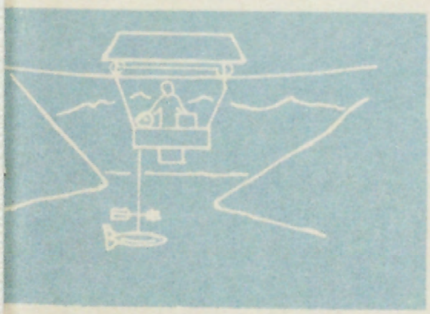
EVALUATION AND DESIGN OF A STREAMFLOW-DATA NETWORK IN WASHINGTON



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Prepared in Cooperation With
State of Washington Department of Ecology

UNITED STATES
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By M. E. Moss and W. L. Haushild

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CONTENTS

ILLUSTRATIONS

TABLES

DEFINITION OF SYMBOLS

a	Regression coefficient.
A_i	Drainage area upstream from ith streamflow station, in square miles.
b_i	Exponent in a log-linear regression relation.
C_v	Coefficient of variation.
e	Base of the natural logarithm.
F	Forest cover, in percent of drainage area.
L	Surface area of lakes, in percent of drainage area.
m_i	Years of record at the ith streamflow station.
N_B	Adjusted number of streamflow stations used in a regression analysis.
NS	Number of stations in a design network.
N_Y	Harmonic-mean length, in years, of the records used in a regression analyses.
NY	Harmonic mean record period, in years, for stations in a design network.
n	Number of streamflow stations used in a regression analysis.
n_v	Number of independent variables used in a regression analysis.
p	Streamflow parameter used as a dependent variable in a regression analysis.
PM	Mean annual precipitation, in inches.
$P(\cdot)$	Probability of the event described within the parentheses.
$P(\cdot\|\cdot)$	Conditional probability of the event described to the left of the vertical bar given that the event to its right has been observed to occur.
P50	Annual peak discharge for an exceedance probability of 2 percent (50-year recurrence interval).
QA	Mean annual discharge.
(QA)	Annual mean-flow series.

QF	Mean annual peak discharge.
(QF)	Annual peak-flow series.
S	Standard error of estimate of a log-linear regression analysis.
SDA	Standard deviation of the mean annual discharge.
SDF	Standard deviation of the mean annual peak discharge.
SN	Mean annual snowfall, in inches.
Y	True average error of prediction of a log-linear regression relation.
Z	A streamflow characteristic used as a dependent variable in a regression analysis.
α	Confidence level.
γ	Model error of a log-linear regression model
ξ	Deviation between the true and predicted values of the logarithm of the dependent variable in a log-linear regression relation.
ρ_c	Cross-correlation coefficient between two streamflow records.
$\phi(C_V)$	Prior probabilities for coefficients of variation.
$\phi(\rho_c)$	Prior probabilities for cross-correlation coefficients.
Σ	Summation of a series of variables.

ENGLISH-METRIC CONVERSIONS

Multiply	By	To obtain
inches	0.02540	meters (m)
	25.40	millimeters (mm)
feet (ft)	.3048	meters (m)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
square miles (mi^2)	2.589	square kilometers (km^2)

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ABSTRACT

A method of evaluating the transferability of streamflow information by regional regression analysis was applied in Washington to several streamflow variables. The annual mean and annual standard deviation were chosen to represent the development potential of the water resource, while the mean, standard deviation, and the 50-year recurrence interval of the annual flood series were chosen to represent flood potential. Low-flow characteristics were not used because of the inability to model them by regression analysis. Ephemeral streams in the vicinity of the Columbia Plateau were ignored for the same reason.

The results of the study indicate that the standard errors of estimate of the regression relations were good approximations of the medians of the Bayesian distributions of estimates of inaccuracy and that for the streamflow variables used in the study, little if any improvement can be expected in the regression relations by the collection of additional streamflow data. Improved transferability of streamflow information for these variables has a prerequisite of more accurate information-transfer models.

It is therefore recommended that the future streamflow-data network contain only those streamflow stations needed to provide data for (1) the design or operation of water-resources projects, (2) the investigation and study of water resources, and (3) monitoring long-term trends in streamflow.

INTRODUCTION

The streamflow data-collection program of the U.S. Geological Survey in the State of Washington has evolved from a need for specific data rather than from a planned information-collection system. Recent increases in cost of operations, restraints on funds and manpower, and public need for more kinds of hydrologic information have made necessary the design of a program that will efficiently produce the types of information needed. The first step in the design of a streamflow data-collection system is an analysis of the present network of stations. Such an analysis must consider the justifications for operating the streamflow stations, the number and location of stations, the length of time the gages should be operated, and the mechanisms for transferring data from points of collection to points where information is needed.

One reason for operating streamflow stations on undeveloped streams is to gain information about the natural streamflow characteristics; information that can be used both at the site where the data are collected and, if an information transfer mechanism exists, at sites where data are not available. This report briefly describes a procedure called Network Analysis for Regional Information (NARI) that estimates the ability of an information transfer mechanism, regional regression analysis, to distill information from an existing gaging network for use in estimating streamflow characteristics at ungaged sites. NARI is used to evaluate selected streamflow characteristics in Washington and results of the evaluation are the bases of recommendations for redesigning the gaging network. This study is the first full-scale implementation of the NARI procedure which was first described by Moss and Karlinger (1974).

Regional regression analysis in hydrology (Benson and Matalas, 1967) is the regression of streamflow characteristics of the drainage basins. The regression analysis uses the characteristics estimated from existing data for gaged sites. Because these estimates are based on finite lengths of station record, they contain time-sampling errors that confound the results of the analysis. In designing a data-collection program to reduce the errors of a regression relation, tradeoffs may be made among operating streamflow stations longer, operating more stations, and refining the form of the regression relation. For a given and fixed information-transfer model, NARI permits the network manager to quantify the tradeoffs between numbers of stations and record lengths and specifies the limits on the accuracy of information transfer that are inherent with that particular model. Therefore, the network manager can decide as to how much effort should be expended on extending existing streamflow records, on establishing new gages, and on developing better regionalization techniques.

The scope of this study does not contain as many streamflow characteristics as have been used in previous studies. Characteristics representative of both development potential and of flood potential were analyzed. Low-flow characteristics were not analyzed because of an inability to model them by regional regression.

PREVIOUS STUDY

As a part of a national streamflow-data evaluation (Benson and Carter, 1973), a streamflow-data program for the State of Washington was proposed (Collings, 1971) and partially implemented. In part, the proposed data program was predicated on the judgment that additional streamflow information was needed to meet prespecified accuracy criteria of 10 equivalent years of record for minor streams (upstream drainage area less than 500 mi^2) and 25 equivalent years of record[a] for principal streams. However, techniques were not available in 1971 for evaluating the effectiveness of increased temporal and spatial samplings of streamflow in reducing estimation error; therefore, the proposed network was determined rather subjectively.

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[a]Equivalent years of record is a measure of the accuracy or information content of an indirect predictive relation, such as a regression relation, expressed in terms of the accuracy of estimation based on an actual streamflow record of finite time span. (See Hardison, 1971.)

NETWORK-DESIGN TECHNIQUE

The design of a streamflow-data network should specify the number and location of the streamflow stations and the period of time they must be operated to attain the objective for which the network is established. If the objective is to provide information such that streamflow characteristics can be estimated at ungaged sites with a prespecified accuracy, a technique developed by Moss and Karlinger (1974) can be used to define the number of stations and the period of record required if the stations are randomly located within the area of interest. Prerequisite to the use of this network-design technique is the existence of sufficient streamflow data to perform a preliminary regression analysis of the type that will be used to transfer the information from the gaged sites to the ungaged sites. The availability of streamflow data in Washington is such that the technique is definitely usable. However, the end product of this technique is not the design of the network, but a plot from which the cost-effectiveness of any network can be evaluated (Moss, 1976). The technique thus provides a means of ranking or comparing the various networks that might be considered.

Inherent within the network-design technique is the probabilistic description of the validity of the underlying regression relation. Validity is measured by the model error, γ, which is the root-mean-square error of prediction of the regression relation if it were calibrated for an infinite number of stations for which infinite years of streamflow records existed. The units of model error used herein are logarithms to the base <u>e</u>. Obviously the data base is not infinite in either time or space, and model error can not be directly measured. Nevertheless, model error is a controlling factor of the efficiency of the regional network, as can be illustrated by the fact that, if model error is sufficiently large, even a massive data-collection program may yield little or no improvement in the accuracy of estimates at ungaged sites.

In general, nothing is known about the magnitude of model error except for the information that can be distilled from some apparent measure of the goodness of the regression, such as the standard error of estimate, S. The distillation mechanism is Bayes' rule, one of the fundamental relations of probability theory. By means of Bayes' rule, model error can be described as

$$P(\gamma | S) = \frac{P(S|\gamma)P(\gamma)}{P(S)} \qquad (1)$$

in which $P(\bullet)$ is the probability of the event described inside the parentheses and | indicates that the value of the parameter or parameters to its right are assumed known. In other words, $P(\gamma | S)$ would be interpreted as the probability of γ given that S is a known value. In Bayesian terminology, $P(S|\gamma)$ is known as the likelihood function and $P(\gamma)$ is known as the prior probability and must be prespecified by the analyst. The initial lack of knowledge concerning model error results in $P(\gamma)$ being diffuse (Benjamin and Cornell, 1970, p. 620-625)--that is, any non-negative value of γ is as equally likely as any other non-negative value. The denominator of equation 1 is defined as summing the product, $P(S|\gamma)P(\gamma)$, over all values of γ for which both probability factors are non-zero.

In the actual implementation of the network-design technique, equation 1 is further complicated by the fact that model error is related to other parameters as well as "goodness of the regression," and that γ is a continuous random variable whereas equation 1 pertains to a discrete random variable. (See Moss and Karlinger, 1974, and Moss 1976, for expanded discussion of these problems and their solutions.) The additional parameters that affect the model error are (1) N_B, the effective number of streamflow stations incorporated into the regression analysis; (2) N_Y, the harmonic mean record length of the streamflow records; (3) C_V, the average coefficient of variation of the streamflow records; and (4) ρ_C, the average cross-correlation coefficient between the pairs of streamflow records. The average serial-correlation coefficient of the streamflow records was found to have only a minor effect on the estimation of model error (Moss and Karlinger, 1974). Thus, the likelihood function of the general expression of equation 1 would be $P(S \mid \gamma, C_V, \rho_C, N_B, N_Y)$. The method used to specify the values of this likelihood function is described subsequently (p. 6-7).

The additional parameters C_V and ρ_C usually are known only with some limited degree of accuracy. Their levels of uncertainty are introduced into the analysis by assigning prior probabilities to their values and including them jointly in the prior-probability part of equation 1. This results in the left side of equation 1 being the joint conditional probability of γ , C_V, and ρ_C, that is,

$$P(\gamma, C_V, \rho_C \mid S, N_B, N_Y) = \frac{P(S \mid \gamma, C_V, \rho_C N_B, N_Y) P(\gamma, C_V, \rho_C)}{P(S)} \qquad (2)$$

where N_B and N_Y are implicit in P(S).

The average predictive accuracy, Y, of a particular regression equation, which is the measure of the effectiveness of the network, cannot be determined exactly but can be described probabilistically in the same manner as model error. If the values of γ, C_V, ρ_C, N_B and N_Y are known, the probability distribution of the predictive accuracy that might result from a regression analysis can be determined by using Monte Carlo simulation (Moss and Karlinger, 1974). Although N_B and N_Y are definable, γ, C_V, and ρ_C are only known within the context of probabilistic weights for various combinations of parameter values as defined by equation 2. Vicens and others (1975) have shown the Bayesian probability distribution to be a valid means of dealing with a random variable that has uncertainty associated with the parameters of its own probability distribution. The Bayesian distribution of Y is

$$P(Y \mid N_B, N_Y) = \sum_{\rho_C} \sum_{C_V} \sum_{\gamma} P(Y \mid \gamma, C_V, \rho_C, N_B, N_Y) P(\gamma, C_V, \rho_C) \quad , \qquad (3)$$

where $P(\gamma, C_v, \rho_c)$ is equivalent to $P(\gamma, C_v, \rho_c \mid S, N_B, N_Y)$ of equation 2. The parameters of the Bayesian distribution--such as its mean, median, or any other parameter--may be used as a surrogate of the value of the regression relation and its underlying streamflow-data base, or the entire Bayesian distribution can be used in an economic analysis to obtain a monetary measure of the value (Attanasi and Karlinger, 1977).

Throughout the above discussion it is assumed that probability distributions of $P(S \mid \gamma, C_v, \rho_c, N_B, N_Y)$ and $P(Y \mid \gamma, C_v, \rho_c, N_B, N_Y)$ existed. However, direct derivation of these distributions from knowledge and from reasonable assumptions about their causal factors has proven intractable. Monte Carlo simulation, which exploits the relative-frequency concept of probability that is familiar to hydrologists in the form of flood-frequency analysis, does provide a means for their definition. In a Monte Carlo simulation, a set of random numbers is used as input to the mathematical or physical system being modeled, and the model of the system processes the random numbers to derive an outcome or measure of that experiment. The experiment is then repeated a sufficient number of times with independent sets of random numbers so that the outcomes can be ordered (in the same way as flood peaks in a frequency analysis), and a probability distribution can be estimated. One advantage of a Monte Carlo simulation over a flood-frequency analysis is that the number of outcomes that are usually generated are many times that commonly available in actual flood records.

The model used to derive the two required probability distributions has two major parts--a simulator of a simple regression analysis and a multisite synthetic streamflow generator. The regression simulator assumes an underlying regression of the form

$$\ln p_i = a + b \ln A_i + \epsilon_i \quad , \qquad (4)$$

where p_i is the value at station $\underline{i}$ of the streamflow parameter that is being regionalized, A_i is the upstream drainage area but also may be considered here as a surrogate for the basin parameters at station $\underline{i}$, ϵ_i is a random component with zero mean and variance equal to γ^2, and $\underline{a}$ and $\underline{b}$ are known coefficients. The values of A_i are assumed to fall randomly between a lower and upper limit. Selection of N_B random values each for A_i and ϵ_i permits the evaluation of p_i at each of the N_B hypothetical streamflow stations. If p_i represents mean streamflow, the assumption of a constant coefficient of variation, C_v, within the area of interest makes possible the computation of a standard deviation, σ_i, for each station from

$$\sigma_i = C_v p_i \qquad (5)$$

The further assumptions that provide the remaining information required for the synthetic streamflow generator are (1) streamflows are log-normally distributed with two parameters, (2) the interstation correlation, ρ_c, is constant between each pair of stations, and (3) serial correlation is insignificant.

The synthetic streamflow generator (Fiering and Jackson, 1971) is simply an algorithm that converts random numbers into a sequence of data that maintains a statistical similarity to a set of input statistics such as mean, standard deviation, and cross and serial correlations. These synthetic data can be used in the same manner as actual streamflow records to compute statistics or to design projects. In the network-design technique, the synthetic streamflows are used to compute a set of estimates of the streamflow parameter, p_i, that can then be returned to the regression simulator for use as dependent variables in a regression analysis.

The regression simulator performs the regression analysis using the estimates of p_i and derives estimates of $\underline{a}$ and $\underline{b}$ and a value of standard error of estimate, S. With the known properties of the underlying regression and the estimates of $\underline{a}$ and $\underline{b}$, it is possible to compute a value of the predictive accuracy, Y, of the regression relation derived from the synthetic data. The pair of values for S and Y summarize the first experiment. Sufficient repetition of the experiment with fixed value of γ, C_v, ρ_c, N_B and N_Y provides enough pairs of S and Y to evaluate their probability distributions. In the network-design technique at least 2,500 repetitions were used for each evaluation of $P(S \mid \gamma, C_v, \rho_c, N_B, N_Y)$ and $P(Y \mid \gamma, C_v, \rho_c, N_B, N_Y)$. By sampling various values of the input parameters, γ, C_v, ρ_c, N_B and N_Y, data were generated so that interpolation schemes have been devised to evaluate probability distributions for a large range of input-parameter values. Thus, the conditional probabilities of S required in equation 2 and of Y required in equation 3 are derived by Monte Carlo simulation.

Equation 3 is the mechanism by which the effects of changes in the existing network can be evaluated. The joint probabilities of γ, C_v, and ρ_c in equation 3 are equally applicable to network configurations other than that from which it was evaluated by means of equation 2. It is therefore possible to generate the Bayesian distribution of Y for a network described by any pair of values of N_B and N_Y by substituting the associated conditional probabilities in the right side of equation 3. As discussed above, the Bayesian distribution of Y provides the means for evaluating the network.

NETWORK ANALYSIS

Physiography and Climate

The varied climate of Washington is caused mostly by two main features: (1) the Cascade Range (fig. 1), which divides the State into eastern and western parts; and (2) the prevailing westerlies that move clouds, formed from moisture gained from the Pacific Ocean, over the State to supply a predominant part of its precipitation. The area west of the Cascade Range generally has a marine climate--with cool, wet winters and warm, relatively dry summers--whereas the area east of the Cascades has a more continental climate--with cold winters and hot, dry summers. (Examples of seasonal distribution are shown by the mean monthly precipitation and air temperatures given in figure 2 and figure 3, respectively.)

The precipitation data (fig. 2) indicate that the seasonal distribution of precipitation throughout the State is similar to the extent that there is a winter peak followed by a recession to a summer minimum and a subsequent rise to the following winter's peak. Although the orographic effects of the mountains and highlands cause variations in the amount of precipitation received by different regions, they do not change the seasonal precipitation pattern. The [U.S.] National Oceanic and Atmospheric Administration (1972) describes the effects of the State's physiography on its climate in more detail and divides the State into 10 regions of similar climate.

The varied topography influences the percentage of precipitation that falls as snow and also causes areal variations in the amount of precipitation. The general trend is one of increased precipitation and more snow with increased elevation, which is accentuated by the orographic uplifting of the prevailing westerlies on the windward sides of the mountains. On the protected lee sides of the mountains, the amount of precipitation as well as the effect of orographic uplifting are less than on the windward slopes. For example, the Cascade Range is the principal feature affecting variations in precipitation in Washington, with precipitation being much higher on the west side than on the east side, as noted in figure 2. Also, in the lowlands of western Washington, the mean annual precipitation at a station near the Pacific Coast, as at station 1 in figure 2, is about five times that at station 2, which is on the lee side of the Olympic Mountains.

Air temperature influences the seasonal pattern of runoff through its effects on the percentage of precipitation that occurs and is stored as snow, and on the timing of the snowmelt periods. Most of the time, snow storage is not a factor in the mild climate of the lowlands of western Washington. Conversely, practically all precipitation during late fall-early spring occurs and is stored as snow which does not melt until late spring in the cold climate of the eastern slopes of the Cascade Range and the northeastern part of Washington. Some part of the annual snowfall may be stored for long periods--measured in years--in the glaciers in the higher parts of the Cascade Range and Olympic Mountains. A part of the snow stored in the west slopes of the Cascade Range, the Olympic Mountains, and the Blue Mountains of southeastern Washington may melt sometime in the period from late fall to early spring. The consequent seasonal distribution of runoff from these areas depends on the percentage of precipitation stored as snow and the timing of the melt periods. Seasonal patterns of runoff in Washington regions are described in the discussion of runoff regimes.

The overall effects of physiography and climate on runoff are such that regression models relating streamflow characteristics to drainage-basin characteristics have limited geographic applicability. In this study six runoff regimes have been identified for the purposes of regression modeling and are described in the following section.

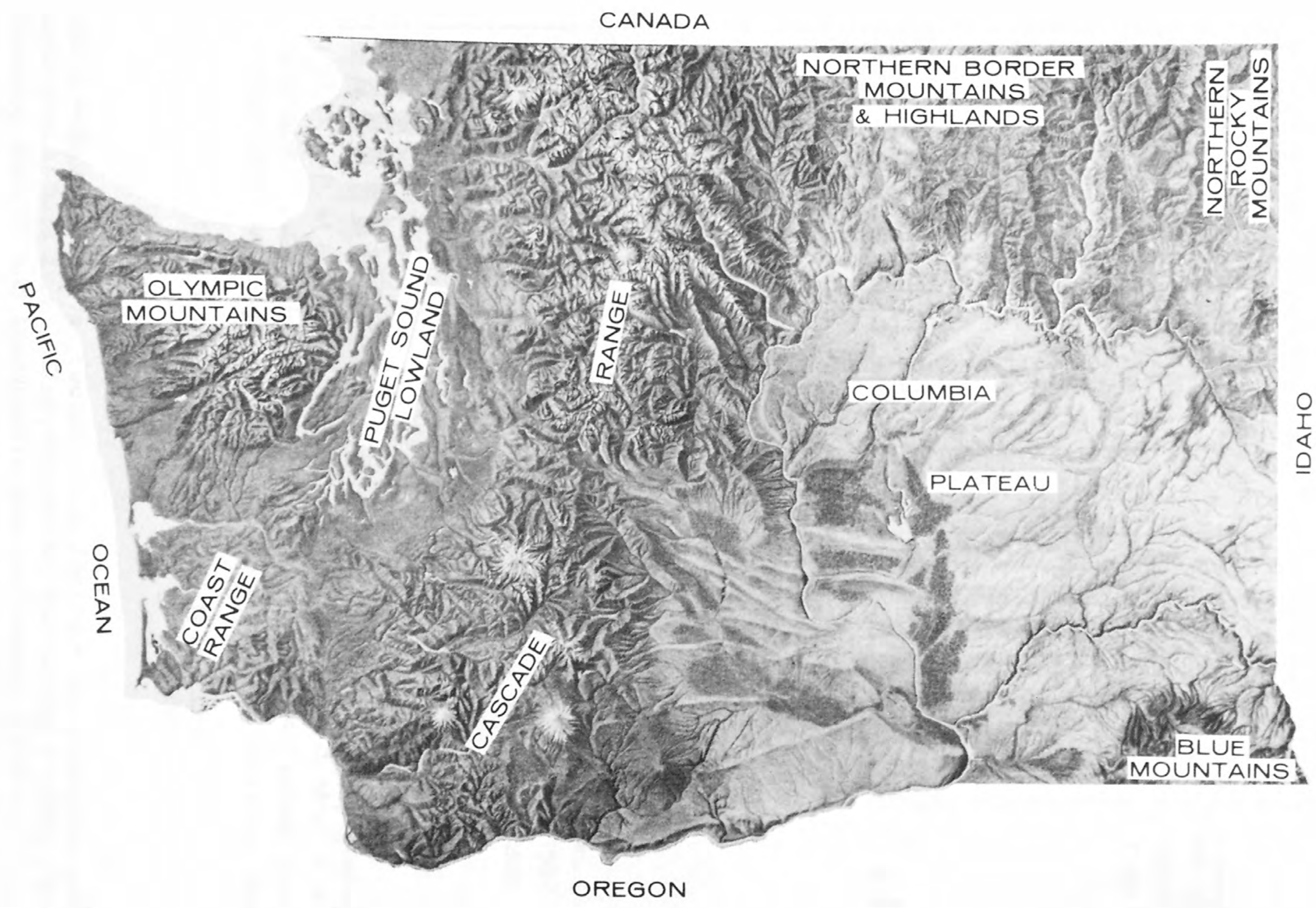

FIGURE 1.--Principal physiographic provinces of Washington.

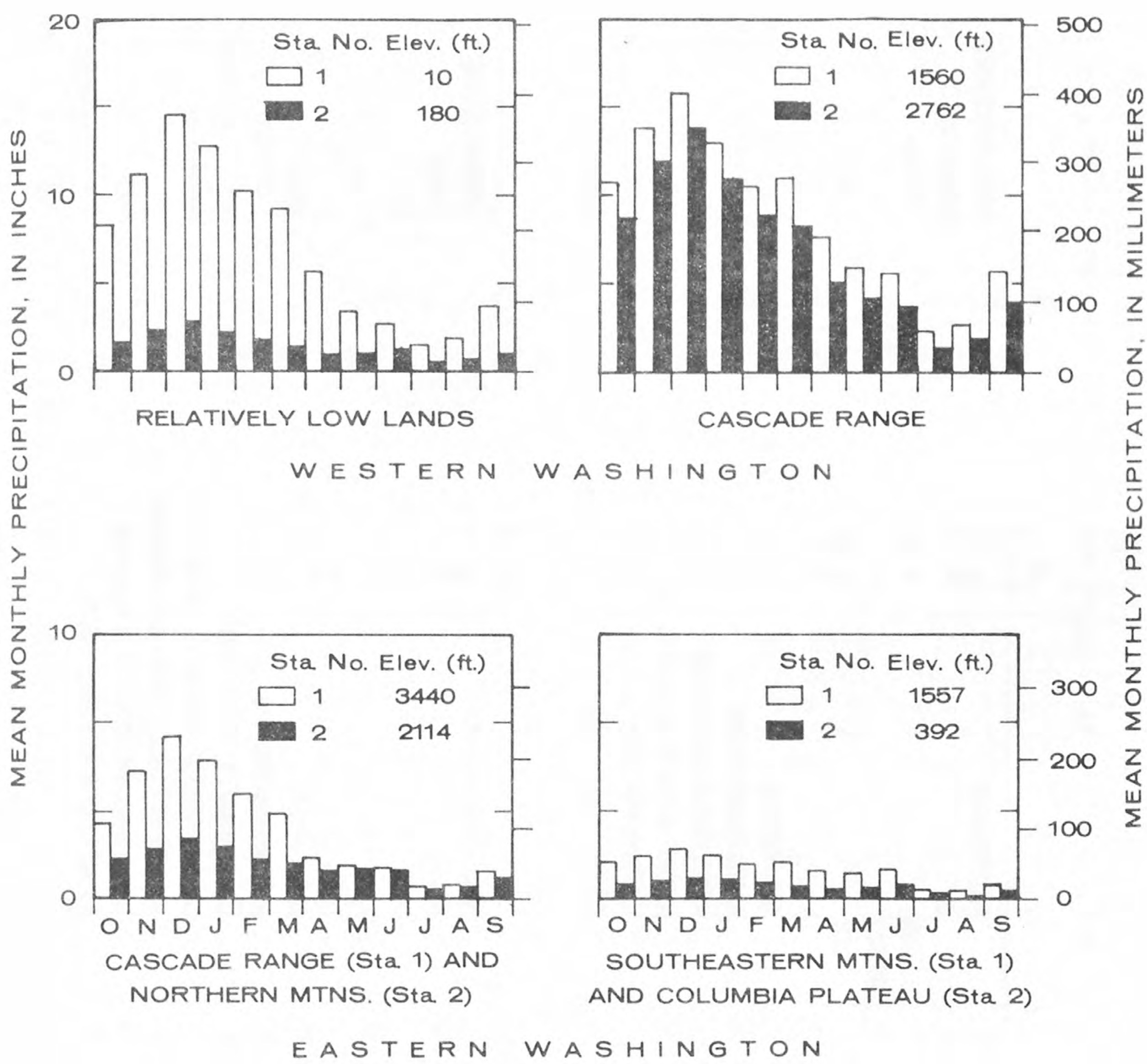

FIGURE 2.--Representative precipitation for four physiographic provinces of Washington. Data from Climatography of the United States, no. 60-45 (National Oceanic and Atmospheric Administration, 1972).

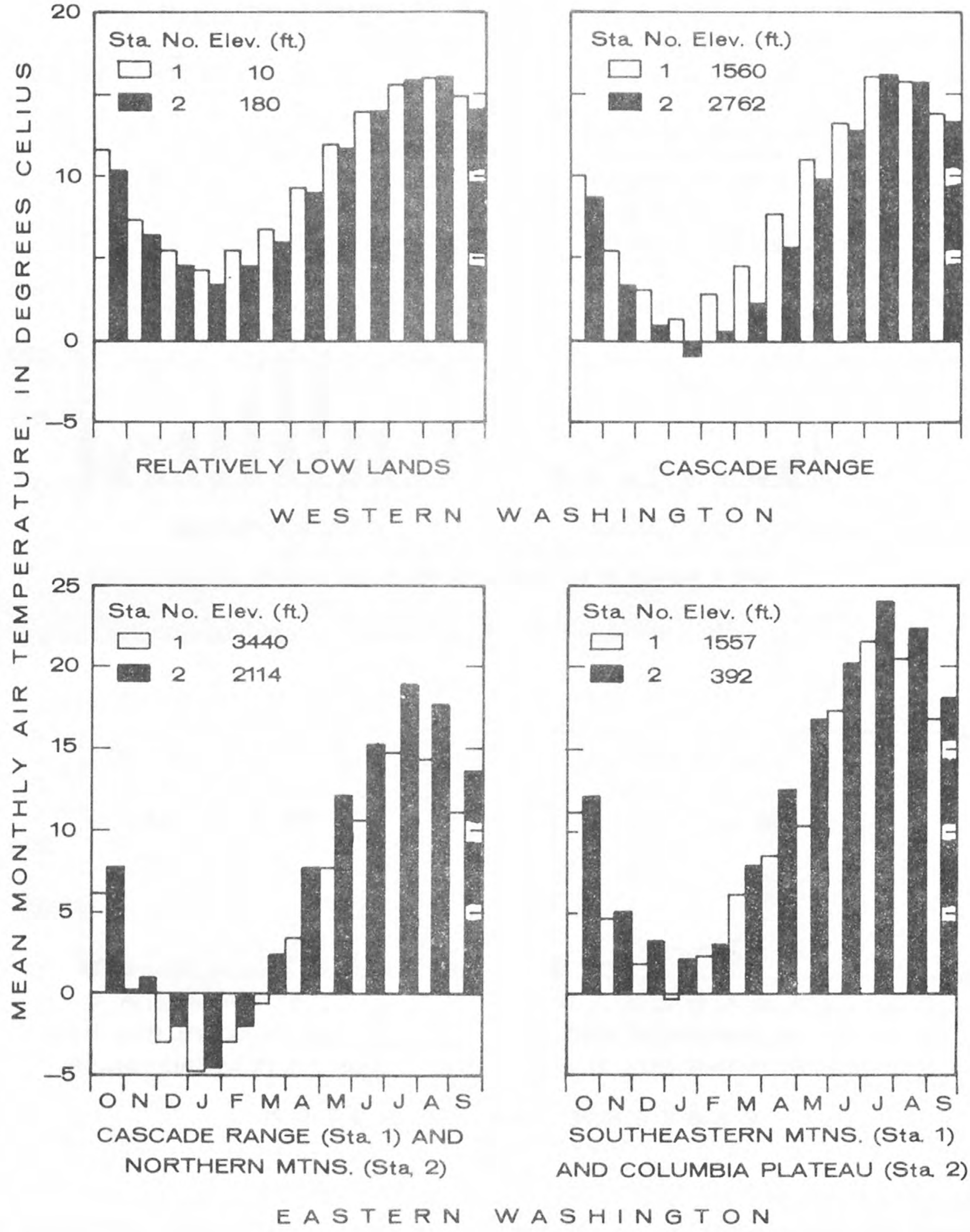

FIGURE 3.--Representative air temperatures for four physiographic provinces of Washington. Data from Climatography of the United States, no. 60-45 (National Oceanic and Atmospheric Administration, 1972).

Regionalization

The term regionalization has been used in hydrology to describe the modeling activities by which streamflow information gathered at stream stations is transferred to sites on streams where little or no actual data exist. However, because the regionalization models do not correctly account for all of the factors that affect streamflow, there is an inherent error in these models. The implicit assumptions of regionalization are that such errors are distributed randomly within the region of applicability of the model, and that the errors are not related to the independent variables. When these assumptions are obviously violated, one of two remedies is usually attempted: (1) a new factor that eliminates the problem is added to the model, or (2) the model is divided either into models of geographical subareas or into models that only are applicable within a limited range of one or more of the independent variables. An example of the second remedy is a relation for estimating mean annual floods that is only applicable to drainage areas greater than some specified size.

Runoff Regimes

Preliminary statewide regression analyses for this study indicated that streamflow characteristics could not be related well to the characteristics describing the varied climate and physiography of Washington. Both regional error patterns and errors related to the basin characteristics were evident. In keeping with the second of the previously discussed remedies (preceding paragraph), the stream basins in Washington were divided into six classes. Each of the six classes has a distinct runoff regime, that is, each has a high degree of homogeneity in the seasonal distribution of mean monthly streamflow at its sites. The three classes used for subdividing most of western Washington were based on the three types of runoff regimes found there; the classes or regimes are definable by the mean annual snowfall and average elevation of the drainage basin. The basins comprising each of the six classes are in only a roughly defined geographical region.

The three classes with runoff regime defined by snowfall and elevation comprise most of the basins in that part of Washington lying west of the crest of the Cascade Range. In the lower elevation basins of western Washington, runoff is distributed seasonally similar to precipitation, with mean monthly streamflows reaching a peak in the winter and a minimum in the summer, as shown in figure 4a. Because of the accumulation and subsequent melting of snow, the seasonal pattern of mean monthly streamflows from basins at middle and higher elevations in western Washington has both a winter and a spring peak, as illustrated in figure 4b. The medium-high and very-high elevation basis were classified into either of two runoff regimes according to whether the magnitude of winter peak or the spring peak dominated the seasonal-runoff pattern. Which peak dominates is related to the amount of snowfall in a basin and the elevation of the basin. Because of the relation of air temperature to basin elevation, elevation generally serves as an index of the snowmelt process. As can be seen in figure 5, seasonal patterns of mean monthly streamflows of basins at high elevations and those medium-high elevation basins with large mean annual snowfalls have dominant spring peaks. These three characteristic types of runoff regimes were found, with one exception as noted below, to provide a positive basis for subdivision of western Washington for the purpose of regionalization of streamflow characteristics.

The runoff regime of the basin above the station, Wynoochee River above Save Creek near Aberdeen (12036000), does not fit the classification indicated in figure 5 for the elevation and snowfall of the basin. The anomaly may be in the mean annual snowfall for the basin, which is located on the southern slopes of the Olympic Mountains, because the mean monthly flows in the Wynoochee River follow a winter-peak pattern as do the flows in streams draining lower elevation basins of western Washington.

Dominant spring peaks occur in the seasonal pattern of monthly mean streamflows of basins on the eastern and southeastern slopes of the Cascade Range, in the northern border mountains of eastern Washington, and in the northernmost part of the west slope of the Cascade Range because much of the precipitation in late fall through early spring is stored as snow and released as snowmelt in the late spring and early summer. This is shown by the hydrograph in figure 4c. This runoff regime is one of those used for regionalization. (See general area that includes these stations in pl. 1.)

Southeastern Washington has a somewhat milder climate and generally lower elevations than the northeastern part of the State. The runoff hydrographs of mean monthly streamflows from basins located there have a single, broad peak that lasts from late winter to early spring (fig. 4d). Stations with runoff regimes defined by this type of hydrograph were found to have consistent regionalization relations, and their general geographical extent is shown by the locations of the appropriate stations in plate 1.

The remaining part of the State--the Columbia Plateau and areas adjacent to it--is characterized by intermittent-flow streams and has been classified as the sixth runoff regime for regionalization of streamflow characteristics.

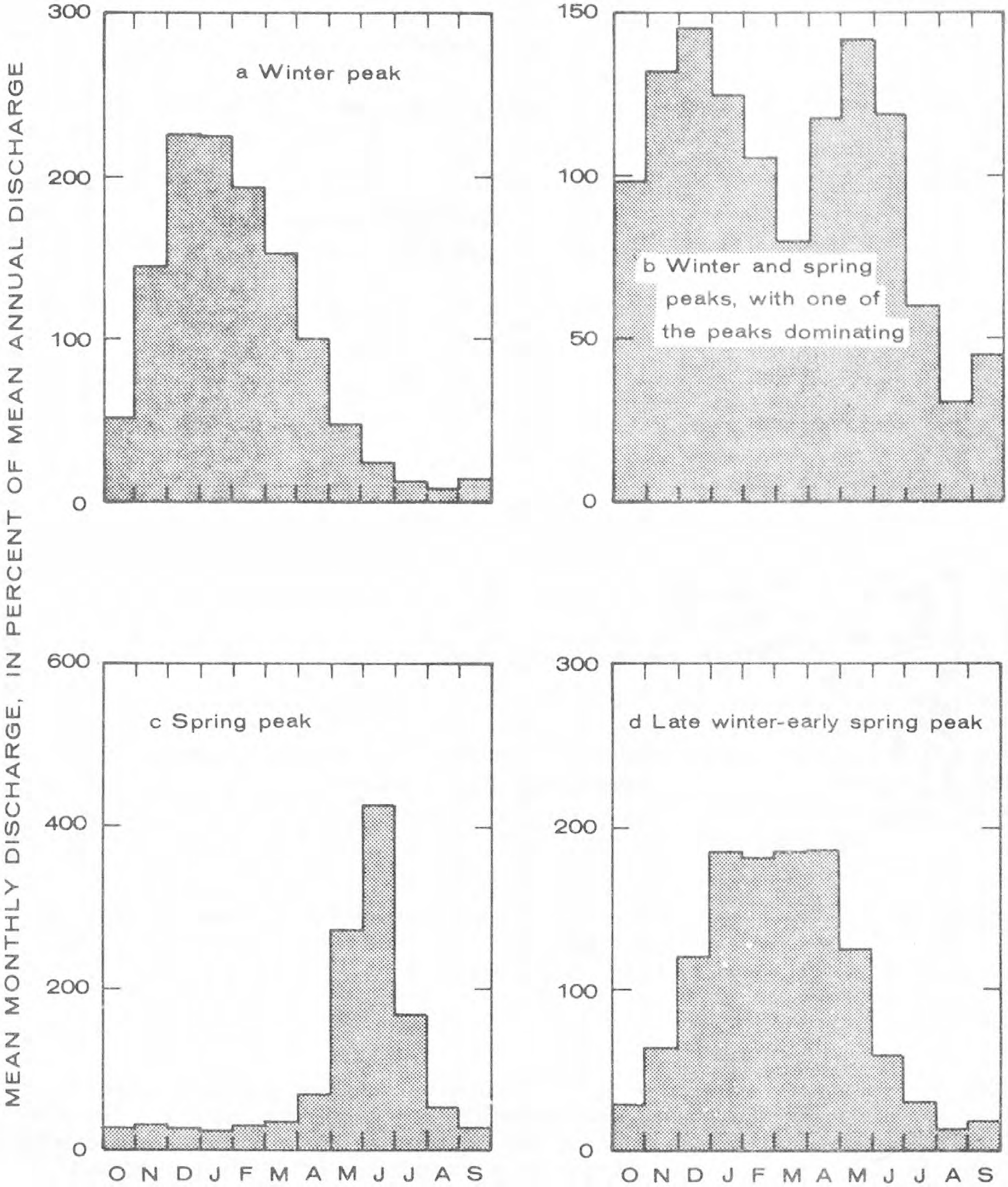

FIGURE 4.--The basic temporal distributions of discharge from natural-flow stream basins of Washington and types of runoff regime distinguished by the distributions.

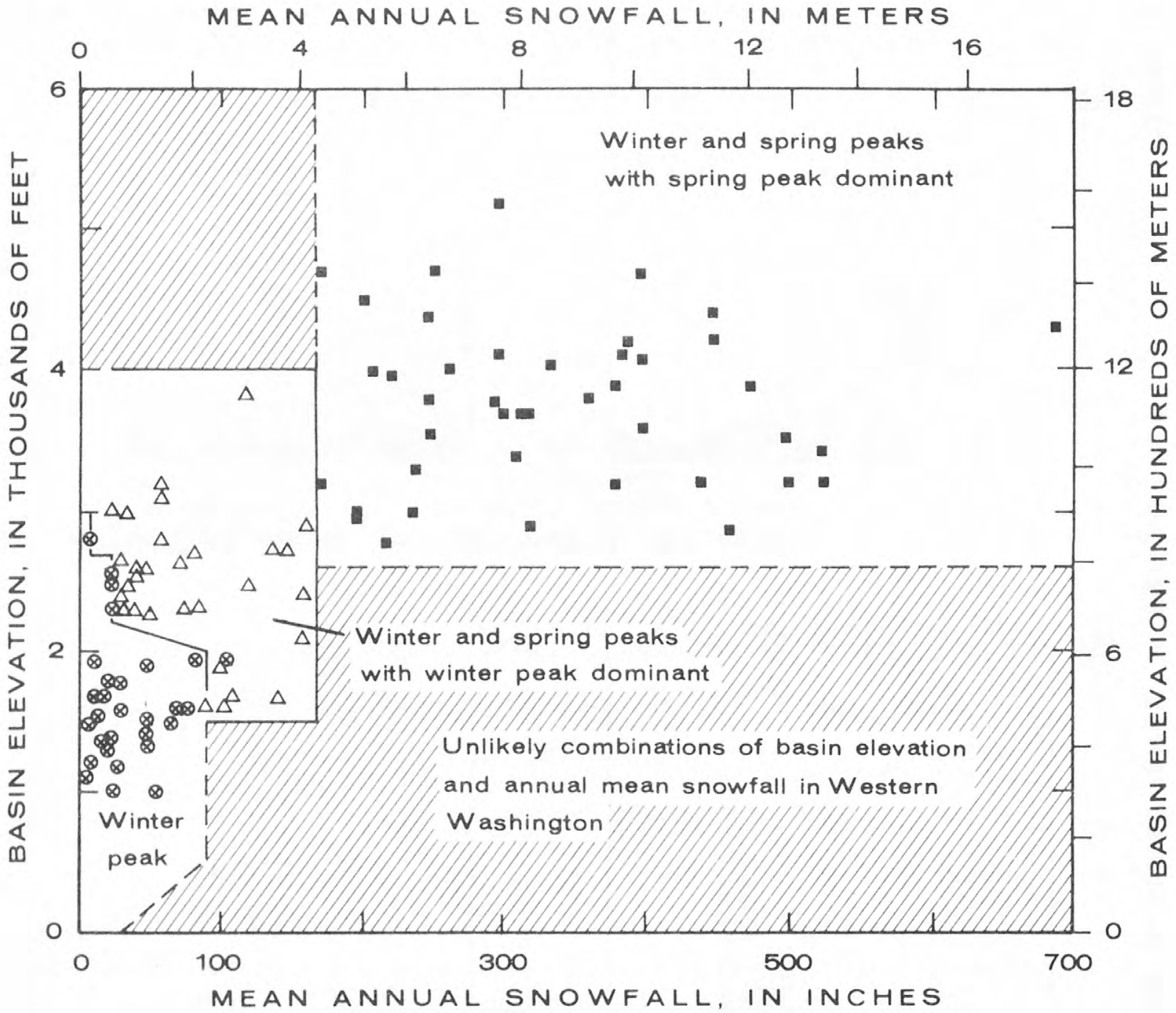

FIGURE 5.--Runoff regimes in western Washington that are distinguished by average elevation and annual mean snowfall of the stream basins. (Runoff from all basins of the Coast Range and southern slopes of the Olympic Mountains is characterized by a winter peak regardless of elevation of and annual snowfall over the basins.)

Data-Selection Criteria

For each streamflow characteristic analyzed, specific criteria were adopted for selection of stations that were to be used in the regression analyses. The criteria, which are subsequently described, took into account (1) the effects of regulation and diversion of streamflows upstream from the stations, (2) the lengths of historical record available at the stations, and (3) existence of ephemeral conditions at the stations. The eligible stations are listed in table 4 (at end of report).

The 97 stations eligible for analysis of annual peak flows in the winter-peak regime of western Washington are more than the maximum number (50) permitted in the network-design analysis. A subset of 33 stations therefore was selected arbitrarily for use in the analysis. The selection process consisted of listing the stations in order of station number, selecting by use of a random process the beginning station from among the first three, and then selecting every third station after the beginning one. The selection process insured the choosing of stations from about the same geographical parts of the region that were represented in the parent set of stations. The range and distribution of dependent and independent variables were about the same for both the subset and the parent group of stations.

Regulation and diversions.--Stations at which a streamflow characteristic differs greatly from what it would be under natural-flow conditions because of regulation, storage, or diversions, are not eligible for regionalization of that particular characteristic. For most stations, eligibility could be determined from the classifications given by Collings (1971) and from the information given in the annual and summary series of streamflow data published by the U.S. Geological Survey. However, eligibility of some stations was not easily determined from these sources, and those stations with questionable eligibility were excluded from an analysis.

Record period.--A general criterion adopted was that record periods should be 20 or more years in order to minimize biases inherent in the network analysis. This criterion was changed to 15 or more years to include more stations in regions having a small number of stations, or to include more small streams in the analyses of means, standard deviations, and extremes of annual peak discharges. Although it is not a requirement of the technique, a subcriterion--requiring that record periods among stations should have concurrent records of 9 or more years--was used so that interstation correlation could be estimated. In regions where the minimum record period of 20 years applied, a sufficient number of stations were available so that only stations operated 9 or more years during the period 1955-74 were used. For regional analyses using a record period of at least 15 years, the only stations used were those with 9 or more years of record during the period 1960-74.

Ephemeral streams.--Stations with no streamflow for all or part of many years were not used in the five runoff-regime regions for which regression and network design were developed in this study. This was because either no data were available for ephemeral streams or ephemeral streams with available data were not eligible due to insufficient length of record, or flow was affected by regulation and (or) diversions.

On the Columbia Plateau and in adjacent areas, flow in most streams is ephemeral and flow in the few perennial streams generally is affected by regulation and (or) diversions. The streamflow data available there are insufficient to fulfill (1) the network-design criterion for minimum length of record, and/or (2) the criterion for number of stations required to obtain significant regression analysis for streamflow characteristics of either the annual mean-flow or the annual peak-flow series. Therefore, objective design of the data network in this sixth runoff regime is not feasible at this time.

Regression Analyses

For each of the five runoff regimes, the relations between streamflow characteristics at the stations and physical and climatic characteristics of the basins (basin characteristics) were determined by multiple-regression analyses. The regression equations are models that may be used to transfer information about streamflow characteristics from the known (the historical network) to the unknown (ungaged sites). A log-linear relation between a streamflow characteristic and the basin characteristics was selected as the model form, and the logarithms of all variable values were used in the regressions. Thus, the model is the one commonly used in regionalization and is of the form:

$$\log Z = \log a + b_1 \log X_1 + b_2 \log X_2 .... b_n \log X_n \quad ,$$

or

$$Z = a X_1^{b_1} X_2^{b_2} X_3^{b_3} .... X_n^{b_n},$$

where Z is a dependent streamflow characteristic (variable), $X_1, X_2 .... X_n$ are independent basin characteristics (variables), <u>a</u> is the regression constant, and $b_1, b_2, ... b_n$ are regression coefficients for the appropriate basin variables.

The method followed in this study consisted of computing the regression equation and checking the regression coefficients for significance at the 90-percent confidence level. As a first step, a computer program--called "step-forward" regression--is used to select the most highly related independent variable and test it for significance. The program (1) selects the next most highly related variable, (2) computes the regression on the two variables, and (3) tests for significance of the two variables; this process is repeated until all the significant variables are included in the regression. In the next step, a computer program--called "step-backward" regression--is used in the evaluation of the deletion of variables that are significant in the "step-forward" regression relation but are "highly correlated" with another variable. The "step-backward" program (1) computes the regression with all independent variables included, (2) eliminates the least significant variable and recomputes the regression, and (3) continues the elimination process until only one independent variable remains. Differences in the standard errors and multiple-correlation coefficients of the various regressions indicate the degree of improvement obtained by inclusion of each independent variable and the degree of sensitivity of the dependent variable to each of the independent variables. The deletion of some specific "highly correlated" variables is discussed further in the next section.

Variables used.--The dependent streamflow variables used in the analyses are the mean, QA, and the standard deviation, SDA, of annual mean discharges; the mean, QF, and standard deviation, SDF, of annual peak discharges; and the flood discharge, P50, for an exceedance probability of 2 percent (recurrence interval of 50 years). As a convenience to users who may need to estimate flood discharges for other exceedance probabilities at ungaged sites, the flood discharges for exceedance probabilities of 10, 4, and 1 percent also were used as dependent variables.

The independent physical and climatic variables found to be useful in the regression anlyses are drainage area (A) in square miles, mean annual precipitation (PM) in inches, area of lakes (L) as a percentage of A, forest cover (F) as a percentage of A, and mean annual snowfall (SN) in inches. Except for snowfall, definitions of and methods for determining the variables are given by Collings (1971). The values used for the variables used in this report may differ from those used by Collings because of recomputations using more recent maps, data, and techniques. For example, P50's were determined from frequency distributions that were computed by using annual peak-flow data available through the 1974 water year and revised techniques recommended by the [U.S.] Water Resources Council (1976).

Mean annual snowfall was estimated from data from snow courses and precipitation stations at the time of the previous network evaluation by Collings (1971) but he did not use it in the analyses. However, it was found to be helpful in the present analyses for defining regions with similar runoff regimes, and was a significant independent variable for one regression equation (table 1).

Some independent variables were "highly correlated" with one another in some regions. The variables most often "highly correlated" were A and L, PM and SN, and F and PM. Because of the redundancy of information contained in the correlated variables, one of them often may be eliminated without significantly affecting the accuracy of estimating the dependent variable. By so doing, the effort required to apply the regression relation to an ungaged site will be reduced. For pairs of variables that were significant in a regression and had a correlation coefficient greater than 0.5, a new regression equation was computed with one of the variables deleted from the analyses. If the resulting changes in the standard error of estimate and the multiple-correlation coefficient indicated a relative insensitivity of the dependent variable to the deleted independent variable, the simpler of the two relations was used in this study.

Regression results.--Regression models for means and standard deviations of annual mean and peak discharges and for 2-percent floodflows are given in table 1 for the five runoff regimes. Regression models of floodflows for exceedance probabilities of 10, 4, 2, and 1 percent are given in table 7, which is at end of report, for the five runoff regimes. The standard error of estimate and the multiple correlation coefficient also are given for each model.

TABLE 1.--Summary of regression analyses of nonregulated streams in Washington

[Regression equations of form: $Z = a\,X_1^{b_1}\,X_2^{b_2}\,X_3^{b_3}\,X_4^{b_4}\,X_5^{b_5}$]

Runoff regime[2]	Stream-flow charac-teristic Z	Regres-sion con-stant a	Regression coefficient, b_i, for:[1] Drain-age area X_1	Precip-itation X_2	Area of lakes X_3	Forest cover X_4	Snow-fall X_5	Standard error Log units	Per-cent	Multiple correla-tion coeffi-cient
Western Washington:										
Winter and spring peaks:										
Winter peak dominant	QA	0.031	0.94	1.19	-0.03	--	--	0.078	18	0.985
	SDA	.0046	1.02	1.15	-.07	--	--	.108	25	.976
	QF	.75	.90	1.12	--	--	--	.144	34	.984
	SDF	2.46	.89	1.19	-.55	--	--	.143	34	.984
	P50	2.16	.89	1.05	--	--	--	.141	33	.984
Spring peak dominant	QA	.025	.98	1.20	--	--	--	.076	18	.993
	SDA	.0051	1.00	1.15	--	--	--	.064	15	.995
	QF	.64	.91	1.83	--	-0.82	--	.121	28	.991
	SDF	.0024	.87	1.80	--	--	0.27	.144	34	.986
	P50	1.27	.88	1.83	--	-.76	--	.120	28	.991
Winter peak	QA	.013	1.00	1.34	--	--	--	.102	24	.991
	SDA	.0066	1.01	1.10	--	--	--	.096	22	.992
	QF	.064	.89	1.55	-.11	--	--	.202	49	.973
	SDF	.082	.80	1.42	--	--	--	.267	68	.945
	P50	.23	.82	1.56	--	--	--	.230	57	.961
Eastern Washington:										
Spring peak	QA	.0032	.96	1.63	--	--	--	.146	35	.975
	SDA	.0041	1.00	1.15	--	--	--	.170	41	.958
	QF	.031	.87	1.64	--	--	--	.208	51	.979
	SDF	.033	.82	1.49	--	--	--	.262	66	.962
	P50	.13	.84	1.51	--	--	--	.215	53	.975
Late winter-early spring peak	QA	.81	.91	--	-.18	--	--	.286	74	.910
	SDA	.052	1.11	--	-.30	--	--	.192	46	.969
	QF	3.05	.93	--	-.41	--	--	.258	65	.961
	SDF	.88	.96	--	-.60	--	--	.320	85	.943
	P50	6.84	.91	--	-.51	--	--	.330	88	.934

[1]Regression coefficients are significant at 10-percent level, except those for QA of the runoff regime with a late winter-early spring peak.

[2]Determined from similarity in hydrographs of mean monthly streamflows.

Network-Design Analysis

Preliminary to the application of the network-design technique, prior probabilities, $\phi(C_V)$, must be assigned to values of the average coefficient of variation, C_V, of the streamflow-data series that are associated with the dependent streamflow variables. For example, both QA and SDA are associated with the series of annual mean flows, and thus they would have identical prior probabilities for C_V. Similarly, QF, SDF, and P50 are associated with the annual peak-flow series.

Values of $\phi(C_V)$ were assigned by making the probability that C_V is within a particular range equal to the observed relative frequency of values of C_V within that range in the actual streamflow records. Because Slack, Wallis, and Matalas (1976) found sampling biases in C_V, this method would be unacceptable if the values of C_V are large ($C_V > 1.0$). However, the sample values of C_V for streamflows in Washington indicate a relatively low level of variability, and the relative frequency procedure will have little effect on the specification of $\phi(C_V)$ when compared with those specified by more elaborate procedures. The values of $\phi(C_V)$ used in this study are given in table 2.

The necessary prior probabilities for cross-correlation coefficient, $\phi(\rho_c)$, are not of the observed streamflow-data series as was the case with C_V but are those of the estimates of the dependent variables derived from the observed data series. The relations that convert the cross-correlation coefficients of the streamflow-data series to the cross correlations of their sample means are given by Moss (1973). These relations were used in this study, in conjunction with the existing streamflow data and the relative-frequency concept, to specify $\phi(\rho_c)$ for both QA and QF. Because methods of estimating the cross correlation of sample values of standard deviations and 50-year floods have not been devised, the prior probabilities of ρ_c for QA were used for SDA and those of QF were used for SDF and P50. The values of $\phi(\rho_c)$ derived from the annual mean flows and the annual peak flows are given in table 2.

TABLE 2.--Prior probability distributions of coefficients of variation and cross-correlation coefficients of annual mean-flow and annual peak-flow series

Runoff regime	Stream-flow series[1]	Probability of C_v for C_v of:[2] 0.3	0.5	0.8	1.0	Probability of ρ_c for ρ_c of:[3] 0.0	0.3	0.5	0.7
Western Washington:									
Winter and spring peaks:									
Winter peak dominant	(QA)	1.00	--	--	--	--	0.20	0.40	0.40
	(QF)	.59	0.41	--	--	0.22	.55	.23	--
Spring peak dominant	(QA)	1.00	--	--	--	.25	.32	.43	--
	(QF)	.20	.58	0.22	--	--	.48	.36	.16
Winter peak	(QA)	.97	.03	--	--	--	.16	.42	.42
	(QF)	.55	.39	.06	--	.28	.59	.13	--
Eastern Washington:									
Spring peak	(QA)	.94	.06	--	--	--	.34	.37	.29
	(QF)	.24	.50	.21	0.05	.28	.50	.15	.07
Late winter-early spring peak	(QA)	.83	.17	--	--	--	.13	.60	.27
	(QF)	.06	.33	.39	.22	.17	.51	.26	.06

[1](QA) - annual mean-flow series; (QF) - annual peak-flow series.

[2]C_v - coefficient of variation.

[3]ρ_c - cross-correlation coefficient.

The results of the regression analyses described in the previous section provide the remainder of the information required in the application of the network-design technique. Two of the input variables are (1) the adjusted number, N_B, of stations used in each of the regression analyses, and (2) the harmonic mean, N_Y, of the lengths of records (in years) that were used to estimate the dependent streamflow variables. These two variables, which specify the level of data availability, are defined as

$$N_B = n - n_v + 1 \quad , \tag{6}$$

and

$$N_Y = \left[\sum_{i-1}^{n} (nm_i)^{-1} \right]^{-1} \quad , \tag{7}$$

where $\underline{n}$ is the number of stations used in the regression, n_v is the number of independent variables in the regression equation, and m_i is the length of existing record, in years, at the ith station. N_B, N_Y, $\underline{n}$ and the median regression error of each regression analyses are given in table 3. The other data that result from the regression analyses are apparent measures of the "goodness of the regression" as defined by the standard errors of estimate, which are given in table 1.

Processing of the input data described above through equations 2 and 3 results in a probabilistic description of the true accuracy of each of the regression equations given in table 1. One means of depicting this probabilistic description is by a cumulative distribution function of its values as is illustrated in figure 6. The confidence level, given as the abscissa of figure 6, is the probability that the true accuracy is less than a particular value of the average regression-equation error given on the ordinate. The cumulative-distribution function presents all of the information that is available about the accuracy of the related regression equation. However, the median value of the cumulative-distribution function is a singular way of describing the regression accuracy. The median error is the value that has a 50-percent confidence level (exceedance probability of 50 percent). The median error of each regression is given in table 3, and the average errors for several levels of confidence are given in table 5 (at end of report).

Medians of the estimates of accuracy that would result from operating networks of other sizes for varying lengths of time are shown in figure 7 for the runoff regime defined by a seasonal pattern of mean monthly streamflow having winter and spring peaks with the spring peak dominant. For each of the five streamflow parameters, QA, SDA, QF, SDF, and P50, the data in figure 7 indicate that relatively little improvement in the accuracy of estimation at ungaged sites can be attained by means of collecting additional streamflow data--neither in terms of added record lengths nor added streamflow stations.

Information similar to that in figure 7 is given in table 5 for each of the five runoff regimes for which regression relations were developed. Interpretations of this information yields conclusions for each of the regimes that is identical to that for the regime of figure 7. The accuracy of estimating the analyzed streamflow characteristics at ungaged sites by regression models is currently limited by the validity of regionalization model and not by the existing streamflow-data base. It is therefore necessary that a better regionalization scheme be developed if improved accuracy is desired for these runoff regimes.

Termination of all streamflow stations operated only for the purpose of regionalization of streamflow characteristics would seem to be the obvious conclusion to be drawn from the above analysis. This is not necessarily valid, however. If better means of regionalization are developed in the future, the improved regionalization models may have a capacity to use data more effectively, and thereby create a valid need for additional data. However, justification for continuation of the current number of streamflow stations would have to be based on decision theory (Raiffa, 1970) because of the uncertainties involved in the research into better regionalization models.

An additional fact of network design is that operation of streamflow stations for justifiable purposes other than regionalization often yields data that can be used in a regionalization technique. Stations that fulfill this dual role also serve as a hedge against the uncertainty about the needs for data to use in future regionalizations. Stations recommended for continued operation in Washington that also will yield regionalization data are identified in the following section.

TABLE 3.--Number of stations, record-period length, and median regression error for present streamflow network

Runoff regime	Stream-flow charac-teristic Z[a]	Num-ber of sta-tions	Adjust-ed num-ber of sta-tions	Harmonic mean record length (years)	Median regression error	
					log units	per-cent
Western Washington:						
Winter and spring peaks:						
Winter peak dominant	QA	19	17	28	0.103	24
	SDA	19	17	28	.114	27
	QF	30	28	19	.141	33
	SDF	30	29	19	.144	34
	P50	30	29	19	.156	37
Spring peak dominant	QA	26	25	28	.085	20
	SDA	26	25	28	.055	13
	QF	41	39	28	.119	28
	SDF	41	39	28	.137	32
	P50	41	39	28	.110	26
Winter peak	QA	35	34	24	.104	24
	SDA	35	34	24	.098	23
	QF	[b]33	31	22	.215	53
	SDF	[b]33	32	22	.264	67
	P50	[b]33	32	22	.235	58
Eastern Washington:						
Spring peak	QA	16	15	28	.144	34
	SDA	16	15	28	.193	47
	QF	38	37	24	(c)	(c)
	SDF	38	37	24	(c)	(c)
	P50	38	37	24	.211	52
Late winter-early spring peak	QA	8	7	30	(c)	(c)
	SDA	8	7	30	(c)	(c)
	QF	18	17	24	(c)	(c)
	SDF	18	17	24	(c)	(c)
	P50	18	17	24	.363	101

[a]QA - mean of annual mean flows.
SDA - standard deviation from annual mean flows.
QF - mean of annual peak flows.
SDF - standard deviation from annual peak flows.
P50 - floodflow with an exceedance probability of 2 percent.

[b]A subset of the 97 stations that are available.

[c]In network-design analysis, data are insufficient to permit determination of error; standard error of regression in table 1 may be used as an estimate.

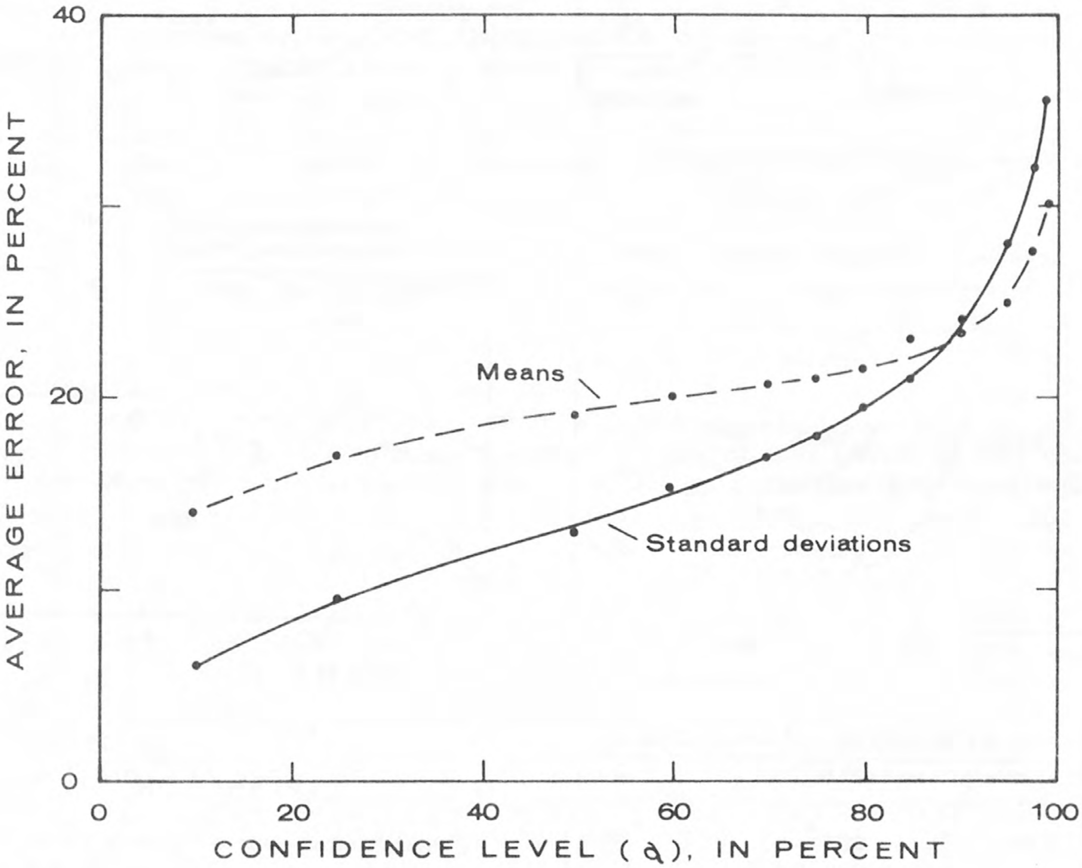

FIGURE 6.--Average error as a function of confidence level for regression models of annual mean flows of streams in a runoff regime having winter and spring peaks with the spring peak dominant.

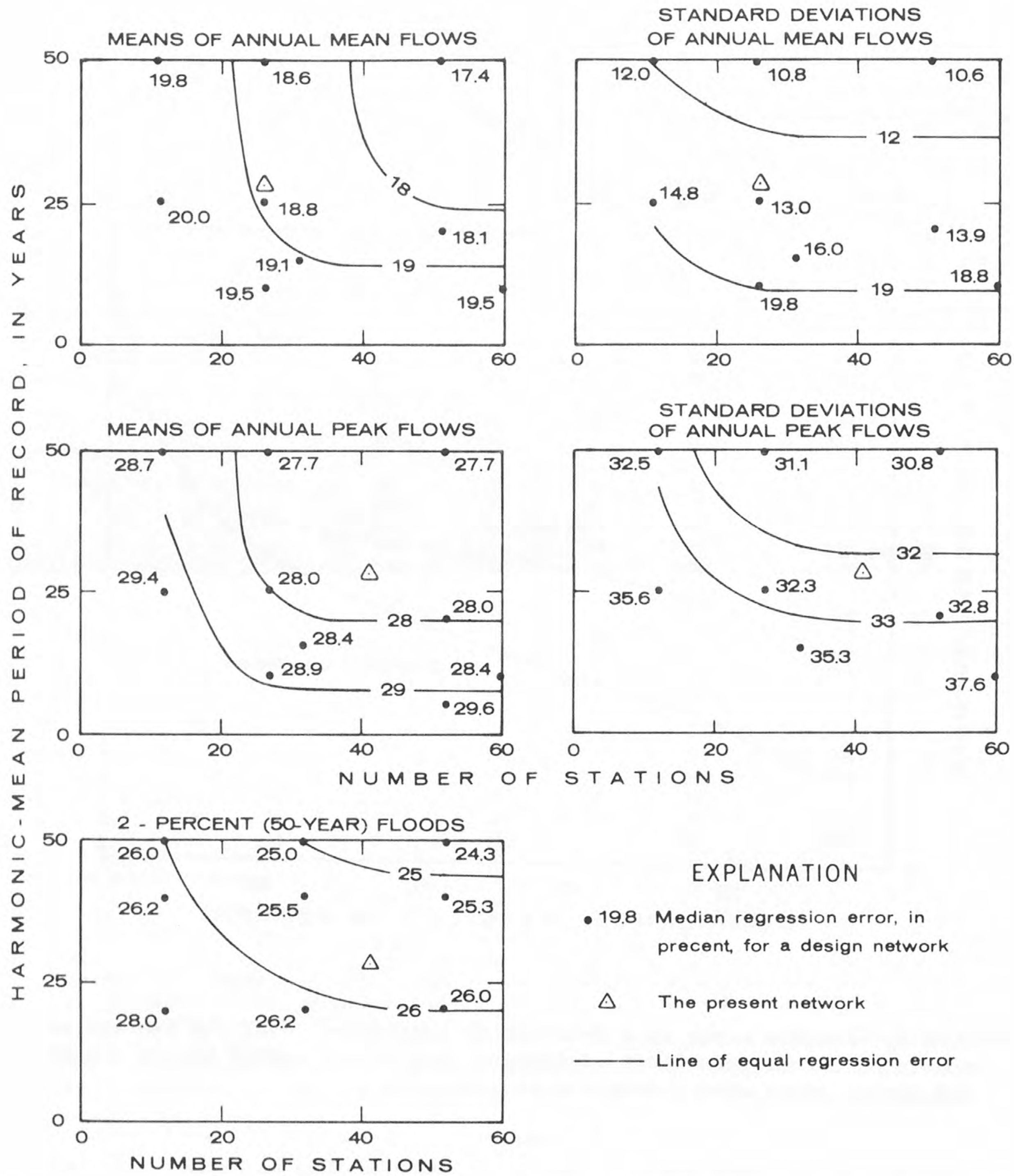

FIGURE 7.--Median percentage errors of regression models for design networks of nonregulated streams in the runoff regime of western Washington which has winter and spring peaks with the spring peak dominant.

NETWORK DESIGN

Historically, stations at which streamflow data have been collected in Washington have been operated for many purposes, for various lengths of time, and with flows determined on a continuous, periodic, or intermittent time basis. The stations comprising the network have changed and will continue to change from year to year to meet the demands for various types of data. The design of a future streamflow-data network can be specified by the addition of stations to, and the discontinuance of, the stations in the current network. Such a specification is given in table 6 (at end of report) for the stations analyzed herein, along with information on (1) whether flow at a station is determined on a continuous or intermittent time basis, (2) the purpose for which the station is currently operated, (3) the current source of funding for station operations, and (4) a recommendation for continuation or discontinuation of operation.

The purposes of the station operations are for (1) determining long-term trends, (2) supplying current data, (3) providing data for research and special studies, and (4) providing hydrologic data for regionalization of streamflow characteristics, this latter being one of the purposes of the study by Collings (1971). Long-term-trend stations, which will be operated indefinitely, provide the data necessary to determine if there are changes and trends in streamflow characteristics of natural-flow streams. So that the stations are more equally distributed among the runoff regimes, the long-term-trend stations recommended now differ from those selected by Collings (1971).

Current streamflow data are needed for (1) accounting and management of water projects and uses such as those for power production, irrigation, and dilution of sewage-treatment plant effluent; (2) forecasting of floods, low flows, or other types of flow; (3) fulfilling compacts or other legal commitments; and (4) determining discharges of constituents (chemical, sediment, and biological) transported by streams. Because these needs usually have a long lifetime, stations supplying these data also are operated for long periods. Research and special-study projects often require current data but only for relatively short periods (maximums of about 5 years).

The hydrologic-data stations proposed in 1971 were justified at that time on the basis of the need for future data that might be needed for regionalization of streamflow characteristics. Continuation of these stations now can be judged according to the results obtained in this network analysis.

For a future Washington streamflow-data network, discontinuation is recommended for all hydrologic-data and special-study stations from which data are not currently needed. The current-data stations for either long-term projects or for research or special studies are recommended for continuation. Also, 21 continuous-record and about 12 annual-peak stations should be continued as long-term-trend stations. The 21 continuous-record stations are listed in table 6. The 12 annual-peak stations shown as long-term-trend stations in table 6 are well distributed among the regions and complement the locations of the continuous-record, long-term stations in a region; however, other stations that also do this could be substituted for any of these 12 stations.

Because the same conclusion resulted from the analysis of each streamflow characteristic in each runoff regime analyzed, the conclusion can be extrapolated to the natural-flow catchments in Washington not included in this study; that is, no station on natural-flow streams could be justifiably operated for the sole purpose of collecting data for regionalization of streamflow characteristics. The only exceptions to this statement are basins on the Columbia Plateau, where the paucity of data and the variation of the runoff regime from those examined herein might over-extend the generality of this conclusion. The continuation of the collection of annual peak-flow data at existing stations in this ephemeral-stream part of Washington (Columbia Plateau) is recommended in the interim until further analysis can determine if and when they should be terminated. Continuous-record stations on the few perennial streams in the ephemeral-stream area should be either continued or discontinued for the same reasons as those for the other five runoff regimes.

SUMMARY AND CONCLUSIONS

A network-design technique developed by Moss and Karlinger (1974) is described and applied in the evaluation and design of a streamflow-data network in Washington State. The technique evaluates the changes in the accuracy of regionalization models that result from changes in lengths of periods of record, or number of stations. The regionalization models for natural-flow streams in Washington are the regression equations for means and standard deviations of the annual mean-flow and peak-flow series and floods with exceedance probabilities of 2 percent. The net work-design analyses indicate that relatively little improvement in the accuracy of estimation at ungaged sites by these models can be attained by collecting additional streamflow data--neither in terms of added record length nor added streamflow stations. If improved accuracy is desired for Washington, the only alternative is the development of better regionalization models.

The Washington network, based on stations operating after the 1975 water year, consists of those proposed for (1) determination of long-term trends in streamflow characteristics; (2) providing current data needed for management and allocation of water, usually over a long-term future period; and (3) providing current data for special study and research projects, usually over a short-term future period. It does not include stations operated to provide data for improving accuracy of present regionalization models; however, the data gained from extended operation of eligible stations for other purposes could be used if a better model is developed in the future.

Regionalization developed for Washington was based on a definition of homogeneous ruoff regimes; that is, the temporal distribution of runoff, as defined by the hydrographs of mean monthly flows at the stations, was similar for all stream basins in a regime. Runoff regimes defined for western Washington stations were classifiable into three distinct types on the basis of the average elevation and mean annual snowfall of the upstream basins. Only two of the three types classified for eastern Washington (classes for eastern Washington differ from those for western Washington), were used in the network-design analyses. Because the streamflow characteristics for the ephemeral streams of the Columbia Plateau and adjacent areas of eastern Washington are not tractable to regression analyses, the techniques described and applied to other regions in this study cannot be used in the design of a network for this region.

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TABLE 4.--Study stations in the runoff regimes of Washington

ANALYSES OF ANNUAL MEAN-FLOW SERIES

WESTERN WASHINGTON

Winter-spring peaks, with winter peak dominant

12039500	Quinault River at Quinault Lake
12041500	Soleduck River near Fairholm
12054500	Hamma Hamma River near Eldon
12054600	Jefferson Creek near Eldon
12060500	South Fork Skokomish River near Union
12083000	Mineral Creek near Mineral
12095000	South Prairie Creek at South Prairie
12142000	North Fork Snoqualmie River near Snoqualmie Falls
12161000	South Fork Stillaguamish River near Granite Falls
12165000	Squire Creek near Darrington
12167000	North Fork Stillaguamish River near Arlington
12209000	South Fork Nooksack River near Wickersham
12209500	Skookum Creek near Wickersham
14127000	Wind River above Trout Creek, near Carson
14128500	Wind River near Carson
14143500	Washougal River near Washougal
14223500	Kalama River below Italian Creek, near Kalama
14235500	West Fork Tilton River near Morton
14242500	Toutle River near Silver Lake

Winter-spring peaks, with spring peak dominant

12048000	Dungeness River near Sequim
12054000	Duckabush River near Brinnon
12056500	North Fork Skokomish River below Staircase Rapids, near Hoodsport
12082500	Nisqually River near National
12092000	Puyallup River near Electron
12097000	White River at Greenwater
12097500	Greenwater River at Greenwater
12104000	Friday Creek near Lester
12104500	Green River near Lester
12105000	Smay Creek near Lester
12114000	South Fork Cedar River near Lester
12115000	Cedar River near Cedar Falls
12115500	Rex River near Cedar Falls
12133000	South Fork Skokomish River near Index
12134500	Skykomish River near Gold Bar
12144000	South Fork Snoqualmie River at North Bend
12186000	Sauk River above Whitechuck River, near Darrington
12189500	Sauk River near Sauk
12205000	North Fork Nooksack River below Cascade Creek, near Glacier
12210500	Nooksack River at Deming
14215000	Rush Creek above Falls, near Cougar
14215500	Curly Creek near Cougar
14216000	Lewis River above Muddy River, near Cougar
14216500	Muddy River below Clear Creek, near Cougar
14232500	Cispus River near Randle
14233400	Cowlitz River near Randle

Winter peak

12010000	Naselle River near Naselle
12011500	Willapa River at Lebam
12020000	Chehalis River near Doty
12027500	Chehalis River near Grand Mound
12030000	Rock Creek at Cedarville
12031000	Chehalis River at Porter
12032500	Cloquallum Creek at Elma
12034200	East Fork Satsop River near Elma
12035000	Satsop River near Satsop
12036000	Wynoochee River above Save Creek, near Aberdeen
12039000	Humptulips River at Humptulips
12040000	Clearwater River near Clearwater
12047500	Siebert Creek near Port Angeles
12050500	Snow Creek near Maynard
12065500	Gold Creek near Bremerton
12068500	Dewatto River near Dewatto
12070000	Dogfish Creek near Poulsbo
12073500	Huge Creek near Wauna
12076500	Goldsborough Creek near Shelton

Winter peak--continued

12079000	Deschutes River near Rainier
12141000	Woods Creek near Monroe
12147500	North Fork Tolt River near Carnation
12153000	Little Pilchuck Creek near Lake Stevens
12168500	Pilchuck Creek near Bryant
12196000	Alder Creek near Hamilton
12201500	Samish River near Burlington
12212000	Fishtrap Creek at Lynden
14212000	Salmon Creek near Battle Ground
14222500	East Fork Lewis River near Heisson
14237000	Klickitat Creek at Mossyrock
14237500	Winston Creek near Silver Lake
14245000	Coweman River near Kelso
14247500	Elochoman River near Cathlamet
14249000	Grays River above South Fork, near Grays River
14250500	West Fork Grays River near Grays River

EASTERN WASHINGTON

Spring peak

12175500	Thunder Creek near Newhalem
12177500	Stetattle Creek near Newhalem
12182500	Cascade River at Marblemount
12396000	Calispell Creek near Dalkena
12401500	Kettle River near Ferry
12407500	Sheep Creek at Springdale
12408300	Little Pend Oreille River near Colville
12408500	Mill Creek near Colville
12451000	Stehekin River at Stehekin
12452800	Entiat River near Ardenvoir
12454000	White River near Plain
12458000	Icicle Creek above Snow Creek, near Leavenworth
12488500	American River near Nile
12500500	North Fork Ahtanum Creek near Tampico
14107000	Klickitat River above West Fork, near Glenwood
14121300	White Salmon River below Cascades Creek, near Trout Lake

Late winter-early spring peak

12424000	Hangman Creek at Spokane
12427000	Little Spokane River at Elk
12431000	Little Spokane River at Dartford
14013500	Blue Creek near Walla Walla
14017000	Touchet River at Bolles
14113000	Klickitat River near Pitt
14010000	South Fork Walla Walla River near Milton, Oregon
14020000	Umatilla River above Meacham Creek, near Gibbon, Oregon

TABLE 4.--Study stations in the runoff regimes of Washington--Continued

ANALYSES OF ANNUAL PEAK-FLOW SERIES
AND 2-PERCENT FLOODS (50-YEAR RECURRENCE INTERVAL)

WESTERN WASHINGTON

Winter-spring peak, with winter peak dominant

12039500	Quinault River at Quinault Lake
12040500	Queets River near Clearwater
12041500	Soleduck River near Fairholm
12054500	Hamma Hamma River near Eldon
12054600	Jefferson Creek near Eldon
12060500	South Fork Skokomish River near Union
12083000	Mineral Creek near Mineral
12095000	South Prairie Creek at South Prairie
12097700	Cyclone Creek near Enumclaw
12117000	Taylor Creek near Selleck
12132700	South Fork Skykomish River tributary at Baring
12135000	Wallace River at Gold Bar
12142000	North Fork Snoqualmie River near Snoqualmie Falls
12143000	North Fork Snoqualmie River near North Bend
12149000	Snoqualmie River near Carnation
12161000	South Fork Stillaguamish River near Granite Falls
12165000	Squire Creek near Darrington
12167000	North Fork Stillaguamish River near Arlington
12189400	Sauk River tributary near Darrington
12209000	South Fork Nooksack River near Wickersham
12209500	Skookum Creek near Wickersham
14127000	Wind River above Trout Creek, near Carson
14128500	Wind River near Carson
14143500	Washougal River near Washougal
14218300	Dog Creek at Cougar
14223500	Kalama River below Italian Creek, near Kalama
14235300	Tilton River near Mineral
14235500	West Fork Tilton River near Morton
14236200	Tilton River above Bear Canyon Creek, near Cinebar
14242500	Toutle River near Silver Lake

Winter-spring peaks, with spring peak dominant

12048000	Dungeness River near Sequim
12053000	Dosewallips River near Brinnon
12054000	Duckabush River near Brinnon
12056500	North Fork Skokomish River below Staircase Rapids,near Hoodsport
12082500	Nisqually River near National
12092000	Puyallup River near Electron
12094000	Carbon River at Fairfax
12096800	Dry Creek near Greenwater
12097000	White River at Greenwater
12097500	Greenwater River at Greenwater
12103500	Snow Creek near Lester
12104000	Friday Creek near Lester
12104500	Green River near Lester
12105000	Smay Creek near Lester
12114000	South Fork Cedar River near Lester
12115000	Cedar River near Cedar Falls
12115300	Green Point Creek near Cedar Falls
12115500	Rex River near Cedar Falls
12130500	South Fork Skykomish River near Skykomish
12131000	Beckler River near Skykomish
12133000	South Fork Skokomish River near Index
12134500	Skykomish River near Gold Bar
12143300	South Fork Snoqualmie River tributary near North Bend
12144000	South Fork Snoqualmie River at North Bend
12144500	Snoqualmie River at Snoqualmie
12186000	Sauk River above Whitechuck River, near Darrington
12189500	Sauk River near Sauk
12204400	Nooksack River tributary near Glacier
12205000	North Fork Nooksack River below Cascade Creek, near Glacier
12210500	Nooksack River at Deming
12211500	Nooksack River near Lynden
14213500	Big Creek below Skookum Meadow, near Trout Lake
14215000	Rush Creek above Falls, near Cougar
14215500	Curly Creek near Cougar
14216000	Lewis River above Muddy River, near Cougar
14216500	Muddy River below Clear Creek near Cougar

Winter-spring peaks, with spring peak dominant--con.

14226500	Cowlitz River at Packwood
14226800	Skate Creek tributary near Packwood
14226900	Skate Creek tributary No. 2 near Packwood
14232500	Cispus River near Randle
14233400	Cowlitz River near Randle

Winter peak

12010000[a]	Naselle River near Naselle
12010600	Lane Creek near Naselle
12011100	North Nemah River tributary near South Bend
12011500[a]	Willapa River at Lebam
12012200	Green Creek near Lebam
12013500	Willapa River near Willapa
12014500[a]	South Fork Willapa River near Raymond
12016700	Joe Creek near Cosmopolis
12017000	North River near Raymond
12019600[a]	Water Mill Creek near Pe Ell
12020000	Chehalis River near Doty
12020500	Elk Creek near Doty
12021000[a]	South Fork Chehalis River at Boistfort
12024000	South Fork Newaukum River near Onalaska
12025000	Newaukum River near Chehalis
12026000[a]	Skookumchuck River near Centralia
12027500	Chehalis River near Grand Mound
12030000	Rock Creek at Cedarville
12031000[a]	Chehalis River at Porter
12032500	Cloquallum Creek at Elma
12034200	East Fork Satsop River near Elma
12034700[a]	West Fork Satsop River tributary near Matlock
12035000	Satsop River near Satsop
12036000	Wynoochee River above Save Creek, near Aberdeen
12039000[a]	Humptulips River at Humptulips
12039050	Big Creek near Hoquiam
12039100	Big Creek tributary near Hoquiam
12039400[a]	Higley Creek near Amanda Park
12040000	Clearwater River near Clearwater
12041600	Soleduck River tributary near Fairholm
12042700[a]	May Creek near Forks
12042900	Grader Creek near Forks
12047100	Lees Creek at Port Angeles
12047500[a]	Siebert Creek near Port Angeles
12049400	Dean Creek at Blyn
12050500	Snow Creek near Maynard
12052400[a]	Penny Creek near Quilcene
12053400	Dosewallips River tributary near Brinnon
12056300	Annas Bay tributary near Potlatch
12061200[a]	Fir Creek tributary near Potlatch
12065500	Gold Creek near Bremerton
12068500	Dewatto River near Dewatto
12070000[a]	Dogfish Creek near Poulsbo
12072000	Chico Creek near Bremerton
12073500	Huge Creek near Wauna
12076500[a]	Goldsborough Creek near Shelton
12078600	Schneider Creek tributary near Shelton
12079000	Deschutes River near Rainier
12088000[a]	Ohop Creek near Eatonville
12102200	Swan Creek near Tacoma
12107200	Deep Creek at Cumberland
12108500[a]	Newaukum Creek near Black Diamond
12113200	Mill Creek near Auburn
12113300	Mill Creek tributary near Auburn
12123300[a]	Evans Creek tributary near Redmond
12124000	Evans Creek above mouth near Redmond
12126000	North Creek near Bothell
12135500[a]	Olney Creek near Gold Bar
12141000	Woods Creek near Monroe
12145500	Raging River near Fall City
12146000[a]	Patterson Creek near Fall City
12147000	Griffin Creek near Tolt
12147500	North Fork Tolt River near Carnation
12148100[a]	South Fork Tolt River tributary near Carnation
12152500	Pilchuck River near Granite Falls
12153000	Little Pilchuck Creek near Lake Stevens
12156400[a]	Munson Creek near Marysville
12164000	Jim Creek near Arlington
12168500	Pilchuck Creek near Bryant

TABLE 4.--Study stations in the runoff regimes of Washington--Continued

Winter peak--Continued

12169500[a]	Fish Creek near Arlington
12196000	Alder Creek near Hamilton
12197200	Parker Creek near Lyman
12200700[a]	Carpenter Creek tributary near Mt. Vernon
12200800	Lake Creek near Bellingham
12201500	Samish River near Burlington
12212000[a]	Fishtrap Creek at Lynden
14125200	Rock Creek near Willard
14126300	Columbia River tributary at Home Valley
14143200[a]	Canyon Creek near Washougal
14144000	Little Washougal River near Washougal
14144550	Shanghai Creek near Hockinson
14144600[a]	Groeneveld Creek near Camas
14212000	Salmon Creek near Battle Ground
14222500	East Fork Lewis River near Heisson
14222700[a]	East Fork Lewis River tributary near Woodland
14223800	Columbia River tributary at Carrols
14237000	Klickitat Creek at Mossyrock
14237500[a]	Winston Creek near Silver Lake
14239100	North Fork Lacamas Creek near Ethel
14239700	Olequa Creek tributary near Winlock
14242600[a]	Toutle River tributary near Castle Rock
14243500	Delameter Creek near Castle Rock
14245000	Coweman River near Kelso
14247500[a]	Elochoman River near Cathlamet
14248100	Risk Creek near Skamokawa
14249000	Grays River above South Fork, near Grays River
14250500[a]	West Fork Grays River near Grays River

[a]Stations in subset used in analyses for winter-peak regime.

EASTERN WASHINGTON

Spring peak

12175500	Thunder Creek near Newhalem
12177500	Stetattle Creek near Newhalem
12182500	Cascade River at Marblemount
12395800	Deer Creek near Dalkena
12395900	Davis Creek near Dalkena
12396000	Calispell Creek near Dalkena
12396100	Winchester Creek near Cusick
12396450	Little Muddy Creek at Ione
12401500	Kettle River near Ferry
12403700	Third Creek near Curlew
12405400	Nancy Creek near Kettle Falls
12407500	Sheep Creek at Springdale
12407700	Chewelah Creek at Chewelah
12408200	Bighorn Creek near Tiger
12408300	Little Pend Oreille River near Colville

Spring peak--Continued

12408400	Narcisse Creek near Colville
12408500	Mill Creek near Colville
12409000	Colville River at Kettle Falls
12433800	Granite Creek near Republic
12445800	Omak Creek tributary near Disautel
12447400	Doe Creek near Winthrop
12451000	Stehekin River at Stehekin
12452800	Entiat River near Ardenvoir
12454000	White River near Plain
12457300	Skinney Creek at Winton
12458000	Icicle Creek above Snow Creek, near Leavenworth
12461200	East Branch Mission Creek tributary near Cashmere
12461500	Sand Creek near Cashmere
12462000	Mission Creek at Cashmere
12480700	Hovey Creek near Cle Elum
12483800	Naneum Creek near Ellensburg
12488300	American River tributary near Nile
12488500	American River near Nile
12500500	North Fork Ahtanum Creek near Tampico
12501000	South Fork Ahtanum Creek at Conrad Ranch, near Tampico
14107000	Klickitat River above West Fork, near Glenwood
14110000	Klickitat River near Glenwood
14121300	White Salmon River below Cascades Creek, near Trout Lake

Late winter-early spring peak

12423900	Stevens Creek tributary near Moran
12424000	Hangman Creek at Spokane
12427000	Little Spokane River at Elk
12429800	Mud Creek near Deer Park
12431000	Little Spokane River at Dartford
12433300	Spring Creek tributary near Reardan
13344500	Tucannon River near Starbuck
13348000	South Fork Palouse River at Pullman
13348500	Missouri Flat Creek at Pullman
13349300	Palouse River tributary at Colfax
13350500	Union Flat Creek near Colfax
14013500	Blue Creek near Walla Walla
14016500	East Fork Touchet River near Dayton
14016600	Hatley Creek near Dayton
14017000	Touchet River at Bolles
14112000	Little Klickitat River near Goldendale
14112500	Little Klickitat River near Wahkiacus
14113000	Klickitat River near Pitt

TABLE 5.--Average regression errors determined for design streamflow networks

Runoff regime	Z[1]	NS[2]	NY[3]	Average regression error, in percent, for confidence level of: 0.10	0.20	0.25	0.50	0.70	0.80	0.90	0.95
Western Washington:											
Winter and spring peaks:											
Winter peak dominant	QA	12	5	18.8	--	21.9	25.5	29.2	31.6	35.8	39.1
		52	5	18.4	--	20.5	24.3	26.7	29.2	32.0	35.0
		27	10	18.4	--	20.5	24.0	27.0	29.2	32.5	35.8
		62	10	18.4	--	20.0	23.5	26.5	28.7	32.0	34.3
		32	15	18.4	--	20.0	23.8	26.7	29.2	32.0	35.0
		52	20	18.4	--	19.3	25.6	25.8	28.7	32.0	33.3
	SDA	12	5	24.8	--	31.8	43.8	57.2	67.2	83.2	99.0
		52	5	22.8	--	29.4	40.4	51.8	60.1	72.4	85.3
		27	10	20.2	--	24.5	30.8	36.6	40.6	47.2	53.5
		62	10	19.3	--	23.8	30.4	36.1	39.9	46.7	52.9
		32	15	17.9	--	22.1	26.2	32.8	36.3	41.4	46.2
		52	20	16.5	--	21.0	26.2	30.8	31.8	37.6	41.9
	QF	12	5	28.2	--	32.5	36.8	41.2	43.7	48.3	53.1
		52	5	26.7	--	31.6	33.8	38.0	40.1	42.7	46.4
		27	10	26.7	--	30.8	33.8	38.0	40.1	42.7	46.4
		62	10	26.2	--	29.9	33.0	37.1	39.4	41.7	45.7
		32	15	26.7	--	30.1	33.8	37.3	39.9	42.4	46.2
		52	20	26.0	--	28.9	32.5	36.6	39.1	40.9	45.4
	SDF	12	5	32.5	--	40.4	51.8	63.6	72.2	86.4	100.9
		52	5	31.8	--	38.6	47.2	54.9	60.7	69.9	79.2
		27	10	26.0	--	31.3	37.3	42.7	46.2	51.3	56.3
		62	10	25.8	--	30.8	36.6	41.9	44.8	50.2	55.2
		32	15	23.8	--	28.9	35.0	39.6	42.7	47.8	51.8
		52	20	21.9	--	27.0	32.5	37.3	40.4	44.0	48.1
	P50	11	10	31.1	34.0	--	41.4	46.2	49.7	55.2	60.7
		31	10	28.9	32.0	--	38.1	42.7	44.6	48.9	52.1
		51	10	28.2	31.8	--	37.6	41.9	43.5	47.8	50.2
		31	19	27.2	31.3	--	37.1	41.7	43.2	47.2	49.7
		11	20	28.9	32.5	--	39.4	44.0	47.5	52.1	56.2
		31	20	27.2	31.3	--	37.1	41.7	42.9	47.0	49.4
		51	20	26.7	31.1	--	36.8	40.9	42.4	45.4	48.3
Spring peak dominant	QA	11	5	16.2	--	17.4	20.5	22.8	24.3	27.0	29.4
		51	5	14.8	--	16.7	19.5	20.7	22.8	24.3	26.5
		26	10	14.4	--	16.7	19.5	20.7	22.1	24.0	26.0
		61	10	14.1	--	16.5	19.5	20.5	21.7	23.5	25.3
		31	15	14.1	--	16.5	19.1	20.7	21.7	23.8	25.5
		51	20	13.7	--	16.5	18.1	20.0	21.0	23.3	24.5
	SDA	11	5	13.7	--	21.4	35.0	49.4	59.5	75.3	89.9
		51	5	11.8	--	19.1	32.8	45.6	54.0	67.2	79.9
		26	10	8.7	--	12.7	19.8	26.5	31.1	38.6	45.9
		61	10	8.2	--	12.0	18.8	25.8	30.6	38.1	45.4
		31	15	7.1	--	10.8	16.0	20.7	24.0	29.9	35.6
		51	20	6.0	--	10.1	13.9	17.9	20.7	25.5	30.1

Runoff regime	Z[1]	NS[2]	NY[3]	Average regression error, in percent, for confidence level of: 0.10	0.20	0.25	0.50	0.70	0.80	0.90	0.95
Winter peak dominant	QA	12	25	18.6	--	21.7	25.3	29.6	31.6	35.8	39.9
		27	25	18.4	--	22.1	23.3	26.5	29.2	32.0	34.3
		12	50	18.6	--	21.4	25.8	28.7	30.6	34.3	38.1
		27	50	18.4	--	19.8	23.8	26.5	28.7	32.0	35.0
		52	50	18.4	--	19.1	25.6	25.5	28.7	32.0	33.3
	SDA	12	25	17.7	--	22.1	28.0	33.0	36.6	41.9	47.2
		27	25	16.5	--	21.0	26.0	30.6	32.8	37.3	41.2
		12	50	16.2	--	21.0	26.0	30.6	33.0	37.8	42.2
		27	50	15.8	--	20.5	25.5	28.2	31.3	35.0	38.1
		52	50	15.5	--	20.2	24.5	27.5	30.8	33.5	37.3
	QF	12	25	27.7	--	32.0	36.1	40.4	42.9	47.8	52.6
		27	25	26.2	--	29.4	33.3	37.1	39.6	41.9	46.2
		12	50	27.0	--	31.8	34.5	39.4	41.4	46.2	50.0
		27	50	26.2	--	29.6	33.0	36.8	39.6	41.9	46.2
		52	50	26.0	--	28.4	32.5	36.3	39.1	40.6	45.4
	SDF	12	25	23.8	--	29.6	36.3	41.7	45.4	51.3	57.5
		27	25	21.9	--	27.0	32.8	37.6	40.6	44.6	48.6
		12	50	21.9	--	27.5	33.5	38.9	42.4	47.5	52.1
		27	50	20.7	--	26.0	31.6	36.8	38.9	43.2	47.5
		52	50	20.7	--	26.0	31.3	36.3	37.8	42.4	45.4
	P50	11	40	24.0	32.0	--	38.6	43.2	46.2	50.5	54.5
		31	40	26.5	31.1	--	36.8	40.4	42.7	45.4	48.6
		51	40	26.2	30.8	--	36.6	39.1	42.2	44.0	48.1
		11	50	27.7	31.8	--	38.6	43.2	45.9	50.2	54.3
		31	50	26.5	31.1	--	36.8	40.1	42.4	45.1	48.6
		51	50	26.0	30.8	--	36.6	38.6	42.2	43.7	48.1
Spring peak dominant	QA	11	25	15.1	--	17.0	20.0	22.1	23.8	26.5	29.2
		26	25	13.7	--	16.5	18.8	20.2	21.4	23.5	25.0
		11	50	14.4	--	16.7	19.8	21.2	23.3	25.3	28.0
		26	50	13.7	--	16.5	18.6	20.2	21.4	23.5	25.5
		51	50	13.4	--	16.2	17.4	20.0	20.5	23.3	24.0
	SDA	11	25	6.9	--	10.6	14.8	18.8	21.7	26.2	30.6
		26	25	6.0	--	9.4	13.0	16.7	19.3	23.3	27.4
		11	50	5.8	--	8.5	12.0	15.3	17.2	20.2	23.3
		26	50	5.3	--	7.1	10.8	13.9	16.0	18.6	21.2
		51	50	5.0	--	6.9	10.6	13.4	15.5	17.9	20.7

TABLE 5.--Average regression errors determined for desiⁿ streamflow networks--Continued

Runoff regime	Z[1]	NS[2]	NY[3]	0.10	0.20	0.25	0.50	0.70	0.80	0.90	0.95
				Average regression error, in percent, for confidence level of:							
Western Washington--continued											
Spring peak dominant (continued)	QF	12	5	24.5	--	28.2	32.3	36.6	39.9	45.4	51.3
		52	5	23.1	--	27.2	29.6	33.3	35.8	40.4	45.4
		27	10	22.8	--	26.0	28.9	31.6	33.8	36.8	39.9
		62	10	22.4	--	25.5	28.4	30.8	33.3	36.3	39.4
		32	15	22.4	--	25.3	28.4	30.6	32.8	35.3	37.8
		52	20	22.1	--	24.5	28.0	29.2	31.1	33.8	36.1
	SDF	12	5	32.3	--	40.6	55.4	72.4	85.6	107	132
		52	5	30.8	--	37.8	50.5	64.4	75.0	92.0	112
		27	10	26.2	--	31.8	38.4	45.1	50.2	59.2	68.7
		62	10	26.0	--	31.3	37.6	44.3	49.4	58.6	68.4
		32	15	24.8	--	29.9	35.3	40.1	43.7	50.5	52.5
		52	20	22.6	--	27.5	32.8	37.1	39.9	44.3	49.7
	P50	12	10	20.5	24.3	--	31.3	36.8	41.2	48.9	56.4
		32	10	18.4	22.4	--	28.9	33.3	36.8	43.5	50.8
		52	10	17.9	21.9	--	26.7	32.3	35.6	41.7	48.9
		41	28	15.3	19.8	--	25.8	28.0	30.8	32.8	35.8
		12	20	17.2	21.4	--	28.0	32.0	34.8	39.6	44.0
		32	20	16.0	20.7	--	26.2	29.9	32.0	35.3	39.1
Winter peak	QA	11	5	20.7	--	23.1	26.5	29.4	31.3	34.5	37.6
		26	10	20.2	--	21.4	24.8	28.0	29.2	31.8	33.5
		31	15	19.8	--	21.4	24.8	27.7	28.7	31.3	33.0
	SDA	11	5	22.4	--	29.2	41.2	55.1	65.3	81.4	97.2
		51	5	21.2	--	26.7	38.1	50.2	58.6	71.8	84.5
		26	10	17.7	--	21.9	27.7	33.3	37.3	44.3	51.0
		61	10	17.2	--	21.4	27.0	32.5	36.8	43.7	50.8
		31	15	16.5	--	20.7	25.3	29.2	32.0	37.1	42.4
		51	20	15.5	--	20.0	23.1	26.7	29.2	33.0	37.1
	QF	12	5	43.7	--	48.9	55.8	62.4	65.6	72.8	79.3
		52	10	41.7	--	46.4	52.9	57.2	60.9	65.0	69.9
		32	15	41.4	--	46.2	52.9	57.2	60.4	64.2	69.0
	SDF	11	5	61.2	--	70.2	83.1	96.4	106	127	151
		26	10	53.7	--	60.7	68.7	75.3	79.9	86.3	92.0
		31	15	53.2	--	59.8	67.2	73.7	77.6	83.1	72.4
	P50	12	10	48.6	54.0	--	63.6	70.9	76.3	84.5	92.7
		32	10	47.5	50.8	--	60.1	65.3	68.4	74.0	78.9
		52	10	46.7	49.7	--	59.5	63.3	67.2	72.4	76.3
		33	22	45.6	49.4	--	58.4	63.0	66.8	72.8	76.0
		12	20	48.1	53.2	--	62.1	69.0	74.0	81.4	88.8
		32	20	46.2	49.4	--	58.9	63.3	67.2	72.8	76.3

Runoff regime	Z[1]	NS[2]	NY[3]	0.10	0.20	0.25	0.50	0.70	0.80	0.90	0.95
				Average regression error, in percent, for confidence level of:							
Spring peak dominant (continued)	QF	12	25	22.8	--	26.5	29.4	32.8	34.8	38.6	42.4
		27	25	22.1	--	24.8	28.0	29.4	31.6	34.0	36.3
		12	50	22.4	--	25.3	28.7	30.8	33.3	36.3	39.6
		27	50	21.9	--	24.3	27.7	29.2	30.6	33.5	35.8
		52	50	21.9	--	23.8	27.7	28.4	29.4	33.3	34.5
	SDF	12	25	24.3	--	29.6	35.6	40.6	44.3	50.8	57.8
		27	25	22.1	--	29.9	32.3	36.8	39.4	43.5	48.1
		12	50	21.7	--	27.2	32.5	37.1	39.9	44.3	49.1
		27	50	20.7	--	25.9	31.1	34.5	36.8	40.1	43.2
		52	50	20.5	--	25.8	30.8	31.8	36.6	38.6	42.2
	P50	52	20	15.8	20.5	--	26.0	28.9	31.3	34.3	37.8
		12	40	15.5	20.2	--	26.2	29.6	32.0	35.3	38.6
		32	40	14.4	18.6	--	25.5	27.2	29.9	32.0	34.3
		52	40	13.9	17.9	--	25.3	26.7	28.9	31.6	33.3
		12	50	14.8	19.3	--	26.0	29.2	31.6	34.5	37.6
		32	50	13.7	17.7	--	25.0	27.0	28.9	31.8	33.3
		52	50	13.2	17.2	--	24.3	26.5	28.2	31.3	32.5
Winter peak	QA	11	25	20.5	--	22.4	26.0	29.4	31.3	35.0	38.4
		26	25	19.5	--	21.2	24.5	27.7	28.4	31.3	33.0
		11	50	20.5	--	21.7	25.3	28.4	30.3	33.0	36.3
	SDA	11	25	16.2	--	20.7	25.0	28.9	31.8	36.6	41.2
		26	25	15.5	--	19.3	22.6	26.5	28.4	32.0	35.6
		11	50	15.5	--	18.8	22.4	26.2	28.2	31.8	35.0
		26	50	15.3	--	17.2	21.2	25.0	26.5	28.9	31.6
		51	50	15.3	--	16.7	21.0	24.0	26.0	28.0	30.8
	QF	12	25	42.7	--	47.8	55.5	61.8	66.5	73.7	80.6
		12	50	42.2	--	47.2	54.0	60.4	63.6	70.9	77.2
	SDF	11	25	54.0	--	61.2	70.9	79.2	78.9	96.4	107
		11	50	53.2	--	60.1	68.1	76.0	81.0	89.2	99.0
	P50	52	20	44.6	48.9	--	56.9	61.8	66.5	70.6	74.4
		12	40	47.8	52.6	--	61.5	68.4	73.1	79.9	86.7
		32	40	44.6	48.9	--	57.8	62.4	66.8	71.8	75.6
		52	40	43.7	48.3	--	55.9	61.2	66.2	69.3	74.0
		12	50	47.8	52.1	--	61.5	68.1	72.8	79.6	86.3
		32	50	44.3	48.9	--	57.5	62.4	66.8	71.5	75.3
		52	50	43.5	48.3	--	55.7	61.2	66.2	69.0	74.0

TABLE 5.--Average regression errors determined for design streamflow networks--Continued

Runoff regime	Z[1]	NS[2]	NY[3]	Average regression error, in percent, for confidence level of: 0.10	0.20	0.25	0.50	0.70	0.80	0.90	0.95	Z[1]	NS[2]	NY[3]	Average regression error, in percent, for confidence level of: 0.10	0.20	0.25	0.50	0.70	0.80	0.90	0.95
Eastern Washington:																						
Spring peak	QA	11	5	25.8	--	30.1	35.6	40.4	44.1	49.1	54.9	QA	11	25	25.3	--	29.9	35.0	40.4	44.0	50.2	56.3
		26	10	25.0	--	28.0	33.8	37.8	40.4	44.8	49.1		11	50	25.3	--	29.4	34.3	39.4	42.7	48.3	53.7
		31	15	24.5	--	27.5	33.0	37.6	40.4	44.8	49.1											
	SDA	11	5	40.1	--	48.9	61.5	74.7	84.5	102	120	SDA	11	25	32.8	--	39.4	48.1	55.7	61.2	69.9	78.2
		51	5	37.8	--	45.9	56.6	66.8	74.0	85.6	97.9		26	25	31.3	--	37.1	44.0	50.5	54.9	61.2	67.5
		26	10	33.8	--	40.4	48.3	55.4	60.4	67.5	74.0		11	50	31.8	--	37.6	45.6	53.2	57.8	65.6	73.4
		61	10	33.0	--	39.6	47.8	54.5	59.5	66.5	73.1		26	50	31.1	--	36.6	42.9	49.1	54.0	60.4	66.5
		31	15	32.3	--	38.4	46.2	53.2	57.2	64.2	70.3		51	50	30.8	--	36.3	42.4	48.6	53.5	59.5	63.9
		51	20	31.3	--	36.8	43.7	50.2	54.5	60.7	66.5											
	QF	11	5	47.2	--	54.6	65.6	77.9	88.4	109	132	QF	11	25	41.2	--	46.4	53.5	59.8	64.7	72.8	82.1
		26	10	41.4	--	46.7	52.6	58.1	61.8	67.5	73.4		11	50	39.3	--	45.4	51.6	56.9	60.7	66.5	73.4
		31	15	40.1	--	45.6	51.3	56.3	59.2	64.2	69.3											
	SDF	11	5	53.7	--	60.4	67.8	75.0	79.2	88.4	97.2	SDF	11	25	52.1	--	59.2	65.9	73.1	77.6	86.3	94.6
		26	10	51.3	--	56.6	62.4	68.1	71.5	76.6	81.0		11	50	51.6	--	58.4	63.9	70.2	75.0	81.4	89.2
		31	15	51.0	--	55.7	61.8	67.5	70.9	76.0	79.2											
	P50	11	10	43.5	48.9	--	58.1	65.3	70.6	78.9	88.4	P50	51	20	39.6	43.5	--	51.3	55.4	55.9	63.0	67.2
		31	10	42.2	47.0	--	54.3	60.1	63.0	68.7	74.4		11	40	41.4	45.9	--	54.5	60.7	64.4	70.9	76.6
		51	10	41.9	45.6	--	53.7	58.4	61.2	66.8	71.8		31	40	38.6	43.2	--	51.0	55.4	59.8	63.0	67.2
		38	24	39.6	43.5	--	51.6	55.7	59.8	63.3	67.5		51	40	38.1	42.7	--	49.7	54.6	58.4	61.5	66.2
		11	20	42.2	47.5	--	55.7	62.1	66.5	73.4	79.9		11	50	40.9	45.6	--	54.6	60.4	64.2	70.2	76.0
		31	20	40.4	44.3	--	52.9	56.9	60.7	65.0	69.0											
Late winter-early spring peak	QA									---- no data ----												
	SDA									---- no data ----												
	QF	31	15	47.2	--	54.9	64.7	72.8	78.2	86.0	93.1											
	SDF									---- no data ----												
	P50	11	10	72.1	83.8	--	111	133	150	178	208	P50	51	20	66.2	75.0	--	96.1	113	122	141	157
		31	10	68.4	79.6	--	102	119	132	152	170		11	40	68.1	79.9	--	104	124	139	163	188
		51	10	67.5	77.9	--	99.0	116	127	146	164		31	40	65.9	74.7	--	96.4	113	123	142	160
		18	24	67.5	78.2	--	101	118	132	152	171											
		11	20	69.3	81.0	--	106	126	142	168	195											
		31	20	66.5	76.3	--	97.9	115	125	145	162											

[1] Streamflow characteristic: QA and SDA are mean and standard deviation of annual mean flows; QF and SDF are mean and standard deviation of annual peak flows; and P50 is the floodflow for an exceedance probability of 2 percent.

[2] Number of stations in the design network.

[3] Harmonic mean record period, in years, for stations in the design network.

TABLE 6.--Network design for study stations in operation after 1975 water year and additional long-term-trend stations selected for each runoff regime

Column 1: C, continuous record of flow; A, annual peak flow determined.

Column 2: C, current-data station; S, research or special-study station; L, long-term-trend station; H, hydrologic station for regionalization of streamflow characteristics.

Column 3: Financing of station: 1, Federal; 2, cooperative program with State or local governments; 3, other Federal agency; 4, combination of 2 and 3; 5, Federal Power Commission.

Column 4: C, recommend continue in operation; D, recommend discontinue operation.

Station number	Station name	Column 1	Column 2	Column 3	Column 4
	Winter-Spring Peaks, with Winter Peak Dominant				
12039500	Quinault River at Quinault Lake	C	C	1	C
12040500	Queets River near Clearwater	C	S	3	C
12041500	Soleduck River near Fairholm	A	S	2	D
12054500	Hamma Hamma River near Eldon	A	S	2	D
12054600	Jefferson Creek near Eldon	A	S	2	D
12060500	South Fork Skokomish River near Union	C	LC	2	C
12083000	Mineral Creek near Mineral	C	C	2	C
12095000	South Prairie Creek at South Prairie	A	S	2	D
12117000	Taylor Creek near Selleck	C	H	2	D
12132700[a]	South Fork Skykomish River tributary at Baring	A	L	2	C
12135000	Wallace River at Gold Bar	C	H	2	D
12142000	North Fork Snoqualmie River near Snoqualmie Falls	C	C	2	C
12143000	North Fork Snoqualmie River near North Bend	A	S	2	D
12149000	Snoqualmie River near Carnation	C	C	2	C
12161000	South Fork Stillaguamish River near Granite Falls	C	C	2	C
12167000	North Fork Stillaguamish River near Arlington	C	C	2	C
12178100	Newhalem Creek near Newhalem	C	L	2	C
12189400[a]	Sauk River tributary near North Bend	A	L	2	C
12209000	South Fork Nooksack River near Wickersham	C	H	2	D
14128500	Wind River near Carson	C	C	2	C
14143500	Washougal River near Washougal	C	C	3	C
14235500	West Fork Tilton River near Morton	A	S	2	D
14236200	Tilton River above Bear Canyon Creek, near Cinebar	C	C	2	C
14242500	Toutle River near Silver Lake	C	LC	2	C
	Winter-Spring Peaks, with Spring Peak Dominant				
12048000	Dungeness River near Sequim	C	A	2	D
12054000	Duckabush River near Brinnon	C	L	2	C
12056500	North Fork Skokomish River below Staircase Rapids, near Hoodsport	C	C	2	C
12082500	Nisqually River near National	C	C	2	C
12092000	Puyallup River near Electron	C	C	2	C
12094000	Carbon River at Fairfax	C	C	3	C
12097500	Greenwater River at Greenwater	C	H	2	D
12104000	Friday Creek near Lester	C	C	2	C
12104500	Green River near Lester	C	C	2	C
12114000	South Fork Cedar River near Lester	C	L	2	C
12115000	Cedar River near Cedar Falls	C	C	2	C
12115300	Green Point Creek near Cedar Falls	A	L	2	C
12115500	Rex River near Cedar Falls	C	C	2	C
12133000	South Fork Skokomish River near Index	C	H	1	D
12134500	Skykomish River near Gold Bar	C	C	2	C
12144000	South Fork Snoqualmie River at North Bend	A	C	2	C
12144500	Snoqualmie River at Snoqualmie	C	C	2	C
12186000	Sauk River above Whitechuck Creek near Darrington	C	L	2	C
12189500	Sauk River near Sauk	C	C	1	C
12204400	Nooksack River tributary near Glacier	A	L	2	C

TABLE 6.--Network design for study stations in operation after 1975 water year and additional long-term-trend stations selected for each runoff regime--Continued

Station number	Station name	Column 1	Column 2	Column 3	Column 4
12205000	North Fork Nooksack River below Cascade Creek, near Glacier	C	C	2	C
12210500	Nooksack River at Deming	C	C	2	C
14213500	Big Creek below Skookum Meadow, near Trout Lake	A	S	2	D
14216000	Lewis River above Muddy River near Cougar	A	S	2	D
14226500	Cowlitz River at Packwood	C	C	2	C
14226800	Skate River tributary near Packwood	A	L	2	C
14232500	Cispus River near Randle	C	LC	2	C
14233400	Cowlitz River near Randle	C	C	5	C
	Winter Peak				
12010000	Naselle River near Naselle	C	L	2	C
12020000	Chehalis River near Doty	C	L	2	C
12025000	Newaukum River near Chehalis	C	C	2	C
12027500	Chehalis River near Grand Mound	C	LC	2	C
12031000	Chehalis River at Porter	C	C	2	C
12034700[a]	West Fork Satsop River tributary near Matlock	A	L	2	C
12035000	Satsop River near Satsop	C	C	2	C
12039000	Humptulips River at Humptulips	C	H	2	D
12039300[a]	North Fork Quinault River near Amanda Park	C	L	1	C
12042900	Grader Creek near Forks	A	S	2	D
12050500	Snow Creek near Maynard	A	S	2	D
12065500	Gold Creek near Bremerton	A	S	2	D
12068500	Dewatto River near Dewatto	A	S	2	D
12072000	Chico Creek near Bremerton	A	S	2	D
12073500	Huge Creek near Wauna	C	L	2	C
12076500	Goldsborough Creek near Shelton	A	S	2	D
12108500	Newaukum Creek near Black Diamond	C	C	3	C
12113300	Mill Creek tributary near Auburn	A	S	2	D
12124000	Evans Creek above mouth near Raymond	C	H	2	D
12141000	Woods Creek near Monroe	A	S	2	D
12145500	Raging River near Fall City	C	C	2	C
12146000	Patterson Creek near Fall City	A	S	2	D
12147000	Griffin Creek near Tolt	A	S	2	D
12147500	North Fork Tolt River near Carnation	C	LC	2	C
12148100[a]	South Fork Tolt River tributary near Carnation	A	L	2	C
12152500	Pilchuck River near Granite Falls	A	S	2	D
12196000	Alder Creek near Hamilton	A	S	2	D
12201500	Samish River near Burlington	A	S	2	D
14144600	Groeneveld Creek near Camas	A	L	2	C
14222500	East Fork Lewis River near Heisson	C	L	2	C
14237500	Winston Creek near Silver Lake	A	S	2	D
14245000	Coweman River near Kelso	C	L	2	C
14247500	Elochoman River near Cathlamet	A	S	2	D
	Spring Peak				
12175500	Thunder Creek near Newhalem	C	C	5	C
12177500	Stetattle Creek near Newhalem	C	C	5	C
12182500	Cascade River at Marblemount	C	H	2	D
12395800[a]	Deer Creek near Dalkena	A	L	2	C
12396000	Calispell Creek near Dalkena	A	S	2	D
12396100	Winchester Creek near Cusick	A	S	2	D
12401500	Kettle River near Ferry	C	C	3	C
12408500	Mill Creek near Colville	C	L	2	C
12409000	Colville River at Kettle Falls	C	C	2	C
12447390[a]	Andrews Creek near Mazama	C	L	2	C

TABLE 6.--Network design for study stations in operation after 1975 water year and additional long-term-trend stations selected for each runoff regime--Continued

Station number	Station name	Column 1	2	3	4
12451000	Stehekin River at Stehekin	C	C	2	C
12452800	Entiat River near Ardenvoir	C	H	2	D
12454000	White River near Plain	C	L	2	C
12458000	Icicle Creek above Snow Creek, near Leavenworth	A	S	2	D
12461200	East Branch Mission Creek tributary near Cashmere	A	S	2	D
12480700[a]	Hovey Creek near Cle Elum	A	L	2	C
12483800	Naneum Creek near Ellensburg	C	H	2	D
12488500	American River near Nile	C	L	2	C
12500500	North Fork Ahtanum Creek near Tampico	C	C	2	C
12501000	South Fork Ahtanum Creek at Conrad Ranch, near Tampico	C	C	2	C
14107000	Klickitat River above West Fork near Glenwood	C	H	2	D
14110000	Klickitat River near Glenwood	A	S	2	D
14121300	White Salmon River below Cascades Creek, near Trout Lake	C	H	2	D
	Late Winter-Early Spring Peak				
12424000	Hangman Creek at Spokane	C	C	2	C
12427000	Little Spokane River at Elk	A	S	2	D
12431000	Little Spokane River at Dartford	C	LC	2	C
13344500	Tucannon River near Starbuck	C	C	3	C
13348000	South Fork Palouse River at Pullman	C	C	3	C
13348500	Missouri Flat Creek at Pullman	C	C	4	C
13349300	Palouse River tributary at Colfax	A	L	2	C
13350500	Union Flat Creek near Colfax	A	S	2	D
14017000	Touchet River at Bolles	C	LC	2	C
14112000	Little Klickitat River near Goldendale	A	S	2	D
14112500	Little Klickitat River near Wahkiacus	C	C	3	C
14113000	Klickitat River near Pitt	C	C	1	C

[a]Station that is not a study station but one recommended as a long-term-trend station.

TABLE 7.--Summary of regression analyses for floodflows of nonregulated streams in Washington

[Regression equations of form: $PN\% = a\, A_1^{b_1}\, A_2^{b_2}\, A_3^{b_3}$]

Runoff regime[2]	Floodflow, PN%[3]	Number of stations	Regression constant a	Regression coefficient, b_i, for:[1] Drainage area A_1	Precipitation A_2	Area of lakes A_3	Standard error: Log units	Percent	Multiple correlation coefficient
Western Washington:									
Winter and spring peaks:									
Winter peak dominant	P10%	30	1.54	0.89	1.06	--	0.141	33	0.984
	P 4%	30	1.94	.89	1.05	--	.140	33	.984
	P 2%	30	2.21	.89	1.04	--	.140	33	.984
	P 1%	30	2.49	.89	1.04	--	.141	33	.984
Spring peak dominant	P10%	41	.027	.90	1.83	--	.128	30	.991
	P 4%	41	.034	.90	1.84	--	.129	30	.990
	P 2%	41	.049	.89	1.80	--	.126	30	.990
	P 1%	40	.056	.88	1.81	--	.129	30	.989
Winter peak	P10%	97	.27	.89	1.40	--	.189	46	.977
	P 4%	97	.38	.88	1.37	--	.194	47	.975
	P 2%	97	.47	.88	1.36	--	.199	48	.974
	P 1%	97	.57	.87	1.34	--	.203	49	.972
Eastern Washington:									
Spring peak	P10%	38	.082	.85	1.53	--	.204	50	.978
	P 4%	38	.11	.84	1.51	--	.208	50	.977
	P 2%	38	.14	.84	1.50	--	.212	52	.975
	P 1%	38	.16	.83	1.50	--	.218	53	.974
Late winter-early spring peak	P10%	18	5.04	.92	--	-0.46	.285	73	.951
	P 4%	18	6.14	.91	--	-.49	.307	81	.943
	P 2%	18	6.89	.91	--	-.51	.325	87	.936
	P 1%	18	7.67	.91	--	-.53	.341	92	.930

[1] Regression coefficients are significant at the 10-percent level.

[2] Determined from similarity in hydrographs of monthly mean streamflows.

[3] The number following the P indicates an exceedance probability, in percent, for the computed floodflow.