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HYDROMETEOROLOGICAL MODEL FOR STREAMFLOW PREDICTION

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CONTENTS

Appendices

ILLUSTRATIONS

TABLES

GLOSSARY

Accuracy. Goodness of fit between observed and predicted runoff. Given as the mean standard error of prediction or coefficient of prediction.

Calibration period. The period of time, in years, used to calculate the coefficients needed for seasonal forecasts in the verification period.

cfs-day. One cubic foot per second for 1 day (2447 m^3).

Coefficient of determination (R^2). A measure of prediction accuracy that compares the variance of predictions with the sample variance. Also, defined as the fraction of the variance explained by a model.

Coefficient of prediction (CP). A measure of forecast accuracy used to assess model reliability, derived from errors resulting from split-sample forecasts.

Forecast (See Prediction).

GWh. 10^9 watt-hours.

Linearized method (L). The technique that revises the initial prediction on the basis of a linear regression of test-season and prediction-season errors made during the verification period.

Mean. Arithmetic average of a sample for a specified period of years.

Mean standard error of prediction (MSEP). The root-mean-square-error divided by the arithmetic mean of the prediction-season runoff. Given as a percent.

Parameter. One of a set of six factors that controls prediction accuracy--for example, the date the winter season begins.

Period. A specified interval of time, in years, used in coefficient calibration, averaging variables, etc.

Prediction. The advance knowledge of a future event, such as seasonal streamflow, given as an approximate quantity and with a pre-determined range of probable error.

Prediction season. A specified interval of time, in days or months, for which a runoff prediction is made.

Residual method (R). A technique that revises the initial prediction on the basis of a linear regression between test-season and prediction-season residuals.

Root-mean-square-error (RMSE). The square root of the mean of the squares of split-sample prediction errors. Also called standard error of prediction.

Standard deviation (SD). The square root of the mean of the squares of the deviation from the arithmetic mean of the sample.

Standard error of estimate. The square root of the mean of the residuals resulting from a linear regression between two variables.

Summer season (See Prediction season).

Test season. A short (1-30 day) pre-forecast season, used to revise an initial prediction and reduce prediction error.

Verification period. The period of time, in years, that split-sample forecasts are made, to be used in evaluating model accuracy and reliability.

Winter season. The season occurring before the test season and used to accumulate precipitation and runoff for estimating basin water storage.

HYDROMETEOROLOGICAL MODEL FOR STREAMFLOW PREDICTION

(HM Model)

by Wendell V. Tangborn

ABSTRACT

The hydrometeorological model described in this manual was developed to predict seasonal streamflow from water in storage in a basin using streamflow and precipitation data. The model, as described, applies specifically to the Skokomish, Nisqually, and Cowlitz Rivers, in Washington State, and more generally to streams in other regions that derive seasonal runoff from melting snow. Thus the techniques demonstrated for these three drainage basins can be used as a guide for applying this method on other streams.

Input to the computer program consists of daily averages of gaged runoff of these streams and daily values of precipitation, collected at Longmire, Kid Valley, and Cushman Dam. An unweighted average of precipitation at Cushman Dam and Kid Valley is used for the prediction of Skokomish River runoff, precipitation at Longmire for the Nisqually River, and an average of precipitation at Kid Valley and Longmire for the Cowlitz River. Predictions are based on estimates of the absolute storage of water, predominantly as snow: storage is approximately equal to basin precipitation less observed runoff. A pre-forecast test season is used to revise the storage estimate and improve the prediction accuracy.

To obtain maximum prediction accuracy for operational applications with this model, a systematic evaluation of several hydrologic and meteorologic variables is

first necessary. Six input options to the computer program that control prediction accuracy are developed and demonstrated in this report. For current predictions on these streams, the parameter value demonstrating the greatest historic precipitation accuracy is provided.

Three methods which utilize different combinations of predictive equations are available. In general, for the greatest accuracy each method will apply to a different season. The computer program automatically selects that method which produced the most accurate predictions over a verification period, using a split-sample technique.

The relationship between observed downstream (adjusted for reservoir storage changes) and predicted upstream runoff is demonstrated and the procedure for making predictions at downstream sites is shown.

Predictions of streamflow can be made at any time and for any length of season although accuracy is usually poor for early-season predictions (before December 1) or for short seasons (less than 15 days). The coefficient of prediction (CP), the chief measure of accuracy used in this manual, approaches zero during the late autumn and early winter seasons and reaches a maximum of about 0.85 during the spring snowmelt season.

The computer program used to make predictions with this model is described and documented.

INTRODUCTION

Predictions of snowmelt runoff in the mountain regions of Western United States have traditionally been based on the relationship between snow surveys and subsequent runoff. The three streams used by the Tacoma City Light Public Utility for hydroelectric power generation are typical of this application and have had snow surveys conducted within their drainage basins since as early as 1940. The purpose of this manual is to describe and document a hydrometeorologic model that will be used to replace the snow survey method as a means to predict seasonal streamflow on Skokomish, Nisqually, and Cowlitz Rivers. The decision to adopt this prediction method was based on an analysis, made by the U. S. Geological Survey in 1976 in cooperation with Tacoma City Light, of predictions produced by both methods during the 1970-76 period. These comparison tests demonstrated that had the HM model been used to predict runoff during the seven snowmelt seasons beginning on January 1 and ending on July 1, the standard error of prediction would have been reduced by an average of 25 percent (Tangborn, 1977).

Since the above test was made, the computer program for the model has been revised extensively to allow more flexibility and to provide greater prediction accuracy. In addition to more accurate predictions, there are other advantages of this model not found in most other methods.

1. The elimination of snow surveys greatly reduces the cost of managing hydroelectric systems.
2. Versatility is increased because predictions can be made at any time for any length of season.
3. Implementation of real-time data collection is simpler and less expensive.

The chief application of this model is for predictions of snowmelt runoff on a seasonal basis (one or more months). However, the model can also be used during the main snowmelt season for short-season predictions (less than one month).

Several model-tuning techniques that affect prediction accuracy are available for use with this method. Each of these options is discussed in this report, and the function of each is demonstrated along with the parameter value, date, or method to be used in the computer program for the greatest accuracy in predicting seasonal streamflow within the three principal drainage basins. However, due to apparent climatic and perhaps man-made changes which affect the hydrology of these streams, the techniques described here for these drainages are valid only in a current application. All possible options and season combinations cannot be covered in this document; such factors as test-season length, optimum precipitation stations, period of record for calibration, and beginning date of the winter season must be reviewed annually, and the indicated corrections or revisions applied as needed for the most accurate runoff predictions of these streams. The computer program presented here is designed to test these options conveniently in order to determine the combination needed for the highest accuracy.

Application of this method to other regions, such as California, Arizona, Montana, Idaho, and Norway, has proven to be possible. However, a thorough analysis of the various options used to minimize prediction error must be made before operational forecasting can be implemented in other areas.

ACKNOWLEDGMENT

The assistance given by Clara Miller in the designing and writing of much of the basic computer program for this model is gratefully acknowledged. William Sikonia's advice and assistance in both computer programming and data-handling techniques were invaluable.

HYDROLOGIC SETTING

The three main basins making up the Tacoma City Light hydroelectric development are located in the eastern Olympic Mountains (the North Fork Skokomish River), and the south-central Cascade Mountains (the Nisqually and Cowlitz Rivers) of Washington State (fig. 1). Total annual hydroelectric production from runoff from these basins (which have a total area of 4,625 km^2 (1,785 mi^2)) is 2580 GWh. Total annual runoff is 8.10 x $10^9 m^3$ (6.56 x 10^6 acre-ft). Thus an average of about 320 Wh of power is produced from each m^3 of annual runoff. The average annual distributions of daily runoff and precipitation are demonstrated in figures 2 and 3, respectively; other pertinent statistics on each river basin and on the precipitation stations used in the model are given in table 1.

DESCRIPTION OF THE MODEL

The basic premise on which this streamflow prediction model is based is that precipitation caught by a sheltered, low-altitude gage is a superior index of total precipitation in a drainage basin than is precipitation caught by an exposed, high-altitude gage or measured by snow-survey observation. This obviously is true only when precipitation occurs in storms that cover large regions. Also, the premise assumes that basin storage (mostly as snow) can be estimated from the difference between calculated basin precipitation and observed runoff; and that if total storage is known, subsequent runoff can be estimated from the direct relationship that exists between basin storage and runoff. In order to determine the relationship of gage precipitation to basin precipitation, and that of basin storage to runoff, statistical linear regressions are made between winter precipitation and annual runoff. To improve this first estimate of basin storage, a short-season (1- to 30-day) test prediction is made just before the main prediction season. The error resulting from this test prediction reveals some added knowledge regarding the amount of stored water available for runoff. An updating of basin storage is then made, improving the accuracy of the main prediction of streamflow.

The selection of optimum precipitation stations and of such variables as the length of test season and starting date of the winter period is accomplished by making retrospective predictions for a large number of years (15 to 20) prior to the desired or current prediction.

Three basic equations form the gist of this model:

$$R^*_s = A_s(p_w + p_t) + B_s - R_w\ R_t \tag{1}$$

$$R^*_t = A_{t1}(p_w) + B_{t1} - R_w \tag{2}$$

$$R^*_t = A_{t2}(p_w + p_t) + B_{t2}\ \ R_w \tag{3}$$

where R^* = predicted runoff,

R = observed runoff,

p = observed gage precipitation (single or an average of stations),

and A_s, B_s, A_{t1}, B_{t1}, A_{t2} and B_{t2} are predictive coefficients determined by a linear regression of these variables. The subscripts s, w, and t denote summer (or prediction), winter and test seasons, respectively (fig. 4). The final predictive equation is derived from a combination of:

Equation 1 only, (method 1),
Equations 1 and 2, (method 2),
Equations 1 and 3, (method 3).

The determination of the combination to be used for a particular forecast is made on the basis of split-sample predications (the predictive coefficients used are those determined the previous year) made for at least 15 years. Generally, method 1 is superior for long-season (several months) predictions made early in the year (for example, December-July); method 2 for long-season predictions made during the main snow-melt season (March-May) and for nearly all short-season (less than a month) predictions; and method 3 is superior for both short– and long–season predictions made at the end of the season or after the main snow-melt season (June-July). For operational applications the computer program presented in this manual is designed to select automatically the prediction from that method which produced the lowest standard error during the verification period.

The derivation of the predictive equations and a detailed description of the model are presented by Tangborn and Rasmussen (1976), Tangborn and Rasmussen (1977), and Tangborn (1977). A recent revision in the basic concept has been the option of including precipitation in the test-season predictive equation (equation 3 and method 3). This addition significantly improves prediction accuracy in the late spring and summer prediction seasons, but it slightly decreases accuracy for earlier and longer seasons. The computer program is designed to make predictions using all three methods, and the year-by-year results for each method can be obtained in an extended output (option 2). Retrospective seasonal forecasts for the 1960-78 period, given as percent of observed runoff, are shown for the three streams in table 2.

PREDICTION ACCURACY ASSESSMENT

Prediction accuracy for these basins was tested by comparing the errors made in retrospective "predictions" using data covering 18 years with the standard deviation from the mean runoff for this 18-year period. Each prediction made from data for this 18-year period was based only on information collected up to the date on which the prediction was made; for example, the predictive coefficients used were obtained from data through the previous year by a splitsampling technique.

The root-mean-square-error (RMSE) of the standard error of prediction is determined by:

$$\mathrm{RMSE} = \left(\frac{\sum_{i=1}^{i=n} E_i^2}{N} \right)^{1/2} \qquad (4)$$

where E is the error for year i and n is the number of years for which test predictions were made. The standard deviation (SD) is determined by:

$$\mathrm{SD} = \left(\frac{\sum_{i=1}^{i=n} \Delta R_i^2}{n-1} \right)^{1/2} \qquad (5)$$

where ΔR_i is the deviation of the observed flow from the average flow for the period of record (n years) under consideration.

The coefficient of prediction (CP), a measure of predictability and of the fraction of the variance explained by the model, is approximated by:

$$\mathrm{CP} = 1 - \frac{(\mathrm{RMSE})^2}{(\mathrm{SD})^2} \qquad (6)$$

The prediction accuracy, given as CP for all downstream sites, is shown for each main season in table 5. For the three upstream sites the CP values produced by daily predictions throughout the December 1 to September 29 season are shown in figure 5.

The main feature of this method of assessing prediction accuracy is that is gives an approximate measure of a predictive model's value over the average flow as a prediction (the standard deviation can be considered an approximation of the error produced by using only the average flow). Thus, a value for CP near 1.00 indicates high accuracy, while a zero or negative value signifies that using the historic average flow as a prediction would be as useful. The earlier the prediction is made each winter, the less likely a predictive model will give positive values for CP; the reason for this is that subsequent precipitation is the dominant factor in producing runoff earlier in the season. There is some limit, less than 1.0, which CP cannot exceed regardless of how accurately basin storage is known. The maximum value is determined by both unpredictable precipitation and evaporative losses from the snowpack during the prediction season. In the computer program CP is designated as RSQ and its value is given on both output options.

The mean standard error of prediction (MSEP=RMSE/RMEAN) is another convenient way of illustrating prediction accuracy, particularly if an approximate measure of the relative mean error is desired (RMEAN is the mean runoff during the prediction season). The coefficient of variation (CV=SD/RMEAN), a measure of relative flow variability, is then easily compared with the mean standard error of prediction. As the coefficient of variation is a rough index of the relative mean error resulting from using the average discharge as a prediction, the difference between this and the mean standard error of prediction provides another useful measure of model value and reliability.

LEAP YEAR

A problem arises when it is necessary to form regressions of historic data which involve leap year. For example, a March 1 prediction with a one day test-season would encounter sets of runoff and precipitation data with unequal periods of record (February 29 would appear only once each 4 years) and prediction accuracy would undoubtedly be impaired. The solution to this dilemma is to place all February 29 values of both precipitation and runoff into February 28, and thus eliminate February 29 as a prediction day. The inability to make a prediction on February 29, when it appears every 4 years, seems to be the only significant effect of this alteration.

OPTIONS TO BE SELECTED BY THE FORECASTER

For a specific prediction day (the date for which the forecaster wishes a prediction), 7 options that determine prediction season and accuracy need to be considered. Each of these is discussed in the following sections, and optimum values to derive maximum accuracy are given for each. It is emphasized that any of these selections is subject to change from one year to the next, and that a review of all parameters should be made prior to the December 1 prediction each year.

Prediction Season Length

The season for which a runoff prediction is desired can range in length from 1 to 314 days (that is, a December 1-September 30 prediction). It does not need to follow the prediction day immediately; for example, a May 1-July 31 prediction can be made on April 25, or on any day previous to May 1 (fig. 4). The slight reduction in accuracy produced by neglecting these few days is outweighed by the advantages in flexibility.

Accuracy increases with season length, and a season less than approximately 5 days long is usually not predictable (CP is equal to or less than zero). However, short-term predictions are feasible, particularly during the main snowmelt season (March-June); if they are attempted their accuracy can be judged on the basis of the CP value.

Precipitation Station Selection

Nearly all weather stations operated by the National Weather Service in or near the three main drainage basins were tested for representativeness of basin precipitation (figure 1). The exceptions were those with long periods of missing or doubtful records. Monthly rather than daily increments of data were used in the evaluation because of the large quantity of data to be processed. The testing consisted of using each precipitation station to make retrospective predictions for the 1960–76 period of the main snowmelt seasons (March-July, April-July, and May-July). Thirty-six stations were initially tested against each of the three drainages that make up the major snowmelt runoff areas for Tacoma City Light's hydroelectric development, and only three (Cushman Dam, Kid Valley, and Longmire) were selected for operational applications (table 3). Of the 25-year period (1952-76) used in the evaluation, all the weather stations had missing records of precipitation, ranging from only a few days to several years. Filling in these missing records was performed by developing a historic relationship with a nearby weather station (one which also proved to be a good predictor of basin precipitation) and using the nearby station's record as a base for reconstructing a synthetic precipitation value. If precipitation observations were not made for several days but the cumulative value was recorded at the end of the missed period, the same base station was used to distribute the observed total through the period of lost record. The station pairings used to reconstruct the record for the three principal precipitation stations are as follows:

Applied Station	Base Station
Cushman Dam	Kid Valley
Kid Valley	Longview
Longmire	Kid Valley

The method used to calculate a missing precipitation value was a simple linear regression between the base and applied station in which the regression line passes through zero,

$$y_d = c\,x_d,$$

where c is a ratio of mean precipitation on those years when both stations had observations of the same day,

x_d = daily value of observed precipitation,

y_d = daily value of calculated precipitation, and

$$c = \frac{\Sigma\, y_d}{\Sigma\, x_d}$$

Precipitation values from the five stations producing the lowest standard error of prediction (for an average of the three snowmelt seasons) were averaged in ascending order. For example, daily values from the two lowest error stations were averaged with a 50 percent weighting for each, the lowest three stations with a 33.3-percent weighting for each, and so forth. The averaged precipitation values for the stations were then applied to each respective basin in a predictive sense for the 1960-76 period; the averaged set producing the lowest standard error was used as the value for the precipitation station for that basin (table 4).

Length of Period of Record

Prediction accuracy is strongly influenced by the period of record used to determine the predictive coefficients. An analysis made for several Sierra Nevada drainage basins suggests that prediction errors for the 1958-73 period are reduced by more than 10 percent by beginning the calibration period in 1952 rather than earlier or later (Tangborn and Rasmussen, 1977). The cause of this sensitivity is not known but it is believed to be related to a subtle but progressive change in climate, manifested by a change in the precipitation-runoff relationship. Preliminary analysis of the Skokomish, Nisqually, and Cowlitz data indicate that the late 1940's or the early 1950's is the optimum beginning time for application of this model to western Washington. However, a detailed analysis comparable to that in the Sierra Nevada is more difficult in this region because many of the precipitation and runoff stations used in this analysis have records that are too short or have been moved from their original sites. Also, there are signs that the optimum starting year is not static but is actually moving forward with time. This suggests that for optimum accuracy the period of record for coefficient calibration must be revised each year. A thorough study of this phenomenon is needed but is not within the scope of this manual. Such a study could easily be the subject of a separate report by itself. For these reasons all retrospective predictions were based on a calibration period beginning in 1952 (fig. 8).

Date of Beginning of Winter Season

The 13-month hydrologic year used in this model is divided into the winter, test, and summer (prediction) seasons. The winter season is defined as the period of each year in which daily values of runoff and precipitation are accumulated to determine basin storage. The average date on which the winter season begins is a sensitive parameter in prediction accuracy, as demonstrated by the results for one of these basins when this date was allowed to range between September 1 and November 30 (fig. 7). As with previous tests, retrospective predictions for the 1960-76 period were used to determine the optimum first day of winter. The dates which produced the lowest standard error for the three drainage basins, and the main prediction seasons, are given in table 5. The date varies with prediction day and there are indications that it also varies from year to year. Further study is needed to determine whether prediction errors can be significantly reduced by defining this day each year by some means related to the basin's absolute water storage. Perhaps a technique that utilizes the optimum beginning date for the test season could be eventually incorporated into the existing program.

Revising the Prediction with a Test Season

Revising the initial prediction by using an antecedent test season usually reduces the prediction error. The manner in which this is accomplished can be illustrated (figs. 9A and 9B) by plotting the initial prediction against test-season errors. The regression line produced by a fit of these points is then used in subsequent analysis to estimate a revised prediction by the test-season error. There are two methods of producing the linear regression line. In the residual method a calibration period is used to form a regression line from residuals; thus it has just one coefficient and passes through the origin (fig. 9A). If split-sample prediction errors are used instead of residuals (linearized method), a regression line of the form y = ax + b results because the average of these errors is not zero and the regression line (fig. 9B) does not pass through the origin. An advantage of the linearized method is that it makes it possible to reduce the mean prediction error by annually revising the relationship between test-season and prediction-season errors. The linearized method also appears to have some climatic implications as it is dependent on the period of years used for calibration. The disadvantage of the linearized method is that one degree of freedom is lost because of the added constant. The analysis made for these drainage basins suggests that the residual method gives the greatest accuracy when the last 18 years of predictions are considered. The linearized option is included here because it is related to the length of the calibration period and will likely be a significant factor when a detailed study of the optimum starting year is made.

Test-Season Length

The length of the test season (applied just prior to the prediction date) can be a critical factor in prediction accuracy. After the final precipitation station averages were selected, each basin was tested (using the station average of daily precipitation) to find the optimum number of days in a test season to produce the lowest standard error of predictions made during 1960-76 period. In most instances for the main snowmelt seasons (March-June to July), a 1 to 3 day season produces the highest accuracy for all of these drainages. A summary of test-season lengths determined for all seasons is given in table 5. Results for one basin and three seasons, when the number of test-season days was allowed to vary between 1 and 52 days, are illustrated in figure 7.

The test season operates by disclosing some knowledge of the error in estimating basin storage (as snow) in the initial determination (equation 1). Underestimating the amount of snow storage will usually produce a negative error (more runoff occurs than expected), and vice versa. However, if meteorological conditions during the test-season were unusual with respect to the effect on runoff, the effect of snow storage will be overridden. Therefore, a probable improvement in prediction accuracy would result by including a method to estimate ablation during the test season, particularly for short-season predictions (1 to 10 days).

RELATIONSHIP OF PREDICTIONS BETWEEN SITES UPSTREAM AND DOWNSTREAM OF RESERVOIRS

Streamflow records collected below a reservoir are subject to sizeable deviations from natural flow because of regulation by the reservoir and of large fluctuations in reservoir levels. Adjustments for changes in reservoir content to determine the natural flow below a reservoir are not always satisfactory because of difficulties in accurately measuring the total change in reservoir storage; these difficulties are probably due chiefly to wind effects and bank storage. Because observed stream discharge is an integral part of the input to this model, accurate records of this variable are essential. Therefore, it is necessary to utilize the upstream gaging station data (above each reservoir) to predict more accurately the inflow to the reservoir. The adjusted streamflow record at the downstream gaging station is usually not as satisfactory for this purpose. Discharge records are also more easily and rapidly obtained at upstream sites because adjustments for storage are not needed.

Comparison tests of prediction accuracy at these below-reservoir sites for the 1960-76 period show that even though the drainage areas for the upper gages represent only 46 to 74 percent of the total areas, superior runoff predictions are produced at the downstream gage when data from just the upstream station are used in the calculations. Disregarding the low-altitude parts of these drainage basins does not appear to impair prediction accuracy because snow storage (on which this model bases the predictions) is usually negligible at lower altitudes in this region. A linear relationship between predicted runoff at the upper gaging stations and observed runoff at the lower stations was developed for the main seasons from 1960-76 predictions. Predictions for the lower gaging stations for other periods are made by the combination of this relationship and the upstream predictions, using the following equation:

$$R_D^{**} = A_1 R_U^{*} + B_1 \tag{9}$$

where R_U^{*} is the predicted runoff of an upstream station and R_D^{**} is the predicted runoff of the downstream site; A_1 and B_1 are coefficients determined by a linear regression fit between predicted upstream and observed downstream runoff.

Linear regressions were also made between the runoff at lower Nisqually River gage (12-0825) plus that of Mineral Creek (12-0830). These results show that more accurate predictions for all seasons can be made by disregarding Mineral Creek runoff in the prediction calculation, even though it is about one-quarter of the total drainage. Similarily, predictions for the main station on the Cowlitz River (14-2380, at Mayfield Dam) were made using the combination of the Cowlitz River near Randle (14-2334) plus Tilton River near Cinnabar (14-2362). More accurate predictions of station 14-2380 can be made for most seasons when the Tilton River runoff is not included with that of the main Cowlitz drainage. (See fig. 1 for locations of these drainages and table 7 for results of these comparisons.)

Below-reservoir predictions

Predictions of total reservoir inflow are automatically made for the three Tacoma City Light basins by utilizing the upstream (above-the-reservoir) gaging–station predictions together with linear coefficients which describe the historic upstream-downstream relationship of observed seasonal runoff (table 6). The computer program is designed to select the correct coefficients from the set shown in table 6, which are read in at the beginning of each run, and to calculate the below-reservoir predicted runoff, the root-mean-square error, and the 95–percent confidence-limit prediction. As the only historical runoff data available at these downstream sites is in monthly increments, it is necessary to have an interpolation procedure in the program to obtain coefficients for seasons beginning within the month (e.g., February 15). Only seasons ending on July 31 and September 30 are shown in table 6; if other season endings are desired, it will be necessary to determine the upstream-downstream relationship for each of these. The downstream prediction is calculated by:

$$R_D^* = A_2 R_U^* + B_2 \qquad (10)$$

where R_D^* = predicted downstream runoff,

R_U^* = predicted upstream runoff, and

A_2, B_2 = linear regression coefficients based on a fit between observed runoff at both sites, for the 1952-76 period.

Note that equation 10 is slightly different than 9.

The root-mean-square error for the downstream prediction is given by:

$$\sigma = \left(A_2^2 \delta^2 + \varepsilon^2\right)^{1/2}, \qquad (11)$$

where σ = root-mean-square error of downstream prediction,

A_2 = slope of regression line (equation 10),

δ = root-mean-square error of upstream prediction,

ε = standard error of a linear regression fit between observed upstream and downstream runoff (equation 10).

The approximate 95 percent confidence limit for the downstream site is given by:

$$R_{95}^* = R_D^* - 1.645\sigma ,$$

and signifies that there is a 95 percent probability that the observed runoff will exceed this value. Examples of both upstream and downstream predictions are shown in Appendices F and G.

PREDICTION PROCEDURE

Data Preparation

No less than 5 years (25 appears to be optimal) of daily values of streamflow and precipitation must be stored in a computer-retrievable form in order to make predictions. These data can be first keypunched onto cards (see format and coding examples in appendix A), then transcribed as card images onto disk or tape. As each prediction requires that both precipitation and runoff data be brought up to date (to the day just before the prediction), some means must be designed to add recent data to the stored historic record. A concatenation technique is demonstrated in appendix I. Streamflow is recorded as mean daily flow in cubic feet per second and precipitation is in inches per day (water equivalent). Both are in the units of collection to avoid conversion errors. Precipitation values are mailed weekly by each observer (fig. 11), but observations can also be obtained by phone for mid-week or emergency predictions. Streamflow observations from the real-time net (station 12-0565, 12-0825, and 14-2334) can be formed into daily averages for more frequent predictions. However, these temporary daily values must eventually be replaced by runoff data that have been adjusted for rating shifts and have had a quality-control review.

Parameter Selection

Each parameter that affects prediction accuracy is selected by a systematic process to reduce prediction error. Implementation of this method in other drainage basins will require detailed testing and analysis. In each of the five following steps the model is first used to obtain the optimum value, method, or precipitation station; operational predictions can then be made with the maximum accuracy. The steps of selection are:

1. Individual precipitation station and the final average to be used for each basin.

2. Period of record used for calibration.

3. Beginning date for the winter season.

4. Test-season length.

5. Residual or linearized method of revising the prediction.

COMPUTER PROGRAM PREPARATION

Parameter cards

There are 6 parameter cards needed for a single prediction (appendix D). The first five cards describe basin number and name, precipitation station number and name(s), beginning and ending years, and the year when retrospective predictions began (for an evaluation of prediction accuracy). The 6th card sets the prediction, test and winter seasons, the linear or ratio and the output print options. As many of the number 6 parameter cards as desired can be included in a single run, thus any of the options designated on this card can be tested simultaneously to obtain maximum prediction accuracy.

A listing of the data and of the parameter cards for a sample run are given in appendix E, and the results of this run in appendix F and G.

Storage and time requirements

The computer program requires approximately 230,000 bytes (8 bits per byte) of core storage for execution on an IBM 370, computer, Model 155. A single prediction, including reading all the necessary data and making test-predictions for 15-20 years to determine accuracy, requires a total of approximately 23 seconds of CPU time. Thus, a prediction made each day from December 1 to September 1 (275 days) would use about 1.75 hours of computer time. Each additional prediction in the same run (corresponding to each additional number 6 parameter card) requires approximately 0.23 seconds.

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Appendix A. Sample precipitation data input (Longmire)

← Daily precipitation, in inches →															
Cols. 1-5	Cols. 6-10	Cols. 11-15	Cols.16-20	Cols. 21-25	Cols. 26-30	Cols. 31-35	Cols. 36-40	Cols. 41-45	Cols. 46-50	Cols. 51-55	Cols. 56-60	Col. 65 Card No.(3 per month)	Cols. 69-72 Water year	Col. 75 Month (Oct=1)	Cols. 77-80 Station index no.
.	.	.56	.78	.03	.77	.	.16	.27	.30	.40	.	1	1976	1	6894
1.20	.	.	.	.23	.81	.67	.42	.47	.39	.05	.01	2	1976	1	6894
.30	1.30	.08	.22	1.14	1.67	.23	.	.	.	.	.	3	1976	1	6894
.48	.12	.97	.	.	.34	1.27	.52	.53	.23	.18	.05	1	1976	2	6894
.	.63	1.08	.29	.41	.	.	.	.	.	.98	.95	2	1976	2	6894
.55	1.45	.84	.21	.	.89	.	.	.	.	.	.	3	1976	2	6894
.06	3.84	1.4	3.23	.02	.	1.51	1.53	.08	.	.	.10	1	1976	3	6894
.74	.	.92	.	.	.	.	.	.	.48	.64	1.53	2	1976	3	6894
.	1.53	.70	.03	.49	.77	.36	.	.	.	.	.	3	1976	3	6894
.	.	.03	1.60	.08	.98	.20	.94	.41	.19	1.49	.83	1	1976	4	6894
.09	1.31	3.57	1.66	.	.14	.	.	.	.09	.40	.	2	1976	4	6894
.	.	1.19	.05	.	.	.	.					3	1976	4	6894
.	.	.	.02	.	.	.	.	.23	.	.06	.97	1	1976	5	6894
.36	.64	.17	1.24	.59	1.27	.16	.21	.	.	.25	.49	2	1976	5	6894
.76	.44	.41	.73	.12	.	.	.	.	.	.	.	3	1976	5	6894
.	.	.	.	.	.	.	.	.	.	.39	.	1	1976	6	6894
.18	.30	.	.	.01	.14	.86	.58	.36	.23	.18	.73	2	1976	6	6894
.47	.43	.65	.57	.35	.	.13	.	.	.	.	.	3	1976	6	6894
.02	.	.	.	.	.16	.	.62	.	.	.48	.	1	1976	7	6894
.	.	.	.78	.	.	.04	.64	.02	.05	.	.23	2	1976	7	6894
.44	.	.	.	.	.	.	.	.	.	.	.	3	1976	7	6894
.	.61	.03	.	.19	.08	.	.	.	.40	.90	.	1	1976	8	6894
.	.	.	.	.	.	.	.33	.	.	.05	.10	2	1976	8	6894
.	.	.45	.35	.03	.48	.08	.	.	.	.	.	3	1976	8	6894
.35	.18	.01	.	.	.	.	.10	.26	.	.05	.41	1	1976	9	6894
.53	.02	.	.	1.35	.	.	.	.	.	.	.	2	1976	9	6894
.15	.	.	.	.	.02	.	.	.	.	.	.	3	1976	9	6894
.32	.15	.20	.34	.35	.	.05	1.35	.11	.	.08	.08	1	1976	10	6894
.	.	.	.	.	.	.	.03	.	.	.	.	2	1976	10	6894
.	.	.	.	.	.	.	.	.	.	.	.	3	1976	10	6894
.	.	.89	.	.05	.06	1.09	.80	.06	.	.	.	1	1976	11	6894
.	.24	.70	.71	.09	.08	.	.55	.	.	.	.	2	1976	11	6894
.53	.26	.01	.	.	.	.	.	.	.	.	.	3	1976	11	6894
.	.	.	.	.07	.17	.10	.	.	.	.	.25	1	1976	12	6894
.02	.32	.22	.	.02	.03	.	.	.	.10	.13	.	2	1976	12	6894
	.	.	.	.	.	.	.	.	.	.	.	3	1976	12	6894

Appendix B. Sample runoff data input (Nisqually R.)

← Mean daily discharge, in cubic feet per second →												Region No.	Card No. (3 per month)	Water year	Month (Oct=1)	Basin No.
Cols. 1-5	Cols. 6-10	Cols. 11-15	Cols. 16-20	Cols. 21-25	Cols. 26-30	Cols. 31-35	Cols. 36-40	Cols. 41-45	Cols. 46-50	Cols. 51-55	Cols. 56-60	Cols. 62-63	Col. 65	Cols. 69-72	Col. 75	Cols. 77-80
444	476	500	440	348	348	282	260	280	300	276	260	12	1	1976	1	825
252	252	380	303	379	567	680	645	595	540	472	432	12	2	1976	1	825
555	698	620	610	1270	2010	1470	0	0	0	0	0	12	3	1976	1	825
1160	1250	1520	1390	1270	1230	1170	1000	872	770	680	625	12	1	1976	2	825
595	1010	1810	1440	1120	926	800	704	640	620	776	1330	12	2	1976	2	825
1420	1560	1320	1090	926	1180	0	0	0	0	0	0	12	3	1976	2	825
3660	7300	8380	8720	3440	2340	2490	3090	2490	1940	1590	1300	12	1	1976	3	825
1050	800	850	820	760	720	690	660	640	800	1000	1500	12	2	1976	3	825
1300	2810	2380	1760	1920	1880	1570	0	0	0	0	0	12	3	1976	3	825
1300	1050	900	1500	1350	1100	1100	1300	1100	960	960	880	12	1	1976	4	825
800	1400	5280	5060	3010	2170	1660	1300	1100	1050	1000	900	12	2	1976	4	825
820	780	1300	1200	1050	984	915	0	0	0	0	0	12	3	1976	4	825
870	835	803	742	671	643	620	593	559	528	525	597	12	1	1976	5	825
605	583	548	720	752	709	637	585	558	556	576	600	12	2	1976	5	825
550	500	540	510	480	0	0	0	0	0	0	0	12	3	1976	5	825
450	420	400	390	380	370	360	360	370	390	380	369	12	1	1976	6	825
364	361	353	366	431	505	503	491	466	546	543	736	12	2	1976	6	825
646	595	560	531	484	478	516	0	0	0	0	0	12	3	1976	6	825
473	451	448	480	567	710	731	994	1010	1010	1190	1070	12	1	1976	7	825
951	855	789	690	635	596	574	697	640	614	590	663	12	2	1976	7	825
669	622	603	647	757	1040	0	0	0	0	0	0	12	3	1976	7	825
1410	1950	1630	1420	1300	1200	1240	1490	1780	1900	1700	1440	12	1	1976	8	825
1500	1470	1330	1360	1340	1140	1050	955	918	972	999	989	12	2	1976	8	825
993	937	1140	1090	967	892	809	0	0	0	0	0	12	3	1976	8	825
747	698	649	620	603	624	672	824	884	973	946	932	12	1	1976	9	825
873	770	877	1740	1560	1490	1540	1410	1230	1090	976	907	12	2	1976	9	825
854	771	797	924	1080	1030	0	0	0	0	0	0	12	3	1976	9	825
991	900	888	930	992	1090	1200	1720	1310	1020	914	926	12	1	1976	10	825
860	878	944	1050	1080	1020	968	974	914	812	908	992	12	2	1976	10	825
968	896	818	788	842	848	776	0	0	0	0	0	12	3	1976	10	825
746	734	770	728	680	746	932	830	734	704	734	746	12	1	1976	11	825
728	610	692	640	545	495	472	595	580	610	620	686	12	2	1976	11	825
764	620	525	595	650	686	770	0	0	0	0	0	12	3	1976	11	825
794	680	630	625	635	545	440	404	404	444	520	490	12	1	1976	12	825
420	472	452	468	456	464	555	650	698	640	525	530	12	2	1976	12	825
530	540	545	595	630	605	0	0	0	0	0	0	12	3	1976	12	825

Appendix C. Example of card input of upstream-downstream relationship, used to calculate below-reservoir prediction.

cols. 2-3	cols. 5-6	cols. 7-12	cols. 13-20	cols. 21-30	cols. 31-40	cols. 41-56	cols. 77-80
3	10	2.150	-31275.	447074.	22566.	LA GRANDE DAM	865
3	12	2.068	-39716.	487650.	22988.	LA GRANDE DAM	865
4	10	2.059	-22173.	372707.	19061.	LA GRANDE DAM	865
4	12	1.977	-30117.	413282.	20080.	LA GRANDE DAM	865
5	10	1.889	-11138.	293267.	18248.	LA GRANDE DAM	865
5	12	1.811	-16820.	333843.	20223.	LA GRANDE DAM	865
6	10	1.781	-8959.	237179.	16388.	LA GRANDE DAM	865
6	12	1.702	-12858.	277755.	18391.	LA GRANDE DAM	865
7	10	1.566	1696.	188644.	14497.	LA GRANDE DAM	865
8	10	1.429	161.	138072.	10095.	LA GRANDE DAM	865
7	12	1.501	1274.	229219.	16392.	LA GRANDE DAM	865
8	12	1.382	317.	178648.	12235.	LA GRANDE DAM	865
9	10	1.286	-219.	80128.	6695.	LA GRANDE DAM	865
9	12	1.262	858.	120704.	9273.	LA GRANDE DAM	865
10	10	1.061	3695.	33212.	2687.	LA GRANDE DAM	865
10	12	1.107	7024.	73788.	5667.	LA GRANDE DAM	865
11	11	1.015	3685.	22472.	1475.	LA GRANDE DAM	865
11	12	1.349	-3219.	40576.	3485.	LA GRANDE DAM	865
12	12	1.744	-6243.	18104.	1645.	LA GRANDE DAM	865
						LA GRANDE DAM	

downstream station no.

dam above downstream station

standard error of linear regression between upstream and downstream runoff (in cfs-days)

average discharge at downstream station (in cfs-days)

intercept (B_2) of linear regression line

slope (A_2) of linear regression line

last month (M4) of prediction season

first month (M_3) of prediction season

Appendix D Parameter card descriptions

Parameter Card Number 1

Column(s)	Name	Description	Format
1-15	STREAM	Stream name	4A4
16-20	NREG	Region number, (R.A.). R.A. = Right adjusted	I5
21-25	NSTA	Basin number, (R.A.).	I5
26-35	DRAREA	Basin drainage area in square miles.	F10.1

Parameter Card 2

Column(s)	Name	Description	Format
1-5	NPRE	Number (4 digit) of precipitation station used for predictions (R.A.).	I5
6-10	NPS	Number of precipitation stations used in averaging (R.A.).	I5

Parameter Card 3

Column(s)	Name	Description	Format
1-12	NPSTA	Name of 1st precipitation station	3A4
13-24	"	" 2nd "	"
25-36	"	" 3rd "	"
37-48	"	" 4th "	"
49-60	"	" 5th "	"

Appendix E. Example of parameter card input (to produce output show in Appendices F and G).

column 1	column 11	column 21	column 31	column 40	columns 44-45	column 47	parameter card no.
NISQUALLY	R	12 0825	133.				1
6894	1						2
LONGMIRE							3
52	78						4
56	60						5
OCT21	MAY 1	MAY 2	JUL31	R	1	1	6-1
OCT21	MAY 1	MAY 2	JUL31	R	1	2	6-2

output print option
test-season length (days)
Linearized or Residual option
date prediction season ends
date prediction season begins
date of prediction
date winter season begins

Appendix D (cont)

Parameter Card 4

Column(s)	Name	Description	Format
1-5	YR1	First year of data 2 digits (R.A.)	I5
6-10	YR2	Last year of data (2 digits), (R.A.) Will include prediction statistics for this year if NCF is zero.	I5
11-15	NCF	Final year (2 digits) if prediction is to be made this year (all averages, standard deviation, other computations are through the previous year only)	I5

Parameter Card 5

Column(s)	Name	Description	Format
1-5	YRERR	Mid-year (2 digits), (Linear error accumulation begins this year). (R.A.)	I5
6-10	YRPRE	The year predictions began (2 digits). (The accumulation of the retrospective standard error of each prediction begins this year). (R.A.)	

Parameter Card Numbers 6 and above

Column(s)	Name	Description	Format
1-3	M1A	Month in which winter season begins (3 letter designation)*	A3
4-5	M1D	Day which winter season begins, R.A.	I2
11-13	M2A	Month in which prediction is made	A3
14-15	M2D	Day of prediction, R.A.	I2
21-23	M3A	Month in which prediction season begins	A3
24-25	M3D	Day which prediction season begins R.A.	I2
31-33	M4A	Month in which prediction season ends	A3
34-35	M4D	Day which prediction season end, R.A.	I2
40	NX	Linearized or residual method (designated by L or R)	A1
44-45	NI	Test-season length (days), R.A.	I5
47	IX	Output option	I2
		1 = Final year prediction summary	
		2 = Full output; year-by-year predictions, winter, test and prediction season values of precipitation and runoff, prediction equation coefficients.	

*SEP, OCT, NOV, DEC, JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG

As many cards as necessary giving these parameters can be added. Each successive card needs only those parameters that are to be changed. If left blank, the original parameter value will be retained in all subsequent calculations.

Appendix F. Sample run, output print option #1

```
 BASIN NO 12  825 NISQUALLY R     PRECIP STA NO 6894
  D.A.=  133.0 SQUARE MILES                     AVG OF LONGMIRE

 [1]METHOD 3        [2]RESIDUAL REVISION       [3]PREDICTION DATE MAY  1 1978


 [4]PREDICTION SEASON MAY  2-JUL 31 78  | [9]PREDICTION              82963. CFS-DAYS
                                        |
 [5]WINTER SEASON    OCT 21-APR 29      |[10]STANDARD ERROR           9610. CFS-DAYS
                                        |
 [6]TEST SEASON LENGTH      1 DAY(S)    |[11]95% CONFIDENCE          67155. CFS-DAYS
                                        |
 [7]OCT 21-APR 30 PRECIP % OF MEAN 105. |[12]STD. DEVIATION          24294. CFS-DAYS
                                        |
 [8]OCT 21-APR 30 RUNOFF % OF MEAN 117. |[13]1952-1978 MEAN          93643. CFS-DAYS

[14]MAY  2-JUL 31 1978 PREDICTED RUNOFF % OF MEAN=   89.

[15]COEFFICIENT OF PREDICTION SINCE 1960    0.844



     DOWNSTREAM STATION  865      LA GRANDE DAM

     [16]PREDICTION=         118320. CFS-DAYS [17]% OF MEAN   87.

     [18]STD ERROR            16943. CFS-DAYS [19]MEAN ERROR = 12.4 %

     [20]95 % CONFIDENCE      90449. CFS-DAYS

     [21]MEAN=               136203. CFS-DAYS
```

Appendix F (continued). Explanation for output given by print option #1

1. Prediction equation which produced the highest CP during the verification period.
2. Method used to revise the storage estimate, using a test-season.
3. Date on which forecast is made.
4. Season for which forecast is made.
5. Season in which basin precipitation and runoff is accumulated.
6. Length of pre-forecast test-season.
7. Dates of the winter plus test-season precipitation and this year's percent of the 1952-77 average.
8. Dates of the winter plus test-season runoff and this year's percent of the 1952–77 average.
9. Predicted runoff for the season given in 4.
10. The root-mean-square-error for this prediction.
11. The 95 percent confidence prediction, signifies that there is a 95 percent probability that the actual runoff will exceed this value.
12. Standard deviation from the mean runoff for this prediction season.
13. The average prediction season runoff for the 1952-77 period.
14. The predicted runoff as a percent of the 1952-77 mean.
15. The coefficient of prediction (CP) for the 1960-77 verification period.
16. The predicted runoff for the downstream station below the La Grande Dam (adjusted for reservoir storage changes).
17. The downstream runoff prediction as a percent of the average for this season.
18. The root-mean-square-error for this prediction.
19. The mean standard error of prediction.
20. The 95 percent confidence prediction for the downstream station.
21. The average (1952-77) runoff at the downstream station for the May 2-July 31 prediction season.

Appendix G. Sample run, output print option #2

```
BASIN  825   PRECIPITATION STATION 6894   PREDICTION SEASON MAY  2-JUL 31
WINTER SEASON OCT 21-APR 29   TEST SEASON APR 30-APR 30   FORECAST MAY  1
   FIRST YEAR   52     MID YEAR FOR LINEAR METHOD   56           OPDAY 5

                         RESIDUAL METHOD , PREDICTION IN 1000 CFS-DAYS

     ACTUAL        NO TEST SEASON                   TEST SEASON   TEST SEASON, PRECIPITATION
YEAR     RS        RS*       E      RMSE          RS**      E      RMSE         RS**      E      RMSE

1960    93.3       70.8   -22.51   22.51          72.6   -20.73   20.73         73.0   -20.37   20.37

1961    92.2       94.9     2.76   16.04          99.8     7.62   15.62         99.9     7.80   15.42

1962    69.7       67.1    -2.63   13.18          72.6     2.90   12.86         73.1     3.41   12.75

1963    59.8       56.6    -3.14   11.52          63.8     4.09   11.32         64.3     4.54   11.27

1964   126.1      123.8    -2.30   10.36         117.5    -8.55   10.83        117.4    -8.73   10.81

1965    72.3       59.5   -12.81   10.81          64.9    -7.34   10.33         65.2    -7.09   10.28

1966    84.4       82.3    -2.02   10.03          80.0    -4.35    9.70         80.0    -4.32    9.66

1967   103.0      109.9     6.87    9.69         107.2     4.15    9.19        107.2     4.14    9.15

1968    73.4       71.2    -2.18    9.17          75.7     2.28    8.70         75.8     2.39    8.67

1969    97.9       81.1   -16.82   10.20          82.1   -15.82    9.65         82.2   -15.72    9.61

1970    75.8       85.9    10.07   10.19          86.1    10.31    9.71         85.9    10.09    9.65

1971   128.5      128.8     0.31    9.75         123.6    -4.90    9.41        123.5    -5.04    9.36

1972   134.6      150.4    15.80   10.34         145.8    11.18    9.56        145.6    10.97    9.49

1973    67.4       75.4     7.91   10.19          74.2     6.72    9.38         74.2     6.78    9.32

1974   138.7      125.4   -13.32   10.43         124.8   -13.91    9.75        124.8   -13.90    9.70

1975   105.8      102.6    -3.22   10.13         100.3    -5.51    9.54        100.3    -5.52    9.49

1976    97.2       78.2   -19.02   10.85          85.9   -11.26    9.65         86.2   -10.98    9.58

1977    67.0       69.8     2.82   10.57          65.9    -1.15    9.38         65.9    -1.12    9.32

1978    69.1       77.3     8.20   10.46          82.8    13.67    9.65         83.0    13.87    9.61

                                                                                                    NYR
MEAN    93.6     27 YRS    -2.38                           -1.61                         -1.52       19
  SD    24.29                                                                                        19
  CV    0.263                                                                                        19
  CP               0.815                          0.842                         0.844               19
```

Appendix G. (continued) Sample run, output print option #2

```
BASIN  825   PRECIPITATION STATION 6894   PREDICTION SEASON MAY  2-JUL 31
WINTER SEASON OCT 21-APR 29   TEST SEASON APR 30-APR 30    FORECAST MAY  1
   FIRST YEAR   52     MID YEAR FOR LINEAR METHOD   56           OPDAY 5

                                              VARIABLES AND COEFFICIENTS

                                                         PREDICTION COEFFICIENTS                                   ERROR COEFFICIENTS
YEAR        WINTER             TEST            AS       BS      AT1      BT1        AT2      BT2         C1        BE1        C2         BE2
          PW       RW       PT       RT        NO TEST          TEST, NO PRECIP        TEST WITH PRECIP
        INCHES  1000.    INCHES  1000.
                CFSDAYS          CFSDAYS

1960    65.17  173.70    0.0      0.81     3365.    26055.    2395.    -7751.    2425.  -10199.     0.068     0.0      0.080     0.0

1961    78.83  198.36    0.17     1.52     3393.    26761.    2433.    -7313.    2458.   -9360.     0.316     0.0      0.334     0.0

1962    54.90  145.51    0.05     0.73     3355.    28972.    2642.   -19424.    2663.  -21361.     0.268     0.0      0.284     0.0

1963    56.41  161.65    0.06     0.60     3331.    30743.    2459.    -5741.    2472.   -7016.     0.247     0.0      0.259     0.0

1964    68.06  133.45    0.08     0.68     3311.    32329.    2269.     8837.    2275.    8025.     0.215     0.0      0.222     0.0

1965    64.64  186.21    0.10     1.17     3318.    32035.    2171.    12847.    2180.   11918.     0.160     0.0      0.167     0.0

1966    46.22  103.35    0.02     0.61     3322.    32677.    2184.    14475.    2191.   13657.     0.204     0.0      0.209     0.0

1967    68.26  149.20    0.0      0.36     3299.    34282.    2315.     5434.    2319.    4878.     0.195     0.0      0.201     0.0

1968    64.15  174.05    0.17     0.78     3277.    35250.    2269.     7475.    2275.    6794.     0.205     0.0      0.210     0.0

1969    59.07  147.10    0.0      0.76     3278.    35294.    2281.     8042.    2287.    7330.     0.197     0.0      0.202     0.0

1970    57.10  139.24    0.60     0.51     3231.    39210.    2267.     9200.    2272.    8598.     0.209     0.0      0.216     0.0

1971    76.53  156.86    0.0      0.73     3266.    36501.    2263.     9517.    2271.    8621.     0.208     0.0      0.215     0.0

1972    92.05  186.00    0.09     0.89     3263.    36636.    2073.    20306.    2085.   19261.     0.191     0.0      0.198     0.0

1973    46.23  114.18    0.0      0.45     3091.    47101.    1809.    36266.    1818.   35441.     0.226     0.0      0.232     0.0

1974    87.21  190.97    0.0      1.06     3141.    43517.    1842.    33901.    1849.   33242.     0.230     0.0      0.237     0.0

1975    63.39  140.07    0.0      0.40     3229.    38357.    1826.    34890.    1833.   34188.     0.226     0.0      0.232     0.0

1976    78.20  211.76    0.0      1.04     3228.    38599.    1830.    34156.    1838.   33447.     0.218     0.0      0.225     0.0

1977    35.15   79.90    0.0      1.00     3296.    34872.    1959.    27166.    1966.   26453.     0.262     0.0      0.268     0.0

1978    67.61  179.67    0.0      0.69     3315.    33552.    2059.    20135.    2064.   19586.     0.260     0.0      0.267     0.0

 SUMMER MEANS:     8.93 = PRECIP              94. = RUNOFF

                   0.254 =RSQ1      0.265 =RSQ2      (SIGNIFICANCE OF TEST-SEASON)
```

Appendix G (continued). Explanation of print option #2

NO TEST SEASON =Prediction results without a test-season, Method #1.

TEST SEASON = Prediction results when test-season is used without precipitation.

TEST SEASON, PRECIPITATION = prediction results when test season is used with precipitation.

RS = observed runoff during the prediction season.

RS^* = predicted runoff during the prediction season.

E = prediction error, $RS^* - RS$

RSME =root-mean-square-error, $\left(\frac{\Sigma E^2}{n}\right)^{1/2}$

MEAN = Average prediction season runoff for the calibration plus verification period.

SD = standard deviation from the mean prediction season runoff.

CV = coefficient of variation of the prediction season mean runoff.

CP = coefficient of prediction for each of the three methods.

Appendix G (continued). Explanation of output print option #2 (variables and coefficients)

Annual values

PW = winter season precipitation in inches

RW = winter season runoff in 1000^s of cfs-days

PT = test-season precipitation

RT = test-season runoff

AS,BS = slope and intercept of line formed by regression of winter plus summer season runoff and winter precipitation

AT1,BT1 = slope and intercept of line formed by regression of winter plus test–season runoff and winter precipitation

AT2,BT2 = slope and intercept of line formed by regression of winter plus test–season runoff and winter plus test-season precipitation

C1, BE1 = slope and intercept of line formed by regression of prediction and test–season errors (no precipitation in test-season)

C2, BE2 = slope and intercept of line formed by regression of prediction and test-season errors (precipitation in test-season)

PRECIP = average summer precipitation in inches

RUNOFF = average summer runoff in 1000^s of cfs-days

RSQ1 = coefficient of determination of linear regression between prediction and test-season errors (no precipitation in test-season)

RSQ2 = coefficent of determination of linear regression between prediction and test-season errors (precipitation included in test-season)

Appendix H. Computer program listing

```
*  T  T    Y *                                                        PAGE
                T[illegible] MODEL  US GEOLOGICAL SURVEY

C       [illegible] PROGRAM. [illegible] MODEL    US GEOLOGICAL SURVEY
C                   [illegible]    WATER RESOURCES DIVISION
C                                 TACOMA, WASHINTON
C       SNOWMELT RUNOFF PREDICTIONS BASED ON LOW ALTITUDE
C       PRECIPITATION AND RUNOFF OBSERVATIONS
C       DATE OF LAST REVISION  DEC 1977
C     **************************************************************
C
        INTEGER YR1,YR2,YR[illegible],YPERR,YRCUR,PAT,SEP
        DIMENSION [illegible](13), Z(13), STREAM(4)
        COMMON /[illegible]/ [illegible],B3
        COMMON /[illegible]/ [illegible],M2,M20,M3,M30,M4,M40,IX,ID,IF
        COMMON /[illegible]/ M1X,[illegible],M2X,M20X,M3X,M30X,M4X,M40X,NX,NXX
        COMMON /[illegible]/ RS(40),ES1(40),ES2(40),ET1(40),ET2(40),NPSTA(3,10)
        COMMON /[illegible]/ [illegible](13),NDAY(13)
        COMMON /[illegible]/ RDAY(13,35,40),PDAY(13,35,40)
        COMMON /SEASON/ RST(40),P[illegible](40),RWT(40),RWTS(40),PS(40)
        COMMON /OSREL/ A(12,12),S(12,12),EA(12,12),DS(12,12),ISTN,DAM(4)
        DATA LT[illegible]/1H[illegible]/,[illegible]T/1HR/,[illegible]/4[illegible]/
        DATA [illegible]//3HSEP,3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJU
       1N,3HJUL,3HAUG,3HSEP/,[illegible]/3HSEP/
        DATA NZ/30,31,30,31,31,28,31,30,31,30,31,31,30/
C       SET [illegible] NDAY EQUAL TO [illegible] AND NZ
C
        DO 10 I=1,13
        [illegible](I)= Z(I)
     10 NDAY(I)=NZ(I)
C
C       YR1 = FIRST YEAR OF DATA
C       YR2 = LAST YEAR OF DATA. USE LAST TWO DIGITS OF THE YEAR
C       IF NCF = ZERO, AVERAGES AND STNDRD DEV ARE FOR ALL YEARS
C       IF NCF = LAST YEAR, FORECAST IS MADE IN LAST YEAR
C       NX = '[illegible]' [illegible], NX ='L' ,LINEARIZED METHOD
C       IX = OUTPUT OPTION . IX = 1 FOR SHORT SUMMARY. THE PREDICTION FOR
C       LAST YEAR ONLY. IX = 2 FOR PREDICTIONS AND ERRORS SHOWN FOR SEVERA
C       YEARS
C       PSUM IS SUM OF [illegible] PRECIPITATION FROM THE FIRST YEAR
C       RSUM IS SUM OF [illegible] SUMMER RUNOFF FROM THE FIRST YEAR
C       YPERR IS THE FIRST YEAR PREDICTION ERRORS ARE ACCUMULATED.
C       TO BE USED IN THE LINEAR METHOD.
C       YRVER IS THE YEAR THAT THE VERIFICATION PERIOD BEGINS
C       JJ = NUMBER OF YEARS [illegible] USED BEFORE THE CALCULATION OF LINEAR
C       ERRORS [illegible]
C       J = NUMBER OF YEARS BEFORE PREDICTIONS BEGIN
C
C        [illegible] PARAMETERS RELATING UPSTREAM-DOWNSTREAM RUNOFF
C        M3 = FIRST MONTH OF PREDICTION SEASON
C        M4 = LAST MONTH OF PREDICTION SEASON
C        AK = SLOPE OF REGRESSION LINE
C        BK = INTERCEPT OF REGRESSION LINE
```

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C          DMEAN = AVERAGE SEASONAL RUNOFF OF DOWNSTREAM STATION           A 510
C          DSE = STANDARD ERROR OF THE UPSTREAM - DOWNSTREAM FIT           A 520
C          ISTN = [illegible] OF THE DOWNSTREAM STATION                    A 530
C                                                                          A 540
   20 READ (5,260) M3,M4,IS,XS,DMEAN,DSE,DM,ISTN                           A 550
      IF (M3.EQ.1) ISTN=ISTNX                                              A 560
      IF (M3.EQ.0) GO TO 30                                                A 570
      A(M3,M4)=XS                                                          A 580
      [illegible](M3,M4)=[illegible]                                       A 590
      DM(M3,M4)=DMEAN                                                      A 600
      DS(M3,M4)=DSE                                                        A 610
      ISTNX=ISTN                                                           A 620
      GO TO 20                                                             A 630
   30 CONTINUE                                                             A 640
C        READ STATION NAME, STATION NUMBER, BASIN NUMBER, DRAINAGE AREA    A 650
C        (MILES)**2                                                        A 660
C        PARAMETER CARD NUMBER ONE                                         A 670
C                                                                          A 680
      READ (5,160) [illegible],[illegible],[illegible]STA,DRAREA           A 690
C        READ PRECIPITATION STATION NUMBER, NUMBER OF STATIONS WHICH WERE  A 700
C        USED TO CALCULATE AVERAGE                                         A 710
C        PARAMETER CARD NUMBER TWO                                         A 720
C                                                                          A 730
      READ (5,170) NPR,NPS                                                 A 740
C        READ NAMES OF PRECIPITATION STATIONS                              A 750
C        PARAMETER CARD NUMBER THREE                                       A 760
C                                                                          A 770
      READ (5,180) ((NPSTA(NJ,I),NJ=1,3),I=1,NPS)                          A 780
C        READ FIRST AND LAST YEAR OF DATA AND NCF                          A 790
C        PARAMETER CARD NUMBER FOUR                                        A 800
C                                                                          A 810
      READ (5,170) YR1,YRN,NCF                                             A 820
C        PARAMETER CARD NUMBER FIVE                                        A 830
C                                                                          A 840
      READ (5,170) YR[illegible]2,YRDRT                                    A 850
      IYR=YR[illegible]2-YR1+1                                             A 860
C        READ PRECIPITATION DATA, DAILY                                    A 870
      CALL DYRD([illegible],PDAY,YR,IPR,YR1,1)                             A 880
C        READ RUNOFF DATA, DAILY                                           A 890
      CALL DYRD([illegible],RDAY,YR,IRO,YR1,0)                             A 900
      IY1=YR1-1                                                            A 910
C         REPLACE 29 FEB DATA BY 28 FEB                                    A 920
      CALL FEB(IYR,IY1)                                                    A 930
      NDAY(5)=28                                                           A 940
C         JJ = NUMBER OF YEARS USED TO CALCULATE INITIAL COEFFICIENTS      A 950
      JJ=YR[illegible]2-YR1+1                                              A 960
      KK=JJ-1                                                              A 970
C         J = NUMBER OF YEARS IN THE CALIBRATION PERIOD                    A 980
      J=YRDRT-YR1+1                                                        A 990
      K=J-1                                                                A1000
```

```
      YRCOE=YRPRE-1                                                     A1010
      IFOR=NCF-YR1+1                                                    A1020
      IY1=YR1                                                           A1030
      IY=0                                                              A1040
   40 CONTINUE                                                          A1050
C     READ SEASONS, TEST SEASON LENGTH, OPTIONS FOR RESIDUAL OR         A1060
C      LINEARIZED METHODS AND OUTPUT                                    A1070
C     M1A = MONTH WHEN WINTER SEASON BEGINS                             A1080
C     M1D = DAY IN M1A WHEN WINTER SEASON BEGINS                        A1090
C     M2A = MONTH WHEN PREDICTION IS MADE                               A1100
C     M2D = DAY IN M2A WHEN PREDICTION IS MADE                          A1110
C     M3A = FIRST MONTH OF PREDICTION SEASON                            A1120
C     M3D = DAY IN M3A WHEN PREDICTION SEASON BEGINS                    A1130
C     M4A =  LAST MONTH OF PREDICTION SEASON                            A1140
C     M4D = DAY IN M4A WHEN PREDICTION SEASON ENDS                      A1150
C     NX = RATIO (R) OF LINEAR (L) OPTION                               A1160
C     NI = LENGTH OF TEST SEASON (IN DAYS)                              A1170
C     IX = 1 ON THE FIRST TEST SEASON CARD IF SUMMARY PAGE DESIRED      A1180
C     IX = 2 WHEN YEAR BY YEAR FORECASTS ARE DESIRED                    A1190
C     PARAMETER CARD NUMBER SIX                                         A1200
C                                                                       A1210
      READ (5,190) M1A,M1D,M2A,M2D,M3A,M3D,M4A,M4D,NX,NI,IX             A1220
      IF (M1A.EQ.SEP) M1A=MTH(1)                                        A1230
      IF (M1D.EQ.99) STOP                                               A1240
      IF (NI.EQ.99) JI=0                                                A1250
C     CHANGES ALPHA MONTH INTO THEIR RESPECTIVE NUMBERS                 A1260
      CALL ALPHA(M1A,MTA,M2A,M3A,M4A,NI,JX,JI)                          A1270
      IF (IX.EQ.1) IY=IY+1                                              A1280
      IF (IY.EQ.2) IY=1                                                 A1290
      IF (IX.EQ.2) IY=0                                                 A1300
      PWTSM=0.                                                          A1310
      RWTSM=0.                                                          A1320
C     PSUM IS SUM OF SUMMER PRECIPITATION FROM FIRST YEAR(YR1)          A1330
C     RSUM IS SUM OF OBSERVED SUMMER RUNOFF FROM FIRST YEAR (YR1)       A1340
      PSUM=0.                                                           A1350
      RSUM=0.                                                           A1360
      L=K                                                               A1370
      IF (NX.EQ.LIN) L=KK                                               A1380
C     PW,PWT,RWT,RWTS,AND PS ARE STORED TO BE USED IN EITHER RESIDUAL OR A1390
C     LINEARIZED METHOD                                                 A1400
      DO 50 N=1,L                                                       A1410
      CALL SUM123(N)                                                    A1420
      PWTSM=PWTSM+PWT(N)                                                A1430
      RWTSM=RWTSM+RWT(N)                                                A1440
      RSOB=RWTS(N)-RWT(N)                                               A1450
      PSUM=PSUM+PS(N)                                                   A1460
      RSUM=RSUM+RSOB                                                    A1470
   50 CONTINUE                                                          A1480
C     STORE THE ERRORS (RESIDUAL OR LINEARIZED METHOD)                  A1490
C      SME IS THE SUM OF THE RESIDUALS FROM THE FIRST YEAR OF THE PERIOD A1500
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C        M IS THE TOTAL NUMBER OF ERRORS STORED                                A1510
         M=0                                                                   A1520
         CALL LC(L,PW,RWT,A1,B1,XBAR,YBAR,VY,VU,FE,RS,MD)                      A1530
         CALL LC(L,PWT,RWT,A2,B2,XBAR,YBAR,VY,VU,FE,RS,MD)                     A1540
         CALL LC(L,PWT,RWTS,A3,B3,XBAR,YBAR,VY,VU,FE,RS,MD)                    A1550
         IF (NX.EQ.LIN) GO TO 70                                               A1560
C         RESIDUAL METHOD                                                      A1570
         SME1=0.                                                               A1580
         SME2=0.                                                               A1590
         SME3=0.                                                               A1600
         SME4=0.                                                               A1610
         DO 60 N=1.K                                                           A1620
         M=M+1                                                                 A1630
         CALL ERS(N.ET1,ET2,ES,M,MD,A1,A2,A3.B1,B2.B3,PW,PWT.PS,RWT,RWTS)      A1640
         CALL SMER(MD,ET1,ET2,ES.SME1,SME2,SME3,SME4.N)                        A1650
      60 CONTINUE                                                              A1660
         GO TO 90                                                              A1670
C         LINEARIZED METHOD WITH A MIDYEAR                                     A1680
      70 DO 80 N=JJ.K                                                          A1690
         CALL SUM123(N)                                                        A1700
         PWTSM=PWTSM+PWT(N)                                                    A1710
         RWTSM=RWTSM+RWT(N)                                                    A1720
         RSOB=RWTS(N)-RWT(N)                                                   A1730
         PSUM=PSUM+PS(N)                                                       A1740
         RSUM=RSUM+RSOB                                                        A1750
         M=M+1                                                                 A1760
      80 CALL ERS(N.ET1,ET2,ES,M.MD,A1,A2.A3,B1.B2.B3.PW,PWT,PS,RWT.RWTS)      A1770
         SME1=1.                                                               A1780
         SME2=1.                                                               A1790
         SME3=1.                                                               A1800
         SME4=1.                                                               A1810
      90 CONTINUE                                                              A1820
         CALL LC(M,ET1,ES,AE1,BE1,XBAR,YBAR.VY.VU,FE,RS,MD)                    A1830
         CALL LC(M,ET2.ES,AE2,BE2,XBAR,YBAR.VY,VU,FE,RS,MD)                    A1840
         LL=JJ                                                                 A1850
         IF (NX.EQ.LIN) GO TO 100                                              A1860
         LL=1                                                                  A1870
         AE1=SME3/SME1                                                         A1880
         AE2=SME4/SME2                                                         A1890
     100 DO 110 N=LL.K                                                         A1900
         RSS=A3*PWT(N)+B3-RWT(N)                                               A1910
         L=N-LL+1                                                              A1920
         ES1(N)=RSS-AE1*ET1(L)-BE1-RWTS(N)+RWT(N)                              A1930
     110 ES2(N)=RSS-AE2*ET2(L)-BE2-RWTS(N)+RWT(N)                              A1940
C        HEADING OF PAGE 1                                                     A1950
         CALL DATES(NT,NTD,N2,N2D)                                             A1960
         IF (IX.EQ.2) GO TO 120                                                A1970
C        HEADING OF SUMMARY PAGE                                               A1980
         WRITE (6.250) NREG.NSTA.STREAM.NPRE.DRAREA.((NPSTA(MJ,I),MJ=1,3),I    A1990
        1=1,NPS)                                                               A2000
```

```
C     HEADING OF SUMMARY SHEET                                          A2010
      GO TO 150                                                         A2020
  120 WRITE (6,220) IDR,IDP,MTH(M3),M3D,MTH(M4),M4D,MTH(M1),M1D,MTH(NT),  A2030
     1NTD,MTH(MT),MTD,MTH(N2),N2D,MTH(M2),M2D,IY1,YRERR                  A2040
      IF (NX.EQ.RAT) GO TO 130                                          A2050
      WRITE (6,200)                                                     A2060
      GO TO 140                                                         A2070
  130 WRITE (6,210)                                                     A2080
  140 WRITE (6,230)                                                     A2090
C     HEADING OF SUMMARY PAGE 2                                         A2100
      WRITE (10,220) IDR,IDP,MTH(M3),M3D,MTH(M4),M4D,MTH(M1),M1D,MTH(NT)  A2110
     1,NTD,MTH(MT),MTD,MTH(N2),N2D,MTH(M2),M2D,IY1,YRERR                 A2120
      WRITE (10,240)                                                    A2130
C     PREDICTIONS FROM DURING VERIFICATION PERIOD                       A2140
  150 LCT=K                                                             A2150
      MTHMT=MTH(NT)                                                     A2160
      MTHNT=MTH(N2)                                                     A2170
      CF=DRAREA*.10586E-2                                               A2180
      CALL ANNL(MD,J,NYR,LCT,YRPRE,YR1,YR2,IFOR,M,CF,PSUM,RSUM,SME1,SME2  A2190
     1,SME3,SME4,PWTSM,RWTSM,M1A,M2A,M3A,M4A,M3DM1,N2D,NI,MTHNT,LIN,RAT,  A2200
     2NX,NTD,MTHMT)                                                     A2210
      GO TO 40                                                          A2220
  160 FORMAT (4A4,I4,I5,F10.0)                                          A2230
  170 FORMAT (12I5)                                                     A2240
  180 FORMAT (5(3A4))                                                   A2250
  190 FORMAT (A3,I2,3(5X,A3,I2),4X,A1,I5,I2)                            A2260
  200 FORMAT (32X,'LINEARIZED METHOD  PREDICTION IN 1000 CFS-DAYS'/)    A2270
  210 FORMAT (32X,' RESIDUAL METHOD , PREDICTION IN 1000 CFS-DAYS'/)    A2280
  220 FORMAT (1H1,2X,'BASIN',I5,3X,'PRECIPITATION STATION',I5,3X,'PREDIC  A2290
     1TION SEASON',1X,A3,I3,'-',A3,I3/3X,'WINTER SEASON ',A3,I3,'-',A3,I  A2300
     23,3X,'TEST SEASON ',A3,I3,'-',A3,I3,'   FORECAST ',A3,I3,/6X,'FIRS  A2310
     3T YEAR',I5,5X,'MID YEAR FOR LINEAR METHOD',I5,10X,'OPDAY 5'/)     A2320
  230 FORMAT (1H ,5X,'ACTUAL',9X,'NO TEST SEASON',16X,'TEST SEASON',3X,'  A2330
     1TEST SEASON, PRECIPITATION',/,1H ,' YEAR',5X,'RS',9X,'RS*',7X,'E',  A2340
     26X,'RMSE',7X,'RS**',6X,'E',6X,'RMSE',7X,'RS**',6X,'E',6X,'RMSE',/)  A2350
  240 FORMAT (1H ,45X,'VARIABLES AND COEFFICIENTS',//,60X,'PREDICTION CO  A2360
     1EFFICIENTS',30X,'ERROR COEFFICIENTS',/2X,'YEAR',7X,'WINTER',12X,'T  A2370
     2EST',10X,'AS',6X,'BS',6X,'AT1',5X,'BT1',6X,'AT2',5X,'BT2',6X,'C1',  A2380
     37X,'BE1',6X,'C2',7X,'BE2',/,11X,'PW',6X,'RW',6X,'PT',6X,'RT',8X,'N  A2390
     40 TEST',8X,'TEST, NO PRECIP',5X,'TEST WITH PRECIP',/6X,2(3X,'INCHE  A2400
     5S  ','1000.'),/,6X,2(10X,'CFSDAYS'),/)                            A2410
  250 FORMAT (1H1,3X,'BASIN NO',I3,1X,I4,4A4,'PRECIP STA NO',I5/5X,'D.A.  A2420
     1=',F7.1,1X,'SQUARE MILES',16X,'AVG OF',3A4/53X,3A4/53X,3A4/53X,3A4  A2430
     2//)                                                               A2440
  260 FORMAT (2I3,F8.0,F6.0,2F10.0,4A4,20X,I4)                          A2450
      END                                                               A2460-
```

```
      SUBROUTINE ANNL(MD,J,NYR,LCT,YRPRE,YR1,YR2,IFOR,M,CF,PSUM,RSUM,SME
     11,SME2,SME3,SME4,PWTSM,RWTSM,M1A,M2A,M3A,M4A,M3DM1,N2D,NI,MTHNT,LI
     2N,RAT,NX,NTO,MTHMT)
C                                  MAKES PREDICTIONS FOR EACH YEAR,
C                                  FINDS STANDARD DEVIATIONS AND
C                                  MEANS,DETERMINES MOST ACCURATE
C                                  PREDICTION AND PRINTS RESULTS
C
      INTEGER YR1,YR2,YRERR,YRPRE,YRCOE,RAT
      COMMON /COEF/ A1,A2,A3,B1,B2,B3
      COMMON /DATE/ M1,M1D,MT,MTD,M2,M2D,M3,M3D,M4,M4D,IX,ID,IE
      COMMON /ERROR/ ES(40),ES1(40),ES2(40),ET1(40),ET2(40),NPSTA(3,10)
      COMMON /MONTH/ MTH(13),NDAY(13)
      COMMON /RAW/ PDAY(13,36,40),RDAY(13,36,40)
      COMMON /SEASN/ PWT(40),PW(40),RWT(40),RWTS(40),PS(40)
      COMMON /DSREL/ A(12,12),B(12,12),DM(12,12),DS(12,12),ISTN,DAM(4)
      RMSE=0.
      RMSE1=0.
      RMSE2=0.
      RSMP=0.
      RSMS=0.
      SET1=0.
      SET2=0.
      SET3=0.
      SUME1=0.
      SUME2=0.
      SUMES=0.
      NCT=0
      JYEAR=YRPRE-1
C
C
      DO 80 N=J,NYR
      JYEAR=JYEAR+1
      NCT=NCT+1
      DNCT=NCT
      NM1=N-1
      C1=SME3/SME1
      C2=SME4/SME2
      CALL LC(NM1,PW,RWT,A1,B1,XBAR,YBAR,VY,VU,FE,RS,MD)
      CALL LC(NM1,PWT,RWT,A2,B2,XBAR,YBAR,VY,VU,FE,RS,MD)
      CALL LC(NM1,PWT,RWTS,A3,B3,XBAR,YBAR,VY,VU,FE,RS,MD)
      CALL LC(M,ET1,ES,AE1,BE1,XBAR,YBAR,VY,VU,FE1,RS,MD)
      CALL LC(M,ET2,ES,AE2,BE2,XBAR,YBAR,VY,VU,FE2,RS,MD)
      CALL SUM123(N)
      M=M+1
      CALL ERS(N,ET1,ET2,ES,M,MD,A1,A2,A3,B1,B2,B3,PW,PWT,PS,RWT,RWTS)
      CALL SMER(MD,ET1,ET2,ES,SME1,SME2,SME3,SME4,M)
C     FINAL PREDICTION
      RSS=A3*PWT(N)+B3-RWT(N)
      RSOB=RWTS(N)-RWT(N)
```

```
      IF (N.EQ.IFOR) GO TO 10
      LCT=LCT+1
      DLCT=LCT
      RSUM=RSUM+RSOB
C     RMEAN IS MEAN RUNOFF FOR THE TOTAL PERIOD ,CALIBRATION PLUS
C      VERIFICATION
      RMEAN=RSUM/DLCT
      RSMS=RSMS+RSOB**2
      PSUM=PSUM+PS(N)
C     PAVE IS MEAN PRECIPITATION FOR THE TOTAL PERIOD
      PAVE=PSUM/DLCT
      PWTSM=PWTSM+PWT(N)
      RWTSM=RWTSM+RWT(N)
C     RSMP IS SUM OF RUNOFF FOR THE VERIFICATION PERIOD
C     RAVE IS MEAN RUNOFF FOR THE VERIFICATION PERIOD
      RSMP=RSMP+RSOB
      RAVE=RSMP/DNCT
      VAR=RSMS/DNCT-RAVE**2
      IF (VAR.LE.0.) VAR=1.
      PWTAV=PWTSM/DLCT
      RWTAV=RWTSM/DLCT
C     STANDARD DEVIATION FOR THE VERIFICATION PERIOD
      SD1=SQRT(VAR)
      GO TO 20
   10 SD1=SD2
   20 CV=SD1/RAVE
      PWPC=(PWT(N)/PWTAV)*100.
      RWPC=(RWT(N)/RWTAV)*100.
      SD2=SD1
C     REVISING PREDICTION
      IF (NX.EQ.LIN) GO TO 30
      AE1=C1
      AE2=C2
      BE1=0.
      BE2=0.
   30 RST1=RSS-AE1*ET1(M)-BE1
      RST2=RSS-AE2*ET2(M)-BE2
      ESS=RSS-RSOB
      ES1(N)=RST1-RSOB
      ES2(N)=RST2-RSOB
      IF (N.EQ.IFOR) GO TO 40
      SUMES=SUMES+ESS**2
      SUME1=SUME1+ES1(N)**2
      SUME2=SUME2+ES2(N)**2
      RMSE=SQRT(SUMES/DNCT)
      RMSE1=SQRT(SUME1/DNCT)
      RMSE2=SQRT(SUME2/DNCT)
      SET1=SET1+ESS
      SET2=SET2+ES1(N)
      SET3=SET3+ES2(N)
```

```
   40 PT=PWT(N)-PW(N)                                                   B1010
      CALL SUM(RT,RDAY,MT,MTD,M2,IE,N)                                  B1020
      CALL SUM(RW,RDAY,M1,M1D,MT,ID,N)                                  B1030
      IF (N.EQ.IFOR) RSOB=0.                                            B1040
      ES1N=ES1(N)                                                       B1050
      ES2N=ES2(N)                                                       B1060
      PWN=PW(N)                                                         B1070
      FEX=1.-(RMSE/SD1)**2                                              B1080
      FEY=1.-(RMSE1/SD1)**2                                             B1090
      FEZ=1.-(RMSE2/SD1)**2                                             B1100
      IF (FEX.GT.FEY.AND.FEX.GT.FEZ) GO TO 50                           B1110
      IF (FEY.GT.FEX.AND.FEY.GT.FEZ) GO TO 60                           B1120
      CFSD=RST2                                                         B1130
      CFSSE=RMSE2                                                       B1140
      METH=3                                                            B1150
      RSQ=FEZ                                                           B1160
      GO TO 70                                                          B1170
   50 CFSD=RSS                                                          B1180
      CFSSE=RMSE                                                        B1190
      METH=1                                                            B1200
      RSQ=FEX                                                           B1210
      GO TO 70                                                          B1220
   60 CFSD=RST1                                                         B1230
      CFSSE=RMSE1                                                       B1240
      METH=2                                                            B1250
      RSQ=FEY                                                           B1260
   70 CFSB=RMEAN                                                        B1270
      CFSSD=SD1                                                         B1280
      ES2N=ES2(N)*.001                                                  B1290
      ES1N=ES1(N)*.001                                                  B1300
      ESX=ESS*.001                                                      B1310
      RMEAX=RMEAN*.001                                                  B1320
      XD1=SD1*.001                                                      B1330
      RZ=RW*.001                                                        B1340
      RX=RT*.001                                                        B1350
      RXT2=RST2*.001                                                    B1360
      RXT1=RST1*.001                                                    B1370
      RSX=RSS*.001                                                      B1380
      RXOB=RSOB*.001                                                    B1390
      RMXE2=RMSE2*.001                                                  B1400
      RMXE1=RMSE1*.001                                                  B1410
      RMXE=RMSE*.001                                                    B1420
      IR3=YR2                                                           B1430
      IR4=YR2                                                           B1440
      IF (M3A.EQ.MTH(3).OR.M3A.EQ.MTH(4)) IR4=YR2-1                     B1450
      IF (N.EQ.IFOR) IR3=YR2-1                                          B1460
      IF (IX.NE.2) GO TO 80                                             B1470
      WRITE (6,170) JYEAR,RXOB,RSX,ESX,RMXE,RXT1,ES1N,RMXE1,RXT2,ES2N,RM B1480
     1XE2                                                               B1490
      WRITE (10,140) JYEAR,PWN,RZ,PT,RX,A3,B3,A1,B1,A2,B2,AE1,BE1,AE2,BE B1500
```

```
     12
  80 CONTINUE
C
C
      IF (M1A.EQ.MTH(1)) M1A=MTH(13)
      RSSPC=(CFSD/CFSB)*100.
C       COEST= 95 % CONFIDENCE FORECAST
      COEST=CFSD-1.645*CFSSE
      IF (COEST.LT.0.) COEST=0.00
      IF (IX.EQ.2) GO TO 110
      IF (NX.EQ.RAT) GO TO 90
      WRITE (6,120) METH,M2A,M2D,IR4
      GO TO 100
  90 WRITE (6,130) METH,M2A,M2D,IR4
 100 WRITE (6,160) M3A,M3D,M4A,M4D,YR2,CFSD,M1A,M1D,MTHMT,NTD,CFSSE,NI,
     1COEST,M1A,M1D,MTHNT,N2D,PWPC,CFSSD,M1A,M1D,MTHNT,N2D,RWPC,YR1,IR3,
     2CFSB,M3A,M3D,M4A,M4D,YR2,RSSPC,YRPRE,RSQ
      CALL DNST(M3A,M3D,M4A,M4D,CFSD,CFSSE)
 110 IF (IX.EQ.1) GO TO 190
C       EAV= AVERAGE ERROR
      EAV1=(SET1/DNCT)*.001
      EAV2=(SET2/DNCT)*.001
      EAV3=(SET3/DNCT)*.001
      WRITE (6,180) RMEAX,LCT,EAV1,EAV2,EAV3,NCT,XD1,NCT,CV,NCT,FEX,FEY,
     1FEZ,NCT
      WRITE (10,150) PAVE,RMEAX,FE1,FE2
 120 FORMAT (1H ,4X,'METHOD',I2,7X,'LINEARIZED REVISION',9X,'PREDICTION
     1 DATE ',A3,I3,1X,'19',I2/)
 130 FORMAT (1H ,4X,'METHOD',I2,7X,'  RESIDUAL REVISION',9X,'PREDICTION
     1 DATE ',A3,I3,1X,'19',I2/)
 140 FORMAT (2H  ,'19',I2,4F8.2,6F9.0,4F9.3,/)
 150 FORMAT (1H0,2X,'SUMMER MEANS:',F8.2,' = PRECIP',F16.0,' = RUNOFF',
     1//,17X,F9.3,' =RSQ1 ',F9.3,' =RSQ2',4X,' (SIGNIFICANCE OF TEST-SEA
     2SON)')
 160 FORMAT (1H0,4X,'PREDICTION SEASON ',A3,I3,'-',A3,2I3,2X,'|',1X,'PR
     1EDICTION',F17.0,' CFS-DAYS'/41X,'|'/5X,'WINTER SEASON',4X,A3,I3,'-
     2',A3,I3,6X,'|',1X,'STANDARD ERROR',F13.0,' CFS-DAYS'/41X,'|'/5X,'T
     3EST SEASON LENGTH',5X,I2,' DAY(S)',4X,'|',1X,'95% CONFIDENCE',F13.
     40,' CFS-DAYS',/41X,'|',/5X,A3,I3,'-',A3,I3,' PRECIP % OF MEAN',F5.
     50,1X,'|',1X,'STD. DEVIATION',F13.0,' CFS-DAYS',/41X,'|',/,5X,A3,I3
     6,'-',A3,I3,' RUNOFF % OF MEAN',F5.0,1X,'|',2X,'19',I2,'-','19',I2,
     7' MEAN',F12.0,' CFS-DAYS',//,5X,A3,I3,'-',A3,I3,' 19',I2,' PREDICT
     8ED RUNOFF',' % OF MEAN=',F6.0,//,5X,'COEFFICIENT OF PREDICTION SIN
     9CE 19',I2,F9.3////)
 170 FORMAT (2H  ,'19',I2,F9.1,3(F11.1,F9.2,F8.2),/)
 180 FORMAT (1H ,99X,'NYR'/1H ,' MEAN',F9.1,I7,' YRS',F9.2,2(19X,F9.2),
     110X,I2,/,1H ,3X,'SD',F9.2,86X,I2,/,1H ,3X,'CV',F9.3,86X,I2,/,1H ,2
     22X,' CP',11X,3(F9.3,19X),I2,/,1H1)
 190 RETURN
      END
```

```
      SUBROUTINE ALPHA(M1A,MTA,M2A,M3A,M4A,NI,JX,JI)
      COMMON /DATE/ M1,M1D,MT,MTD,M2,M2D,M3,M3D,M4,M4D,IX,ID,IE
      COMMON /DATEX/ M1X,M1DX,M2X,M2DX,M3X,M3DX,M4X,M4DX,NX,NXX
      COMMON /MONTH/ MTH(13),NDAY(13)
      DATA L/3H   /,IR/1H /
C                                  CHANGES THE ALPHABETIC MONTH
C            SUBROUTINE ALPHA      CHARACTERS TO THEIR RESPECTIVE
C                                  NUMBERS.
      IF (IX.EQ.0) IX=JX
      JX=IX
      IF (NI.EQ.0) NI=JI
      JI=NI
C
C     SET THE DAY
      IF (M1D.EQ.0) GO TO 10
      M1DX=M1D
   10 M1D=M1DX
      IF (M2D.EQ.0) GO TO 20
      M2DX=M2D
   20 M2D=M2DX
      IF (M3D.EQ.0) GO TO 30
      M3DX=M3D
   30 M3D=M3DX
      IF (M4D.EQ.0) GO TO 40
      M4DX=M4D
   40 M4D=M4DX
C
C     SET THE FIRST WINTER MTH
      DO 50 I=1,13
      IF (M1A.EQ.L) GO TO 70
      IF (M1A.EQ.MTH(I)) GO TO 60
   50 CONTINUE
   60 M1=I
      M1X=M1A
   70 M1A=M1X
C
C     SET THE  LAST WINTER MTH
      DO 80 J=M1,13
      IF (M2A.EQ.L) GO TO 100
      IF (M2A.EQ.MTH(J)) GO TO 90
   80 CONTINUE
   90 M2=J
      M2X=M2A
  100 M2A=M2X
C
C     SET THE TEST MTH
      MT=M2
      MTD=M2D-NI
      IF (MTD.GT.0) GO TO 110
      MT=M2-1
```

```
      MTD=MTD+NDAY(MT)
  110 CONTINUE
      MTA=MTH(MT)
C
C     SET THE FIRST MTH OF PREDICTION
      DO 120 I=M2,13
      IF (M3A.EQ.L) GO TO 140
      IF (M3A.EQ.MTH(I)) GO TO 130
  120 CONTINUE
  130 M3=I
      M3X=M3A
  140 M3A=M3X
C
C      SET THE LAST MTH OF PREDICTION
      DO 150 J=M3,13
      IF (M4A.EQ.L) GO TO 170
      IF (M4A.EQ.MTH(J)) GO TO 160
  150 CONTINUE
  160 M4=J
      M4X=M4A
  170 M4A=M4X
C
C      SET RATIO  OR LINEAR
      IF (NX.EQ.IR) GO TO 180
      NXX=NX
  180 NX=NXX
      RETURN
      END
```

```
      SUBROUTINE AVAR(N,X,AVE,VAR,MD)
      DIMENSION X(MD)
C                                 SUMS X AND Y SQUARED FOR LINEAR
C                                 REGRESSION,FINDS AVERAGES AND
C                                 VARIANCE
      SX=0.
      SX2=0.
      T=N
      DO 10 I=1,N
      SX=SX+X(I)
   10 SX2=SX2+X(I)**2
      AVE=SX/T
      VAR=SX2/T-AVE**2
      RETURN
      END
```

```
      SUBROUTINE DATES(NT,NTD,N2,N2D)
      COMMON /DATE/ M1,M1D,MT,MTD,M2,M2D,M3,M3D,M4,M4D,IX,ID,IE
      COMMON /MONTH/ MTH(13),NDAY(13)
C     OPDAY
C                                FINDS END OF WINTER SEASON
C                                GIVEN TEST SEASON LENGTH
C                                IN DAYS.
C                                FOR WRITING PURPOSES ONLY
      NT=MT
      NTD=MTD-1
      IF (NTD.GT.0) GO TO 10
      NT=MT-1
      NTD=NDAY(NT)
   10 N2=M2
      N2D=M2D-1
      IF (N2D.GT.0) GO TO 20
      N2=M2-1
      N2D=NDAY(N2)
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DNST(M3A,M3D,M4A,M4D,CFSD,CFSSE)
      COMMON /DSREL/ A(12,12),B(12,12),DM(12,12),DS(12,12),ISTN,DAM(4)
      COMMON /MONTH/ MTH(13),NDAY(13)
C
C     SELECTS CORRECT SEASONAL RELATIONSHIP BETWEEN UPSTREAM AND
C      DOWNSTREAM SITES. CALCULATES THE DOWNSTREAM PREDICTION
C      PRINTS RESULTS
C
      DO 10 I=1,13
      IF (M3A.EQ.MTH(I)) GO TO 20
   10 CONTINUE
   20 M3=I-1
      ND=NDAY(I)
      DO 30 I=1,13
      IF (M4A.EQ.MTH(I)) GO TO 40
   30 CONTINUE
   40 M4=I-1
      X1=M3D-1
      X2=ND
      DR1=X1/X2
      IF (M3.NE.M4) GO TO 50
      AX=A(M3,M4)
      BX=B(M3,M4)*(1.-DR1)
      DX=DM(M3,M4)*(1.-DR1)
      SX=DS(M3,M4)*(1.-DR1)
      GO TO 60
   50 AX=(A(M3+1,M4)-A(M3,M4))*DR1+A(M3,M4)
      BX=(B(M3+1,M4)-B(M3,M4))*DR1+B(M3,M4)
      DX=(DM(M3+1,M4)-DM(M3,M4))*DR1+DM(M3,M4)
      SX=(DS(M3+1,M4)-DS(M3,M4))*DR1+DS(M3,M4)
   60 RD=AX*CFSD+BX
      SE=SQRT((AX*CFSSE)**2+SX**2)
      RD95=RD-1.645*SE
      RDPC=(RD/DX)*100.
      SEF=(SE/DX)*100.
      WRITE (6,70) ISTN,DAM,RD,RDPC,SE,SEF,RD95,DX
   70 FORMAT (8X,'DOWNSTREAM STATION',1X,I4,5X,4A4//10X,'PREDICTION=',F1
     15.0,1X,'CFS-DAYS',3X,'% OF MEAN',1X,F5.0//10X,'STD ERROR',9X,F8.0,
     21X,'CFS-DAYS',2X,'MEAN ERROR =',F5.1,1X,'%'//10X,'95 % CONFIDENCE'
     3,1X,F10.0,1X,'CFS-DAYS'//10X,'MEAN=',1X,F20.0,1X,'CFS-DAYS')
      RETURN
      END
```

```
      SUBROUTINE DYRD(MD,X,N,ID,IY1,IX)
      DIMENSION X(13,36,MD), T(36), NDAY(13)
      COMMON /MONTH/ MZ(13),NX(13)
C                                           READS DAILY VALUES OF PRECIP AND
C                                           RUNOFF AND CONVERTS A 12 MONTH WATER
C                                           YEAR TO A 13 MONTH YEAR BEGINNING
C                                           WITH SEPTEMBER
      ISET=IX+13
C
      DO 10 I=1,12
   10 NDAY(I)=NX(I+1)
C
      DO 20 J=1,13
      DO 20 K=1,36
      DO 20 I=1,MD
   20 X(J,K,I)=0.
C
      NM1=N-1
      I1=IY1-1
C     SEARCH FOR THE YEAR AND OCTOBER
C
   30 READ (ISET,130,END=150) IYR,MT,ID
      IF (IYR.LT.I1) GO TO 30
      IF (MT.NE.11) GO TO 30
C      READ DATA FROM SEP OF THE YEAR BEFORE IY1
      READ (ISET,120,END=150) (T(K),K=1,36)
C
      DO 40 K=1,31
   40 X(1,K,1)=T(K)
C     READ DATA
C
      DO 70 IYR=1,NM1
      DO 70 MTH=2,13
      M=MTH-1
      READ (ISET,100,END=150) (T(K),K=1,12),MT,(T(K),K=13,36)
      IF (MT.NE.M) GO TO 90
      ND=NDAY(MT)
C
      DO 50 K=1,ND
      X(MTH,K,IYR)=T(K)
   50 CONTINUE
C
      IF (MTH.NE.13) GO TO 70
      DO 60 K=1,ND
   60 X(1,K,IYR+1)=T(K)
   70 CONTINUE
C
C      READ DATA FOR THE LAST YEAR
      DO 80 J=2,13
      READ (ISET,140,END=150) (T(K),K=1,12),MT
```

```
      READ (ISET,120,END=150) (T(K),K=13,36)                                   F 510
      ND=NDAY(MT)                                                              F 520
      DO 80 K=1,ND                                                             F 530
      X(J,K,N)=T(K)                                                            F 540
   80 CONTINUE                                                                 F 550
C                                                                              F 560
      READ (ISET,100,END=150)                                                  F 570
      GO TO 150                                                                F 580
   90 WRITE (6,110) IYR,MT,ID                                                  F 590
  100 FORMAT (12F5.0,13X,I2/(12F5.0))                                          F 600
  110 FORMAT (1H ,'NOT ENOUGH PRECIP OR RUNOFF DATA OR DATA OUT OF ORDER       F 610
     1 ',3I5)                                                                  F 620
  120 FORMAT (12F5.0)                                                          F 630
  130 FORMAT (70X,I2,1X,I2,1X,I4//)                                            F 640
  140 FORMAT (12F5.0,13X,I2)                                                   F 650
      STOP                                                                     F 660
  150 RETURN                                                                   F 670
      END                                                                      F 680-
```

```
      SUBROUTINE ERS(N,ET1,ET2,ES,M,MD,A1,A2,A3,B1,B2,B3,PW,PWT,PS,RWT,R

      SUBROUTINE ERS(N,ET1,ET2,ES,M,MD,A1,A2,A3,B1,B2,B3,PW,PWT,PS,RWT,R  G  10
     1WTS)                                                                G  20
      DIMENSION ET1(MD), ET2(MD), ES(MD), PW(MD), PWT(MD), PS(MD), RWT(M  G  30
     1D), RWTS(MD)                                                        G  40
      ET1(M)=A1*PW(N)+B1-RWT(N)                                           G  50
      ET2(M)=A2*PWT(N)+B2-RWT(N)                                          G  60
      RSS=A3*PWT(N)+B3                                                    G  70
      ES(M)=RSS-RWTS(N)                                                   G  80
      RETURN                                                              G  90
      END                                                                 G 100-
```

```
      SUBROUTINE FEB(NYR,IR1)
      COMMON /RAW/ PDAY(13,36,40),RDAY(13,36,40)
C                                            COMBINES 28TH AND 29TH
C                                            FEBRUARY DATA EACH LEAP YEAR
      DO 10 IYR=1,NYR
      I=IR1+IYR
      IF (MOD(I,4).NE.0) GO TO 10
      PDAY(6,28,IYR)=PDAY(6,28,IYR)+PDAY(6,29,IYR)
      RDAY(6,28,IYR)=RDAY(6,28,IYR)+RDAY(6,29,IYR)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LC(N,X,Y,A,B,XBAR,YBAR,VY,VU,FE,R,MD)
      DIMENSION X(MD), Y(MD)
C        OPDAY
C                                REGRESSES RUNOFF AND PRECIP,TEST
C                                SEASON AND PREDICTION SEASON ERRORS
C                                FOR LINEAR METHOD,GIVES
C                                COEFFIENTS,MEANS,VARIANCE,
C                                AND COEFFIENT OF DETERMINATION.
      CALL AVAR(N,X,XBAR,VX,MD)
      CALL AVAR(N,Y,YBAR,VY,MD)
      IF (VX) 20,20,10
   10 IF (VY) 20,20,30
   20 A=0.
      B=YBAR
      R=0.
      FE=0.
      VU=VY
      GO TO 50
   30 T=N
      SXY=0.
      DO 40 I=1,N
   40 SXY=SXY+X(I)*Y(I)
      VXY=SXY/T-XBAR*YBAR
      A=VXY/VX
      B=YBAR-A*XBAR
      R=A*SQRT(VX/VY)
      FE=R**2
      VU=VY*(1.-FE)
   50 RETURN
      END
```

```
      SUBROUTINE SMER(MD,ET1,ET2,ES,SE1,SE2,SE3,SE4,L)                  J  10
      DIMENSION ET1(MD), ET2(MD), ES(MD)                                J  20
      SE1=SE1+ET1(L)**2                                                 J  30
      SE2=SE2+ET2(L)**2                                                 J  40
      SE3=SE3+ET1(L)*ES(L)                                              J  50
      SE4=SE4+ET2(L)*ES(L)                                              J  60
      RETURN                                                            J  70
      END                                                               J  80-
```

```
      SUBROUTINE SUM(SUMY,Y,I,ID,K,KD,N)
C                                         SUMS PRECIP AND RUNOFF FOR
C                                         EACH SEASON.
      DIMENSION Y(13,36,40), MDAY(13), ND(13)
      COMMON /MONTH/ MTH(13),NDAY(13)
C
      DO 10 L=1,13
      MDAY(L)=1
   10 ND(L)=NDAY(L)
      SUMY=0.
      J=K
      JD=KD
C      IF THE DAY BEFORE THE NEXT SEASON IS THE END OF A MTH, THEN KD
C     WILL EQUAL 0
      IF (KD.GT.0) GO TO 20
      J=J-1
      JD=ND(J)
   20 MDAY(I)=ID
      ND(J)=JD
      DO 30 II=I,J
      NDY=ND(II)
      MD=MDAY(II)
      DO 30 JJ=MD,NDY
   30 SUMY=SUMY+Y(II,JJ,N)
      RETURN
      END
```

```
      SUBROUTINE SUM123(N)
C                                   DETERMINES SEASONS FOR WHICH
C                                   PRECIP AND RUNOFF ARE TO BE
C                                   SUMMED.
      COMMON /DATE/ M1,M1D,MT,MTD,M2,M2D,M3,M3D,M4,M4D,IX,ID,IE
      COMMON /RAW/ P(13,36,40),R(13,36,40)
      COMMON /SEASN/ PWT(40),PW(40),RWT(40),RWTS(40),PS(40)
C     WINTER PRECIP
      IE=M2D-1
      ID=MTD-1
      CALL SUM(Y,P,M1,M1D,MT,ID,N)
      PW(N)=Y
C     WINTER AND TEST PRECIP
      CALL SUM(Y,P,M1,M1D,M2,IE,N)
      PWT(N)=Y
C     SUMMER PRECIP
      CALL SUM(Y,P,M3,M3D,M4,M4D,N)
      PS(N)=Y
C     WINTER AND TEST RUNOFF
      CALL SUM(Y,R,M1,M1D,M2,IE,N)
      RWT(N)=Y
C     WINTER, TEST AND SUMMER RUNOFF
      CALL SUM(Y,R,M3,M3D,M4,M4D,N)
      RWTS(N)=Y+RWT(N)
      RETURN
      END
```

Appendix I. Sample job core language and cancatenation of recent runoff and precipitation data

```
//COP1 EXEC PGM=IEBGENER,TIME=1,COND=(0,LT),REGION=104K
//SYSIN DD DUMMY
//SYSPRINT DD DUMMY
//SYSUT2 DD DSN=&&TEP1,DISP=(NEW,PASS),UNIT=SYSDK,
// SPACE=(TRK,(34,34)),DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400)
//SYSUT1 DD *
  .    .02  .    .    .    .    .    .    .    .09  .14  .      1   1979  1 1252
  .    .    .    .01  .    .    .    .04  .    .    .    .07    2   1979  1 1252
  .    .    .    .30  .30  .01  .    .    .    .    .    .      3   1979  1 1252
  .    .20  .74 1.77  .    .    .01  .56  .    .    .    .      1   1979  2 1252
  .    .    .11  .99  .21  .44 1.41  .01  .    .    .01  .02    2   1979  2 1252
  .04  .    .02  .36  .13 1.15  .    .    .    .    .    .      3   1979  2 1252
  .21  .02  .21  .56  .03  .    .    .    .44  .50  .81  .      1   1979  3 1252
  .    .37  .15  .38  .31  .04  .00  .02  .12  .31  .11  .11    2   1979  3 1252
  .    .    .    .    .    .25  .    .    .    .    .    .      3   1979  3 1252
/*
//COP2 EXEC PGM=IEBGENER,TIME=1,COND=(0,LT),REGION=104K
//SYSIN DD DUMMY
//SYSPRINT DD DUMMY
//SYSUT2 DD DSN=&&TER1,DISP=(NEW,PASS),UNIT=SYSDK,
// SPACE=(TRK,(34,34)),DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400)
//SYSUT1 DD *
  278  261  247  234  223  213  205  199  195  201  197  179 12 1   1979  1  565
  171  165  160  156  151  147  142  139  134  129  129  142 12 2   1979  1  565
  125  120  116  120  138  121  115    0    0    0    0    0 12 3   1979  1  565
  111  127  692 1070  380  292  384  432  294  248  221  205 12 1   1979  2  565
  188  178  176  310  336  276  250  223  208  196  186  183 12 2   1979  2  565
  186  176  192  251  224  315    0    0    0    0    0    0 12 3   1979  2  565
  292  252  291  308  253  225  205  196  195  250  524  345 12 1   1979  3  565
  286  348  296  274  272  244  222  209  202  235  225  292 12 2   1979  3  565
  224  209  186  163  155  145    0    0    0    0    0    0 12 3   1979  3  565
/*
// EXEC FTG1CLG,REGION.GO=305K
//FORT.SYSIN DD *

 **********  COMPUTER PROGRAM  ***************

/*
//GO.SYSIN DD *
  3 10 1.436   9705.   232399.     7003. CUSHMAN                             575
  3 12 1.409  12271.   246075.     7836.                                     575
  4 10 1.401   8600.   190227.     6525.                                     575
  4 12 1.376  10553.   203903.     7352.                                     575
                                        CUSHMAN DAM
 SKOKOMISH R      12 0565   57.2
 1252    2
 CUSHMAN DAM KID VALLEY
   52   79   79
   56   60
SEP 1     DEC31     JAN 1     JUL31    R   25 1
   99
/*
//FT06F001 DD SYSOUT=A
//FT10F001 DD SYSOUT=A,DCB=(RECFM=UA,BLKSIZE=133)
//FT13F001 DD DSN=AG40XMR.WVTLIB(SK520565),LABEL=(,,,IN),
// UNIT=3330,VOL=SER=SYS010,DISP=SHR
// DD DSN=&&TER1,DISP=(OLD,DELETE)
//FT14F001 DD DSN=AG40XMR.WVTLIB(PREC1252),LABEL=(,,,IN),
// UNIT=3330,VOL=SER=SYS010,DISP=SHR
// DD DSN=&&TEP1,DISP=(OLD,DELETE)
```

TABLE 1. Drainage basin characteristics and precipitation stations used in model

	Drainage basins							Precipitation stations			
	Index number	Area		Mean Altitude		Mean annual runoff (1952-76)		Name(s)	Number	Mean Annual Precipitation (1952-76)	
Stream name		(mi^2)	(km^2)	(ft)	(m)	(cfs-days)	(m)			(in)	(m)
North Fork Skokomish River below Staircase Rapids, near Hoodsport.	12-0565	57.2	148	3230	985	201,640	3.33	Cushman Dam Kid Valley (average).	1252	82.3	2.09
Skokomish River near Hoodsport.	12-0575	93.7	243	2607	795	201,540	3.04	Cushman Dam Kid Valley (average).	1252	82.3	2.09
Nisqually River near National.	12-0825	133.	344	3780	1152	292,850	2.08	Longmire	6894	85.8	2.18
Nisqually River at La Grande.	12-0865	292	756	3030	924	565,680	1.83	Longmire	6894	85.8	2.18
Cowlitz River near Randle.	14-2334	1030	2668	3600	1098	1,842,700	1.69	Longmire Kid Valley (average).	1272	73.9	1.88
Cowlitz River below Mayfield Dam.	14-2380	1400	3626	2351	991	2,475,000	1.67	Longmire Kid Valley (average).	1272	73.9	1.88

TABLE 2A. South Fork Skokomish River near Hoodsport, Washington (12-0565)

Accuracy of retrospective forecasts for seasons ending on July 31.
Given as percent of observed (predicted/observed) x 100.

	Date of Forecast							
Year	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr. 1	May 1	June 1	July 1
1960	104	99	94	96	103	101	126	150
61	83	77	79	93	107	98	103	207
62	149	155	121	107	118	129	155	163
63	118	116	100	105	106	96	96	120
64	113	118	147	126	120	109	100	104
65	145	145	123	128	116	133	152	144
66	105	106	94	81	97	89	80	81
67	84	94	114	102	105	96	83	95
68	83	80	94	106	116	101	102	151
69	98	102	88	82	75	74	71	99
70	112	111	131	121	125	138	129	139
71	87	102	90	97	108	111	114	88
72	88	88	74	84	94	107	104	85
73	115	131	133	116	116	91	72	85
74	75	79	99	105	103	105	97	96
75	113	114	117	117	119	118	119	136
76	99	106	111	111	97	102	118	107
77	155	128	88	70	91	83	85	44
78	105	113	107	108	105	105	127	158
MSEP	20	20	19	14	13	15	20	32
CV	21	23	23	26	25	31	37	52

MSEP = Mean standard error of prediction
CV = coefficient of variation

TABLE 2B. Nisqually River near National, Washington (12-0825)

Accuracy of retrospective forecasts for seasons ending on July 31.
Given as percent of observed (predicted/observed) x 100.

	Date of Forecast							
Year	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr. 1	May 1	June 1	July 1
1960	98	94	78	76	77	78	108	111
61	87	79	74	92	94	108	108	114
62	109	116	109	95	98	105	107	104
63	117	110	89	101	114	108	103	117
64	93	85	99	86	88	93	87	79
65	88	91	106	108	97	90	83	75
66	125	113	111	104	101	95	91	100
67	97	95	114	115	114	104	96	105
68	99	96	93	99	107	102	100	142
69	101	101	109	100	91	84	81	104
70	99	95	113	103	103	113	113	100
71	80	81	96	101	102	96	95	81
72	71	74	84	92	99	106	106	117
73	133	159	141	117	114	110	113	106
74	77	77	93	88	88	91	87	84
75	91	99	109	105	100	95	92	71
76	86	99	108	105	103	88	85	91
77	157	139	91	78	94	98	108	90
78	113	147	125	111	111	120	134	128
MSEP	18	21	15	11	10	10	12	19
CV	19	22	23	24	22	26	29	30

MSEP = Mean standard error of prediction
CV = Coefficient of variation

TABLE 2C. Cowlitz River near Randle, Washington (12-2334)

Accuracy of retrospective forecasts for seasons ending on July 31.
Given as percent of observed (predicted/observed) x 100.

	Date of Forecast							
Year	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr. 1	May 1	June 1	July 1
1960	109	100	83	94	94	98	123	121
61	101	92	82	101	103	120	136	129
62	114	118	113	93	95	90	92	82
63	128	109	102	107	111	106	139	125
64	108	102	113	106	111	108	82	72
65	90	87	107	110	84	75	104	120
66	124	108	111	107	110	98	108	97
67	99	109	119	124	122	117	105	136
68	103	96	96	103	112	113	88	170
69	96	91	96	92	81	77	70	91
70	95	85	114	117	113	120	108	118
71	81	87	96	104	104	95	89	79
72	69	77	76	85	87	93	99	119
73	134	137	129	119	118	94	106	127
74	72	77	81	82	84	88	79	80
75	89	95	98	92	87	77	92	81
76	93	107	109	103	102	101	120	104
77	175	140	88	68	74	72	110	64
78	110	143	116	116	114	117	146	154
MSEP	21	18	16	13	13	15	20	27
CV	24	27	27	28	27	32	40	48

MSEP = Mean standard error of prediction
CV = Coefficient of variation

TABLE 3 Precipitation stations tested for use in the model

Precipitation stations		Drainage Basin (Name/Index No.)		
Name	Index number	N. Fork Skokomish R. above Staircase Rapids 12 0565	Nisqually R. near National 12 0825	Cowlitz R. near Randle 14 2334
		Mean standard error of prediction (RMSE/MEAN) for the 1960-76 verification period.		
Aberdeen	0008	0.193	0.186	0.243
Aberdeen	0013	.244	.218	.289
Battleground	0482	.251	.208	.242
Bremerton	0872	.239	.216	.264
Cathlamet	1205	.387	.268	.335
Cedar Lake	1233	.260	.201	.250
Centralia	1276	.242	.184	.229
Chimacum	1414	.232	.223	.257
Clearwater	1496	.295	.243	.317
Cougar	1760	.282	.186	.227
Cushman Dam	1934	.187*	.217	.285
Cushman P.H. #2	1939	.264	.220	.298
Mossyrock Dam	2350	.278	.175	.218
Electron	2493	.268	.205	.243
Elma	2531	.226	.220	.245
Glenoma	3177	.278	.176	.203
Grapeview	3284	.310	.209	.277
Kid Valley	4201	.189*	.149	.168*
Landsburg	4486	.283	.200	.263
Longview	4769	.230	.166	.185
Mayfield Dam	5100	.225	.151	.177
Merwin Dam	5305	.215	.165	.211
Mineral	5425	.277	.195	.238
Mt. Adams	5659	.211	.209	.240
Packwood	6262	.298	.174	.201
Palmer	6295	.285	.221	.264
Pt. Greenville	6584	.328	.283	.362
Quilcene	6846	.224	.228	.270
Longmire	6894	.259	.126*	.170*
Ohanepecosh	6896	.261	.175	.219
Paradise	6898	.266	.219	.249
Randle	6909	.276	.187	.226
Rimrock	7038	.286	.212	.228
Snoqualmie Falls	7773	.232	.164	.189
Toledo	8500	.252	.224	.188
Vancouver	8773	.282	.220	.243
Mean Coefficient of variation (CV)		.261	.232	.243

*Designates stations used in model.

TABLE 4. Accuracy of the three highest stations used in estimating precipitation and the results of equal weighted averaging of these stations.

North Fork Skokomish River above Staircase Rapids (12-0565)

Precipitation stations		RMSE/MEAN	Averages,	(RMSE/MEAN)
Name	No.		Index No.	
Cushman Dam	1934	0.187		
Kid Valley	4201	.189	1252*	0.158
Aberdeen	0008	.193	1253	.176
Mt. Adams	5659	.211	1254	.170
Merwin Dam	5305	.215	1255	.173
		Nisqually River near National (12-0825)		
Longmire	6894*	.126		
Kid Valley	4201	.149	1272	0.134
Mayfield Dam	5100	.151	1273	.137
Snoqualmie Falls	7773	.164	1274	.141
Merwin Dam	5305	.165	1275	.136
		Cowlitz River near Randle (14-2334)		
Kid Valley	4201	.168		
Longmire	6894	.170	1432*	0.161
Mayfield Dam	5100	.177	1433	.162
Longview	4769	.185	1434	.157
Toledo	8500	.188	1435	.157

*Designates stations used for operational predictions.

TABLE 5. Optimum test-season lengths and winter season beginning dates for the main prediction seasons.

	N. Fk. Skokomish R. (12-0565)		Nisqually R. (12-0825)		Cowlitz R. (14-2334)	
Prediction season	Test-season length (Days)	Start winter season (Date)	Test-season length (Days)	Start winter season (Date)	Test-season length (Days)	Start winter season (Date)
Dec. 1-Sept. 30	25	Oct. 17	29	Oct. 13	31	Oct. 13
Jan. 1-Sept. 30	17	Oct. 17	17	Oct. 19	17	Oct. 19
Feb. 1-Sept. 30	25	Sept. 1	27	Oct. 11	18	Sept. 23
Mar. 1-Sept. 30	27	Sept. 1	3	Oct. 5	17	Sept. 1
Apr. 1-Sept. 30	2	Sept. 1	1	Oct. 9	3	Sept. 1
May 1-Sept. 30	3	Sept. 21	1	Oct. 21	1	Sept. 15
June 1-Sept. 30	8	Sept. 25	2	Oct. 21	2	Oct. 29
July 1-Sept. 30	21	Oct. 1	6	Oct. 13	1	Nov. 25
Aug. 1-Sept. 30	6	Oct. 15	3	Oct. 13	2	Nov. 21
Sept. 1-Sept. 30	6	Oct. 23	6	Oct. 9	3	Nov. 27

TABLE 6A. Relationship between seasonal streamflow at gaging stations upstream and downstream from reservoirs. (1952-76)

Main basin North Fork Skokomish River near Hoodsport 12-0575 (adjusted discharge)

Upstream gage North Fork Skokomish River below Staircase Rapids 12-0565

	Regression coefficients in cfs-days				
Season	A	B	R^{2*}	Mean (12-0575)	Standard Error
Dec. - July	1.436	9700	0.969	232400	7000
Dec. - Sept.	1.409	12300	0.965	246100	7800
Jan. - July	1.401	8600	0.970	190200	6500
Jan. - Sept.	1.376	10600	0.966	203900	7400
Feb. - July	1.349	6700	0.946	149900	6900
Feb. - Sept.	1.318	9400	0.942	163600	7800
Mar. - July	1.267	7800	0.965	119200	5100
Mar. - Sept.	1.251	9400	0.964	132900	5800
Apr. - July	1.147	8700	0.976	92400	3400
Apr. - Sept.	1.148	9900	0.971	106100	4400
May - July	1.129	4000	0.978	68900	3000
May - Sept.	1.137	4900	0.972	82600	4000
June - July	1.096	2100	0.982	40200	1900
June - Sept.	1.107	3300	0.974	53900	2900
July - July	1.056	1100	0.983	15400	900
July - Sept.	1.087	2500	0.961	29100	2200
Aug. - Sept.	1.233	300	0.906	13700	1600
Sept. - Sept.	1.541	-1000	0.922	6400	1100

$*R^2$ = coefficient of determination.

TABLE 6B. Relationship between seasonal streamflow of gaging stations upstream and downstream from reservoirs. (1952-76)

Main basin Nisqually River near La Grande 12-0865 (adjusted discharge)

Upstream gage Nisqually River near National 12-0825

	Regression coefficients in cfs-days				
Season	A	B	R^{2*}	Mean (12-0865)	Standard Error
Dec. - July	2.150	-31300	0.921	447100	22600
Dec. - Sept.	2.068	-39700	0.926	487700	2300
Jan. - July	2.059	-22200	0.931	372700	19100
Jan. - Sept.	1.977	-30100	0.931	413300	20100
Feb. - July	1.889	-11100	0.907	293300	18200
Feb. - Sept.	1.811	-16800	0.899	333800	20200
Mar. - July	1.781	-9000	0.900	237200	16400
Mar. - Sept.	1.702	-12900	0.890	277800	18400
Apr. - July	1.566	1700	0.864	188600	14500
Apr. - Sept.	1.501	1300	0.854	151900	16400
May - July	1.429	200	0.907	138100	10100
May - Sept.	1.382	300	0.893	129000	12200
June - July	1.286	-200	0.911	80100	6700
June - Sept.	1.262	900	0.885	120700	9300
July - July	1.061	3700	0.905	33200	2700
July - Sept.	1.107	700	0.839	73800	5700
Aug. - Sept.	1.349	-3200	0.775	40600	3500
Sept. - Sept.	1.744	-6200	0.900	18100	1600

$*R^2$ = coefficient of determination.

TABLE 6C. Relationship between seasonal streamflow at gaging stations upstream and downstream from reservoirs. (1952-76)

Main basin Cowlitz River at Mossyrock Dam 14-2348 (adjusted discharge)

Upstream gage Cowlitz River near Randle 14-2334

Regression coefficients in cfs-days

Season	A	B	R^{2*}	Mean (14-2348)	Standard Error
Dec. - July	1.113	15900	0.995	1700400	23700
Dec. - Sept.	1.108	16800	0.996	1820400	23500
Jan. - July	1.105	17400	0.996	1464700	20200
Jan. - Sept.	1.100	17500	0.996	1584600	20300
Feb. - July	1.097	900	0.994	1224600	20400
Feb. - Sept.	1.092	9400	0.995	1344600	21000
Mar. - July	1.079	11500	0.996	1036200	16100
Mar. - Sept.	1.075	11400	0.996	1156200	16700
Apr. - July	1.056	17400	0.994	878400	15400
Apr. - Sept.	1.055	17100	0.995	998400	16000
May - July	1.057	7200	0.995	695100	13700
May - Sept.	1.055	700	0.996	815100	14400
June - July	1.062	-500	0.996	411300	9900
June - Sept.	1.058	-400	0.996	531200	10700
July - July	1.051	500	0.995	149700	4400
July - Sept.	1.046	900	0.997	269700	5300
Aug. - Sept.	1.044	-100	0.997		1800
Sept. - Sept.	1.081	-200	0.997		800

$^*R^2$ = coefficient of determination.

TABLE 6D. Relationship between seasonal streamflow at gaging stations upstream and downstream from reservoirs. (1952-76)

Main basin Cowlitz River below Mayfield Dam 14-2380 (adjusted discharge)

Upstream gage Cowlitz River near Randle 14-2334

Regression Coefficients in cfs-days

Season	A	B	R^{2*}	Mean (14-2380)	Standard Error
Dec. - July	1.337	14100	0.988	2037500	43900
Dec. - Sept.	1.312	34100	0.989	2170700	44800
Jan. - July	1.314	8600	0.	1730200	46500
Jan. - Sept.	1.288	27600	0.985	1863400	47800
Feb. - July	1.283	-8000	0.978	1414100	46800
Feb. - Sept.	1.257	9500	0.979	1547300	49400
Mar. - July	1.228	8300	0.979	1174300	41300
Mar. - Sept.	1.206	23700	0.980	1307500	43600
Apr. - July	1.155	28400	0.971	970500	38800
Apr. - Sept.	1.140	42900	0.972	1103700	41600
May - July	1.129	8700	0.977	743400	31200
May - Sept.	1.115	23100	0.978	876600	34600
June - July	1.125	-1800	0.988	434400	17200
June - Sept.	1.106	11600	0.986	567600	21700
July - July	1.064	5100	0.990	156100	6500
July - Sept.	1.048	20100	0.980	289300	13200
Aug. - Sept.	1.085	8500	0.932	133200	8900
Sept. - Sept.	1.319	-5500	0.967	58200	3500

$*R^2$ = coefficient of determination.

TABLE 7 Comparison of predictions at downstream gaging stations with and without runoff data from low altitude drainages.
Values are coefficient of prediction (CP) for downstream forecasts.

	Nisqually River near La Grande (12-0865)		Cowlitz River below Mayfield Dam (14-2380)	
Season	Nisqually River near National 12-0825 only	Nisqually River plus Mineral Creek near Mineral 12-0825 and 12-0830	Cowlitz River near Randle 14-2334 only	Cowlitz River and Tilton Creek near Cinnabar 14-2334 and 14-2362
Dec. - July	0.057	0.000	0.107	.102
Dec. - Sept.	.062	.012	.113	.108
Jan. - July	.197	.087	.375	.373
Jan. - Sept.	.222	.111	.385	.383
Feb. - July	.478	.440	.505	.508
Feb. - Sept.	.513	.486	.533	.536
Mar. - July	.689	.650	.658	.655
Mar. - Sept.	.706	.676	.671	.669
Apr. - July	.663	.633	.657	.652
Apr. - Sept.	.700	.676	.689	.685
May - July	.748	.682	.738	.730
May - Sept.	.758	.725	.753	.746
June - July	.785	.556	.645	.627
June - Sept.	.780	.638	.668	.653
July - July	.425	.193	.479	.459
July - Sept.	.658	.514	.590	.574
Aug. - Sept.	.471	.532	.532	.529
Sept. - Sept.	.534	.593	.280	.287

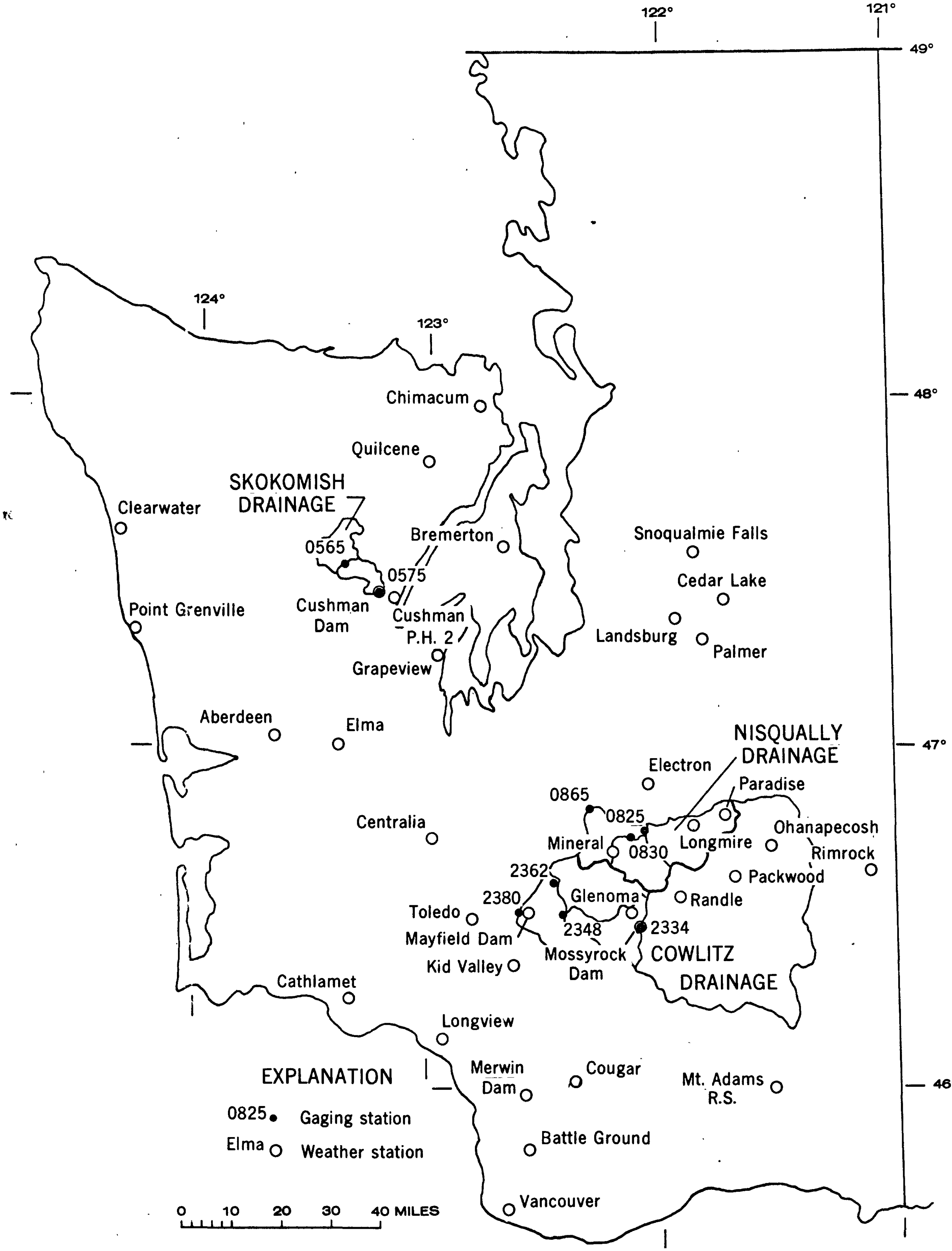


FIGURE 1. Location of the Skokomish, Nisqually and Cowlitz River drainages and the National Weather Service stations tested for use in the HM Model

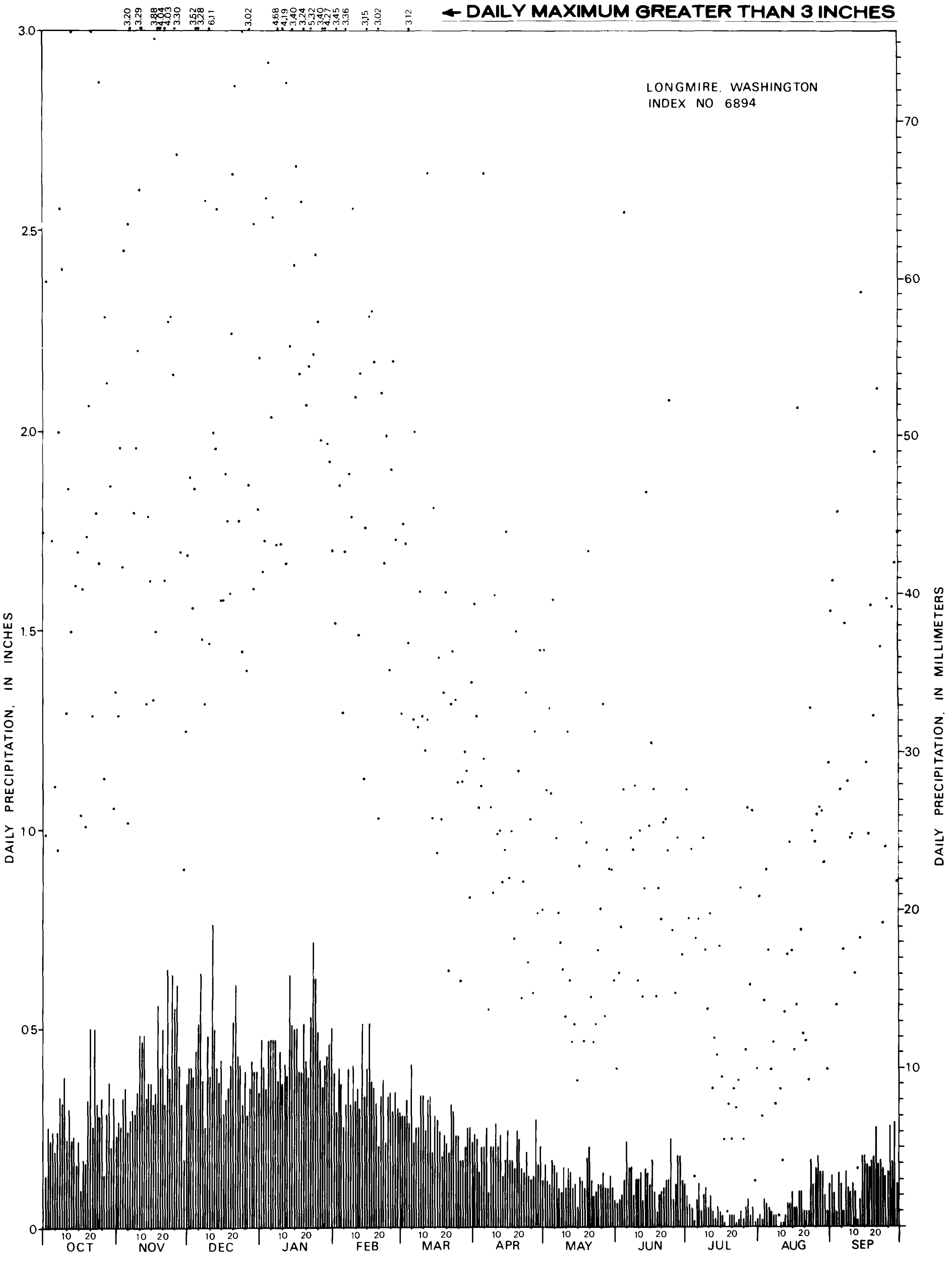


FIGURE 2. Daily average (bars) and daily maximum (dots) precipitation at Longmire for the 1945-74 period

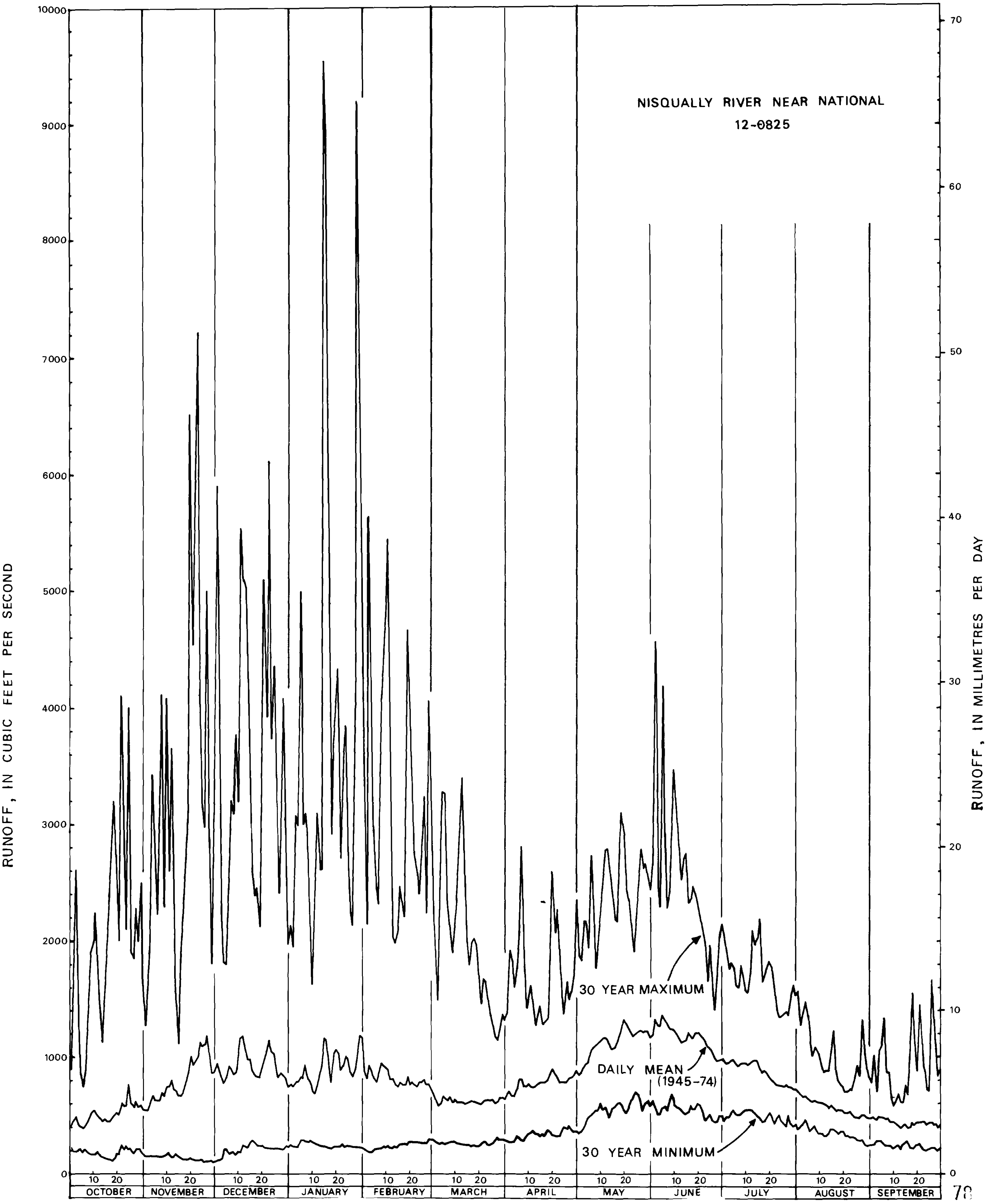


FIGURE 3. Daily average, maximum and minimum runoff of the Nisqually River near National for the 1945-74 period

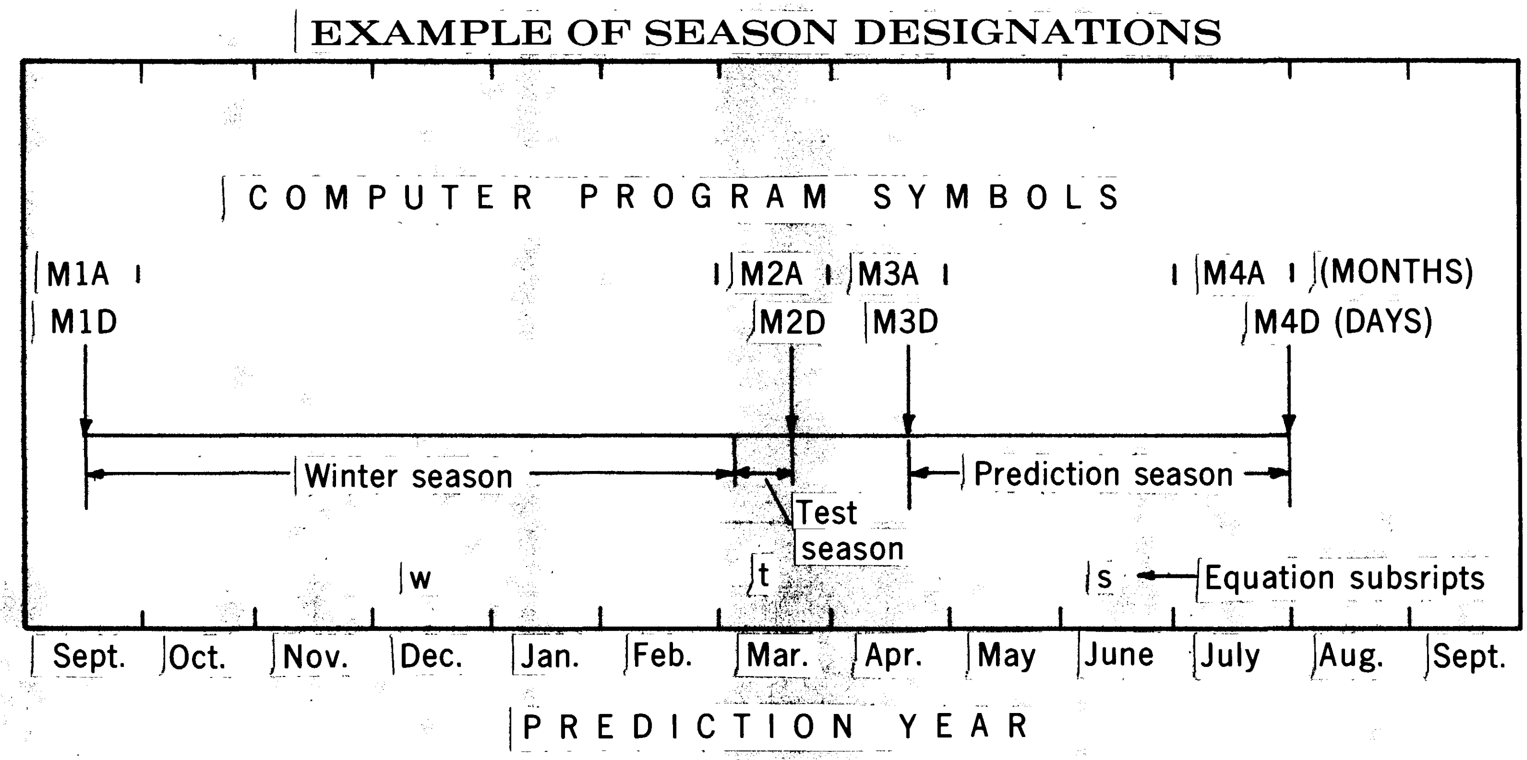


FIGURE 4. Example of the three seasons used in the model, showing the prediction equation subscripts and computer program symbols.

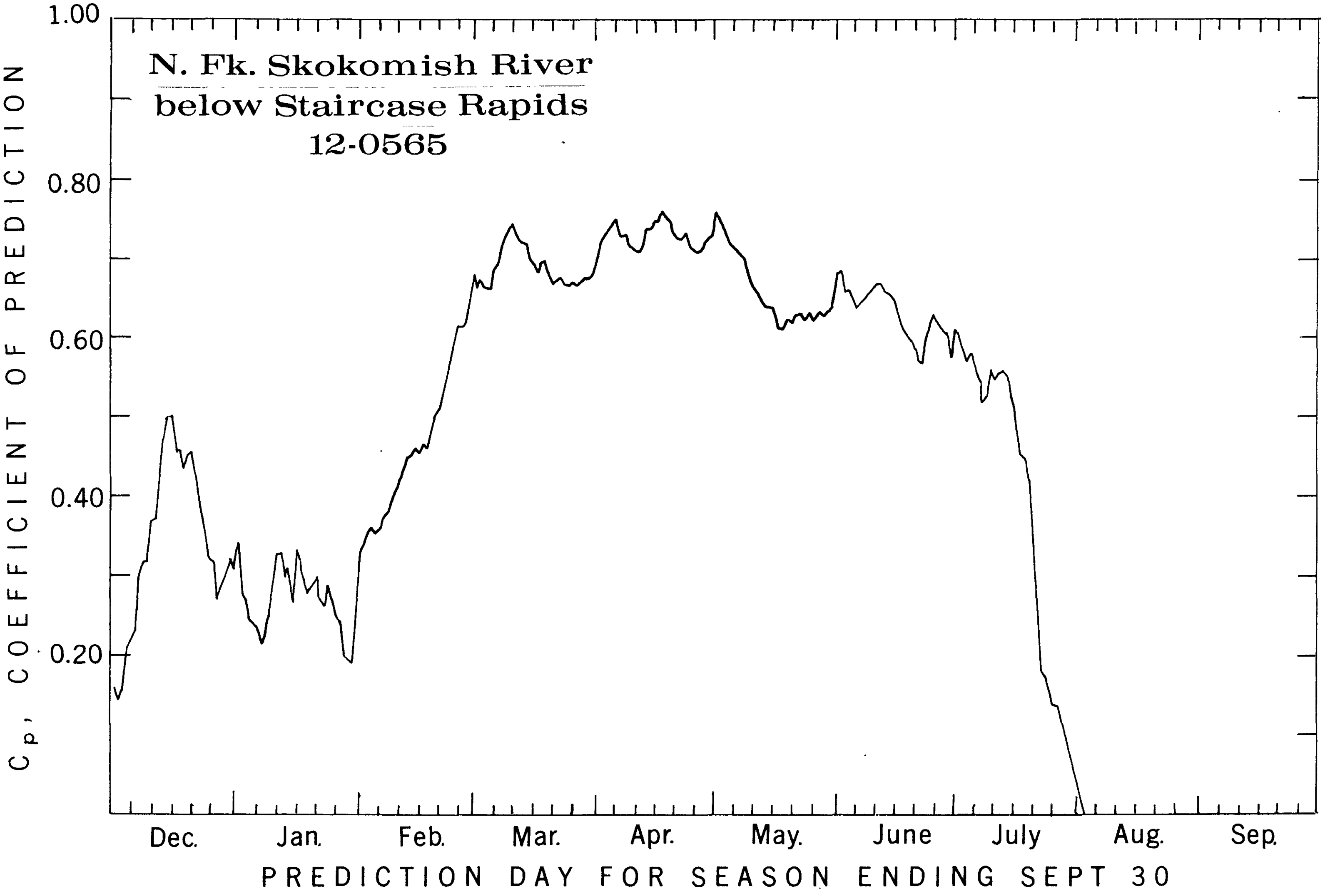


FIGURE 5. Examples of prediction accuracy as a function of prediction date

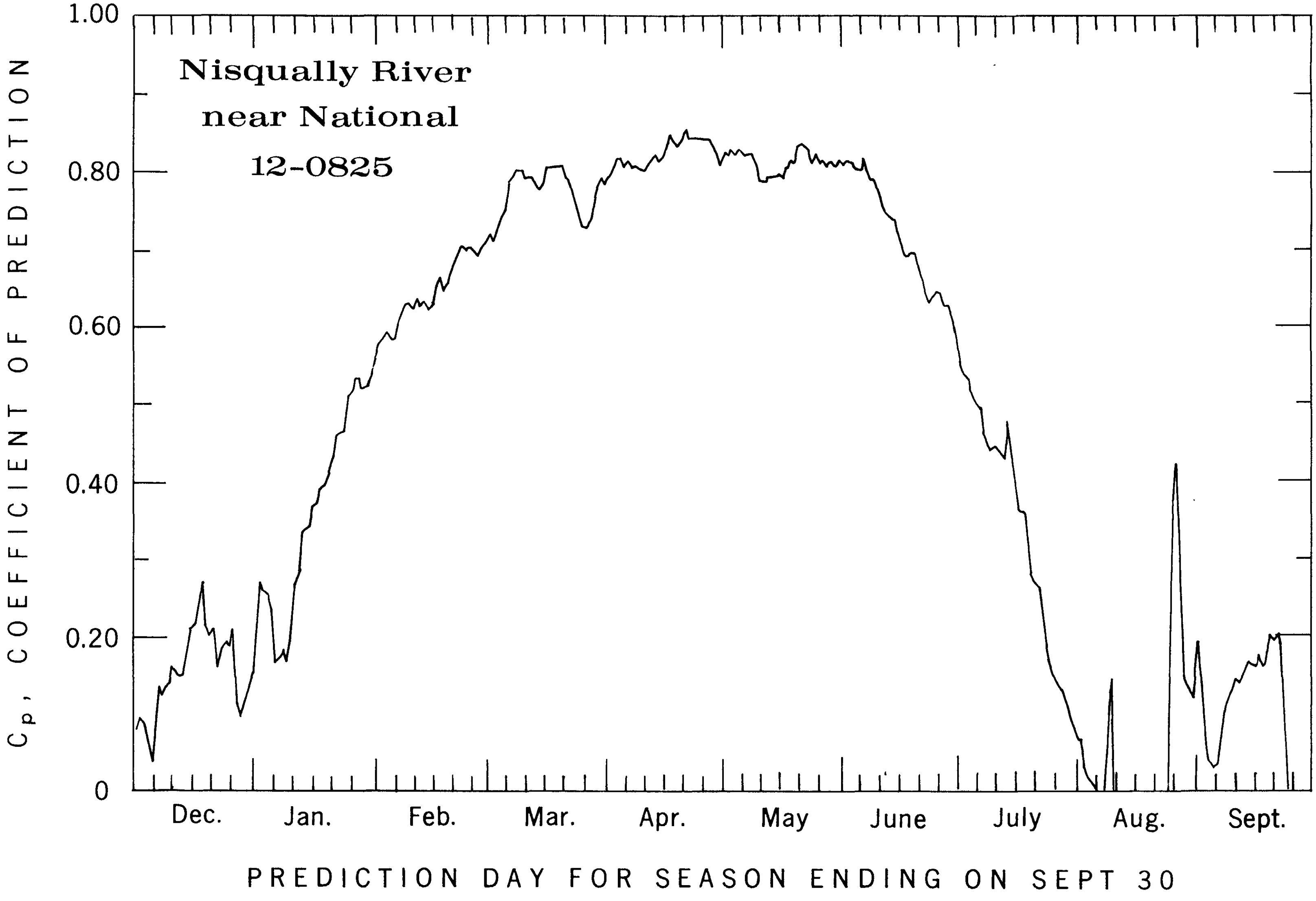

Nisqually River
near National
12-0825
1.00
0.80
0.60
0.40
0.20
0
C_p, COEFFICIENT OF PREDICTION
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
PREDICTION DAY FOR SEASON ENDING ON SEPT 30

Figure 5 B

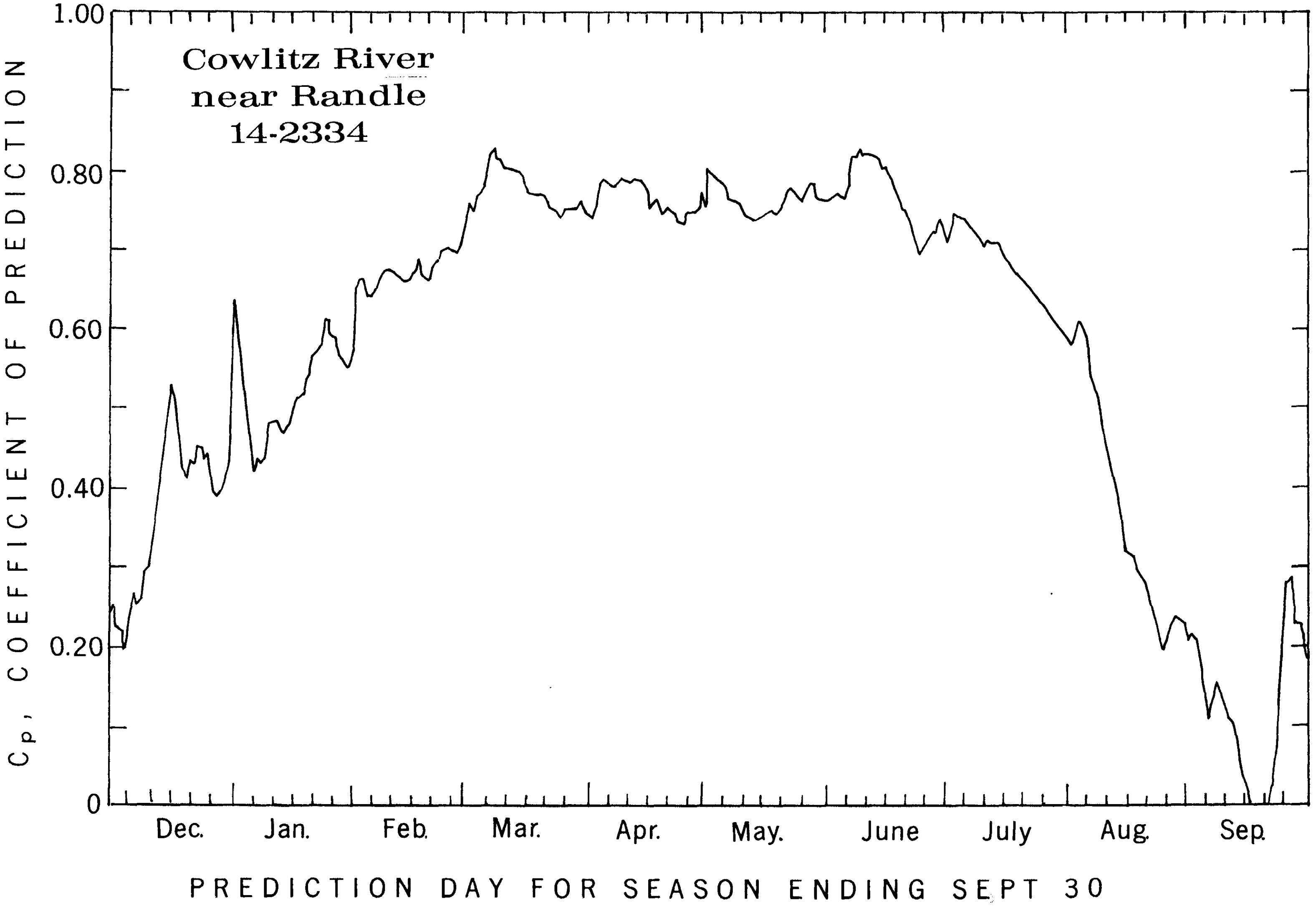

Cowlitz River
near Randle
14-2334
1.00
0.80
0.60
0.40
0.20
0
Cp, COEFFICIENT OF PREDICTION
Dec.
Jan.
Feb.
Mar.
Apr.
May.
June
July
Aug.
Sep.
PREDICTION DAY FOR SEASON ENDING SEPT 30

Figure 5 C

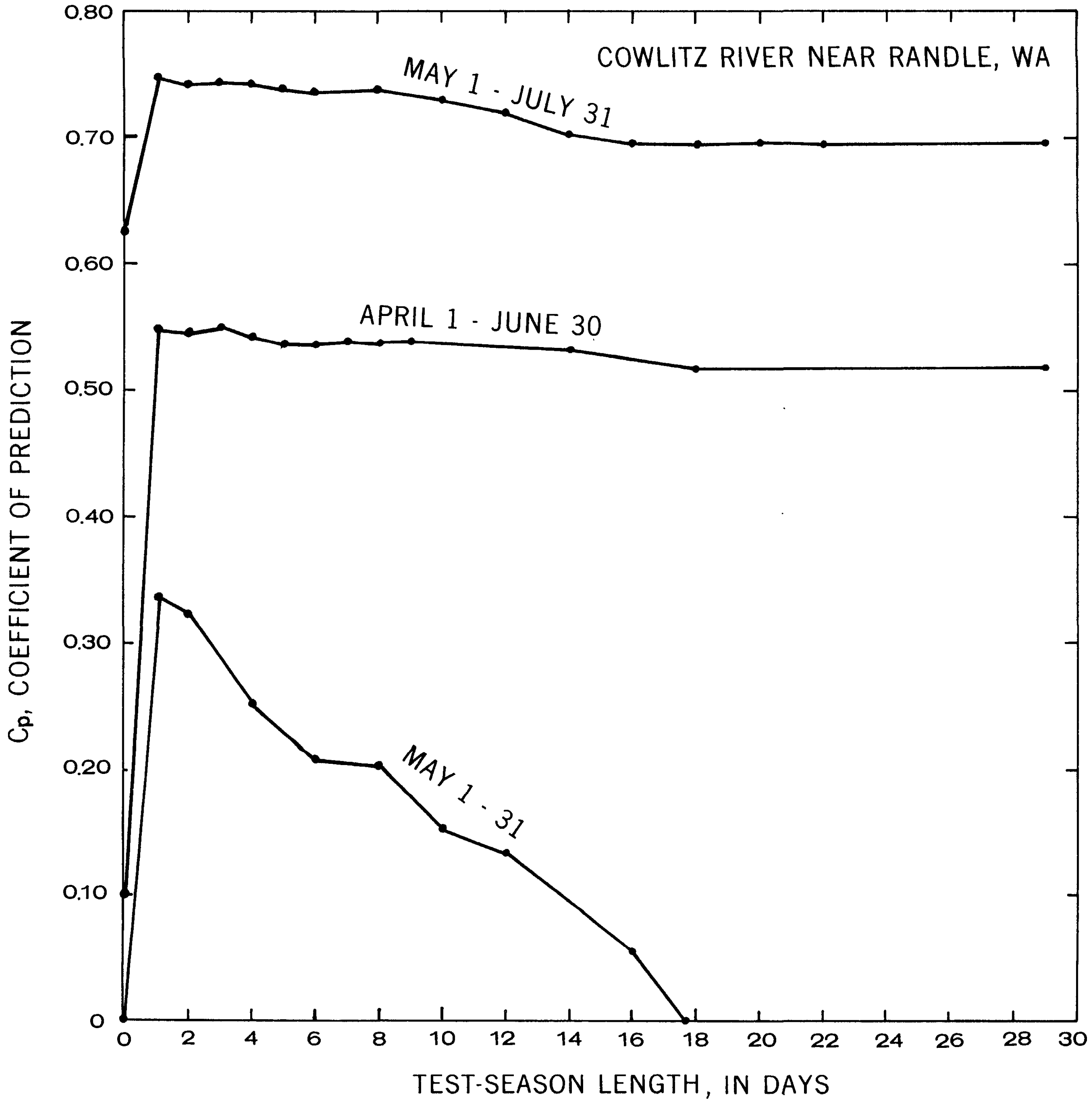


FIGURE 6. An example of the effect of test-season length on prediction accuracy

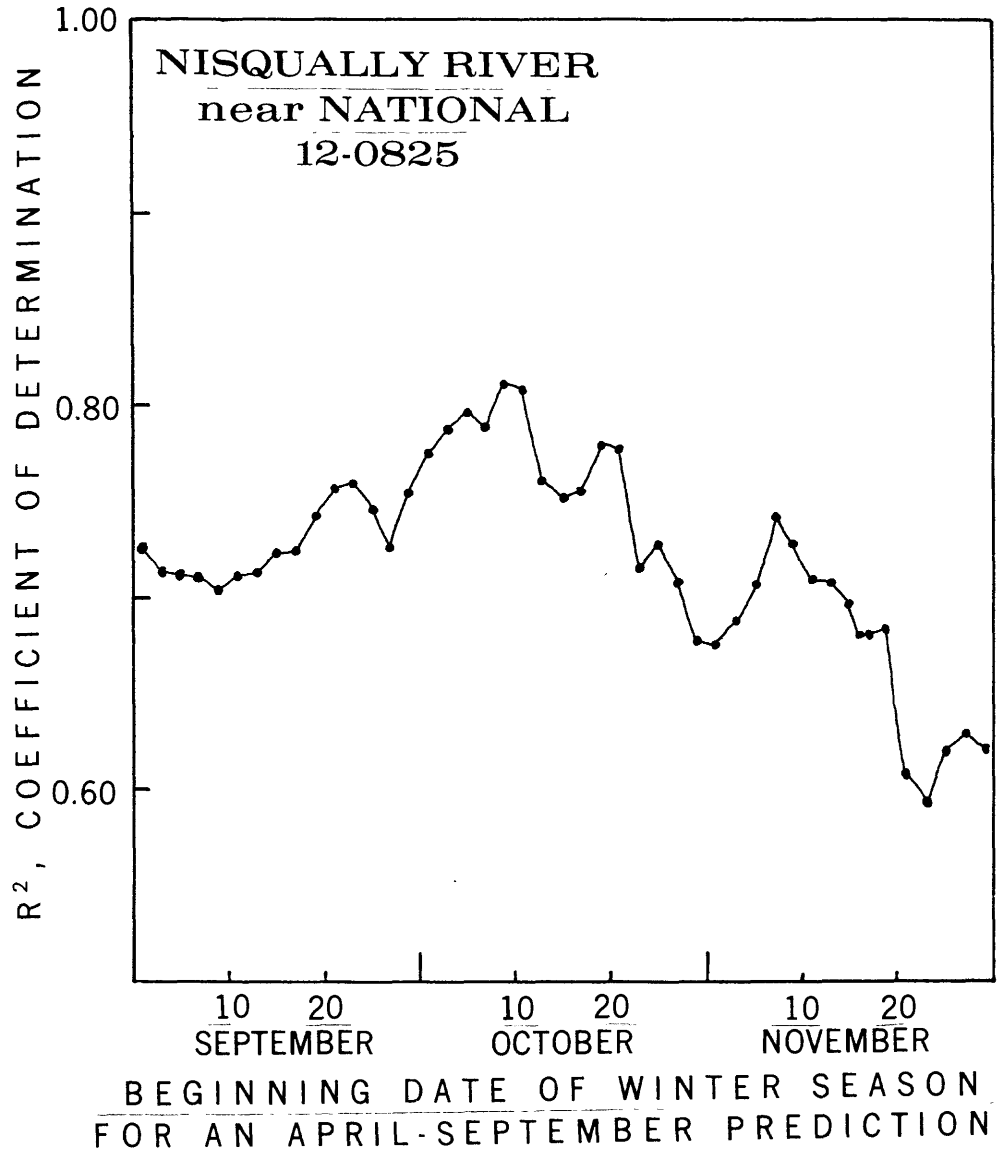


FIGURE 7. An example of the effect of the beginning winter date on prediction accuracy.

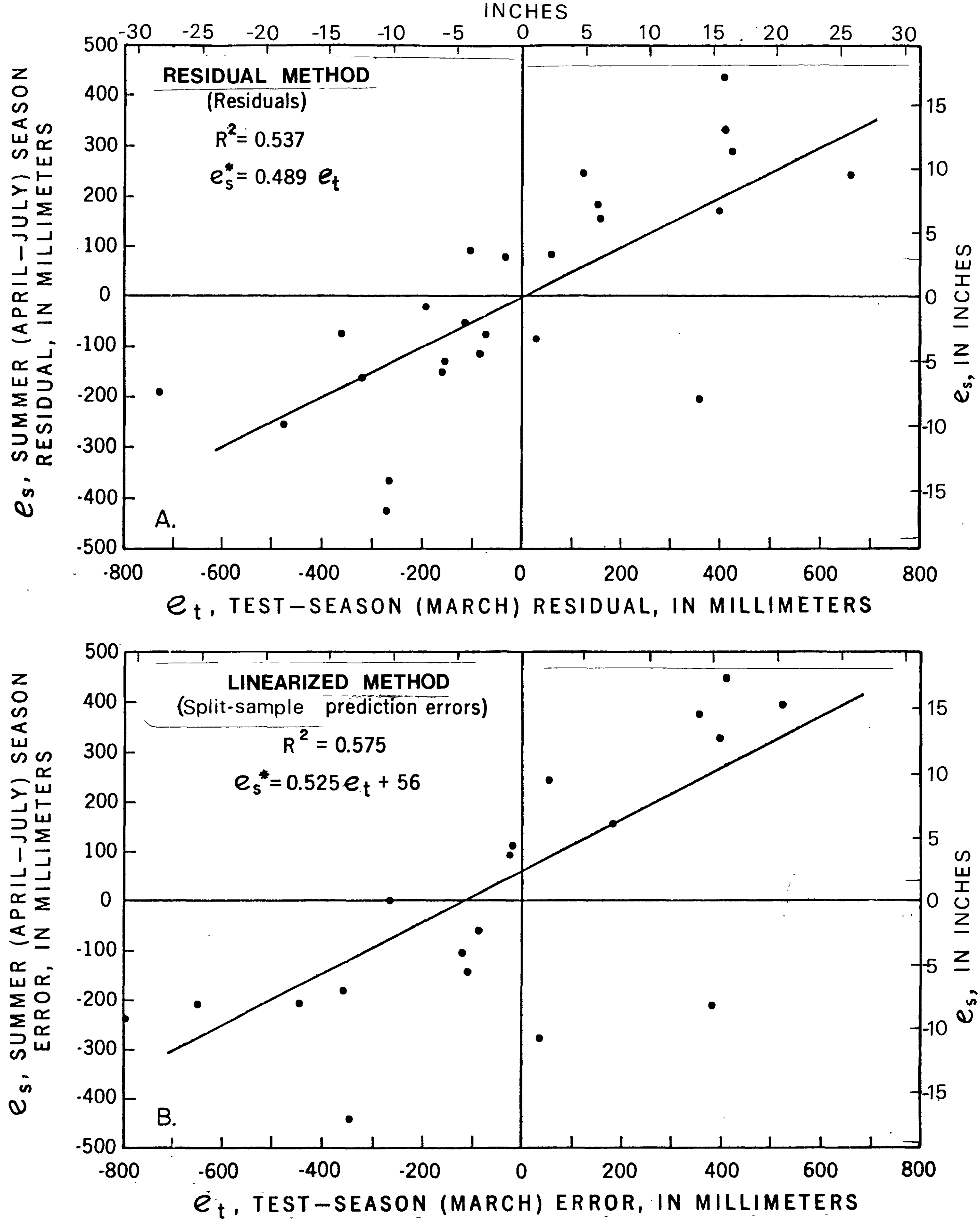


FIGURE 9. Graphs demonstrating the relationship between test and prediction season errors, and the linearized and residual technique of revising the predictions.

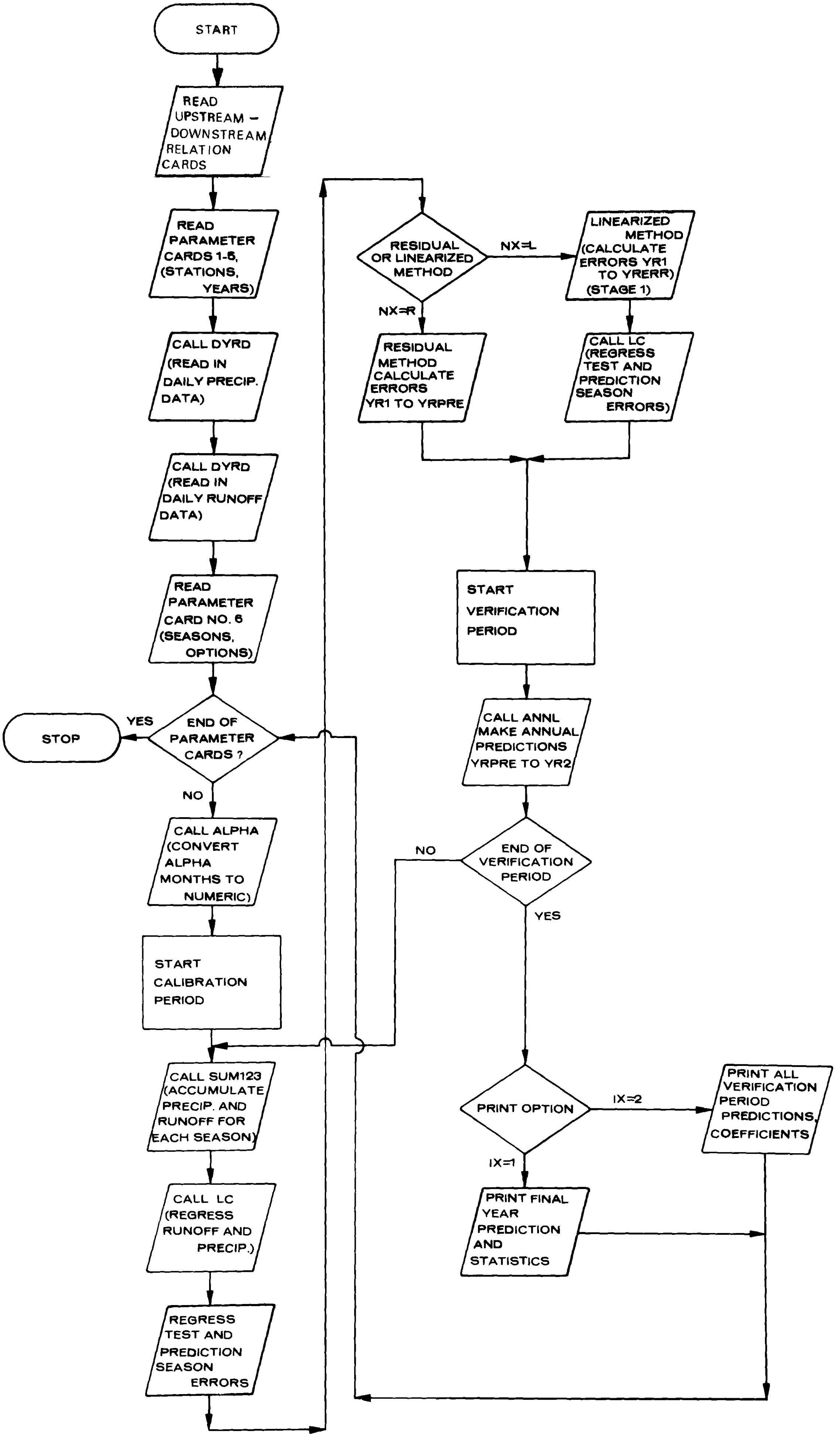
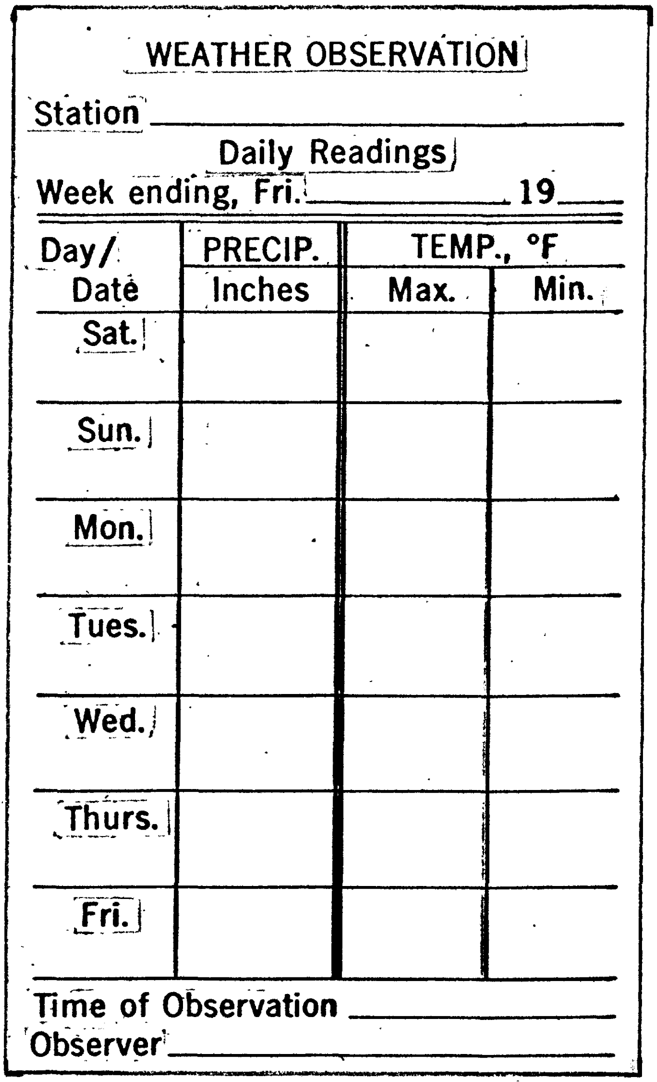


FIGURE 10.

A generalized flow-chart of the HM Model



WEATHER OBSERVATION

Station ____________________

Daily Readings

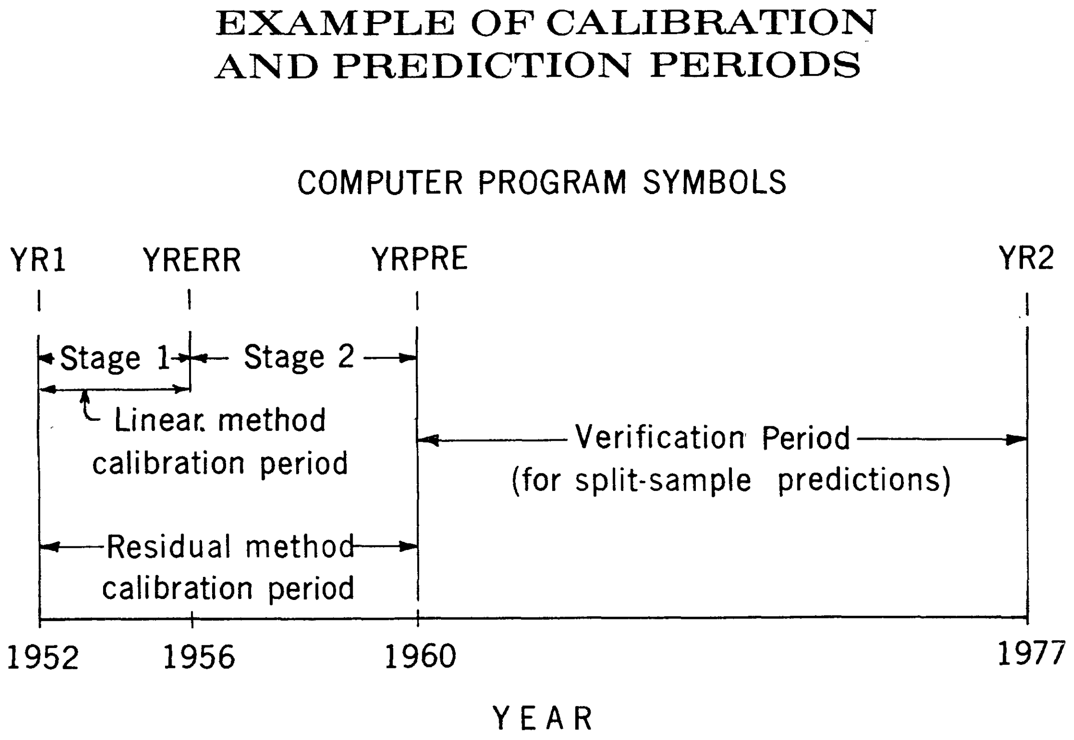
Week ending, Fri. ____________ 19____

Day/ Date	PRECIP. Inches	TEMP., °F Max.	 Min.
Sat.			
Sun.			
Mon.			
Tues.			
Wed.			
Thurs.			
Fri.			

Time of Observation ____________

Observer ____________________

FIGURE 11. Postal card used by weather station observers to forward meteorologic data to the forecast office each week.



EXAMPLE OF CALIBRATION AND PREDICTION PERIODS

FIGURE 8. Sketch demonstrating the period of record used in making split-sample predictions-