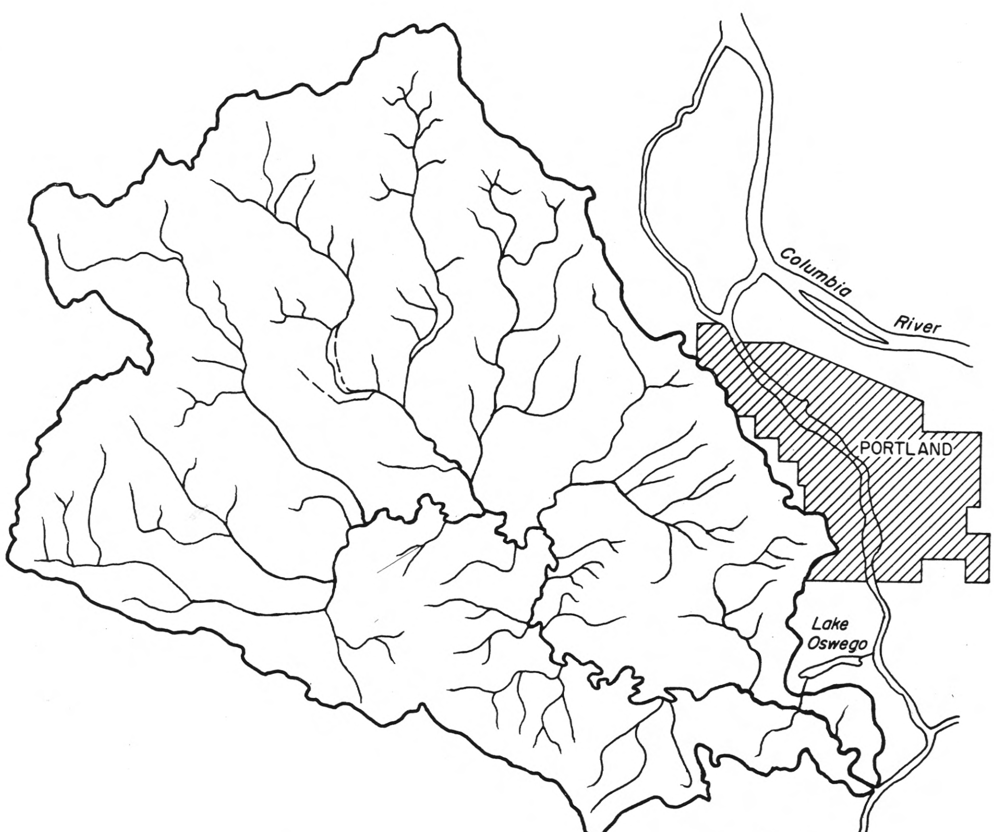
Appraisal of Streamflow in the Tualatin River Basin, Oregon



OPEN-FILE REPORT . . . 1972

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

APPRAISAL OF STREAMFLOW IN THE TUALATIN RIVER BASIN, WASHINGTON COUNTY, OREGON

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By C. H. Swift III

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Prepared in cooperation with Washington County

OPEN-FILE REPORT

Portland, Oregon

1971

CONTENTS

ILLUSTRATIONS

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TABLES

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By C. H. Swift III

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ABSTRACT

This report describes the within-year time distribution of streamflow; the magnitude and frequency of annual minimum, mean, and maximum flows; and the within-year storage required to sustain selected flows in the Tualatin River basin. The report does not include an appraisal of instantaneous peak discharges in the basin.

Data were derived by statistical methods and are adequate for general water-development planning. A duration hydrograph provides a general description of the within-year time distribution of streamflow. Generalized equations based on a sample of gaged flows are presented for estimating magnitude and frequency of flows at ungaged sites. Generalized storage relations are included for estimating storage requirements at gaged and ungaged sites.

INTRODUCTION

Purpose and Scope

Streamflow is a natural resource that varies in magnitude with respect to both time and place. Most of the problems associated with developing, managing, and controlling that resource stem from those variations in magnitude.

The purpose of this report is to appraise streamflow variations in the Tualatin River basin and to provide planners and engineers with the technical data that are essential for sound water-development planning. The data describe the within-year time distribution of streamflow and show the magnitude and frequency of minimum, mean, and maximum flows. Because storage of water is a frequently used method of reducing the natural variability of streamflow, data for determining within-year storage requirements are also presented. The report contains no data on instantaneous peak flows, as flood peaks and inundation in the basin are being studied by the U.S. Army Corps of Engineers.

Statistical techniques were used to analyze basic data from stream-gaging stations because such techniques furnish objective methods of appraising time and place variability. Basic data believed to represent natural or unregulated streamflow were used in the analyses because such data provide a consistent basis for evaluating alterations to the natural flow regimen. General statistical methods used in hydrologic studies are described in a report by Riggs (1968a).

Basic Streamflow Data

Basic data analyzed for this appraisal are records of discharge at stream-gaging stations and current-meter measurements of discharge at supplemental sites.

The U.S. Geological Survey, in cooperation with other agencies, has operated 11 stream-gaging stations in the Tualatin River basin, nine of which stations are used in this appraisal. To obtain a better statistical sample of streamflow time and place distributions, records for 18 stations adjacent to the Tualatin River basin are also included in the appraisal. The 27 station records analyzed are identified in table 1 by stream name, place name, and station number. Also shown in table 1 are period of record analyzed, drainage area, and mean annual precipitation for each stream basin.

Locations of the 11 stream-gaging stations in the Tualatin River basin are shown in figure 1. Station and site numbers are in downstream order. An 8-digit numbering system is used, but nonessential zeros and the first four digits are eliminated in this report (for example, 14-2075.00 is shown as 75.0). Records for stations 50.0 and 70.0 were not used in the statistical analyses for this report because those for station 50.0 are insufficient in length and those for station 70.0 are records of diversion to Lake Oswego.

Current-meter measurements of discharge have been made by several different agencies at about 70 supplemental sites in the basin. Those measurements were used to estimate certain streamflow characteristics for this report. Locations and abbreviated identification numbers for all gaging stations and supplemental-measurement sites in the basin are shown on plate 1.

Records of discharge at gaging stations and at some supplemental-measurement sites in the basin have been published in water-supply papers and open-file reports of the U.S. Geological Survey. Records of measurements at other sites in the basin are contained in publications of the Oregon State Engineer, the Oregon State Game Commission, and the Oregon State Water Resources Board. Summaries of annual low flows and annual high flows at nine of the gaging stations in the basin have been published by the U.S. Geological Survey (Swift, 1966, p. 154-165).

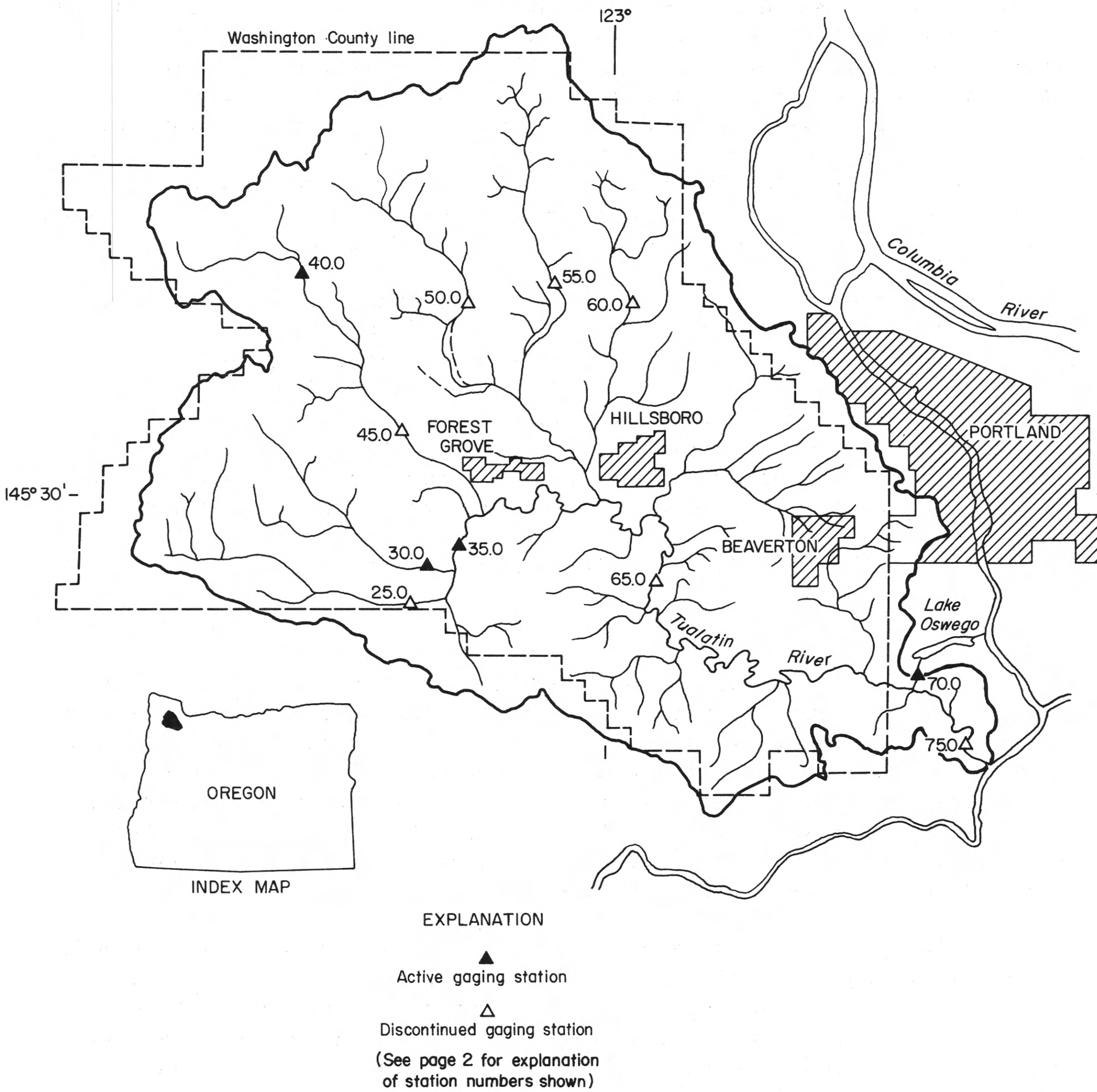

Figure 1.--Locations of stream-gaging stations in the Tualatin River basin.

Acknowledgments

This report is the result of a cooperative program between the Washington County Board of Commissioners and the U.S. Geological Survey, Water Resources Division, Oregon District. Credit is due Mr. Larry A. Bissett, former director, City-County Planning Staff; Mr. Kenneth A. Meng, chief, Engineering Division, Washington County; Mr. Dale C. Johnson, director, Washington County Department of Planning; and Mr. Richard Milbrodt, Washington County administrative officer, for their combined efforts in planning and developing this program. The report was prepared by the U.S. Geological Survey under the general supervision of Stanley F. Kapustka, district chief, Oregon District.

Acknowledgment is made to the following agencies that have cooperated through the years in collection of streamflow records in the Tualatin River basin: the office of the Oregon State Engineer, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation. Credit is also due the following agencies that have contributed their records of discharge measurements at numerous sites in the basin: the office of the Oregon State Engineer, the Oregon State Game Commission, the Fish Commission of Oregon, and the U.S. Army Corps of Engineers.

WITHIN-YEAR TIME DISTRIBUTION OF STREAMFLOW

Daily Flows

One of the basic problems confronting water-development planners stems from variations in streamflow that seldom coincide with variations in demand for water within a year; that is, streamflow may be low when water is needed most and high when needed least. To best control and utilize the streamflow resource, the planner needs to know when flows are likely to be low or high. Information on the natural variability of flows within a year can be of value in planning for efficient use of water and is presented in this section.

A daily-discharge hydrograph portrays the discharge of a stream in chronological sequence throughout a selected period of time. It is usually prepared from gaging-station records to isolate a complete annual cycle of either high or low flow. The hydrograph year is either (1) a water year ended September 30 and designated by the calendar year in which it ended or (2) a climatic year begun April 1 and designated by the calendar year in which it began.

The discharge hydrograph shown in figure 2 portrays the streamflow discharged from the Tualatin River basin each day of the 1965 water year; it indicates the extent to which streamflow varied from day to day during that year and illustrates the seasonal pattern of streamflow characteristic of most years. For each day, the discharges shown represent the daily mean discharge in the Tualatin River at gaging station 75.0 added to the daily mean discharge in the Oswego Canal diversion to Lake Oswego at gaging station 70.0. The record of those combined discharges is referred to hereafter as record for station 75.0.

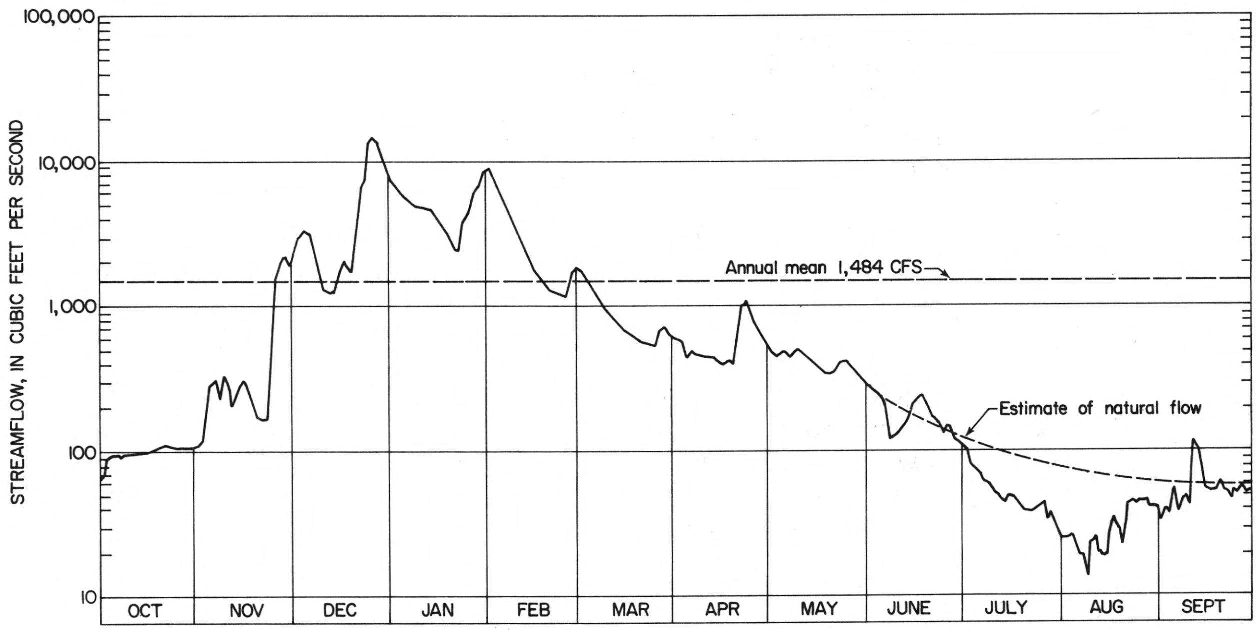

Figure 2.--Hydrograph of streamflow discharged from the Tualatin River basin during the 1965 water year.

Figure 2 shows occasional rapid decreases in streamflow during June to September that are caused by water diverted in addition to that at Oswego Canal. The dashed line that represents natural streamflow for June-September 1965 simulates the general shape of spring to summer recessions during years when there were few, if any, additional diversions. According to that estimated recession, additional diversion reduced total flow from the basin for the 1965 water year by less than 1 percent, flow for the 4 summer months by about 30 percent, and flow on some days by as much as 80 percent.

Both the natural flow of a stream and the demands made on that flow, such as diversion for irrigation or municipal water supply, vary from one year to the next. Demand on flow varies somewhat regularly or progressively from year to year, whereas natural streamflow varies irregularly. Over a period of years, variation in the mean discharges of a stream for any particular day or within-year period of days may be considerable. For instance, annual discharge from the Tualatin River basin ranged from as little as 49 percent to as much as 178 percent of the average annual discharge of 1,487 cfs (cubic feet per second) during the period 1929-63.

A duration hydrograph illustrates when flows are likely to be lowest or highest by showing the extent of variation in daily flows over a period of years. It shows the range in daily flows that has been observed and associates daily magnitude of flow with the percentage of time that that magnitude has been exceeded.

The duration hydrograph shown in figure 3 represents the percentage of years the indicated daily mean discharges were exceeded on each calendar date during 1929-47 at station 75.0. That 19-year period was selected, even though record from 1929-67 is available for station 75.0, because diversion had much less effect on daily mean discharges during that early period than it does now. Station 75.0 was selected because no other station in the basin has a record of natural or nearly natural flow for that many years. However, the duration hydrograph shown probably is typical of the general seasonal pattern of flow that would be found for other streams in the basin for the same period of record, 1929-47.

Although both daily-discharge hydrographs and duration hydrographs present discharges chronologically and exhibit similar seasonal patterns, they cannot be interpreted in the same way. Daily-discharge hydrographs show the actual sequence in which streamflow varied during particular years. In a daily-discharge hydrograph, discharge for any one day is influenced by the discharge for the previous day. Duration hydrographs show the extent to which streamflow might vary over a period of years. Day-to-day discharges shown in duration hydrographs are usually not related except perhaps for a few very short periods of days; that is, duration hydrographs do not usually show the actual sequence in which flows might vary during any one year.

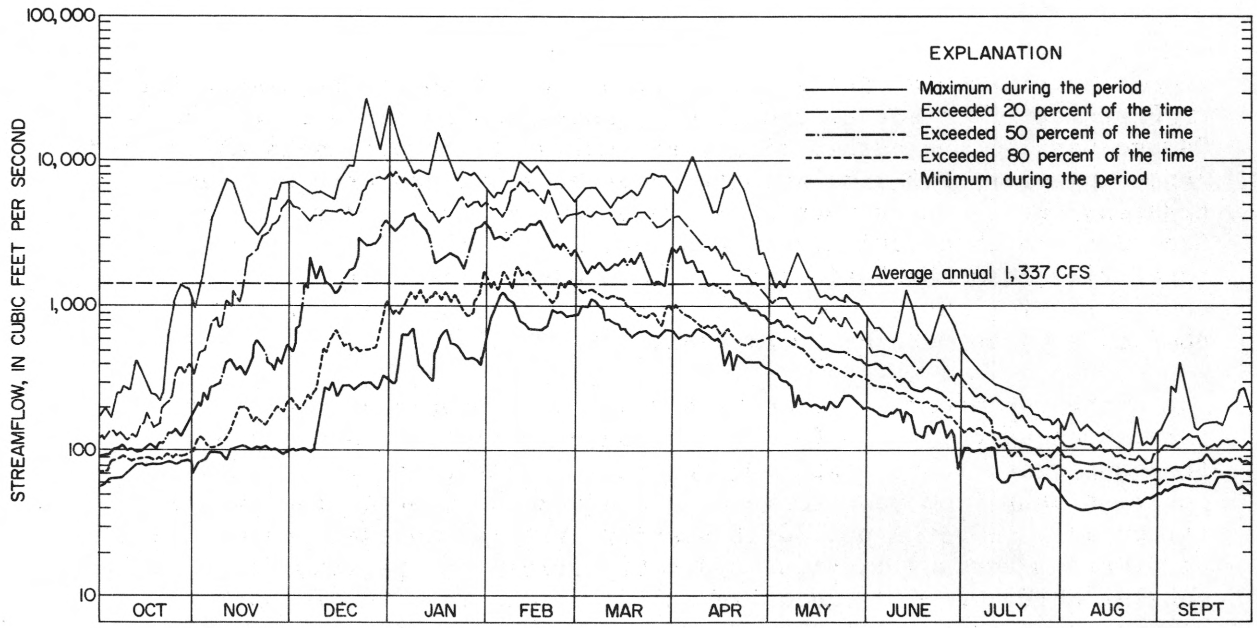

Figure 3.--Duration hydrograph of streamflow discharged from the Tualatin River basin during the 19-year period, 1929-47.

Duration hydrographs do, however, describe the "when" of streamflow in terms of the likelihood that discharges on a given day within a future year will exceed certain magnitudes. It is assumed that the variability of natural streamflow that occurred in the past is representative of the variability that may be expected in the future. On the basis of this assumption, there is a 60-percent chance that future discharges will be within the limits of the 20- and 80-percent graphs (fig. 2). Also, because the minimum graph represents the lowest daily flows in 19 years of record, there is a 1 in 19 chance or a 5-percent chance that future flows will be equal to or less than the minimum flows shown.

Monthly Flows

The bar graphs in figure 4 are similar in concept and meaning to the duration hydrographs, but describe the variability of monthly mean flows and volumes of flow instead of the variability of daily mean flows. The graphs again represent record for station 75.0, but discharge and volume were plotted on a linear scale to place high flows and low flows in proper perspective. The graphs show the maximum, minimum, and median (flow exceeded 50 percent of the time), and average monthly mean flows.

In the Tualatin River basin, there is a great difference between the volumes of streamflow occurring during the rainy winter months and those occurring during the summer growing season. The average annual volume of water discharged from this basin is about 1 million acre-feet, but not all this water is available when needed. On the average, only about 10 percent of that volume is discharged during May through October and only about 4 percent during June through September. In contrast, about 40 percent of the average annual volume is discharged from the basin during January and February and about 70 percent during December through March.

MAGNITUDE AND FREQUENCY OF STREAMFLOW

Frequency Curves

A serious problem confronting planners is the variation in magnitude of annual low, mean, and high flows that occurs from year to year. For sound utilization and control of the streamflow resources, consideration should be given to how often flows are likely to reach certain minimums or maximums. The likelihood of exceeding a particular high flow or not exceeding a particular low flow can be estimated from frequency curves based on past records of flow.

A frequency curve of streamflow relates magnitude of discharge to recurrence interval. Recurrence interval, or return period as it is sometimes called, is the average length of time in years between exceedences or nonexceedences of a particular magnitude of discharge.

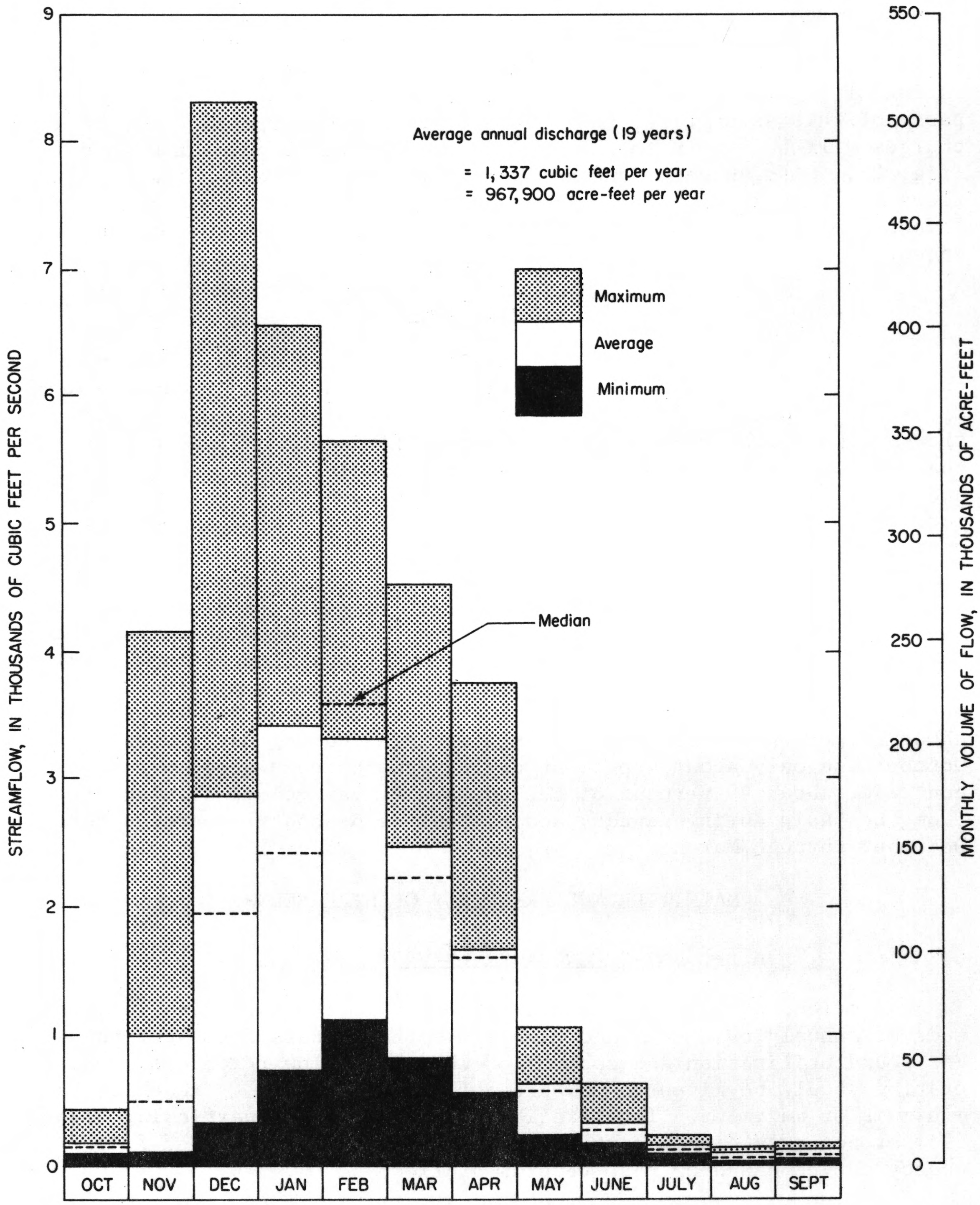

Figure 4.--Bar graphs summarizing monthly mean streamflow discharged from the Tualatin River basin during the 19-year period, 1929-47.

The frequency curves shown in figure 5 span the entire range of streamflow, except for instantaneous flood peaks, in the Tualatin River at station 75.0. These curves were prepared according to graphical fitting methods described by Riggs (1968b). The discharges shown represent lowest mean and highest mean discharges for selected durations, or periods of consecutive days, ranging from 1 day to 1 year. Highest mean discharges and all 365-day (annual mean) flows are based on water-year periods, and lowest mean discharges are based on climatic-year periods. As an example of how the curves are interpreted, at average intervals of 2 years, discharge from the Tualatin River basin can be expected to exceed an annual maximum 7-day mean of 8,100 cfs or to fall below an annual minimum 7-day mean of 64 cfs. Flows at a 2-year recurrence interval are sometimes called median-annual flows because they represent the middle value of annual flows when annual flows for a given duration are arranged in order of magnitude.

Frequency curves were prepared for all nine gaging stations in the basin, and selected data from those curves are summarized in table 2. The summary data represent (1) lowest mean discharges corresponding to selected durations and recurrence intervals between nonexceedences, (2) average annual flows, and (3) highest mean discharges corresponding to selected durations and recurrence intervals between exceedences.

Frequency curves were also prepared for 18 gaging stations (identified in table 1) on streams adjacent to the Tualatin River basin. Data from those curves are not summarized here, but are available for inspection in the office of the U.S. Geological Survey, Oregon District, Portland, Oreg. The curves for those 18 gaging stations were defined by log-Pearson Type III probability analysis, which is described in Bulletin 15 prepared by the Hydrology Committee of the Water Resources Council (1967).

Generalization of Magnitude and Frequency

One of the principal reasons for collecting streamflow data is to provide a basis for generalized definition of the occurrence of water in all streams, gaged or ungaged. Generalized streamflow information is needed by planners and engineers if they are to develop comprehensive plans for water utilization and control.

Multiple regression is the most efficient of presently available methods of generalizing streamflow information. It is a statistical method of relating streamflow characteristics to topographic and climatic characteristics of drainage basins that affect streamflow. This method is described by Thomas and Benson (1969).

Briefly, multiple regression is an analysis technique that provides a mathematical equation of the most accurate relation between a single dependent variable (a particular characteristic of streamflow) and whatever independent variables (topographic and climatic characteristics) are used. It also provides a measure of the accuracy of the developed equation by showing the range of errors (known as the standard error of estimate) that may be expected from use of the equation. Approximately

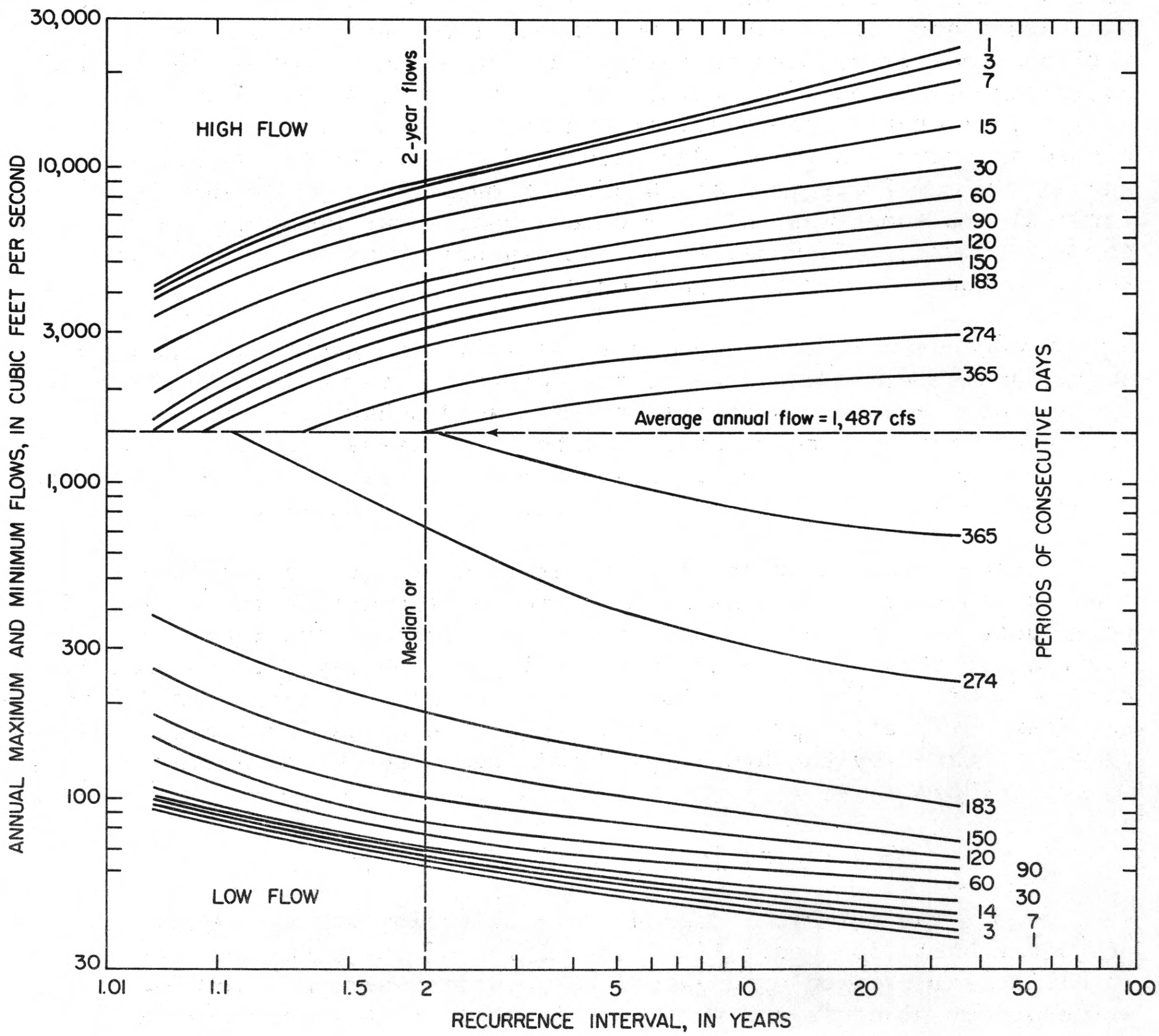

Figure 5.--Frequency curves of annual maximum and minimum flows discharged from the Tualatin River basin.

two-thirds of the times that the equation is used, it provides estimates of a streamflow characteristic accurate to within one standard error, and approximately 95 percent of the times it provides estimates accurate to within two standard errors.

Multiple regression was used to test, by statistical significance and improvement in standard error, the effectiveness of several topographic and climatic characteristics in describing the variability of selected magnitude and frequency data among the 27 gaging stations used in this report. The topographic and climatic characteristics tested were drainage area in square miles, area-weighted mean basin altitude in feet, slope of main channel between gage and basin border in feet per mile, and area-weighted mean annual precipitation in inches on each basin. Low flows are controlled by subsurface characteristics for which no variable can be obtained simply. Because experience in similar analyses has shown that the use of some low-flow indexes can improve the relations, the median annual 7-day minimum flows were included as independent variables(referred to as "7-day low flow" on Plate 1).

Generalization of Annual Minimum Discharges

Riggs (1965) describes some of the many factors that influence the low flows of streams and concludes that "only a very rough estimate of low-flow characteristics may be made for an ungaged stream." That was also the conclusion reached upon examining the results of multiple regressions for streams in and around the Tualatin River basin. None of the four topographic and climatic characteristics used, and no combination of them, could satisfactorily explain the areal variation of annual minimum flows in the basin. The best accuracy achieved in the minimum-flow regressions with topographic and climatic characteristics was a standard error of estimate of $\pm$52 percent, using drainage area and mean basin altitude.

Standard errors of regressions of annual minimum flows range from $\pm$2.7 to $\pm$16.1 percent for 2-year minimums, from $\pm$5.2 to $\pm$15.9 percent for 10-year minimums, and from $\pm$7.2 to $\pm$18.9 percent for 20-year minimum flows. The regressions were limited to annual minimum flows at a maximum duration of 90 days on the premise that minimums for durations between 90 days and 1 year are of little value in water-development planning.

The regression equations that were developed are summarized in table 3 for 2-year minimums, in table 4 for 10-year minimums, and in table 5 for 20-year minimum flows. The plus or minus percent standard error of estimate that can be expected is also shown for each equation. Equations for all durations and recurrence intervals are in the form:

$$Y = a(M)^b$$

where

Y represents the annual minimum flow in cfs for a selected duration and recurrence interval,

M represents the median annual 7-day minimum flow in cfs,

a represents a constant summarized in tables 3-5, and

b represents an exponent summarized in tables 3-5.

Because the median (2-year) annual 7-day minimum flow is used as an index to annual minimum flows of other durations and recurrence intervals in these equations, that index must be known before the equations can be used. Riggs (1965) states that "if some measurements of base flow are made at the site, the low-flow characteristics may be estimated from a relation with the flows at a nearby gaging station." The correlation of measured discharges at ungaged sites with concurrent flows at gaging stations is perhaps the only practical method of estimating the median annual 7-day minimum flow with any degree of accuracy for ungaged sites.

An example of the relation of eight measurements at an ungaged site on the Tualatin River with concurrent daily mean discharges at a gaged site on Gales Creek is shown in figure 6. Entering that relation with the median annual 7-day minimum flow of 7.2 cfs for gaging station 40.0 provides an estimate of 8.6 cfs for that same flow characteristic at the ungaged site. It is recommended that this procedure for estimating median annual 7-day minimum flows be followed for any ungaged site for which the magnitude and frequency of low flow are to be investigated. Preferably, the measurements should be made as flows are receding during different times of the year and in several different years.

Estimates of median annual 7-day minimum flow have been made for about 120 gaged and ungaged sites on streams in the Tualatin River basin using the foregoing procedures or modifications of those procedures. Those estimates, converted to cubic feet per second per square mile (cfsm), are shown on plate 1 for each of the sites. Also shown are the site identification numbers, the boundary of the basin drained by the stream, and the drainage area of the basin.

Discharges are shown on the map (pl. 1) in units of cubic feet per second per square mile for two reasons. First, they show in terms of areal runoff which parts of the basin are most or least productive of

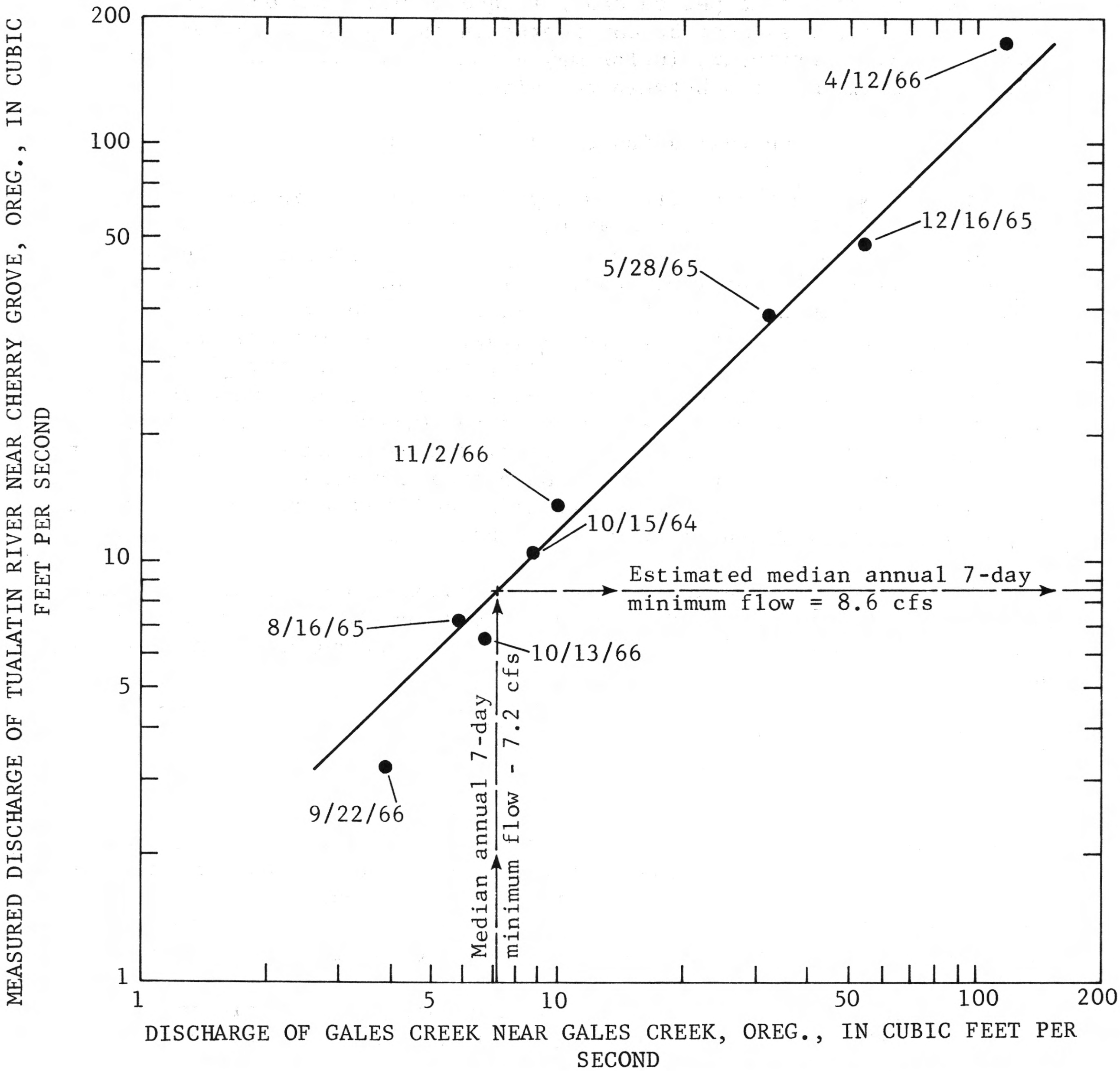

Figure 6.--Relation of low-flow measurements of Tualatin River (ungaged at site 23.2) to concurrent daily mean flows of Gales Creek (gaged by station 40.0).

streamflow. Second, under some conditions, those units may be used directly to estimate median annual 7-day minimum flows without correlation with gaged flows. Such estimates can be made for locations on a stream between sites for which median annual 7-day minimum flows have been determined previously. The estimates are made by interpolation of the flows in cubic feet per second per square mile from one site to another. Tributaries must be considered in making the interpolation, however, because tributary inflow may account for nearly all the difference in minimum flows between two sites.

Generalization of Annual Discharges

Multiple regressions were developed for annual mean discharges exceeded 4, 10, 20, 50, 80, and 90 percent of the time and of average mean annual discharge in relation to the four topographic and climatic characteristics. Of the four characteristics, drainage area and precipitation were found to be the most significant and were used in the final regression analysis. For the average annual discharge regression, the standard error was ± 17.0. Standard errors ranged from ± 15.2 percent for annual mean discharge exceeded 4 percent of the time to ± 20.8 percent for annual mean discharges exceeded 90 percent of the time. Drainage area was the single most significant basin characteristic, but regression equations using only drainage area had standard errors of ± 41.0 percent for average annual discharge and ranged from ± 36.1 percent to ± 45.3 percent for annual mean discharge.

The regression equations using both drainage area and mean annual precipitation are summarized with their corresponding accuracies (table 6). All the equations for average annual flow and annual mean flows are of the form:

$$Y = a(A)^{b_1}(P)^{b_2}$$

where

Y represents either annual mean discharge exceeded during the indicated percentages of climatic and water years or average annual discharge, in cubic feet per second,

A represents the drainage area for a stream site,

P represents the area-weighted mean annual precipitation in inches on the drainage basin, minus 20 inches (P-20),

a represents a constant summarized in table 6, and b_1 and b_2 represent exponents summarized in table 6.

Drainage areas used for the regression were planimetered from appropriate 1:62,500-scale topographic maps. Values of mean annual precipitation were estimated by visually weighting precipitation shown on an isohyetal map on the basis of the area to which each isoline applied. To more nearly linearize the equations, 20 inches was subtracted from the mean annual precipitation values for the regression.

Data for all 27 stations on streams in and around the Tualatin River basin were used to develop the equations.

Generalization of Annual Maximum Discharges

As was determined from the analysis of annual mean and average annual discharges, multiple regressions for annual maximum discharges indicated that equations using drainage area and mean annual precipitation were the most accurate. Standard errors ranged from ±20.2 percent to ±33.6 percent for 2-year maximums, ±21.4 percent to ±31.9 percent for 10-year maximums, and ±22.4 percent to ±31.4 percent for 25-year annual maximum flows.

The regression equations that were developed are summarized with their corresponding standard errors in table 7 for 2-year maximums, in table 8 for 10-year maximums, and in table 9 for 25-year annual maximum flows. The regressions for annual maximum flows were defined for flows with durations of as much as 60 days. The equations for all durations and recurrence intervals are of the same form as shown for annual mean and average annual flows, except that Y represents the annual maximum flow in cubic feet per second for a selected duration and recurrence interval.

Summary of Average Annual and Annual Minimum and Maximum Flows

The eight major contributing subbasins of the Tualatin River basin are shown in figure 7. For each of these subbasins, the drainage areas, median annual 7-day minimum flows, average annual flows, and median annual 1-day maximum flows are summarized by the bar graphs in figure 8. The bar graphs represent percentages of the area or discharge of the Tualatin River basin, thus indicating the relative influence of each subbasin on total outflow from the basin.

Gales Creek is the largest single contributor of streamflow to the Tualatin River, but the Upper Tualatin River contributes nearly as much. The eight major subbasins contribute an aggregate of 78 percent of the low flow and 69 percent of the average flow from 68 percent of the basin area.

The total of 95 percent of high flow from the eight subbasins is somewhat misleading because peak floodflows are seldom synchronized at the confluences of streams. Because of the resulting peak-flow attenuation, the percentage of floodflow that actually arrives at the mouth of the Tualatin River from each subbasin is reduced, perhaps nearly in proportion to average annual flow. It is interesting to note from the various possible combinations of subbasins that the Upper Tualatin River, Gales Creek, and East Fork Dairy Creek contribute 58 percent of the low flow and 37 percent of the average flow from only 27 percent of the basin area. Dairy Creek, which is the combination of McKay Creek and East and West Forks of Dairy Creek, contributes 26 percent of both the low flow and the average flow from 30 percent of the basin area.

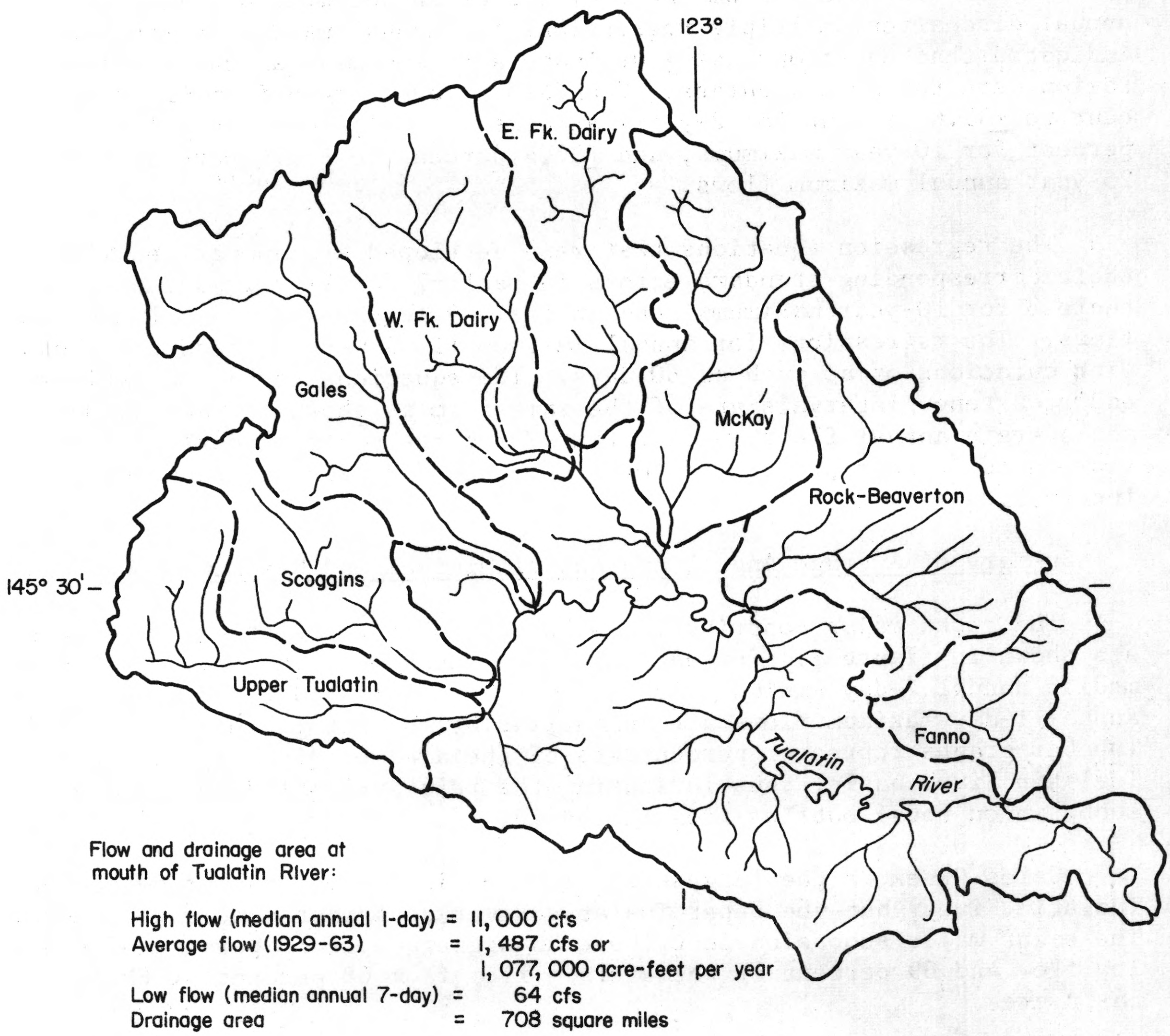

Figure 7 --Major subbasins of the Tualatin River basin.

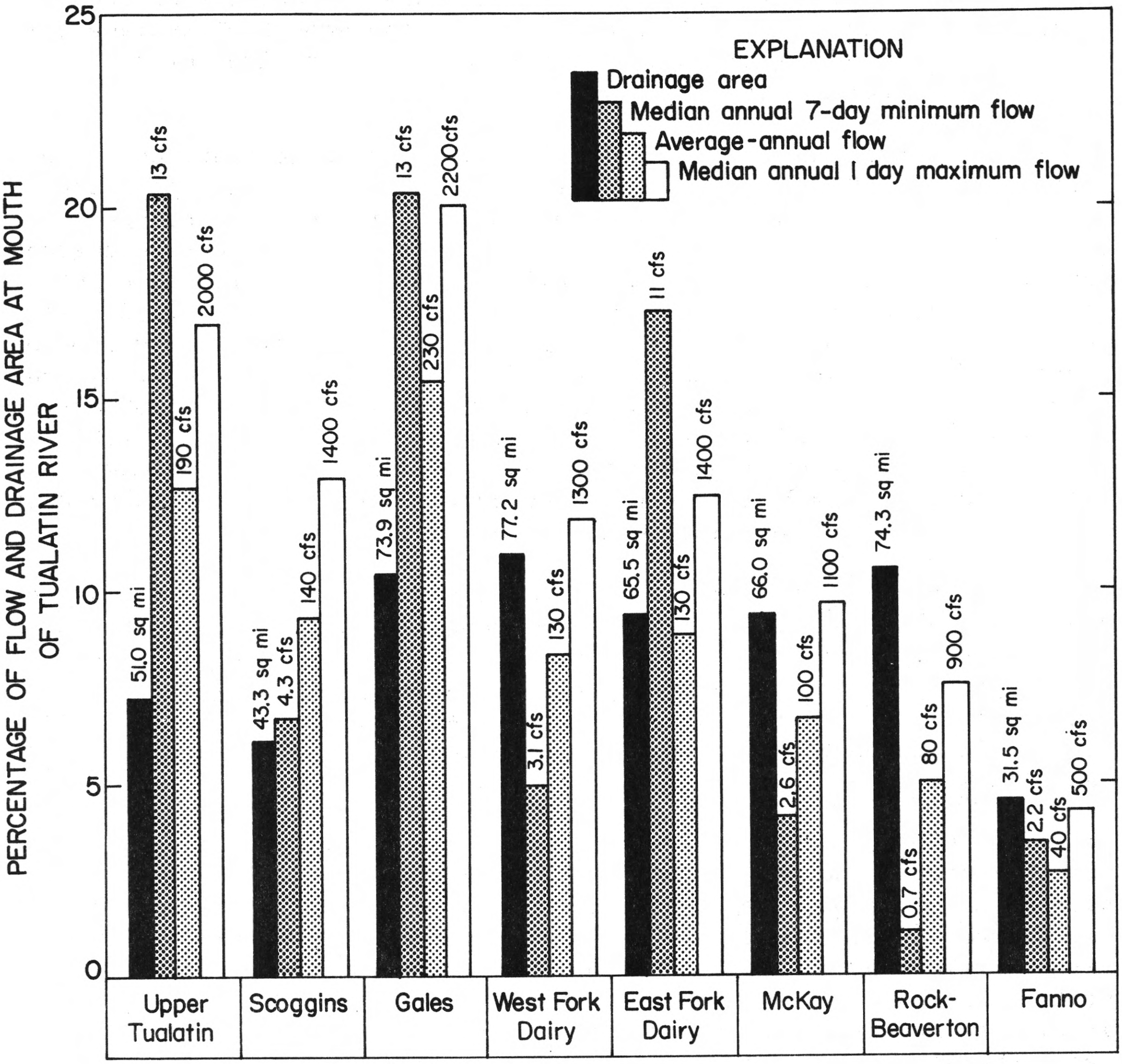

Figure 8.--Streamflow distribution by major contributing subbasins in the Tualatin River basin.

WITHIN-YEAR STORAGE REQUIREMENTS

Storage-Frequency Curves

Storage of winter flows to reduce floodflow or to augment summer low flow, or both, is one way of reducing the variability of natural streamflow, thus alleviating some of the problems caused by that variability. To use storage effectively as a means of controlling the streamflow resource, it is important to know the amount of storage required at a certain recurrence interval to sustain a given draft or release rate from storage.

Storage-frequency curves relate volume of storage required to recurrence interval and to rate of draft or release from storage. The storage-frequency curves in figure 9 show the within-year storage volumes required at 2-, 5-, and 20-year recurrence intervals to augment low flows and sustain various minimum draft rates or to reduce high flows and maintain various maximum release rates at station 75.0. As an example of how the curves are interpreted, the within-year volume of storage required to sustain a minimum draft rate of 300 cfs during low-flow periods can be expected to exceed 35,000 cfs-days or 70,000 ac-ft (acre-feet) at average intervals of 20 years. Similarly, the within-year volume of storage required to reduce floodflows to a maximum release rate of 6,000 cfs can be expected to exceed 105,000 cfs-days or 210,000 ac-ft at average intervals of 20 years.

The techniques used in preparing the curves shown in figure 9 are described by Riggs (1964). The volumes shown by the curves represent storage requirements for constant draft or release rates which are chosen according to the degree of control desired. Losses or gains from evaporation, transpiration, seepage, and precipitation may be considered in conjunction with draft and release rates, but have not been taken into account for the data contained in this report.

The practical within-year maximum draft and minimum release rates were selected at 50 percent and 200 percent, respectively, of the average annual flow. Those selections, although somewhat arbitrary, were based on what might reasonably be expected as possible extremes, either minimum or maximum, of annual mean flow for any one year. If draft or release rates in excess of their respective limits are needed, it will be necessary to consider carryover or multiyear storage to avoid deficiencies in successive years of severe extremes. Such considerations, however, are beyond the scope of this report.

Storage-frequency data were computed for all nine gaging stations in the basin and also for the 18 other stations identified in table 1. Selected data from the storage-frequency computations for the nine stations are summarized in table 10. Similar data for the 18 other stations are available for inspection at the office of the U.S. Geological Survey, Oregon District, Portland, Oreg. The draft rates shown in table 10 correspond in magnitude to 0.1, 0.2, 0.3, 0.4, and 0.5 of the average annual discharge at the stations. The release rates correspond to two, three, four, six, and eight times the average annual discharge at the stations.

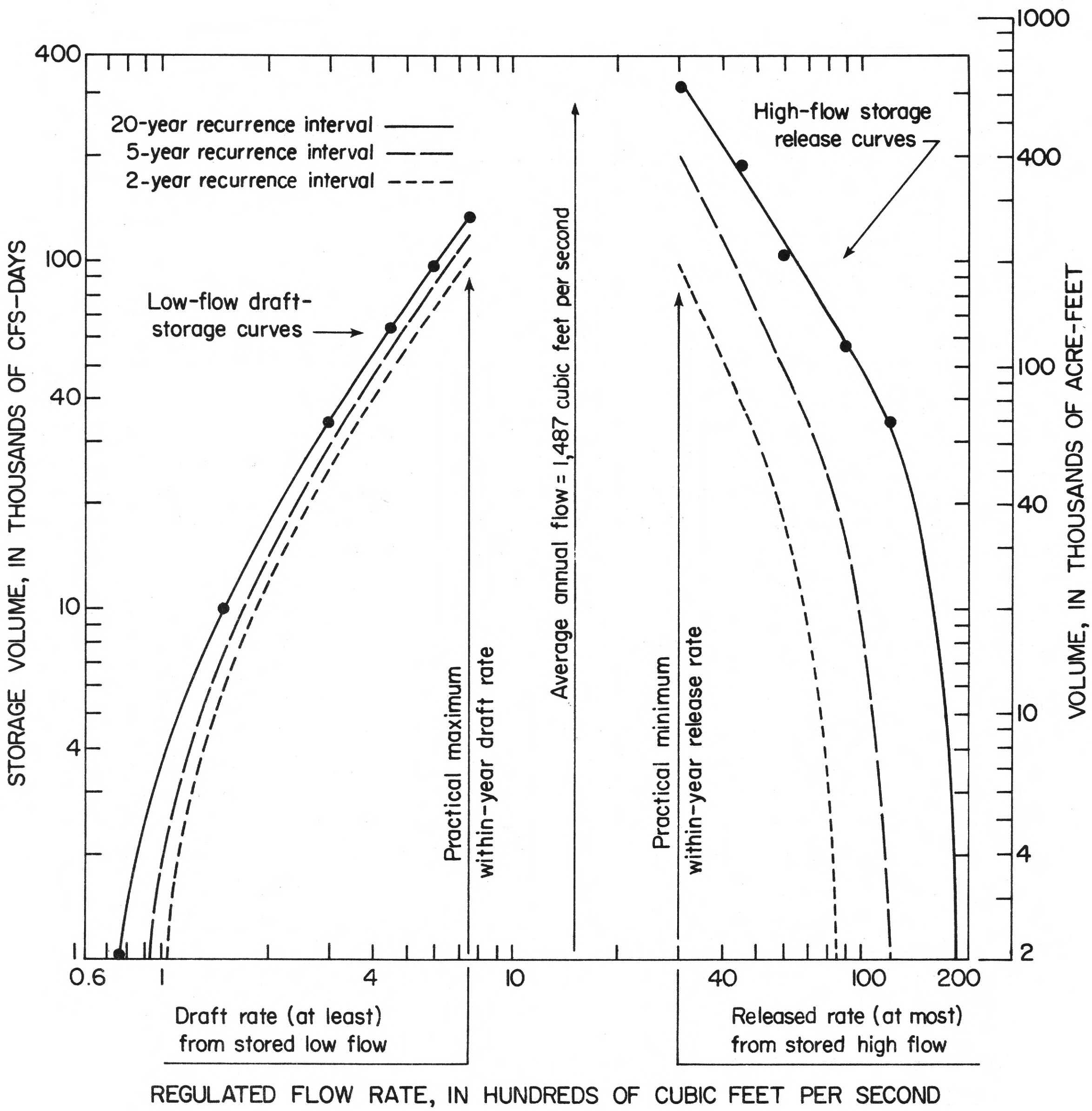

Figure 9.--Storage-frequency curves of volume requirements for augmenting low flows or reducing high flows discharged from the Tualatin River basin.

Generalization of Storage-Frequency Data

To fully examine storage as a means of controlling the variability of streamflow, planners and engineers need storage-frequency information that is sufficiently generalized for application to streams other than those that are gaged.

The technique used to generalize within-year storage requirements for this report is described by H. C. Riggs, U.S. Geological Survey (written commun., 1964). Briefly, a parameter that describes the low-flow characteristics of a stream is used as an index to within-year frequency-draft-storage requirements. Similarly, a parameter that describes the high-flow characteristics of a stream is used as an index to within-year frequency-release-storage requirements. The parameters selected as the low-flow index is the median annual 7-day minimum flow, and the selected high-flow index is the median annual 3-day maximum flow.

Figure 10 shows the relation between draft, within-year storage required, and median annual 7-day minimum flow for a 5-year recurrence interval, based on the storage-frequency data for the 27 gaging stations on streams in and around the Tualatin River basin. Figure 11 shows a similar relation for a 20-year recurrence interval.

To use these relations for an ungaged site, it is necessary to first estimate the median annual 7-day minimum flow for that site. The method for making that estimate requires some low-flow discharge measurements and is described in the section entitled "Generalization of annual minimum discharges" (p. 11). Because the draft, index flow, and storage units were reduced to rates and volumes per square mile of drainage area in preparing the generalized relations, the estimated median annual 7-day minimum flow also has to be reduced to cubic feet per second per square mile to use the relations. The draft-storage relations are defined only for within-year storage requirements; therefore, draft rates are limited to a maximum equivalent to 0.5 times the average annual flow, in cubic feet per second.

Figure 12 shows the relation between release rate, within-year storage required, and median annual 3-day maximum flow for a 10-year recurrence interval. Figure 13 shows a similar relation for a 25-year recurrence interval. As are the generalized draft-storage curves (figs. 10, 11), these relations are also based on storage-frequency data for the 27 gaging stations in and around the Tualatin River basin.

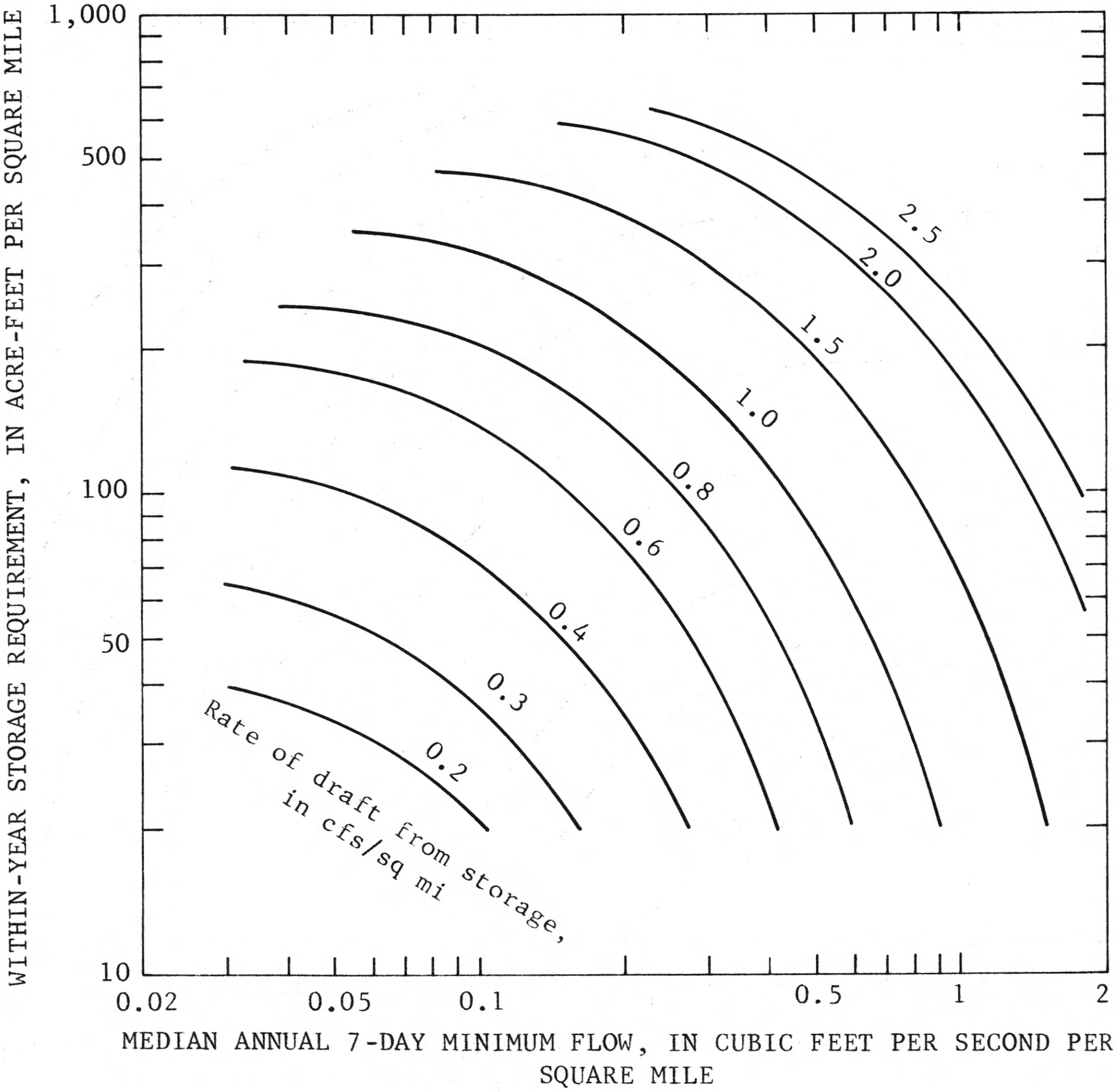

Figure 10.--Regional draft-storage curves for a 5-year recurrence interval (0.1 x avg ann. flow < draft rate < 0.5 x avg ann. flow).

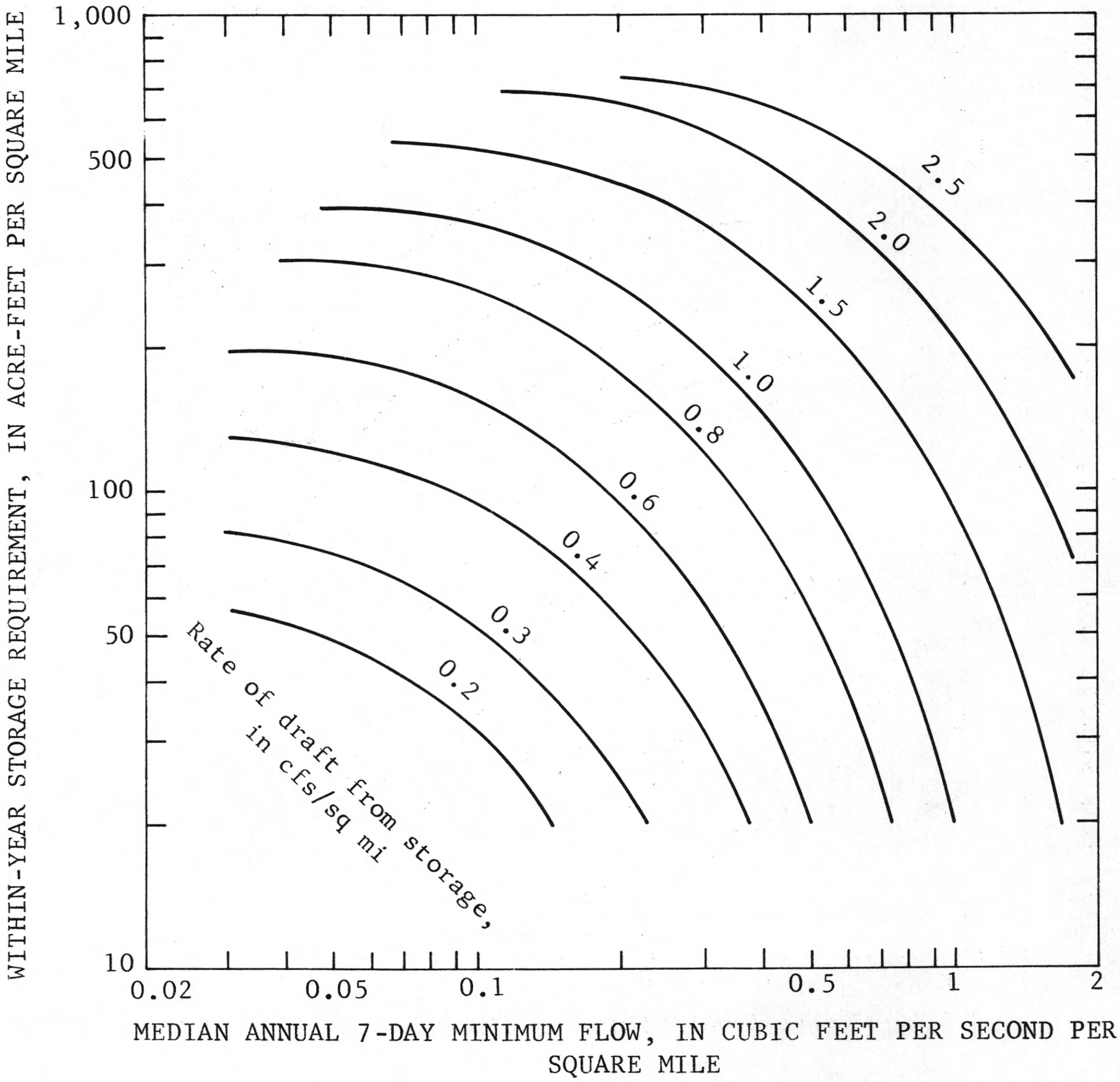

Figure 11.--Regional draft-storage curves for a 20-year recurrence interval (0.1 x avg ann. flow < draft rate < 0.5 x avg ann. flow).

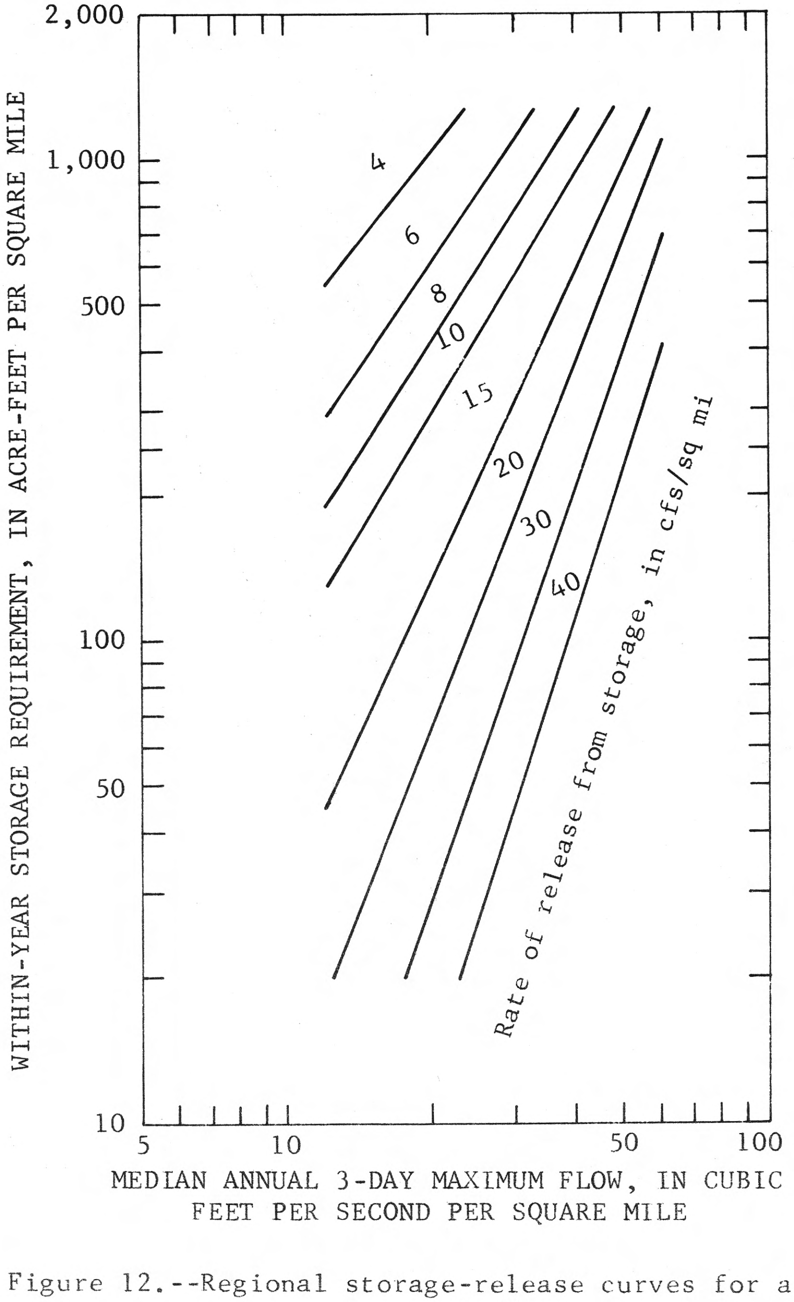

Figure 12.--Regional storage-release curves for a 10-year recurrence interval (2 x avg ann. flow > release rate > 8 x avg ann. flow).

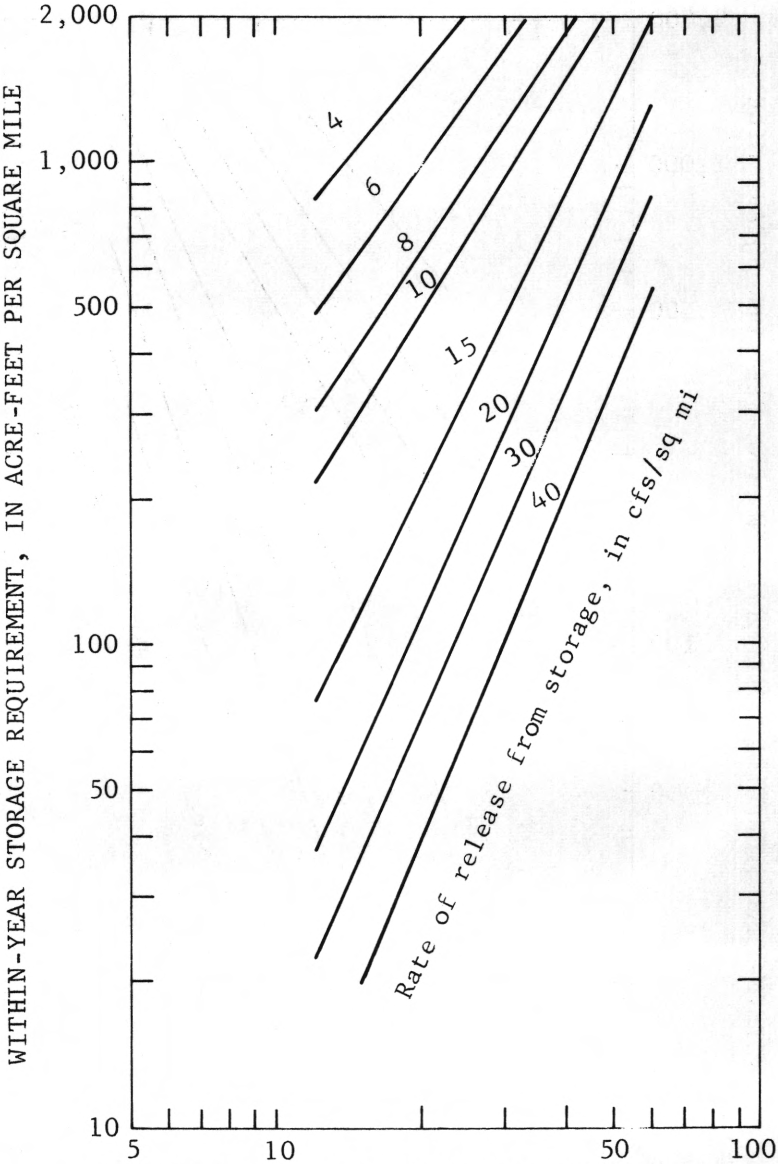

Figure 13.--Regional storage-release curves for a 25-year recurrence interval (2 x avg ann. flow < release rate < 8 x avg ann. flow).

To use the storage-release curves for estimating storage requirements at an ungaged site, it is necessary to first estimate the median annual 3-day maximum flow for that site. That estimate may be made, after previously determining the drainage area and mean annual precipitation for the site, by applying the equation shown in table 7,

$$Y = 1.78(A)^{1.00}(P)^{.72}$$

where

Y represents the median annual 3-day maximum flow.

Again, as used in the generalized draft-storage curves, rates and volumes used in these relations are reduced to units of cubic feet per second per square mile. Also, release rates are limited to a minimum equivalent to two times the average annual flow, in cubic feet per second. Otherwise, carryover storage will become a consideration.

The relations are adequate for preliminary planning even though they do not consider such details as evaporation losses and reservoir sites.

SUMMARY

By presenting and describing technical data on the amount, time distribution, and geographic distribution of natural streamflow in the Tualatin River basin, this report shows when and where water from streams is most and least abundant. By describing a procedure for determining the storage required to maintain different draft or release rates at selected recurrence intervals of flow extremes, this report also shows one way of reducing the time and place variability of natural streamflow. The report therefore provides much of the information needed for planning optimum water use and water control.

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Year	WSP	Year	WSP	Year	WSP	Year	WSP	Year	WSP
1899	38	1912	332-C	1925	614	1937	834	1949	1154
1900	51	1913	362-C	1926	634	1938	864	1950	1184
1901	75	1914	394	1927	654	1939	884	1951	1218
1902	85	1915	414	1928	674	1940	904	1952	1248
1903	100	1916	444	1929	694	1941	934	1953	1288
1904	135	1917	464	1930	709	1942	964	1954	1348
1905	178	1918	484	1931	724	1943	984	1955	1398
1906	214	1919-20	514	1932	739	1944	1014	1956	1448
1907-8	252	1921	534	1933	754	1945	1044	1957	1518
1909	272	1922	554	1934	769	1946	1064	1958	1568
1910	292	1923	574	1935	794	1947	1094	1959	1638
1911	312	1924	594	1936	814	1948	1124	1960	1718

Note: Earlier records of streamflow are published in reports listed in Water-Supply Paper 1718.

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Table 1.--Gaging-station records analyzed

Stream and place name	Station number (14-)	Period of record analyzed (water years)	Drainage area (sq mi)	Mean annual precipitation (inches)
Salmon River near Government Camp, Oreg.	1340.0	1911, 1927-63, 1965-66	8.7	100
Sandy River near Marmot, Oreg.	1370.0	1912-15, 1917-18, 1920-66	262	90
Little Sandy River near Bull Run, Oreg.	1415.0	1920-66	22.3	90
Washougal River near Washougal, Wash.	1435.0	1945-64	108	81
South Yamhill River near Willamina, Oreg.	1925.0	1935-66	133	74
Willamina Creek near Willamina, Oreg.	1930.0	1935-66	64.7	66
South Yamhill River near Whiteson, Oreg.	1940.0	1941-63, 1966	502	59
Molalla River above Pine Creek, near Wilhoit, Oreg.	1985.0	1936-63, 1966	97.0	99
Molalla River near Canby, Oreg.	2000.0	1929-59, 1965-66	323	71
Pudding River near Mount Angel, Oreg.	2010.0	1940-63	204	67
(Tualatin River basin)				
Tualatin River at Gaston, Oreg.	2025.0	1941-56	48.3	67
Scoggins Creek near Gaston, Oreg.	2030.0	1941-66	43.3	71
Tualatin River near Dilley, Oreg.	2035.0	1940-66	125	65
Gales Creek near Gales Creek, Oreg.	2040.0	1936-45, 1956-66	33.2	70
Gales Creek near Forest Grove, Oreg.	2045.0	1941-56	66.1	63
East Fork Dairy Creek at Mountaindale, Oreg.	2055.0	1941-51	43.4	56
McKay Creek near North Plains, Oreg.	2060.0	1941-43, 1949-56	27.6	48
Tualatin River at Farmington, Oreg.	2065.0	1940-58	560	53
Tualatin River at West Linn, Oreg.	2075.0	1929-66	706	51
Clackamas River at Big Bottom, Oreg.	2080.0	1921-63, 1965-66	136	69
Johnson Creek at Sycamore, Oreg.	2115.0	1941-66	28.2	47
Salmon Creek near Battleground, Wash.	2120.0	1944-64	18.3	60
East Fork Lewis River near Heisson, Wash.	2225.0	1930-66	125	89
Elochoman River near Cathlamet, Wash.	2475.0	1941-64	65.8	87
Nehalem River near Foss, Oreg.	3010.0	1940-60, 1963-66	667	80
Wilson River near Tillamook, Oreg.	3015.0	1915, 1932-60	161	116
Trask River near Tillamook, Oreg.	3025.0	1932-55, 1964-66	145	112

Table 2.--Summary of annual maximum and minimum flows from Tualatin River basin station frequency curves[1/]

Station number	Recurrence interval, in years	Annual minimum flows, in cubic feet per second, for indicated periods of consecutive days												Average annual flow, in cfs	Annual maximum flows, in cubic feet per second, for indicated periods of consecutive days											
		1	3	7	14	30	60	90	120	150	183	274	365		365	274	183	150	120	90	60	30	15	7	3	1
14-2025.0	2	12	12	2/13	14	15	17	20	23	28	40	127	200	2/188	200	270	370	410	460	520	570	700	980	1,280	1,550	2,000
	5	9.3	9.7	10	11	12	14	16	20	25	32	103	155		252	320	460	530	580	650	700	920	1,180	1,500	2,100	2,650
	10	8.0	8.4	8.8	9.2	10	12	14	16	21	28	82	130		275	340	510	570	640	720	790	1,000	1,300	1,680	2,500	3,200
	20	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	110		285	360	540	610	690	780	880	1,100	1,450	1,850	3,000	3,800
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
14-2030.0	2	2.6	3.4	2/4.3	5.0	5.7	7.0	8.2	11	15	22	82	140	2/137	140	185	260	285	315	360	390	510	670	850	1,100	1,400
	5	1.7	2.3	2.8	3.5	4.0	5.2	6.1	8.0	11	16	53	104		170	230	330	365	405	470	530	660	830	1,060	1,320	1,650
	10	1.6	2.0	2.4	2.9	3.4	4.5	5.3	6.9	9.3	13	40	86		190	255	365	415	450	525	600	730	890	1,170	1,450	1,800
	20	1.5	1.8	2.2	2.5	3.0	3.9	4.6	6.0	7.8	11	31	72		208	275	390	450	485	555	650	770	920	1,250	1,550	1,900
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	62		220	290	405	465	500	570	670	790	940	1,310	1,610	1,970
14-2035.0	2	13	14	2/16	17	18	21	25	31	41	62	215	400	2/383	400	540	740	840	910	1,050	1,150	1,500	1,870	2,450	3,200	4,100
	5	10	11	13	13	14	16	19	25	34	50	155	310		480	640	900	1,040	1,150	1,260	1,440	1,820	2,300	3,000	3,900	5,100
	10	9.1	9.7	11	12	12	15	17	22	30	44	125	260		520	690	980	1,120	1,250	1,390	1,600	2,080	2,600	3,400	4,500	6,000
	20	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	220		560	750	1,050	1,200	1,320	1,510	1,800	2,350	2,900	3,800	5,100	6,900
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	190		590	800	1,100	1,250	1,400	1,620	1,950	2,600	3,200	4,200	5,600	7,800
14-2040.0	2	6.0	6.7	2/7.2	7.5	8.1	8.8	9.6	11	15	20	57	108	2/126	108	130	190	210	250	290	320	400	560	760	1,080	1,400
	5	4.7	5.4	5.9	6.2	6.5	7.0	7.8	8.6	10.5	13.5	35	80		140	180	250	280	310	360	400	550	750	1,000	1,450	2,000
	10	4.2	4.8	5.4	5.7	6.0	6.4	7.2	7.8	8.6	11	27	67		165	220	300	330	350	400	460	650	900	1,200	1,750	2,400
	20	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
14-2045.0	2	9.8	10	2/11	12	13	15	17	21	27	38	133	230	2/215	230	300	420	480	520	580	630	800	1,100	1,400	1,800	2,250
	5	6.9	7.6	8.2	8.8	10	12	13	16	21	30	94	170		280	380	530	610	700	780	860	1,140	1,480	1,800	2,350	3,000
	10	5.5	6.2	6.7	7.3	8.4	9.6	11	14	18	26	74	135		320	430	610	710	810	940	1,050	1,400	1,700	2,100	2,800	3,600
	20	4.5	5.0	5.6	6.1	7.1	8.1	9.4	12	16	23	59	110		360	490	690	800	930	1,110	1,240	1,700	2,000	2,500	3,250	4,300
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
14-2055.0	2	10	10	2/11	11	12	13	14	16	19	24	64	112	2/106	112	140	190	210	240	260	290	360	480	650	800	1,020
	5	8.6	8.8	9.0	9.4	10	11	12	13	16	19	44	77		140	180	250	280	310	350	410	510	660	850	1,020	1,300
	10	7.7	7.9	8.1	8.4	9.2	10	11	12	14	16	34	60		150	195	275	310	350	390	470	600	780	990	1,190	1,460
	20	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
14-2060.0	2	1.5	1.7	2/1.9	2.1	2.4	2.8	3.2	4.0	5.0	7.4	37	70	2/61.9	70	98	140	165	185	215	235	315	415	520	650	760
	5	1.0	1.2	1.4	1.5	1.7	2.0	2.4	2.9	3.5	4.4	20	46		89	125	180	210	235	270	300	390	530	670	880	1,090
	10	.8	.9	1.1	1.2	1.4	1.6	2.0	2.3	2.7	3.3	14	35		101	140	200	240	265	305	345	445	610	780	1,070	1,360
	20	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
14-2065.0	2	39	42	2/43	46	51	58	69	87	120	175	700	1,310	2/1,300	1,310	1,750	2,500	2,850	3,300	3,800	4,100	5,200	6,700	8,300	9,400	10,000
	5	29	32	32	35	40	47	56	71	95	137	430	950		1,750	2,300	3,300	3,900	4,400	5,100	5,500	6,900	8,700	10,700	12,500	13,700
	10	24	27	27	30	35	42	50	64	81	116	315	770		1,980	2,550	3,750	4,550	5,000	5,700	6,300	7,900	9,700	12,000	14,000	16,500
	20	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	620		2,120	2,800	4,150	5,100	5,500	6,200	7,100	8,800	10,600	13,500	16,500	20,000
	35	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/		3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
14-2075.0	2	63	63	2/64	65	69	77	85	103	130	190	750	1,490	2/1,487	1,490	2,000	2,800	3,200	3,500	4,000	4,500	5,600	7,000	8,100	8,900	9,200
	5	51	53	55	57	60	68	75	88	107	145	410	1,050		1,900	2,500	3,600	4,200	4,700	5,300	5,800	7,400	9,100	11,300	12,500	13,000
	10	46	48	50	52	56	63	70	80	93	125	320	860		2,100	2,800	4,000	4,700	5,200	6,000	6,700	8,400	10,700	14,000	15,500	16,500
	20	42	44	46	48	53	59	65	72	82	110	270	760		2,250	2,950	4,300	5,000	5,700	6,400	7,700	9,500	12,500	17,000	19,000	21,000
	35	39	41	43	45	50	56	62	68	75	98	245	710		2,350	3,050	4,500	5,300	6,000	6,800	8,500	10,300	14,000	20,000	23,000	25,000

1/ All flows in this table are averages for the periods indicated; average annual flow is the computed or adjusted average for the period 1929-63.
2/ Index flow.
3/ Flow for this period and recurrence interval was not determined because of length of record, type of record, or both.

Table 3.--Summary of regression equations for 2-year annual minimum flows

Regression equation: $Y = a(M)^b$

where

Y = 2-year annual minimum flow, in cfs, for indicated duration, and

M = median annual 7-day minimum flow, in cfs.

Duration, in days	1	3	7	14	30	60	90
Regression constant a	0.80	0.89	1.00	1.12	1.28	1.54	1.80
Regression coefficient b	1.04	1.02	1.00	.98	.97	.96	.96
Percentage standard error	8.4	4.0	0	2.7	4.8	11.2	16.1

Table 4.--Summary of regression equations for 10-year annual minimum flows

Regression equation: $Y = a(M)^b$

where

Y = 10-year annual minimum flow, in cfs, for indicated duration, and

M = median annual 7-day minimum flow, in cfs.

Duration, in days	1	3	7	14	30	60	90
Regression constant a	0.43	0.49	0.57	0.64	0.74	0.92	1.11
Regression coefficient b	1.11	1.09	1.06	1.05	1.03	1.01	.99
Percentage standard error	15.9	12.5	10.3	7.3	5.2	6.2	8.7

Table 5.--Summary of regression equations for 20-year annual minimun flows

Regression equation: $Y = a(M)^b$

where

Y = 20-year annual minimum flow, in cfs, for indicated duration, and

M = median annual 7-day minimum flow, in cfs.

Duration, in days	1	3	7	14	30	60	90
Regression constant a	0.37	0.41	0.48	0.54	0.63	0.79	0.96
Regression coefficient b	1.13	1.11	1.08	1.07	1.05	1.02	1.00
Percentage standard error	18.9	16.1	13.4	10.6	8.2	7.2	8.0

Table 6.--Summary of regression equations for annual mean flows and average annual flow

Regression equation: $Y = a(A)^{b_1}(P)^{b_2}$

where

Y = the average annual flow or the annual mean flow exceeded during the indicated percentage of years,

A = drainage area at site, in square miles, and

P = mean annual precipitation, in inches, minus 20 inches.

	Climatic years			Average	Water years			
Percentage of years exceeded	90	80	50	annual	50	20	10	4
Regression constant a	0.044	0.053	0.076	0.077	0.077	0.118	0.140	0.163
Regression coefficient b_1	.97	.98	.99	.99	.99	.99	1.00	1.00
Regression coefficient b_2	1.09	1.07	1.02	1.01	1.02	.95	.92	.90
Percentage standard error	20.8	19.6	17.8	17.0	17.1	15.8	15.4	15.2

Table 7.--Summary of regression equations for 2-year annual maximum flows

Regression equation: $Y = a(A)^{b_1}(P)^{b_2}$

where

Y = 2-year annual maximum flow, in cfs, for indicated duration,

A = drainage area at site, in square miles, and

P = mean annual precipitation, in inches, minus 20 inches.

Duration, in days	1	3	7	15	30	60
Regression constant a	1.60	1.78	1.67	1.19	0.78	0.56
Regression coefficient b_1	.93	1.00	1.01	1.01	1.02	1.01
Regression coefficient b_2	.89	.72	.64	.67	.70	.73
Percentage standard error	32.2	33.6	29.6	27.0	22.4	20.2

Table 8.--Summary of regression equations for 10-year annual maximum flows

Regression equation: $Y = a(A)^{b_1}(P)^{b_2}$

where

Y = 10-year annual maximum flow, in cfs, for indicated duration,

A = drainage area at site, in square miles, and

P = mean annual precipitation, in inches, minus 20 inches.

Duration, in days	1	3	7	15	30	60
Regression constant a	3.15	2.20	2.01	1.82	1.18	0.93
Regression coefficient b_1	.94	.99	1.01	1.01	1.02	1.02
Regression coefficient b_2	.81	.78	.70	.65	.68	.67
Percentage standard error	31.9	27.4	25.3	24.0	23.2	21.4

Table 9.--Summary of regression equations for 25-year annual maximum flows

Regression equation: $Y = a(A)^{b_1}(P)^{b_2}$

where

Y = 25-year annual maximum flow, in cfs, for indicated duration,

A = drainage area at site, in square miles, and

P = mean annual precipitation, in inches, minus 20 inches.

Duration, in days	1	3	7	15	30	60
Regression constant a	3.50	1.91	1.70	1.75	1.23	1.02
Regression coefficient b_1	.93	.98	1.00	1.01	1.02	1.03
Regression coefficient b_2	.84	.87	.78	.68	.69	.67
Percentage standard error	31.4	26.5	24.5	23.9	24.6	22.4

Table 10.--Summary of storage-frequency data for gaging stations in the Tualatin River basin

Station number	Draft rate, in cfs	Storage to augment low flows, in thousands of acre-feet		Release rate, in cfs	Storage to reduce high flows, in thousands of acre-feet	
		5-year R.I.	20-year R.I.		10-year R.I.	25-year R.I.
	20	2.0	5.4	400	54	78
	40	7.0	11	610	24	40
14-2025.0	60	13	15	810	15	24
	80	20	25	1,200	6.8	12
	100	28	33	1,600	4.2	9.2
	14	1.8	2.4	280	38	56
	28	5.6	6.6	420	19	30
14-2030.0	42	10	12	560	11	15
	56	15	17	830	5.6	7.8
	70	21	24	1,100	3.4	5.6
	40	6.4	8.6	800	108	140
	80	18	22	1,200	58	82
14-2035.0	119	30	36	1,600	38	50
	159	46	54	2,400	22	32
	199	62	72	3,200	13	22
	11	.7	.9	220	30	38
	22	3.6	4.4	330	16	19
14-2040.0	33	7.2	9.0	440	13	15
	44	11	14	660	9.4	12
	56	17	22	880	6.8	9.2
	23	1.8	3.6	460	70	130
	46	7.8	11	690	34	90
14-2045.0	69	16	20	920	20	56
	92	25	31	1,400	8.8	26
	115	34	42	1,800	4.8	12
	10	0	.1	220	28	36
	21	1.8	2.4	320	16	22
14-2055.0	32	5.0	6.2	430	9.6	15
	43	9.0	11	650	3.6	5.2
	53	13	16	860	1.8	2.2
	7	1.0	1.6	140	30	40
	14	3.3	4.6	210	16	24
14-2060.0	21	6.0	7.4	280	9.2	11
	28	9.2	11	420	5.2	6.0
	35	12	15	570	2.6	3.0
	136	15	21	2,700	460	750
	271	58	70	4,100	250	430
14-2065.0	407	108	128	5,400	130	220
	542	164	198	8,100	48	90
	678	222	270	10,800	19	48
	149	15	21	3,000	450	650
	298	60	70	4,400	240	400
14-2075.0	446	114	140	5,900	120	220
	595	172	200	8,900	40	120
	744	235	280	11,900	10	74

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