STATISTICAL ANALYSIS FOR STREAMFLOW PREDICTION

by

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Thesis submitted to the Graduate Faculty of the Virginia Polytechnic Institute in candidacy for the degree of MASTER OF SCIENCE in Civil Engineering

May, 1965

Blacksburg, Virginia
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I. INTRODUCTION

The prediction of stream discharges is a problem which has been attempted many ways. Although most investigations are concerned with floods, droughts are also of importance to any person with interest in a river. Business interests are dependent upon the river's resources, and certainly the welfare of the people living adjacent to the river depends upon the river's actions. There is property damage, and consequently financial loss, caused by both floods and droughts each year. The loss of human life as a result of the river ravages cannot be estimated monetarily.

Correct prediction of discharges would not only provide safety for the people along a river, but it would also provide the information needed for the design of storage facilities. The numerous benefits from storage are apparent -- not the least of which is flood protection.

If a relationship could be established which would relate flow amounts for a group of watersheds, the problem of prediction of discharges would be partially solved. The following analysis of average monthly flows attempts to establish such a relationship.

If a particular watershed is known to vary greatly in its monthly discharges, its coefficient of variation is expected to be large with respect to other areas with less
variation in their discharges. Synthesis of streamflow data is made from the prediction of the standard deviation by methods involving techniques such as Markov chains. Since the coefficient of variation is a quotient which is not affected by the number of values of the random variable, it was the logical choice for comparison.

There remained the problem of choosing some means of comparing the flow parameter to the watershed. The most fundamental basin parameter is the area. Therefore, it was the object of this project to compare the coefficients of variation to the drainage areas.

A flow duration curve is used to predict the potential of a stream for water supply. The flow-duration curve, which is obtained for a particular basin, is a frequency relationship of discharge; it is the more basic prediction relationship for stream flow estimation. The shape of the flow-duration curve roughly indicates the coefficient of variation for that basin. The range of the discharges on a particular flow-duration curve dictates the level of the coefficient of variation; therefore, it can be concluded that the coefficient of variation is a function of the flow-duration curve.
II. LITERATURE SURVEY

In the investigation of the literature on the subject of streamflow prediction, it was found that there exists very little information on the topic as stated herein. There is an abundance of information on flood prediction, and there are also technical papers on drought prediction; however, no attempt has been made to cover the entire range from lowest to highest flows. As might be anticipated, the investigations into flood prediction are much more thorough and span a greater period of time. In recent years, drought studies have become the topic of much more investigation.

In almost every case encountered, the drainage area was the parameter investigated first or the item which headed the list of considerations in multiple regression studies. M. A. Benson (1), in his flood investigations in the Southwest, stated that the drainage area size was the most important single factor in areas of rainfall as well as in areas of snowmelt. His primary interest was the variation of flood magnitudes and frequencies.

M. C. Matalas (2) made rather recent investigations into low flow probability distribution. His approach to the subject differed from others that were encountered. He was careful in his selection of areas to be studied, but generally only one river was investigated throughout its
entire reaches. He then compared his data to four theoretical probabilities for comparison fit.

In other works with low-flow frequency, Hardison and Martin (3) made adjustments to data to fit curves of discharge versus the recurrence interval. Their work was more general and was developed to serve the entire eastern United States east of the Mississippi. Low-flow prediction was shown to be very valuable in the estimation of impounded volumes needed to maintain water supplies.

Factors which influenced flood recurrence over a vast area of the eastern United States were studied by Benson (2). Although he used a statistical multiple regression method of comparison, he concluded that the area of the drainage basin was of primary importance and main channel slope was of secondary importance. Although other items were considered, these two items were the most significant to his study.

In New Mexico, flood frequency investigations were published by Leon A. Wiard (8). In the prediction of flood discharges, the drainage basin area was the only physical parameter found to be of significance to the flood frequency relationship. The discharge function used in the flood magnitude relationship was the mean annual flow. It was felt that in an area of consistent runoff, the average annual
runoff would be an indicator of discharge trends, but in an area where great fluctuation occurs, a shorter time period was needed as a base.

In the southeastern United States, Speer and Gamble (6) reached the same conclusions about runoff amounts and drainage area relationships as did Wiard (7) in New Mexico. In the northeastern United States, an investigation was made by Sopper and Lull (5) which paralleled this study closely. The geographical area was very carefully investigated, and separation was made by the physical characteristics of each section; their thoroughness produced results with consistent accuracy.

In the light of these studies, it was felt that the drainage area should be the physical parameter to be compared to the average monthly flows.
III. ANALYTICAL METHOD

The coefficient of variation of monthly flows was the statistical function used for comparison within a geographical area. Attention was given to assure the selection of basins with sufficient data to yield accurate statistics. No basins were used which had fewer than fifty monthly discharge values. Within this constraint, the parameter produces a result which is not related to the number of values of the random variable. The standard deviation gives an indication as to whether the distribution of the random variable for an area differs appreciably from a normal distribution with standard deviation of unity. The coefficient of variation is the quotient of the standard deviation and the mean of that data (7).

It was proposed that data be examined for selected watersheds and the value of the coefficient of variation be computed. A comparison was made with a representative number of basins for a particular region.

A digital computer expedited the calculations of these statistics. To have handled this amount of data and to have calculated values of such magnitude as these, by any other available method than that which was used would have been far too impractical.
IV. INVESTIGATION

The shaded areas of Figure 1 show those portions of each region which were used in this investigation. The selection of basins for analysis by this proposed method was not arbitrary. Figure 2 is an example of how the gages were located in the Ohio River Basin. The selection of this example was arbitrary and shows that the selection of stations covers the region under investigation as thoroughly as possible. It was essential to the success of this study that all variables of climate, geology, and precipitation be held as nearly constant as possible by a careful selection of basins. Basins were intentionally chosen which were tributary to other basins; likewise, basins were compared to basins in other watersheds.

Atlantic Slopes

In the eastern United States, the area under consideration was the Tidewater and Piedmont regions of Virginia and North Carolina. The selection of basins to study was determined by that area which did not fall on the mountain slopes. No attempt was made to separate the Piedmont from the Tidewater regions; an insufficient number of basins were available to establish a relationship for either area separately. A more detailed investigation might warrant this separate
consideration. As in every region studied, a full range of areas was required. An effort was exerted to get basins of every intermediate size from several square miles to fifteen hundred square miles or larger -- depending upon the region. Considerably more recorded data was available for the eastern United States. Most gaging stations in this region are older, and it was also noted that generally the river was more extensively gaged than in any other region of the United States.
Figure 1. Regions of United States Used for Investigation.

Shaded regions indicate those regions used in the investigation. Corresponding numbers are those part numbers of the water supply papers.
Figure 2. Basins Under Investigation, Ohio River Basin.

The numbers underlined are those used for study.
The Great Plains region of the Missouri River Basin in the vicinity of Sioux City, Iowa, was another region studied. Two items were noted: the discharge per square mile of drainage area was much less than in the East, and the seasonal effect on streamflow was apparent. After careful consideration of the information obtained from this region, insufficient data points existed to establish a relationship.

In this area the rainfall was primarily limited to the spring season. A large percentage of the total streamflow was recorded during the period from March to July each year. Consequently, in an effort to establish a relationship for this region, seasonal examination was made. This produced essentially the same poor results. Generally the basin areas were larger than in other regions. A great variation in these large basins was noticed. This effect was inconsistent with that which would have been anticipated from extrapolation in other regions.

Ohio River Basin

The Ohio River Basin exhibited individual characteristics. In this area care was exerted to be certain that only those streams were examined which were not affected by regulation or diversion. Again, as in the Atlantic slope basins, only those basins that were completely off of the
western mountain slopes were considered in this part of the study. The entire Ohio River Basin was considered as the feasible region, within the limitations mentioned. Greater variation was noted in the northern region of this area. The terrain in this area is flatter than the rolling, hilly region to the south. Since this northern region is close to the Great Lakes, the runoff in this region is affected by the lakes, causing more variation in the streamflow data.

An attempt was made to examine regions in the Western United States. For this portion of the investigation the mountain slopes in Washington and Oregon were chosen to represent one type terrain; for a different region the Central Valley of California was chosen as the second region.

**Pacific Mountain Slopes**

In the Columbia River Basin difficulty was encountered in finding streams not drastically affected by diversion or regulation. Streams which had appreciable regulation were eliminated from consideration. It was necessary to use basins which were affected by diversion although if diversion was considerable, they were avoided. The results formed a straight line nearly parallel to the area axis. As might be anticipated, the points of data were more scattered than in other regions. This was caused by
regulated basins being compared with unregulated basins. The high amount of regulation tends to retard any fluctuation of the discharge in some basins and this was confirmed by this analysis (see Figure 8). In a region of high regulation, as this region is, this method of prediction is adequate to accomplish those results. It is not advisable to attempt an investigation where some basins are regulated and some not.

**Central Valley of California**

The Central Valley of California was an area also regulated to some minor extent. Most regulation was for irrigation and although relatively insignificant, was avoided. The smaller basins were noted as more variable than the larger. This gives the impression that rainfall which might approach serious flood levels for small basins, affected the larger stations only to minor degrees. The steepness of the curve indicated that fluctuation of streams was a problem for this region.

**Lower Mississippi River**

As shown by the relationship for the lower Mississippi River (Figure 6) there was very little scatter of points of data. Basins were examined both east and west of the river, but care was taken to stay close enough to the river so that the topography was not affected within the region. The results were plotted and found to be very good. This along
with the closeness to fit to a straight line led the author to conclude with high degree of confidence that this method was very effective in the prediction of flow quantities in this region. With the experience obtained from the Missouri River, the areas were limited to two thousand square miles.
V. CONCLUSIONS

This investigation had as its primary basis the assumption that streamflow prediction was dependent upon geographical area. The regions under investigation were:

1. Middle Atlantic slopes
2. Missouri River tributaries
3. Ohio River Basin
4. Lower Mississippi River Basin
5. Central Valley of California
6. Pacific mountain slopes

From the curves of coefficient of variation versus the drainage area for each geographical area, the trend was toward diminishing variation for increasing area. The one exception to this was the Missouri River Basin.

After consideration of several plots of the data, the best relationship between the variables was the log-log plot. It was apparent from this plot that the straight line was the best fit of the data points. The steepness of the graph indicated whether a stream was susceptible to rapid fluctuations in discharge. Some scatter of data points was noticed in all areas of investigation. It was felt that if the choice of geographical areas had been even more limited, less variation would have occurred.
In the region of Middle Atlantic slopes, confidence can be felt in the use of this relationship. The fit to the straight line relationship shows that the points do not vary appreciably at any point from that line (Figure 3).

The Missouri River Basin does not provide a relationship by this method. As a suggestion to the solution of the problem in this region, closer physiographic analysis is needed. Also it is suggested that a smaller range of basins be examined (Figure 4).

In the Ohio River basin a relationship was established upon which much confidence can be placed. The resulting plot shows that from the beginning and throughout the range of areas, the relationship function accurately fits the data (Figure 5).

The lower Mississippi River basins provide a relationship but not quite the range of areas as in other regions. The scatter of points is moderate but nevertheless the relationship is established (Figure 6). In this area, perhaps more effort could be exerted to eliminate this variation of data. The solution would probably be to limit the geographical area to only those close to the Mississippi River; and, consider those farther away from the river in separate studies.

In both the Central Valley of California and the Pacific mountain slopes, more variation of data points on the
curves occurred than is desirable. This was due to regulation of some streams and natural, undisturbed condition in other streams. The Central Valley displayed a steeper curve showing more fluctuation among smaller and larger basins (Figure 7).

Generally, this method is quite useful in streamflow prediction. Its value is apparent in the several cases where the straight line relationship was established on the log-log plot. In the one region where no relationship existed, it is believed that with more constraints, a relationship could be established. One general improvement might add accuracy to the results; to take more care in selection of basins within a physiographic area would possibly be an advantageous contribution to the result.

It is believed that all other variables should remain the same. With particular reference to the time base of streamflow data, it is believed that the monthly flow is the optimum. To use a shorter base would cause more variation in the calculated values and possibly resulting in no conclusions being made. A longer time period would be of very little value in flow prediction. To predict an average annual flow tells very little - if anything at all - about the action of a river during that year.
FIGURE 3. COEFFICIENT OF VARIATION VS. AREA, MIDDLE ATLANTIC SLOPES.
Figure 4. Coefficient of Variation vs. Area, Missouri River Tributaries
FIGURE 5. COEFFICIENT OF VARIATION VS. AREA, OHIO RIVER BASIN.
FIGURE 6. COEFFICIENT OF VARIATION VS. AREA, LOWER MISSISSIPPI RIVER BASIN.
FIGURE 7. COEFFICIENT OF VARIATION VS. AREA, CENTRAL VALLEY OF CALIFORNIA
FIGURE 8. COEFFICIENT OF VARIATION VS. AREA, PACIFIC MOUNTAIN SLOPES.
VI. ACKNOWLEDGEMENTS

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The author wishes also to express his appreciation to Dr. James M. Wiggert, thesis advisor, for his suggestions and guidance. Dr. Wiggert's advice and constructive criticisms were very much appreciated during the research investigation.
VII. BIBLIOGRAPHY


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IX. APPENDIX I
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2. MISSOURI RIVER BASIN IN VICINITY OF SIOUX CITY, IOWA

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<td>KEYA PABA RIVER NEAR HIDDEN TIMBER, S D</td>
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<td>South Loup River at St Michael, Nebr</td>
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<tr>
<td>Spring Creek at Cushing, Nebr</td>
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3. OHIO RIVER BASIN

U.S.G.S. WATER SUPPLY PAPERS 1305, 1725

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<tr>
<td>CHARTIERS CREEK AT CARNEGIE, PA</td>
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<td>MAHONING RIVER AT ALLIANCE, OHIO</td>
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<td>BEECH CREEK NEAR BOLRON, OHIO</td>
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<td>DEER CREEK NEAR LIMAVILLE, OHIO</td>
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<td>W BR MAHONING RIVER NEAR NEWTON FALLS, OHIO</td>
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<td>EAGLE CREEK AT PHALANX STATION, OHIO</td>
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<td>MIDDLE ISLAND CREEK AT LITTLE, W VA</td>
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<td>MIDDLE BR NIMISHILLEN CREEK AT CANTON, OHIO</td>
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<td>NIMISHILLEN CREEK AT NORTH INDUSTRY, OHIO</td>
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HOME CREEK NEAR NEW PHILADELPHIA, OHIO 1.6
TOUBY RUN AT MANSFIELD, OHIO 5.2
KOKOSING RIVER AT MOUNT VERNON, OHIO 200.
KILLBUCK CREEK AT KILLBUCK, OHIO 466.
MILL CREEK NEAR COSHOCTON, OHIO 27.5
SALT FORK NEAR CAMBRIDGE, OHIO 55.6
WAKATOMIKA CREEK NEAR FRAZEYSBURG, OHIO 140.
LITTLE SANDY RIVER NEAR GRAYSON, KY 402.
TYGARTS CREEK AT OLIVE HILL, KY 59.6
TYGARTS CREEK NEAR GREENUP, KY 242.
SCIOTO RIVER AT LA RUE, OHIO 255.
LITTLE SCIOTO RIVER ABOVE MARION, OHIO 70.
SCIOTO RIVER NEAR PROSPECT, OHIO 571.
MILL CREEK NEAR BELLEPOINT, OHIO 181.
SCIOTO BIG RUN AT BRIGGSDALE, OHIO 11.
PAINT CREEK NEAR GREENFIELD, OHIO 251.
ROCKY FORK NEAR BARRETT'S MILLS, OHIO 141.
PAINT CREEK NEAR BOURNEVILLE, OHIO 808.
SALT CREEK AT TARLTON, OHIO 10.6
TAR HOLLOW CREEK AT TER HOLLOW ST PARK, OHIO 1.5
OHIO BRUSH CREEK NEAR WEST UNION, OHIO 388.
4. LOWER MISSISSIPPI RIVER BASIN
U.S.G.S. WATER SUPPLY PAPERS 1311, 1731

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<td>CASTOR RIVER AT ZALMA, MO</td>
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<td>MAYFIELD CREEK AT LOVELACEVILLE, KY</td>
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<td>OBION CREEK AT PRYORSBURG, KY</td>
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<td>ST FRANCIS RIVER NEAR PATTERSON, MO</td>
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<td>JAMES RIVER AT GALENA, MO</td>
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5. CENTRAL VALLEY OF CALIFORNIA

U.S.G.S. WATER SUPPLY PAPERS 1315A, 1735

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<td>DINKEY CREEK AT MOUTH, CALIF</td>
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<td>MERCED RIVER AT HAPPY ISLES BRICGE, NEAR</td>
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<td>DEER CREEK NEAR CALIF HOT SPRINGS, CALIF</td>
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<td>South Fork Tule River near Porterville, CA</td>
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<td>N Fork Kings River below Meadow Brook, Calif</td>
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<td>Helms Creek at Sands Meadow, Calif</td>
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<td>Rancheria Creek near Smith Meadow, Calif</td>
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<td>Los Gados Creek near Coalinga, Calif</td>
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<td>N Fork San Joaquin River below Iron Creek, Calif</td>
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<td>West Fork Granite Creek near Timber Knob, Calif</td>
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<td>Bear Creek near Vermillion, Calif</td>
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<td>Jackass Creek near Jackass Meadow, Calif</td>
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<td>Chiquito Creek near Arnold Meadow, Calif</td>
<td>59.6</td>
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<td>Pitman Creek near Tamarack, Calif</td>
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<td>Wiskey Creek near North Fork, Calif</td>
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<td>Fine Gold Creek near Friant, Calif</td>
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<tr>
<td>Tenaya Creek near Yosemite, Calif</td>
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6. PACIFIC MOUNTAIN SLOPES IN WASHINGTON AND OREGON
U.S.G.S. WATER SUPPLY PAPERS 1316, 1318, 1736, 1738

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<td>405 JOHN DAY RIVER AT PICTURE GORGE</td>
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<td>440 MIDDLE FK JOHN DAY RIVER AT RITTER, O</td>
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<td>460 N FK JOHN DAY RIVER AT MONUMENT, ORE</td>
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<td>465 JOHN DAY RIVER AT SERVICE CREEK, ORE</td>
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<td>915 METOLIUS RIVER NEAR GRANDVIEW, ORE</td>
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<td>1070 KLICKTAT RIVER ABOVE WEST FORK, NEAR GLENWOOD</td>
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<td>1120 LITTLE KLICKTAT RIVER NEAR GOLDENELLE, WASH</td>
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<td>1130 KLICKITAT RIVER NEAR PITT, WASH</td>
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<td>1230 WHITE SALMON RIVER NEAR HUSUM, WASH</td>
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<td>185 WALLA WALLA RIVER NEAR TOUCHET, WASH</td>
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<td>200 UMATILLA RIVER ABOVE MECHAM CREEK NEAR GIBB</td>
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<td>395 SO FK JOHN DAY RIVER NEAR DAYVILLE, O</td>
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<td>160 DRY CREEK NEAR WALLA WALLA, WASH</td>
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<td>165 E. FK Touchet River near Dayton, Wash</td>
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<td>225 McKay Creek near Pilot Rock, Oregon</td>
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<td>250 Birch Creek at Rieth, Oregon</td>
<td>291.</td>
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<tr>
<td>375 Strawberry Creek above Slide Creek</td>
<td>7.</td>
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<td>410 Desolation Creek near Dale Oregon</td>
<td>108.</td>
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<tr>
<td>420 Camas Creek near Lehman, Oregon</td>
<td>61.</td>
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<td>425 Camas Creek near Ukiah, O</td>
<td>121.</td>
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<tr>
<td>445 Fox Creek at Gorge near Fox, Ore</td>
<td>90.2</td>
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<td>750 Squaw Creek near Sisters, Ore</td>
<td>54.8</td>
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<tr>
<td>780 Beaver Creek near Paulina, Ore</td>
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<tr>
<td>785 N FK Crooked River above Deep Creek, O</td>
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<td>955 Warm Springs River at Hehe Mill</td>
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<td>1045 Fifteenmile Creek near Wrentham, ORE</td>
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<td>1050 Eight Mile Creek near Boyd, ORE</td>
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<tr>
<td>1125 Little Klickitat River near Wahiakus, Wash</td>
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<td>1280 Panther Creek near Carson, Wash</td>
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MIDDLE ATLANTIC SLOPE BASINS IN VIRGINIA AND NORTH CAROLINA

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MISSOURI RIVER BASIN IN VICINITY SIOUX CITY, IOWA

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</table>
## CENTRAL VALLEY CALIFORNIA

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<tr>
<th>No.</th>
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<th>Coefficient of Variation</th>
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<td>Coefficient of Variation</td>
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</table>
Statistical Analysis for Streamflow Prediction

For the six regions taken under investigation a statistical analysis of mean monthly flows was attempted. The relationship was established for all but one region.

The analysis compared the coefficient of variation of the monthly flows to the size of the drainage area for each basin in a region. The regions were defined by basins of similar topography and climate. Streamflow prediction would be made by mathematical synthesis from the standard deviation parameter computed from the graphical relationships established for each region.

The value of such a relationship was evidenced by the general consistency of the results.