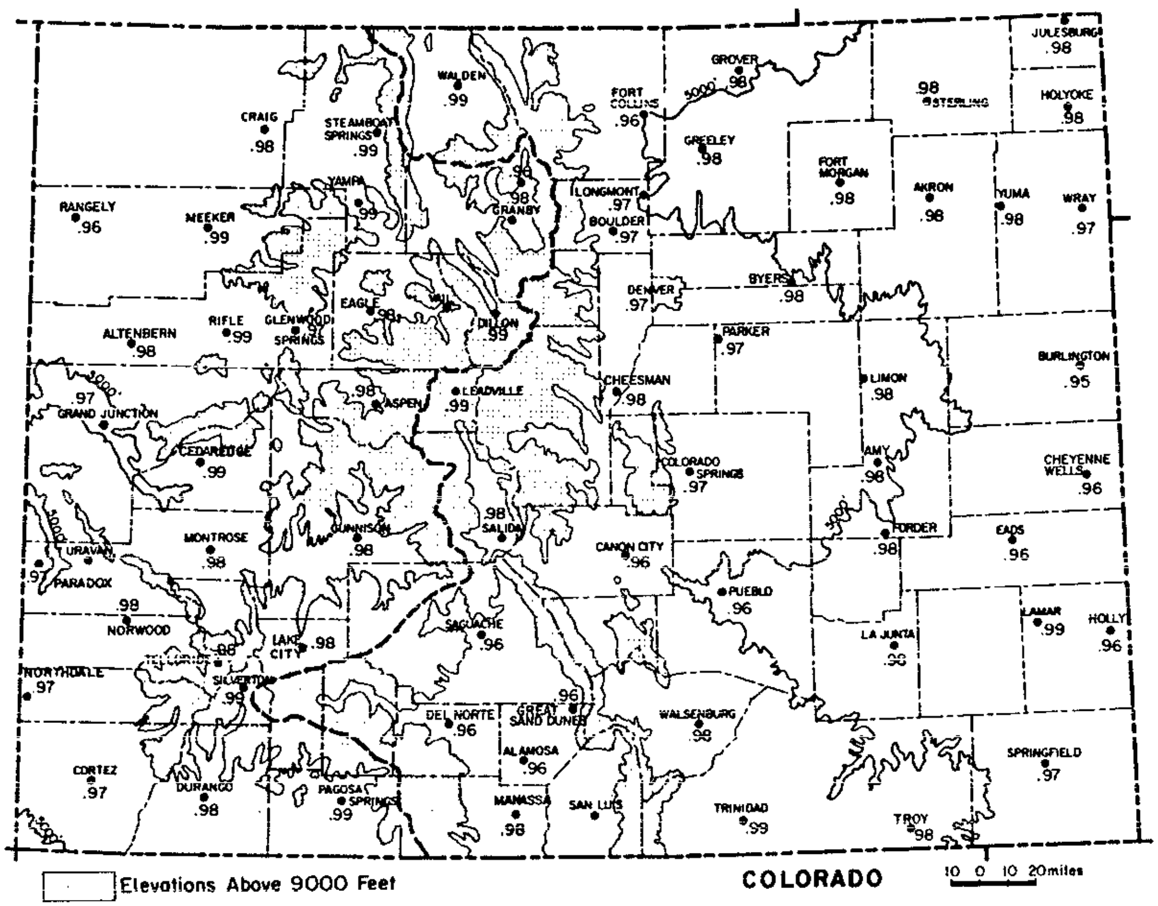

Figure 8. The ratio of the median annual precipitation (nonexceedance probability of 0.5 based on 1951-1970 Gamma fitted data) to the average annual precipitation 1951-1980 for selected Colorado locations. This ratio is defined as factor M.

Values in Fig. 8 are designated as factor (M). Average precipitation values, 1951-1980, will be designated by PA. Thus, the 0.50 probability precipitation, P(0.50) is:

$$P(0.50) = M \times PA .$$

The values in Fig. 8 are all less than 1.00. They range from a minimum of 0.95 at Burlington to a maximum of 0.99 at many locations. No isolines of M have been drawn on the map since the range of values is so small. Data points have been placed on the map and it is rather easy to estimate M within ± 0.01 for any location in the entire state. The characteristic that the median is less than the average is typical for precipitation in most parts of the world, especially dry climates. A few wet years increase the average value but are offset by a greater number of below average years.

2) Precipitation in dry years. One definition of a dry year for any location in Colorado is a year when the precipitation total is in the lowest 20% of all yearly totals. The threshold precipitation value that separates a dry year (by this definition) from a near normal or wet year is the precipitation total which is not exceeded 20% of the time. This is known as the 0.20 nonexceedance probability. The ratio of the 0.20 probability precipitation value to the median (0.50) value indicates the magnitude difference between a dry year and a "normal" year. The ratio of the 0.20 probability precipitation to the 0.50 probability precipitation is designated as factor (D) and is shown in Fig. 9. This factor may be used with the preceeding factors to determine the 0.20 probability precipitation from the average annual precipitation map, P(0.20), from the following relation:

$$P(0.20) = D \times M \times PA .$$

The values of D in Fig. 9 range from a minimum of 0.72 in the San Luis Valley to 0.86 near the Continental Divide. A large value of D is related to a stable climate region with only small year to year variations from the median. For example, a value of 0.86 indicates that the location has only a 14% reduction of precipitation from the median for a rather dry year. At the other extreme a low value of 0.72 indicates that a reduction of at least 28% in precipitation occurs in a dry year. The pattern in Fig. 9 indicates that the precipitation has a smaller variation in the mountains and a larger variation in the San Luis Valley, northern Front Range, and east central plains. Most of the Western Slope is of a moderate variability and a few locations in the Eastern Plains have smaller variability. Figure 9 can be read to an estimated accuracy of $\pm$ 0.02 for determination of the 0.20 probability precipitation value for a given location.

3) Precipitation in wet years. Using a similar definition, a wet year in Colorado is defined as a year when the total precipitation is in the wettest 20% of all yearly totals. The threshold value separating a wet year from all other years is therefore a precipitation amount with exactly a 0.80 nonexceedance probability. The ratio of the 0.80 probability precipitation value to the median (0.50 probability) value indicates the relative difference between a wet year and the median year. The ratio of the 0.80 probability precipitation to the 0.50 probability precipitation is designated as factor (W) and is given in Fig. 10. This factor may be used with other factors to determine the 0.80 probability precipitation, P(0.80) as follows:

$$P(0.80) = W \times M \times PA \ .$$

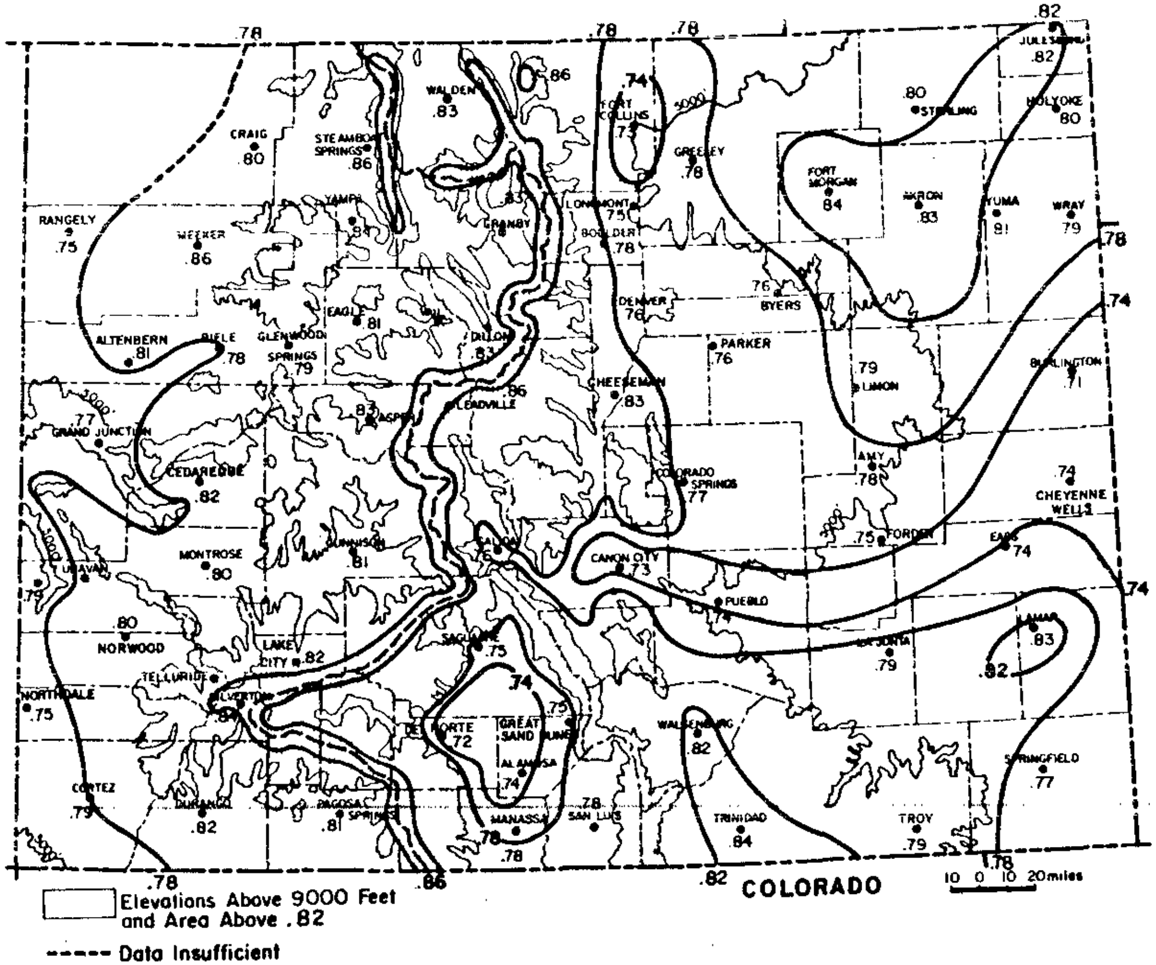

Figure 9. The ratio of the annual precipitation amount with a nonexceedance probability of 0.20 (based on 1951 1970 Gamma-fitted data) to the median precipitation amount. This ratio is defined as factor D and represents the relationship between precipitation in a dry year and the median year. The 9000 foot elevation contour may be used to estimate the position of the 0.82 contour line.

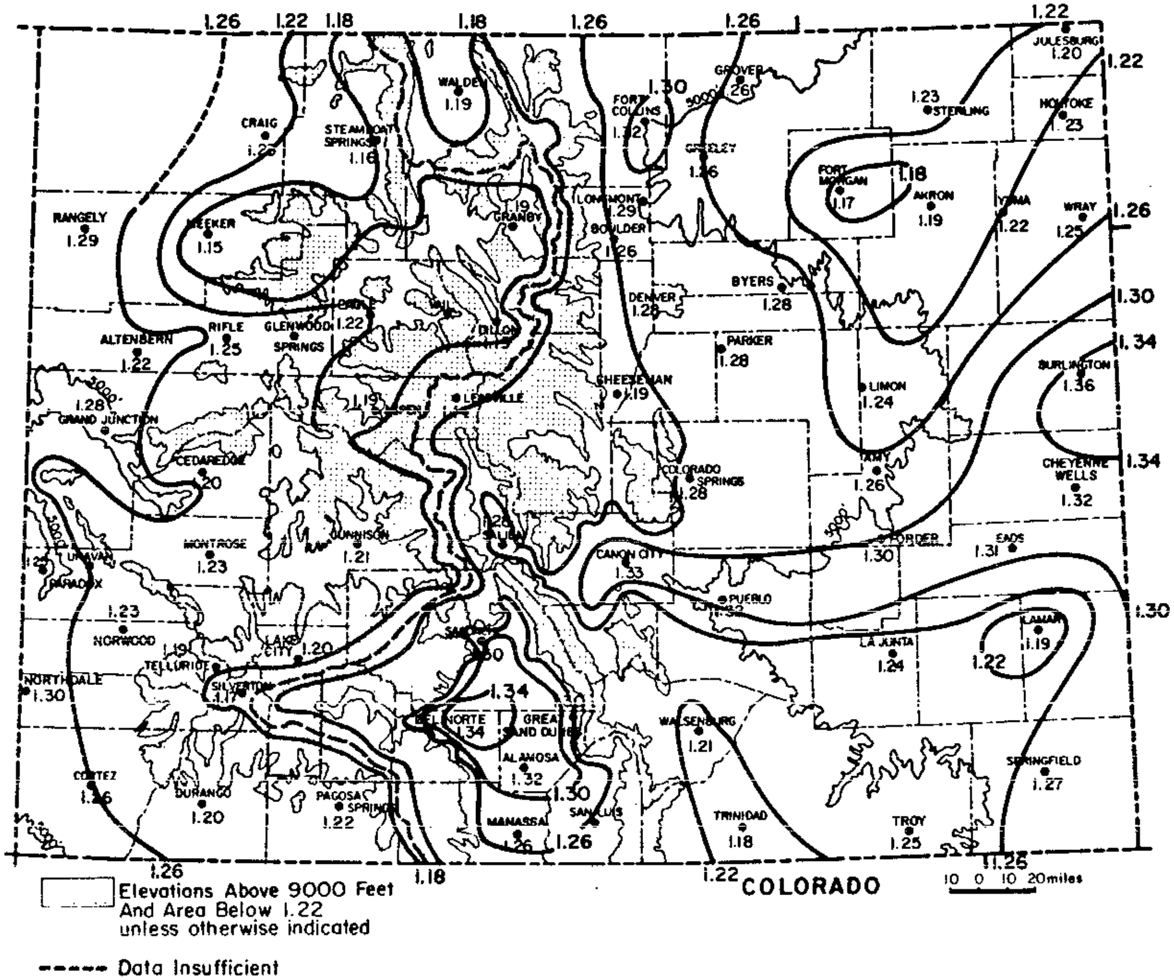

Figure 10. The ratio of the annual precipitation amount with a nonexceedance probability of 0.80 (based on 1951-1970 Gamma-fitted data) to the median precipitation amount. This ratio is defined as factor $\bar{W}$ and represents the relationship between precipitation in a wet year and the median year. The 9000 foot contour line approximates the position of the 1.22 contour line unless otherwise indicated.

The values of W in Fig. 10 range from a minimum of 1.18 near Fort Morgan and several mountain areas to a maximum of 1.34 near Burlington. If the probability distribution of precipitation was symmetric about the median, then Fig. 9 would be a reciprocal image of Fig. 10. In fact, the distribution is not symmetric and the figures are not images, but they are very similar. Areas of high D have a low W which indicate a small variability, while areas with low D have a high W and a larger variability. The Eastern Plains and the Western Slope both reflect similar patterns. The limited data from higher elevations in the mountains do not indicate nearly as much uniformity. All of the high elevation sites have values of 1.20 or smaller. The smallest contour is 1.18 which could incorporate most of the areas near the Continental Divide.

4) Caution. A strong caution is needed in regard to the use of the variability maps. The data used were for annual precipitation. Similar values for D and W at high elevations in Colorado may lead one to think that the mountains are all rather similar in precipitation mechanisms, storm size and frequency, and seasonal traits. Beware! Precipitation in the mountain varies enormously from north to south. The southern mountains are much more variable in winter precipitation than the northern mountains and the reverse occurs in the summer season. The two regions have many important climatic differences which simply do not appear in these annual variability statistics.

VI. References

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VII. Appendix

Index of precipitation stations and their annual and seasonal precipitation averages used in producing the 1951-1980 Colorado average annual precipitation map.

This index is divided into 4 sections according to the data priority ranks described in Section IV. Within each ranking, stations are listed in alphabetical order using the names and index numbers given them by their supervising agencies. For each station, latitude, longitude and elevation are given followed by a tabulation of precipitation averages for winter (October-April), summer (May-September) and annual. The location given for each station is the 1980 location or the location when the station was last in existence. Nearly all the stations listed here are affiliated with either the National Weather Service or the USDA Soil Conservation Service.

No index of priority 5 station was prepared. That group included a wide variety of stations of variable record length, uncertain data quality, and assorted affiliation. Precise locations were not known for all stations.

Index and precipitation averages for all
Priority 1 (complete 30-year) stations.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Akron FAA AP	0114	40°10'	103°13'	4663	30	4.56	11.09	15.65
Altenbern	0214	39 30	108 23	5690	30	9.01	6.31	15.32
Blanca	0776	37 26	105 31	7750	30	2.55	5.16	7.71
Bonny Lake	0834	39 38	102 11	3748	30	4.72	11.64	16.36
Boulder	0848	40 00	105 16	5420	30	8.04	10.10	18.14
Breckenridge	0909	39 29	106 02	9580	30	9.89	9.36	19.25
Cedaredge	1440	38 54	107 56	6244	30	6.62	4.86	11.48
Center 4SSW	1458	37 44	106 08	7683	30	2.68	4.24	6.92
Cheesman	1528	39 13	105 17	6875	30	6.40	9.57	15.97
Cheyenne Wells	1564	38 49	102 21	4250	30	3.88	11.13	15.01
Climax	1660	39 22	106 11	11350	30	14.26	9.15	23.41
Cochetopa Crk	1713	38 26	106 46	8000	30	5.07	5.64	10.71
Colo Natl Mon	1772	39 06	108 44	5780	30	6.13	4.39	10.52
Colo Springs WSO AP	1778	38 49	104 43	6090	30	4.34	11.07	15.41
Del Norte	2184	37 40	106 21	7880	30	4.03	5.61	9.64
Denver	2220	39 45	104 52	5283	30	6.59	8.74	15.33
Dillon	2281	39 38	106 02	9065	30	7.72	7.05	14.77
Doherty Ranch	2312	37 23	103 53	5130	30	4.68	7.95	12.63
Dolores	2326	37 28	108 30	6950	30	11.58	6.43	18.01
Durango	2432	37 17	107 53	6600	30	11.32	7.27	18.59
Eads	2446	38 29	102 47	4215	30	4.35	9.74	14.09
Eagle FAA AP	2454	39 39	106 55	6500	30	5.50	4.73	10.23
Estes Park	2759	40 23	105 31	7525	30	4.74	9.07	13.81
Flagler 2NW	2932	39 19	103 05	4975	30	4.28	11.33	15.61
Fleming 1S	2944	40 40	102 50	4250	30	5.35	11.87	17.22
Fort Collins	3005	40 35	105 05	5001	30	5.76	8.71	14.47
Fort Morgan	3038	40 15	103 48	4320	30	3.51	8.94	12.45
Fowler	3079	38 07	104 02	4328	30	3.33	6.85	10.18
Fruita	3146	39 10	108 44	4510	30	4.77	3.41	8.18
Gateway 1SW	3246	38 41	108 59	4560	30	6.37	4.38	10.75
Genoa 1W	3258	39 17	103 32	5610	30	3.98	10.58	14.56
Grand Junction WSO AP	3488	39 07	108 32	4850	30	4.67	3.28	7.95
Grand Lake 1NW	3496	40 16	105 50	8720	30	10.77	9.34	20.11
Grnd Lake 6SSW	3500	40 11	105 52	8288	30	6.81	6.97	13.78
Grt Sand Dunes	3541	37 43	105 32	8120	30	3.39	6.66	10.05
Green Mnt Dam	3592	39 53	106 20	7740	30	8.08	7.23	15.31

Priority 1 (complete 30-year) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Hamilton	3738	40°22'	107°37'	6230	30	10.63	7.01	17.64
Hayden	3867	40 29	107 15	6375	30	9.74	6.26	16.00
Hermit 7ESE	3951	37 46	107 08	9000	30	8.00	7.37	15.37
Holly	4076	38 03	102 07	3390	30	3.91	10.50	14.41
Holyoke	4082	40 35	102 18	3730	30	5.05	12.57	17.62
Ignacio 1N	4250	37 08	107 38	6460	30	8.21	5.96	14.17
John Martin Dm	4388	38 04	102 55	3814	30	3.22	7.96	11.18
Kassler	4452	39 30	105 06	5500	30	8.01	9.18	17.19
Kauffman 4SSE	4460	40 51	103 54	5250	30	3.62	9.45	13.07
LaJunta FAA AP	4720	38 03	103 31	4190	30	3.73	7.28	11.01
Lake City	4734	38 02	107 19	8670	30	7.02	6.39	13.41
Lamar	4770	38 05	102 37	3620	30	4.57	9.95	14.52
Leroy 5WSW	4945	40 31	103 00	4470	30	5.74	11.64	17.38
Little Hills	5048	40 00	108 12	6140	30	6.99	5.99	12.98
Longmont 2ESE	5116	40 10	105 04	4950	30	5.30	7.68	12.98
Mancos	5327	37 21	108 19	6975	30	9.39	6.57	15.96
Mesa Verde NP	5531	37 12	108 29	7070	30	10.87	6.63	17.50
Montrose #1	5717	38 29	107 53	5785	30	4.76	4.05	8.81
Montrose #2	5722	38 29	107 53	5785	30	4.73	4.27	9.00
North Lake	5990	37 13	105 03	8800	30	8.70	11.45	20.15
Ordway	6131	38 13	103 45	4310	30	3.61	7.16	10.77
Otis 11NE	6192	40 16	102 50	4180	30	3.81	10.80	14.61
Parker 6E	6326	39 32	104 39	6310	30	4.20	8.83	13.03
Pyramid	6796	40 14	107 05	8009	30	12.81	7.16	19.97
Rocky Ford 2SE	7167	38 02	103 42	4170	30	3.73	7.31	11.04
Rye	7315	37 55	104 56	6790	30	10.46	12.23	22.69
Saguache	7337	38 05	106 09	7700	30	3.20	5.35	8.55
Shoshone	7618	39 34	107 14	5933	30	12.73	7.10	19.83
Steamboat Spr	7936	40 30	106 50	6770	30	15.53	7.91	23.44
Sterling	7950	40 37	103 11	3940	30	4.11	10.90	15.01
Tacoma	8154	37 31	107 47	7300	30	12.05	9.45	21.50
Taylor Park	8184	38 49	106 37	9210	30	8.85	6.97	15.82
Telluride	8204	37 56	107 49	8800	30	12.00	9.61	21.61
Trinidad FAA	8434	37 15	104 20	5750	30	4.54	7.72	12.26

Priority 1 (complete 30-year) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Troy 1SE	8468	37°08'	103°18'	5610	30	4.00	9.91	13.91
Vallecito Dam	8582	37 22	107 35	7650	30	15.43	10.11	25.54
Vona	8722	39 18	102 44	4500	30	5.00	10.72	15.72
Walsenburg	8781	37 38	104 47	6150	30	7.01	7.89	14.90
Waterdale	8839	40 26	105 12	5230	30	6.17	9.63	15.80
Westcliffe	8931	38 08	105 29	7860	30	6.22	8.40	14.62
Winter Park	9175	39 54	105 46	9060	30	16.53	10.75	27.28
Wray	9243	40 04	102 14	3560	30	5.01	12.01	17.02
Yampa	9265	40 09	106 54	7890	30	8.15	7.82	15.97

Index and precipitation averages for all Priority 2 (25-29 complete year) stations.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Alamosa WSO AP	0130	37°27'	105°52'	7536	28	2.79	4.36	7.15
Allenspark	0183	40 12	105 32	8500	28	10.07	10.77	20.84
Ames	0228	37 52	107 53	8700	29	13.54	11.17	24.71
Aspen	0270	39 11	106 50	7930	28	12.12	7.62	19.74
Bailey	0454	39 24	105 29	7725	28	5.95	9.65	15.60
Burlington	1121	39 19	102 16	4165	26	4.73	10.60	15.33
Byers 5ENE	1179	39 45	104 08	5100	29	4.91	9.86	14.77
Canon City	1294	38 26	105 16	5343	28	5.07	7.48	12.55
Cherry Crk Dm	1547	39 39	104 51	5647	28	6.61	10.09	16.70
Cimarron	1609	38 33	107 33	6900	27	7.16	5.75	12.91
Cortez	1886	37 22	108 33	6212	27	7.52	5.05	12.57
Crested Butte	1959	38 52	106 58	8900	28	16.57	8.11	24.68
Delta	2192	38 45	108 04	4930	25	3.72	3.43	7.15
Fort Lewis	3016	37 14	108 03	7600	28	10.39	7.22	17.61
Fountain	3063	38 41	104 42	5570	27	4.27	9.97	14.24
Georgetown	3261	39 43	105 42	8610	27	6.25	8.93	15.18
Glenwood Springs 1N	3359	39 34	107 20	5823	28	9.67	6.59	16.26
Guffey 10SE	3656	38 41	105 23	8200	28	5.12	10.16	15.28
Gunnison	3662	38 32	106 56	7664	28	5.72	5.03	10.75
Haswell	3828	38 27	103 09	4520	27	3.64	8.69	12.33
Julesburg	4413	41 00	102 15	3469	27	5.21	11.94	17.15
Karval	4444	38 44	103 32	5075	28	3.59	9.07	12.66
Kit Carson 6S	4603	38 42	102 46	4231	25	3.75	9.68	13.43
Las Animas	4834	38 04	103 13	3890	28	3.89	8.32	12.21
Leadville	4884	39 14	106 18	10050	25	8.89	6.55	15.44
Manassa	5322	37 10	105 56	7687	25	2.64	4.60	7.24
Monte Vista	5706	37 34	106 09	7657	29	2.70	4.30	7.00
Northdale	5970	37 49	109 01	6680	29	6.94	4.94	11.88
Norwood	6012	38 08	108 17	7020	28	7.33	6.56	13.89

Priority 2 (25-29 complete year) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Ouray	6203	38°01'	107°40'	7840	28	12.25	8.67	20.92
Pagosa Springs	6258	37 16	107 01	7238	29	11.25	7.78	19.03
Palisade	6266	39 07	108 21	4800	28	5.01	3.93	8.94
Paradox 1W	6315	38 23	108 59	5530	26	6.84	5.08	11.92
Pitkin	6513	38 36	106 32	9200	28	9.79	7.86	17.65
Placerville	6524	38 01	108 03	7320	27	9.43	7.68	17.11
Pueblo WSO AP	6740	38 17	104 31	4639	26	3.89	7.13	11.02
Rangely 1E	6832	40 05	108 46	5290	27	4.92	4.30	9.22
Rico	7017	37 42	108 02	8780	29	15.73	10.49	26.22
Rifle	7031	39 32	107 48	5320	28	6.51	4.75	11.26
Rush 4N	7287	38 53	104 06	6110	26	3.27	9.55	12.82
Silverton	7656	37 48	107 40	9322	26	12.00	10.33	22.33
Spicer	7848	40 27	106 28	8380	28	6.89	7.00	13.89
Springfield	7862	37 24	102 37	4410	29	4.64	10.00	14.64
Stonington	7992	37 17	102 11	3800	28	4.13	10.58	14.71
Stratton	8008	39 18	102 36	4390	29	4.86	11.15	16.01
Sugarloaf Reservoir	8064	39 15	106 22	9738	25	10.88	6.92	17.80
Trinidad	8429	37 10	104 29	6030	26	4.63	8.97	13.60
Walden 2	8756	40 44	106 17	8115	29	4.14	5.71	9.85
Windsor 2SE	9147	40 28	104 52	4760	28	4.34	7.80	12.14
Yuma	9295	40 08	102 44	4135	26	5.31	11.34	16.65

Index and adjusted precipitation averages for all Priority 3 (15-24 complete years) stations.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Amy	0242	38°53'	103°39'	5240	22	(*)	(*)	11.61
Antero Resvr	0263	39 00	105 53	8920	19			9.21
Aroya 6NE	0343	38 55	103 05	4790	22			10.95
Ayer Ranch	0437	39 01	104 36	7230	19			18.19
Berthoud Pass	0674	39 48	105 47	11310	17			36.93
Bonham Resvr	0825	39 06	107 53	9850	16			31.75
Brandon	0895	38 27	102 27	3930	22			12.38
Branson	0898	37 01	103 53	6290	22			16.02
Buena Vista	1071	38 51	106 08	7930	24			10.03
Butler Ranch	1157	38 02	104 28	4850	24			12.20
Campo 7S	1268	37 01	102 34	4300	21			15.22
Castle Rock	1401	39 22	104 52	6200	17			14.77
Collbran 1W	1741	39 14	107 59	5960	21			12.99
Craig	1928	40 32	107 33	6230	23			13.14
Delhi	2178	37 38	104 01	5090	24			12.87
Denver City	2225	39 45	104 59	5320	23			12.33
Dinosaur N.M.	2286	40 14	108 58	5921	15			10.70
Eastonville 1NNW	2494	39 05	104 34	7250	24			16.37
Elbert	2593	39 13	104 33	6740	17			15.64
Electra Lake	2624	37 33	107 48	8400	13*			24.72
Evergreen	2790	39 38	105 19	7000	19			18.43
Forder 8S	2997	38 33	103 41	4780	23			11.83
Fort Lupton	3027	40 04	104 47	5020	24			12.12
Fraser	3113	39 57	105 50	8560	23			19.27
Gardner	3222	37 46	105 11	6960	18			12.00
Grand Junction 6ESE	3489	39 03	108 27	4760	17			8.13
Grant	3530	39 28	105 41	8667	17			15.14
Greeley UNC	3553	40 25	104 42	4715	16			11.93
Grover 10W	3643	40 52	104 25	5080	18			14.83
Hawthorne	3850	39 56	105 17	5920	21			20.25
Hot Sulphur Springs 2SW	4129	40 03	106 08	7600	22			12.91

Priority 3 (15-24 complete years) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Idaho Springs	4234	39°45'	105°31'	7560	18	(*)	(*)	14.47
Idalia	4242	39 44	102 18	3965	24			16.91
Independence Pass 5SW	4270	39 05	106 37	10550	12*			28.23
Kremmling 1E	4664	40 04	106 23	7399	15			11.76
Lake George 8SW	4742	38 55	105 29	8515	21			11.82
Lakewood	4762	39 45	105 08	5637	18			15.64
Lime 3SE	5001	38 07	104 35	4900	15			11.77
Limon 10SSW	5015	39 09	103 46	5560	20			14.45
Limon	5017	39 16	103 42	5360	20			14.06
Marvine	5408	40 02	107 31	7340	20			20.00
Maybell	5446	40 31	108 05	5920	18			11.88
Meeker	5484	40 02	107 54	6240	19			17.65
Meredith	5507	39 22	106 45	7825	16			15.60
New Raymer	5922	40 36	103 51	4783	14*			15.01
Palisade Lakes 6SSE	6271	37 26	107 09	8090	20			21.96
Palmer Lake	6280	39 07	104 55	7280	15			19.31
Paonia 1SW	6306	38 52	107 36	5580	23			11.99
Parshall 10SSE	6342	39 55	106 07	8270	19			16.09
Penrose	6410	38 27	105 04	5410	21			12.34
Pueblo City Reservoir	6743	38 17	104 39	4690	19			10.71
Pueblo Army Depot	6763	38 19	104 21	4730	18			10.16
Red Feather Lakes 2SE	6925	40 47	105 33	8170	24			17.09
Ruxton Park	7309	38 51	104 59	9050	21			22.84
Salida	7370	38 32	106 00	7060	19			11.20
Sargents	7460	38 24	106 26	8470	22			12.67
Sedalia 4SSE	7510	39 23	104 57	6000	21			15.08
Sedgwick 5S	7515	40 51	102 31	3990	21			17.97
Springfield 7WSW	7866	37 23	102 44	4580	24			14.34
Squaw Mountain	7881	39 41	105 30	11500	16			25.42

Priority 3 (15-24 complete years) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	Oct-Apr. (in)	May-Sep. (in)	Ann Ave. (in)
Tacony 10SE	8157	38°23'	104°04'	4960	24	(*)	(*)	9.87
Twin Lakes Reservoir	8501	39 05	106 19	9300	24			8.89
Two Buttes	8510	37 34	102 24	4060	14*			12.72
Uravan	8560	38 22	108 44	5010	19			11.74
Wagon Wheel Gap 3N	8742	37 48	106 50	8500	20			11.66
Wetmore	8986	38 13	105 06	6580	16			19.22
Wolf Creek Pass 1E	9181	37 29	106 47	10640	19			41.56
Wolf Creek Pass 4W	9183	37 29	106 52	9430	17			40.39
Yellow Jacket 2W	9275	37 31	108 45	6860	18			14.89

(*) No seasonal adjusted averages calculated for priority 3 stations due to short and inconsistent record lengths.

* Data used even though period of record less than 15 year minimum requirement.

Index and estimated precipitation averages for all Priority 4 (seasonal snowpack data) stations.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	(1) Oct-Apr. (in)	(2) May-Sep. (in)	Ann Ave. (in)
Antero	05L05			9200	15	3.37	6.90	10.27
Alexander Lk	07K05	39°02'	107°56'	10000	30	27.20	10.50	37.70
Apishapa	05M07	37 20	105 04	10000	18	10.00*	12.00	22.00
Arrow	05K06	39 55	105 45	9680	30	15.00	9.00	24.00
Aspen	06K22	39 09	106 49	9700	21	21.09	9.00	30.09
Baltimore	05K23	39 54	105 37	8800	20	9.29	10.50	19.79
Bear River	07J03	40 13	107 05	9100	25	15.09	8.50	23.59
Bennett Crk	05J33	40 34	105 35	9300	15	8.94	10.50	19.44
Berthoud Falls	05K13	39 47	105 49	10500	30	14.56	12.00	26.56
Berthoud Pass	05K03	39 50	105 46	9700	30	18.92	12.00	30.92
Berthoud Summit	05K14	39 49	105 47	11320	30	23.00	12.50	35.50
Bigelow Divide	05L03	38 03	105 07	9350	19	9.32	13.00	22.32
Big South	05J03	40 38	105 47	8600	30	8.00*	11.00	19.00
Blue Mesa	07L02	38 22	107 27	8700	22	10.00*	6.00	16.00
Blue River	06K21	39 23	106 04	10500	24	12.00*	10.00	22.00
Boulder Falls	05J25	40 01	105 15	10000	29	15.43	12.50	27.93
Bourbon	05M05	37 12	105 08	9750	25	8.92	13.00	21.92
Brown Cabin	05M04	37 32	105 15	9725	16	8.50*	9.00	17.50
Buffalo Pass	06J23	40 35	106 43	10250	10	53.00	14.00	67.00
Burro Mountain	07K02	39 52	107 37	9400	30	22.91	9.50	32.41
Butte	06L11	38 54	106 56	10000	16	18.54	10.00	28.54
Cameron Pass	05J01	40 32	105 54	10285	30	32.00	13.00	45.00
Cascade	07M05	37 38	107 48	8850	30	16.15	9.00	25.15
Chambers Lake	05J02	40 37	105 50	9000	30	11.97	11.00	22.97
Clark	06J13	40 43	106 53	7800	13	15.91	10.00	25.91
Cochetopa Pass	06L06	38 10	106 37	10000	30	8.00*	9.50	17.50
Columbine Lodge	06J03	40 24	106 37	9165	30	27.50*	13.50	41.00
Como	05K25			10370	14	8.50	10.00	18.50
Cooper Hill	06K23	39 22	106 16	11000	21	15.00	10.00	25.00
Copeland Lake	05J18	40 12	105 34	8600	30	7.00*	12.00	19.00
Crested Butte	06L01	38 53	107 00	8900	30	18.00*	10.00	28.00
Culebra	05M03	37 10	105 12	10000	30	13.00*	11.00	24.00
Cunbres Pass	06M07	37 02	106 27	10000	30	24.88	11.50	36.38
Deadman Hill	05J06	40 48	105 45	10220	29	18.50*	11.00	29.50
Deer Ridge	05J17	40 23	105 37	9050	30	7.50*	11.00	18.50
Dry Lake	06J01	40 32	106 47	8200	30	25.00*	12.00	37.00

Priority 4 (seasonal snowpack data) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	(1) Oct-Apr. (in)	(2) May-Sep. (in)	Ann Ave. (in)
East Fork	06K17	39°20'	106°12'	10700	29	12.50*	10.50	23.00
Elk River	06J15	40 51	106 58	8600	30	25.00*	11.00	36.00
Empire	05K10	39 46	105 42	9700	30	9.40	11.00	20.40
Fiddler Gulch	06K05	39 23	106 17	11000	29	17.10	12.00	29.10
Fish Creek	06J24	40 30	106 41	10100	11	50.00	14.00	64.00
Four Mile Park	06K07	39 04	106 28	9700	30	6.00*	8.00	14.00
Fremont Pass	06K08	39 22	106 12	11400	30	19.50	10.00	29.50
Frisco	06K13	39 32	106 08	9300	26	10.09	10.00	20.09
Garfield	06L08	38 32	106 16	9900	21	15.79	10.00	25.79
Geneva Park	05K11	39 32	105 44	9750	30	6.00*	11.00	17.00
Glen Mar	06K20	39 55	106 06	8870	30	12.05	9.00	21.05
Gore Pass	06J11	40 04	106 34	8900	30	14.29	9.50	23.79
Granby	05J16	40 12	106 02	8700	30	10.66	7.00	17.66
Grand Lake	05J19	40 16	105 50	8600	30	12.60	9.00	21.60
Grizzly Peak	05K09	39 39	105 52	11100	30	21.50	12.00	33.50
Hahns Peak	06J14	40 48	106 58	8500	21	20.00*	11.00	31.00
Hermit Lake	05L04			10400	10	11.00*	11.00	22.00
Hidden Valley	05J13	40 24	105 39	9550	30	13.43	11.00	24.43
Hiway	06M19	32 28	106 48	10700	25	30.00	16.00	46.00
Hoosier Pass	06K01	39 20	106 03	11400	30	14.80	11.00	25.80
Horseshoe Mtn	06K35			11400	14	12.50	11.00	23.50
Hourglass Lake	05J11	40 33	105 37	9500	30	10.50*	11.50	22.00
Howardville	07M13			9800	16	14.13	11.00	25.13
Independence Pass	06K04	39 04	106 37	10600	30	20.00*	10.00	30.00
Ironton Park	07M06	37 58	107 40	9600	29	17.00	8.00	25.00
Ivanhoe	06K10	39 06	106 31	10400	30	21.50*	10.00	31.50
Jefferson Crk	05K08	39 27	105 53	10100	30	11.50*	10.50	22.00
Joe Wright	05J37	40 31	105 51	10120	14	30.00	13.00	43.00
Jones Pass	05K21	39 46	105 50	10400	24	17.07	12.50	29.57
Keystone	07L04	38 43	107 02	9950	20	24.80	11.00	35.80
Kiln	06K30	39 19	106 37	9600	14	15.64	9.50	25.14
Lake City	07M08	39 59	107 15	10200	29	9.50*	10.00	19.50
Lake Humphrey	06M15	37 40	106 52	9200	30	8.54	9.00	17.54
Lake Irene	05J10	40 25	105 49	10600	30	25.00	12.00	37.00
La Manga	06M11			10000	18	24.88	15.00	39.88

Priority 4 (seasonal snowpack data) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	(1) Oct-Apr. (in)	(2) May-Sep. (in)	Ann Ave. (in)
Lapland	05K07	39°54'	105°54'	9300	30	13.66	11.00	24.66
La Plata	07M10	37 25	108 04	9340	14	23.24	15.00	38.24
La Veta Pass	05M01	37 36	105 13	9300	30	10.73	12.00	22.73
Lift	06K27	39 11	106 51	11250	24	21.00	10.00	31.00
Lizard Head	07M03	37 48	107 56	10200	30	20.50*	13.00	33.50
Lone Cone	08M07	37 53	107 58	9950	16	20.12	10.00	30.12
Longs Peak	05J22	40 16	105 36	10500	30	14.70*	13.50	28.20
Lost Lake	05J23	40 39	105 51	9300	30	15.19	11.00	26.19
Loveland Pass	05K05	39 41	105 52	10600	30	18.50*	11.50	30.00
Loveland Lift	05K24	39 40	105 54	11100	17	24.50	12.00	36.50
Love Lake	06M20	37 40	107 03	10000	17	13.00*	9.50	22.50
Lulu	05J07	40 27	105 53	10200	30	22.00	12.00	34.00
Lynx Pass	06J06	40 05	106 40	8900	30	16.30*	8.00	24.30
Mesa Lakes	08K04	39 03	108 04	10000	30	20.85	9.00	29.85
Middle Fork	05K04	39 52	106 04	9000	30	13.17	9.00	22.17
Milner Pass	05J24	40 25	105 49	10100	29	16.30*	10.00	26.30
Mineral Creek	07M14	37 51	107 45	10300	30	18.90*	11.00	29.90
Molas Creek	07M12	37 43	107 42	10700	30	16.70*	12.00	28.70
Monarch Lakes	05J14	40 06	105 44	8500	24	14.91	10.00	24.91
Monarch Pass	06104	38 32	106 19	10500	30	20.60*	10.00	30.60
Mosquito Creek	06K34			11200	14	11.00	11.00	22.00
McClure Pass	07K08	39 07	107 20	9500	27	19.47	10.00	29.47
McClure Pass#2	07K09			9500	30	18.85	10.00	28.85
McIntyre	05J15	40 45	106 00	9100	24	14.70	10.00	24.70
McKenzie Gulch	06K28	39 32	106 47	8500	19	8.38	10.00	18.38
Nast	06K06	39 21	106 42	8700	29	10.00*	9.50	19.50
Northgate	06J07	40 57	106 17	8500	30	9.09	8.50	17.59
North Inlet Grand Lake	05J09	40 17	105 46	9000	30	12.24	10.50	22.74
North Lost Trail Creek	07K01	39 05	107 11	9200	30	19.42	10.00	29.42
Pando	06K19	39 28	106 20	9500	29	12.69	8.50	21.19
Park Cone	06L02	38 49	106 35	9600	30	13.43	7.50	20.93
Park Reservoir	07K06	39 02	107 52	9900	30	30.06	10.00	40.06
Park View	06J02	40 22	106 07	9200	30	12.56	9.50	22.06
Pass Creek	06M18	37 33	106 46	9200	25	15.28	11.00	26.28
Phanton Valley	05J04	40 24	105 51	9050	30	14.23	9.00	23.23
Pine Creek	05J31	40 47	105 32	7900	20	7.00*	9.00	16.00
Platoro Dam	06M09	37 20	106 31	9950	27	20.35	10.00	30.35
Pool Table Mnt	06M14	37 48	106 48	10000	30	7.50*	8.00	15.50

Priority 4 (seasonal snowpack data) stations continued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	(1) Oct-Apr. (in)	(2) May-Sep. (in)	Ann Ave. (in)
Porcupine	07M20	37°51'	107°10'	10400	30	13.00*	9.00	22.00
Porphyry Creek	06L03	38 29	106 20	10750	30	20.00*	9.00	29.00
Purgatory	07M22			10000	13	24.53	9.50	34.03
Rabbit Ears	06J09	40 21	106 33	9550	27	32.00*	13.00	45.00
Ranch Creek	05K18	39 57	105 43	9400	24	13.00*	11.00	24.00
Red Feather	05J20	40 49	105 39	9000	30	11.50*	10.00	21.50
Red Mntn Pass	07M15	37 50	107 43	11000	30	35.00	11.00	46.00
Rico	07M01	37 41	108 02	8700	30	14.00*	11.00	25.00
Rio Blanco	07J01	40 03	107 18	8500	30	22.43	10.00	32.43
River Springs	06M05	37 03	106 16	9300	30	8.00*	8.00	16.00
Roach	06J12	40 56	106 08	9400	28	23.92	9.00	32.92
Saint Elmo	06L05			10600	17	15.00*	10.00	25.00
Santa Maria	07M17	37 49	107 07	9700	30	6.50*	9.00	15.50
Shrine Pass	06K09	39 32	106 13	10700	30	21.00	13.50	34.50
Silver Lakes	06M04	37 22	107 24	9600	30	8.50*	10.00	18.50
Silverton Sub Station	07M04	37 48	107 39	9400	28	10.00*	10.50	20.50
Snake River	05K16	39 37	105 56	9700	30	11.00*	11.00	22.00
Spud Mountain	07M11	37 43	107 45	10700	30	27.00*	11.50	38.50
Summit Ranch	06K14	39 43	106 09	9300	30	10.09	8.00	18.09
Summitville	06M06	37 27	106 36	11500	25	23.00	16.00	39.00
Telluride	07M02	37 55	107 48	8600	30	13.00*	10.50	23.50
Tennessee Pass	06K02	39 22	106 20	10200	30	12.50*	8.00	20.50
Thunderhead	06J30			9100	14	30.32	12.00	42.32
Tomichi	06L07	38 29	106 23	10500	21	15.00*	8.00	23.00
Tower	06J29	40 32	106 40	10560	16	58.00	15.00	73.00
Trickle Divide	07K05	39 08	107 54	10000	30	31.79	10.50	42.29
Trinchera	05M08	37 22	105 15	11000	14	11.50*	11.00	22.50
Trout Crk Pass	06L12			10050	14	6.00*	8.00	14.00
Trout Lake	07M09	37 50	107 53	9700	30	18.50*	12.00	30.50
Twin Lakes Tunnel	06K03	39 04	106 32	10100	30	13.30*	10.50	23.80
Two Mile	05J26	40 23	105 42	10500	29	19.00	11.30	30.30
University Camp	05J08	40 03	105 35	10500	30	23.00	12.50	35.50
Upper Rio Grande	07M16	37 45	107 22	9350	30	9.58	10.00	19.58
Upper San Juan	06M03	37 29	106 51	10200	30	36.27	13.00	49.27

Priority 4 (seasonal snowpack data) stations cortinued.

Station Name	Index Number	Lat. deg min	Long. deg min	Elev ft.	Complete Years of Data 1951-80	(1) Oct-Apr. (in)	(2) May-Sep. (in)	Ann Ave. (in)
Vail Pass	06K15	39°36'	106°16'	10000	24	20.60	12.00	32.60
Vasquez	05K19	39 54	105 49	9600	24	16.26	10.00	26.26
Ward	05J21			9500	30	11.00*	11.00	22.00
Westcliffe	05L02	38 06	105 36	9500	28	9.50*	11.00	20.50
Wild Basin	05J05	40 13	105 36	10000	30	14.50	13.00	27.50
Willow Creek Pass	06J05	40 20	106 06	9500	30	16.50*	12.00	28.50
Wolf Crk Pass	06M01	37 29	106 47	10200	30	35.00*	15.00	50.00
Wolf Creek Summit	06M17	37 29	106 49	11000	30	36.00*	15.00	51.00
Yampa View	06J10	40 22	106 46	8500	30	22.29	12.00	34.29

(1) Oct-Apr average precipitation estimated from April 1 average snowpack water content.

(2) May-Sep average precipitation estimated from nearby stations and from 1931-1960 analysis.

* Regression relationship modified to improve estimate.