ESTIMATING LONG-TERM STATISTICS FOR ANNUAL
PRECIPITATION FOR SIX REGIONS OF THE UNITED STATES
FROM TREE-RING DATA

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FOREWORD

This paper presents an application of dendroclimatology, a discipline which uses the annual growth layers of trees (rings) to study past climate. This application has grown out of a 10-year project sponsored by the National Science Foundation, current grant ATM-77-19216, which is a long-term project aimed at reconstructing past spatial patterns in climate from spatial patterns in tree growth. We have used the technology and reconstructions from this long-term project to calculate certain climatic statistics for use in the Nuclear Regulatory Commission Nuclear Waste Management Program. Details of the methodology used in this study are published elsewhere (Fritts, Lofgren, and Gordon, 1979).

The application utilizes reconstructions of annual precipitation from 1602 through 1961, averaged over a number of precipitation stations in six climatic regions in the United States and southwestern Canada. The averaged reconstructions are then used to assess the long-term means and the variability of climate for 360 years. The computer software and selected results which were a part of this application are described in the Appendices. We wish to acknowledge Ann Marek, who helped edit and computer process this manuscript, and Dorothy Larson, who helped with the graphics for this report. The facilities of the University of Arizona Computing Center were used for this project.

ABSTRACT

Spatial anomalies of seasonal precipitation for the United States and southwestern Canada have been reconstructed from 1602 through 1961 using dendrochronological and multivariate techniques on 65 arid-site tree-ring chronologies from western North America. Seasonal reconstructions are averaged to obtain mean annual precipitation values for six regions of importance to the Nuclear Regulatory Commission (NRC) Nuclear Waste Management Program (NWMP). Statistics calculated from the regionally averaged annual values for 25-year and longer intervals show annual precipitation in the seventeenth through nineteenth centuries to be lower than in the twentieth century for three regions in the American Southwest and higher for one region in the Northwest and two regions in the East. The variability of precipitation generally was higher in the past three centuries than in the present century. Twenty-five-year intervals with noteworthy statistics are identified and important results are summarized and tabulated for use in the hydrologic modeling of the NWMP. Additional research is recommended to incorporate temperature and precipitation into a single hydrologic parameter.

INTRODUCTION

The climate of North America during the 1930's through 1960's has been unusually mild in certain localities and as such is not representative of conditions in the longer-term past (Bryson and Hare, 1974). Therefore, the climatic suitability of sites being considered by the NWMP should not be evaluated exclusively with existing meteorological records. Climatic parameters should be assessed in terms of more representative long-term climatic information. Proxy records (substitutes for meteorological data) can be used to extend our knowledge of climate backward in time (Barry *et al.*, 1979). The extended record allows an assessment of past climatic variations and can be used to place the twentieth century anomalies in proper perspective.

There are many types of proxy records of climate, but most of them cannot be resolved into variations of less than 100 years (Barry *et al.*, 1979). Layers in some lake sediments and glacial ice may approximate annual increments, but the layers cannot be reliably dated to the exact year of formation. In addition, the availability of many proxy data is restricted to relatively few localities over the world. Tree-ring chronologies, however, overcome those problems. They are generally available in all temperate and subarctic

forested regions, and they have a more precise time resolution with dating possible to the exact season and/or year (Fritts, 1976). Historical data on climate also have a similar time resolution, sometimes to the exact moment an event occurred. But unlike tree rings, they can reflect subjective interpretations of past events and lack continuity over both space and time.

This paper reviews how climatic information can be derived from well-dated tree-ring records and used to assess past variations in climate. Reconstructions of past precipitation variations are described and applied to questions of interest to the NWMP. Statistics of climatic variations in six selected regions of the United States and southwest Canada are analyzed in time increments of 25 years from AD 1602 through 1961 and compared to twentieth century "normal" data.

TREE RINGS AS PROXIES OF CLIMATIC VARIATIONS

Generally, one growth ring is formed each year in temperate-climate trees, and its width can vary as a function of different limiting factors, including climate. The size, structure, and chemical composition of these rings provide climatic information only when the tree growth has been limited in some way by one or more factors of climate throughout a portion of the year (Fritts, 1976; LaMarche, 1974, 1978; Stockton and Meko, 1975). The skilled dendroclimatologist can recognize and select trees with potential climatic information from the structure of the tree crown and trunk and from the appearance of the rings. The rings of the selected trees are sampled by means of a coring tool which extracts a pencil-sized cylinder of wood from the trunk. A complete sample often includes cores from 10 to 25 climate-stressed trees growing on similar sites in a local area. The cores are processed to determine the width and detailed structure of the annual growth layers. Because nonclimatic factors can obscure the effects of climate, the rings are examined, studied carefully, and screened for such problems before they are dated and measured.

In years particularly unfavorable to growth, the rings are narrow, and in some trees no ring is formed at all. In other seasons, an unusual period of drought during the growing season may cause some trees to produce more than one ring for that year. These factors can make dating difficult. Therefore, just as simple counts of layered sediments and ice cores are unreliable, a simple count of the rings from the outside to the center of a living tree is an unreliable method for dating the formation of each ring. A more reliable dating technique, called crossdating, uses identifiable ring patterns which are characteristic of unique time periods, with each period exhibiting a particular sequence of climatic conditions.

Using these identifiable ring patterns, the size and appearance of rings are matched with those in other trees from the same collection site to locate improperly interpreted growth rings that cause the ring patterns for that site to be nonsynchronous. Some types of discrepancies among trees indicate that no ring is visible on the sample and other types indicate the presence of a double or false ring. These discrepancies are identified and corrections are made for them. When all ring sequences are matched correctly, an accurate date is assigned to each ring before measuring the width.

The crossdating procedure is tedious and time-consuming, but it is an essential part of all dendroclimatological work. Because of the demonstrated accuracy of crossdating (LaMarche and Harlan, 1973), dendroclimatology can deal with precisely dated variations in growth patterns over both space and time.

The use of the ring-width data in a climatological study requires the removal of any variability in the ring widths that is not climatically induced. One well-recognized nonclimatic factor is a decrease in ring width with increasing tree age. This systematic change in ring width is eliminated using a procedure called standardization, in which each measurement of ring width for a particular year is divided by the expected growth for that tree and age on the particular site (Fritts, 1976; LaMarche 1978). The standardized values are then averaged with those of the other sampled trees from the same site to obtain mean yearly values of growth relative to the tree's age. Thus, a tree-ring chronology is formed as the mean time series of the standardized yearly ring widths for a particular sample of trees (Fritts, 1976; LaMarche, 1974; Stockton and Meko, 1975).

More than a thousand chronologies are now available from North American conifers, and collecting, research, and analysis programs have begun in most temperate regions of the world (LaMarche, 1978). We have selected 65 of the best chronologies from western North America for our particular analysis (Fig. 1) (Fritts and Shatz, 1975). Each chronology represents a sample of two cores each from 10 or more trees of one of the following species: Douglas-fir (*Pseudotsuga menziesii*), bigcone-spruce (*P. macrocarpa*), ponderosa pine (*Pinus ponderosa*), pinyon pine (*P. edulis*), timber pine (*P. flexilis*), bristlecone pine (*P. longaeva*), Jeffrey pine (*P. jeffreyi*), and white fir (*Abies concolor*).

RECONSTRUCTING SPATIAL VARIATIONS IN CLIMATE: CALIBRATION

The climate-growth relationship is highly complex and is poorly understood in detail. Tree growth responds to many climatic factors whose influence on growth, and hence the chronologies, can vary throughout the year (Fritts, 1974, 1976). The diagram in Figure 2 illustrates some of the complexities in the growth response in which the climate for year t may include factors such as temperature, precipitation, sunshine, and wind, which vary in their importance throughout the winter, spring, summer, and autumn months.

The growth layer is formed in the spring and summer and may be directly affected by climate during that time. During autumn and winter, the so-called seasons of dormancy, climatic factors have important effects on soil moisture recharge, production and storage of food in the tree, and root growth. In addition, there are many lagging effects of climate during year t which can affect growth in the succeeding years $t+1$ through $t+k$ shown in Figure 2. The climate in the preceding year, $t-1$, may not only influence the following year's ring width, but may also control the formation of leaves and roots which are in turn related to the efficiency of the tree in the following years, t , $t+1$,

through ~~it~~. This produces an autocorrelation in the chronologies where narrow rings tend to be followed by narrow rings, even though the climate of the second year was favorable to growth (Fig. 2). All of these interrelationships should be considered when the climatic information for a particular year is extracted from ring-width data.

Because of the complexities in the climate-growth relationship, maps of climatic variations made by simple deduction from maps of tree-growth anomalies (Fritts, 1965, 1976) can only be considered as unrefined representations of past climate. Dendroclimatologists now recognize the complexity of the system they are dealing with, and multivariate regression techniques are employed to decode the climate information contained in the chronologies (Fritts, 1976; Fritts et al., 1971; Webb and Clark, 1977). The use of multivariate techniques allows individual climatic factors to be portrayed in a direct manner.

Figure 3 depicts how the multivariate regression techniques are used to obtain estimates of climatic parameters. In essence, lagged ring-width measurements (X's) are compared to climatic observations, and from these comparisons, coefficients (b's) are obtained. In this manner, the ring

widths are calibrated with the climatic observations. The products of the coefficients and ring widths are then summed to produce the estimate of the climatic parameter. The resultant calibration equation can then be applied to ring-width measurements for past years to reconstruct the climatic conditions responsible for the observed patterns in growth. The actual calibration procedure is complex and is described in detail elsewhere (Blasing, 1978; Fritts, 1976; Fritts, Lofgren, and Gordon, 1979).

It must be noted that the coefficients derived in this manner are unique for each climatic record and chronology that are compared in the calibration procedure. In this paper the years 1901 through 1962 are used as the calibration period, the period for which there are both tree-ring and meteorological observations. The use of a different calibration period would alter the derived coefficients and hence the estimates of past climate. The period 1901-1962 represents the longest calibration period possible and, therefore, should produce the most stable climatic estimates.

Calibrations are individually made for each climatic variable and season, but are collectively made for a number of climatic stations arranged in a grid network. Because

climate is spatially continuous it can be correlated over large areas. Therefore, the climatic grids can extend well beyond the region covered by the tree-ring chronologies. This spatial continuity of climate and the ability to estimate climatic variables over large areas has been studied by Kutzbach and Guetter (in press).

The set of 65 western tree-ring chronologies (Fig. 1) was calibrated with three climatic variables for four seasons and over several grids. These grids were: 1) 96 points of sea level pressure covering an area from 80°W to 100°E longitude and from 20°N to 70°N latitude, 2) 77 temperature stations in the United States and southwestern Canada, and 3) 96 precipitation stations over the same area used for temperature. The seasons used were: winter: December-February; spring: March-June; summer: July-August; and autumn: September-November. The 96-station precipitation grid was used for this report.

Thus, the tree-ring chronologies were transformed into estimates of each climatic variable for each season and for each station in the grid for the period 1602-1900. The time series of estimates at each station is collectively called the reconstruction. The patterns in past climate present in these reconstructions can be portrayed for each season and year by the preparation of maps, the plotting of time series, and the presentation of descriptive statistics.

EVALUATING THE RELIABILITY OF A RECONSTRUCTION

The types of lagged relationships that are combined in a regression equation can be varied, and some equations may result in more reliable estimates of climate than others. Because the best combination of climate estimators cannot be chosen a priori, a number of reconstructions are made using different combinations of lagged estimators. It is then necessary to use an objective approach to select the most reliable reconstruction. A first approximation of the reliability of a reconstruction can be obtained by examining certain statistics calculated over the period of calibration from the reconstruction and the actual data. The most important of these statistics is the percent variance calibrated.

PERCENT VARIANCE CALIBRATED

The percent variance calibrated is the percent of the total variation, in the actual climatic data that is accounted for by the reconstructed climatic data within the calibration period. A percent variance calibrated that is too low indicates that the particular combination of climate estimators used is a poor choice because the resulting reconstruction contains little information about the actual

climatic variations that occurred. The percent variance calibrated can be increased by making better combinations of climate estimators, but it can be artificially increased by making the combination too complex. The penalty for having too complex a model is a reconstruction which, while closely matching climatic variations in the calibration period, is highly susceptible to large errors in climate estimates made for years outside the calibration period.

A truly reliable reconstruction is one that performs well both on the calibration data and on independent data, i.e., data not used in calibration. Ultimately, the only means of determining the true reliability of a reconstruction is to compare it to independent climatic information.

VERIFICATION WITH INDEPENDENT DATA

The independent climatic information used for verification can include meteorological measurements, proxy information including tree-ring chronologies not used in the calibration, and various types of historical evidence. Each type of information has its strengths and weaknesses, and all three can be used to verify different features of the reconstructions.

Verification with independent meteorological measurements is the most objective and precise method of testing reliability, and for that reason it has the greatest scientific value. Independent meteorological measurements are compared directly with the reconstructions on a station-by-station basis and the similarity measured with five objective statistics (Fritts, Lofgren, and Gordon, 1979) that are tested for significance at the 95% level (Table I). The results are expressed as the percentage of stations passing each test. A percentage of tests passing that is greater than the 5% expected by chance supports the contention that the reconstruction does contain valid climatic information. It should be noted, however, that these five statistics measure only the similarity in the temporal patterns of variation and do not take into account the magnitude of the errors. A sixth statistic, the reduction of error (Lorenz, 1956; Fritts, 1976), reflects the magnitude of the errors or differences between the estimates and the actual measurements. The reduction of error (RE) is calculated for each station as follows:

$$RE = 1 - SSR/SSM$$

where SSR is the sum of the squares of the errors, and SSM is the sum of the squares of the deviations of the actual data from the mean value during the calibration period. The interpretation of RE can be quite complicated, but in essence, RE represents a comparison between the mean square error of the estimates and the mean square error obtained if

the calibration period mean had been substituted for the estimates (Kutzbach and Guetter, in press; Lorenz, 1956).

The RE statistic can range from minus infinity to a maximum value of one. A value of one indicates a perfect prediction and a value of zero demonstrates that on the average the predictive skill of the calibration equation for an individual year is no better than the prediction using the calibration period mean. Any positive value of RE clearly indicates that the predictive equation has some skill and that the reconstruction is of value. The value of RE is hypersensitive to small errors, however, and positive values may be ruled out by only a few bad estimates. Because of this sensitivity positive RE statistics are difficult to obtain in practice, and situations often arise in which a station may have a negative RE statistic and yet still pass a majority of the other verification tests.

The six statistics described thus far are obtained for individual stations. It is also desirable to have verification statistics which describe the performance of the reconstruction at all the stations collectively. This is done by combining the station sums in the RE calculations and thus obtaining a pooled reduction of error statistic. In recognition of the hypersensitivity of RE to small errors

and the fact that we cannot identify the cause of negative RE statistics at individual stations, the estimates at any station which had a negative RE are replaced by the calibration mean prior to pooling with the sums at other stations. This procedure has the effect of compromising the reconstructions because the estimate errors for many of the years tested were certainly less than those obtained by using the mean as a substitute estimate, but at the same time the effect of any extreme errors is eliminated. This pooled RE statistic is reported here for the reconstruction over all stations collectively.

A second overall test of the reconstruction is made by pooling the independent estimates and observations for all years and stations. A contingency table of nine equally probable classes is then constructed and tested using the chi-square statistic (Panofsky and Brier, 1965).

The statistics for the independent period are usually lower (less often significant) than those for the calibration period. In part this is undoubtedly the result of overspecification, but other sources of error also exist. One such source is inherent errors in the early meteorological data used for verification. A careful screening and checking of all meteorological data used in

the calibration period was made (Dewitt, 1978), but adequate records, time, or resources were not available to review the independent data from the nineteenth century. Therefore, many errors are likely to be present in these early data. Some uncertainties due to different times of observation, kinds of instruments, exposures, and general lack of quality control over collection and transcription have been identified (Kennedy, in preparation). The failures of independent verification tests may be attributed to these types of errors as well as to poor climatic reconstruction.

MODEL SELECTION, AVERAGING, AND TESTING
OF THE ANNUAL RECONSTRUCTIONS

The data for this report were obtained as follows:

1) Calibrations were optimized for the 36 precipitation stations for each season by a canonical stepwise multiple regression procedure (Fritts, Lofgren, and Gordon, 1979). The resultant reconstructions were then verified using independent data. The model structure was varied as to the number and combination of lagging relationships used. The best structure for each season was selected based upon both the calibration and verification statistics. Two to three of the best models were combined by averaging their reconstructions, and new calibration and verification statistics were calculated. There was generally some improvement after averaging, thus the final models chosen for each season were combinations of two to three separate calibrations. Earlier developmental reconstructions used by Potter (1979) were chosen using calibration statistics alone without the aid of verification. Therefore, the developmental reconstructions are likely to contain overspecification and more serious errors in the 1602-1900 interval than in the final reconstructions used here.

2) The four seasonal reconstructions were then totaled to obtain the December-November annual reconstruction. Each annual reconstruction was assigned the year of the January month. The calibration and verification statistics for the annual reconstruction (shown in Table I) were obtained by comparisons with the corresponding monthly meteorological data pooled in the same manner.

COMPARISON OF THE DEVELOPMENTAL AND FINAL PRECIPITATION RECONSTRUCTIONS

CALIBRATION AND VERIFICATION STATISTICS

Selected values of these statistics for both the developmental and final model are included in Table II. It should be noted that the percent variance calibrated loses its precise meaning for averaged reconstructions such as the annual results presented here. However, the square of the Pearson correlation coefficient between the reconstructed annual values and the actual annual values for the period 1901-1962 can be interpreted as the percent variance calibrated for the annual models (Table II). Both reconstructions were subjected to verification tests made on both the independent and dependent (calibration) periods. There were 84 of the 96 precipitation stations tested, each with seven or more years of independent data with an average length of 26 years. For the final model, 19% of all the verification tests on independent data were significant, and 88% of the tests were significant for the calibration period (Tables I and II).

The developmental model accounted for 50% of the calibration variance, possibly the result of overspecification, while the final, more conservative model calibrated 25% of the variance (Table II). Significant verification statistics increased from 15% for the developmental model to 19% for the final model, and percent positive reduction of error statistics increased from 37% to 52%. The pooled reduction of error statistics were 0.10 and 0.12 for the developmental and final models. The chi-square values were 101 and 176 for the two models, and these values are well above the value of 83 expected by chance at the 95% probability level. These data indicate that the final model appears to be an improvement over the developmental model even though there is less variance calibrated.

COMPARISONS OF THE RECONSTRUCTIONS OVER CLIMATOLOGICAL REGIONS

The 96-station precipitation grid was divided into 11 climatological regions (Fig. 4) and the reconstructions and observational data averaged over the stations in each region. These regions were chosen to be of comparable size and to contain nearly equal numbers of stations.

Six of these regional reconstructions were selected to be of possible interest to the NWMP. The names and grid numbers of the selected regions shown in Figure 4 are also listed in Table III. Forty-two of the stations chosen for detailed study in these six regions had sufficient independent data (at least seven years) for verification.

One important attribute of these reconstructions is that some of the small-scale and high-frequency variations have been eliminated by the calibration process. In addition, some of the variability among the 96 precipitation stations is eliminated when the reconstructions are averaged by region. However, the amounts of correlated variance between the meteorological data and reconstructions appear to increase for the final reconstruction when the statistics are tabulated by region in Table IV for both the developmental (1) and final reconstructions (2). Row 4 contains the percent variances calibrated averaged for all stations included in the region. Next, the averaged reconstructions and observational data in each region were correlated, and the square of the correlation coefficient times 100 shows the relative agreement between the regional reconstructions and actual data (Row 5). These regional data were filtered using a low-pass digital filter with a 50% pass at a frequency of one cycle per eight years (Fritts, 1976). The filtered reconstructions and

meteorological data for each region were correlated, and the square of the correlation coefficient times 100 was again used to measure the agreement after filtering (Row 6). The change from Row 4 to 5 measures the effect of regionalizing the reconstructions on the amount of agreement with actual data, and the change from Row 5 to 6 represents the additional effect on the agreement of removing fluctuations at frequencies higher than one cycle per eight years. In moving from Row 4 to Row 6 the total amount of variance decreases, but the percentage of agreement between the reconstructions and actual data time series increases. Row 7 is the percentage change between Rows 4 and 6 due to the space and time averaging.

The percentage figures for Region 1 indicate that the developmental model calibrated 51% of the variance for individual stations, but the regionally averaged reconstructions showed 59% agreement. After filtering, the agreement increased to 78%, which is a 53% change due to both space and time averaging. However, the final model (2) calibrated less variance for the individual stations because the more rigorous selection reduced the amount of overspecification in the model structure. On the other hand, the relative improvement of agreement due to both space and time averaging increased by 121%. Similar comparisons for the statistics of other regions show poor

initial calibration but a greater percentage improvement after space and time averaging, except in the case of the Southwest Deserts. In general, the regional data for the Intermountain Basins show the highest agreement while the data for the Southeast show the lowest agreement.

The percent of verification tests passed (Row 8, Table IV) was larger for the final model for four of the six regions. The correlation squared (Row 9) was greater for the final model in all cases. The pooled reduction of error statistics (Row 10) were greater in the final model for half of the regions.

The final reconstruction appears to be superior to the developmental reconstruction when tested with independent data, but on a region-by-region basis, the developmental reconstruction seems to be superior for Regions 3 and 10 (Intermountain Basins and Southeast). In the remaining portions of this paper we present and describe the results of only the final reconstruction. However, for analyses of the Intermountain Basins and the Southeast, the reconstructions submitted earlier and described by Potter (1979) might be equally valid.

COMPARISON OF TWENTIETH CENTURY OBSERVATIONS
WITH RECONSTRUCTIONS FOR THE SEVENTEENTH
THROUGH NINETEENTH CENTURIES

FREQUENCY DISTRIBUTIONS

To facilitate comparisons between the climate of the twentieth century and that of earlier centuries, it was necessary to adjust the variance and means of the reconstructions. The reconstructions are derived by means of multiple regression techniques which reduce the reconstructed variance in proportion to one minus the square of the correlation coefficient. For example, the mean ratio between the standard deviation for the actual climatic data for the 11 regions and the reconstructions for 1901-1961 is 2.12, i.e., the standard deviation of the actual data is, on the average, 2.12 times that of the reconstructed. The method of adjustment used here (described on page 1-11, Appendix 1A) forces the reconstructed variance to equal the variance of the actual observations for the calibration period. The adjustment is thus applied to the independent period increasing the range of the reconstructed variations.

The actual meteorological data and the reconstructions were then sorted into equal-sized precipitation classes and the frequency of occurrence in each class tabulated. This allows comparisons of the adjusted reconstructions for the 1901-1961 period with the actual meteorological measurements and with adjusted estimates for the 1602-1961 period. Figures 5, 6, and 7 show the class interval frequency distributions for 1) adjusted reconstructions for 1602-1961, 2) adjusted reconstructions for 1901-1961, and 3) observed meteorological records for 1901-1961. Table V includes the frequencies of the adjusted reconstructions for 1602-1961, 1901-1961, 1901-1930, and 1931-1960. There is general agreement between the observed and reconstructed precipitation for the 1901-1961 interval, although there are some differences. In the three arid regions (Regions 3, 4, and 6), the data are skewed because of one especially wet year which was not well reconstructed (Figs. 5 and 6).

The reconstructions for 1901-1961 can be compared to the reconstruction for 1602-1962 to assess the relative changes due to the larger sample of climatic variations (Table V). The Columbia Basin, the Great Lakes and Midwest, and the Southeast all show an increase in frequency of wet years in the longer time period, and in the Columbia Basin there is a decrease in the low precipitation classes but not the extremely dry class. The Intermountain Basins and the

Southwest Deserts show marked increases in the frequencies of dry years and a decrease in the frequencies of wet years in the longer time period. The reconstructions for the Southern Plains show little overall difference in the two time periods.

THE STATISTICS OF VARIATIONS IN SUBPERIODS

The reconstructions were analyzed over subperiods of 25 years, 100 years, and the entire 1602-1961 period (see Appendix 2, Tables 1-18). The means and standard deviations for three "control" periods (1901-1961, 1901-1930, and 1931-1960) (see Appendix 1A, p. 1-11) were compared to the means and standard deviations for each subperiod. Table VI summarizes some of the more outstanding differences. The mean for 1901-1930 was smaller than the mean for 1901-1961 only for Regions 1 and 10. For Regions 3, 4, 6, and 9 the means for 1931-1960 were smaller than the 1901-1930 mean. The standard deviations for 1901-1930 are smaller than for 1931-1960 in Regions 3 and 6. They are larger for the other regions when comparing the same subperiods.

As shown in the frequency distribution (Figs. 5, 6, and 7), the mean precipitation was higher for 1602-1961 than for the 1901-1961 control period in Regions 1, 9, and 10 and lower in Regions 3, 4, and 6. The standard deviations for this longer interval were substantially larger for all regions. Some differences occur due to variations in the statistics of the three control periods.

The highest and lowest 25-year statistics are also presented along with their departures from the three control periods. The information in Table VI and the tables in the Appendices can be used to estimate some of the variations in climatic extremes that can occur based upon a 360-year-long record. The sample provided by the reconstruction is five to six times as large as the available climatic record from the same area. Because of the larger sample size, the derived statistics can be considered to be a more reliable estimate of long-term expectations than the statistics for the shorter twentieth century meteorological record.

CONCLUSIONS

To aid in the assessment of climatic effects on ground water recharge and ultimately on the performance of proposed waste repositories, we have applied the techniques described herein and in Appendix 1 to six regions of the United States. These reconstructions of climate show that the past annual precipitation of Region 1 (Columbia Basin), Region 9 (Great Lakes and Midwest), and Region 10 (Southeast) was estimated to have been substantially higher in the seventeenth through nineteenth centuries than in the 1901-1961 period. On the average, precipitation was 210 to 320 mm greater for at least one 25-year period in these regions, and no lower than 20 to 60 mm below the twentieth century average for any one 25-year period.

Region 3 (Intermountain Basins), Region 4 (Southwest Deserts), and Region 6 (Southern Plains) were reconstructed to have been considerably drier in the 1602-1900 period than in the twentieth century (Table VI). In Region 4, all 25-year average precipitation values were 5 to 56 mm below the 1901-1961 averages. In Region 3 the average values ranged from 49 mm above to 54 mm below the 1901-1961 averages, and in Region 6 the average values ranged from 36 mm above to 63 mm below the 1901-1961 values. Regions 1

(Columbia Basin), 9 (Great Lakes and Midwest), and 10 (Southeast) were reconstructed to have been wetter in the 1602-1900 period, and the average values within that period ranged from 323 mm above to 63 mm below the 1901-1961 values.

Standard deviations were higher on the average for most time periods within the seventeenth through nineteenth centuries than they were for the twentieth century. In addition, as the average reconstructed precipitation increased in the past, the standard deviations of the reconstructions also became higher.

RECOMMENDATIONS

Temperature variations in the four seasons can influence evapotranspiration and deplete moisture near the soil surface before it enters the deeper layers of the aquifer, reducing the amount of recharge. Therefore, better assessments of the effect of climatic variations on aquifer recharge would be made by directly estimating evapotranspiration. This could be accomplished by converting monthly temperature and precipitation into evapotranspiration using the Thornthwaite water budget (Palmer, 1965). After subtracting evapotranspiration, the remainder could be used as an index to the amount of water entering the hydrologic system. These values can be calibrated directly with the tree-ring data as was done for precipitation, and yearly reconstructions used to assess past fluctuations in the aquifer recharge. Calculations of this kind would be better calibrated with tree rings than annual precipitation because tree rings reflect variations in the water balances of the tree system more than they reflect precipitation measurements.

Figure 1. The 65 tree-ring chronologies used to reconstruct climate.

Figure 2. A model of the tree-ring width response to the limiting effects of year t climate.

Figure 3. A multiple linear transfer function with coefficients (t) used to transform ring widths in years $t-1$ to $t+k$ into estimates of year t climate.

FIGURE 4

Figure 4. The 96-station precipitation grid divided into 11 climatological regions.

FIGURE 5

Figure 5. The frequencies of annual precipitation in several equal-sized classes expressed in millimeters for the six selected regions: (1) observed for 1901-1961, (2) reconstructed for 1901-1961 and adjusted to have comparable means and standard deviations, and (3) reconstructed for 1602-1961 using the same adjustments applied to the 1901-1961 reconstructions. Figure 5 is for Region 1, Columbia Basin, and Region 3, Intermountain Basins.

FIGURE 6

Figure 6. Same as Fig. 5, but for Region 4, Southwest Deserts, and Region 6, Southern Plains.

FIGURE 7

Figure 7. Same as Fig. 5, but for Region 9, Great Lakes and Midwest, and Region 10, Southeast.

TABLE I. Summary of Verification Test Results for Final Reconstructions
Used in This Analysis

Test	Independent Period ¹	Calibration Period ²
Correlation coefficient, %	27	96
Correlation on first differences, %	23	94
Sign agreement, %	18	84
Sign agreement on first differences, %	7	74
Product means, %	18	91
Total tests passed, %	19	88
Reduction of error greater than zero, %	52	98
Chi-square value for pooled data ³	176	1,670

¹All available data prior to 1901.

²1901-1961.

³95% critical level = 83.

TABLE II. Calibration and Verification Statistics for Two Models
Used to Reconstruct Annual Precipitation

	Developmental Model	Final Model
Dependent Data (1901-1961)		
Variance Calibrated, %	50	25
Independent Data (Earlier than 1901)		
Verification Tests Significant, %	15	19
Reduction of Error Greater than Zero, %	37	52
Pooled Positive Reduction of Error ¹	.10	.12
Chi-square ²	101	176

¹Negative values set to zero and values weighted for sample size before pooling.

²95% critical level = 83.

TABLE III. Station Names and Numbers Included in Each Region of Precipitation Grid

REGION		STATION	
Name	Number	Name	Number
Columbia Basin	1	Lewiston	27
		Porthill	28
		Kalispell ¹	47
		Baker	64
		Roseburg	65
		Aberdeen	83
		Colville	84
		Port Angeles	85
		Kamloops ¹	95
Intermountain Basins	3	Independence ¹	9
		Durango ¹	18
		Grand Junction ¹	19
		Montrose	20
		Boise	26
		Elko	51
		Reno	52
		Heber	78
		Moab	79
		Parowan	80
		Tooele ¹	81
Southwest Deserts	4	Flagstaff ¹	2
		Phoenix	3
		Tucson	4
		Yuma	5
		Needles ¹	11
		Albuquerque	54
		State Univ.	56
		El Paso	76
Southern Plains	6	Canon City	17
		Trinidad ¹	21
		Roswell ¹	55
		Amarillo	74
		Cheyenne	88
Great Lakes and Midwest	9	Chicago	29
		Indianapolis	30
		Alpena	39
		Detroit	40
		Marquette	41
		St. Louis	43
		Buffalo	58
		Dayton	62
		Madison	87
Southeast	10	Birmingham	1
		Jacksonville	22
		Tallahassee	23
		Tampa	24
		Macon	25
		Baton Rouge	35
		Shreveport	36
		Knoxville	70
		Memphis	71
		Nashville	72

¹Denotes station not verified (<7 years of independent data).

TABLE IV. Percent Variance Agreement and Selected Verification Statistics
for the Reconstructed and Actual Measurements of Annual Precipitation
Tabulated by Region

1. <u>Region Name</u>	Columbia Basin		Inter- mountain Basins		South- west Deserts		Southern Plains		Great Lakes and Midwest		South- east	
2. <u>Region Number</u>	1		3		4		6		9		10	
3. <u>Model</u> ¹	1	2	1	2	1	2	1	2	1	2	1	2
<u>Calibration r^2</u>												
4. Individual Stations ²	51	29	54	34	60	31	51	24	39	14	41	13
5. Regional Reconstructions ³ Unfiltered	59	39	76	57	77	53	64	48	52	24	54	24
6. Regional Reconstructions ³ Filtered	78	64	94	87	84	38	66	65	77	51	62	42
7. $\frac{\text{Row 6} - \text{Row 4}}{\text{Row 4}} \times 100$	53	121	74	156	40	23	29	171	97	264	51	223
<u>Verification Statistics</u> <u>Individual Stations</u>												
8. % Statistics Significant	20	31	26	20	10	27	7	20	7	16	4	0
9. Avg. $r^2 \times 100$	7	10	16	17	7	12	9	14	4	6	3	5
10. Overall Reduction of Error	.26	.17	.38	.14	.10	.24	.10	.15	.01	.08	.11	.01

¹Developmental model is number 1, final model is number 2.

²Correlations squared for individual stations averaged.

³Individual station reconstructions and actual data averaged by region and the correlations between the two squared before and after filtering.

TABLE V.a. Reconstructed Yearly Precipitation Expressed as Frequencies of Occurrences Within Five Equal-sized Classes for 1602-1961, 1901-1961, 1901-1930, and 1931-1960

Region 1: The Columbia Basin				
Upper and Lower Class Boundaries in Millimeters	<u>1602-1961</u>	<u>1901-1961</u>	<u>1901-1930</u>	<u>1931-1960</u>
888-1020	.04	.00	.00	.00
756-888	.23	.08	.06	.10
624-756	.39	.44	.30	.57
492-624	.28	.43	.56	.30
360-492	.05	.05	.07	.03

TABLE V.b. Reconstructed Yearly Precipitation Expressed as Frequencies of Occurrences Within Five Equal-sized Classes for 1602-1961, 1901-1961, 1901-1930, and 1931-1960

Region 3: Intermountain Basins				
Upper and Lower Class Boundaries in Millimeters	<u>1602-1961</u>	<u>1901-1961</u>	<u>1901-1930</u>	<u>1931-1960</u>
401-459	.02	.00	.00	.00
343-401	.09	.13	.17	.10
285-343	.28	.44	.53	.37
227-285	.34	.28	.27	.30
169-227	.23	.15	.03	.23
111-169	.05	.00	.00	.00

TABLE V.c. Reconstructed Yearly Precipitation Expressed as Frequencies of Occurrences Within Six Equal-sized Classes for 1602-1961, 1901-1961, 1901-1930, and 1931-1960

Region 4: Southwest Deserts				
Upper and Lower Class Boundaries in Millimeters	<u>1602-1961</u>	<u>1901-1961</u>	<u>1901-1930</u>	<u>1931-1960</u>
366-431	.01	.03	.03	.03
301-366	.05	.05	.10	.00
236-301	.24	.34	.30	.40
171-236	.34	.38	.47	.27
106-171	.29	.18	.07	.30
41-106	.08	.02	.03	.00

TABLE V.d. Reconstructed Yearly Precipitation Expressed as Frequencies of Occurrences Within Six Equal-sized Classes for 1602-1961, 1901-1961, 1901-1930, and 1931-1960

Region 6: Southern Plains				
Upper and Lower Class Boundaries in Millimeters	<u>1602-1961</u>	<u>1901-1961</u>	<u>1901-1930</u>	<u>1931-1960</u>
573-691	.01	.03	.03	.03
455-573	.19	.20	.20	.16
337-455	.48	.51	.54	.50
219-337	.27	.25	.23	.26
101-219	.04	.02	.00	.03

TABLE V.e. Reconstructed Yearly Precipitation Expressed as Frequencies of Occurrences Within Six Equal-sized Classes for 1602-1961, 1901-1961, 1901-1930, and 1931-1960

Upper and Lower Class Boundaries in Millimeters	Region 9: Great Lakes and Midwest			
	<u>1602-1961</u>	<u>1901-1961</u>	<u>1901-1930</u>	<u>1931-1960</u>
1186-1310	.02	.00	.00	.00
1062-1186	.09	.00	.00	.00
938-1062	.22	.12	.16	.07
814-938	.40	.57	.60	.54
690-814	.24	.28	.20	.37
566-690	.04	.03	.03	.03

TABLE V.f. Reconstructed Yearly Precipitation Expressed as Frequencies of Occurrences Within Six Equal-sized Classes for 1602-1961, 1901-1961, 1901-1930, and 1931-1960

Upper and Lower Class Boundaries in Millimeters	Region 10: Southeast			
	<u>1602-1961</u>	<u>1901-1961</u>	<u>1901-1930</u>	<u>1931-1960</u>
1615-1805	.04	.00	.00	.00
1425-1615	.22	.10	.13	.03
1235-1425	.40	.49	.33	.67
1045-1235	.29	.30	.33	.27
855-1045	.06	.12	.20	.03

TABLE VI. The Reconstructed Means and Standard Deviations¹ for Three Different Control Intervals and 1602-1961, and the Highest and Lowest Values for 25-Year Intervals, Expressed as a Departure from the Values of the Three Control Intervals

	<u>Region 1</u>		<u>Region 3</u>		<u>Region 4</u>		<u>Region 6</u>		<u>Region 9</u>		<u>Region 10</u>	
	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>	<u>Mean</u>	<u>S.D.</u>
Control Intervals												
1901-1961	631	87	287	49	227	59	394	84	845	79	1250	140
1901-1930	612	89	301	42	237	60	403	81	854	84	1224	160
1931-1960	650	83	275	53	217	59	382	86	835	75	1268	111
Departure for 1602-1961												
from 1901-61	55	36	-21	11	-29	6	-13	6	45	48	61	33
from 1901-30	75	34	-35	19	-39	5	-22	8	37	43	87	14
from 1931-60	36	40	-9	8	-19	6	-1	3	56	52	42	63
Highest 25-Year Value												
First Year of Interval	1626	1676	1602	1602	1826	1726	1626	1651	1626	1826	1626	1651
departure from 1901-61	210	57	49	29	-5	15	36	17	215	67	323	39
departure from 1901-30	230	55	35	37	-15	14	26	20	206	62	350	20
departure from 1931-60	191	60	61	26	5	16	47	14	226	71	305	69
Lowest 25-Year Value												
First Year of Interval	1676	1651	1651	1626	1876	1626	1851	1751	1851	1876	1851	1751
departure from 1901-61	-20	3	-54	-14	-56	-16	-63	-14	-34	5	-63	-21
departure from 1901-30	0	1	-68	-6	-66	-17	-72	-12	-42	1	-37	-41
departure from 1931-60	-39	6	-41	-17	-47	-15	-51	-17	-23	10	-82	8

¹Expressed as mm of precipitation.

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APPENDIX 1A
REGIONAL TIME SERIES ANALYSIS PROGRAM PACKAGE

INTRODUCTION

The major purpose of the Climate Reconstruction 3 Project under the direction of H. C. Fritts at the Laboratory of Tree-Ring Research is to use climatic data to calibrate the tree-ring data to produce seasonal and annual reconstructions of climate back to the year 1602. Climatic reconstructions consist of a climatic estimate for each year reconstructed for each station in the grid used.

In order to analyze larger geographical areas of the United States and Canada, the reconstructions may be "regionalized," or averaged over specified regions of the grid to produce time series for that region. The tasks of averaging and analyzing the averaged values are the functions of the programs described in this document. Program CCLTIM denormalizes and averages the individual station reconstructed estimates; Program CCROSS calculates

statistics for unfiltered and low-pass filtered periods for actual and reconstructed values and also calculates adjusted statistics for comparisons between actual data and reconstructions; Program CPROB examines the frequency domains of actual and reconstructed values and compares the statistics of past periods with periods within the present century.

These programs are written in FORTRAN Extended Version 4 for use on the CYBER 175 computer, but may be used and maintained through disk storage on the CYBER or DEC-10 computer. Each program may be used alone or in combination with the other programs.

CCLTIM

General Description

Program CCLTIM extracts time series files from climatic reconstruction or actual data files. CCLTIM reads the following files:

1. seasonalized climatic reconstructions or seasonalized actual data as output by PRINCY (program package which seasonalizes data and extracts principal components),
2. reconstruction statistics including standard deviations of residuals and calibrated variance by station,
3. station identification numbers,
4. station means and standard deviations for the calibration period, and
5. grid point numbers for all regions and all grids.

From these files, time series are extracted and written on an output file. Lines of header are written and regionalized values follow. Standard errors, if desired, follow immediately in the same format (Fig. 1; see Appendix 1B). In addition, another file is written containing the mean calibrated variances for the calibration period for each region averaged from individual station

calibrated variances read from file 2 (Fig. 2). See Section II for the exact formats of these files.

Procedure of Extracting Time Series

NOTE

CCLTIM is capable of extracting individual station time series and this option will be included in our description even though the option has, to date, not been tested for the most recent version of the program. Though it does not really belong in a "regionalizing" effort, it is conceivable that this option will prove useful in the future.

CCLTIM begins by reading the entire climatic reconstruction file or actual data and storing them; specified beginning and ending years are located in the array. Sums, sums of squares, sums of variances, variances, and standard errors for each year are calculated if standard errors are requested. For individual grid point time series, standard errors may be calculated, but yearly standard errors will be identical to one another and meaningless.

Equations

Table I (p. 1-22, Appendix 1B) is a description of the equations used for the various conditions of data. Equations marked with an at symbol (@) may be performed on individual grid point series.

NOTE

Throughout this section, actual variable names are used in equations to avoid confusion with other variables. The more routine calculations are usually performed in subroutines and standard notation will be used to represent these operations here, but many equations are quite program-specific and are identified as they appear in the code for the benefit of the programmer who must locate them in the future.

Basic units used for data and standard errors are degrees Fahrenheit for temperature and inches for precipitation, but conversion to degrees Centigrade or millimeters may be done as in Equations 1 and 2. (See p. 1-18, Appendix 1B.)

In addition, an average of the percent variance calibrated for each region is calculated by averaging individual station percent variances over the number of grid points.

CCROSS

General Description

Program CCROSS reads the actual and reconstructed time series files and average calibrated variance file output from Program CCLTIM. It then calculates for each region the means and standard deviations of actual data and reconstructions for several time periods and writes a summary table (Fig. 3).

1. means, standard deviations, and percent variances are calculated for unfiltered and low-pass filtered actual data and reconstructions for the "common period" or a set of years common to both the actual and reconstructed series. If the common period is not specified by the user, it is defined as the calibration period. The first year of the common or calibration period is always 1901 while the last year varies from 1960 to 1963, depending on the model and season used for reconstruction;
2. means and standard deviations are calculated for unfiltered reconstructions for the periods 1602-1900, and 1602 through the last year of the calibration period;

3. means and standard deviations are calculated for unfiltered actual data for the period 1901-1970;
4. comparisons between the actual means and standard deviations and the precalibration period (1602-1900) and full period (1602-196-) are made using a correction ratio (the ratio of the actual common period standard deviation to the reconstructed common period standard deviation). This ratio is multiplied by the reconstruction period standard deviation to "inflate" the variance in the reconstruction and thus allow comparisons between the past reconstructed estimates and the more variable actual calibration period series (see "Comparative Statistics" section below).

Statistics

General Statistics. Means and standard deviations are calculated for the following data sets:

1. actual common period, (1901-196-), unfiltered
2. reconstruction common period, unfiltered
3. actual common period, low-pass filtered
4. reconstruction common period, low-pass filtered
5. reconstruction precalibration period (1602-1900), unfiltered

6. reconstruction full period (1602-196-), unfiltered
7. actual full period (1901-1970), unfiltered

Means are calculated as the sum of the data values divided by the number of years in the time period. Standard deviations are calculated as in Equation 3.

Four different percent variances are calculated:

1. percent variance of the reconstruction due to low-pass filtering (RECPCT) as in Equation 4,
2. mean percent variances (VARIND) for a region for the calibration period obtained by a simple average of station percent variances. The station percent variance values are read from the calibration statistics file.
3. percent variances between actual and reconstructed unfiltered series for the control period (PVABC) calculated as in Equation 5 and expressed as percentages.
4. percent variances between actual and reconstructed low-pass filtered series for the control period (PVABCL) as in Equation 5 and expressed as percentages.

For further explanation of Equation 5, see Davis, J. C., 1973. Statistics and Data Analysis in Geology, John Wiley and Sons, Inc., New York.

Comparative Statistics. The following comparative statistics are calculated:

1. correction ratio (CRATIO) of the actual standard deviations for the common period (SDBC) to the reconstructed standard deviation of the same period (SDAC) as in Equation 6,
2. difference (AVDIFF) between unfiltered reconstruction mean, 1602-1900 (A2BAR) and the actual mean, 1901-1970 (BBAR) as in Equation 7,
3. ratio (PCTDIF) of diff (AVDIFF) to actual mean (BBAR), expressed as a percentage (Eq. 8),
4. adjusted standard deviation for precalibration period, 1602-1900 (ADJSDR), derived from the unfiltered reconstruction standard deviation of that period (SDA2) as in Equation 9,
5. adjusted standard deviation for full period, 1602-196- (ADJSDT), derived from the unfiltered standard deviation of that period (SDA) as in Equation 10,
6. difference (SDD) of adjusted standard deviation, 1602-1900 (ADJSDR), minus the actual full period standard deviation, 1602-196- (SDB), as in Equation 11,
7. ratio (PCTSDD) of SDD to standard deviation of actual full period, 1602-196- (SDB), expressed as a percentage (Eq. 12).

Scaling Factor. In addition, scaling factors for low-pass filtered standard errors (SCALE) are calculated for each region as the ratio of the low-pass filtered, reconstruction control period standard deviation (SDACL) to the unfiltered reconstruction control period standard deviation (SDAC as in Equation 13). These scaling factors are multiplied by the standard errors when low-pass filtered reconstructed time series are to be plotted by programs CCPLLOT and LPPLLOT.

Output. Output consists of a table containing all the above statistics (Fig. 3) except the scaling factors which are output on a separate file (Fig. 4).

CPROB

General Description

Program CPROB examines two time series, one actual and one reconstructed, and compares the frequencies of occurrences of class intervals in the calibration period and in the entire reconstruction period. The user is allowed to select "control periods" or subsets of the calibration period, in which frequencies of actual and reconstructed values are compared, theoretical probabilities are calculated for the intervals, and a chi square test is performed. The user is also allowed to select a number of "reconstruction periods," or subsets of the entire reconstruction period, to compare with the reconstruction control period frequencies. Interval size is determined by the program on the basis of the minimum interval size and the total number of classes specified by the user and the means and distributions of the data being analyzed. (See "Selection of Class Intervals" section later in this document.)

The reconstructed estimates to be analyzed are "adjusted" using the actual and reconstruction means and standard deviations for the calibration period. The variance of a reconstruction during the calibration period has been forced to be smaller than the variance of actual data for the same period. In order to make a valid comparison, the entire reconstruction time series must be adjusted for the change in variance as in Equation 14. If precipitation is being

analyzed, all negative values resulting from this adjustment are reset to zero.

CPROB produces four tables (Figs. 5-8) for each region or set and each control period. The contents of each table are described in the next section.

Output and Statistics

Table I--Control Period Frequencies and Statistics. Table I of CPROB output (Fig. 5) contains interval counts and frequencies of actual and reconstruction values for the particular control period, differences between reconstruction and actual frequencies, and the following theoretical probabilities:

1. probability that a climatic measurement in any year (X) will fall within the interval, i.e., it will be greater than the lower limit of the class (LL) and equal to or less than the upper class limit (UL),
2. probability that X will be equal to or less than the lower class limit, and
3. probability that X will be greater than the upper class limit.

These probabilities are determined by finding the Z-value or normal curve equivalent of the upper and lower class limits using the reconstruction mean and standard deviation for the

control period to normalize the limits, as in Equation 15.

NOTE

Though calculation is done progressively from minimum to maximum, the table is printed out in reverse order, from the maximum as Class 1 to the minimum as Class n (up to 20).

Control period statistics also appear in Table I. In general, basic statistics are calculated as in Equations 16, 17, and 18. In addition, control period minima and maxima are located and the differences between all reconstruction and actual statistics are calculated. The last items in Table I are the results of the chi square test, which are discussed in the next section.

Table II--Contingency Table and Chi Square Results (Eq. 6). Printing of Table II is optional--the only item that appears here and not in Table I is the contingency table for the actual and reconstruction counts.

Chi square is calculated as in Equation 19, and degrees of freedom are calculated as in Equation 20. If a row or column total is zero, that category is combined with the adjacent category and the degrees of freedom are reduced accordingly (Eq. 20) for the particular cell. For degrees of freedom greater than 30, the critical chi square value is approximated as in Equation 21.

When chi square is significant, the coefficient of contingency which measures the degree of relatedness of the two series, is calculated as in Equation 22.

NOTE

The classes used for the chi square test are arbitrary and not equally probable, and sample sizes are often too small to make statements about significance, so the researcher should use these chi square results cautiously.

Table III--Reconstruction Period Frequencies (Fig. 7).

Table III, like Table I, presents the class frequencies and theoretical probabilities for a control period as the first lines in the table, and proceeds to list the frequencies of the reconstruction periods along with the differences between the recon period and control period frequencies as well as the theoretical probabilities of the same class intervals determined by the same process as the control period probabilities, but now reconstruction period statistics are used to normalize the class bounds as in Equation 23. Up to 50 reconstruction periods may be analyzed in this fashion.

Table IV--Reconstruction Period Statistics (Fig. 8).

Table IV lists the reconstruction statistics of the control period (from Table I), and follows these with the statistics of all the reconstruction periods as well as the differences between the reconstruction period and control period

statistics. All reconstruction period statistics and differences are also averaged, and the user should note that this average may be meaningless if unequal or overlapping series are used.

Selection of Class Intervals. Class intervals are selected by Program CPRDB through a process of surveying all the data to be analyzed, determining means, maxima, and minima of all periods, and adjusting the interval range so that no data value will be out of bounds.

In order to ensure comparability of the regional analyses, the user defines a "minimum interval size" (RMININT), or the smallest interval to be allowed for a class (e.g., a quarter-degree for temperature or a millimeter for precipitation). All classes will be multiples of the minimum interval. The program reads the actual data and the adjusted reconstruction for all time periods and means, mins, and maxes are calculated for each. For each region, the largest time period maximum and smallest time period minimum are selected.

In addition, a "grand mean" (GRANDMN) is calculated which is the mean of all period means for all regions. The minimum interval size is multiplied by half of the total number of specified classes, to obtain a value for the variable RANGE. The value of RANGE is then tested against the absolute value of the largest departure of the max or min (SETMAXD) of each

region from the GRANDMN. If SETMAXD for a region is greater than RANGE, the minimum interval (RMININT) is multiplied by a variable, MULT, which has the value of 2 and is increased by 1 for each additional time the product does not exceed SETMAXD. When RANGE finally does exceed SETMAXD, RANGE is added to GRANDMN to yield the interval maximum (VMAX) and subtracted from GRANDMN to yield the interval minimum (VMIN). The boundaries of the intervals are then rounded off to the nearest tenth if VMAX is less than 100 or to the nearest unit if VMAX is greater than or equal to 100.

If precipitation is being analyzed, the program checks to see if VMIN is positive or negative. If it is negative, it is reset to zero and vmax is adjusted proportionately. This scheme prevents the occurrence of a time series value falling out of the defined bounds except in the rare case when the boundary rounding causes one value to fall just outside the calculated limits. In such a case, the value is included in the nearest class and an error message is printed on the program output, but usually the value is near enough to the boundary that the problem is negligible. See Figure 5 for an example of a set of defined intervals.

APPENDIX 1B

Equations, Tables, and Figures for
Regional Time Series Job Stream

EQUATIONS USED IN
REGIONAL TIME SERIES
PROGRAM PACKAGE

CCLTIM

1) Centigrade conversion: $C = 5(F-32)/9$

2) Millimeter conversion: $M = (25.4)I$

CCROSS

3) Standard deviations:

$$s_x = \sqrt{\frac{n\sum(X)^2 - (\sum X)^2}{n(n-1)}}$$

4) Percent variance due to low-pass filter:

$$\text{RECPCT} = \frac{(\text{SDACL})^2}{(\text{SDAC})^2} * 100$$

$$5) \quad r_m = \frac{n * (\sum AB) - \sum A \sum B}{\sqrt{[n * \sum A^2 - (\sum A)^2] [n * \sum B^2 - (\sum B)^2]}}$$

or

$$r_m = \frac{\text{cov}_{A,B}}{s_A s_B}$$

where

A is time series 1,

B is time series 2,

n^* is the number of overlapped positions between the two series,

m is the positive or negative lag index,

r is the cross correlation,

s_A is the standard deviation of A

s_B is the standard deviation of B,

$\text{cov}_{A,B}$ is the covariance of A and B

NOTE: In CCROSS, r_m is multiplied by 100 to express percent variance calibrated.

Equations 6 through 12 are comparative statistics.

$$6) \quad \text{CRATIO} = \frac{\text{SDBC}}{\text{SDAC}}$$

$$7) \quad \text{AVDIFF} = (\text{A2BAR} - \text{BBAR}) * \text{CRATIO}$$

$$8) \quad \text{PCTDIF} = \frac{\text{AVDIFF}}{\text{BBAR}} * 100$$

$$9) \quad \text{ADJSDR} = \text{SDA2} * \text{CRATIO}$$

$$10) \quad \text{ADJSDT} = \text{SDA} * \text{CRATIO}$$

$$11) \quad \text{SDD} = \text{ADJSDR} - \text{SDB}$$

$$12) \quad \text{PCTSDD} = (\text{SDD}/\text{SDB}) * 100$$

$$13) \quad \text{Scaling factor:}$$

$$\text{SCALE} = \frac{\text{SDACL}}{\text{SDAC}}$$

CPROB

$$14) \quad \text{Adjustment of denormalized values:}$$

Denormalized reconstruction estimates are adjusted for comparison to actual data via the following equation:

$$\hat{X}_r = [(X_r - \bar{X}_r) \left(\frac{s_a}{s_r} \right)] + \bar{X}_a$$

where

$\hat{X}_r$ is the adjusted reconstruction estimate for year i,

X_r is the nonadjusted reconstruction estimate for year i,

$\bar{X}_r$ is the mean of nonadjusted reconstruction estimates for the calibration period,

s_a is the standard deviation of actual data for the calibration period,

s_r is the standard deviation of reconstruction estimates for the calibration period, and

$\bar{X}_a$ is the mean of actual data for the calibration period.

- 15) Normalization of control period class limits for probability calculation:

$$UL = \frac{((I * RANGE) + VMINI) - RCPMN}{RCPSD}$$

where

I is the interval number,

RCPMN is the reconstructed control period mean,

RCPSD is the reconstructed control period standard deviation,

UL is the normalized upper limit of the interval, and

VMINI is the minimum of the data range.

16) Mean: $\bar{X} = \frac{\sum X}{n}$

17) Standard deviation: $s_x = \sqrt{\frac{n\sum(X)^2 - (\sum X)^2}{n(n-1)}}$

18) First-order autocorrelation: $r_1 = \sum(X_i - \bar{X})(X_{i-1} - \bar{X}) / s_x^2$

19) Chi square (χ^2): $h_{mn} = k_m \left(\frac{r_n}{\sum r} \right)$ and $\chi^2 = \sum \left(\frac{(f_{mn} - h_{mn})^2}{h_{mn}} \right)$

where

f_{mn} is the count within a cell mn of the contingency table,

r_n is the total count in row n,

k_m is the total count in column m, and

$\sum r$ is the grand total (r_n or k_m).

20) Degrees of freedom: $ndf = (nn-1) (mm-1)$

where

nn is the number of nonzero rows, and
 mm is the number of nonzero columns.

21) Critical chi square value approximation for degrees of freedom greater than 30:

$$\chi_{\alpha}^2 = \frac{\left(X_{\alpha} + \sqrt{2n-1} \right)^2}{2}$$

where

χ_{α}^2 is the critical value of chi square for the chosen significance level or alpha (α),

X_{α} is the normal curve approximate (Z-value) of the chosen level of significance (1.645 in CPROB), and

n is the number of degrees of freedom.

22) Coefficient of contingency: $C = \sqrt{\frac{\chi^2}{\chi^2 + \Sigma r}}$

23) Normalization of reconstruction period class limits for probability calculation:

$$UL = \frac{((I * RANGE) + VMINI) - RPMN}{RPSD}$$

where

I , $RANGE$, and $VMINI$ are the same as in Equation 15,

$RPMN$ is the mean of the reconstruction period, and

$RPSD$ is the standard deviation of the reconstruction period.

- E. DeWitt
 March, 1979

<u>Statistic</u>	<u>Recon. Normalized</u>	<u>Actual Normalized</u>	<u>Recon. Denormalized</u>	<u>Actual Nonnormalize</u>
X(norm) =	----	$\frac{(X(LL) - FMN(LI))}{SDV(LI)}^@$	----	----
XDN =	----	----	$(X(LL)*SDV(LI)) + FMN(LI)^@$	----
XS =	----	----	ΣXDN	----
XSQ =	$\Sigma (X(LL))^2$	$\Sigma (X(LL))^2$	ΣXDN^2	$\Sigma (X(LL))^2$
SPROD =	$\Sigma (SDR(LI))^2$	----	$\Sigma (SDR(LI)*SDV(LI))^2$	----
SSD =	$\frac{XSQ - (NGP*TS^2)}{NGP-1}$	$\frac{XSQ - (NGP*TS^2)}{NGP-1}$	$\frac{(XSQ - \frac{XS^2}{NGP})}{NGP-1}$	$\frac{XSQ - (NGP*TS^2)}{NGP-1}$
SE =	$\sqrt{\frac{SSD + \frac{SPROD}{NGP}}{NGP}}$	$\sqrt{\frac{SSD}{NGP}}$	$\sqrt{\frac{SSD + \frac{SPROD}{NGP}}{NGP}}$	$\sqrt{\frac{SSD}{NGP}}$
TS =	$\frac{\Sigma X(LL)}{NGP}$	$\Sigma \left(\frac{X(LL) - FMN(LI)}{SDV(LI)} \right)$	$\frac{\Sigma XDN}{NGP}$	$\frac{\Sigma X(LL)}{NGP}$

where

FMN is the calibration mean for a particular grid point,
 LI is the array of grid point numbers included in the regional average,
 LL is the location in the X array of a particular station and year,
 NGP is the number of grid points in a region,
 SDV is the calibration standard deviation for a particular grid point,
 SDR is the calibration standard deviation of the residuals for a particular grid point,
 SE is the standard error for year m,
 SPROD is the sum of squared or scaled standard deviations of residuals,
 SSD is the variance for year m over NGP grid points,
 TS is the averaged or individual time series value for year m,
 X is the time series value read from input data file,
 XDN is a denormalized data value calculated for all years and grid points desired
 XS is the sum of denormalized values for year m over NGP grid points, and
 XSQ is the sum of normalized, nonnormalized, or denormalized values for year m over NGP grid points.

@Calculation is made for individual station values as well as for averaged values.

```

03/09/79 10.25.26 CCLTIM AW152R.M12 REAL
FILE: AW152R.M12 CREATED 03/09/79 AT 10.25.25.

SELECTED TIME SERIES FROM THE FOLLOWING DATA FILE:

REAL      PRECIPITATION, 52 STATIONS, REAL
MONTHS DECIFIED PERIOD 1901:1970  MODEL
AVG. OF GRID PTS:  22 23 26 33 34 42 43 44 52
PRECIPITATION IN MILLIMETERS.

DATA:
AW152RAV 11901 285.383 268.563 270.510 283.916 204.922 229.034 259.108 271.752 281.793 209.070
AW152RAV 11911 191.431 232.862 219.622 252.194 141.514 101.324 194.028 312.144 285.033 209.070
AW152RAV 11921 287.725 153.324 260.941 219.710 263.333 231.320 260.042 173.054 147.348 235.260
AW152RAV 11931 171.394 261.156 264.442 337.570 283.311 263.554 206.653 253.708 230.192 311.178
AW152RAV 11941 182.400 213.840 242.202 167.983 179.533 345.342 203.890 238.365 220.890 266.431
AW152RAV 11951 294.809 230.058 340.021 343.403 154.448 227.554 220.407 247.424 300.115 213.727
AW152RAV 11961 252.655 185.313 171.986 227.810 128.330 227.554 73.925 140.549 102.113 271.582
S.E.      1901 109.026 101.671 105.043 95.199 53.339 121.688 56.723 111.592 107.306 43.246
S.E.      1911 74.471 92.628 83.653 92.290 43.339 121.688 107.568 111.592 107.306 43.246
S.E.      1921 112.297 72.330 94.339 97.734 105.634 97.806 107.568 111.592 107.306 43.246
S.E.      1931 81.755 114.209 116.290 157.559 117.275 95.538 97.128 145.520 98.711 116.186
S.E.      1941 81.795 74.022 82.263 72.355 54.557 101.540 84.132 145.610 78.342 114.486
S.E.      1951 111.644 78.340 138.310 139.496 53.332 119.558 71.555 110.739 70.878 88.947
S.E.      1961 107.120 57.103 59.467 89.720 104.014 93.334 123.105 80.854 91.234 10.015

FILE: AW152R.M12 CREATED 03/09/79 AT 10.25.25.

SELECTED TIME SERIES FROM THE FOLLOWING DATA FILE:

REAL      PRECIPITATION, 52 STATIONS, REAL
MONTHS DECIFIED PERIOD 1901:1970  MODEL
AVG. OF GRID PTS:  5  6  7  9 11 12 13 14 15
PRECIPITATION IN MILLIMETERS.

DATA:
AW152RAV 21901 229.785 194.564 193.012 156.934 217.173 189.597 312.533 245.787 346.379 192.955
AW152RAV 21911 241.074 113.820 154.545 155.251 142.344 133.525 205.644 121.807 159.923 109.643
AW152RAV 21921 241.067 297.575 141.280 90.142 142.635 183.906 253.210 126.033 138.543 143.941
AW152RAV 21931 152.674 257.415 192.306 188.158 231.623 251.174 243.492 205.065 172.793 217.819
AW152RAV 21941 421.217 231.817 253.336 218.157 157.403 177.800 198.693 105.658 164.423 208.457
AW152RAV 21951 177.234 203.417 177.222 165.714 142.925 192.433 219.258 282.617 141.772 276.427
AW152RAV 21961 115.147 255.891 124.121 155.175 149.542 142.525 149.493 134.428 74.037 226.427
S.E.      1901 52.864 98.392 67.737 55.740 39.032 45.735 53.707 52.713 49.108 33.750
S.E.      1911 37.077 35.129 32.052 50.370 72.507 43.638 43.520 30.532 30.128 41.704
S.E.      1921 82.717 35.129 24.402 28.982 43.238 43.638 43.520 30.532 30.128 41.704
S.E.      1931 21.722 30.020 29.609 39.545 27.672 45.744 45.744 45.744 45.744 45.744
S.E.      1941 71.303 61.320 37.747 44.135 42.707 40.071 15.174 40.185 34.513 62.847
S.E.      1951 55.142 54.514 88.652 41.675 38.937 40.071 34.070 52.334 34.105 30.904
S.E.      1961 47.607 28.732 27.413 39.855 47.371 39.745 34.350 41.034 66.567 60.744

FILE: AW152R.M12 CREATED 03/09/79 AT 10.25.25.

```

Figure 1-1. Example of time series file with standard errors as created by CCLTIM.

```

03/27/79 09.28.35 CCLTIM RWI96R.VI4
RWI96RAV 1: 37.8
RWI96RAV 2: 45.4
RWI96RAV 3: 40.6
RWI96RAV 4: 45.8
RWI96RAV 5: 39.7
RWI96RAV 6: 33.9
RWI96RAV 7: 34.1
RWI96RAV 8: 34.6
RWI96RAV 9: 35.1
RWI96RAV10: 29.3
RWI96RAV11: 29.3

```

Figure 1-2. Example of average calibrated variance created by CCLTIM.

Figure 1-3. See page 1-25.

```

03/27/79 09.28.52 CCROSS RWI96R.ST4
.459
.566
.590
.464
.588
.446
.478
.402
.433
.464
.369

```

Figure 1-4. Example of scaling factor file created by CCROSS.

LABORATORY OF TREE-RING RESEARCH, U. OF ARIZONA.
PROGRAM CCROSS. 03/13/79 10:50:30

ANALYSIS OF TIME SERIES.

FILE 1: RW152R.MT3
RECON WINTER PRECIPITATION: 52 STATIONS.
MONTHS DEC:FEB PERIOD 1602:1962 MODEL 191 18MRM
FULL MODEL NAME: 18R15MR15M + 19R151

FILE 2: AW152R.MT1
REAL WINTER PRECIPITATION: 52 STATIONS.
MONTHS DEC:FEB PERIOD 1901:1970 MODEL REAL

PRECIPITATION IN MILLIMETERS
MEANS FOR 6 REGIONS

REGION NO.	1901-1962 UNFILTERED		1901-1962 RECON		1901-1962 LOW-PASS FILTER		1901-1962 PERCENT VARIANCE		1602-1900 UNFILTERED		1602-1900 RECON		1602-1962 UNFILTERED		1602-1962 RECON		IND STA		PERCENT UNFIL		PERCENT RECON	
	MEAN	SD	MEAN	SD	MEAN	SD	LOW-PASS	VARIANCE	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	STA	IND	UNFIL	RECON	UNFIL	RECON
1	242.7	51.39	241.7	28.92	243.0	21.63	241.5	15.00	261.5	27.76	207.0	27.01	258.1	28.91	207.6	25.05	38.2	43.3	43.3	54.1	54.1	54.1
2	211.3	71.35	210.3	44.69	211.4	35.52	210.4	25.43	207.0	57.01	207.0	57.01	207.6	55.05	207.6	55.05	49.9	52.9	52.9	74.7	74.7	74.7
3	84.4	27.29	84.5	19.79	84.5	11.95	84.5	12.26	84.3	22.43	84.3	22.43	84.3	21.94	84.3	21.94	49.0	64.3	64.3	90.4	90.4	90.4
4	55.3	27.33	55.3	18.22	55.2	8.67	55.4	8.03	47.6	22.64	47.6	22.64	48.9	22.11	48.9	22.11	47.7	57.1	57.1	60.9	60.9	60.9
5	51.7	12.82	51.7	6.93	51.7	6.74	51.4	4.21	52.1	6.90	52.1	6.90	52.0	6.60	52.0	6.60	37.7	44.4	44.4	69.3	69.3	69.3
6	41.2	15.90	41.1	10.34	41.2	7.30	41.2	5.00	39.7	12.78	39.7	12.78	40.0	12.39	40.0	12.39	34.4	53.5	53.5	84.4	84.4	84.4
MEAN	114.4	34.35	114.1	21.48	114.5	15.30	114.1	11.65	115.4	24.92	115.4	24.92	115.1	24.55	115.1	24.55	42.8	52.7	52.7	68.8	68.8	68.8

COMPARATIVE STATISTICS

REGION	1901-1970 UNFILTERED ACTUAL SD		SD ACTUAL (1901-1962) (/SD RECON (1901-1962)		MEAN DIFF 1602-1900 MINUS 1901-1970		PERCENT MEAN DIFF		ADJ SD 1602-1962		STANDARD DEVIATION DIFF FROM 1901-1970		PCT DIFF 1901-1970	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	DIFF	MEAN	SD	MEAN	SD	MEAN	DIFF
1	244.50	51.09	1.78	1.78	30.22	12.4	12.4	12.4	51.37	49.34	-1.75	49.34	-3.4	1
2	209.63	76.16	1.60	1.60	-4.21	-2.0	-2.0	-2.0	87.88	91.01	14.86	91.01	19.5	2
3	84.79	28.00	1.38	1.38	-7.74	-9	-9	-9	30.30	30.93	2.03	30.93	10.5	3
4	55.54	28.09	1.50	1.50	-11.97	-21.6	-21.6	-21.6	33.17	33.93	5.86	33.93	20.9	4
5	51.84	12.57	1.85	1.85	-5.53	-1.0	-1.0	-1.0	12.76	12.75	18	12.75	1.4	5
6	40.22	15.78	1.54	1.54	-7.74	-1.8	-1.8	-1.8	19.06	19.66	3.88	19.66	24.6	6
MEAN	114.42	35.28	1.61	1.61	2.18	-2.1	-2.1	-2.1	39.09	39.61	4.33	39.61	12.2	

Figure 1-3. Example of CCROSS output table.

PROGRAM CPORR, RUN ON 03/08/79 AT 14.33.08 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. PAGE 3 OF 70
 ACTUAL FILE: AAN96R.MT1 RECON FILE: RAN96R.MT1 MODEL (CODED): ANREC127R CONTROL PERIOD 1: 1901-1960
 ACTUAL ID: AAN96RAV 3 RECON ID: RAN96RAV 3 SET 2. MODEL (FULL): RECON ANN PRECIP (YR DEC-NOV)

AVG. OF GRID PTS: 9 18 19 20 26 51 52 78 79 80 81

COUNTS, FREQUENCIES OF OCCURRENCE, AND THEORETICAL PROBABILITIES FOR 51.00 INTERVALS

INTERVAL NUMBER	UPPER LIMIT (UL)	LOWER LIMIT (LL)	ACTUAL COUNT	ACTUAL FREQ	PFCON COUNT	RECON CP FREQ	DIFF RECON- ACTUAL FREQ	THEORETICAL PROBABILITIES (X = DATA VALUE)		
								UL>X>LL	X>LL	X>UL
1	1103.00	1103.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
2	1052.00	1052.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
3	1001.00	1001.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
4	950.00	950.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
5	899.00	899.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
6	848.00	848.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
7	797.00	797.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
8	746.00	746.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
9	695.00	695.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
10	644.00	644.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
11	593.00	593.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
12	542.00	542.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
13	491.00	491.00	0	0.00	0	0.00	0.00	0.00	1.00	0.00
14	440.00	440.00	2	.03	0	0.00	0.00	0.00	1.00	0.00
15	389.00	389.00	9	.15	19	.02	-.02	.02	.98	.02
16	338.00	338.00	15	.25	19	.32	-.07	.13	.84	.16
17	287.00	287.00	27	.45	21	.35	-.10	.35	.49	.51
18	236.00	236.00	0	.12	1	.15	-.03	.03	.15	.85
19	185.00	185.00	0	0.00	1	.02	.02	.02	0.00	.98
20										

STATISTICS

 CONTROL PERIOD MEAN: 287.63 287.63
 CONTROL PERIOD SD: 49.69 49.69
 MAXIMUM 429.45 396.84
 MINIMUM 194.77 169.63
 FIRST-ORDER SERIAL CORR: .06 .36

CHI SQUARE IS 93.54 WITH 20 DEGREES OF FREEDOM
 THIS VALUE IS SIGNIFICANT AT THE 0.95 LEVEL
 COEFFICIENT OF CONTINGENCY: .781
 TOTAL NUMREP OF DATA VALUES IS LESS THAN 5 PER CELL OF NONZERO MATRIX.

Figure 1-5. Example of Table I, CPORR output.

PROGRAM CPRCS, RUN ON 03/08/79 AT 14.33.08 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. PAGE 4 OF 70

ACTUAL FILE: AAN96R.MT1 RECON FILE: RAN96R.MT1 MODEL (CODED): ANREC1278 CONTROL PERIOD 1: 1901-1960

ACTUAL ID: AAN96RAV 3 RECON ID: RAN96RAV 3 SET 2. MODEL (FULL): RECON ANN PRECIP (YR DEC-NOV)

AVG. OF GRID PTS: 9 18 19 20 26 51 52 78 79 80 81

CONTINGENCY TABLE FOR ACTUAL AND RECON CONTROL PERIOD VALUES

	ACTUAL																			
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
RECON 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CHI SQUARE IS 93.54 WITH 20 DEGREES OF FREEDOM
 THIS VALUE IS SIGNIFICANT AT THE 0.95 LEVEL
 COEFFICIENT OF CONTINGENCY: .781
 TOTAL NUMBER OF DATA VALUES IS LESS THAN 5 PER CELL OF NONZERO MATRIX.

Figure 1-6. Example of Table II, CPROB output.

```

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 03/08/79 AT 14.33.09          PAGE 46 OF 70

FILE: RAN96R.MT1  ANNUAL 96 GRID  PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 983.00 MIN 303.00

ID: RAN96RAV 1  MODEL (CODE0): ANREC1278  MODEL (FULL): RECON ANN PRECIP (YR DEC-NOV)

CONTROL PERIOD 2: 1931-1960, SET NO. 1.  AVG. OF GRID PTS: 27 28 47 64 65 83 84 85 95

FREQUENCIES OF OCCURRENCES IN 34.00 INTERVALS FOR PAST RECONSTRUCTION PERIODS
AND DIFFERENCES OF A CONTROL PERIOD FROM THESE FREQUENCIES

INTERVAL
MAXIMUM (UL)
MINIMUM (LL)

1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20
949. 915. 881. 847. 813. 779. 745. 711. 677. 643. 609. 575. 541. 507. 473. 439. 405. 371. 337.

CP 2 1931-1960  FREQ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
UL>X>LL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
X>UL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

RP 1 1602-1625  FREQ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
DIFF 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

THEORETICAL UL>X>LL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
PROBABILITIES X>UL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

RP 2 1626-1650  FREQ 0.04 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
DIFF 0.04 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

THEORETICAL UL>X>LL 0.04 0.03 0.05 0.07 0.09 0.10 0.11 0.11 0.10 0.09 0.07 0.05 0.03 0.02 0.01 0.01 0.00 0.00 0.00
PROBABILITIES X>UL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

PP 3 1651-1675  FREQ 0.04 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
DIFF 0.04 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

THEORETICAL UL>X>LL 0.01 0.01 0.02 0.04 0.07 0.10 0.12 0.14 0.13 0.12 0.09 0.07 0.04 0.02 0.01 0.00 0.00 0.00 0.00
PROBABILITIES X>UL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

RP 4 1676-1700  FREQ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
DIFF 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

THEORETICAL UL>X>LL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
PROBABILITIES X>UL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

RP 5 1701-1725  FREQ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
DIFF 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

THEORETICAL UL>X>LL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
PROBABILITIES X>UL 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

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Figure 1-7. Example of Table III, CPROB output.

FILE: RAN96P.MT1 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX1560.00 MIN 0.00
 ID: RAN96RAV11 MODEL (CODED): ANREC1278 MODEL (FULL): RECON ANN PRECIP (YR DEC-NQV)
 CONTROL PERIOD 1: 1901-1960, SET NO. 5. AVG. OF GRID PTS: 37 38 53 57 66 67 82 86
 PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 03/08/79 AT 14.33.09 PAGE 45 OF 70

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP=CONTROL PERIOD* *RP=RECON PERIOD*		MEAN	DIFF	SD	OIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP 1	1901-1960	998.49		96.70		1187.70		760.27		.10	
RP 1	1602-1625	1101.87	103.38	119.41	22.71	1334.59	166.89	968.52	108.26	-.04	-.13
RP 2	1626-1650	1192.36	193.87	124.60	27.90	1533.36	365.66	981.99	121.72	-.42	-.32
RP 3	1651-1675	1086.73	88.24	107.60	10.56	1263.76	76.06	863.31	105.24	-.25	-.35
RP 4	1676-1700	1033.81	35.32	111.26	14.56	1310.38	122.67	857.83	152.81	-.04	-.06
RP 5	1701-1725	1061.69	63.10	83.72	-12.32	1186.63	91.33	917.08	152.56	-.16	-.07
RP 6	1726-1750	1062.23	63.74	80.38	-16.00	1279.06	118.36	882.19	110.94	-.20	-.10
RP 7	1751-1775	1078.64	53.75	111.42	-16.28	1246.07	59.14	920.21	159.68	-.17	-.15
RP 8	1776-1800	1092.75	94.26	87.80	-18.90	1269.07	81.36	911.33	1151.06	-.27	-.17
RP 9	1801-1825	1084.34	85.41	91.47	-5.23	1259.76	72.06	870.95	122.53	-.34	-.09
RP 10	1826-1850	1081.08	17.59	90.72	-5.98	1232.43	55.30	738.17	111.57	-.19	-.14
RP 11	1851-1875	1087.08	88.59	103.51	6.14	1263.36	76.03	822.83	117.80	-.34	-.05
RP 12	1876-1900	1103.71	105.23	127.84	31.53	1306.06	365.66	871.03	110.76	-.40	-.30
RP 13	1901-1925	1063.71	62.82	103.26	9.58	1269.07	118.36	738.80	121.46	-.33	-.24
RP 14	1926-1950	1041.25	77.67	109.26	12.56	1353.36	365.66	738.80	121.46	-.33	-.24
RP 15	1951-1975	1076.17	64.68	111.00	14.30	1553.36	365.66	738.80	121.46	-.33	-.24
RP 16	1976-1990	1063.17									
RP 17	1991-1990										
RP AVERAGE		1075.47	77.60	101.95	5.25	1331.81	144.71	852.94	92.67	.20	.10

Figure 1-8. Example of Table IV, CPROB output.

APPENDIX 2

Statistics for Reconstructions by
25-Year, 100-Year, 300-Year, and
360-Year Intervals as Compared to
1901-1961 Statistics

TABLE 2-2. Summary Table for Region 3, Intermountain Basins. Control Period: 1901-1961.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18
 FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1271.00 MIN 111.00
 ID: RAN96RAV 3 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 3: 1901-1961, SET NO. 2. AVG. OF GRID PTS: 9 18 19 20 26 51 52 78 79 80 81

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP-CONTROL PERIOD* *RP-RECON PERIOD*	MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP 3 1901-1961	287.21		49.38		386.79		178.89		.28	
RP 1 1602-1625	335.88	48.66	78.78	29.40	489.33	102.54	192.67	13.79	.70	.42
RP 2 1625-1650	236.41	-30.80	35.83	-13.55	352.17	-36.62	187.04	18.84	.57	-.12
RP 3 1650-1675	233.69	-31.52	56.55	7.19	349.95	-36.84	113.04	-65.84	.52	.29
RP 4 1675-1700	266.19	-26.03	54.97	7.59	352.09	-27.70	156.72	-61.76	.36	.24
RP 5 1700-1725	241.75	-25.47	60.96	5.26	355.32	-27.67	148.14	-22.17	.29	.01
RP 6 1725-1750	265.37	-41.84	58.32	11.58	365.09	-21.76	152.52	-30.72	.33	.06
RP 7 1750-1775	257.20	-30.01	54.94	18.95	361.71	-21.51	174.53	-26.37	.20	.07
RP 8 1775-1800	243.59	-33.62	49.41	5.32	365.64	-21.14	150.93	-28.26	.43	.15
RP 9 1800-1825	273.50	-13.71	66.36	.04	401.13	14.85	138.91	-40.95	.31	.26
RP 10 1825-1850	241.94	-45.27	55.67	16.30	406.86	2.35	176.15	-38.74	.20	.03
RP 11 1850-1875	266.46	-20.75	55.58	6.21	485.32	20.08	113.04	-65.84	.32	.07
RP 12 1875-1900	272.38	-14.81	59.23	19.85	489.09	102.54	148.14	-30.75	.22	.45
RP 13 1900-1925	246.37	-30.83	57.05	7.67	406.86	-1.70	138.91	-40.48	.42	.05
RP 14 1925-1950	256.68	-30.53	61.88	8.53	489.32	102.54	113.04	-65.84	.22	.14
RP 15 1950-1975	261.01	-25.53	60.64	12.50	489.32	102.54	113.04	-65.84	.50	.23
RP 16 1975-1900	266.01	-21.20		11.27						

TABLE 2-3. Summary Table for Region 4, Southwest Deserts. Control Period: 1901-1961.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18
 FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1341.00 MIN 41.00
 ID: RAN96RAV 4 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 3: 1901-1961, SET NO. 3. AVG. OF GRID PTS: 2 3 4 5 11 54 56 76

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP-CONTROL PERIOD* *RP-RECON PERIOD*		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP 3	1901-1961	226.99		59.35		387.82		98.08		.13	
RP 1	1602-1625	199.91	-27.08	73.30	13.96	332.98	-54.84	47.13	-50.94	.69	.56
RP 2	1626-1650	194.19	-32.80	43.66	-15.69	272.99	-114.83	116.53	18.46	.23	.10
RP 3	1651-1675	188.86	-38.13	66.99	17.65	315.84	-73.98	46.47	-51.60	.46	.37
RP 4	1676-1700	200.14	-26.85	69.80	10.45	314.49	-73.32	50.65	-47.42	.29	.07
RP 5	1701-1725	217.34	-50.65	72.03	13.26	343.53	-48.39	79.94	-18.98	.14	.16
RP 6	1726-1750	176.97	-50.02	74.61	15.26	339.42	-77.41	55.21	-42.87	.36	.01
RP 7	1751-1775	184.21	-42.78	58.14	-1.21	310.41	-77.64	88.81	-9.27	.40	.23
RP 8	1776-1800	185.91	-41.08	64.78	5.43	329.69	-87.92	54.75	-13.33	.34	.27
RP 9	1801-1825	175.87	-51.12	58.44	-2.01	309.89	-87.92	89.97	-43.11	.23	.09
RP 10	1826-1850	222.07	-44.97	57.98	3.69	316.46	-60.37	54.38	-18.70	.29	.15
RP 11	1851-1875	192.52	-34.21	64.43	-3.69	276.27	-60.84	52.36	-45.31	.46	.35
RP 12	1876-1900	170.74	-56.47	58.58	4.23	332.98	-111.54	49.37	-51.87	.38	.18
RP 13	1901-1925	195.74	-31.26	68.61	9.27	343.53	-54.29	55.27	-42.87	.31	.23
RP 14	1926-1950	191.11	-35.88	62.32	2.97	326.95	-60.87	52.56	-45.31	.38	.18
RP 15	1951-1975	190.30	-36.69	65.73	5.38	343.53	-54.29	46.47	-51.60	.37	.25
RP 16	1976-1900	192.37	-34.62	65.73	5.38	343.53	-54.29	46.47	-51.60	.37	.25
RP 17	1602-1961	198.24	-28.76	65.08	5.73	387.82	0.00	46.47	-51.60	.37	.25

TABLE 2-5. Summary Table for Region 9, Great Lakes and Midwest. Control Period: 1901-1961.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18

FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1310.00 MIN 70.00

ID: RAN96RAV 9 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV

CONTROL PERIOD 3: 1901-1961, SET NO. 5. AVG. OF GRID PTS: 29 30 39 40 41 43 58 62 87

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP=CONTROL PERIOD* *RP=RECON PERIOD*		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL	R	DIFF
CP 3	1901-1961	845.22		78.92		1053.71		668.55		.18		
RP 1	1602-1625	1066.29	201.07	121.70	42.78	1303.18	249.47	845.95	177.40	.21		.04
RP 2	1626-1650	1060.31	215.09	109.90	30.98	1286.49	232.78	885.55	217.07	.51		.33
RP 3	1651-1675	915.61	70.40	119.59	40.67	1123.77	70.05	717.62	49.07	.32		.19
RP 4	1676-1700	829.12	-16.09	105.99	27.07	1063.96	10.24	677.14	8.58	.36		.12
RP 5	1701-1725	874.05	28.84	99.20	20.28	1047.47	-6.24	676.96	8.41	.30		.08
RP 6	1726-1750	913.76	68.54	93.71	14.79	1097.22	55.31	783.37	114.65	.09		.01
RP 7	1751-1775	831.92	-13.29	115.33	36.42	1066.51	12.79	656.26	-3.18	.24		.07
RP 8	1776-1800	861.61	16.39	112.79	33.87	1120.30	66.56	722.35	-25.20	.51		.33
RP 9	1801-1825	929.51	84.29	109.05	30.13	1176.88	62.17	655.68	-12.87	.49		.26
RP 10	1826-1850	874.08	28.87	145.92	67.00	1116.27	-17.76	660.68	-7.87	.08		.25
RP 11	1851-1875	811.61	-33.61	84.62	9.70	1035.95	121.17	655.68	-12.87	.42		.47
RP 12	1876-1900	851.83	-10.62	88.26	5.34	983.61	-70.10	660.68	-7.87	.64		.08
RP 13	1901-1925	921.99	110.77	148.14	69.22	1303.18	249.47	656.35	-12.87	.25		.33
RP 14	1926-1950	870.33	25.12	108.14	29.22	1174.88	66.58	643.35	-25.20	.50		.38
RP 15	1951-1975	867.76	22.54	116.08	37.16	1174.88	121.17	643.35	-25.20	.50		.38
RP 16	1976-1900	899.82	54.60	132.29	47.37	1303.18	249.47	643.35	-25.20	.50		.38
RP 17	1901-1961	890.57	45.35	126.44	47.52	1303.18	249.47	643.35	-25.20	.50		.38

TABLE 2-6. Summary Table for Region 10, Southeast. Control Period: 1901-1961.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18
 FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1900.00 MIN 0.00
 ID: RAN96RAV10 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 3: 1901-1961, SET NO. 6. AVG. OF GRID PTS: 1 22 23 24 25 35 36 70 71 72

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP=CONTROL PERIOD* *RP=RECON PERIOD*		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP 3	1901-1961	1249.89		140.34		1560.24		944.81		.13	
RP 1	1602-1625	1381.72	131.83	136.67	-3.66	1668.27	108.03	1061.52	116.71	.20	.07
RP 2	1626-1650	1573.23	323.34	137.39	-3.95	1794.47	234.23	1312.50	367.68	.18	.05
RP 3	1651-1675	1389.94	140.05	179.65	39.32	1743.47	183.07	1005.62	60.81	.10	-.03
RP 4	1676-1700	1222.24	-127.65	127.41	-32.93	1424.17	-315.33	972.70	27.55	.00	-.27
RP 5	1701-1725	1375.70	125.81	173.27	-32.94	1875.51	-315.33	1093.81	148.89	.00	-.23
RP 6	1726-1750	1272.91	-32.02	137.87	-22.46	1532.90	-90.34	979.81	35.00	.00	-.26
RP 7	1751-1775	1216.94	-73.43	118.42	-21.08	1469.90	23.22	1008.31	63.50	.03	-.41
RP 8	1776-1800	1323.32	82.72	162.58	24.03	1583.66	20.46	914.62	30.19	.28	-.10
RP 9	1801-1825	1366.61	116.49	134.37	-4.45	1580.70	136.75	1035.78	-90.24	.03	-.12
RP10	1826-1850	1146.40	-162.49	139.88	2.09	1697.19	-93.98	1039.05	94.72	.18	.05
RP11	1851-1875	1237.55	-12.34	142.37	2.09	1503.49	234.00	916.70	-20.12	.07	-.31
RP12	1876-1900	1291.89	142.00	191.43	51.09	1466.26	315.33	884.62	27.55	.49	-.36
RP13	1901-1925	1291.89	30.86	158.78	18.48	1825.57	315.33	884.70	-60.12	.27	.15
RP14	1926-1950	1291.89	73.16	161.82	37.21	1875.57	315.33	884.70	-60.12	.28	.15
RP15	1951-1975	1291.89	60.77	173.82	33.49	1875.57	315.33	884.70	-60.12	.40	.27
RP16	1976-1990	1323.06		177.55							
RP17	1991-1999	1310.66		173.82							

TABLE 2-7. Summary Table for Region 1, Columbia Basin. Control Period: 1901-1930.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18
 FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1020.00 MIN 360.00
 ID: RAN96RAV 1 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 1: 1901-1930, SET NO. 1. AVG. OF GRID PTS: 27 28 47 64 65 83 84 85 95

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

*****CONTROL PERIOD***** *****RECON PERIOD*****		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL N DIFF	
CP 1	1901-1930	611.76		89.09		860.58		479.70		- .08	
RP 1	1602-1625	788.43	176.67	115.81	26.71	954.19	93.61	602.12	122.42	.19	.27
RP 2	1626-1650	641.52	229.76	106.17	17.07	1010.51	149.62	627.29	147.59	.44	.52
RP 3	1651-1675	722.93	111.17	89.88	54.79	890.20	29.62	588.74	109.04	.10	.19
RP 4	1676-1700	611.64	35.81	143.70	1.73	907.87	27.29	419.25	-90.45	.34	.43
RP 5	1701-1725	647.58	95.73	90.82	3.99	802.84	-57.74	503.50	23.80	-.25	-.16
RP 6	1726-1750	707.22	65.46	93.08	31.82	861.08	.42	521.70	42.97	-.10	-.01
RP 7	1751-1775	681.82	70.06	120.91	31.66	846.31	20.50	478.73	-10.75	.31	.39
RP 8	1776-1800	755.72	143.96	111.75	31.75	904.33	-14.27	468.95	-86.00	.27	.35
RP 9	1801-1825	633.90	22.14	120.84	35.53	800.82	133.75	565.71	-52.03	.53	.62
RP 10	1826-1850	619.55	77.79	97.62	18.27	805.89	-59.76	457.67	-29.93	.21	.30
RP 11	1851-1875	690.61	78.85	107.36	12.17	832.21	-34.69	451.91	-27.79	.19	.27
RP 12	1876-1900	740.65	128.89	101.26	53.82	1010.51	28.37	451.91	-60.45	.35	.43
RP 13	1602-1700	678.53	66.77	145.91	16.40	881.08	149.92	468.95	-10.75	.57	.65
RP 14	1701-1800	674.95	63.18	105.49	28.81	994.33	133.75	427.67	-52.03	.13	.22
RP 15	1801-1900	697.90	86.14	117.90	37.17	994.33	149.92	427.67	-52.03	.49	.57
RP 16	1602-1800	686.61	74.84	126.26	33.89	1010.51	149.92	419.25	-80.45	.44	.53
RP 17	1802-1901			122.99							

TABLE 2-9. Summary Table for Region 4, Southwest Deserts. Control Period: 1901-1930.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.16												
FILE: RAN96R.MT2	ANNUAL 96 GRID	PRECIPITATION IN MILLIMETERS.	RANGE ANALYZED: MAX 1341.00	MIN	41.00							
ID: RAN96RAV 4	MODEL (CODED):	ANNREC679	MODEL (FULL):	ANNUALCOMBINED DEC-NOV								
CONTROL PERIOD 1: 1901-1930, SET NO. 3.	AVG. OF GRID PTS:	2	3	4	5	11	54	56	76			
STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD												

CP-CONTROL PERIOD	MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF		
RP-RECON PERIOD												
CP 1 1901-1930	236.98		60.37		376.77		98.08		-.08			
RP 1 1602-1625	199.91	-37.07	73.30	12.94	332.98	-43.80	47.13	-50.94	69	.77		
RP 2 1626-1650	194.86	-42.12	43.66	-16.70	315.84	-103.79	116.53	-18.46	23	.55		
RP 3 1651-1675	188.86	-48.08	66.99	6.63	314.49	-60.94	46.47	-51.46	26	.29		
RP 4 1676-1700	200.14	-36.84	69.80	9.43	343.53	-33.23	96.10	-47.62	20	.44		
RP 5 1701-1725	176.97	-60.01	72.63	12.26	333.95	-37.37	79.96	-1.98	29	.38		
RP 6 1726-1750	184.21	-52.77	58.14	14.23	310.41	-66.37	55.21	-42.67	14	.22		
RP 7 1751-1775	185.91	-51.07	64.78	-2.23	315.17	-61.60	88.81	-9.23	36	.44		
RP 8 1776-1800	185.87	-61.11	58.44	4.41	319.89	-76.88	89.97	-43.31	40	.33		
RP 9 1801-1825	175.87	-14.96	57.33	-1.92	316.46	-60.31	84.38	-48.11	23	.48		
RP 10 1826-1850	172.02	-44.20	64.98	-3.04	326.95	-49.82	84.38	-13.70	23	.31		
RP 11 1851-1875	192.72	-66.46	58.46	4.61	326.27	-100.50	52.76	-45.31	29	.27		
RP 12 1876-1900	170.52	-41.25	63.56	-1.91	332.98	-43.80	46.47	-51.60	34	.57		
RP 13 1901-1925	195.74	-45.87	68.61	8.25	343.53	-38.62	55.21	-45.31	29	.37		
RP 14 1926-1950	191.11	-46.68	62.32	1.95	343.53	-33.23	55.21	-45.31	36	.40		
RP 15 1951-1975	190.30	-44.61	64.73	4.36	343.53	-33.23	46.47	-51.60	31	.44		
RP 16 1976-1900	192.37	-38.74	65.08	4.71	387.82	-11.04	46.47	-51.60	38	.45		
RP 17 1901-1981	198.24								37	.45		

TABLE 2-10. Summary Table for Region 6, Southern Plains. Control Period: 1901-1930.

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FILE:  RAN96R.MT2  ANNUAL 96 GRID  PRECIPITATION IN MILLIMETERS. RANGE ANALYZED:  MAX 1281.00  MIN 101.00
                                ID:  RAN96RAV 6  MODEL (CODEO):  ANNREC679  MODEL (FULL):  ANNUALCOMBINED DEC-NOV
                                CONTROL PERIOD 1:  1901-1930, SET NO. 4.  AVG. OF GRID PTS:  17 21 55 74 88
PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18

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STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

[illegible]

TABLE 2-11. Summary Table for Region 9, Great Lakes and Midwest. Control Period: 1901-1930.

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PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18

FILE:  RAN96R.MT2  ANNUAL 96 GRID  PRECIPITATION IN MILLIMETERS.  RANGE ANALYZED:  MAX 1310.00  MIN  70.00
      ID:  RAN96RAV 9  MODEL (CODED):  ANNKEC679  MODEL (FULL):  ANNUALCOMBINED DEC-NOV
      CONTROL PERIOD 1:  1901-1930, SET NO. 5.  AVG. OF GRID PTS:  29 30 39 40 41 43 58 62 87

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STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

CP=CONTROL PERIOD*
RP=RECON PERIOD *

*CP=CONTROL PERIOD *	*RP=RECON PERIOD *	MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL	R	DIFF
CP 1	1901-1930	854.02		83.71		1053.71		668.55		.02		
RP 1	1602-1625	1046.29	192.27	121.70	7.99	1303.71	249.478	845.95	177.40	.21		19
RP 2	1626-1650	1060.31	206.20	109.59	37.08	1286.77	237.00	845.95	177.00	.12		19
RP 3	1651-1675	1015.12	91.81	1105.59	325.28	1123.96	10.02	777.61	8.58	.32		34
RP 4	1676-1700	824.04	-24.89	109.20	110.03	1045.42	10.25	677.61	8.58	.36		34
RP 5	1701-1725	873.73	-29.04	99.37	110.03	1045.42	10.25	677.61	8.58	.09		34
RP 6	1726-1750	913.09	-29.74	115.40	131.68	1109.37	12.51	685.62	11.45	.09		34
RP 7	1751-1775	861.92	-27.59	112.33	39.08	1069.37	16.21	675.62	11.45	.18		34
RP 8	1776-1800	869.61	75.99	112.09	22.41	1116.30	16.21	675.62	11.45	.18		34
RP 9	1801-1825	829.50	25.06	145.02	22.41	1116.30	16.21	675.62	11.45	.18		34
RP 10	1826-1850	874.63	-2.82	88.26	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 11	1851-1875	861.93	17.89	84.46	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 12	1876-1900	861.93	17.89	108.14	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 13	1901-1925	870.33	13.37	108.06	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 14	1926-1950	867.76	16.78	132.6	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 15	1951-1975	890.82	45.05	132.6	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 16	1976-1990	890.82	45.05	132.6	62.55	1103.33	12.77	655.62	11.45	.19		34
RP 17	1991-1961	890.82	45.05	132.6	62.55	1103.33	12.77	655.62	11.45	.19		34

TABLE 2-12. Summary Table for Region 10, Southeast. Control Period: 1901-1930.

FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1900.00 MIN 0.00
 ID: RAN96RAV10 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 1: 1901-1930, SET NO. 6. AVG. UF GRID PTS: 1 22 23 24 25 35 36 70 71 72

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP-CONTROL PERIOD* *RP-RECON PERIOD*		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP 1	1901-1930	1223.56		159.64		1560.24		944.81		-.02	
RP 1	1602-1625	1381.72	158.16	136.67	-22.96	1668.27	108.03	1061.52	116.71	.20	.20
RP 2	1626-1650	1573.23	349.67	137.30	-22.25	1794.47	234.00	1312.50	367.68	.18	.18
RP 3	1651-1675	1389.24	166.38	127.41	-20.02	1743.47	183.23	1005.81	60.81	.10	.10
RP 4	1676-1700	1222.24	152.33	127.27	-32.22	1424.17	-136.07	1972.36	27.55	-.10	-.10
RP 5	1701-1725	1373.70	122.14	137.87	-13.64	1875.51	-315.33	1093.70	148.89	-.60	-.60
RP 6	1726-1750	1272.91	129.34	118.87	-21.76	1532.51	-27.73	1979.81	35.00	-.13	-.13
RP 7	1751-1775	1216.32	98.62	162.42	-40.76	1469.90	-90.32	1008.31	63.50	-.28	-.28
RP 8	1776-1800	1323.44	108.88	134.58	-2.78	1583.46	23.22	1914.78	-30.19	.03	.03
RP 9	1801-1825	1366.61	143.05	164.37	-20.06	1580.70	20.46	1035.05	90.96	.24	.24
RP 10	1826-1850	1366.61	137.16	139.80	-4.73	1697.14	136.90	1036.09	94.22	.18	.18
RP 11	1851-1875	1386.40	-37.05	139.80	-19.73	1503.49	-56.75	884.70	-28.72	-.19	-.19
RP 12	1876-1900	1237.55	13.98	191.43	-31.79	1766.26	-93.98	972.36	-60.15	.47	.47
RP 13	1602-1700	1391.89	168.32	142.78	31.79	1794.57	234.00	914.70	27.12	.27	.27
RP 14	1701-1800	1297.22	57.66	158.62	-8.85	1875.14	315.33	884.70	-60.12	.28	.28
RP 15	1801-1900	1240.75	57.49	161.82	2.18	1697.14	136.90	884.70	-60.12	.42	.42
RP 16	1602-1900	1323.06	99.49	177.25	17.91	1875.57	315.33	884.70	-60.12	.40	.40
RP 17	1602-1961	1310.66	87.10	173.82	14.19	1875.57	315.33	884.70	-60.12	.42	.42

TABLE 2-16. Summary Table for Region 6, Southern Plains. Control Period: 1931-1960.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18
 FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1281.00 MIN 101.00
 ID: RAN96RAV 6 MODEL (CODE0): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 2: 1931-1960, SET NO. 4. AVG. OF GRID PTS: 17 21 55 74 88

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP-CONTROL PERIOD* *RP-RECON PERIOD*		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP 2	1931-1960	382.48		86.31		591.16		210.44		.39	
RP 1	1602-1625	400.26	17.78	100.17	13.87	547.65	-43.51	154.98	-59.46	.72	.33
RP 2	1626-1650	429.56	47.08	171.17	-13.14	546.35	-44.81	151.86	-81.42	.20	-.19
RP 3	1651-1675	385.37	2.88	100.61	-14.30	542.53	-48.63	108.82	-101.92	.23	-.05
RP 4	1676-1700	379.21	-3.28	93.22	6.91	553.13	-38.03	130.53	-179.92	.57	-.16
RP 5	1701-1725	416.67	33.75	98.16	11.86	581.93	41.65	251.74	41.87	.09	-.30
RP 6	1726-1750	351.61	-30.81	86.04	-16.26	473.08	-9.23	212.31	38.74	.15	-.24
RP 7	1751-1775	342.21	-40.27	69.54	-16.77	499.18	-118.08	246.13	32.83	.36	-.03
RP 8	1776-1800	382.61	.16	75.33	-12.56	493.27	-97.89	243.09	34.65	.14	-.24
RP 9	1801-1825	351.51	-30.97	73.16	-10.98	604.81	-13.67	197.10	-25.87	.05	-.02
RP 10	1826-1850	424.38	41.23	93.17	6.85	489.29	-101.87	184.58	-85.86	.19	-.34
RP 11	1851-1875	331.25	-51.90	74.13	-12.14	494.55	-196.61	124.82	-101.63	.46	-.07
RP 12	1876-1900	352.59	-20.99	82.13	6.36	553.13	-38.03	108.82	-85.86	.45	-.06
RP 13	1901-1925	398.58	16.10	86.44	2.13	632.81	41.65	124.58	-101.63	.43	-.04
RP 14	1926-1950	373.19	-9.29	86.98	3.67	604.81	41.65	108.82	-101.63	.43	-.04
RP 15	1951-1975	364.91	-17.57	90.23	2.92	632.81	41.65	108.82	-101.63	.39	.00
RP 16	1976-1900	378.83	-3.65								
RP 17	1901-1961	381.41	-1.07	89.20	2.89						

TABLE 2-17. Summary Table for Region 9, Great Lakes and Midwest. Control Period: 1931-1960.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18
 FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1310.00 MIN 70.00
 ID: RAN96RAV 9 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV
 CONTROL PERIOD 2: 1931-1960, SET NO. 5. AVG. OF GRID PTS: 29 30 39 40 41 43 58 62 87

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

***** *CP=CONTROL PERIOD* *RP=RECON PERIOD*		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP	2	1931-1960									
RP	1	1602-1625	834.55	74.66	52.33	687.36	350.85	845.95	158.59	.30	-.09
RP	2	1625-1650	1046.31	121.70	1303.18	845.95	334.16	885.55	198.18	.21	.21
RP	3	1650-1675	915.61	104.59	1286.47	885.55	171.44	717.62	30.23	.32	.06
RP	4	1675-1700	829.12	119.59	1123.77	717.62	111.63	677.14	-10.41	.36	.00
RP	5	1700-1725	874.05	105.20	1063.96	677.14	111.63	676.96	-95.89	.30	-.21
RP	6	1725-1750	913.76	99.20	1047.47	676.96	156.89	783.27	-21.99	.09	-.06
RP	7	1750-1775	831.92	93.71	1109.22	783.27	114.19	665.37	-31.13	.18	.21
RP	8	1775-1800	861.61	112.79	1066.51	665.37	163.97	622.69	35.13	.24	.06
RP	9	1800-1825	929.51	106.05	1120.27	622.69	222.55	643.35	-44.01	.29	.19
RP	10	1825-1850	874.08	145.92	1174.88	643.35	83.62	655.68	-26.68	-.08	.38
RP	11	1850-1875	811.61	88.62	1035.95	655.68	31.28	660.68	-10.23	.42	.12
RP	12	1875-1900	855.83	84.26	1303.18	660.68	350.85	677.14	-31.10	.25	-.05
RP	13	1900-1925	961.99	148.14	1120.30	677.14	222.55	643.35	-44.01	.20	.20
RP	14	1925-1950	870.33	108.14	1174.88	643.35	350.85	643.35	-44.01	.20	.20
RP	15	1950-1975	867.76	116.08	1303.18	643.35	350.85	643.35	-44.01	.20	.20
RP	16	1975-1990	899.82	132.29	1303.18	643.35	350.85	643.35	-44.01	.20	.20
RP	17	1990-1961	890.57	126.44	1303.18	643.35	350.85	643.35	-44.01	.20	.20

TABLE 2-18. Summary Table for Region 10, Southeast. Control Period: 1931-1960.

PROGRAM PROB FREQUENCY ANALYSIS, RUN ON 07/06/79 AT 11.13.18

FILE: RAN96R.MT2 ANNUAL 96 GRID PRECIPITATION IN MILLIMETERS. RANGE ANALYZED: MAX 1900.00 MIN 0.00

ID: RAN96RAV10 MODEL (CODED): ANNREC679 MODEL (FULL): ANNUALCOMBINED DEC-NOV

CONTROL PERIOD 2: 1931-1960, SET NO. 6. AVG. OF GRID PTS: 1 22 23 24 25 35 36 70 71 72

STATISTICS AND DIFFERENCES BETWEEN PAST RECONSTRUCTION PERIODS AND A CONTROL PERIOD

*****		MEAN	DIFF	SD	DIFF	MAX	DIFF	MIN	DIFF	FIRST- ORDER SERIAL R	DIFF
CP-CONTROL PERIOD											
RP-RECON PERIOD											
CP 2	1931-1960	1268.21		110.50		1507.67		1038.15		.50	
RP 1	1602-1625	1381.72	113.51	136.67	26.18	1668.27	160.60	1061.52	23.37	.20	-.32
RP 2	1626-1650	1373.23	305.02	137.39	26.69	1794.24	286.57	1312.50	274.35	.18	-.32
RP 3	1651-1675	1389.94	121.73	129.65	69.12	1743.47	235.80	1005.62	-32.52	.10	-.60
RP 4	1676-1700	1222.24	-45.98	127.41	16.92	1424.17	-83.50	972.36	-65.78	-.10	-.60
RP 5	1701-1725	1375.70	107.49	137.27	62.78	1875.57	367.90	1093.70	55.56	-.13	-.63
RP 6	1726-1750	1272.91	-51.69	137.87	27.38	1532.51	-37.83	979.81	-58.33	-.28	-.78
RP 7	1751-1775	1216.94	55.10	118.87	8.92	1469.90	73.03	1008.31	-23.52	.03	-.47
RP 8	1776-1800	1323.32	64.23	162.42	51.92	1583.46	73.78	1014.62	-2.90	.18	-.26
RP 9	1801-1825	1332.44	94.39	139.58	29.39	1580.70	189.47	1035.78	122.05	.19	-.32
RP10	1826-1850	1366.61	-81.81	164.37	29.87	1697.14	-4.18	916.09	-153.45	-.07	-.43
RP11	1851-1875	1186.40	-81.81	139.88	31.88	1503.49	-41.41	884.70	-65.78	.49	-.01
RP12	1876-1900	1237.55	-30.67	142.37	80.93	1466.26	286.50	972.36	-123.45	.27	-.22
RP13	1602-1700	1391.89	123.00	191.43	48.29	1794.24	367.90	884.70	-153.45	.28	-.08
RP14	1701-1800	1297.22	12.54	158.78	51.32	1875.57	189.47	884.70	-153.45	.42	-.10
RP15	1801-1900	1280.75	54.84	161.82	67.05	1675.14	367.90	884.70	-153.45	.40	
RP16	1602-1900	1323.06	42.44	177.55	63.33	1875.57	367.90	884.70	-153.45		
RP17	1602-1961	1310.66		173.82							