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Prediction equations were developed for estimating the flow regime at ungaged stream locations in the Oregon coastal range. Principal components analysis was used to screen the initial data set of physiographic and meteorological parameters. The final regression equations for predicting mean monthly flow had standard errors of estimate ranging from 3 to 42 percent, with an average standard error of 13.5 percent. A linear prediction equation was found to give the best results for drainage basins larger than 150 square miles, while a logarithmic equation gave best results for basins of less than 150 square miles in area. A simple linear relationship was also established between mean monthly flow and the standard deviation of monthly flow. A test on an independent sample indicated that the monthly estimates of standard deviation made using the simple linear relations were comparable to those reported by others using equations containing physiographic and meteorological parameters.

Equations were also developed to forecast monthly streamflow for Oregon coastal streams. When observed rainfall for the current month was used, the average standard error of the forecast equations was 18 percent. The use of the National Weather Service's 30-day precipitation outlooks in forecasting monthly streamflow was also investigated. The results showed that the forecasts based upon the 30-day outlook precipitation were worse than those based upon median historical precipitation. It was suggested that the monthly streamflow forecast equations could best be applied on a probability basis.

Prediction of Monthly Streamflows for Oregon Coastal Basins Using Physiographic and Meteorological Parameters

by

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I. INTRODUCTION

In the northwestern United States, as with other sections of the country, multiple demands are being placed upon the water resource. The coastal areas of Oregon are being considered as possible sites for industry and nuclear power stations. Such sites would create a potential hazard to the fish and shellfish of the coastal area. A knowledge of the flow regime of the coastal streams and their discharge into the estuaries and an ability to forecast monthly streamflow would improve the intelligent multiple use of the fresh water resource.

The desirability of predicting mean monthly flows and standard deviations for ungaged areas and of forecasting monthly streamflow for gaged locations is readily apparent. In the first instance, prediction of the range of possible flow from ungaged areas might prove valuable in a multiple use study of the coastal water resource. Such predictions might also be useful in design studies of future reservoir sites. In the second case, a reliable estimate of the coming month's discharge would assist in reservoir regulation planning. Also, an accurate estimate of the amount of freshwater (dilution flow) entering an estuary during a month would contribute to better planning of some estuarine activities. Careful planning will have to be carried out in the coastal zone to preserve the natural resources while meeting the multiple demands. Modern computer techniques allow estuarine areas to be modeled. Again, the amount of freshwater flowing into an estuary will be an important input to any computer model.

The objectives of this thesis are twofold: (1) to develop a method to predict mean monthly flow and standard deviations of monthly flow for ungaged Oregon coastal streams, and (2) to forecast monthly streamflow at gaged locations on the Oregon coast. The first objective was achieved by developing a set of mean monthly flow prediction equations, using physiographic and meteorological parameters. The second objective was met by deriving a set of monthly equations for gaged locations which enable forecasts of monthly flow to be made. In particular, the advisability of using the 30-day precipitation outlook issued by the National Weather Service to "forecast" monthly flow is investigated. The term "forecast" is probably a misnomer in this context since the ability to predict monthly weather sequences is doubtful. The resulting forecasts should be labeled monthly flow "outlooks."

II. LITERATURE REVIEW

Estimating the flow characteristics in gaged and ungaged areas has been pursued by many investigators. Most predictions have involved the mean annual flow, the mean annual flood (that flood with a recurrence interval of 2.33 years), the peak flow, or the storm volume. Predicting any of these flows involves the use of a mathematical model with components to index the underlying physical processes that control water yield. Ideally, a set of physical and climatic parameters would be used which include all of the important factors that influence the runoff process. In reality, the available factors are not the basic underlying controls, but are merely indices of the real hydrologic system.

Predicting Mean Annual Flows for Ungaged Areas

Idson (1959) pointed out that the rate of annual runoff from a river is a function of climate, relief, the infiltration and water retaining properties of the soil and the geologic structure of the basin. The vegetal cover and land use practices will also play an important part in controlling water yield from a watershed.

Many parameters have been utilized by various authors to index these basic controls. Benson (1962), in a study conducted in New England, found that drainage area, main channel slope, percent of area in lakes and ponds, and rainfall intensity for 24 hours with the same recurrence interval as the peak flood were the significant variables. Wong (1963), in summarizing the work of previous authors, stated that the factors most significantly related to mean annual runoff are drainage area, channel slope, mean distance to basin outlet, mean basin altitude, basin time lag, surface storage, climate, vegetation, and soil. Lull and Sopper (1967) used average annual precipitation, average seasonal precipitation, precipitation intensity (24 hour, 2 year return period), mean maximum basin temperature in July, mean basin latitude, elevation of the gaging station, main channel slope, percent of the basin covered by forest, and percent of the basin area in lakes and swamps to predict annual and seasonal streamflow. Pentland and Cuthbert (1971) used a similar set of variables to predict mean monthly flow in the New Brunswick area of Canada. In a study conducted in England, the drainage area, drainage density and a rainfall intensity function were used to predict the mean annual flow (Rodda, 1967). Basin elevation, slope and rise were found to be most important in predicting water yield from high mountain watersheds in the western United States (Julian, Morel-Seytoux and Yevjevich, 1967). Gladwell (1970) found basin slope, an index of basin radiation, basin aspect and length of the basin were most important in predicting mean annual and mean monthly flow.

The vegetation factor most frequently used has been the percent of the total basin area forested. Anderson (1967), Mustonen (1967), and Lystrom (1970) all found a forest cover parameter to be important in predicting water yield.

A variety of statistical approaches have been applied to the various index parameters listed above. Julian, Morel-Seytoux, and Yevjevich (1967) used regression analysis and Taylor's series analysis to estimate the mean annual specific yield in cubic feet per second per square mile (cfsm). A set of physiographic parameters was used and both methods produced comparable results in all prediction equations. Mustonen (1967), working with watersheds in Finalnd, used a regression model to predict mean annual runoff. Lull and Sopper (1967) applied regression analysis to predict both mean annual flow and the seasonal streamflow. In two studies conducted in the northwestern United States, regression analysis was applied to a set of index parameters with various degrees of success (Lystrom, 1970; Thomas and Harenberg, 1970). In one of these studies, conducted in Oregon, standard errors of estimate ranged from 15 to 50 percent in the monthly streamflow prediction equations (Lystrom, 1970). All of the papers above were concerned with predicting mean annual flow from ungaged areas.

Predicting Peak Flows and the Mean Annual Flood

Other authors have dealt with the problem of estimating peak flow and the mean annual flood. Some of the earliest efforts in hydrologic prediction were concerned with estimating peak flow by such means as the rational method (see Chow, 1964, Section 14 for a historical sketch of the rational method). Anderson and Hobba (1959) used a set of climatic and physiographic variables to predict mean annual floods from snowmelt in the northwestern United States. Their variables included such terms as: fall, winter, and spring rainfall; the average spring temperature; a slope parameter; and the drainage area. Benson (1962, 1964) estimated mean annual floods of various recurrence intervals for streams in New England and in the southwestern United States. His variables included the drainage area, main channel slope, the percentage of the total basin area covered by lakes and swamps, basin length, basin rise, mean annual precipitation, and a rainfall intensity term. The resulting prediction equations had standard errors ranging from 25 to 33 percent of the respective recurrence intervals. In another study conducted in the Willamette Valley of Oregon, a regression equation was used to predict the mean annual flood (Hudzikiewicz, 1968). In a study conducted in Great Britain, Rodda (1969) developed a regression equation with a coefficient of determination (R^2) of .81.

Review of the Use of Multivariate Statistical Methods in Prediction

Recently some of the multivariate statistical methods have been used to develop prediction equations. Investigators using the regression analysis approach have long recognized that high intercorrelations among predictive parameters produce unstable and physically unrealistic coefficients. Principal components analysis provides a means of selecting statistically independent parameters. Wong (1963) used principal components analysis to develop a powerful prediction equation. Eighty percent of the variance in mean annual flood of New England streams was explained using length of main stream and average land slope as parameters.

Several other authors have also applied principal components analysis to watershed prediction problems. Anderson (1967) used principal components analysis to screen the initial set of variables and chose an independent set of prediction variables. Six variables from an original set of 30 were chosen to predict sediment yield. In another study, principal components analysis was used to select variables to predict peak flow on small research watersheds in the San Dimas Experimental Forest in California (Rice, 1970). Gladwell (1970) used the method of regression on principal components and multiple regression on the original variables to develop prediction equations for mean monthly flow on streams in the state of Washington.

The predictor variables were a set of physiographic parameters, including a basin aspect term, a basin rise term, a basin length term, and a variable to index the solar radiation that the basin received. Generally, good results were achieved in tests on independent basins. Gladwell suggested that some of the larger predictive errors were due to regional nonhomogeneity.

Stochastic methods have also been applied to define mean monthly flow. These procedures have been used to simulate runoff records when the population mean and standard deviation can be estimated. The approach is primarily useful in extending the runoff record for planning purposes. Obviously, stochastic models cannot be applied directly in ungaged areas since a knowledge of the streamflow mean and standard deviation is required. However, the methods used in this thesis to estimate mean monthly flow and standard deviation of monthly flow could be combined with the simulation techniques to generate flow regimes from ungaged areas. Fiering (1964) and Beard (1967) have both used a stochastic model to simulate monthly flow.

Review of Statistical Modeling Assumptions and Limitations

From the previous paragraphs it is apparent that many different approaches have been applied to predict water yield for various periods. Some form of regression analysis has generally been used to establish the prediction equation. The success of the regression approach is related to the degree to which the assumptions of the regression model were violated. The basic model assumptions are: (1) the errors about the regression line are normally distributed with a mean of zero and a variance of σ^2; (2) the independent variables are random and uncorrelated; and (3) the independent variables are sampled without error. All of these assumptions may be violated in a particular hydrologic investigation. Several statistical texts and several studies have pointed out that the multiple regression method will give a best-fit equation even if the assumption of homoscedasticity of errors about the regression line is not met. However, statistical tests of significance of the regression equation will not be meaningful if the assumption is violated (Sharp _et al._, 1960; Draper and Smith, 1966; Julian, Morel-Seytoux and Yevjevich, 1967).

Using highly correlated independent variables also causes problems. In a study conducted in Finland, Mustonen (1967), concluded that intercorrelation between the independent variables did not invalidate the prediction model. Julian, Morel-Seytoux and Yevjevich (1967) made a similar conclusion, but pointed out that high intercorrelations made it impossible for the regression model to evaluate the absolute contribution of each independent variable; hence, the relative importance of each variable could not be determined. They further indicated that high intercorrelations will cause the algebraic signs of the variables to be inconsistent with good hydrologic reasoning. Some of the aforementioned problems are demonstrated in the studies by Sharp et al. (1960), Hudzikiewicz (1968), and Lee and Bray (1969).

In the early 1960's, investigators began to look for statistical methods to circumvent the problem of highly correlated variables. Principal components analysis and factor analysis have proven most useful in handling this problem. Both methods examine the correlation matrix and eliminate all redundant factors, and produce an underlying set of statistically independent variables. The resulting components have either been used directly in a regression analysis or the component loadings have been used to select a set of nearly independent variables for regression. The prediction equations resulting from these methods have the following properties: (1) the equations make physical sense, (2) the coefficients are stable and give a true indication of the importance of each variable, (3) excellent results are obtained even with small sample sizes, and (4) a more realistic estimate of the error of prediction can be made (Wong, 1963; Wallis, 1965; Anderson, 1967; Eiselstein, 1967; Rice, 1967; Wong and Huber, 1967; Wallis, 1968; Shelton and Sewell, 1969; Gladwell, 1970; Rice, 1970; Haan and Allen, 1972).

In many instances transformations of the original variables have been performed before a regression or principal components analysis is started. Logarithmic transformations of variables have often been used in hydrologic studies. This transformation has usually been applied to normalize the distribution of each variable. However, it is not a requirement of the regression model that each variable be normally distributed. Mustonen (1967) points out that transformations have often been applied to hydrologic variables without considering whether or not the particular transformation fits good hydrologic reasoning. D. V. Anderson (1967) agrees with the comments of Mustonen and further states that the logarithmic transformation tends to demagnify inaccuracies at the higher values. Conversely, logarithmic transformations tend to magnify the inaccuracies for small values. This particular property should prove useful in developing the equations of this study.

Review of Methods for Predicting Standard Deviations of Monthly Flows

In order to apply the methods of simulation an estimate of the standard deviation of monthly flow is also necessary. Two studies conducted in the western United States involved a set of variables similar to those mentioned previously in the literature review to predict the standard deviation of monthly flow (Lystrom, 1970; Thomas and Harenberg, 1970). In both studies the results were generally worse than for the prediction equations of mean annual or mean monthly flow. In one case, the standard deviation was predicted with a standard error ranging from 22 to 62 percent; in the other case the standard error varied from 30 to 100 percent of the mean monthly standard deviation.

Waitt and O'Neill (1969) and Gladwell (1970) both established a simple relation between mean annual discharge and the standard deviation of annual discharge. Waitt and O'Neill (1969) developed a relation of the form,

$$\sigma_Q = ae^{-b\overline{Q}} \tag{1}$$

where a and b are coefficients and where the mean annual flow, $\overline{Q}$, and the standard deviation of annual flow, σ_Q, are in terms of logarithmic units. Gladwell used linear and logarithmic equations to relate mean annual flow and standard deviation of annual flow, with the linear equation being the better predictor. The prediction equation had the form,

$$\overline{Q} = b + a\sigma_Q \tag{2}$$

where $\overline{Q}$ and σ_Q are the mean annual flow and the standard deviation of the annual flow, respectively, and where a and b are constants determined by regression analysis.

Review of Methods Used to Forecast Monthly Flows

Some of the earliest work on predicting water yield for specific time periods was done by the Tennessee Valley Authority (Snyder, 1964). A mathematical model was developed using a nonlinear least squares technique. The method predicts water yield for specific periods, such as a month. The basic components of the model are: (1) an immediate flow function, including a precipitation and a loss term; (2) a delayed runoff function, written as a weighted sum of the previous months' flows; (3) a time trend function, represented by a time series of the form,

$$f(t) = b_1T_1 + b_2T_2 + b_3T_3 + \ldots + b_mT_m \qquad (3)$$

where each T is a specific period of time, usually a year, and the subscripted b terms are coefficients. The model was tested on 11 sets of monthly runoff data with drainage areas ranging from 3.7 acres to 667 square miles. The average coefficient of determination (R^2) was 0.88 and the standard error was 17 percent of the monthly mean. The time trend function had unrealistic coefficients and was not used in the final equation.

In another study, Sharp et al. (1960) used a multiple regression technique to predict monthly streamflow on the Delaware River basin in Kansas. Their linear regression model included monthly precipitation, monthly precipitation exceeding five inches, antecedent monthly precipitation, groundwater storage, monthly temperature, and several land-use parameters. The resulting monthly equations had R^2 values ranging from .59 to .95 and the standard error varied from 32 to 120 percent of the monthly mean. Three major reasons for these rather poor results were suggested: (1) some of the predictor variables were highly correlated, resulting in unrealistic signs on some of the parameters; (2) much of the winter precipitation falls as snow and does not run off until spring, but no variable was used to index this process; (3) estimates of basin precipitation may have been inaccurate especially in the midwestern United States area where areal distribution may vary widely over short distances because of small-scale convective storms.

Greening and Law (1969) used a method similar to that in the Tennessee Valley Authority study to predict monthly runoff for a stream in the southeastern United States. Their model consisted of an antecedent surface runoff component, an antecedent groundwater runoff component, and runoff from precipitation falling during the forecast month. To estimate the amount of surface runoff carryover, a 24 hour unit hydrograph was applied to the rain that fell during the last five days of the previous month. The groundwater component was the weighted sum of the mean monthly flow for the previous three months. The amount of runoff from the current month's rain was a function of the initial soil moisture regime. Good results were achieved using the model when the current month's precipitation was treated as a known quantity. The authors also applied the model using the National Weather Service's 30-day precipitation outlook. The results from this test were only slightly better than those attributable to chance. The authors point out that the temporal distribution of monthly rainfall is important in predicting monthly yield and that no technique is currently available for predicting the distribution of rainfall beyond the first few days. They also found that using the 30-day temperature outlook as an index to monthly evapotranspiration increased rather than decreased the predictive error.

The Hartford River Forecast Center of the National Weather Service developed a monthly flow prediction method for streams in the northeastern United States (Hopkins, 1971). Monthly weights were developed for each month. When applied to each monthly rainfall amount these may be considered to be runoff coefficients. Monthly flow forecasts are derived from the antecedent rainfall for the previous two-month period and precipitation for the current month. The latter is based upon the most probable precipitation, a reasonable minimum precipitation (90% chance of exceedence), and a reasonable maximum precipitation (10% chance of exceedence). The forecast equations for each basin are derived through a multiple regression approach. The monthly flow outlooks are regularly published in a water supply outlook for the northeastern United States.

Bonné (1971) developed a multiple regression model for monthly streamflow which used as variables the previous month's streamflow, the current month's precipitation, the previous month's precipitation, and a winter precipitation sum to index snowpack accumulation. This model was superior to a Markovian model based only on previous streamflow.

Other investigations have been concerned only with predicting low flow for specific periods. The flow in a river during low-flow periods is dependent upon three main factors: (1) the storage of water in the river basin at the beginning of the period, (2) the rate at which this storage is exhausted, and (3) the additional supply by precipitation (Popov, 1964).

Popov developed an equation to predict the recession segment of a streamflow series in which additional runoff due to rainfall was not an important component. His forecast equation had the form,

$$Q_t = (Q_0 - q)e^{-\beta t} + q \tag{4}$$

where, Q_t, is the discharge at any time t after initiation of the period, Q_0 is the initial discharge, q is the base flow discharge, and β is the recession constant. The numerical value of β is derived for each basin and for each different time period. The value for base flow is calculated at the start of each forecast period. This method does not account for streamflow increases due to rainfall during the low flow period.

In some areas, rainfall during the low flow period may be an important factor in the resultant flow sequence. In an Illinois study, precipitation was found to explain more than 70 percent of the variation of streamflow exhibited during 15 low-flow periods on eight watersheds (Huff and Changnon, 1964). Schofield (1960) found the monthly cumulative departure from the mean for rainfall, the monthly cumulative departure from the mean for mean air temperature, and the monthly cumulative departure from the mean for sunshine to be important in predicting water table levels in a New Zealand basin. Mann and Rasmusson (1960) used an antecedent precipitation index, a seasonal parameter, and forecast period rainfall to predict 28-day most probable flow during the low flow period on streams in the Mississippi River system. Tests carried out using normal precipitation during the forecast month produced an average standard error of 33 percent.

Riggs (1953, 1961) and Riggs and Hanson (1969) have developed several methods for forecasting seasonal low flow. One method, in which recession curves are drawn to estimate the assured flow during the low flow period, is similar to the approach of Popov (1964). The authors found that recession curves of different slopes occurred during the spring and summer months. They suggest that the change in slope during the summer months is a function of the evapotranspiration rate changes during the summer. Several other graphical forecast methods for low-flows were described by the author, using various periods of flow, or in the case of runoff from snow, using the water equivalent at several snow courses in the basin.

From the previous paragraphs it is evident that only a small body of research has been carried out on the problem of forecasting flow for specific periods. The need for such forecasts exists and will increase with time.

III. THE PRINCIPAL COMPONENTS METHOD

Description of Principal Components

Principal components analysis is employed whenever it is desirable to investigate whether a single universe of P dimensions can be represented in fewer than P dimensions or when it is desirable to represent a series of measurements by a single index value. We may view the universe as composed of P vectors, one for each of the variables involved. The length of each vector is equal to the variance of that attribute and the cosine of the angle between any two vectors is equal to the correlation coefficient of those two parameters. We want to transform the variables in such a way that the angle between the newly formed vectors equals 90° with a resultant correlation of zero. Each transformed variable component progressing from the first, accounts for as much of the combined variance of the original variables as possible (Clarkson, 1967; Gladwell, 1970).

Finding the principal components involves solving a matrix of the form,

$$(A-\lambda I)x = 0 \qquad (5)$$

where A is a square matrix of order n by n, λ is called a characteristic root or eigenvalue, I is the identity matrix, and x is called an eigenvector. The equation represented by (5) will be a set of n homogeneous linear equations in n unknowns. Such a set of equations can be solved only when,

$$|A-\lambda I| = 0 . \tag{6}$$

The expansion of this determinant will lead to an algebraic equation whose roots give the permissible values of λ. These are called eigenvalues of A, and the equation is called the characteristic equation of the matrix. Corresponding to each eigenvalue will be an eigenvector.

The solution of the determinant represented above for the case of a simple 2 x 2 matrix has been illustrated by Johnston (1963) as follows:

$$|A-\lambda I| = 0 \tag{7}$$

or

$$\begin{vmatrix} a_{11}-\lambda & a_{12} \\ a_{21} & a_{22}-\lambda \end{vmatrix} = 0 \tag{8}$$

from which it may be determined that

$$\lambda^2 - (a_{11}+a_{22})\lambda + (a_{11}a_{22}-a_{12}a_{21}) = 0 . \tag{9}$$

Solving this quadratic equation results in

$$\lambda_1 = \frac{1}{2}[(a_{11}+a_{22}) + ((a_{11}-a_{22})^2-4(a_{11}a_{22}-a_{12}a_{21}))^{1/2}]$$
$$\lambda_2 = \frac{1}{2}[(a_{11}+a_{22}) - ((a_{11}-a_{22})^2-4(a_{11}a_{22}-a_{12}a_{21}))^{1/2}] . \tag{10}$$

For specific A matrices, such as 2 x 2 in the example, Equation (5) is used with λ_1, and λ_2 respectively. Thus, for λ_1,

$$\left[\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} - \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_1 \end{bmatrix}\right] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0$$

or,

$$\begin{bmatrix} a_{11}-\lambda_1 & a_{12} \\ a_{21} & a_{22}-\lambda_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0 . \tag{11}$$

The solution for $x_1 + x_2$ is made subject to the orthogonality restriction: that is,

$$x_1^2 + x_2^2 = 1 . \tag{12}$$

The same procedure is followed to solve for the characteristic vectors associated with λ_2. These two vectors, then, determine the coefficient for two linear combinations (components) of the original variables which provide new variables that are statistically independent.

Each principal component is a linear function of the original variables. The first component explains the maximum amount of the total variance. The second component has its axis oriented orthogonally to the first component and explains the maximum amount of the remaining variance. Each component is independent of its predecessor and explains a lesser amount of the total sample variance.

Use of Principal Components

In some studies the principal components have been used as new variables. In that case, a regression analysis is performed with the principal components as variables (Gladwell, 1970; Haan and Allen, 1972). Both authors found that using the principal components in a regression analysis did not result in prediction equations superior to those developed by multiple regression on the original variables.

Other authors have used the principal components method to select a nearly independent set of predictor variables. The usual method is to select the variable with the highest loading in each component as potential predictors. Previous studies have shown that variables should not be selected from components with eigenvalues less than 0.3 (Wong, 1963; Anderson, 1967; Rice, 1967, 1970; Wang and Huber, 1967; Shelton and Sewell, 1969). Daling and Tamura (1970) carried the principal components results one step further. In their method the dependent variable is entered in a multiple regression with the principal components that have eigenvalues greater than 0.3. Then, the variable with the highest simple correlation with the dependent variable was chosen from each component that significantly reduced the unexplained variance of the dependent variable.

IV. STUDY AREA

Description of Study Area

The study area includes the watersheds on the north and central Oregon coast. This comprises all of the streams west of the Coast Range from the Nehalem River on the north to the Siuslaw River on the south. Figure 1 shows the locations of the streams in the study area and of the hydrometeorological stations.

The major portion of runoff from these basins is associated with cyclonic storm activity in the winter months. Low summer rates of flow reflect a lack of rainfall as the area's weather is dominated by the mid-Pacific, high pressure system. Normal annual precipitation varies from 40 inches along the immediate coast to as much as 200 inches along the crest of the Coast Range (Columbia-North Pacific Region, Comprehensive Framework Study, 1969).

Silty loam soils predominate in the north and mid-coastal subregion. The Astoria-Melby and Haplumbrepts soils series are mixed with gravelly residuum-colluvium from sedimentary rock. The seccond most dominant soils association is the Klickitat-Hembre group, a silty-clay loam soil mixed with rocky residuum-colluvium. The permeability of the subsoil is moderate for these groups (0.5 to 2.5 in/hr). This subsoil overlays a substratum of bedrock that is nearly impervious. The total water holding capacity of these soils ranges

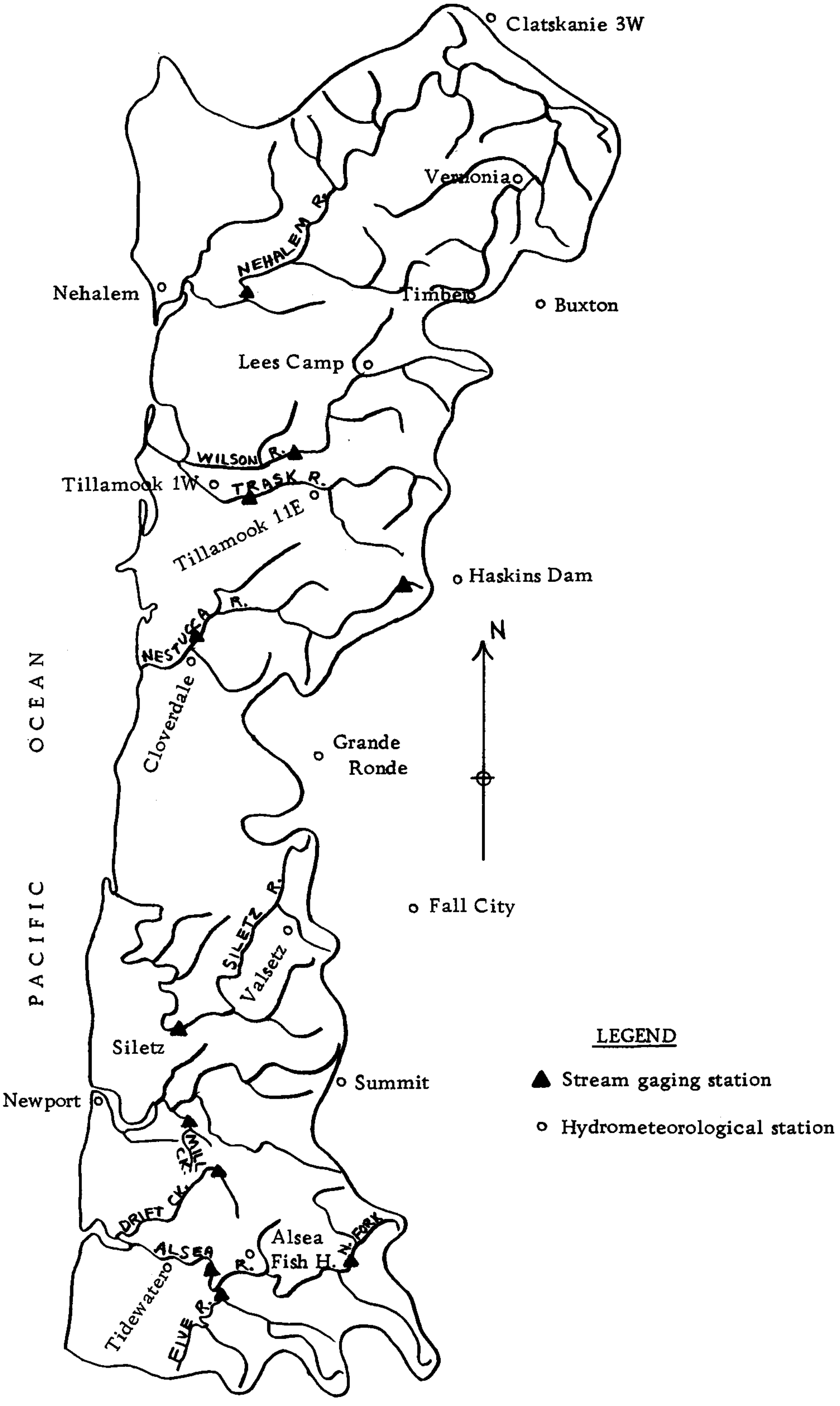


Figure 1. North and mid-coastal drainage basins.

from less than six inches to more than ten inches (Columbia-North Pacific Region, Comprehensive Framework Study, 1970).

Ninety percent of the mid and north coastal subregions are forested. The remaining ten percent is crop and rangelands. The forest lands are approximately 50 percent public owned and 50 percent private owned. The major tree species is the Douglas-fir, with western hemlock, Sitka spruce, and Port Orford cedar, and western red cedar also present (Columbia-North Pacific Region, Comprehensive Framework Study, 1970).

Selection of Study Basins

Initially, a group of watersheds to be used in developing the prediction equations for mean monthly flow were selected. The records of runoff for western Oregon were used to identify those stations with good or excellent records, as specified by the U.S. Geological Survey. Basins with major diversions or reservoir regulations were excluded from the study. The desired period for computing mean monthly flow was 1940 to 1969, because only three coastal streams have records of flow prior to 1940. Also, the measurement of streamflow in the earlier years was less precise than during recent periods. However, because only a small number of locations in the study area had runoff records for the entire 1940 to 1969 period, stations with runoff records of five years and greater were selected. These stations, their drainage area, and length of record are shown in Table 1. Table A1 in the Appendix summarizes the monthly flow in cubic feet per second per square mile (cfsm) and mean monthly flow in day second feet (dsf) and (cfsm) for the selected stations. The mean monthly flow for the short period stations was then adjusted to the 1940 to 1969 period by correlation with the nearest long-term station. This step was necessary since the base period should be identical for all stations used in developing the mean monthly flow prediction equations. A short period record may give an entirely unrepresentative sample of the actual flow regime.

Table 1. Description of gaging stations selected for study.

River and Location	Drainage Area, Square Miles	Length of record, Years
Nehalem River near Foss	667	30
Wilson River near Tillamook	161	39
Trask River near Tillamook	145	33
Nestucca River near Fairdale	6.18	10
Nestucca River near Beaver	180	5
Siletz River at Siletz	202	45
Mill Creek near Toledo	4.15	10
North Fork Alsea River at Alsea	63.00	12
Five Rivers near Fisher	114	7
Alsea River near Tidewater	334	30
Drift Creek near Salado	20.60	10

Ideally, some of the basins in the study area would be set aside to test the resulting prediction equations. However, the small number of runoff stations available precluded such an approach. Two test basins near the study area were selected for test of the prediction equations. One, the North River near Raymond, is on the Wasington coast immediately to the north of the study area. The other, the West Fork of the Millicoma River near Allegany is on the southern Oregon coast near Coos Bay.

In the development of equations to forecast monthly streamflow, another group of watersheds was selected. In this instance, those basins with eight or more years of record, rating good or excellent by the U.S. Geological Survey, were chosen for the study. Again, stations with substantial diversions above the gaging site or reservoir regulations were excluded from the study. This group of watersheds includes all of those used in the first part of the thesis except for the Nestucca River near Beaver and Five Rivers near Fisher. It is not essential in developing prediction equations for monthly streamflow that all stations have the same period of record. No attempt was made to extend the period of record for the short term stations. In some instances the monthly flow for adjacent watersheds can be quite different. Thus, the estimation of monthly runoff values of short record stations for several years by correlation analysis with nearby basins would introduce new sources of error in the forecast equations.

V. PHYSICAL AND CLIMATOLOGICAL FACTORS INVESTIGATED

The variables used in this study are described below, together with the method for computing each variable. A summarized list of the parameters is shown in Table 2.

Physiographic Parameters for Prediction of Mean Monthly Flows

Drainage Area (DA)

Drainage area has been an important predictive variable in nearly all studies reviewed. Basin drainage areas above each gaging station were taken from the U.S. Geological Survey water-supply papers.

Total Drainage Length (TDL).

Total drainage length is defined as the maximum stream distance between the gaging station and the extension of the upper end of the stream to the basin divide. At a junction in the stream the main channel is defined as the stream which drains the greatest area. The measurements of total drainage length were made on U.S. Geological Survey maps with a scale of 1:62,500. Total drainage length is highly correlated with drainage area and thus must not be used in the same prediction equation. It has been pointed out in several studies that

Table 2. Parameters used in development and testing of mean monthly flow equations.

Basin Name	DA (sq mi)	MCS (ft/mile)	TDL (miles)	DD (mi/sq mi)	FOREST (%)	LIFT (ft)	BAS (deg)	LAT	INTEN (in/3hr)	NAP (in)	MBE (ft)	SOILS
Nehalem River near Foss	667	6.4	104.0	1.64	85	1100	250	5.70	1.20	82	1100	4.7
Wilson River near Tillamook	161	50.4	32.3	1.40	10	1750	280	5.48	1.40	103	2200	5.6
Trask River near Tillamook	145	62.0	29.7	1.75	35	1300	250	5.43	1.50	103	1700	5.6
Nestucca River near Fairdale	6.18	62.5	3.2	2.62	95	450	280	5.32	1.35	110	2200	5.0
Nestucca River near Beaver	180	58.8	35.5	1.75	98	1200	290	5.27	1.20	105	1250	4.7
Siletz River at Siltez	202	41.8	35.7	2.08	60	1050	320	4.72	1.65	118	1150	5.1
Mill Creek near Toledo	4.15	389.0	2.6	2.49	97	500	200	4.58	1.30	88	600	5.4
North Fork Alsea River at Alsea	63.00	44.2	16.6	2.68	85	1000	360	4.38	1.35	98	1450	5.2
Five Rivers near Fisher	114	46.6	17.5	2.63	93	700	220	4.33	1.25	100	750	4.6
Alsea River near Tidewater	334	21.9	45.0	2.46	80	900	250	4.38	1.35	93	950	5.0
Drift Creek near Salado	20.60	113.2	6.5	2.63	98	700	200	4.52	1.25	95	1150	5.6
North River near Raymond	219	5.4	59.5	2.38	92	400	270	6.80	1.20	85	400	4.3
West Fork Millicoma River near Allegany	46.50	38.0	28.0	3.00	99	1000	340	3.47	1.45	93	1300	5.6

during the period of the year that soil moisture is low, basin response to precipitation events is derived mainly from direct precipitation on the stream channel and on areas near the stream where soil moisture is relatively higher than for other parts of the watershed (Hewlett and Hibbert, 1967; Betson, 1964; Kirkby and Chorley, 1967; Dickinson and Whiteley, 1970; Dunne and Black, 1970). It is expected that total drainage length would be a better index of basin response than drainage area during these dry periods.

Main Channel Slope (MCS)

The main channel slope is found by computing the slope between the point on the main channel at which ten percent of the total area is drained and the point at which 85 percent of the total area is drained. This particular slope parameter was chosen by Benson (1959) for its ease of computation and for its high correlation with peak flow. In all other studies the slope parameter has been positively related to runoff. This reflects faster concentration time of stream discharges as slope increases.

Drainage Density (DD)

Drainage density is defined as, $\frac{\Sigma L}{DA}$, the sum of all stream lengths for all streams in the basin (ΣL) divided by the drainage area (DA). This variable is computed by measuring the length of all streams in the drainage basin, and summing them, and then dividing by the drainage area. The measurements were taken from U.S. Geological Survey topographic maps with a scale of 1:62, 500. Since the maps are developed during different times of the year, the stream lengths as shown on the topographic maps are not consistent from one to the other. To solve this problem, the upper end of all streams was extended to the basin divide as suggested by Morisawa (1957).

Jacob (1943) and Horton (1945) first suggested drainage density as a basin index characteristic. Both authors point out that as the transmissibility of the soil decreases, the drainage density increases. As the drainage density increases, the stream system is more efficient in collecting and conducting the rainfall input (Hudzikiewicz, 1968). Langbein (1947) and Carlston (1963) have also discussed the importance of drainage density in controlling water yield.

Percent of Area Forested (FOREST)

The percentage of forest cover in a basin has been found to be an important variable and should be included if it can be treated as a random variable (Lull and Sopper, 1967; Lystrom, 1970; Pentland and Cuthbert, 1971).

This variable was computed by planimetering the area shaded in green on the latest available U.S. Geological Survey map (scale 1:62, 500). The ratio of this area to the total basin area multiplied by

100 gives the percentage of the basin forested. In a review of literature concerning water yield, Hibbert (1967) concluded that water yield increases as forest cover decreases and, conversely, establishment of forest cover on sparsely vegetated land will decrease water yield. Hewlett (1970), in a study on water yield from clear cut areas, substantiated this conclusion. Rothacher (1970) reached a similar conclusion in a study in the western Cascades of Oregon. The change in water yield with forest cover is primarily due to differences in evapotranspiration. Removing a stand reduces evapotranspiration. The increase in water yield obtained by removing a stand can be attributed to changes in root distribution and to decreased interception losses (Douglass, 1967).

Mean Basin Elevation (MBE)

This variable is taken from the hypsometric curve (graph of percent of basin area vs elevation) for each basin and is the elevation in feet of the 50 percent point. This variable indexes the accumulation of snow in the basin during the winter season and would be expected to be negatively related to runoff during the winter months.

Airmass Lift (LIFT)

Airmass lift is defined as the difference in elevation between that at the gaging station and that at the 50 percentile point on the hypsometric curve. The variable, as used in this study, is meant to index the orographic effect on an airmass as it rises over the Coast Range. The rise in the first 50 percent of the basin was used because it was felt that this would be a better index to the orographic processes in the basin than the total basin rise. The lift factor might also index the depth and types of soils and the vegetation in a basin. However, in the study area the rise of the Coast Range is too small to cause a marked change in vegetation type. An elevation or basin rise term has been used by many investigators. In all cases the lift parameter has been positively related to runoff (Benson, 1962, 1964; Julian, Morel-Seytoux and Yevjevich, 1967; Gladwell, 1970; Lystrom, 1970; Thomas and Harenberg, 1970).

Basin Aspect (BAS)

The orientation of a basin with respect to incoming solar radiation has a bearing on basin yield. Basins oriented to the south receive the greatest amount of radiation and tend to have greater potential for evapotranspiration. These basins would be expected to have relatively lower yields. Douglass (1967) found that aspect of a basin profoundly affected radiation received, especially during the spring, fall, and winter. An aspect variable has been used in studies by Julian, Morel-Seytoux and Yevjevich (1967); Gladwell (1970); and Thomas and Harenberg (1970).

The basin aspect term used in this thesis has its principal axis oriented in the N-S direction. The aspect for a basin facing directly south is 360°. A basin facing directly north has an aspect of 180°. The basin aspect for watersheds facing directly west or east is 270°.

Gage Latitude (LAT)

This parameter is the latitude of the gage as taken from U. S. G. S. water supply papers. Before the regression analysis, 40 was subtracted from each latitude in order to magnify the differences in latitude. A latitude variable has been used in most cases to index snow accumulations in winter season and snowmelt runoff in spring season (Julian, Morel-Seytoux and Yevjevich, 1967; Lull and Sopper, 1967; Thomas and Harenberg, 1970). The latitude parameter in this study was meant to index storm frequency. In a paper by Schermerhorn (1967), normal annual precipitation for coastal stations was found to increase about eight percent per degree of latitude change from south to north.

Soils Index (SOILS)

The soils index is computed according to the method outlined in the National Engineering Handbook of the Soil Conservation Service (SCS, 1971). Data for computation of the soils index were taken from the soils association and land use maps in the Columbia-North Pacific

Region, Comprehensive Framework Study, Appendix IV, Volume 2 (1970). The first step in computing the soils index is to classify the soils in the particular basin. The classes of soils are: Class A - high infiltration rates and high rate of water transmission; Class B - moderate infiltration rate and moderate rate of water transmission; Class C - slow infiltration rate and slow rate of water transmission; Class D - very slow infiltration and very slow rate of transmission. The National Engineering Handbook of the Soil Conservation Service lists major soils and their classification in the aforementioned groups. A soils map was placed over each drainage basin and the percentage of each soils group in the basin was computed by the grid-square method. The runoff curve number can then be determined for each soil-cover complex and a basin average runoff curve determined. The soils index is computed by the equation $S = 1000/CN - 10$, where CN is the runoff curve number.

Several investigators have employed a soils term in their respective prediction equations. Lystrom (1970) used a soil index identical to that used in this thesis. His classifications were used in this study for those basins which he and the author both studied. Gladwell (1970) used a soils parameter based upon a classification system similar to the Soil Conservation Service method. He and Lystrom both found that the soils parameter was not highly important in the resulting prediction equations. In a Finnish study, a percentage of area with coarse soils was found to be a significant variable in predicting mean annual runoff (Mustonen, 1967). Rice (1970) used a measure of the mean soil depth in a basin as an index parameter for predicting peak discharge from an area. The soil variable had a high loading in a factor analysis but was not included in the regression equations.

The soils parameter used in this paper is expected to index the ability of a basin's soil mass to transmit rainfall input to the stream channel. Infiltration rates in the study area range from 0.8 to 2.5 in/hr (Columbia-North Pacific Region, Comprehensive Framework Study, 1970), while the average maximum hourly rainfall rates along the Oregon coast range from 0.5 to 1.0 in/hr (Pacific Northwest River Basins Commission, 1969). This would indicate that overland flow is minimal in this area except during major rain storms. Thus, the bulk of the rainfall reaches the stream after first passing through some portion of the soil. Several papers have outlined the importance of subsurface flow in water yield from forested areas (Whipkey, 1965; Hewlett and Hibbert, 1967; Pierce, 1967; Dunne and Black, 1970).

Climatological Factors for Prediction of Mean Monthly Flows

Normal Annual Basin Precipitation (NAP)

The mean annual basin precipitation was found by overlaying the basin area with an isohyetal map prepared by the U.S. Weather Bureau and the U.S. Department of Agriculture (1965) and computing the basin normal value by the grid-square method. The basin normals could also be derived by planimetering the area between isohytal lines and arriving at a basin average. Some form of precipitation index, either annual or seasonal,was used in almost every study mentioned in the literature review.

Basin Winter Precipitation Intensity (INTEN)

This parameter was estimated from data taken from a report compiled by the Pacific Northwest River Basins Commission (1970). For each station available in western Oregon the maximum rainfall expressed in in/3 hr was tabulated and averaged for the months of November to February. A basin value was then estimated by using the closest available climatological stations. It was expected that basins with the more intense winter rainfall would have a greater percentage of the rainfall input go to direct runoff and thus would tend to have greater runoff during the winter months and lesser runoff during the spring and summer months.

Variables Used in Forecasting Monthly Flows

Listed below are the basic variables chosen to use in developing forecast equations for monthly streamflow.

Monthly Flow

The monthly flow in cfs per square mile (cfsm) was used as the dependent variable. As indicated previously, only the observed record was used to develop the forecast equations.

Monthly Precipitation

Precipitation stations were selected from those available in the Oregon coastal area. In each case the selected precipitation data were plotted on a double mass curve against an area mean, and the precipitation values were adjusted whenever a significant change in slope occurred. In most cases, such a change in slope was due to a rain gage being moved. The resulting adjusted monthly precipitation values were used to develop variables in the prediction equations. For each of the study basins, an initial linear regression run was made using monthly precipitation for stations in or near the particular watershed. The regression weights from these analyses were used to assign relative weights to each individual precipitation station. These weights were then adjusted proportionately to a sum of unity. Finally, the derived relative weights were further adjusted by multiplying each station weight by the ratio of mean monthly flow to mean monthly precipitation. This procedure removes an inherent weighting due to differences in normal annual rainfall amounts at the various precipitation stations. A final precipitation index was then formed by multiplying each station's precipitation amount by its derived weight and summing the result. The final stations and weights for each forecast month are shown in Table 3. This variable was then used with other parameters to forecast the monthly streamflow.

How reliable the available precipitation stations will be for estimating the basin rainfall amounts is questionable. Rainfall amounts in the coastal area of Oregon are quite uniform, with most of the rain resulting from broad scale cyclonic storms that transit the region. There is a marked change in precipitation amounts from the coastline to the crest of the Coast Range due to the orographic influence. A good sampling of precipitation stations is available at low, middle and high elevations. McCulloch and Booth (1970), in a study to estimate basin precipitation by linear regression methods using available precipitation stations, found a maximum yearly cumulative error of 4 percent and an individual monthly maximum error of 17 percent in their basin precipitation estimates.

Table 3. Precipitation stations and weights used in each monthly equation.

	November		January		April		August	
Drainage Basin	Station	Weight	Station	Weight	Station	Weight	Station	Weight
Nehalem River near Foss			Vernonia	0.25			Timber	0.11
	Vernonia	0.45	Clatskanie 3W	0.59	Timber	1.03	Clatskanie 3W	0.02
	Clatskanie 3W	0.29	Timber	0.20	Clatskanie 3W	0.17	Vernonia	0.09
Wilson River near Tillamook	Lees Camp	0.47	Lees Camp	0.51	Timber	1.67	Timber	0.54
	Tillamook 1 W	0.14	Tillamook 1W	0.32	Lees Camp	0.17	Lees Camp	0.07
	Timber	0.25	Timber	0.20	Tillamook 1W	0.12		
Trask River near Tillamook					Haskins Dam	1.03		
	Tillamook 11E	0.60	Tillamook 11E	0.77	Tillamook 1W	0.24	Tillamook 11E	0.38
					Tillamook 11E	0.11		
Nestucca River near Fairdale	Cloverdale	0.35	Haskins Dam	0.55	Haskins Dam	1.42	Cloverdale	0.09
	Tillamook 11E	0.14	Tillamook 11E	0.23			Haskins Dam	0.26
Siletz River at Siletz	Valsetz	0.43	Valsetz	0.32	Valsetz	0.68	Newport	0.43
	Grande Ronde	0.43	Summit	0.86	Newport	0.38	Grande Ronde	0.19
Mill Creek near Toledo	Summit	0.34						
	Tidewater	0.17	Summit	0.68	Summit	0.28	Newport	0.16
	Newport	0.10	Tidewater	0.26	Tidewater	0.49	Summit	0.16
Drift Creek near Salado	Alsea Fish Hatchery	0.48	Summit	0.90	Summit	0.81	Summit	0.35
	Summit	0.17	Tidewater	0.19	Tidewater	0.31	Tidewater	0.08
N. F. Alsea River at Alsea					Summit	0.32		
	Summit	0.29	Summit	0.48	Fall City	0.51	Summit	0.23
	Fall City	0.18	Tidewater	0.33	Tidewater	0.13	Tidewater	0.14
Alsea River near Tidewater	Alsea Fish Hatchery	0.24	Summit	0.73	Tidewater	0.68	Alsea Fish Hatchery	0.11
	Tidewater	0.17	Alsea Fish Hatchery	0.19	Summit	0.35	Summit	0.15
							Tidewater	0.08

Antecedent Flow

This variable is expected to index two separate features of the coastal flow regime. The antecedent flow is expressed in cfsm. During the late summer and fall months the flow during the previous month is a reliable index of the soil moisture conditions. The greater the flow in the previous month the larger the percentage of runoff from rainfall in the current month. Fiering (1964), Greening and Law (1969) and Bonné (1971) all used some form of antecedent flow as one of the predictive variables. In the discussion on prediction of low flow it was pointed out that a simple graphical relation between the flow in the current month and the flow in the previous month will give reliable estimates of the subsequent period flow. This was especially true in cases when precipitation was light during the low flow season (Riggs and Hanson, 1969). The previous month's streamflow is expected to be an important variable in both November and August and perhaps in the other months for some basins.

The monthly flow for December and January is also used as an index variable. This parameter is expected to be related to the percent of winter rainfall input that goes to direct runoff (surface and subsurface flow) and the percent that enters baseflow. High flow during the winter months indicates greater amounts of direct runoff and therefore less water retained in the soil for augmenting spring runoff.

End-of-Month Flow

The flow, in day second feet (dsf), for the last five days and the last ten days of each of the study months was computed for each station. The end-of-month flow term is expressed as the sum of the flow in dsf divided by the drainage area of the basin, all multiplied by 10^{-1}. These variables are meant to index the carryover of direct runoff from a storm near the end of the month into the following month. A similar variable was used by Greening and Law (1969).

Snow Water Equivalent

The Soil Conservation Service measures snow depths and water equivalents in Oregon every month beginning on January 1 and continuing until May 1. However, the Marys Peak snow course is the only site measured in the Coast Range. This snow course is not a particularly good index to the snowpack of the entire Coast Range, but it is used in this development merely as an index of the accumulated snow at the beginning of the forecast month. Bonné (1971) was the only investigator whose work was reviewed who included an index term for snow accumulation in his model.

VI. PREDICTION OF MEAN MONTHLY FLOW AND STANDARD DEVIATIONS OF MONTHLY FLOW-- RESULTS AND DISCUSSION

Analysis of Principal Components

The first step in the statistical procedures was to perform a principal components analysis on the variables selected for predicting mean monthly flows. The results from the principal components analysis were then used in the final selection of variables.

The component loadings for each eigenvector, the eigenvalues for each component, and the cumulative proportion of the total variance explained by each component are shown in Table 4. A graphic example of the first two components is shown in Figure 2. The cosine of the angle between any two of these vectors is equal to the correlation coefficient of those two parameters. The length of each vector is equal to the variance of that parameter.

The results in Table 4 show that only the first seven components have eigenvalues greater than 0.3. Other components had lower eigenvalues and were not included in the table. Only these first seven components were used in selecting predictor variables. The first seven components contain 96 percent of the total variance present in the original 11 variables.

The next step in the analysis was to examine the first seven principal components in an attempt to assign names to the basic factors which these components represent. Component loadings of

Table 4. Principal components and the eigenvalue and cumulative proportion of the variance explained by each component.

		Principal Components						
No.	Variables	No. 1	2	3	4	5	6	7
1	Main channel slope	-0. 1671	0. 3020	0. 4737	0. 0109	0. 4179	0. 4994	0. 1921
2	Normal annual precipitation	0. 3214	0. 3350	-0. 0654	-0. 0596	-0. 6868	0. 2379	0. 3312
3	Drainage density	-0. 2828	0. 4292	-0. 2798	0. 1336	0. 1309	-0. 0392	-0. 1724
4	Lift	0. 3810	-0. 2245	-0. 0286	-0. 1353	0. 3581	-0. 1324	0. 6948
5	Latitude	0. 3639	-0. 1335	0. 2501	0. 3095	0. 0778	0. 4688	-0. 2598
6	Rainfall intensity	0. 2512	0. 2364	0. 0888	-0. 7223	-0. 0182	0. 1769	-0. 2924
7	Mean basin elevation	0. 4346	0. 1108	-0. 0348	0. 3866	0. 0307	-0. 1302	-0. 1887
8	Soils	0. 2077	0. 1698	0. 5174	-0. 1714	0. 0799	-0. 6002	-0. 1930
9	Basin aspect	0. 1558	0. 1330	-0. 5600	-0. 2673	0. 3954	0. 1128	-0. 0859
10	Total drainage length	0. 0546	-0. 6355	-0. 0415	-0. 1983	-0. 0691	0. 1809	-0. 2878
11	(Basin aspect)(Mean basin elevation)	0. 4346	0. 1598	-0. 1938	0. 2302	0. 1828	-0. 0339	-0. 1576
Eigenvalue of each component		4. 0441	2. 1722	2. 0251	1. 0224	0. 5351	0. 4073	0. 3764
Cumulative proportion of total variance explained		0. 37	0. 57	0. 75	0. 84	0. 89	0. 93	0. 96

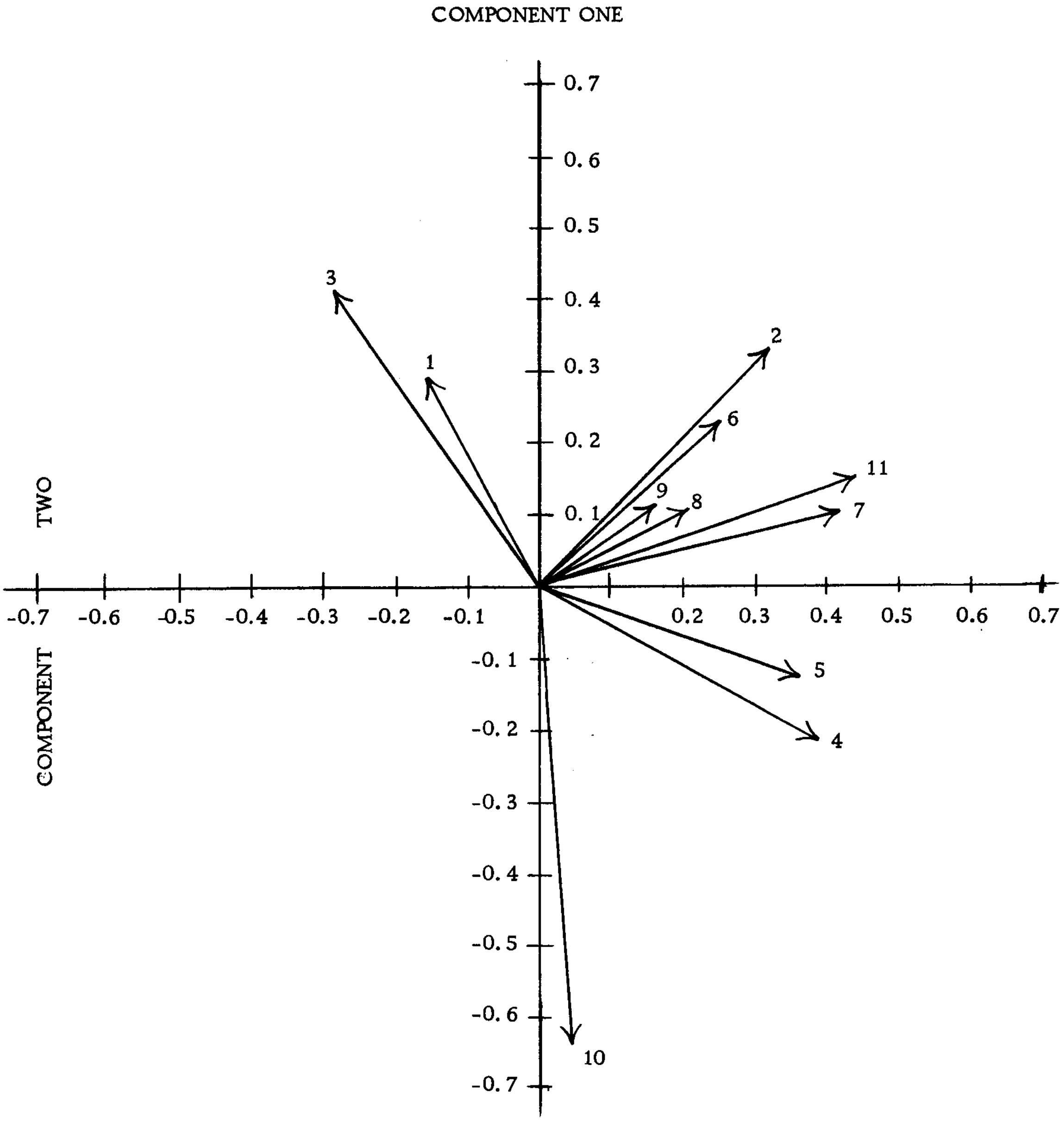


Figure 2. Location of the first and second component vectors for 11 variables in two dimensions.

0.4 and greater were used to interpret the meaning of each component.

Often in principal components analysis, the first component will be a mean response with nearly equal loadings on most of the variables. Such was the case in this analysis and an interpretation was not attempted on component one. Component two had high loadings on drainage density and total drainage length. This component was called drainage system efficiency. The greater is the drainage density, the shorter is the concentration time in a drainage basin. Conversely, the longer the main channel is, the more attenuation of the rainfall input and the longer the concentration time.

The third component had high loadings on slope, soils and aspect. This component was named a basin loss function. Basins with steep slopes and soils with high transmission rates will have lesser amounts of soil moisture available for evapotranspiration during the late spring and early summer. Those drainage basins facing south will tend to have greater amounts of evapotranspiration during all periods of the year.

Component four had a high loading on intensity. Thus, the component was called a rainfall intensity function. The variable for mean basin elevation also received a significant loading in the component. This is probably due to a general increase in rainfall rates with elevation.

Component five was called a drainage-basin storm interaction term. Main channel slope, normal annual precipitation, basin lift and basin aspect received high loadings. Drainage basins with steep slopes and high values of basin lift and an aspect that faces into the prevailing wind are more effective in turning atmospheric moisture content into rainfall.

Component six had high loadings on slope, latitude and soils. This component was called a soils-cover function. The type of vegetation in a basin will vary with both slope and latitude.

The seventh component had a high loading on only one parameter, lift. The next highest factor is normal annual basin precipitation. This combination suggests a relation to the orographic influence. The orographic effect is quite pronounced in the Oregon Coastal area with normal annual rainfall amounts varying from 40 inches along the coast to as much as 200 inches along the Coast Range crest.

Admittedly, naming the components is a highly subjective process and certainly other names might be assigned to some of the components. However, a great deal can be learned by studying the loading in each component and investigating the meaning of each component.

Regression on Selected Variables

A regression of the principal components on each month's mean flow was performed. In all cases each of the first seven components explained some portion of the unexplained variance. The variables with high loadings in each component were then inspected and the variable having the highest simple correlation with the mean monthly flow was selected as a potential predictive variable. The correlation matrices of selected parameters and mean monthly flows is given in Table 5.

The variables chosen for each month were subjected to a stepwise linear regression. In each case the residual errors were examined and other possible variables were selected by plotting the new variable against the residual errors. This process was continued until no further reduction of the unexplained variance was achieved. The residual errors for each month were also plotted and examined for violation of the normal distribution of residual errors as required in the regression model. No significant departure from a normal distribution were noted.

Using linear equations produced good results for the larger basins and very poor results for small basins. It seemed reasonable that a logarithmic transformation which magnified the error of small basins and demagnified errors of large basins would result in better predictive equations for the smaller basins. This premise was tested for all of the monthly equations. For the basins in this study area logarithmic transformations yielded superior predictive equations for basins of 150 sq mi and less. The resulting prediction equations, both linear and logarithmic, are shown in Table 6. The plotted results are

Table 5. Correlation matrices of variables used in mean monthly flows prediction.

		Variables											
No.	Variable	No. 1	2	3	4	5	6	7	8	9	10	11	12
1	Main channel slope	1.0000	-0.1427	.1832	-0.3499	-0.0382	.0717	-0.2597	.3371	-0.4536	-0.4824	-0.3262	-0.4508
2	Normal annual precip.	-0.1427	1.0000	-0.1009	.2829	.3156	.5037	.5688	.2374	.2653	-0.3678	.5944	-0.0319
3	Drainage density	.1832	-0.1009	1.0000	-0.6163	-0.5750	-0.1842	-0.3236	-0.3637	.2236	-0.6439	-0.2112	-0.3919
4	Basin lift	-0.3499	.2829	-0.6163	1.0000	.5130	.2956	.5206	.2229	.2703	.3258	.5582	.5387
5	Gage latitude	-0.0382	.3156	-0.5750	.5130	1.0000	.1686	.6554	.4039	-0.1122	.2234	.5401	.3881
6	Intensity	.0717	.5037	-0.1842	.2956	.1686	1.0000	.2348	.4735	.2947	-0.0806	.3413	.0985
7	Mean basin elevation	-0.2597	.5688	-0.3236	.5206	.6554	.2348	1.0000	.3232	.2207	-0.1094	.9491	.0625
8	Soils	.3371	.2374	-0.3637	.2229	.4039	.4735	.3232	1.0000	-0.3302	-0.2275	.1912	-0.3107
9	Basin aspect	-0.4536	.2653	.2236	.2703	-0.1122	.2947	.2207	-0.3302	1.0000	-0.0603	.5003	.1556
10	Total drainage length	-0.4824	-0.3678	-0.6439	.3258	.2234	-0.0806	-0.1094	-0.2275	-0.0603	1.0000	-0.1353	.7180
11	(BAS)(MBE)	-0.3262	.5944	-0.2112	.5582	.5401	.3413	.9491	.1912	.5003	-0.1353	1.0000	.0893
12	November flow	-0.4508	-0.0319	-0.3919	.5387	.3881	.0985	.0625	-0.3107	.1556	.7180	.0893	1.0000
13	October flow	-0.4484	.0473	-0.3145	.5340	.2521	.0993	.0813	-0.4282	.2710	.6945	.1423	.9525
14	December flow	-0.4525	-0.1442	-0.2413	.4301	.2038	-0.1312	-0.0187	-0.5814	.2118	.6828	.0388	.9318
15	January flow	-0.4554	-0.1307	-0.2869	.4562	.2802	-0.0828	-0.0154	-0.4869	.1789	.7185	.0302	.9607
16	February flow	-0.4569	-0.2224	-0.1643	.3386	.1203	-0.1562	-0.0925	-0.6213	.1638	.6935	-0.0412	.9139
17	August flow	-0.4678	.0042	-0.1677	.4765	.0982	-0.0730	.0115	-0.5993	.3085	.5050	.1005	.8467

Table 5. Continued.

		Variables				
No.	Variable	No. 13	14	15	16	17
1	Main channel slope	-0.4484	-0.4525	-0.4554	-0.4569	-0.4678
2	Normal annual precip.	.0473	-0.1442	-0.1307	-0.2224	.0042
3	Drainage density	-0.3145	-0.2413	-0.2869	-0.1643	-0.1677
4	Basin lift	.5340	.4301	.4562	.3386	.4765
5	Gage latitude	.2521	.2038	.2802	.1203	.0982
6	Intensity	.0993	-0.1312	-0.0828	-0.1562	-0.0730
7	Mean basin elevation	.0813	-0.0187	-0.0154	-0.0925	.0115
8	Soils	-0.4282	-0.5814	-0.4869	-0.6213	-0.5993
9	Basin aspect	.2710	.2118	.1789	.1638	.3085
10	Total drainage length	.6945	.6828	.7185	.6935	.5050
11	(BAS)(MBE)	.1423	.0388	.0302	-0.0402	.1005
12	November flow	.9525	.9318	.9607	.9139	.8467
13	October flow	1.0000	.9429	.9273	.9106	.9333
14	December flow	.9429	1.0000	.9857	.9863	.9449
15	January flow	.9273	.9857	1.0000	.9723	.9061
16	February flow	.9106	.9863	.9723	1.0000	.9114
17	August flow	.9333	.9449	.9061	.9114	1.0000

		1	2	3	4	5	6
1	Main channel slope	1.0000	-0.1427	.1862	-0.3499	-0.0382	.0717
2	Normal annual precip.	-0.1427	1.0000	-0.1009	.2829	.3156	.5037
3	Drainage density	.1832	-0.1009	1.0000	-0.6163	-0.5750	-0.1842
4	Basin lift	-0.3499	.2829	-0.6163	1.0000	.5130	.2956
5	Gage latitude	-0.0382	.3156	-0.5750	.5130	1.0000	.1686
6	Intensity	.0717	.5037	-0.1842	.2956	.1686	1.0000
7	Mean basin elevation	-0.2597	.5688	-0.3236	.5206	.6554	.2348
8	Soils	.3371	.2374	-0.3637	.2229	.4039	.4735
9	Basin aspect	-0.4536	.2653	.2236	.2703	-0.1122	.2947
10	Total drainage length	-0.4824	-0.3678	-0.6439	.3258	.2234	-0.0806
11	(BAS)(MBE)	-0.3262	.5944	-0.2112	.5582	.5401	.3413
12	March flow	-0.4663	-0.1116	-0.3610	.4887	.3502	.0097
13	April flow	-0.4361	-0.0603	-0.4140	.5195	.4333	.1188
14	May flow	-0.4698	-0.0391	-0.3534	.5150	.3430	.1030
15	June flow	-0.4833	.0000	-0.2775	.5040	.2328	-0.0237
16	July flow	-0.4741	.0646	-0.3344	.5822	.3057	.0566
17	September flow	-0.4656	.0764	-0.2909	.5601	.2375	.0706

Table 5. Continued.

No.	Variable	Variables					
		No. 7	8	9	10	11	12
1	Main channel slope	-0.2597	.3371	-0.4536	-0.4824	-0.3262	-0.4663
2	Normal annual precip.	.5688	.2374	.2653	-0.3678	.5944	-0.1116
3	Drainage density	-0.3236	-0.3637	.2236	-0.6439	-0.2112	-0.3610
4	Basin lift	.5206	.2229	.2703	.3258	.5582	.4887
5	Gage latitude	.6554	.4039	-0.1122	.2234	.5401	.3502
6	Intensity	.2348	.4735	.2947	-0.0806	.3413	.0097
7	Mean basin elevation	1.0000	.3232	.2207	-0.1094	.9491	-0.0017
8	Soils	.3232	1.0000	-0.3302	-0.2275	.1912	-0.3491
9	Basin aspect	.2207	-0.3302	1.0000	-0.0603	.5003	.0996
10	Total drainage length	-0.1094	-0.2275	-0.0603	1.0000	-0.1353	.7573
11	(BAS)(MBE)	.9491	.1912	.5003	-0.1353	1.0000	.0176
12	March flow	-0.0017	-0.3491	.0996	.7573	.0176	1.0000
13	April flow	.0460	-0.2114	.0820	.7456	.0528	.9857
14	May flow	.0184	-0.3100	.1146	.7127	.0428	.9913
15	June flow	-0.0043	-0.5087	.2508	.6306	.0632	.9374
16	July flow	.9714	-0.4061	.2309	.6079	.1293	.9345
17	September flow	.0791	-0.4523	.3039	.5688	.1526	.8945

No.	Variable	13	14	15	16	17
1	Main channel slope	-0.4361	-0.4698	-0.4833	-0.4741	-0.4656
2	Normal annual precip.	-0.0603	-0.0391	.0000	.0646	.0764
3	Drainage density	-0.4140	-0.3534	-0.2775	-0.3344	-0.2909
4	Basin lift	.5195	.5150	.5040	.5822	.5601
5	Gage latitude	.4333	.3430	.2328	.3057	.2375
6	Intensity	.1188	.1030	-0.0237	.0566	.0706
7	Mean basin elevation	.0460	.0184	-0.0043	.0714	.0791
8	Soils	-0.2114	-0.3100	-0.5087	-0.4061	-0.4523
9	Basin aspect	.0820	.1146	.2508	.2309	.3039
10	Total drainage length	.7456	.7127	.6306	.6979	.5688
11	(BAS)(MBE)	.0528	.0428	.0632	.1293	.1526
12	March flow	.98570	.9913	.9374	.9345	.8945
13	April flow	1.0000	.9869	.8914	.9002	.8610
14	May flow	.9869	1.0000	.9355	.9421	.9072
15	June flow	.8914	.9355	1.0000	.9894	.9810
16	July flow	.9002	.9421	.9894	1.0000	.9760
17	September flow	.8610	.9072	.9810	.9760	1.0000

Table 6. Prediction equations and summary of statistics for mean monthly flows (dsf).

Month	Method	Prediction Equations	Standard Error % of Mean	Level of Significance	F Value
October	Linear	$\bar{Q}$ = -2194.91 + 11.914(TDL) + 16.702(NAP) + 13.185(SOILS) - 10.480(BAS) + 1.608(LIFT)	30	.01	16.0
	Nat. Log.	ln $\bar{Q}$ = 21.14 + 1.408 ln(TDL) + 4.387 ln(NAP) - 1.717 ln(BAS) + 0.472 ln(LIFT) + 1.401 ln(SOILS)	8	.01	191.6
November	Linear	$\bar{Q}$ = -5947.06 + 43.661(TDL) + 44.338(NAP) + 40.777(SOILS) - 32.035(MBE) + 41.593(LIFT) - 21.016(BAS)	18	.01	40.3
	Nat. Log.	ln $\bar{Q}$ = -13.66 + 1.375 ln(TDL) + 3.570 ln(NAP) - 1.291 ln(BAS) + 0.406 ln(LIFT) - 0.162 ln(MBE) + 0.861 ln(SOILS)	6	.01	259.8
December	Linear	$\bar{Q}$ = -4119.79 + 9.249(DA) + 1.146(LIFT) + 45.264(NAP) - 3.058(MBE) - 25.084(BAS)	9	.01	184.5
	Nat. Log.	ln $\bar{Q}$ = -7.20 + 0.924 ln(DA) + 1.851 ln(NAP) + 0.518 ln(LIFT) - 0.611 ln(BAS)	4	.01	998.8
January	Linear	$\bar{Q}$= -5097.05 + 9.851(DA) + 45.917(NAP) + 85.090(LIFT) - 43.454(MBE) - 13.691(BAS) + 19.308(SOILS)	8	.01	205.0
	Nat. Log.	ln $\bar{Q}$ = 4.56 + 0.935 ln(DA) + 1.599 ln(NAP) + 0.486 ln(LIFT) - 0.411 ln(BAS) - 0.152 ln(MBE) + 0.171 ln(SOILS)	3	.01	1196.6
February	Linear	$\bar{Q}$ = -4719.91 + 10.225(DA) + 37.104(NAP) + 49.306(LIFT) - 35.669(MBE) + 27.299(SOILS) - 6.739(BAS)	7	.01	279.4
	Nat. Log.	ln $\bar{Q}$ = -4.59 + 0.976 ln(DA) + 1.240 ln(NAP) + 0.534 ln(SOILS) - 0.146 ln(MBE) + 0.265 ln(LIFT) - 0.261 ln(BAS)	3	.01	987.3
March	Linear	$\bar{Q}$ = 176.12 + 5.836(DA) + 79.368(LIFT) + 196.333(INTEN) - 49.547(SOILS) - 22.589(BAS)	12	.01	116.7
	Nat. Log.	ln $\bar{Q}$ 4.58 + 0.843 ln(DA) + 1.506 ln(LIFT) + 0.625 ln(INTEN) - 1.515 ln(SOILS) - 0.311 ln(BAS)	7	.01	243.7

Table 6. Continued.

Month	Method	Prediction Equations	Standard Error % of Mean	Level of Significance	F Value
April	Linear	$\bar{Q} = -1380.99 + 3.995(DA) + 11.210(NAP) + 17.107(LIFT) + 51.098(INTEN) - 17.436(DD)$	14	.01	81.4
	Nat. Log.	$\ln \bar{Q} = -3.86 + 0.922 \ln(DA) + 1.406 \ln(NAP) - 0.502 \ln(DD) + 0.299 \ln(INTEN) + 0.099 \ln(LIFT)$	4	.01	625.8
May	Linear	$\bar{Q} = -547.41 + 2.012(DA) + 10.252(NAP) - 15.515(DD)$	20	.01	60.4
	Nat. Log.	$\ln \bar{Q} = -6.01 + 0.939 \ln(DA) + 1.911 \ln(NAP) - 0.459 \ln(DD)$	7	.01	426.1
June	Linear	$\bar{Q} = -312.02 + 0.886(DA) + 6.516(NAP) - 11.364(DD)$	23	.01	38.3
	Nat. Log.	$\ln \bar{Q} = -6.06 + 0.924 \ln(DA) + 1.983 \ln(NAP) - 0.757 \ln(DD)$	11	.01	199.2
July	Linear	$\bar{Q} = -17.58 + 0.326(DA) + 14.078(LIFT) + 3.480(NAP) - 5.990(SOILS) - 2.368(BAS)$	42	.05	6.5
	Nat. Log.	$\ln \bar{Q} = -4.38 + 0.749 \ln(DA) + 2.744 \ln(NAP) + 1.339 \ln(LIFT) - 0.769 \ln(BAS) - 1.998 \ln(SOILS)$	11	.01	94.6
August	Linear	$\bar{Q} = -226.49 + 0.242(DA) + 6.527(LIFT) + 2.454(NAP) - 1.782(BAS)$	29	.01	16.0
	Nat. Log.	$\ln \bar{Q} = -11.01 + 0.815 \ln(DA) + 1.030 \ln(LIFT) + 2.512 \ln(NAP) - 0.836 \ln(BAS)$	9	.01	198.7
September	Linear	$\bar{Q} = -509.93 + 2.73(TDL) + 3.998(NAP) + 5.133(LIFT) - 2.344(BAS) + 2.712(SOILS)$	28	.01	16.5
	Nat. Log.	$\ln \bar{Q} = -25.32 + 1.418 \ln(TDL) + 4.365 \ln(NAP) + 2.035 \ln(SOILS) - 1.164 \ln(BAS) + 0.341 \ln(LIFT)$	8	.01	189.0

shown in Figure 3.

Discussion of Prediction Equations

The resulting prediction equations are quite good with standard errors (expressed as percent of the mean monthly flow) ranging from 3 to 42 percent. The larger predictive errors occur during the summer and early fall. The average standard error for basins greater than 150 sq mi is 20 percent. For basins smaller than 150 sq mi the average standard error is 7 percent. Since in each case the flows for the entire group of basins were predicted using either the linear or the logarithmic equations and the standard error computed accordingly, a realistic average standard error for the entire group of basins is 13.5 percent. In most cases, the derived equations produced a high F value, indicating the power of the predictive equations. The F value is the ratio of the mean square error due to regression and the mean square error due to residual variation. High values of F indicate that the regression line explains a large amount of the total sum of squares of deviation of the observations from the mean. The algebraic signs of each month's variables made good hydrologic sense.

In every case a measure of basin size is the first parameter to enter the equation. TDL was used for the months of September, October and November. This reflects the fact that during the fall,

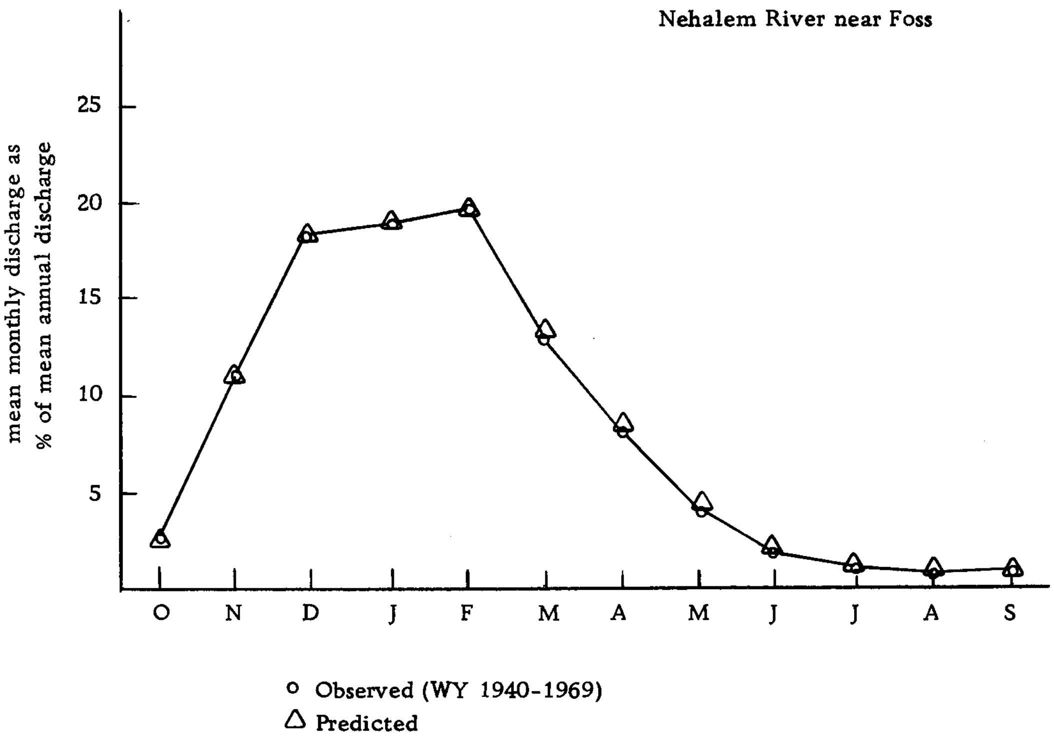
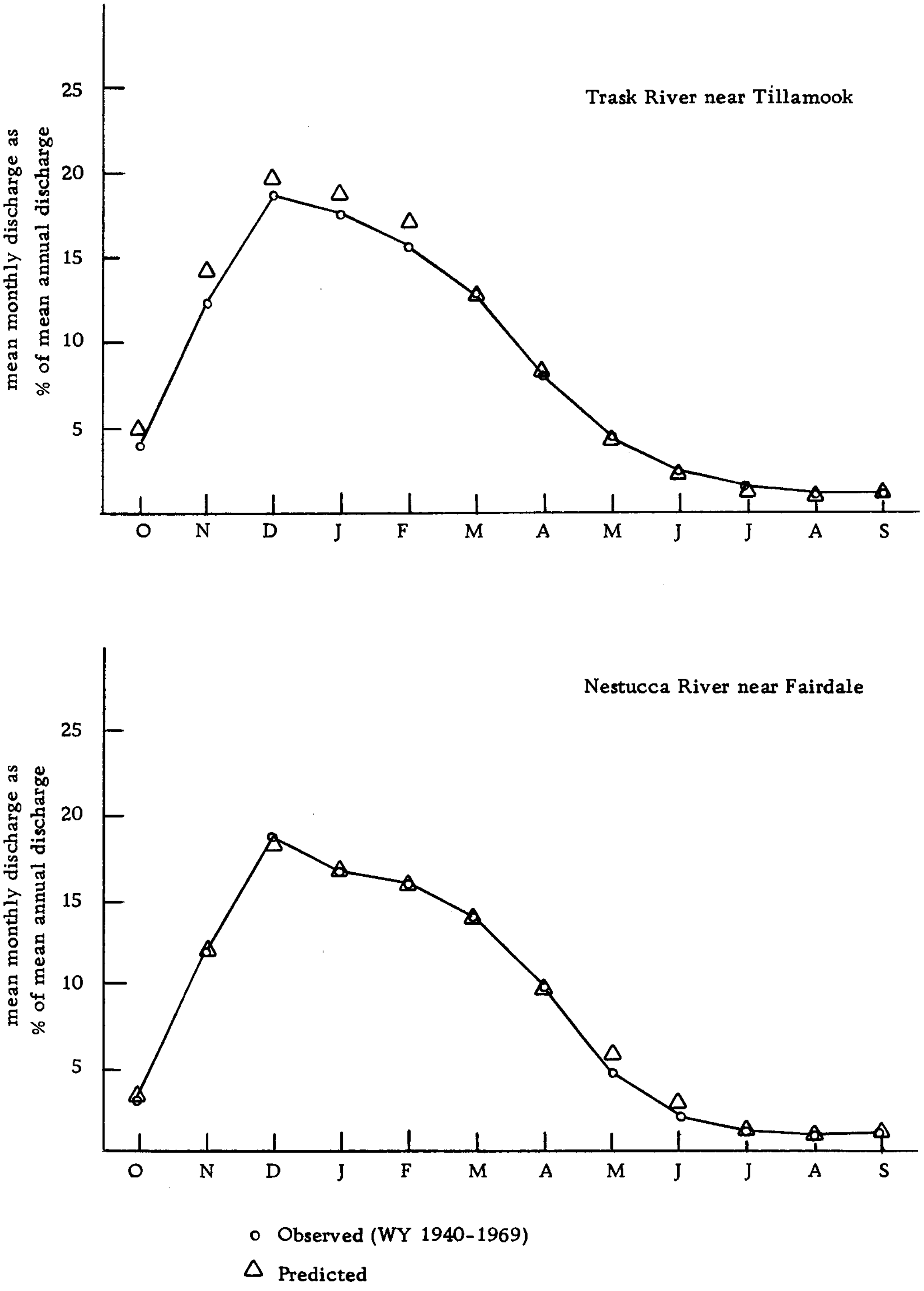


Figure 3. Plot of observed and predicted mean monthly flow.



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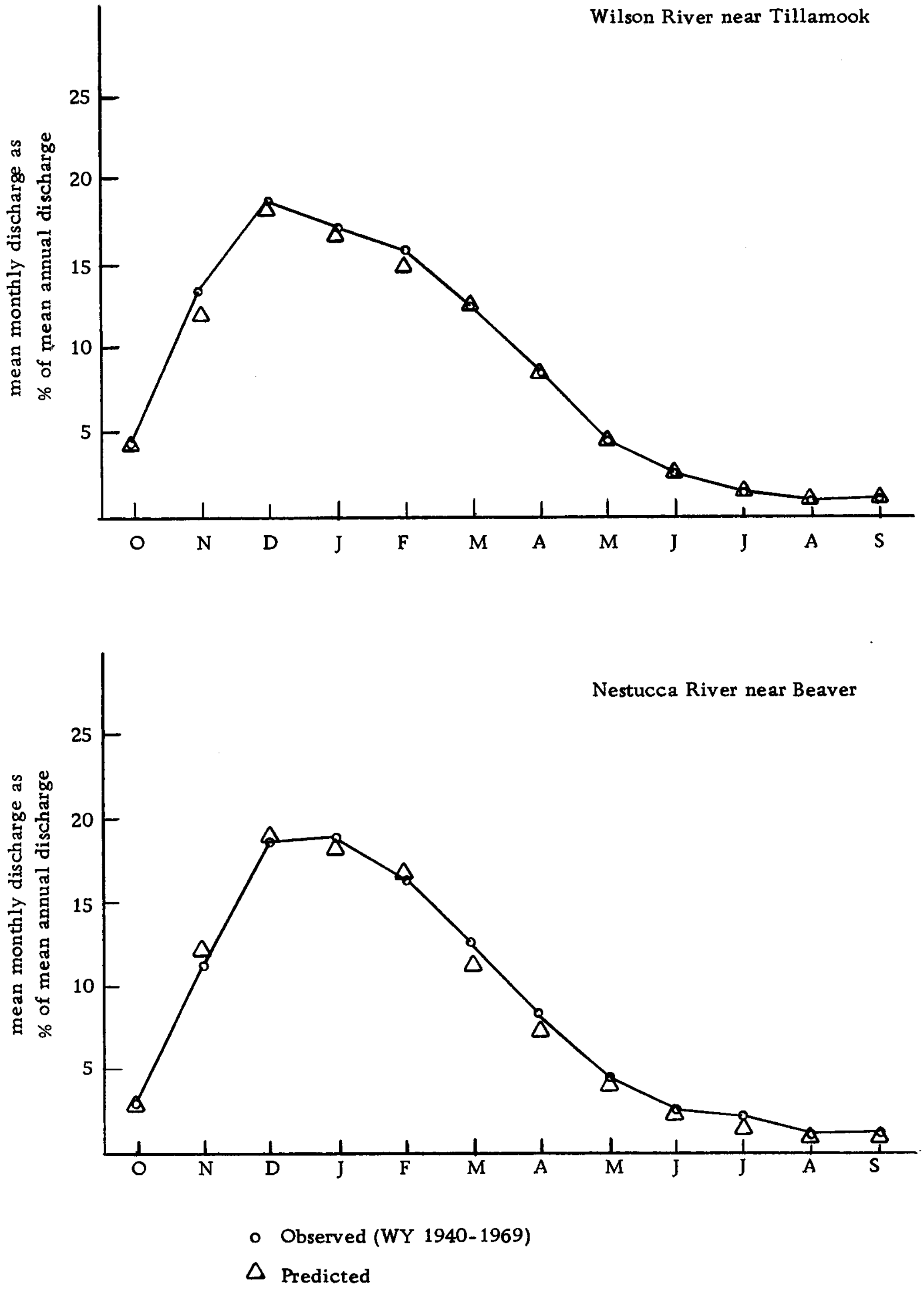

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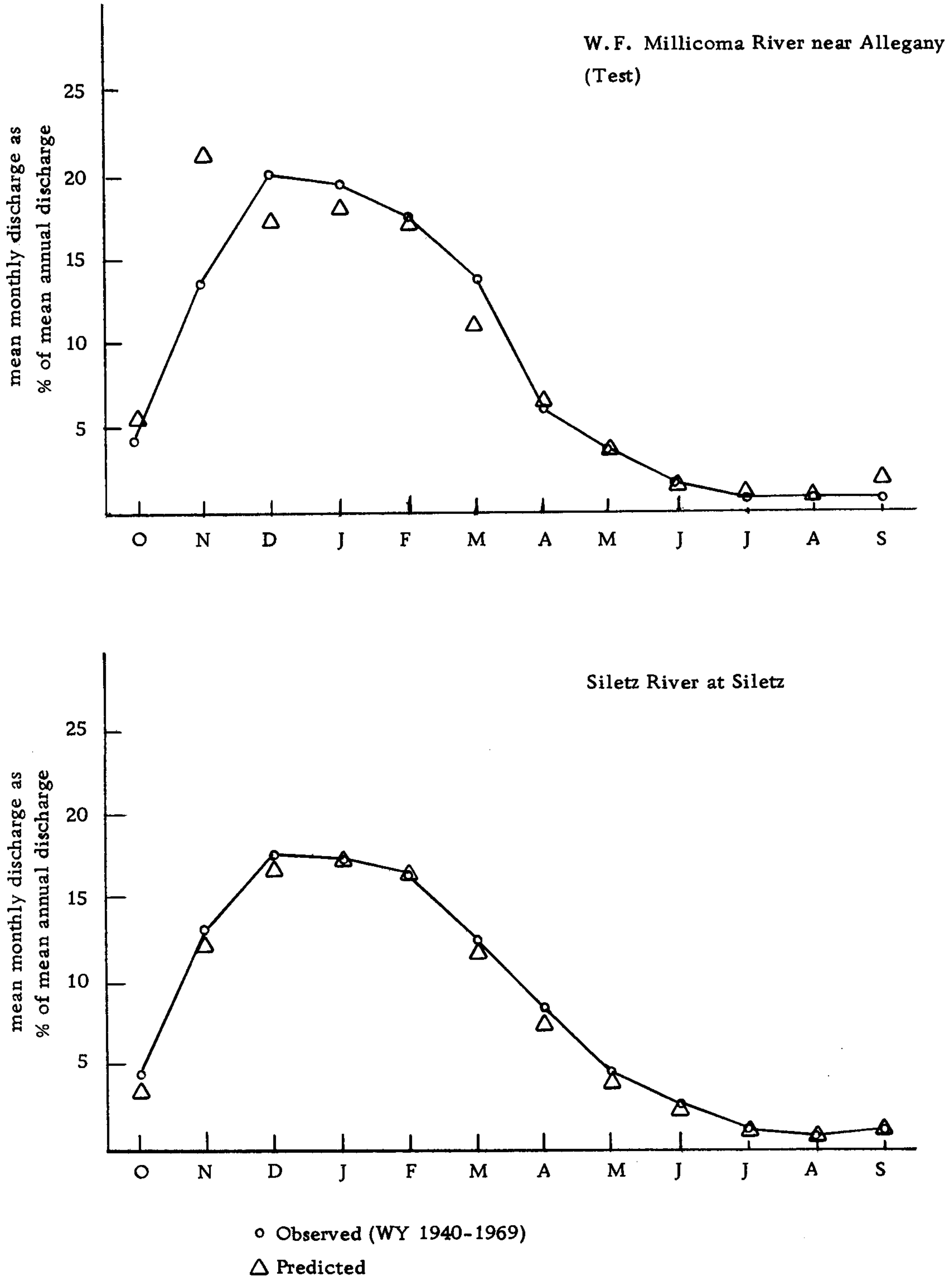

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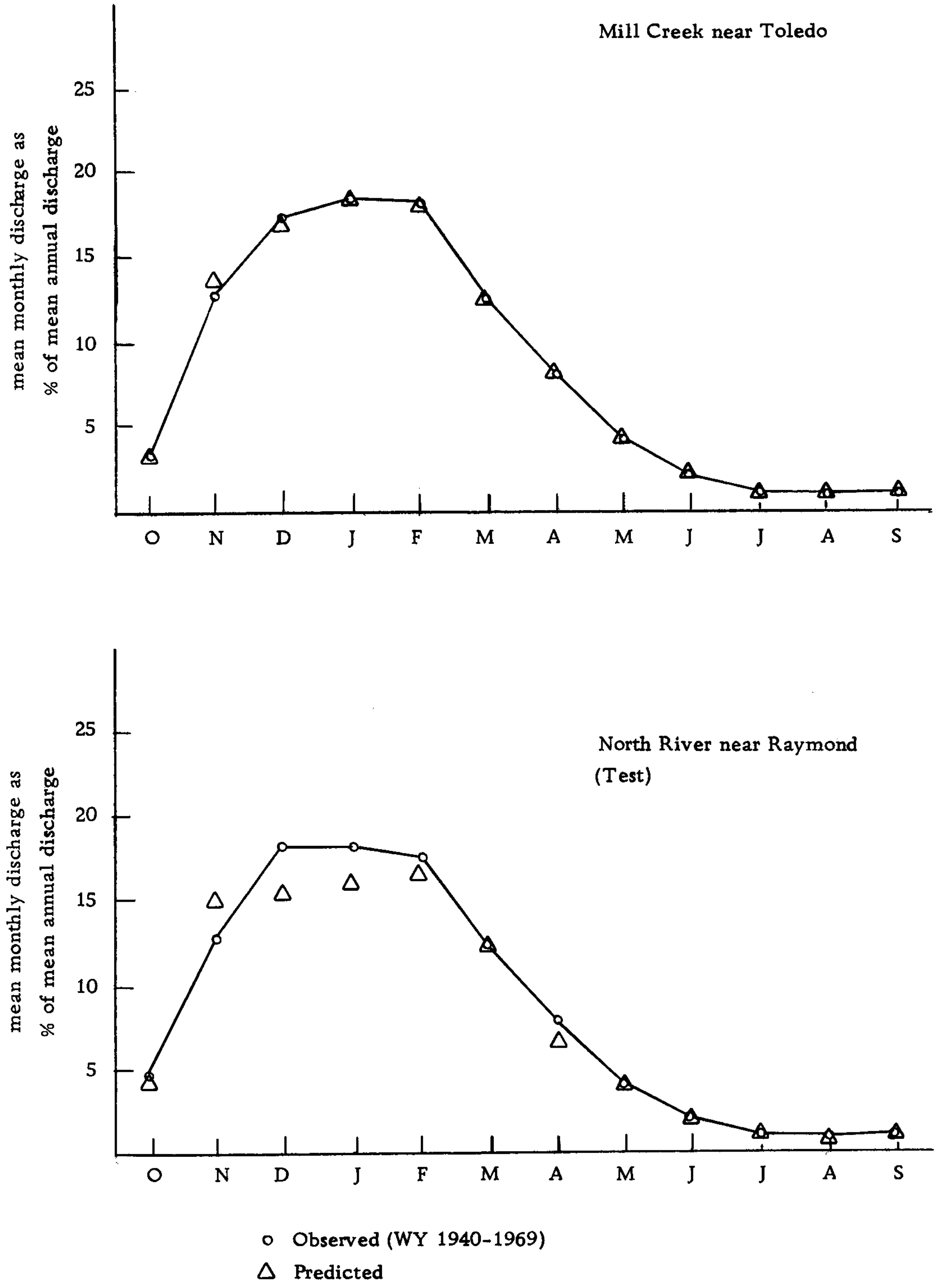

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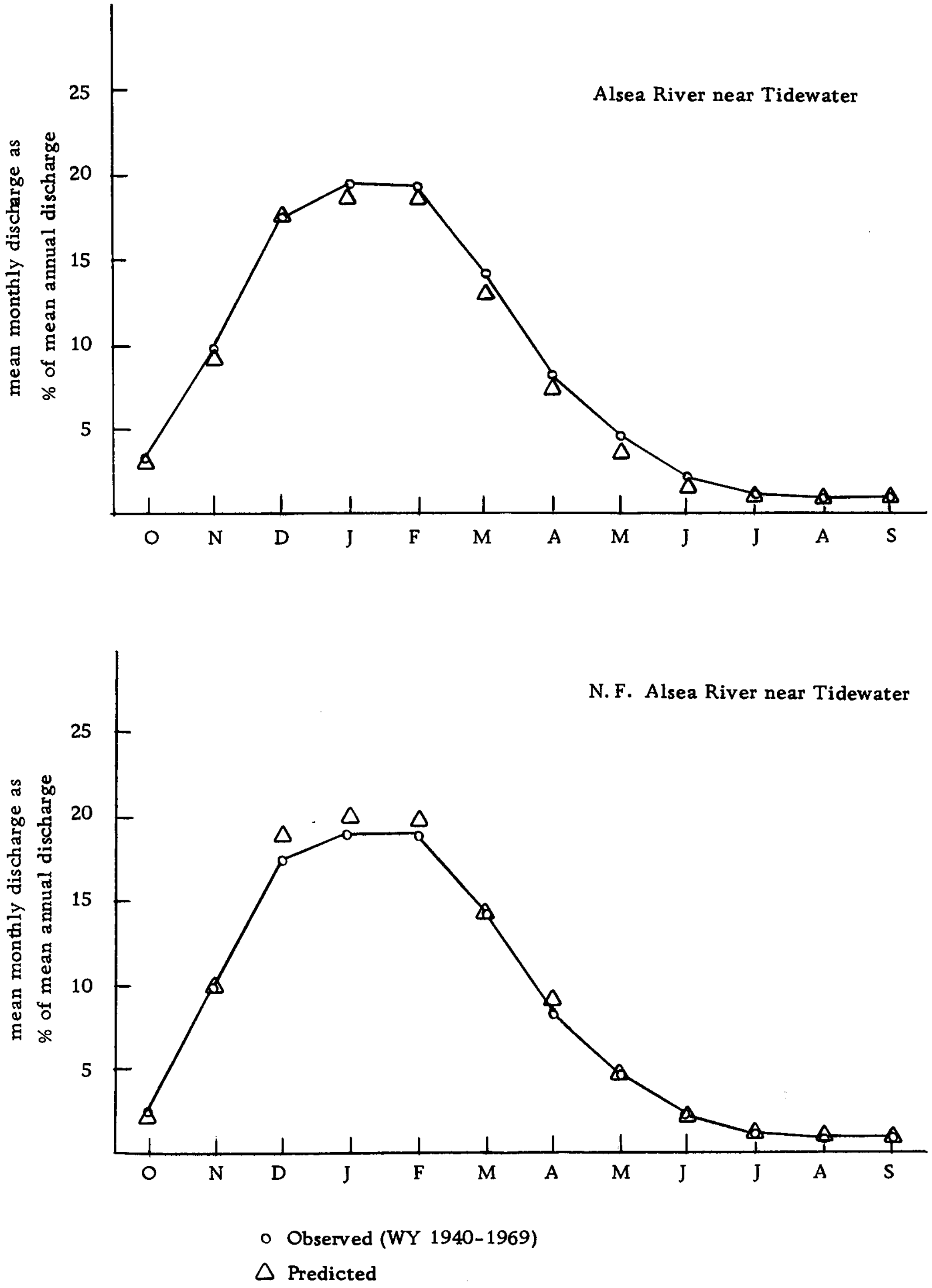

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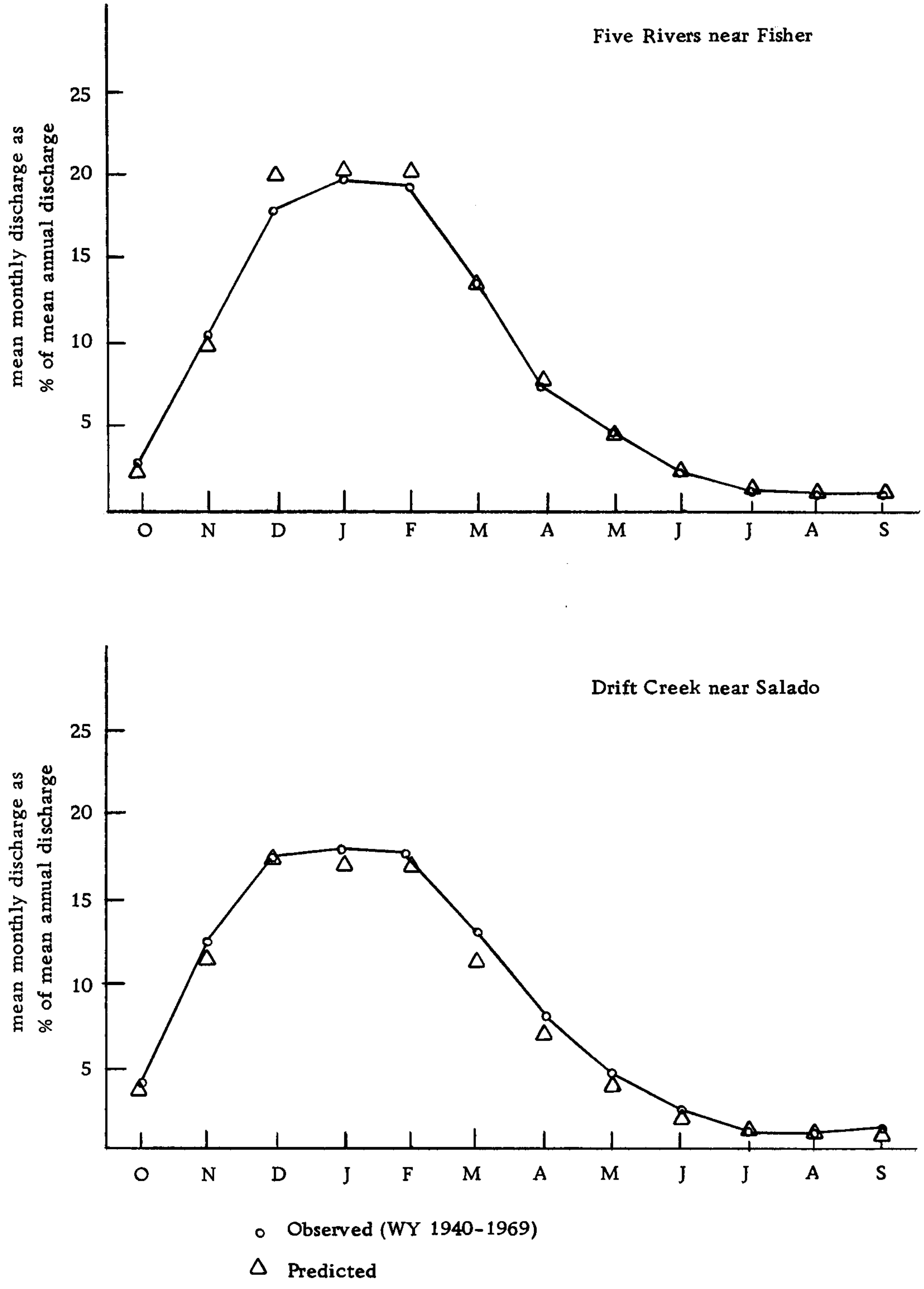

Figure 3. Continued.

before the basin soil moisture is fully recharged, the derived runoff from precipitation events comes mainly from rain falling directly on the stream channel and from areas near the stream where soil moisture is relatively high. The next variable to enter the equation was usually LIFT, and its sign was always positive. During the period of the year when migratory cyclones transit the area, usually fall, winter, and spring, this is an index of the orographic lift given to an airmass as it crosses the basin. NAP is present in all but one equation and is always positively related to runoff. BAS is also present in most of the forecast equations. It is always negatively related to mean monthly flow. This result is expected during periods of the year when evapotranspiration is high. The presence of the aspect term in equations for the winter months is indicative of the fact that north-facing forest slopes will have negligible evapotranspiration while, south-facing slopes will have some small amount of evapotranspiration even during the winter months. A water balance using the Thornthwaite method for Hyslop Farm, Corvallis, Oregon, during the year 1965 indicates evapotranspiration losses of about three inches during the November to February period. The SOILS variable is present in all but two months. It is not present in the equation for December reflecting the fact that soils in the area are usually thoroughly wetted and passing most of the rainfall input to streamflow.[1] Its absence

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[1] From the author's personal experience with the Streamflow Synthesis and Reservoir Regulation (SSARR) model at the Portland River Forecast Center. This model was originally conceived by Mr. D.M. Rockwood, Chief, Water Control Branch, Corps of Engineers, North Pacific Division, Portland, Oregon.

from the equation for August can be explained by the fact that soil moisture values are low and most of the rainfall input is stored in the soil or lost to evapotranspiration. The soils term is positive during the months of September, October, November, January and February. This reflects the fact that soils with higher values of the SOILS index have greater ability to transmit the rainfall input. DD entered the equations for the months of April, May and June. The negative sign indicates the ability of basins with high drainage densities to convert winter rainfall into direct runoff. Basins with lesser drainage densities will retain more water in the soil system and have relatively higher flows during the spring season.

Two other variables occur in the forecast equations, both are related to the precipitation processes. INTEN appears in the equations for March and April. MBE is present in the equations for November, December, January, and February. The MBE variable was tested during the spring months but it did not improve the prediction equations.

Latitude was not used in the final regression analysis because it was found to be highly correlated with several other index variables, resulting in algebraic signs on the variable which did not fit sound hydrologic reasoning.

In the final regression analysis the percent of the basin forested also was not used because the FOREST variable is not random in the area studied. The Tillamook Burn destroyed most of the forest cover in the basins in the north coastal area while the percentage of forest cover in the rest of the study area is affected mainly by logging practices.

The results from the two test basins indicate that the prediction equations will give reliable results for ungaged locations. The average error, expressed as percent of the mean annual streamflow, is 0.7 percent for the 11 basins used in developing the prediction equations and 1.1 percent for the test basins.

Prediction of Standard Deviation of Monthly Flow

It was mentioned in the literature review that a simple relation had been found between the mean annual flow and the standard deviation of annual flow. It is reasonable that a similar simple relation can be established between mean monthly flow and the standard deviation of monthly flow. Consequently, a regression analysis was performed for the basins in the study area relating each basin's mean monthly flow to its monthly standard deviation. The results substantiated the conclusions of Waitt and O'Neill (1969) and Gladwell (1970). The resulting prediction equations had standard errors of estimate ranging from 8 to 25 percent of the mean monthly standard error. The prediction equations and plotted results are shown in Figure 4.

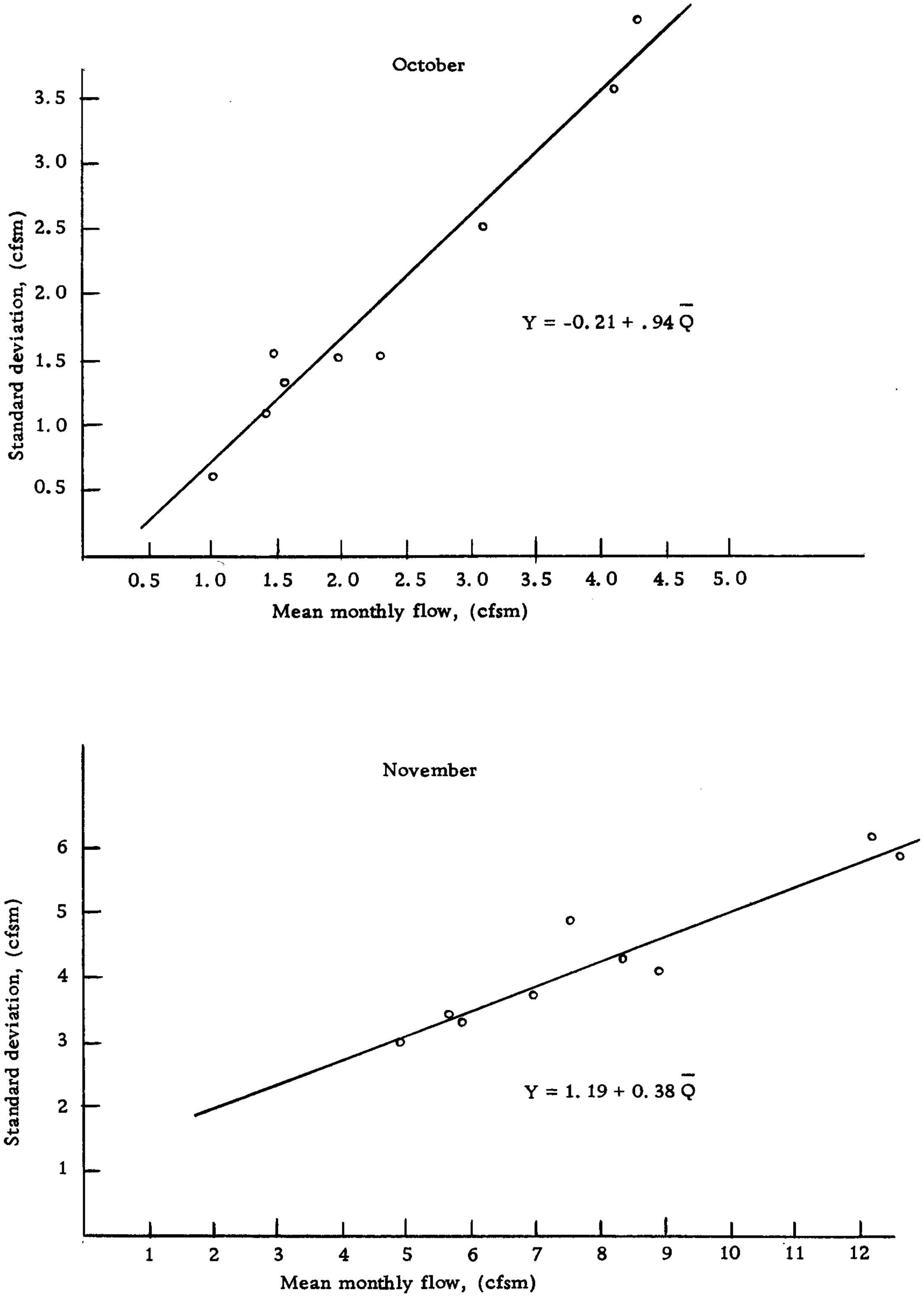
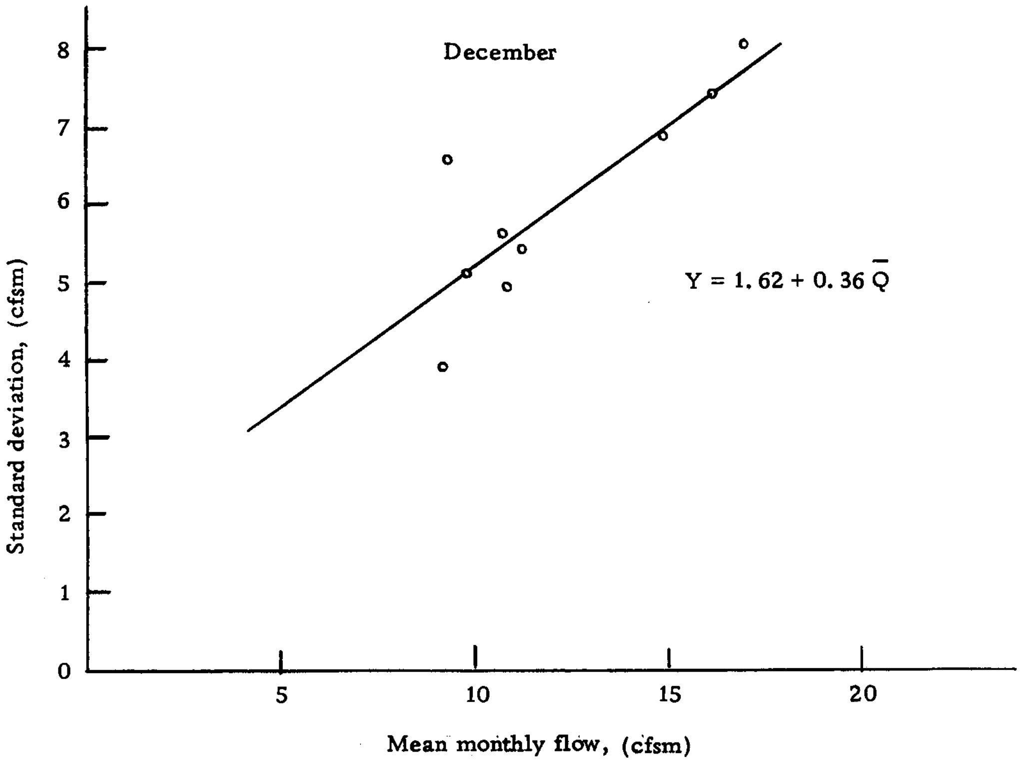
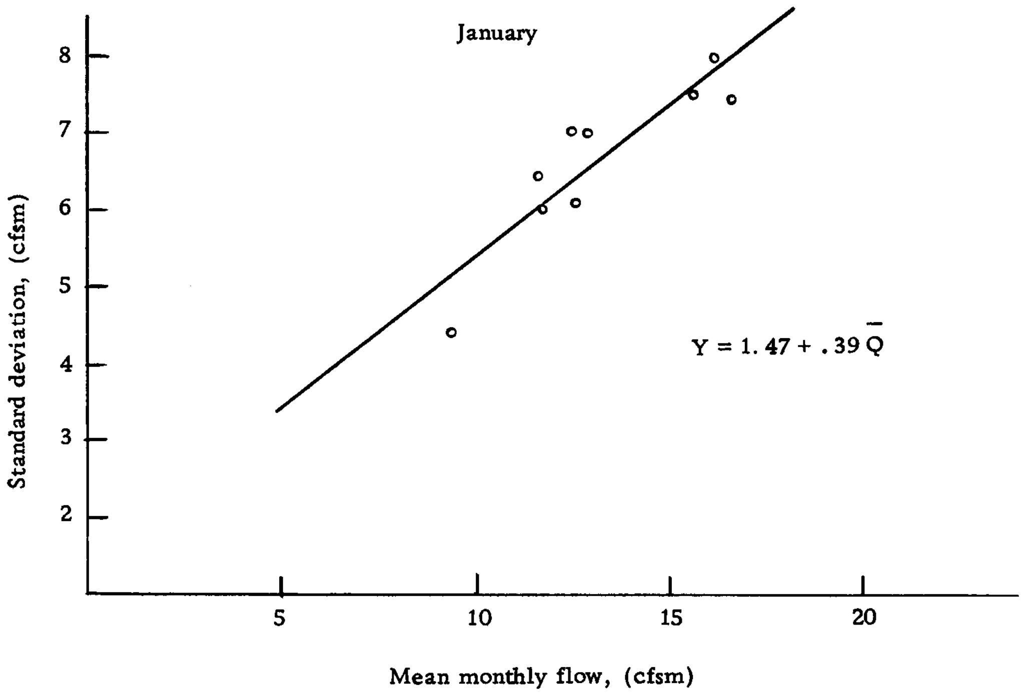


Figure 4. Monthly standard deviations predicted from mean monthly flow.





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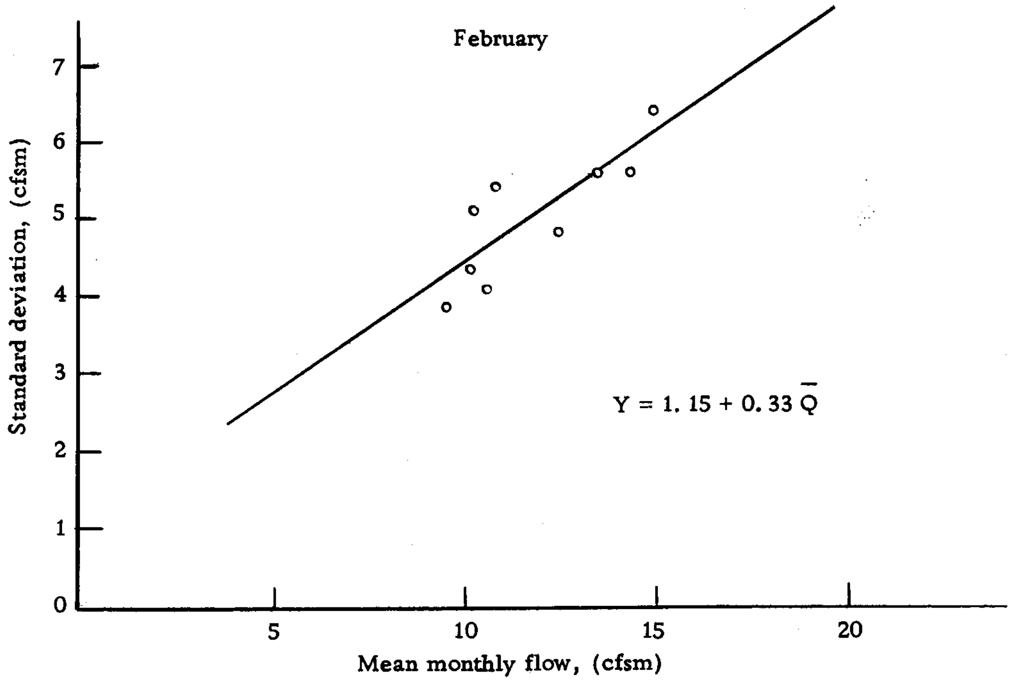

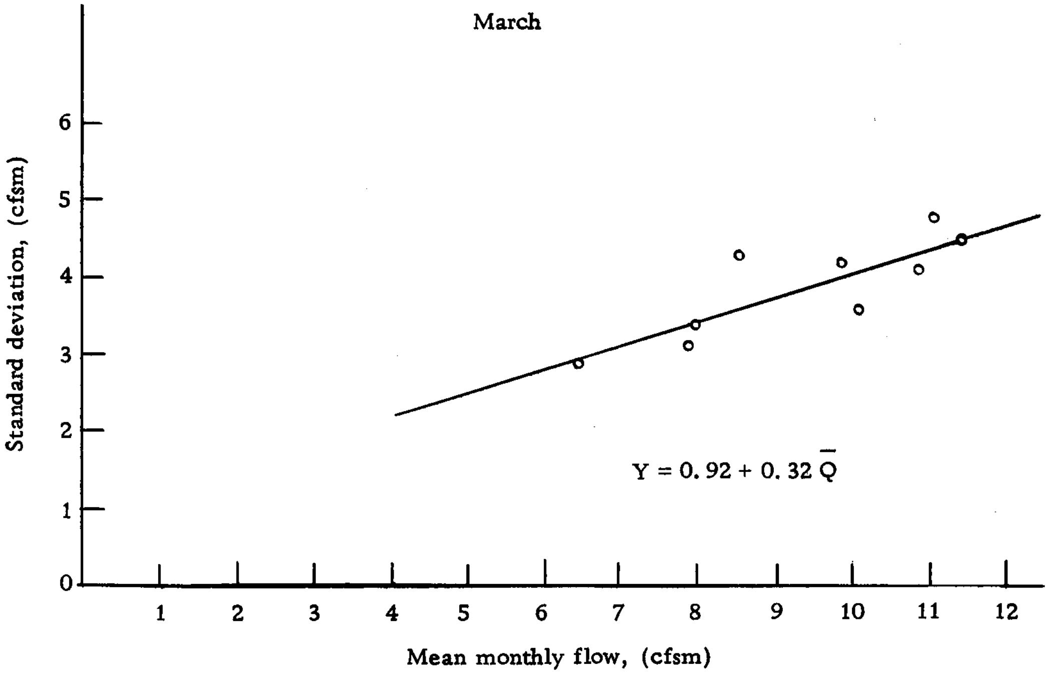

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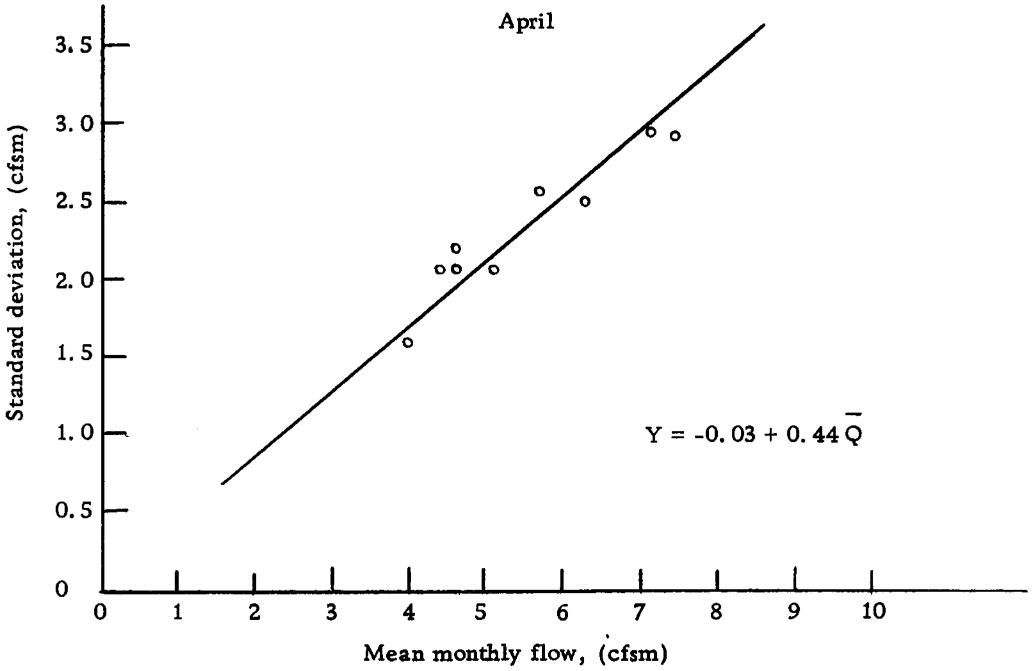

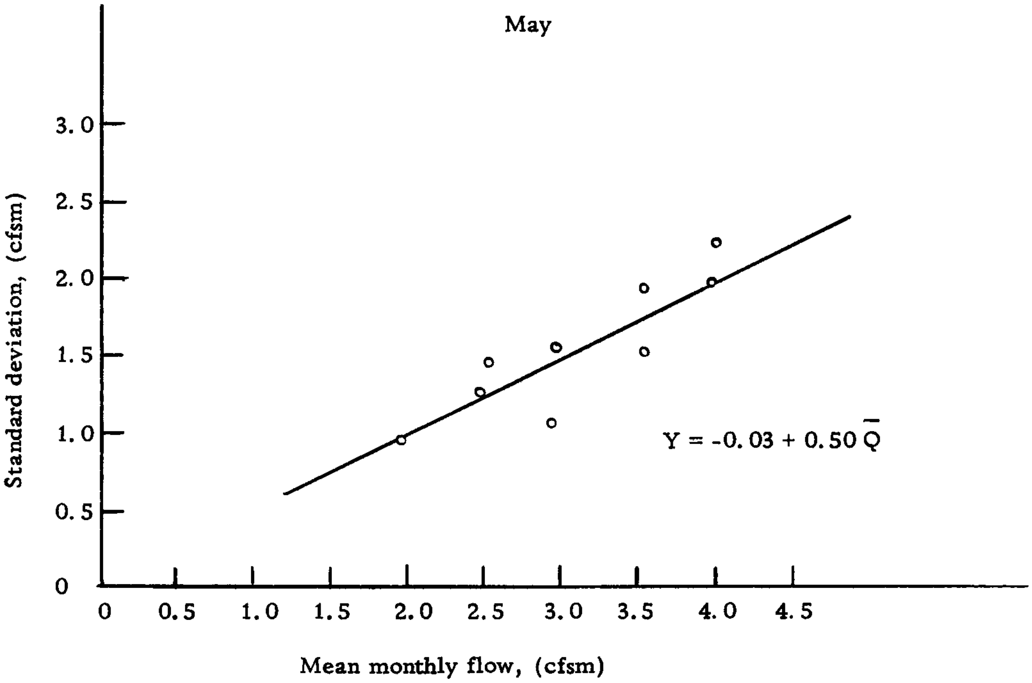

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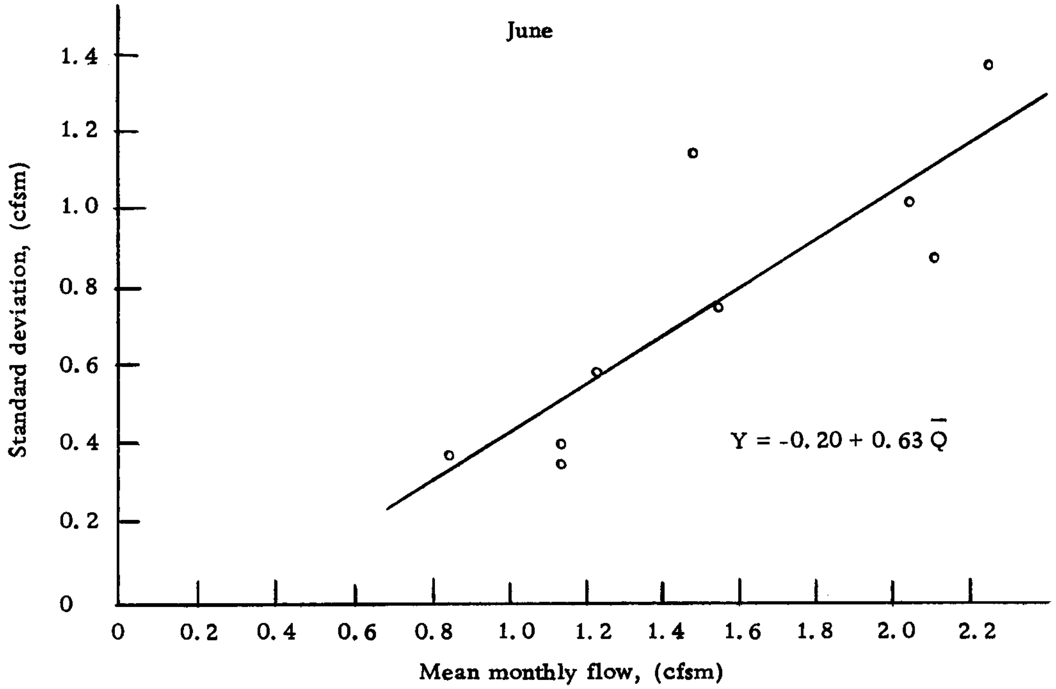

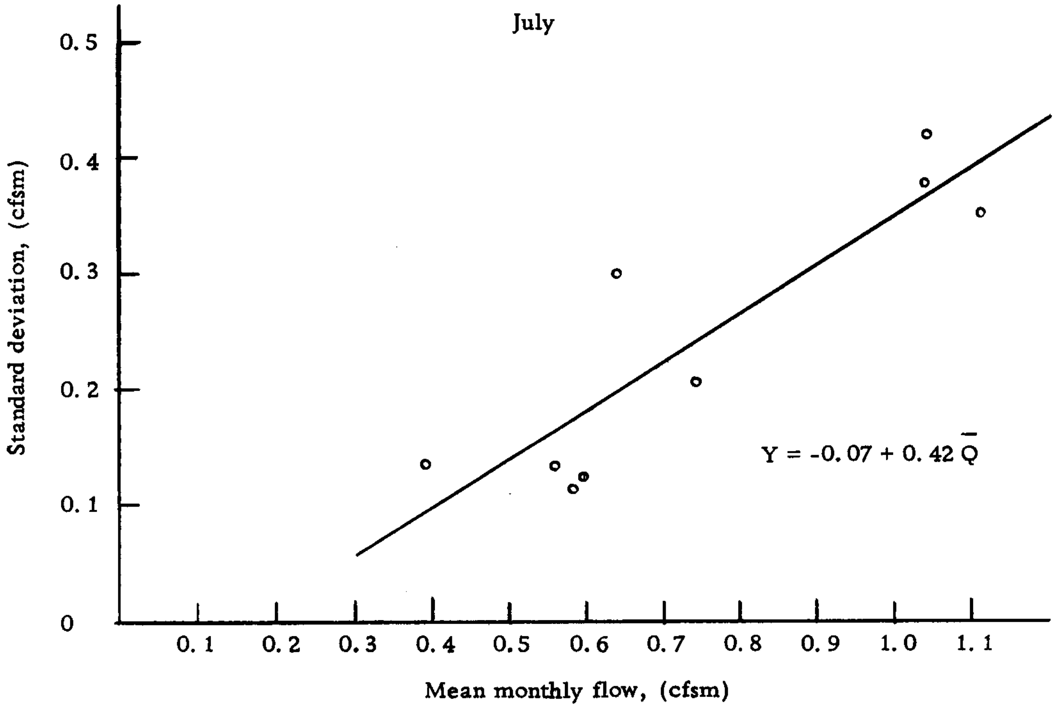

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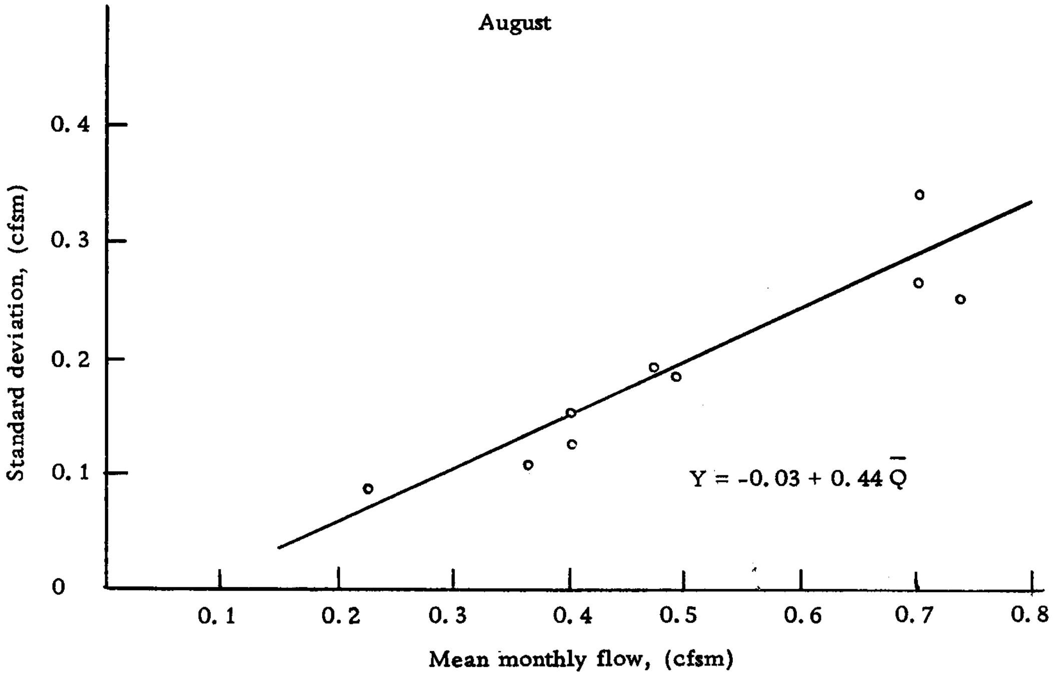


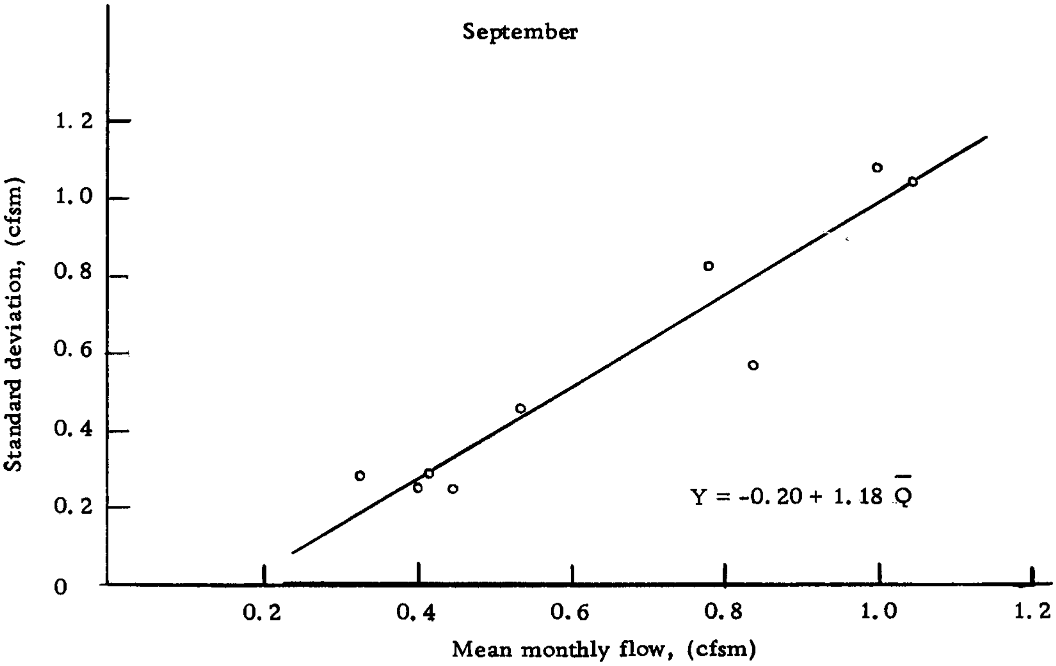


Figure 4. Continued.

These relations may be used to estimate a watershed's standard deviation after the mean monthly discharge has been predicted. Using these derived mean monthly flows to estimate the standard deviation of a basin will introduce some error into the estimates. Further error occurs because the mean monthly flows and standard deviations of monthly flow are derived from only a small sample of the total population mean and standard deviation. Small sample sizes may have quite different means and standard deviations than the population values. However, the results should be comparable to the estimates made using prediction equations with physiographic and meteorological parameters.

To test this contention, the computed mean monthly flows for the West Fork of the Millicoma River near Allegany were used with the relations in Figure 4 to compute monthly standard deviations. These derived standard deviations are shown plotted against the observed standard deviation in Figure 5. The error of prediction, expressed as percent of the observed standard deviations, ranged from 0 to 100 percent for the 12 month period. The average error for the 12 month period was 37 percent. This result is comparable to those achieved by Lystrom (1970) and Thomas and Harenberg (1970). Both authors used a set of physiographic and meteorological parameters to predict standard deviations of monthly flow.

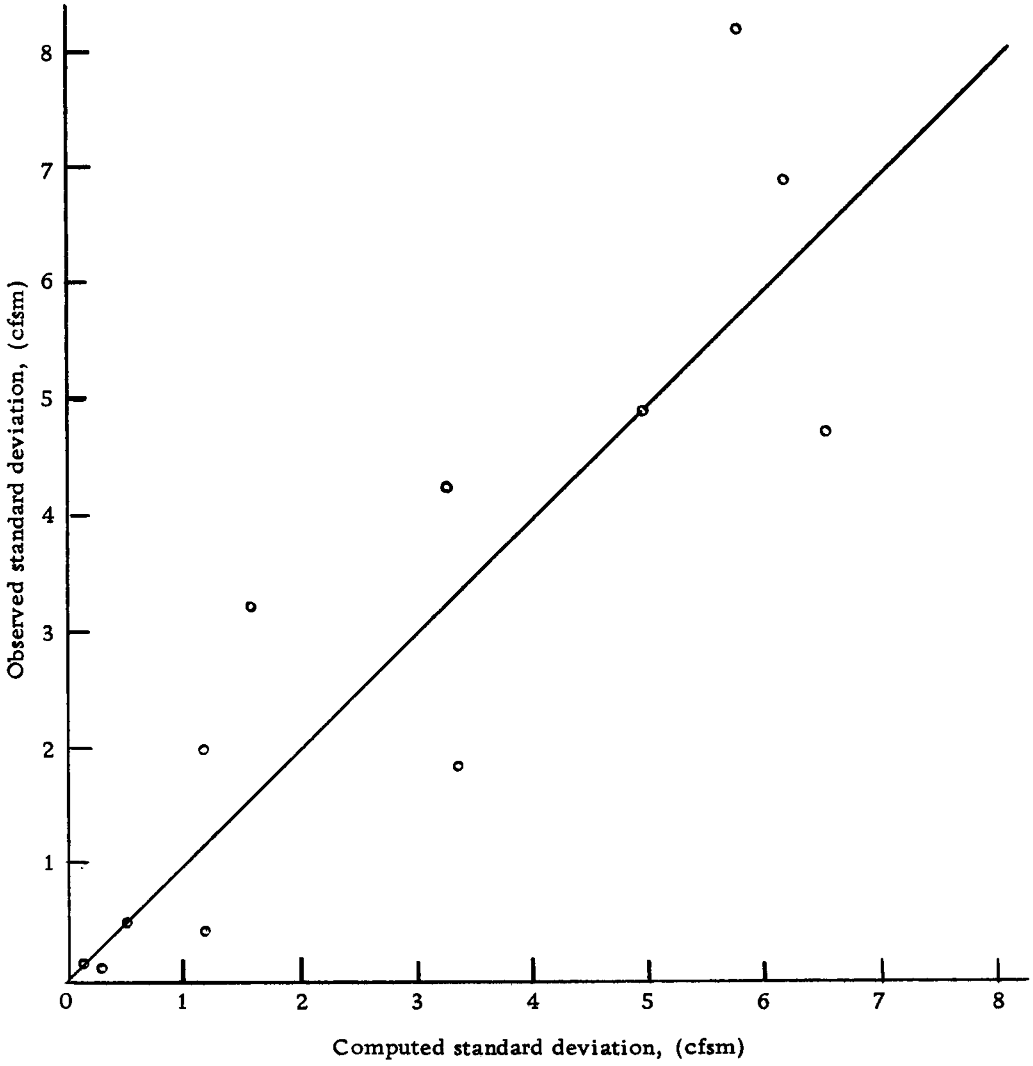


Figure 5. Comparison of computed and observed standard deviations of monthly flow for W.F. Millicoma River near Allegany.

VII. FORECASTING OF MONTHLY FLOWS--
RESULTS AND DISCUSSION

Selection of Months for Developing Forecast Equations

Four months were selected from the water year to reflect the total range in flow present in the Oregon coastal streams: November, January, April, and August. The flow for the month of November varies from near baseflow levels in years when fall precipitation is lacking to high flood flows in years when the basin soil moisture deficit has been satisfied by the late-summer and early-fall precipitation. The month of January was chosen because in most years the coastal soils are fully recharged and rainfall input is transmitted at a maximum rate. The month of April was selected for the study because the flow regime varies widely. The monthly runoff values range from flow of nearly the magnitude of the winter peak flow to flows near base flow levels. Snowmelt runoff was a further complicating factor in the month of April. Lastly, the month of August was selected for study because flow during this month was almost entirely baseflow, with occasional streamflow responses from heavy summer rain.

Discussion of Forecast Equations

For each of the months in this part of the study (November, January, April and August), a regression analysis was made for all nine watersheds included in the investigation. After each regression the residual errors were plotted against other potential variables and this process was continued until no further reduction of the unexplained variance could be achieved.

November Forecast Equations

It was mentioned previously that flow in November varies from near base flow levels in some years to high flood flows in other years. In the monthly forecast equations the precipitation index (PI) and the flow in the month of October (QOCT) were the only variables used. Several other variables were tested (i. e., mean basin temperature, end-of-month flow, and linear and logarithmic time trend terms) but none of these improved the forecast equations. The flow during the month of October was a good index of the soil moisture conditions in November. The greater the flow in October the more runoff from rainfall to be expected in November.

It is interesting to note that the coefficients assigned to the October flow for each basin (see Table 7) are closely related to the drainage density for each basin. The watersheds with high drainage densities (2.5 to 3.0 mi/sq mi) have the greater coefficient (0.8 to 1.5), while the basins with low drainage densities (1.0 to 2.0 mi/sq mi) have the lowest coefficients (0.3 to 0.7). This correlation is

Table 7. Monthly forecast equations and statistical results.

Station	Prediction Equations and Month	Standard Error, % of Mean	Level of Significance	F Value
	November			
Nehalem River near Foss	$Q_{cfsm} = -2.33 + 1.21(PI) + 0.82(QOCT)$	23	.01	69.096
Wilson River near Tillamook	$Q_{cfsm} = -2.93 + 1.05(PI) + 0.50(QOCT)$	16	.01	100.508
Trask River near Tillamook	$Q_{cfsm} = -1.82 + 1.09(PI) + 0.32(QOCT)$	19	.01	35.381
Nestucca River near Fairdale	$Q_{cfsm} = -6.01 + 1.74(PI) + 0.96(QOCT)$	20	.01	40.787
Siletz River at Siletz	$Q_{cfsm} = -3.48 + 1.14(PI) + 0.43(QOCT)$	18	.01	98.840
Mill Creek near Toledo	$Q_{cfsm} = -5.91 + 1.64(PI) + 0.92(QOCT)$	29	.01	12.992
Drift Creek near Salado	$Q_{cfsm} = -4.59 + 1.32(PI) + 0.79(QOCT)$	18	.01	32.895
N.F. Alsea River at Alsea	$Q_{cfsm} = -3.56 + 1.41(PI) + 1.46(QOCT)$	23	.01	38.642
Alsea River near Tidewater	$Q_{cfsm} = -2.57 + 1.18(PI) + 0.94(QOCT)$	28	.01	41.517
	January			
Nehalem River near Foss	$Q_{cfsm} = -0.32 + 0.88(PI) + 0.14(QTEN)$	16	.01	108.230
Wilson River near Tillamook	$Q_{cfsm} = -1.07 + 1.01(PI) + 0.12(QFIVE)$	12	.01	204.859
Trask River near Tillamook	$Q_{cfsm} = -2.51 + 1.00(PI) + 0.38(QFIVE)$	11	.01	101.025
Nestucca River near Fairdale	$Q_{cfsm} = +0.16 + 0.98(PI)$	15	.01	85.279
Siltez River at Siletz	$Q_{cfsm} = +0.65 + 1.05(PI)$	14	.01	314.48
Mill Creek near Toledo	$Q_{cfsm} = -3.03 + 0.99(PI) + 0.35(QWGT)$	13	.01	92.657
Drift Creek near Salado	$Q_{cfsm} = -1.05 + 1.00(PI) + 0.18(QFIVE)$	17	.01	44.207
N.F. Alsea River at Alsea	$Q_{cfsm} = -2.41 + 1.17(PI) + 0.03(QTEN)$	16	.01	68.463
Alsea River near Tidewater	$Q_{cfsm} = -1.15 + 1.03(PI) + 0.49(QOCT)$	14	.01	146.084

Table 7. Continued.

Station	Prediction Equations and Month	Standard Error, % of Mean	Level of Significance	F Value
	April			
Nehalem River near Foss	$Q_{cfsm} = -0.62 + 0.75(PI) + 0.21(QTEN) + 0.03(SNOW)$	19	.01	39.854
Wilson River near Tillamook	$Q_{cfsm} = +0.32 + 0.62(PI) + 0.26(QFIVE) + 0.08(SNOW) + 0.07(QMAR)$	17	.01	27.722
Trask River near Tillamook	$Q_{cfsm} = -1.57 + 0.67(PI) + 0.14(QMAR) + 0.33(QFIVE) + 0.07(SNOW)$	16	.01	17.781
Nestucca River near Fairdale	$Q_{cfsm} = -0.89 + 0.37(PI) + 0.09(QMAR) + 0.46(QFIVE) + 0.15(SNOW)$	20	.05	8.585
Siletz River at Siletz	$Q_{cfsm} = -.130 + 0.79(PI) + 0.13(QMAR) + 0.22(QFIVE) + 0.02(SNOW)$	16	.01	39.726
Mill Creek near Toledo	$Q_{cfsm} = +3.86 + 0.66(PI) - 0.11(QDEJA)$	29	.01	9.840
Drift Creek near Salado	$Q_{cfsm} = -0.06 + 0.53(PI) + 0.45(QFIVE)$	16	.01	34.472
N.F. Alsea River at Alsea	$Q_{cfsm} = +1.15 + 0.64(PI) + 0.22(QFIVE) - 0.03(QDEJA)$	18	.01	26.262
Alsea River near Tidewater	$Q_{cfsm} = +0.26 + 0.71(PI) + 0.27(QFIVE)$	22	.01	40.666
	August			
Nehalem River near Foss	$Q_{cfsm} = +0.06 + 0.17(PI) + 0.10(QJUJY) + 0.001(SNOW)$	17	.01	32.458
Wilson River near Tillamook	$Q_{cfsm} = +0.21 + 0.17(PI) + 0.12(QJUJY) + 0.003(SNOW)$	20	.01	23.651
Trask River near Tillamook	$Q_{cfsm} = +0.20 + 0.14(PI) + 0.14(QJUJY)$	11	.01	54.963
Nestucca River near Fairdale	$Q_{cfsm} = +0.01 + 0.22(QJUJY) + 0.004(SNOW)$	17	.01	17.992
Siletz River at Siletz	$Q_{cfsm} = +0.15 + 0.25(PI) + 0.12(QJUJY)$	21	.01	60.132
Mill Creek near Toledo	$Q_{cfsm} = +0.23 + 0.03(PI) + 0.10(QJUJY)$	28	.05	5.997
Drift Creek near Salado	$Q_{cfsm} = +0.12 + 0.10(PI) + 0.14(QJUJY)$	9	.01	80.336
N.F. Alsea River at Alsea	$Q_{cfsm} = +0.19 + 0.15(PI) + 0.09(QJUJY)$	10	.01	49.363
Alsea River near Tidewater	$Q_{cfsm} = +0.16 + 0.15(PI) + 0.08(QJUJY)$	13	.01	56.896

reasonable because watersheds with high drainage densities are more efficient in transmitting the rainfall input to streamflow.

January Forecast Equations

In the equations for January the precipitation index was the most important variable. This was reasonable because a high proportion of the rainfall input becomes streamflow during this month. In some basins the precipitation index alone resulted in the best forecast equation. In most of the forecast equations for the month of January some form of antecedent flow index was included. An end-of-month flow term (QTEN or QFIVE) was used in the equations for six of the watersheds to index direct runoff from a storm near the end of December which carried over into January. In the Mill Creek basin a weighted sum of the flow in October, November, and December (QWGT) was found to be significant. The flow during the month of October (QOCT) was a significant variable in the equation for the Alsea River near Tidewater. It is difficult to explain why this variable was important only in this watershed. The significance derived partly from one year in which the highest residual error when using the precipitation index alone corresponded to the highest October flow. However, the flow in October was still significant after that one year was removed.

It is instructive to look for relations between the physiographic parameters discussed earlier in this thesis and the variables which appear in the January equations. With one exception, the basins with an end-of-month flow term are those with the highest value of the soils index. This reflects the ability of basins with a high soils index to transmit the moisture input as direct runoff.

April Forecast Equations

April is another month in which the flow regime can vary widely from one year to the next. Properly indexing the flow was difficult. In April, as with the previous two months, the precipitation index was the most important variable and was the first to enter the forecast equations in all cases. The next most significant parameter was the flow in the last five or ten days of the previous month. The forecast equation for Mill Creek did not include the flow at the end of the previous month as one of the predictor variables. There appears to be no rational explanation for the exclusion of this parameter in the Mill Creek basin.

The flow for the entire month of March (QMAR) was found to be a significant variable in four of the watersheds. These included three of the four basins with the smallest drainage density. A watershed with a low drainage density would retain more of the rainfall input in the soil which would, in turn, delay its reaching the stream as runoff.

The February 1 snow water equivalent at Marys Peak (SNOW) significantly reduced the unexplained variance in the five northern basins in the study area. There were two reasons for using the February snow water equivalent term rather than that for March 1 or April 1. Snow water equivalent values for March 1 were not available for the whole study period. The April 1 snow measurements at the Marys Peak site were not representative of the snow cover in the northern basins of the study area because the Marys Peak snow measuring site is poorly located in an area of wind drift accumulation of snow and limited exposure to the sun.

The flow in the months of December and January (QDEJA) entered the equations for only two of the basins, the North Fork of the Alsea River and Mill Creek. The physical relevance of this term in these two basins is questionable. The significance might result from chance correlations in the short period of record for these stations.

A mean basin temperature parameter and the two time trend terms were tried in the month of April but did not reduce the unexplained variance.

August Forecast Equations

As might be expected, the first variable to enter the regression equation for the month of August was the antecedent flow term. This term was the average of the flows in the months of June and July (QJUJY). The next variable to enter the equations in all but one case was the precipitation index. In the few years during which rainfall for the month of August was heavy, the inclusion of the precipitation index resulted in much superior forecasts. In three of the northern basins, the Nehalem, the Wilson, and the Nestucca Rivers, the February 1 snow term significantly reduced the unexplained variance. No other variable was found that further reduced the standard error in the August forecast equations.

Discussion of Variables Not Included in the Final Equations

A basin temperature term was considered as a part of the model but rejected before the final regression analysis was performed. A basin temperature term would primarily index evapotranspiration losses. A basin temperature term might also be used during the winter to index precipitation which falls as snow and does not run off until a later month. Considering the ultimate aim of this development, the forecast of monthly flow using the 30-day precipitation outlook, adding a 30-day forecast temperature term would only compound the prediction problem. A temperature term was tested for all of the months of this study but did not materially reduce the unexplained variance. The basin loss is somewhat accounted for by the weighting procedure used in deriving the precipitation term. The weights for the month of August ranged from 0.1 to 0.5, indicating that most of the rainfall input does not contribute to runoff. In the month of November, the weights ranged from 0.2 to 0.6, indicating that something less than half the rainfall input actually becomes streamflow. For the months of January and April the weights ranged from 0.4 to greater than 1.0, indicating a high proportion of rainfall input becoming streamflow.

A time trend term was also considered for the months in this study. This parameter was expected to index the change in the flow regime due to forest fires or logging operations in the study basins. The only major forest fire in the Oregon coastal area was the Tillamook Burn which occurred in the 1930's in the northern basins. Timber harvesting prior to the 1950's was considerably less than present levels. A coastal windstorm in 1951 caused heavy blowdown in the study area which was followed by salvaging and by insect infestation, which required more salvaging. The rate of timber harvest in the area has been quite steady through the period 1960 to 1970 (Boring, 1971).

Plotting the residual errors from each forecast equation with time did not indicate any significant time trend in the data. Rothacher (1970) suggests a reason for these results. He states that though the on-site increases in runoff may be large, the increase may be largely obscured on the larger watersheds harvested on a long-term sustained-yield basis. The only long term records available in the study area are for watersheds of greater than 150 square miles.

Discussion of the Statistics of the Final Regression Equations

A summary of the final forecast equations and resultant statistics is shown in Table 7. The coefficients of the parameters in the equations for the watersheds with short periods of record are somewhat suspect. In these short periods of record the coefficients may be as much due to chance correlations between variables as to any real physical relation to the dependent variable. A summary of the average standard error, expressed as percent of the mean monthly flow, for each of the watersheds for the four months of the study is given in Table 8. The average standard errors of the forecast equations range from 14 to 25 percent, with all but one watershed, Mill Creek, averaging less than 20 percent.

Table 8. Average standard errors for months of November, January, April and August.

Basin	Standard Error, % of Mean Monthly Flow	Basin	Standard Error % of Mean Monthly Flow
Nehalem River near Foss	19	Mill Creek near Toledo	25
Wilson River near Tillamook	16	N. F. Alsea River at Alsea	17
Trask River near Tillamook	14	Alsea River near Tidewater	19
Nestucca River near Fairdale	18	Drift Creek near Salado	15
Siletz River at Siletz	17		

As a final test of the forecast equations, the monthly flows for water year 1971 were predicted using the derived parameters. The results of this test are given in Figure 6. The average error of these forecasts, expressed as percent of the observed flow for each month, are as follows: November, 16 percent; January, 13 percent; April, 19 percent; and August, 11 percent. The accuracy of these forecasts are within the degree of accuracy achieved in forecasting flows for the historical period. The results presented here are comparable to those achieved by Greening and Law (1969). In that study, the predictive error in a test period, expressed as percent of the observed runoff, ranged from 14 to 24 percent. With the exception of the forecasts for the month of January 1971, no consistent bias is indicated. Two factors contributed to the low estimate of flows for the month of January. First, several climatological stations equalled or exceeded their previous maximum three-hourly precipitation rate during the month of January, 1971 (Pacific Northwest River Basins Commission, 1970). Secondly, 10 to 25 inches of snow fell on the coastal area between January 11 and January 13. Warm temperatures, heavy rain, and strong southwesterly winds melted this snow in a 24-36 hour period (U.S. Weather Bureau, 1971). These factors combined to produce a higher percent of runoff than the derived precipitation weights for January can yield.

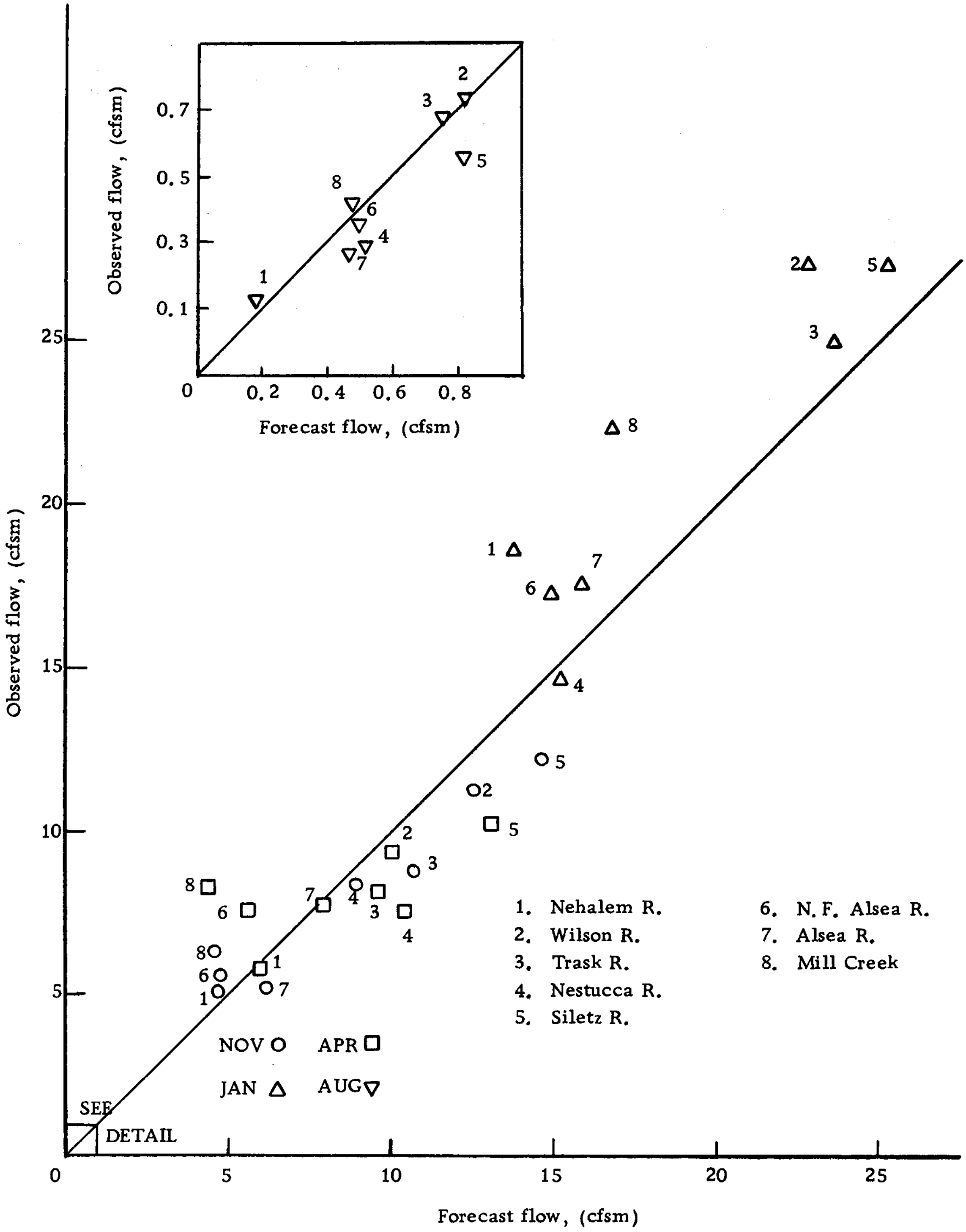


Figure 6. Comparison of observed and forecast flow from derived equations using observed data during water year 1971.

Using the 30-Day Precipitation Outlook to Forecast Monthly Flows

This final section investigates the use of the National Weather Service's 30-day precipitation outlook in forecasting monthly streamflow. Several authors have previously concluded that the skill in forecasting monthly precipitation is only slightly better than chance (Greening and Law, 1969; Riggs and Hanson, 1969; U.S. Weather Bureau, 1961). In the following pages this contention is tested using the water years 1968-1971 for the watersheds and months used in this investigation.

Description of the Test Procedure

The National Weather Service's 30-day precipitation outlook classifies monthly precipitation into three categories; light, moderate, and heavy. The precipitation limits have been computed such that one-third of the observed amounts occur in each of these three classes. Each month a precipitation outlook map is prepared for the United States and Canada depicting the categories mentioned above (U.S. Weather Bureau, 1961). From this map the precipitation outlook class for a particular drainage basin can be found. This precipitation outlook can then be used in the monthly forecast equations developed in this study.

In order to apply the monthly precipitation outlook, the class limits for the rainfall stations used in the monthly forecast equations had to be determined. The monthly rainfall amounts for each station were arrayed from the smallest to the largest. The value below which one-third of the cases fell was taken as the class limit between light and moderate. The value below which two-thirds of the cases fell was taken as the class limit between moderate and heavy. The midpoints of these classes were taken as the station values to use when light, moderate, or heavy rain is indicated. The class medians and the class limits for each of the stations used in the monthly forecast equations are shown in Table 9.

The water years 1968-1971 were selected as the test period. This recent period was chosen so that any new skill in forecasting of monthly precipitation might be included. The precipitation outlook maps for the months of November, January, April, and August were studied and a precipitation class was chosen for each basin for each of the four months during the four years of the test period. If a watershed fell totally inside one of the classes, the median of that class was taken as the forecast value. If, on the map depicting monthly precipitation outlooks, the line between classes passed through a basin, the class limit was taken as the forecast. After all the basins were classified, the amount of precipitation corresponding to these categories for each station were used to predict the monthly streamflow using the forecast equations shown in Table 7.

Table 9. Class medians and class limits of monthly precipitation for stations used in the precipitation indexes.

Month and Class	Stations and Monthly Precipitation (inches) at the Class Medians and Class Limits							
November	Alsea Fish Hat.	Clatskanie 3W	Cloverdale	Fall City	Grande Ronde	Haskins Dam	Lees Camp	Newport
Light	7.65	4.17	7.07	4.71	5.43	5.09	9.14	4.91
Light-moderate	13.03	6.40	8.68	7.21	7.56	7.51	13.17	7.62
Moderate	13.77	8.25	11.98	11.34	9.22	10.33	16.11	9.28
Moderate-heavy	16.93	9.30	13.55	13.80	10.91	13.73	21.28	11.98
Heavy	20.25	13.20	16.27	16.42	13.00	16.50	25.86	14.52
	Summit	Tidewater	Tillamook 1W	Tillamook 11E	Timber	Valsetz	Vernonia	
Light	4.44	7.26	5.20	7.92	4.02	10.98	4.13	
Light-moderate	6.38	12.12	9.60	12.66	6.18	12.58	5.49	
Moderate	9.11	13.38	12.08	15.56	8.93	16.45	6.70	
Moderate-heavy	12.12	16.08	15.48	18.51	11.48	22.78	8.61	
Heavy	13.94	19.12	18.57	23.84	14.52	28.65	10.22	
January	Alsea Fish Hat.	Clatskanie 3W	Cloverdale	Fall City	Grande Ronde	Haskins Dam	Lees Camp	Newport
Light	7.27	4.91	6.86	6.47	5.74	7.98	9.42	5.59
Light-moderate	11.51	6.27	9.80	8.92	7.49	8.82	14.25	6.20
Moderate	16.07	8.63	11.63	10.83	10.45	11.58	15.89	9.37
Moderate-heavy	21.69	11.50	15.80	17.46	14.00	15.87	21.36	14.69
Heavy	25.72	14.22	19.42	19.05	16.43	20.20	24.02	17.33
	Summit	Tidewater	Tillamook 1W	Tillamook 11E	Timber	Valsetz	Vernonia	
Light	5.80	8.21	7.67	9.63	5.30	9.44	3.99	
Light-moderate	7.92	11.77	10.59	14.33	6.73	13.69	5.85	
Moderate	9.07	15.72	12.51	19.70	10.64	18.65	7.05	
Moderate-heavy	13.15	21.60	16.83	24.37	12.08	25.60	9.53	
Heavy	16.37	23.88	18.03	26.40	15.00	30.79	11.05	

Table 9. Continued.

Month and Class	Stations and Monthly Precipitation (inches) at the Class Medians and Class Limits							
April	Alsea Fish Hat.	Clatskanie 3W	Cloverdale	Fall City	Grande Ronde	Haskins Dam	Lees Camp	Newport
Light	2.51	1.77	3.76	1.76	1.60	2.23	3.79	2.63
Light-moderate	4.79	2.50	4.88	2.58	2.35	3.04	5.07	3.21
Moderate	5.75	3.61	5.61	3.21	3.01	3.62	5.82	4.57
Moderate-heavy	7.98	4.31	6.07	4.24	3.99	4.40	8.27	5.03
Heavy	9.72	5.67	8.18	6.71	5.25	8.11	9.41	6.98
	Summit	Tidewater	Tillamook 1W	Tillamook 11E	Timber	Valsetz	Vernonia	
Light	2.21	2.75	2.87	3.18	1.40	4.14	1.23	
Light-moderate	3.03	4.80	4.87	5.35	2.52	5.33	2.13	
Moderate	3.92	6.24	5.49	6.05	3.00	7.89	2.30	
Moderate-heavy	5.02	7.44	6.64	8.10	3.91	9.72	3.82	
Heavy	6.64	9.72	8.53	11.47	5.06	11.61	4.49	
August	Alsea Fish Hat.	Clatskanie 3W	Cloverdale	Fall City	Grande Ronde	Haskins Dam	Lees Camp	Newport
Light	0.01	0.26	0.32	0.01	0.06	0.08	0.20	0.23
Light-moderate	0.37	0.54	0.90	0.16	0.23	0.20	0.60	0.53
Moderate	0.55	0.79	0.97	0.32	0.42	0.53	1.12	0.75
Moderate-heavy	1.43	1.65	2.20	0.68	0.97	0.80	2.50	1.34
Heavy	2.62	2.15	2.70	1.10	1.07	1.39	3.35	2.40
	Summit	Tidewater	Tillamook 1W	Tillamook 11E	Timber	Valsetz	Vernonia	
Light	0.05	0.13	0.52	0.59	0.15	0.37	0.10	
Light-moderate	0.24	0.44	0.82	0.70	0.20	0.60	0.20	
Moderate	0.46	0.51	1.19	1.73	0.40	1.05	0.30	
Moderate-heavy	0.94	1.21	1.87	2.66	0.88	2.40	1.18	
Heavy	1.61	2.44	3.34	3.87	1.53	3.94	1.90	

Another set of forecasts was made using the median historical precipitation for each station for each of the test months. A comparison between the forecasts made based upon median precipitation and the forecasts made based upon the 30-day outlook should indicate whether any degree of skill is involved in using the monthly precipitation outlooks.

Results for the Test Period

In Figure 7 the results of the forecasts during the test period are summarized. The average error, expressed as percent of the observed runoff, is given for eight of the nine study basins. One watershed, Drift Creek near Salado, is not included because this gaging station was discontinued in water year 1971. Each average error is the mean of the errors for the four year period for each month. Three forecasts are displayed: (1) a forecast based upon observed monthly rainfall, (2) a forecast based upon median monthly precipitation and (3) a forecast based upon the 30-day precipitation outlook. The error, expressed as percent of the observed flow and averaged by month for all of the watersheds, is shown in Table 10.

On the average, the forecast using observed monthly rainfall gave the smallest percentage errors. Forecasts based upon median precipitation and 30-day outlook precipitation gave larger percentage errors. The worst forecasts resulted from using the 30-day outlook

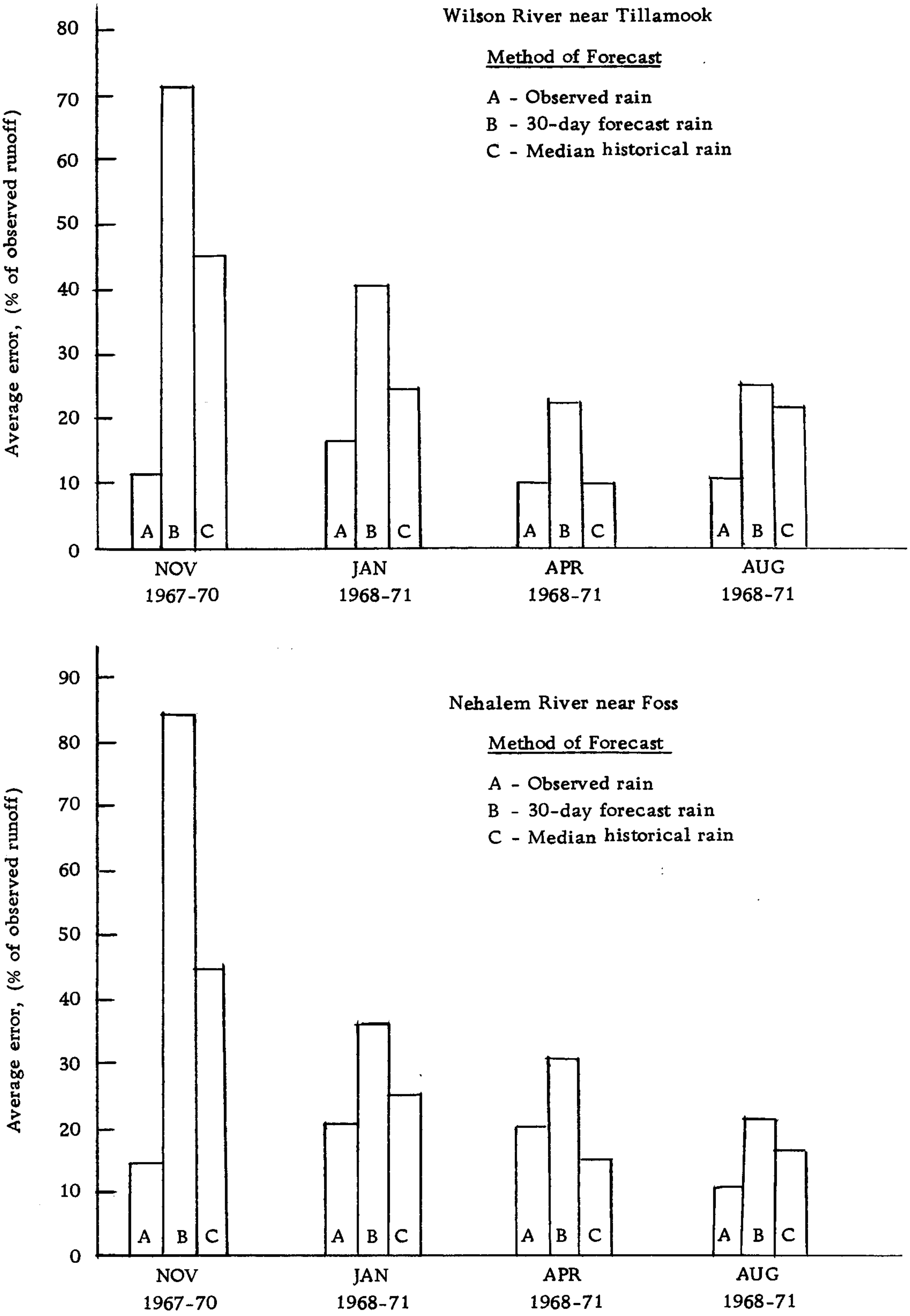
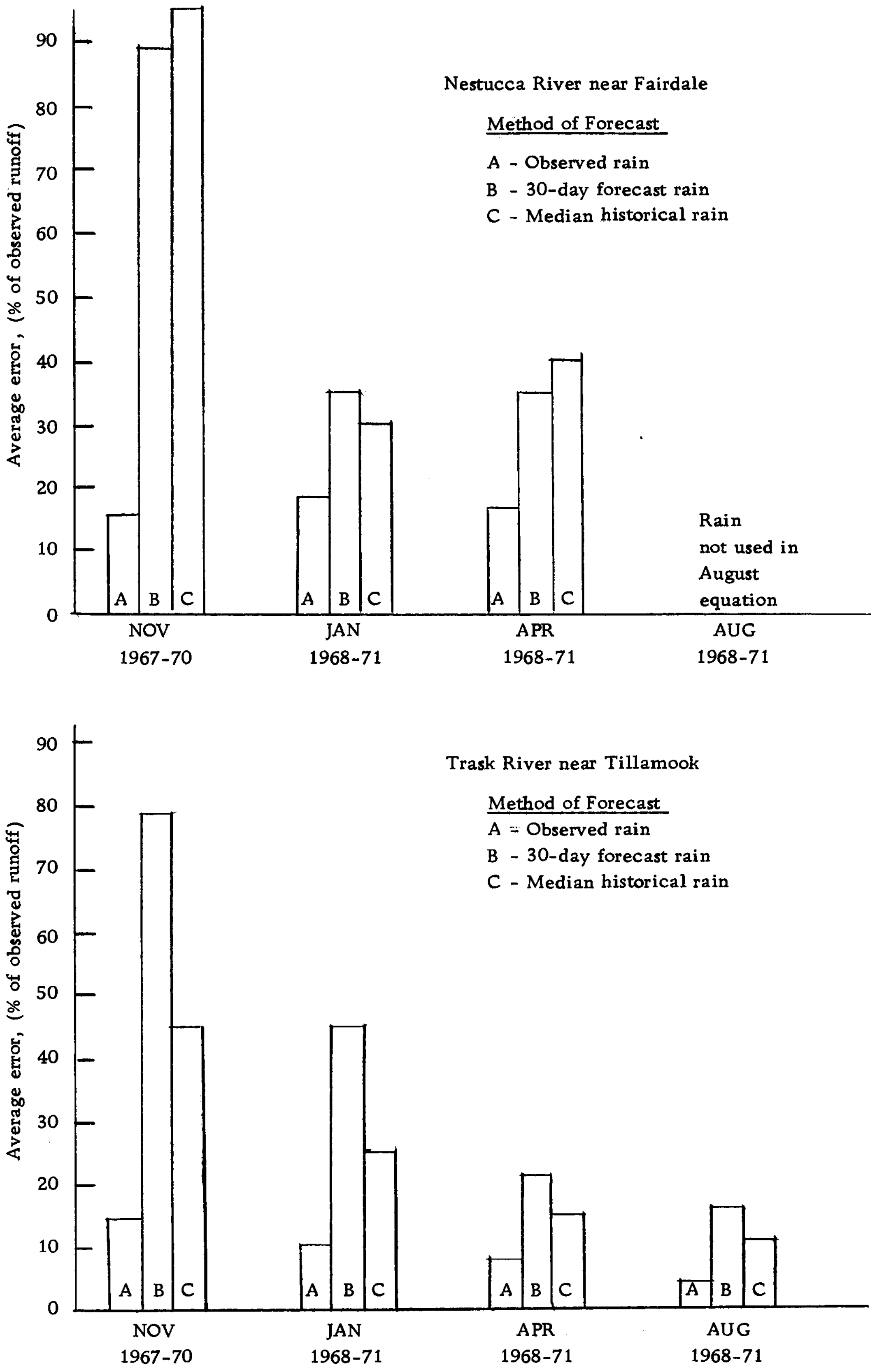


Figure 7. Average percent error of flow forecasts by three methods.



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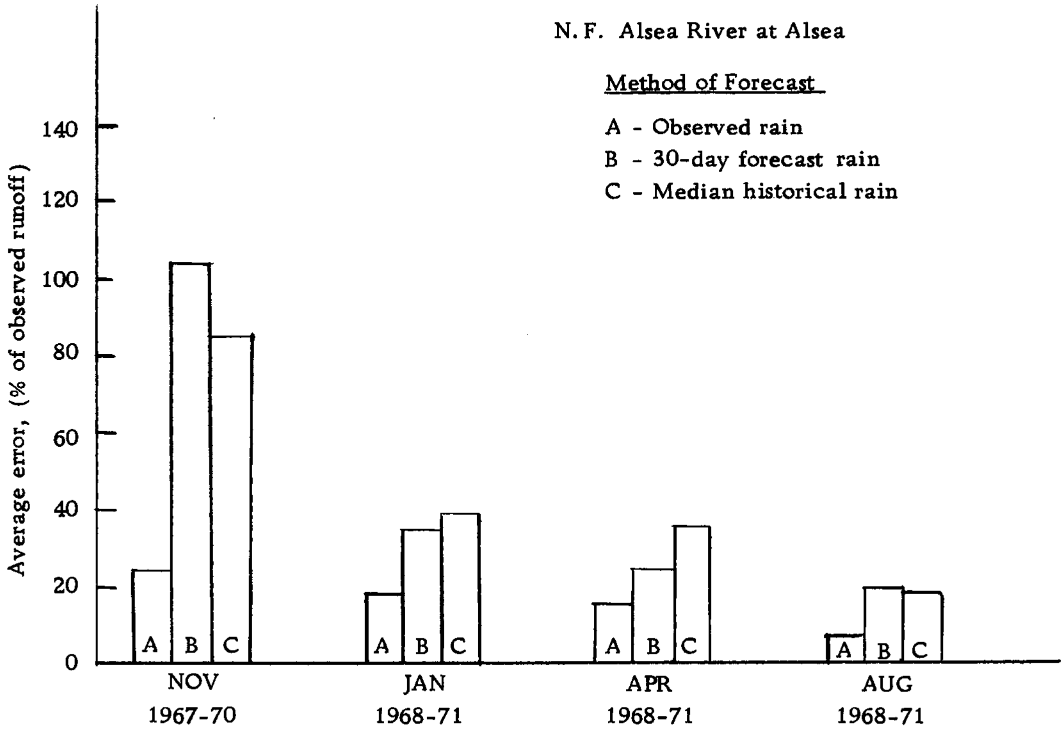

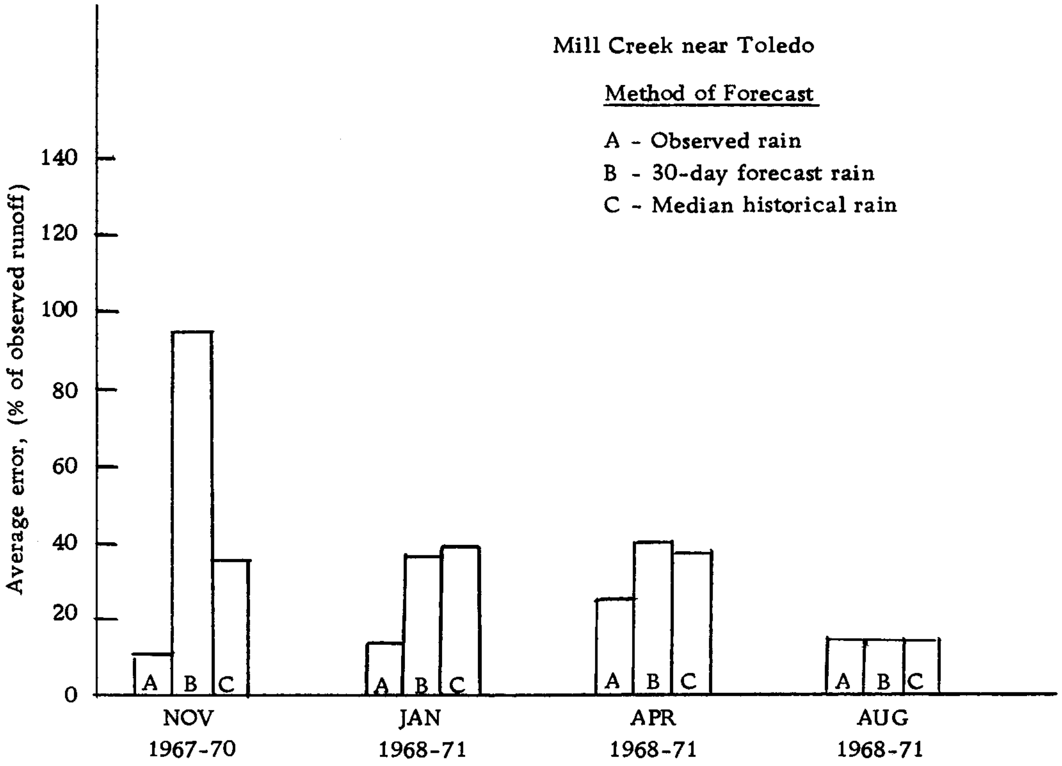

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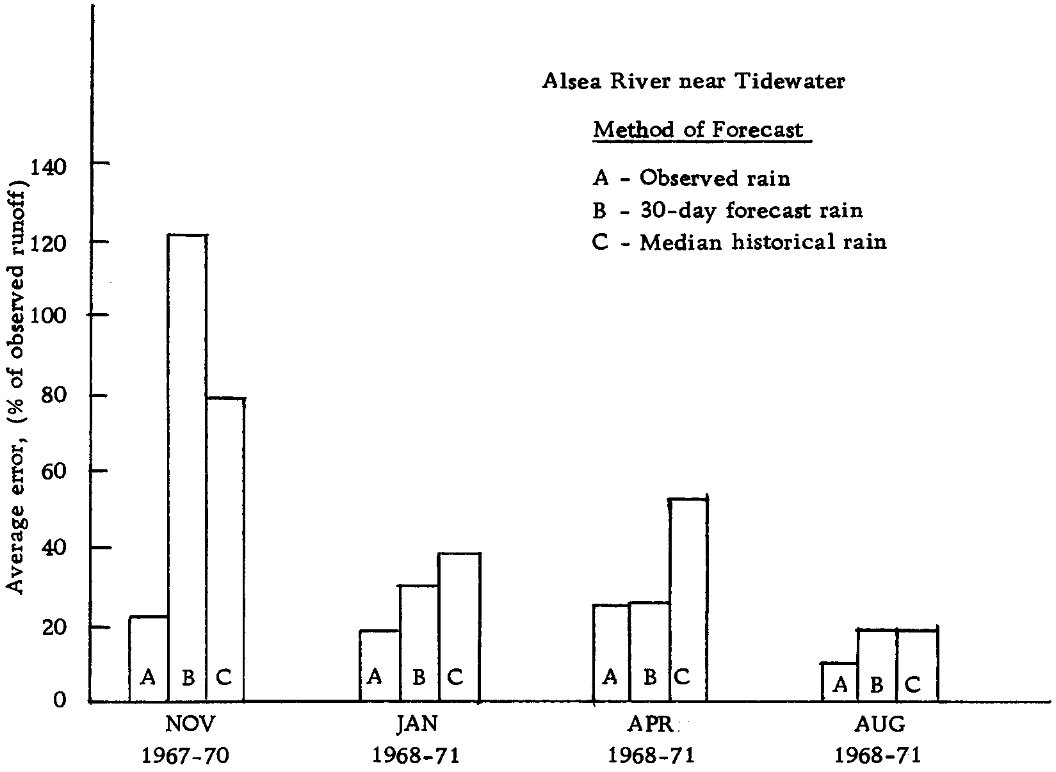

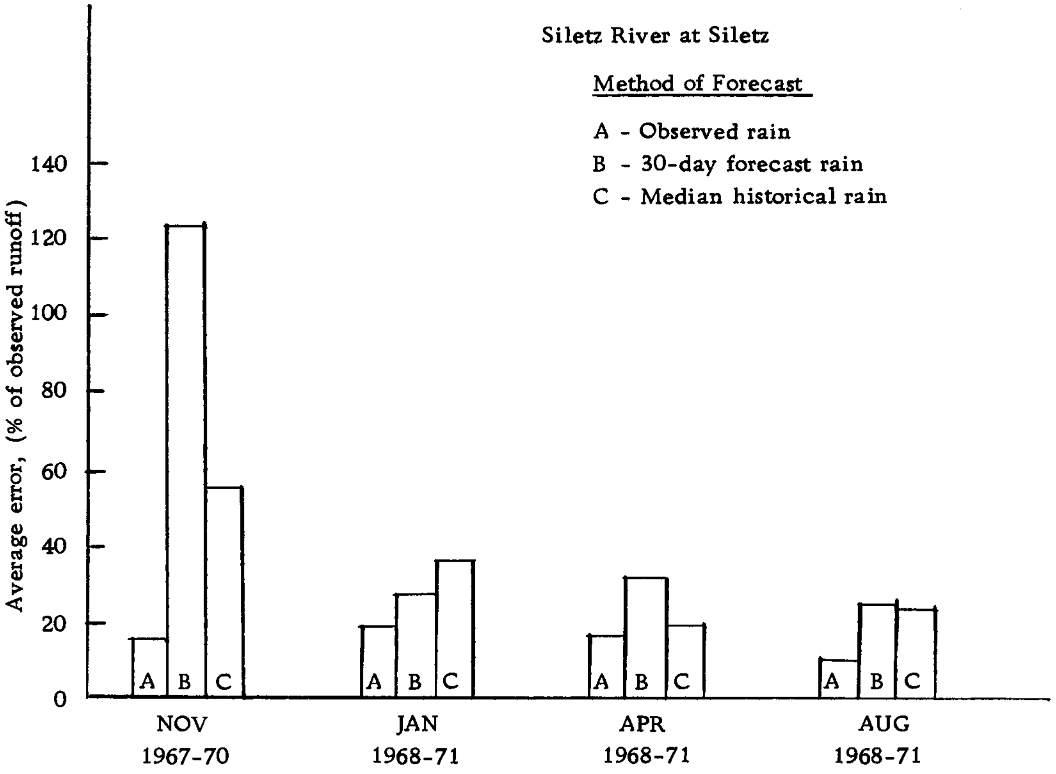

Figure 7. Continued.

precipitation. In all but one of the individual cases the observed monthly rainfall produced a forecast equal to or better than that produced by the other methods. When forecasts based upon median historical and 30-day precipitation are compared, median historical rainfall yielded a superior forecast 20 times, the 30-day outlook gave a better forecast 9 times, and in two cases the forecast errors were identical.

Table 10. Summary of errors by month for each forecast method (% of observed runoff).

November			January		
Obs'd	30-day	Median	Obs'd	30-day	Median
16	92	64	17	36	32
April			August		
Obs'd	30-day	Median	Obs'd	30-day	Median
18	29	28	10	21	18

These results agree with those of Greening and Law (1969). The use of the 30-day outlook precipitation did not result in consistently better forecasts than those based upon median rainfall. The average error, during the test period, of forecasts made using 30-day precipitation outlooks was 45 percent of the observed runoff. The largest errors occurred in November 1967 when heavy rain was indicated and the observed precipitation fell in the light category.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and Recommendations From Work on Prediction of Mean Monthly Flows and Standard Deviations of Monthly Flows

Monthly equations were developed in this study which can be used to predict mean monthly flows and standard deviations of monthly flows at ungaged stream locations. Two sets of prediction equations were developed for predicting mean monthly flows: a set of linear equations was derived to be used on basins 150 sq mi in area and greater; and a set of logarithmic equations was derived to be used on basins less than 150 sq mi in area. The use of logarithmic equations substantially improved the predictions of flows for the smaller basins compared to the use of linear equations. The principal variables important in predicting mean monthly streamflow were found to be the drainage area, total drainage length, airmass lift, basin aspect, soils index, mean basin elevation, drainage density, normal annual precipitation, and rainfall intensity. The relative importance of these parameters varied with the month of the year.

Tests conducted on two independent data sets indicate that the mean monthly flow prediction equations will give reliable results when applied in ungaged areas.

It was found that total drainage length was a better index of runoff during the months of September, October, and November than was drainage basin area. This corroborates the variable source area theory mentioned in the discussion of the total drainage length variable.

A simple relationship was found between mean monthly flows and the standard deviations of monthly flow. A test on an independent data set indicated that the relations will yield results comparable to those achieved by using equations with physiographic and climatological variables as predictors.

The derived equations should be useful as a water management tool. The flow regime from ungaged areas can be estimated by computing relatively few simple parameters. The methods of this thesis, combined with a synthesis method such as used by Beard (1967), can be used to generate a hydrologic series to be used in design studies. The method is particularly useful in areas such as the Oregon coast where streamflow data are sparse and generally of short duration.

Conclusions and Recommendations From Work on Forecasting of Monthly Flow

The forecasting of the historical monthly flows at gaged sites for the nine watersheds was found to be quite good. The average standard error for all basins was 18 percent of the mean monthly flow. However, these forecasts were made with the monthly rainfall value known. In actual application the rainfall during the forecast month would not be known but would have to be estimated in some manner.

During the four year test period monthly flow forecasts were made using observed precipitation, median historical precipitation, and 30-day outlook precipitation. When forecasts made using 30-day outlook rainfall and median rainfall were compared, the 30-day outlook precipitation did not result in a consistently better forecast of monthly runoff. Of the 31 case in the test period, forecasts based upon median precipitation gave a better forecast 20 times.

Because the prediction of monthly flow based upon forecast precipitation does not give reliable results, the methods of this section might best be applied on a probability basis. A forecast could be made for each of the basins included in the study using light, moderate, and heavy rainfall amounts. Such an approach would give a water manager some indication of the possible range of flow to be expected in the following month.

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APPENDIX

Table A1. Monthly flow and mean monthly flow for study basins.

Water	Monthly Flow, cfsm											
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Nehalem River near Foss; drainage area 667 sq mi												
1940	0.34	0.55	9.44	6.40	13.40	6.84	3.46	3.62	0.53	0.25	0.16	0.19
41	0.58	2.73	5.63	7.65	3.00	2.28	1.72	2.27	0.87	0.33	0.24	1.13
42	1.83	4.75	12.90	4.11	7.85	3.25	1.87	1.99	1.65	0.64	0.29	0.18
43	0.36	10.10	10.80	6.44	11.50	3.97	6.45	1.55	0.89	0.42	0.27	0.20
44	1.31	2.16	4.95	5.81	4.62	3.76	3.73	1.36	0.83	0.32	0.19	0.20
45	0.29	2.41	2.14	6.84	8.80	10.40	5.37	2.52	0.88	0.30	0.17	0.48
46	0.30	8.43	10.60	11.60	11.20	6.83	3.60	1.12	0.68	0.60	0.23	0.20
47	1.33	9.51	14.00	6.68	8.78	3.75	2.26	0.80	0.83	0.45	0.23	0.27
48	4.42	8.00	5.78	9.56	10.10	5.78	4.72	4.54	0.98	0.42	0.27	0.34
49	1.01	6.30	13.70	2.94	18.70	5.54	1.97	2.19	0.53	0.30	0.19	0.62
1950	0.53	5.29	8.75	12.00	16.70	11.60	5.56	1.74	0.64	0.31	0.20	0.16
51	2.37	8.43	11.10	14.10	10.90	7.06	2.76	1.17	0.49	0.22	0.12	0.14
52	3.48	5.40	10.80	6.60	9.18	5.66	2.64	1.28	0.57	0.27	0.15	0.12
53	0.11	0.30	4.57	17.60	7.77	5.40	3.16	2.60	1.24	0.51	0.27	0.24
54	1.25	4.69	12.20	14.00	15.00	4.39	5.35	0.94	1.05	0.60	0.29	0.37
55	1.05	5.14	6.60	7.69	6.18	7.07	7.27	2.16	0.80	0.57	0.27	0.30
56	3.76	13.30	17.10	14.50	5.79	13.00	4.15	0.89	0.68	0.30	0.24	0.23
57	1.60	3.07	7.06	3.26	8.88	8.25	4.45	1.32	0.70	0.35	0.26	0.16
58	0.36	2.13	11.70	9.90	11.00	3.68	6.61	1.42	0.81	0.29	0.13	0.15
59	0.54	8.36	7.57	13.70	7.05	5.45	4.42	2.78	1.34	0.57	0.23	1.31
1960	2.79	5.60	5.91	4.87	11.40	6.77	7.11	3.73	1.17	0.34	0.23	0.18
61	0.96	11.00	4.77	8.03	17.60	12.90	3.18	2.36	0.56	0.25	0.14	0.19
62	0.98	3.64	10.30	4.80	4.22	6.10	4.35	2.86	0.98	0.34	0.26	0.27
63	2.12	9.32	6.14	3.11	9.43	4.44	6.57	2.82	0.67	0.42	0.31	0.31
64	1.49	9.19	4.81	17.90	5.12	7.90	2.37	1.48	0.77	0.39	0.33	0.27
65	0.39	3.46	14.20	14.50	7.03	2.61	1.76	1.57	0.53	0.23	0.14	0.12
66	0.25	3.55	5.31	14.00	6.29	10.60	2.21	0.89	0.46	0.27	0.12	0.15
67	0.59	2.40	14.30	13.40	6.39	6.36	2.96	1.13	0.46	0.21	0.09	0.10

Table A1. Continued.

Water Year	Monthly Flow, cfsm Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1968	2.39	2.60	7.64	8.42	12.60	6.40	3.28	1.49	2.39	0.45	0.47	0.79
69	2.63	8.37	12.70	8.32	8.60	6.26	3.52	1.42	0.75	0.51	0.19	0.34
$\overline{\text{cfsm}}$	1.38	5.73	9.12	9.29	9.54	6.48	3.99	1.93	0.86	0.34	0.22	0.32
$\overline{\text{dsf}}$	920.46	3820.00	6083.04	6196.43	6363.18	4322.16	2661.33	1287.31	573.62	253.46	146.74	213.44
Wilson River near Tillamook; drainage area 161 sq mi												
1931	---	---	---	---	---	---	---	---	---	---	0.60	0.75
32	4.96	13.90	13.80	17.00	13.60	20.50	11.20	2.64	1.15	0.75	0.61	0.47
33	1.22	18.30	21.00	18.00	12.50	17.80	7.78	8.58	5.41	1.28	0.73	2.45
34	7.35	7.09	49.30	23.00	4.43	10.90	5.64	4.59	1.18	0.81	0.61	0.77
35	12.90	24.50	19.10	18.90	9.56	12.60	6.98	2.71	1.21	1.06	0.65	0.82
36	1.33	4.90	8.93	27.90	12.60	10.30	3.91	5.75	2.90	1.64	0.88	0.74
37	0.55	0.54	13.20	5.80	16.40	13.00	15.70	5.41	3.93	1.88	1.04	0.74
38	2.65	22.40	24.70	13.20	9.80	14.00	8.92	2.71	1.13	0.69	0.48	0.46
39	1.37	8.97	10.80	12.60	16.40	9.51	2.63	1.25	1.56	0.96	0.55	0.46
1940	1.67	2.60	18.90	9.43	20.40	11.50	5.72	5.39	1.12	0.67	0.49	0.48
41	2.14	6.81	8.83	12.70	4.64	3.67	3.02	4.35	1.76	0.90	0.74	4.72
42	4.91	9.08	19.60	6.38	11.20	5.93	3.54	3.88	3.63	1.75	0.89	0.60
43	1.34	20.60	20.00	10.40	18.40	8.85	11.10	2.99	2.45	1.15	0.78	0.56
44	3.06	4.93	10.50	9.69	8.68	6.74	7.53	2.53	2.26	0.84	0.54	0.64
45	1.05	7.23	5.36	14.10	15.90	15.70	8.80	5.64	1.69	0.80	0.57	2.72
46	1.30	19.40	19.50	18.90	17.20	12.50	7.01	2.21	1.66	1.87	0.76	0.61
47	3.87	17.30	23.30	12.20	14.00	7.62	5.90	1.72	2.87	1.40	0.77	1.45
48	14.00	14.30	10.40	15.30	16.30	10.10	9.68	8.72	1.96	0.96	0.69	1.06
49	3.65	13.90	21.90	4.36	26.80	10.80	4.50	5.79	1.17	0.78	0.57	0.57
1950	2.86	14.70	15.70	19.20	22.10	20.70	11.30	4.15	1.50	0.79	0.67	0.59
51	8.08	16.40	19.50	22.00	18.50	10.50	5.36	2.80	1.26	0.65	0.43	0.70
52	12.20	11.40	17.10	10.70	15.40	9.53	5.91	2.81	1.34	0.80	0.52	0.42
53	0.36	0.92	10.80	36.30	14.60	9.09	5.48	5.76	2.55	1.20	0.98	0.89

Table A1. Continued.

Water Year	Monthly Flow, cfsm											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1954	3.77	12.30	23.20	21.50	22.30	7.64	9.36	1.69	2.95	1.67	0.87	1.00
55	3.86	12.10	12.00	11.20	11.50	12.10	13.00	5.16	1.81	1.27	0.74	0.77
56	9.99	24.70	27.50	21.90	7.11	22.90	7.79	1.99	1.69	0.79	0.65	0.55
57	4.43	6.50	15.10	5.14	15.10	13.60	6.66	2.70	1.99	1.11	0.84	0.51
58	1.25	5.86	23.50	19.10	18.10	5.72	12.20	2.52	1.26	0.64	0.43	0.44
59	1.47	18.70	14.30	21.60	9.98	9.13	9.16	5.40	3.21	1.54	0.67	4.91
1960	9.17	10.40	9.89	8.44	17.40	10.70	10.90	7.07	2.23	0.85	0.75	0.57
61	2.90	22.30	8.79	14.80	28.70	19.60	5.14	4.28	1.24	0.66	0.42	0.54
62	3.67	9.63	17.90	8.81	7.27	10.50	8.08	5.60	1.66	0.78	0.77	0.96
63	5.78	18.40	10.90	5.91	14.10	6.58	10.70	4.89	1.27	0.86	0.80	0.74
64	4.03	17.10	8.96	28.50	8.25	12.00	4.75	3.12	1.86	1.09	1.31	0.74
65	1.52	11.50	28.40	21.10	12.30	3.71	3.65	3.23	1.35	0.67	0.50	0.39
66	0.81	8.07	8.57	24.30	9.63	16.50	5.25	1.96	1.08	0.71	0.39	0.40
67	2.43	7.05	23.00	20.70	9.09	10.40	5.73	2.38	1.04	0.49	0.28	0.25
68	7.68	7.01	13.90	12.60	22.60	11.70	5.25	2.88	4.58	0.99	1.49	2.17
69	5.13	15.60	19.50	13.70	11.40	10.30	8.07	3.54	2.09	1.24	0.64	1.48
$\overline{\text{cfsm}}$	4.23	12.30	17.04	15.72	14.32	11.45	7.46	3.97	2.03	1.03	0.69	1.03
$\overline{\text{dsf}}$	681.03	1980.30	2743.44	2530.92	2305.52	1843.45	1201.06	639.17	326.83	165.83	111.09	165.83

Trask River near Tillamook; drainage area 145 sq mi

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1931										1.11	0.61	0.68
32	3.70	12.00	11.10	15.10	11.10	17.70	9.80	2.96	1.30	0.83	0.65	0.53
33	1.04	13.10	18.80	17.60	11.80	16.40	6.78	6.97	4.18	1.34	0.77	1.81
34	5.84	6.93	36.10	20.20	3.80	7.70	4.27	2.83	1.21	0.81	0.61	0.68
35	8.96	21.60	17.50	14.60	7.69	11.80	6.82	2.63	1.36	1.16	0.73	0.73
36	1.05	3.17	6.68	24.20	10.20	9.45	3.81	4.74	2.66	1.52	0.84	0.70
37	0.56	0.51	10.40	5.56	13.60	11.00	12.80	4.24	3.48	1.80	1.03	0.76
38	2.18	18.70	20.90	11.50	8.71	13.10	7.20	2.78	1.26	0.76	0.57	0.51
39	1.17	8.12	8.88	10.70	15.70	8.24	2.52	1.29	1.54	0.93	0.55	0.45

Table A1. Continued.

Water Year	Monthly Flow, cfsm											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1940	1.46	1.86	14.10	7.97	18.60	10.50	5.03	5.16	1.28	0.75	0.54	0.54
41	1.49	5.04	7.07	10.60	4.20	3.05	2.80	3.46	1.78	0.97	0.77	3.24
42	4.16	7.41	18.00	5.81	10.80	5.10	3.29	3.59	3.19	1.81	1.01	0.71
43	1.19	18.50	19.50	10.90	17.10	8.26	10.00	3.24	2.63	1.31	0.87	0.62
44	2.98	4.64	9.55	7.94	8.10	6.21	7.17	2.99	3.15	1.10	0.68	0.72
45	0.93	5.48	4.99	13.20	14.20	14.50	8.65	4.75	1.90	0.99	0.65	1.75
46	1.00	14.50	17.60	17.40	16.20	12.50	5.84	2.34	1.62	1.67	0.75	0.58
47	3.00	14.60	23.80	11.20	12.30	6.90	5.36	1.87	2.85	1.56	0.82	1.06
48	10.90	13.40	9.33	13.80	15.40	9.73	9.09	7.78	2.25	1.16	0.78	0.76
49	2.73	12.00	22.10	4.50	24.10	9.31	3.79	5.04	1.43	0.95	0.67	0.64
1950	2.10	10.50	14.50	17.00	20.30	17.40	9.08	3.82	1.73	0.97	0.69	0.57
51	5.77	13.50	15.40	21.30	14.20	9.98	4.73	3.01	1.47	0.83	0.58	0.59
52	9.76	9.33	16.50	9.91	14.00	9.76	5.03	2.34	1.28	0.80	0.55	0.47
53	0.35	0.68	7.04	30.60	14.20	10.30	5.11	5.09	2.66	1.22	1.03	0.84
54	2.38	10.70	20.70	18.00	19.30	6.97	8.16	2.08	3.10	1.70	0.98	1.01
55	2.86	8.73	10.70	10.60	10.40	12.40	12.00	4.50	1.91	1.38	0.78	0.76
1962	3.33	8.83	14.60	8.34	6.57	9.99	7.55	5.10	1.97	0.97	0.74	0.70
63	3.42	15.20	8.74	4.92	11.10	6.75	9.70	4.89	1.61	1.01	0.83	0.80
64	2.58	13.60	8.03	26.20	7.68	11.40	4.94	3.12	1.89	1.04	0.92	0.74
65	1.11	8.13	25.60	21.00	9.52	3.80	2.76	2.98	1.49	0.77	0.54	0.43
66	0.71	5.59	7.48	20.80	8.94	14.10	4.34	1.97	1.23	0.79	0.45	0.48
67	1.77	5.49	18.40	18.00	9.93	10.80	5.48	2.28	1.11	0.62	0.40	0.38
68	5.05	5.02	11.80	9.35	18.40	10.00	5.24	3.05	4.37	1.19	1.26	1.50
69	4.45	13.30	18.40	13.00	11.30	9.16	6.43	3.12	2.13	1.46	0.72	0.88
$\overline{\text{cfsm}}$	3.12	9.69	14.82	14.12	12.48	10.33	6.24	3.63	2.06	1.17	0.76	0.86
$\overline{\text{dsf}}$	452.40	1405.05	2148.90	2047.40	1809.60	1497.85	904.80	526.35	298.70	169.65	110.20	124.70

Table A1. Continued.

Water Year	Monthly Flow, cfsm											
	Oct	Nov	Dec	Jan	Feb	Mar	Arp	May	June	July	Aug	Sept
Nestucca River near Fairdale; drainage area 6. 18 sq mi												
1960										0.57	0.41	0.32
61	0.89	12.20	6.00	9.77	21.70	18.80	5.81	4.17	1.05	0.50	0.30	0.34
62	1.96	5.65	12.70	6.07	7.83	9.37	7.23	4.16	1.37	0.57	0.39	0.48
63	4.58	17.00	6.72	3.38	8.61	6.26	8.40	4.27	1.03	0.66	0.40	0.40
64	1.30	9.20	6.55	20.60	6.33	8.45	3.53	2.02	1.20	0.60	0.44	0.36
65	0.47	6.18	19.40	14.60	8.79	3.72	2.33	2.04	0.80	0.35	0.25	0.19
66	0.41	4.39	5.94	16.50	8.74	14.00	5.42	1.39	0.77	0.48	0.28	0.29
67	1.09	3.74	17.30	15.90	6.88	8.82	5.11	1.96	0.85	0.38	0.24	0.25
68	2.79	3.60	10.60	8.69	15.90	8.99	3.61	2.07	2.65	0.68	0.74	0.85
69	3.76	11.40	16.80	9.19	6.69	9.27	7.21	3.50	1.07	0.77	0.52	1.71
$\overline{\text{cfsm}}$	1.91	8.15	11.33	11.63	10.16	9.74	5.41	2.84	1.20	0.56	0.40	0.52
$\overline{\text{dsf}}$	11.80	50.37	70.02	71.87	62.79	60.19	33.43	17.55	7.43	3.46	2.47	3.21
Nestucca River near Beaver; drainage area 180 sq mi												
1965	0.96	6.91	23.90	21.00	9.79	3.62	2.61	2.28	1.11	0.56	0.39	0.33
66	0.59	5.54	8.27	19.00	8.53	13.50	3.77	1.58	1.02	0.68	0.37	0.41
67	1.59	5.41	17.20	17.20	9.47	10.10	5.66	2.29	1.04	0.54	0.27	0.30
68	3.63	4.15	10.30	8.37	16.60	9.02	4.83	2.78	4.35	1.07	1.39	1.52
69	4.14	12.10	18.00	12.60	11.30	7.81	5.30	2.95	2.42	1.72	0.66	0.85
$\overline{\text{cfsm}}$	2.08	6.82	15.53	15.63	11.14	8.81	4.43	2.38	1.99	0.91	0.62	0.68
$\overline{\text{dsf}}$	374.40	1227.60	2795.40	2813.40	2005.20	1585.80	797.40	428.40	358.20	163.80	11.60	122.40

Table A1. Continued.

Water Year	Monthly Flow, cfsm											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Siletz River at Siletz, Oregon; drainage area 202 sq mi												
1925			13.00	30.90	21.80	5.25	5.93	3.98	3.15	1.10	0.61	0.48
26	0.42	6.13	16.10	9.61	23.20	5.15	1.90	4.40	2.00	0.80	0.93	3.02
27	16.70	28.30	20.20	21.00	21.50	8.04	4.36	4.67	2.37	1.00	0.53	3.12
28	14.90	25.70	14.10	18,10	8.14	19.60	17.30	3.30	0.71	0.66	0.46	0.46
29	2.21	9.46	11.40	11.80	6.62	8.53	15.10	2.59	3.14	1.69	0.54	0.49
1930	0.86	0.36	11.90	7.06	26.55	9.51	6.13	5.74	2.16	0.78	0.53	0.53
31	0.72	4.16	4.26	10.90	5.88	13.70	12.30	1.63	1.96	1.17	0.80	0.69
32	5.10	15.80	14.70	18.70	11.40	22.40	10.10	2.48	1.05	0.71	0.49	0.40
33	1.49	14.80	24.20	21.40	16.70	18.20	6.81	12.60	6.91	1.23	0.63	2.44
34	6.15	7.46	38.40	22.00	3.72	9.81	5.11	2.04	0.83	0.53	0.45	0.42
35	7.29	23.40	17.90	13.70	7.00	12.90	6.11	2.46	1.07	0.80	0.45	0.58
36	0.78	3.70	7.07	27.30	9.45	9.09	4.05	4.99	2.86	1.44	0.71	0.61
37	0.43	0.39	11.00	7.76	17.00	10.20	17.50	4.63	6.57	1.82	0.78	0.56
38	2.33	23.70	25.80	14.90	14.20	19.00	8.64	2.73	1.02	0.58	0.38	0.39
39	0.90	8.39	9.93	11.90	19.80	9.47	2.57	1.15	1.36	0.93	0.51	0.45
1940	1.70	1.85	17.30	10.00	23.30	13.40	6.02	5.77	1.06	0.59	0.39	0.41
41	1.44	6.77	9.01	13.80	4.60	2.76	2.80	4.38	1.58	0.76	0.53	3.78
42	3.02	9.05	21.80	7.26	12.20	5.90	3.13	4.25	3.00	1.75	0.83	0.53
43	0.81	23.50	23.20	12.70	18.10	9.70	10.70	3.03	2.83	1.21	0.85	0.62
44	5.68	6.02	9.62	8.49	9.20	6.93	7.01	2.54	2.74	0.86	0.53	0.49
45	0.66	6.22	5.61	15.85	17.00	13.55	9.30	7.53	1.72	0.78	0.51	1.88
46	0.84	18.10	19.80	18.50	16.10	13.60	5.65	1.85	1.75	2.10	0.81	0.70
47	5.02	17.80	25.40	11.30	13.70	8.05	6.49	1.76	4.34	1.66	0.98	1.23
48	15.00	14.20	8.59	14.80	15.80	9.97	10.30	7.64	1.57	0.90	0.65	0.74
49	3.52	10.50	23.60	5.22	30.00	8.53	3.67	6.43	1.24	0.84	0.64	0.76
1950	2.42	12.10	15.50	22.00	23.40	19.20	8.08	3.87	1.39	0.71	0.58	0.56
51	8.07	18.50	20.70	25.90	15.10	11.00	4.94	4.43	1.41	0.73	0.45	0.78
52	14.40	9.07	17.60	13.40	17.50	10.70	5.89	2.53	1.18	0.71	0.48	0.40

Table A1. Continued.

Water	Monthly Flow, cfsm											
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1953	0.37	0.81	9.57	37.90	19.10	11.50	5.44	7.00	3.29	1.13	0.85	0.78
54	3.22	15.70	24.80	19.70	20.20	8.32	9.80	1.84	3.38	1.95	1.03	1.26
55	3.16	8.61	13.00	10.90	10.70	12.50	13.60	4.19	1.67	1.25	0.75	1.15
56	9.98	22.00	25.10	26.90	9.68	21.30	7.07	2.25	1.42	0.73	0.49	0.51
57	3.97	5.17	15.70	5.88	13.60	15.80	7.00	2.79	1.70	0.98	0.74	0.41
58	1.32	6.02	23.50	16.70	20.00	6.32	12.30	2.53	1.10	0.59	0.38	0.58
59	1.23	18.10	13.30	21.00	12.70	8.96	7.53	6.72	3.43	1.32	0.63	5.63
1960	8.35	8.41	9.51	9.07	19.30	11.30	10.80	7.16	2.32	0.79	0.68	0.48
61	2.43	23.80	7.29	12.40	27.70	21.30	5.93	5.22	1.52	0.75	0.47	0.51
62	2.92	8.94	17.60	8.53	9.44	11.60	7.76	5.76	1.65	0.78	0.69	0.82
63	4.49	20.00	9.23	5.44	13.80	7.88	12.00	6.02	1.37	0.96	0.57	0.71
64	2.92	14.80	8.80	26.90	7.14	11.70	4.36	2.65	1.81	1.15	1.21	0.76
65	1.14	10.60	31.60	26.50	9.52	3.95	4.19	2.87	1.27	0.62	0.41	0.29
66	0.56	8.00	11.30	22.50	8.89	16.30	4.46	1.62	0.92	0.61	0.36	0.42
67	2.05	8.35	18.70	21.60	10.20	10.60	7.06	2.60	1.04	0.52	0.32	0.31
68	5.39	5.19	14.20	10.50	22.80	9.65	4.97	2.92	5.45	1.03	2.07	2.26
69	6.88	17.90	22.70	16.70	14.40	8.01	6.05	3.43	2.80	1.92	0.73	1.20
$\overline{\text{cfsm}}$	4.16	12.00	16.30	16.12	15.07	11.36	7.52	4.07	2.20	1.02	0.65	1.01
$\overline{\text{dsf}}$	840.32	2424.00	3292.60	3256.24	3044.14	2294.72	1519.04	822.14	444.40	206.04	131.30	204.02
Alsea River near Tidewater; drainage area 334 sq mi												
1940	0.48	0.34	6.68	6.01	13.60	8.41	3.46	2.73	0.76	0.40	0.24	0.27
41	0.60	3.07	5.91	9.19	3.10	1.81	2.08	2.75	0.93	0.46	0.35	1.35
42	0.82	4.20	12.80	6.00	9.17	3.05	1.90	2.13	1.41	0.75	0.41	0.29
43	0.34	10.70	15.80	11.60	10.90	5.31	6.93	1.84	1.29	0.58	0.43	0.30
44	2.21	2.90	5.07	4.93	5.10	4.66	4.51	1.78	1.13	0.51	0.33	0.29
45	0.30	2.10	2.40	7.17	11.40	10.20	5.99	4.69	1.48	0.59	0.36	0.47
46	0.31	8.30	11.40	11.60	10.10	7.71	2.98	1.23	0.86	0.61	0.33	0.39
47	1.48	10.40	12.40	5.32	8.72	6.10	4.47	1.21	1.99	0.73	0.49	0.43

Table A1. Continued.

Water	Monthly Flow, cfsm											
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1948	7.55	7.86	5.43	12.60	9.90	7.04	6.70	4.39	1.46	0.69	0.44	0.41
49	0.71	3.93	13.70	4.13	19.70	5.00	2.22	3.28	0.88	0.49	0.32	0.31
1950	0.46	3.51	6.72	16.60	16.70	11.20	4.17	2.13	0.91	0.48	0.31	0.29
51	4.25	12.38	11.90	18.32	11.80	9.40	2.98	2.48	0.96	0.51	0.27	0.25
52	4.79	7.47	14.80	12.30	12.40	8.11	3.11	1.41	0.85	0.55	0.33	0.26
53	0.23	0.45	4.83	23.60	11.60	8.67	3.85	4.64	2.17	0.81	0.57	0.40
54	1.16	8.33	15.80	16.90	14.60	6.17	6.38	1.38	0.97	0.57	0.41	0.48
55	1.08	4.34	8.06	8.09	5.99	9.38	9.50	2.69	0.96	0.66	0.33	0.42
56	3.00	11.80	20.30	20.20	9.68	13.10	4.45	1.32	0.74	0.41	0.27	0.28
57	1.17	1.95	6.60	4.46	9.18	11.90	4.64	2.09	1.10	0.57	0.40	0.28
58	0.57	1.60	12.00	11.10	14.60	5.30	6.80	2.07	0.97	0.45	0.25	0.28
59	0.41	6.94	5.58	16.40	10.70	5.32	3.70	2.13	1.13	0.56	0.31	1.05
1960	1.56	2.04	3.40	4.84	13.70	8.63	7.16	5.02	1.83	0.68	0.41	0.31
61	0.57	10.00	4.94	7.18	19.00	15.40	4.11	3.54	1.18	0.55	0.32	0.32
62	0.88	3.45	9.68	4.38	7.71	10.30	4.27	3.01	1.12	0.56	0.39	0.38
63	1.92	6.75	5.69	2.54	10.20	6.91	9.59	5.53	1.23	0.70	0.39	0.43
64	0.88	7.37	4.56	18.50	5.25	7.90	2.45	1.51	0.87	0.53	0.39	0.28
65	0.31	3.77	22.20	18.00	6.55	2.87	2.34	1.60	0.78	0.40	0.28	0.18
66	0.35	3.66	7.84	16.60	5.83	12.70	2.66	0.99	0.53	0.35	0.20	0.21
67	0.43	3.26	10.50	13.65	6.85	7.27	4.35	1.67	0.76	0.37	0.22	0.19
68	1.65	2.09	8.83	7.20	14.00	6.10	2.64	1.72	1.99	0.62	0.70	0.67
69	2.36	8.47	17.20	11.90	12.20	6.13	2.86	1.76	1.02	0.62	0.33	0.46
$\overline{\text{cfsm}}$	1.43	5.45	9.77	10.78	10.67	7.74	4.41	2.49	1.14	0.56	0.37	0.40
$\overline{\text{dsf}}$	477.62	1820.30	3263.18	3600.52	3563.78	2585.16	1472.94	831.66	380.76	187.04	123.58	133.60

Mill Creek near Toledo; drainage area 4.15 sq mi

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1960	3.83	3.25	4.75	4.75	14.50	6.65	7.30	5.57	1.53	0.50	0.43	0.25
61	0.88	15.10	4.31	8.46	21.90	17.30	4.05	2.99	1.01	0.53	0.35	0.32
62	1.17	4.44	11.40	4.51	6.99	9.66	4.90	3.95	1.25	0.60	0.37	0.36

Table A1. Continued.

Water Year	Monthly Flow, cfsm											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1963	2.05	7.32	5.41	2.56	9.76	7.00	8.98	5.71	1.53	0.50	0.43	0.25
64	1.00	9.51	6.10	19.90	5.29	8.90	2.82	1.79	1.17	0.77	0.68	0.43
65	0.25	6.59	19.60	18.10	6.62	2.55	2.57	2.21	1.04	0.57	0.53	0.21
66	0.30	4.61	11.40	15.20	5.74	13.10	2.94	1.18	0.52	0.38	0.25	0.29
67	0.74	4.98	13.20	15.80	9.19	9.22	6.52	1.92	0.53	0.27	0.20	0.17
68	2.32	3.26	11.20	7.77	16.20	8.06	3.60	2.11	4.49	0.54	0.82	1.14
69	3.58	11.50	19.10	17.40	13.00	2.89	2.07	1.69	2.01	1.40	0.48	0.45
$\overline{\text{cfsm}}$	1.61	6.97	10.65	11.45	10.92	8.53	4.58	2.91	1.48	0.63	0.45	0.40
$\overline{\text{dsf}}$	6.68	28.93	44.20	47.55	45.32	35.40	19.01	12.08	6.14	2.61	1.87	1.66

North Fork Alsea River at Alsea; drainage area 63 sq mi

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1958	0.54	1.43	11.90	9.75	13.40	4.44	6.25	1.98	0.98	0.57	0.32	0.31
59	0.43	6.73	5.10	16.10	10.40	6.00	3.78	2.19	1.19	0.62	0.35	1.05
1960	1.56	2.13	3.57	4.87	13.30	8.90	7.03	4.71	1.71	0.70	0.49	0.36
61	0.60	11.00	4.21	6.78	19.20	15.00	3.56	3.24	1.10	0.58	0.38	0.37
62	0.89	3.86	10.60	4.21	7.17	10.60	4.79	3.38	1.19	0.60	0.43	0.42
63	2.05	7.32	5.41	2.56	9.76	7.00	8.98	5.71	1.28	0.75	0.41	0.41
64	0.76	7.38	4.14	18.10	4.79	7.49	2.56	1.65	0.88	0.56	0.44	0.34
65	0.34	4.08	26.10	20.40	6.51	2.92	2.03	1.60	0.87	0.45	0.31	0.24
66	0.39	3.35	5.97	15.90	5.60	12.10	2.63	1.06	0.62	0.44	0.27	0.30
67	0.56	2.93	8.52	13.30	6.52	7.42	4.89	1.79	0.80	0.41	0.26	0.26
68	1.54	1.90	8.21	6.70	14.80	5.57	2.56	1.81	1.84	0.65	0.73	0.75
69	2.34	8.57	16.70	10.60	11.90	8.11	3.22	1.83	0.99	0.65	0.39	0.56
$\overline{\text{cfsm}}$	1.00	5.06	9.20	10.77	10.28	7.96	4.36	2.58	1.12	0.58	0.40	0.45
$\overline{\text{dsf}}$	63.00	318.78	579.60	678.51	647.64	501.48	274.68	162.54	70.56	36.54	25.20	28.35

Table A1. Continued.

Water	Monthly Flow, cfsm											
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Five Rivers near Fisher; drainage area 114 sq mi												
1959	0.38	7.33	5.68	16.80	10.10	5.53	3.82	2.20	1.09	0.54	0.29	1.07
1960	1.57	1.96	3.71	5.65	15.10	9.03	7.41	5.51	1.95	0.67	0.45	0.30
61	0.63	11.70	5.43	7.79	20.70	16.30	4.26	3.80	1.22	0.54	0.31	0.31
62	0.93	3.76	10.20	4.58	8.57	10.90	4.38	3.18	1.16	0.55	0.37	0.39
63	3.34	7.71	6.30	3.12	11.10	7.61	9.80	5.54	1.17	0.73	0.40	0.47
68	2.10	2.84	10.60	8.05	15.40	6.64	2.68	1.72	2.39	0.64	0.76	0.68
69	2.80	9.68	19.00	13.30	13.10	5.76	2.66	1.70	0.98	0.65	0.35	0.51
$\overline{\text{cfsm}}$	1.54	6.42	8.70	8.32	13.45	8.83	4.63	3.38	1.43	0.62	0.42	0.44
$\overline{\text{dsf}}$	175.56	733.02	991.80	965.58	1532.16	1005.48	526.68	385.32	161.88	70.68	47.88	50.16
Drift Creek near Salado; drainage area 20.6 sq mi												
1959	0.56	11.50	7.52	18.60	11.80	7.23	4.58	3.81	1.68	0.78	0.42	3.00
60	4.32	4.08	5.97	7.09	17.30	9.08	8.69	6.55	1.97	0.77	0.52	0.35
61	1.02	15.40	5.24	9.27	24.80	18.90	4.36	4.10	1.24	0.62	0.42	0.48
62	2.01	6.41	13.90	5.73	8.64	11.90	6.02	4.06	1.45	0.72	0.56	0.60
63	3.30	13.50	7.38	3.67	12.60	8.20	11.30	6.41	1.43	0.97	0.52	0.61
65	---	---	---	---	---	---	---	---	1.12	0.60	0.41	0.31
66	0.47	5.95	10.00	20.20	7.51	16.10	2.97	1.21	0.69	0.48	0.28	0.28
67	1.36	7.56	16.40	18.20	8.20	10.30	5.95	1.86	0.86	0.45	0.28	0.26
68	3.45	3.57	11.80	8.42	17.50	8.39	4.22	2.86	3.39	0.86	0.94	1.01
69	4.04	11.30	19.50	12.70	13.80	7.21	3.36	2.13	1.63	1.11	0.54	0.71
$\overline{\text{cfsm}}$	2.28	8.81	10.86	11.54	13.57	10.81	5.72	3.67	1.55	0.75	0.54	0.85
$\overline{\text{dsf}}$	46.97	181.49	223.72	237.72	279.54	222.69	117.83	65.60	32.0	15.50	11.12	17.51