TECHNIQUES FOR ESTIMATING FLOOD-PEAK DISCHARGES OF RURAL, UNREGULATED STREAMS IN OHIO

By G. F. Koltun and John W. Roberts

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Final report on an
INVESTIGATION AND ANALYSIS OF FLOODS
FROM SMALL NORTHWESTERN, STRIP-MINED,
AND FORESTED DRAINAGE BASINS IN OHIO

Prepared in cooperation with the
OHIO DEPARTMENT OF TRANSPORTATION
and the
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FEDERAL HIGHWAY ADMINISTRATION

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Columbus, Ohio
1990
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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer metric (International System) units to the inch-pound units in this report, values may be converted by use of the following factors:

<table>
<thead>
<tr>
<th>Multiply inch-pound unit</th>
<th>By</th>
<th>To obtain metric unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>inch (in.)</td>
<td>25.4</td>
<td>millimeter (mm)</td>
</tr>
<tr>
<td>foot (ft)</td>
<td>0.3048</td>
<td>meter (m)</td>
</tr>
<tr>
<td>mile (mi)</td>
<td>1.609</td>
<td>kilometer (km)</td>
</tr>
<tr>
<td>foot per mile (ft/mi)</td>
<td>0.1894</td>
<td>meter per kilometer (m/km)</td>
</tr>
<tr>
<td>square mile (mi²)</td>
<td>2.590</td>
<td>square kilometer (km²)</td>
</tr>
<tr>
<td>cubic foot per second (ft³/s)</td>
<td>0.02832</td>
<td>cubic meter per second (m³/s)</td>
</tr>
<tr>
<td>acre-foot (acre-ft)</td>
<td>0.001233</td>
<td>cubic hectometer (hm³)</td>
</tr>
</tbody>
</table>

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$^\circ\text{C} = [^\circ\text{F} - 32]/1.8$$

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called “Sea Level Datum of 1929.”
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ABSTRACT

Multiple-regression equations are presented for estimating flood-peak discharges having recurrence intervals of 2, 5, 10, 25, 50, and 100 years at ungaged sites on rural, unregulated streams in Ohio. The average standard errors of prediction for the equations range from 33.4 percent to 41.4 percent.

Peak-discharge estimates determined by log-Pearson Type III analyses using data collected through the 1987 water year are reported for 275 streamflow-gaging stations. Ordinary least-squares multiple-regression techniques were used to divide the State into three regions and to identify a set of basin characteristics that help explain station-to-station variation in the log-Pearson estimates. Contributing drainage area, main-channel slope, and storage area were identified as suitable explanatory variables.

Generalized least-squares procedures, which include historical flow data and account for differences in the variance of flows at different gaging stations, spatial correlation among gaging station records, and variable lengths of station record, were used to estimate the regression parameters. Weighted peak-discharge estimates computed as a function of the log-Pearson Type III and regression estimates are reported for each station. A method is provided to adjust regression estimates for ungaged sites by use of weighted and regression estimates for a gaged site located on the same stream.

Limitations and shortcomings cited in an earlier report on the magnitude and frequency of floods in Ohio are addressed in this study. Geographic bias is no longer evident for the Maumee River basin of northwestern Ohio. No bias is found to be associated with the forested-area characteristic for the range used in the regression analysis (0.0 to 99.0 percent), nor is this characteristic significant in explaining peak discharges. Surface-mined area likewise is not significant in explaining peak discharges, and the regression equations are not biased when applied to basins having approximately 30 percent or less surface-mined area. Analyses of residuals indicate that the equations tend to overestimate flood-peak discharges for basins having approximately 30 percent or more surface-mined area.
INTRODUCTION

Previous reports on the magnitude and frequency of floods in Ohio (Cross, 1946; Cross and Webber, 1959; Cross and Mayo, 1969; Webber and Bartlett, 1977) presented methods for estimating flood-peak discharges of rural, unregulated streams. Webber and Bartlett (1977) developed equations for estimating flood-peak discharges; however, they noted bias for basins that are heavily forested or are located within the Maumee River basin of northwestern Ohio. Furthermore, the 1977 equations are not applicable to basins that have substantial areas of surface mining or urbanization. Techniques for determining flood-flow frequency have been revised since the 1977 equations were developed (Interagency Advisory Committee on Water Data, 1982), and 12 additional years of flood-peak data (1976 through 1987) have been collected.

Purpose and Scope

The purpose of this report is to present techniques for estimating flood-peak discharges for rural, unregulated streams in Ohio. Better representation of flood-peak discharges is emphasized for basins that (1) are located within the Maumee River basin of northwestern Ohio, (2) have been subjected to surface mining and are either unreclaimed or have undergone various degrees of reclamation, or (3) are heavily forested. Multiple-regression equations are given for estimating flood-peak discharges having recurrence intervals of 2, 5, 10, 25, 50, and 100 years at ungaged sites. A method also is provided to adjust discharges estimated for an ungaged site by using weighted and regression flood-frequency estimates for a streamflow-gaging station located on the same stream. Computed flood-frequency discharge estimates are presented for each of the 275 streamflow-gaging stations used in this study. Examples of how to use the multiple-regression equations and the discharge-adjusting method also are provided. For the convenience of the user, the techniques and examples of their use immediately follow the introduction. Methods used to develop the regression equations and weighted estimates of peak discharge are presented in the latter sections of the report.

Approach

Flood-frequency curves were developed for 275 streamflow-gaging stations on rural, unregulated streams following guidelines suggested by the Interagency Advisory Committee on Water Data (1982). Of these 275 stations, 249 are in Ohio (fig. 1, in pocket), thirteen are in Indiana, nine are in Pennsylvania, and four are in Michigan. All 275 streamflow-gaging stations had 10 or more years of recorded annual peak-discharge data.

The data base for this study included 166 continuous-record streamflow-gaging stations, 88 partial-record crest-stage streamflow-gaging stations, and 21 stations having
both continuous and partial records. Thirty of the partial-record stations (fig. 1) were established for this study to provide better representation of flood-peak discharges on basins that (1) are located within the Maumee River basin of northwestern Ohio, (2) have been subjected to surface mining, or (3) are heavily forested. Flood-frequency curves were developed for each of the 30 partial-record crest-stage stations from 10 years of flood-peak discharge data collected from water years1 1978 through 1987. Basins substantially affected by urbanization were not included in the data base; however, Sherwood (1986) presents techniques for estimating flood-peak discharges, flood volumes, and hydrograph shapes for streams draining small (less than 4.10 square miles) urbanized basins in Ohio.

Ordinary and generalized least-squares multiple-regression techniques were used to develop equations that relate flood-peak discharges having recurrence intervals of 2, 5, 10, 25, 50, and 100 years to selected basin characteristics for the 275 streamflow-gaging stations.

Acknowledgments

This report was prepared in cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. Flood-peak discharge data from the network of 30 partial-record crest-stage stations were collected under this cooperative agreement. The remaining streamflow data used in this study have been collected under cooperative agreements with other Federal, State, and local agencies.

TECHNIQUES FOR ESTIMATING FLOOD-PEAK DISCHARGES

The following basin characteristics, determined from U.S. Geological Survey 7.5-minute topographic quadrangle maps, are used in multiple-regression equations to estimate flood-peak discharges having recurrence intervals of 2, 5, 10, 25, 50, and 100 years at ungaged sites on rural, unregulated streams in Ohio (table 1):

Contributing drainage area (CONTDA), in square miles; area measured in a horizontal plane that contributes surface runoff to a specified location on a stream. This area may be located inside or outside of the natural topographic divides of the basin.

1 A water year is the 12-month period from October 1 through September 30, and is designated by the calendar year in which it ends.
Table 1.--Equations for estimating flood-peak discharges of rural, unregulated streams in Ohio

<table>
<thead>
<tr>
<th>Equation number</th>
<th>Equation</th>
<th>Average standard error of prediction (in percent)</th>
<th>Average equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Q&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(RC)(CONTDA)&lt;sup&gt;0.782&lt;/sup&gt;(SLOPE)&lt;sup&gt;0.172&lt;/sup&gt;(STORAGE+1)</td>
<td>-0.297</td>
<td>41.4</td>
</tr>
<tr>
<td>(2) Q&lt;sub&gt;5&lt;/sub&gt;</td>
<td>(RC)(CONTDA)&lt;sup&gt;0.769&lt;/sup&gt;(SLOPE)&lt;sup&gt;0.221&lt;/sup&gt;(STORAGE+1)</td>
<td>-0.322</td>
<td>33.9</td>
</tr>
<tr>
<td>(3) Q&lt;sub&gt;10&lt;/sub&gt;</td>
<td>(RC)(CONTDA)&lt;sup&gt;0.764&lt;/sup&gt;(SLOPE)&lt;sup&gt;0.244&lt;/sup&gt;(STORAGE+1)</td>
<td>-0.335</td>
<td>33.4</td>
</tr>
<tr>
<td>(4) Q&lt;sub&gt;25&lt;/sub&gt;</td>
<td>(RC)(CONTDA)&lt;sup&gt;0.760&lt;/sup&gt;(SLOPE)&lt;sup&gt;0.264&lt;/sup&gt;(STORAGE+1)</td>
<td>-0.347</td>
<td>34.1</td>
</tr>
<tr>
<td>(5) Q&lt;sub&gt;50&lt;/sub&gt;</td>
<td>(RC)(CONTDA)&lt;sup&gt;0.757&lt;/sup&gt;(SLOPE)&lt;sup&gt;0.276&lt;/sup&gt;(STORAGE+1)</td>
<td>-0.355</td>
<td>35.0</td>
</tr>
<tr>
<td>(6) Q&lt;sub&gt;100&lt;/sub&gt;</td>
<td>(RC)(CONTDA)&lt;sup&gt;0.756&lt;/sup&gt;(SLOPE)&lt;sup&gt;0.285&lt;/sup&gt;(STORAGE+1)</td>
<td>-0.363</td>
<td>36.3</td>
</tr>
</tbody>
</table>

where RC is the regression constant for a region from the following matrix:

<table>
<thead>
<tr>
<th>Region</th>
<th>Q&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Q&lt;sub&gt;5&lt;/sub&gt;</th>
<th>Q&lt;sub&gt;10&lt;/sub&gt;</th>
<th>Q&lt;sub&gt;25&lt;/sub&gt;</th>
<th>Q&lt;sub&gt;50&lt;/sub&gt;</th>
<th>Q&lt;sub&gt;100&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>56.1</td>
<td>84.5</td>
<td>104</td>
<td>129</td>
<td>146</td>
<td>167</td>
</tr>
<tr>
<td>B</td>
<td>40.2</td>
<td>58.4</td>
<td>69.3</td>
<td>82.2</td>
<td>91.2</td>
<td>99.7</td>
</tr>
<tr>
<td>C</td>
<td>93.5</td>
<td>133</td>
<td>159</td>
<td>191</td>
<td>214</td>
<td>236</td>
</tr>
</tbody>
</table>

CONTDA is the contributing drainage area (in square miles),

SLOPE is the main-channel slope (in feet per mile), and

STORAGE is the storage area (in percent).

Table 2.--Statistics of selected basin characteristics for streamflow-gaging stations, by region

[CONTDA, contributing drainage area; ft/mi, feet per mile; mi<sup>2</sup>, square miles]

<table>
<thead>
<tr>
<th>Region</th>
<th>Statistic</th>
<th>CONTDA (mi&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>SLOPE (ft/mi)</th>
<th>STORAGE (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Maximum</td>
<td>7,422</td>
<td>994</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.012</td>
<td>1.4</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>295</td>
<td>52.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>64.2</td>
<td>12.6</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>Maximum</td>
<td>6,330</td>
<td>500</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.040</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>353</td>
<td>28.3</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>55.0</td>
<td>8.0</td>
<td>0.0</td>
</tr>
<tr>
<td>C</td>
<td>Maximum</td>
<td>3,630</td>
<td>145</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.260</td>
<td>3.4</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>330</td>
<td>30.8</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>96.5</td>
<td>13.6</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Main-channel slope (SLOPE), in feet per mile; computed as the difference in elevation at points 10 and 85 percent of the distance along the main channel from a specified location on the channel to the topographic divide, divided by the channel distance between the two points.

Storage area (STORAGE); the percentage of the contributing drainage area occupied by lakes, ponds, and swamps as explicitly shown on U.S. Geological Survey 7.5-minute topographic quadrangle maps.

The multiple-regression equations are applicable to each of three regions delineated on figure 1. The appropriate regression constant must be selected from the regression constant matrix (table 1) to estimate a flood-peak discharge for a specified recurrence interval at an ungaged site within a particular region.

Before using the equations, tests for extrapolation should be made by comparing each measured basin-characteristic value for the ungaged site to the ranges of basin-characteristic values in the regression data set for each region (table 2), or by following the more rigorous procedures outlined in Appendix A. Use of the regression equations is not recommended when a basin-characteristic value is outside the range.

It is suggested that the reader refer to the section “Assessment of the Multiple-Regression Equations” for further information on the accuracy, sensitivity, and limitations of the equations.

**Estimating Flood-Peak Discharge for a Site on an Ungaged Stream**

The technique for estimating flood-peak discharge for a site on an ungaged stream is illustrated in the following example. The 100-year flood-peak discharge is needed for a site on an ungaged stream in Butler County, Ohio. First, it is confirmed that the basin is rural and the stream is unregulated. Then, by locating the site on figure 1 (in pocket), the Region C multiple-regression equation for estimating 100-year flood-peak discharges is chosen (table 1, page 4):

\[
Q_{100} = 236 \times (\text{CONTDA})^{0.756} \times (\text{SLOPE})^{0.285} \times (\text{STORAGE} + 1)^{-0.363}.
\]
Basin characteristics for the ungaged site are determined:

\[
\text{CONTDA} = 0.290 \text{ square miles} \\
\text{SLOPE} = 93.0 \text{ feet per mile} \\
\text{STORAGE} = 0.0 \text{ percent}
\]

These values are substituted into the Region C equation:

\[
Q_{100} = 236 (0.290)^{0.756} (93.0)^{0.285} (0.0+1)^{-0.363}
\]

\[
Q_{100} = 337 \text{ cubic feet per second.}
\]

**Estimating Flood-Peak Discharge for an Ungaged Site on a Gaged Stream**

The technique for estimating flood-peak discharge for an ungaged site on a gaged stream is illustrated in the following example. The 25-year flood-peak discharge is needed for an ungaged site on the Licking River in Licking County, Ohio. This site is located upstream from the discontinued streamflow-gaging station, Licking River at Toboso, Ohio (03147000). First, it is confirmed that the basin is rural and the stream is unregulated. Then, by locating the ungaged site on figure 1 (in pocket), the Region A multiple-regression equation for estimating 25-year flood-peak discharges is chosen (table 1, page 4):

\[
Q_{25} = 129 (\text{CONTDA})^{0.760} (\text{SLOPE})^{0.264} (\text{STORAGE} +1)^{-0.347}
\]

Basin characteristics for the ungaged site are determined:

\[
\text{CONTDA} = 537 \text{ square miles} \\
\text{SLOPE} = 10.7 \text{ feet per mile} \\
\text{STORAGE} = 0.6 \text{ percent}
\]

These values are substituted into the Region A equation:

\[
Q_{25} = 129 (537)^{0.760} (10.7)^{0.264} (0.6 + 1)^{-0.347}
\]

\[
Q_{25} = 24,300 \text{ cubic feet per second.}
\]
If the contributing drainage area of an ungaged site on a gaged stream is between 50 and 150 percent of the contributing drainage area of a gaged site on the same stream, then the following method of adjusting the estimated flood-peak discharge of the ungaged site is suggested:

\[ Q_{t,a \text{ (ungaged)}} = Q_{t,r \text{ (ungaged)}} \left( R - \frac{2(\Delta \text{CONTDA}) (R - 1)}{\text{CONTDA (gaged)}} \right), \quad (7) \]

where

\[ R = \frac{Q_{t,w \text{ (gaged)}}}{Q_{t,r \text{ (gaged)}}} \]

and \( Q_{t,a \text{ (ungaged)}} \) is the adjusted flood-peak discharge estimate having a recurrence interval of \( t \) years for the ungaged site; \( Q_{t,r \text{ (ungaged)}} \) is the multiple-regression equation estimate of flood-peak discharge having a recurrence interval of \( t \) years for the ungaged site; \( Q_{t,w \text{ (gaged)}} \) is the weighted flood-peak discharge estimate having a recurrence interval of \( t \) years for the gaged site, reported in table 3; \( Q_{t,r \text{ (gaged)}} \) is the multiple-regression equation estimate of flood-peak discharge having a recurrence interval of \( t \) years for the gaged site, reported in table 3; \( \Delta \text{CONTDA} \) is the absolute value of the difference between the contributing drainage areas of the gaged site and the ungaged site; and \( \text{CONTDA (gaged)} \) is the contributing drainage area of the gaged site, reported in table 4 (at back of report).

This method (1) adjusts the regression estimate for the ungaged site by the ratio \( R \) when the contributing drainage area of the ungaged site equals the contributing drainage area of the gaged site and (2) prorates the adjustment to one as the contributing drainage area of the ungaged site approaches either 50 percent or 150 percent of the contributing drainage area of the gaged site.
The 537-square-mile drainage area for the ungaged site on the Licking River is between 50 and 150 percent of the 672-square-mile drainage area of the discontinued streamflow-gaging station, Licking River at Toboso, Ohio. Flood-peak discharges having recurrence intervals of 25 years are determined for both sites:

\[ Q_{25r\text{ (ungaged)}} = 24,300 \text{ cubic feet per second (as determined above)} \]

\[ Q_{25w\text{ (gaged)}} = 31,500 \text{ cubic feet per second (table 3)} \]

\[ Q_{25r\text{ (gaged)}} = 129 (\text{CONTDA})^{0.760}(\text{SLOPE})^{0.264}(\text{STORAGE+1})^{-0.347} \]

(Region A equation from table 1)

where the basin characteristics for the gaged site (table 4) are

\begin{align*}
\text{CONTDA} &= 672 \text{ square miles;} \\
\text{SLOPE} &= 8.2 \text{ feet per mile;} \\
\text{STORAGE} &= 0.8 \text{ percent.}
\end{align*}

These values are substituted into the Region A equation:

\[ Q_{25r\text{ (gaged)}} = 129(672)^{0.760}(8.2)^{0.264}(0.8+1)^{-0.347} \]

\[ Q_{25r\text{ (gaged)}} = 25,800 \text{ cubic feet per second.} \]

The absolute value of the difference between contributing drainage areas of the gaged site and the ungaged site (\(\Delta\text{CONTDA}\)) is computed as 135 square miles (672 square miles minus 537 square miles).

These discharge and contributing-drainage-area values are substituted into the equation for adjusting the estimated flood-peak discharge of the ungaged site--

\[ Q_{25a\text{ (ungaged)}} = 24,300 \left[ \left( \frac{31,500}{25,800} \right) - \left( \frac{2(135)}{672} \right) \left( \frac{31,500}{25,800} - 1 \right) \right] \]

\[ Q_{25a\text{ (ungaged)}} = 27,500 \text{ cubic feet per second.} \]
DEVELOPMENT OF FLOOD-FREQUENCY CURVES FOR STREAMFLOW-GAGING STATIONS

Flood-frequency curves were developed for 275 streamflow-gaging stations on rural, unregulated streams having at least 10 years of annual peak-discharge data. Interagency Advisory Committee on Water Data (1982) guideline's for determining flood-flow frequency were followed.

A flood-frequency curve relates annual flood-peak magnitudes to annual exceedance probability. Annual exceedance probability can be expressed as the chance, in percent, of a given flood magnitude being exceeded in any one year. Recurrence interval, which is the reciprocal of the annual exceedance probability, is the average number of years between exceedances of a given flood magnitude. The occurrence of floods is considered to be random in time; therefore, no schedule of regularity is implied. The occurrence of a flood having a 100-year recurrence interval (1-percent annual exceedance probability) does not guarantee that a flood of equal or greater magnitude will not occur the following year or even the following week.

Observed annual flood-peak discharges were transformed to base 10 logarithms and fit to a Pearson Type III distribution. Low outliers were deleted, and adjustments were made for high outliers in light of historic flood information. Station skew was weighted with skew values from a generalized skew map (Interagency Advisory Committee on Water Data, 1982).

The flood-peak discharge at selected annual exceedance probabilities was computed by the equation:

\[ \log(Q) = \bar{X} + KS, \]

where \( \bar{X} \) is the mean of the logarithms of the observed annual flood-peak discharges;

\( S \) is the standard deviation of the logarithms of the observed annual flood-peak discharges; and

\( K \) is a function of the weighted skew coefficient and the selected annual exceedance probability.

These computed log-Pearson Type III flood-peak discharge estimates and their associated recurrence intervals (2, 5, 10, 25, 50, and 100 years) are presented in table 3 (at back of report).
DEVELOPMENT OF MULTIPLE-REGRESSION EQUATIONS

Multiple-linear-regression techniques were used to relate selected basin characteristics (table 4, at back of report) to flood-peak discharges with 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals for the 275 streamflow-gaging stations. In multiple-linear regression, the dependent variable is assumed to be a linear function of two or more regressor variables. The general form of the multiple-regression equation used in this study is:

\[
\log(Q_t) = \log(C) + b_1 \log(X_1) + b_2 \log(X_2) + \ldots + b_p \log(X_p),
\]

where \( Q_t \) is the estimated flood peak discharge, in cubic feet per second, having a \( t \)-year recurrence interval, where \( t \) equals 2, 5, 10, 25, 50, or 100;

\( C \) is a constant;

\( b_i \) is the regression coefficient for the \( i \)-th regressor variable \( (i=1, \ldots, p) \);

\( X_i \) is the \( i \)-th regressor variable \( (i=1, \ldots, p) \); and

\( p \) is the total number of regressor variables in the equation.

For computational convenience, the above equation is presented in this report in the algebraically equivalent form:

\[
Q_t = C(X_1)^{b_1} (X_2)^{b_2} \ldots (X_p)^{b_p}.
\]

Selection of Regressor Variables

Ordinary least-squares (OLS) multiple-regression analyses were performed using the SAS\(^2\) statistical procedures RSQUARE and STEPWISE (SAS Institute, 1982) to determine the optimum set of regressor variables. A variety of independent variables providing measures of different basin characteristics were explored as potential regressor variables. These independent variables listed here and explained in Appendix B included contributing drainage area, main-channel slope, main-channel length, mean basin elevation, basin elevation index, basin shape index, storage area, forested area, surface-mined

\(^2\)Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.
area, mean annual precipitation, mean minimum January temperature, and 24-hour, 2-year rainfall. The final selection of regressor variables, however, was based on the following criteria:

1. The choice of regressor variables, as well as the signs and magnitudes of their associated regression coefficients, must be hydrologically plausible in the context of peak flows. This criterion takes precedence over all other criteria.

2. All regressor variables should be statistically significant at the 95-percent confidence level.

3. The choice of regressor variables, within the constraints of criteria 1 and 2, should minimize the prediction error sum of squares (PRESS) and maximize the coefficient of determination ($R^2$, a measure of the proportion of the variation in the dependent variable accounted for by the regression equation).

The variables selected using the criteria described above include (1) the contributing drainage area (CONTDA), (2) main-channel slope (SLOPE), and (3) storage area (STORAGE). Surface-mined area and forested area, two independent variables that were emphasized in this analysis, are not statistically significant in explaining peak discharges.

**Analysis of Data on a Statewide Basis**

Multiple-regression analyses were first performed on data from the 275 rural, unregulated streamflow-gaging stations in Ohio and adjacent states in an attempt to develop equations that would be applicable statewide. Plots of residuals, the differences between the log-Pearson Type III and regression estimates of peak discharge, for the statewide equations showed evidence of a geographic bias. Consequently, additional regression analyses were performed for selected regions in Ohio.

**Analysis of Data by Selected Regions**

The State was divided into regions using information on topography, drainage-basin boundaries, and areal trends of residuals for the statewide equations as guides. The locations of region boundaries were chosen so that no unregulated streams were crossed. The regionalization process served to compensate for the geographic bias observed in the statewide residual plots, which was not otherwise accounted for in the regression model. Geographic bias is not evident in the Maumee River basin of northwestern Ohio as had been previously observed by Webber and Bartlett (1977).
Regionalization was accomplished in the regression model by means of a set of indicator variables. The indicator-variable method was used in lieu of separate regression analyses because it gives one estimate of the common error variance for the State and provides more residual degrees of freedom than would result from fitting separate regressions. The effect of the indicator variable is an adjustment in the intercept term for the logarithmic form of the regression equation. For the reader's convenience, the intercept term is combined with the constant and separate equations are reported for each region. Additional information on the use of indicator variables in multiple-regression analyses is provided by Montgomery and Peck (1982).

Ohio ultimately was divided into three regions using the information and method described above. These regions are shown on figure 1.

**Generalized Least-Squares Regression**

After an acceptable set of regressor variables were determined and the State was regionalized using OLS techniques, generalized least-squares (GLS) regressions were performed. Stedinger and Tasker (1985) found that the GLS procedure provides more accurate parameter (regression coefficient) estimates, better estimates of the accuracy with which the regression model's coefficients are being estimated, and almost unbiased estimates of the model error.

Unlike the OLS procedure, the GLS procedure takes into consideration the variance and spatial correlation structure of the streamflow characteristics and weights each observation accordingly (Tasker and others, 1986). In addition, the time-sampling error in the estimated \( Q_t \) streamflow characteristic is accounted for in evaluating the accuracy of the regression equation. A third advantage to the GLS procedure is that historical peak-flow data can be considered in computing the time sampling error in \( Q_t \).

The GLS analyses were performed using procedures incorporated into ANNIE/WDM, a set of programs designed for the storage and interactive analysis of watershed and time-series data (Lumb and others, 1989). The equations developed by generalized least-squares regression are reported for the three regions in table 1.

Weighted estimates of the t-year peak discharges are reported in table 3 for the 275 streamflow-gaging stations. The weighted estimates are preferred for gaged sites over the log-Pearson Type III estimates or the regression estimates alone because they represent a weighted average of two independent estimates. The weighted estimates were
\[ Q_{t,w} = 10 \left( \frac{\log(Q_{t,o})(\omega) + \log(Q_{t,r})(\omega_e)}{\omega + \omega_e} \right) \]

where \( Q_{t,o} \) is the log-Pearson Type III estimate of the \( t \)-year peak discharge;

\( Q_{t,r} \) is the regression estimate of the \( t \)-year peak discharge;

\( \omega_e \) is the equivalent years of record for the regression estimate as defined by Hardison (1971); and

\( \omega \) is either the systematic record length, in years, if no historic peak discharge data are available for the site,

or

the effective record length, in years, as determined below, if historic peak discharge data are available for the site—

\[ \omega = \omega_s + (A \cdot D), \]

where \( A = 0.55 - 0.1 \cdot (\ln(P/(1-P))) \);

\[ P = 1 - \frac{N_p}{(\omega_h + \omega_s)}; \]

\[ D = \min(200,(\omega_h - \omega_s)); \]

\( N_p \) is the number of historic peaks;

\( \omega_h \) is the historic record length, in years; and

\( \omega_s \) is the systematic record length, in years.
ASSESSMENT OF THE MULTIPLE-REGRESSION EQUATIONS

Tests for Collinearity

Tests for collinearity, the condition where regressor variables exhibit near linear dependencies, were conducted using SAS. Severe collinearity can cause appreciable round-off errors in the regression calculations. Moderate collinearity can have a destabilizing effect on parameter estimates, although estimates of the dependent variable may not be adversely affected.

A moderate level of collinearity (defined here as a condition number between 3 and 5 in combination with two or more regressors having variance-decomposition proportions greater than 0.5) is found between the variables CONTDA and SLOPE as determined by eigensystem analysis (SAS, 1982; Belsley and others, 1980). This moderate collinearity should not harm estimation if the conditions for estimation are confined to the regressor space within which the collinearity holds (Montgomery and Peck, 1982). The implication of this constraint is that extrapolation to combinations of regressor variables not represented in the development of the regression equation may lead to poor estimates of \( Q_t \). Past experience with equations developed by Webber and Bartlett (1977), in which these variables also are present together, has demonstrated that satisfactory estimation, without extrapolation, can be done in spite of the collinearity.

Tests for Constant Residual Variance

Tests for constancy of residual variance were performed by plotting the regression residuals against the corresponding estimate of the dependent variable and by plotting the regression residuals against the corresponding values of each individual regressor variable by the SAS procedures REG and PLOT. The equations presented in this report have constant residual variance (characterized by a relatively uniform band of points around the line corresponding to the zero residual), which indicates that the residuals are not a function of regressor magnitude. More specifically, the residuals are not a function of contributing drainage area, main-channel slope, or storage area, thus, the regression equations are equally applicable for the full ranges of these characteristics used in the regression analysis (table 2).

Residuals also were plotted against independent variables not selected for use in the regression equations. These plots can reveal inadequacies in the regression equations caused by parametrical bias or the omission of an important explanatory variable. The residual variance associated with the variable representing forested area appears to be constant. This indicates that there is no bias associated with forested area for the range
(0.0 to 99.0 percent) used in the regression analysis. This lack of bias suggests that the regression equations are applicable to heavily forested basins (assuming the limitations discussed in the section "Limitations of the Equations" are met). The bias noted by Webber and Bartlett (1977) for heavily forested basins could have resulted from a limited or an unrepresentative sample. Residual variance is relatively constant for basins having approximately 30 percent or less surface-mined area. Consequently, unbiased estimates of peak discharge are obtained for those basins.

The equations tend to overestimate peak discharges for basins having approximately 30 percent or more surface-mined area. To illustrate this, average and median ratios of the log-Pearson Type III estimates to regression estimates for the 10 basins with greater than 30 percent surface-mined area are reported in the following table:

<table>
<thead>
<tr>
<th>Recurrence interval (years)</th>
<th>Average ratio of log-Pearson Type III estimate to the regression estimate</th>
<th>Median ratio of log-Pearson Type III estimate to the regression estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.94</td>
<td>0.74</td>
</tr>
<tr>
<td>5</td>
<td>0.87</td>
<td>0.62</td>
</tr>
<tr>
<td>10</td>
<td>0.87</td>
<td>0.59</td>
</tr>
<tr>
<td>25</td>
<td>0.89</td>
<td>0.58</td>
</tr>
<tr>
<td>50</td>
<td>0.93</td>
<td>0.59</td>
</tr>
<tr>
<td>100</td>
<td>0.97</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Accuracy of the Equations

Accuracy of the equations is assessed in terms of the average standard error of prediction and the average equivalent years of record. The average standard error of prediction, a measure of the average expected accuracy with which estimates of peak discharges can be made, was computed by taking the square root of the sum of the average model and sample error variances. The average standard error of prediction was converted to an average percent standard error of prediction by methods described by Hardison (1971). The average equivalent years of record represents an estimate of the number of years of actual stream-flow record required at a site to achieve an accuracy equivalent to the regional regression estimate. The average equivalent years of record is computed as part of the GLS analysis using the method described by Hardison (1971).
The average standard error of prediction and average equivalent years of record are reported along with the regression equations in Table 1.

The accuracy of individual discharge estimates can be assessed by computing individual estimates of the model and sample error variances. Techniques for computing these error variance estimates and confidence intervals are discussed in Appendix A.

**Sensitivity Analysis**

Sensitivity analyses were conducted for the $Q_2$ and $Q_{100}$ regression equations. For a given equation, one regressor variable at a time was varied from its mean value in fixed increments while the remaining regressor variables were held constant at their mean values. In this way, the effects on the $Q$ discharge that are attributable to changes in each of the regressor variables were measured. Figures 2 and 3 show the percentage of change in the estimated $Q_2$ and $Q_{100}$ values, respectively, as a result of varying the regressor variables from +50 percent to -50 percent of their means. The dependent variable ($Q_2$ or $Q_{100}$) will be least affected by changes in regressor variables that plot closest to the horizontal dashed line. Conversely, the dependent variable is most sensitive to changes in variables that plot farthest from the horizontal dashed line. For example, the sensitivity plots for 2- and 100-year peak discharges show that the computation of $Q_2$ and $Q_{100}$ are most sensitive to changes in the contributing-drainage-area variable (CONTDA).

The basin-characteristics data used in the multiple-regression equations are generally computed or estimated from U.S. Geological Survey 7.5-minute topographic quadrangle maps. The sensitivity plots illustrate the relative magnitude of errors that could be introduced through inaccurate determination of basin characteristics. Although SLOPE and STORAGE are less sensitive than CONTDA, erroneous measures of these variables also could significantly effect the magnitude of the estimated flood-peak discharge.

Because the regional regression equations for a given recurrence interval differ only in their constants, all regions share the same sensitivity characteristics.

**Limitations of the Equations**

The multiple-regression equations for estimating flood-peak discharges should only be used for unregulated streams draining rural basins. In general, basins having usable storage of less than 103 acre-feet per square mile are considered to be unregulated; however, the flood-peak discharges for an ungaged site located directly below a large reservoir could be considered to be regulated regardless of the usable storage criterion (Benson, 1962).
Figure 2.—Sensitivity of computed 2-year flood-peak discharges to change in regressor variables in the multiple-regression equations.
Figure 3. Sensitivity of computed 100-year flood peak discharges to change in regressor variables in the multiple-regression equations.
The applicability of the equations is unknown when the basin-characteristic values associated with an ungaged site are outside a space defined by the basin characteristics of the regression data set. This space, called a regressor variable hull (RVH), contains as many dimensions as there are regressor variables in the regression equation (Montgomery and Peck, 1982). If the point defined by the basin characteristics for the ungaged site lies within or on the boundary of the RVH, then the estimation involves interpolation. If the point lies outside the RVH, then the estimation would require extrapolation, which may lead to poor performance of the regression equation. The preferred method for testing for extrapolation involves matrix computations (discussed in Appendix A) that are somewhat unwieldy for routine use. An alternative method of testing for extrapolation, although less rigorous, involves comparing the individual basin characteristics of the ungaged site to the ranges of values observed in the original data for each region. Table 2 presents these ranges so that tests for extrapolation can be made. Use of the regression equations is not recommended when a basin characteristic value is outside the range.

The equations are applicable to basins having surface-mined areas; however, they should be used with caution for streams draining basins with approximately 30 percent or more surface-mined area. Tests for constant residual variance indicate a tendency to overestimate flood-peak discharges above this percentage.

SUMMARY

Flood frequency curves were developed for 275 streamflow-gaging stations on rural, unregulated streams in Ohio and adjacent states. Log-Pearson Type III estimates of flood-peak discharge having recurrence intervals of 2, 5, 10, 25, 50, and 100 years are reported.

Ordinary least-squares multiple-regression techniques were used to divide the State into three regions and identify a set of basin characteristics that help explain station-to-station variation in flood-peak discharge. Contributing drainage area (CONTDA), main-channel slope (SLOPE), and storage area (STORAGE) were identified as suitable explanatory variables.

Equations were developed for estimating flood-peak discharges at ungaged sites on rural, unregulated streams in Ohio. Generalized least-squares (GLS) regression analyses were used to estimate the regression parameters. The average standard errors of prediction for the equations range from 33.4 percent to 41.4 percent. Guidelines for use of the equations are presented along with examples.
Weighted estimates of the $t$-year peak discharges were computed for each gaging station in the GLS analysis from the log-Pearson Type III and regression estimates. These weighted estimates are reported along with the regression estimates. A method is provided to adjust regression estimates for ungaged sites as a function of contributing drainage area and the weighted and regression estimates for a gaged site located on the same stream.

Limitations and shortcomings noted by Webber and Bartlett (1977) in their report on the magnitude and frequency of floods in Ohio are addressed in this study. Thirty partial-record crest-stage streamflow-gaging stations were established specifically to provide better representation of flood-peak discharges on basins that (1) are located within the Maumee River basin of northwestern Ohio, (2) have been subjected to surface mining and are either unreclaimed or have undergone various degrees of reclamation, or (3) are heavily forested. Geographic bias is no longer evident for the Maumee River basin of northwestern Ohio as a result of additional streamflow-gaging stations, 12 additional years of flood-peak data, and (or) regionalization. No bias is found to be associated with the forested-area characteristic for the range used in the regression analysis (0.0 to 99.0 percent), nor is this characteristic significant in explaining peak discharges. Surface-mined area likewise is not significant in explaining peak discharges, and the regression equations are not biased when applied to basins having approximately 30 percent or less surface-mined area. Analyses of residuals indicate that the equations tend to overestimate flood-peak discharges for basins having approximately 30 percent or more surface-mined area. Therefore, the regression equations presented in this report are applicable to basins that are heavily forested and to basins that have been subjected to surface mining; however, potential bias associated with basins having 30 percent or more surface-mined area should be considered when making flood-peak discharge estimates.
SELECTED REFERENCES


21


Ohio Division of Water, 1962, Hydrologic atlas of average annual precipitation, temperature, streamflow, and water loss in Ohio: Ohio Department of Natural Resources, Ohio Water Plan Inventory Report 13, 4 p.


DATA TABLES
Table 3.--Flood-frequency data for streamflow-gaging stations

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Record number of water years</th>
<th>Largest recorded discharge magnitude (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03022500</td>
<td>French Creek at Saegerstown, Pa.</td>
<td>41°42'50&quot;</td>
<td>80°08'50&quot;</td>
<td>10700 14700 17400 21000 23700 26600</td>
<td>19 1913 1913 26300</td>
<td>19 1913 1913 26300</td>
</tr>
<tr>
<td>03023000</td>
<td>Cussewago Creek near Meadville, Pa.</td>
<td>41°40'20&quot;</td>
<td>80°12'55&quot;</td>
<td>1540 2110 2540 3130 3610 4130</td>
<td>28 1911-38 1913 5250</td>
<td>28 1911-38 1913 5250</td>
</tr>
<tr>
<td>03086100</td>
<td>Big Sewickley Creek near Ambridge, Pa.</td>
<td>40°36'27&quot;</td>
<td>80°09'49&quot;</td>
<td>622 1010 1320 1790 2180 2630</td>
<td>16 1963-78 1975 2540</td>
<td>16 1963-78 1975 2540</td>
</tr>
<tr>
<td>03086500</td>
<td>Mahoning River at Alliance</td>
<td>40°55'58&quot;</td>
<td>81°05'41&quot;</td>
<td>2250 3580 4640 6220 7580 9090</td>
<td>46 1942-87 1959 9740</td>
<td>46 1942-87 1959 9740</td>
</tr>
<tr>
<td>03087000</td>
<td>Beech Creek near Bolton</td>
<td>40°58'50&quot;</td>
<td>81°08'50&quot;</td>
<td>1080 1580 1910 2310 2600 2890</td>
<td>11 1944-54 1950 2210</td>
<td>11 1944-54 1950 2210</td>
</tr>
<tr>
<td>03088000</td>
<td>Deer Creek at Limeville</td>
<td>40°58'45&quot;</td>
<td>81°09'35&quot;</td>
<td>1060 1350 1560 1830 2050 2270</td>
<td>15 1942-55 1959 3660</td>
<td>15 1942-55 1959 3660</td>
</tr>
<tr>
<td>03089500</td>
<td>Mill Creek near Berlin Center</td>
<td>41°00'01&quot;</td>
<td>80°58'07&quot;</td>
<td>972 1360 1620 1940 2180 2420</td>
<td>36 1942-77 1946 1900</td>
<td>36 1942-77 1946 1900</td>
</tr>
<tr>
<td>03090500</td>
<td>Mahoning River near Berlin Center</td>
<td>41°02'54&quot;</td>
<td>81°00'05&quot;</td>
<td>5560 7430 8560 9910 10800 11700</td>
<td>12 1931-42 1937 8630</td>
<td>12 1931-42 1937 8630</td>
</tr>
<tr>
<td>03092000</td>
<td>Allegheny River near Pinecraft</td>
<td>41°08'23&quot;</td>
<td>80°59'43&quot;</td>
<td>1120 1720 2190 2880 3470 4130</td>
<td>46 1942-87 1959 3890</td>
<td>46 1942-87 1959 3890</td>
</tr>
<tr>
<td>03092090</td>
<td>West Branch Mahoning River near Ravenna</td>
<td>41°09'41&quot;</td>
<td>81°11'50&quot;</td>
<td>887 1340 1680 2150 2540 2950</td>
<td>22 1966-87 1979 2810</td>
<td>22 1966-87 1979 2810</td>
</tr>
<tr>
<td>03092100</td>
<td>Hinkley Creek near Charlestown</td>
<td>41°09'10&quot;</td>
<td>81°10'05&quot;</td>
<td>334 503 636 828 990 1170</td>
<td>23 1947-69 1959 2400</td>
<td>23 1947-69 1959 2400</td>
</tr>
</tbody>
</table>
Table 3.—Flood-frequency data for streamflow-gaging stations—Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Record number of water years</th>
<th>Largest recorded discharge (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03092500</td>
<td>West Branch Mahoning River near Newton Falls</td>
<td>41°10'18&quot;</td>
<td>81°01'16&quot;</td>
<td>2570 3750 4570 5650 6480 7340 40 1927-66 1959 8340</td>
<td>40 1927-66 1959 8340</td>
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<tr>
<td>03092600</td>
<td>Ormond Creek near Newton Falls</td>
<td>41°11'20&quot;</td>
<td>81°01'05&quot;</td>
<td>37 66 89 121 147 175 13 1950-62 1956 103</td>
<td>13 1950-62 1956 103</td>
<td></td>
</tr>
<tr>
<td>03093000</td>
<td>Eagle Creek at Phalanx Station</td>
<td>41°15'40&quot;</td>
<td>80°57'16&quot;</td>
<td>2600 3740 4510 5490 6220 6960 58 1927-34 1979 8150</td>
<td>58 1927-34 1979 8150</td>
<td></td>
</tr>
<tr>
<td>03094900</td>
<td>Walnut Creek at Cortland</td>
<td>41°19'49&quot;</td>
<td>80°43'28&quot;</td>
<td>488 816 1050 1370 1610 1860 31 1947-77 1959 1470</td>
<td>31 1947-77 1959 1470</td>
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<tr>
<td>03096000</td>
<td>Mosquito Creek at Niles</td>
<td>41°11'02&quot;</td>
<td>80°45'39&quot;</td>
<td>1580 2450 3060 3840 4450 5050 14 1930-43 1943 3080</td>
<td>14 1930-43 1943 3080</td>
<td></td>
</tr>
<tr>
<td>03098500</td>
<td>Mill Creek at Youngstown</td>
<td>41°04'19&quot;</td>
<td>80°41'26&quot;</td>
<td>1480 2430 3270 4400 5430 6600 35 1913 1913 7140</td>
<td>35 1913 1913 7140</td>
<td></td>
</tr>
<tr>
<td>03098700</td>
<td>Crab Creek at Youngstown</td>
<td>41°07'20&quot;</td>
<td>80°38'08&quot;</td>
<td>671 861 992 1160 1290 1430 24 1959-82 1959 2140</td>
<td>24 1959-82 1959 2140</td>
<td></td>
</tr>
<tr>
<td>03101000</td>
<td>Sugar Run at Pymatuning Dam, Pa.</td>
<td>41°29'50&quot;</td>
<td>80°27'55&quot;</td>
<td>540 1020 1430 2050 2610 3230 21 1935-55 1937 2800</td>
<td>21 1935-55 1937 2800</td>
<td></td>
</tr>
<tr>
<td>03102500</td>
<td>Little Shenango River at Greenville, Pa.</td>
<td>40°26'19&quot;</td>
<td>80°22'35&quot;</td>
<td>2530 3750 4630 5840 6800 7820 69 1914-18 1959 8540</td>
<td>69 1914-18 1959 8540</td>
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</tr>
<tr>
<td>03102900</td>
<td>Clear Creek at Oilville</td>
<td>41°26'45&quot;</td>
<td>80°39'56&quot;</td>
<td>64 125 178 261 335 421 31 1947-77 1958 749</td>
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<tr>
<td>03102950</td>
<td>Pymatuning Creek at Kinsman</td>
<td>41°26'34&quot;</td>
<td>80°35'18&quot;</td>
<td>1580 2040 2330 2660 2900 3120 22 1966-87 1985 2740</td>
<td>22 1966-87 1985 2740</td>
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</tr>
</tbody>
</table>
### Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge (ft³/s, for indicated recurrence interval, in years)</th>
<th>Period of record</th>
<th>Calendar year (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03104760</td>
<td>Hartlogg Run near Greenfield, Pa.</td>
<td>41°11'10&quot;</td>
<td>80°19'38&quot;</td>
<td>175 273 342 434 504 577 12 1969-80 1980 398</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03106000</td>
<td>Connocuensing Creek near Zelienople, Pa.</td>
<td>40°49'01&quot;</td>
<td>80°14'33&quot;</td>
<td>8060 10300 12700 15100 17000 18900 71 1916-66 1924 23000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03106500</td>
<td>Slippery Rock Creek at Wurtemburg, Pa.</td>
<td>40°53'02&quot;</td>
<td>80°14'02&quot;</td>
<td>7290 10300 12300 14900 16800 18800 74 1912-32 1937 19000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03109000</td>
<td>Lisbon Creek at Lisbon</td>
<td>40°46'55&quot;</td>
<td>80°45'53&quot;</td>
<td>382 614 797 1060 1290 1540 35 1947-81 1958 1500</td>
<td></td>
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</tr>
<tr>
<td>03109500</td>
<td>Little Beaver Creek near East Liverpool</td>
<td>40°40'33&quot;</td>
<td>80°32'27&quot;</td>
<td>9310 13700 16800 21100 24600 28200 72 1916-87 1941 25000</td>
<td></td>
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<td>03110000</td>
<td>Yellow Creek near Hammondsville</td>
<td>40°32'16&quot;</td>
<td>80°43'31&quot;</td>
<td>3190 4530 5490 6770 7780 8840 47 1941-87 1952 9580</td>
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<tr>
<td>03110980</td>
<td>Consol Run at Bloomingdale</td>
<td>40°19'56&quot;</td>
<td>80°48'44&quot;</td>
<td>6 12 17 24 30 37 10 1978-87 1980 17</td>
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</tr>
<tr>
<td>03111450</td>
<td>Branson Run at Georgetown</td>
<td>40°12'26&quot;</td>
<td>80°55'22&quot;</td>
<td>52 84 109 143 170 199 10 1978-87 1978 134</td>
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<tr>
<td>03111455</td>
<td>South Fork Short Creek at Georgetown</td>
<td>40°12'27&quot;</td>
<td>80°55'12&quot;</td>
<td>199 208 382 475 544 612 10 1978-87 1980 380</td>
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<td></td>
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<tr>
<td>03111470</td>
<td>Little Piney Fork at Parlett</td>
<td>40°18'07&quot;</td>
<td>80°50'55&quot;</td>
<td>62 129 191 231 385 497 10 1978-87 1987 222</td>
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<td>03111490</td>
<td>Piney Fork Tributary near Piney Fork</td>
<td>40°16'18&quot;</td>
<td>80°50'48&quot;</td>
<td>12 24 35 53 71 92 10 1978-87 1978 73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.--Flood-frequency data for streamflow-paging stations--Continued

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in $\text{ft}^3/\text{s}$, for indicated recurrence interval, in years</th>
<th>Record Number of water years</th>
<th>Largest recorded discharge calendar magnitude year ($\text{ft}^3/\text{s}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0311500</td>
<td>Short Creek near Dillonvale</td>
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<td>Graham Run near Bloomfield</td>
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<td>Buffalo Run Tributary near Dexter City</td>
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<td>03116000</td>
<td>Tuscarawas River at Clinton</td>
<td>40°55'40&quot;</td>
<td>81°37'58&quot;</td>
<td>1320 1810 2130 2540 2840 3140 52 1927-78 1935 2700</td>
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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

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<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in $\text{ft}^3/\text{s}$, for indicated recurrence interval, in years</th>
<th>Record number of years</th>
<th>Largest recorded discharge (ft$^3$/s)</th>
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<td>Little Chippewa Creek near Smithville</td>
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<td>Sandy Creek at Sandyville</td>
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<td>491 436 488 753 938 1070 1160 1180 1370 1560</td>
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<td>274 356 419 481 481 481 481 481 481 481</td>
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[ft$^3$/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates.]
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft^3/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft^3/s. for indicated recurrence interval, in years</th>
<th>Number of water years</th>
<th>Period</th>
<th>Cal- Magni-</th>
<th>Largest recorded discharge (ft^3/s)</th>
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<tr>
<td>03125300</td>
<td>West Branch Spencer Creek at Hendrysburg</td>
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<td>1950 740</td>
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<td>03125450</td>
<td>Robinson Run near Hendrysburg</td>
<td>40°05'08&quot; 81°10'27&quot;</td>
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<td>1978 147</td>
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<td>03127950</td>
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<td>Touby Run at Mansfield</td>
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<td>1967 1030</td>
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<td>1987 21300</td>
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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge (in ft³/s, for indicated recurrence interval, in years)</th>
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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

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<th>Record</th>
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<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Record number of water years</th>
<th>Largest recorded discharge</th>
<th>Calendar Magnitude (ft³/s)</th>
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<td>Tupper Creek at Devola</td>
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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Record Period</th>
<th>Largest recorded discharge</th>
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<td>233</td>
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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates.]
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

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<tr>
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<th>Flood-peak discharge in $\text{ft}^3/\text{s}$, for indicated recurrence interval, in years</th>
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<th>Largest recorded discharge (ft$^3$/s)</th>
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<td>40°06'13&quot; N</td>
<td>82°53'03&quot; W</td>
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[ft$^3$/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
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<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
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<th>Largest recorded discharge (ft³/s)</th>
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<td>83°23'08''</td>
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<td>West Branch Tar Hollow State Park</td>
<td>39°23'35''</td>
<td>82°45'12''</td>
<td>55 109 153 213 261 310</td>
<td>28 1950-77</td>
<td>1968 72</td>
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<tr>
<td>03235500</td>
<td>Tar Hollow Creek at Tar Hollow State Park</td>
<td>39°23'22''</td>
<td>82°45'03''</td>
<td>109 212 307 462 607 780</td>
<td>32 1947-78</td>
<td>1968 957</td>
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<td>03235995</td>
<td>Salt Creek near Londonderry</td>
<td>39°17'26''</td>
<td>82°44'45''</td>
<td>10800 16200 20500 26800 32200 38200</td>
<td>30 1938-50</td>
<td>1966 59000</td>
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</table>

[Record Largest discharge periods indicated in parentheses.]
### Table 3.--Flood-frequency data for streamflow-gaging stations--Continued.

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft$^3$/s, for indicated recurrence interval, in years</th>
<th>Record number of water years</th>
<th>Largest recorded discharge (ft$^3$/s)</th>
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<tbody>
<tr>
<td>03236090</td>
<td>South Branch Little Salt Creek near Jackson</td>
<td>39°00'50&quot;</td>
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<td>170 316 444 645 826 1040</td>
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<td>1978-87 1980 555</td>
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<td>03236100</td>
<td>South Branch Little Salt Creek at Jackson</td>
<td>39°02'38&quot;</td>
<td>82°38'35&quot;</td>
<td>660 887 1030 1200 1310 1430</td>
<td>31 1947-77</td>
<td>1968 1400</td>
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<tr>
<td>03237095</td>
<td>Devers Run at Lucasville</td>
<td>38°52'54&quot;</td>
<td>83°01'13&quot;</td>
<td>190 243 277 319 350 380</td>
<td>10 1978-87</td>
<td>1982 330</td>
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<td>03237210</td>
<td>Rose Run near Portsmouth</td>
<td>38°48'07&quot;</td>
<td>82°59'03&quot;</td>
<td>1110 1980 2620 3450 4070 4690</td>
<td>25 1960</td>
<td>1964-87 1960 7320</td>
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<td>03237280</td>
<td>Uppar Twin Creek at McGaw</td>
<td>38°38'37&quot;</td>
<td>83°12'57&quot;</td>
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<td>22 1956-77</td>
<td>1956 720</td>
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<td>03237300</td>
<td>West Branch Turkey Run near Winchester</td>
<td>38°56'56&quot;</td>
<td>83°40'19&quot;</td>
<td>199 353 485 688 868 1080</td>
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<td>03237500</td>
<td>Ohio Brush Creek near West Union</td>
<td>38°48'13&quot;</td>
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<td>Harwood Creek near Fayetteville</td>
<td>39°07'51&quot;</td>
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<td>133 221 286 375 445 519</td>
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<td>Whiteoak Creek near Georgetown</td>
<td>38°51'29&quot;</td>
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<td>03239000</td>
<td>Little Miami River near Selma</td>
<td>39°48'36&quot;</td>
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<td>1390 2930 4270 6300 8060 10000</td>
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<td>03239500</td>
<td>North Fork Little Miami River near Pitchin</td>
<td>39°49'40&quot;</td>
<td>83°46'38&quot;</td>
<td>378 848 1330 2180 3030 4110</td>
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<td>1959 3350</td>
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Table 3.--Flood-frequency data of streamflow-gaging stations--Continued

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<th>Record Number</th>
<th>Record Period</th>
<th>Largest recorded discharge</th>
<th>Calculated Magnitude (ft³/s)</th>
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<td>1948-77</td>
<td>1820</td>
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**Note:** For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates.
Table 3.—Flood-frequency data for streamflow-gaging stations—Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
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<tbody>
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<td></td>
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<td>* 03242500</td>
<td>Little Miami River near Fort Ancient</td>
<td>39°22'42&quot;</td>
<td>84°05'32&quot;</td>
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<td>Todd Fork near Roachester</td>
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<td>* 03245500</td>
<td>Little Miami River at Milford</td>
<td>39°10'17&quot;</td>
<td>84°17'53&quot;</td>
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<td>03246500</td>
<td>East Fork Little Miami River at Williamsburg</td>
<td>39°03'09&quot;</td>
<td>84°03'02&quot;</td>
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<td>Patterson Run near Owensville</td>
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<td>* 03247500</td>
<td>East Fork Little Miami River at Perintown</td>
<td>39°08'13&quot;</td>
<td>84°14'17&quot;</td>
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<td>40°20'50&quot;</td>
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<td>Stony Creek near De Graff</td>
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<td>83°54'36&quot;</td>
<td>1040</td>
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<td>1110</td>
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<td>03261500</td>
<td>Great Miami River at Sidney</td>
<td>40°17'13&quot;</td>
<td>84°09'00&quot;</td>
<td>6800</td>
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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Station Latitude Longitude</th>
<th>Cal.-Magni. years</th>
<th>Cal.- Magni. discharge (ft³/s)</th>
<th>Record Period</th>
<th>Largest recorded discharge (ft³/s)</th>
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<td>03262750</td>
<td>Millers Ditch at Tipp City</td>
<td>39°57'59&quot; 84°10'22&quot;</td>
<td>1986-82</td>
<td>1981</td>
<td>17</td>
<td>6251</td>
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<td>03263100</td>
<td>Poplar Creek near Tipp City</td>
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<td>1986-82</td>
<td>1981</td>
<td>17</td>
<td>6251</td>
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<td>03263700</td>
<td>Bridge Creek near Vandalia</td>
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<td>1981</td>
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<td>6251</td>
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<td>03264000</td>
<td>Greenville Creek near Greenville</td>
<td>39°06'08&quot; 84°25'48&quot;</td>
<td>1986-82</td>
<td>1981</td>
<td>17</td>
<td>6251</td>
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<tr>
<td>03265000</td>
<td>Hog Run Tributary at Pleasant Hill</td>
<td>40°04'31&quot; 83°41'58&quot;</td>
<td>1986-82</td>
<td>1981</td>
<td>17</td>
<td>6251</td>
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<td>03267000</td>
<td>Mad River near Zanesfield</td>
<td>39°56'50&quot; 83°40'50&quot;</td>
<td>1986-82</td>
<td>1981</td>
<td>17</td>
<td>6251</td>
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<tr>
<td>03268000</td>
<td>Buck Creek at New Eagle City</td>
<td>39°56'50&quot; 83°40'50&quot;</td>
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<td>1981</td>
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<td>Beaver Creek at New Eagle City</td>
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<td>1981</td>
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</table>
Table 3. Flood-frequency data for streamflow-gaging stations—Continued

(ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates.)

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<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Record number of water years</th>
<th>Largest recorded discharge (ft³/s)</th>
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<tbody>
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<td>1850 2670 3590 4540 5280 6030 1590 2610 3360 4340 5090 5860</td>
<td>21 1943-59</td>
<td>1948 4980</td>
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<td>Buck Creek at Springfield</td>
<td>39°55'57&quot;</td>
<td>83°49'02&quot;</td>
<td>3180 5440 7200 9730 11800 14100 4260 6680 8790 11300 13200 15200</td>
<td>56 1913</td>
<td>1929 13000</td>
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<td>03269500</td>
<td>Mad River near Springfield</td>
<td>39°55'23&quot;</td>
<td>83°52'13&quot;</td>
<td>7770 12700 16400 21600 25900 30500 10300 15600 19800 25000 28900 33000</td>
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<td>1913 55400</td>
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<td>Great Miami River at Dayton</td>
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<td>84°11'51&quot;</td>
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<td>Wolf Creek at Trotwood</td>
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<td>Sevenmile Creek at Camden</td>
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<td>Sevenmile Creek at Collinsville</td>
<td>39°31'23&quot;</td>
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<td>Collins Creek at Collinsville</td>
<td>39°35'05&quot;</td>
<td>84°36'53&quot;</td>
<td>240 352 422 504 562 616 203 365 488 645 765 881</td>
<td>17 1966-82</td>
<td>1968 409</td>
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</table>
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft$^3$/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft$^3$/s, for indicated recurrence interval, in years</th>
<th>Record number of water years</th>
<th>Largest recorded discharge Cal- Magnitud- endar year (ft$^3$/s)</th>
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<td>39°27'30&quot;</td>
<td>84°32'50&quot;</td>
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<td>Great Miami River at Hamilton</td>
<td>39°23'28&quot;</td>
<td>84°34'20&quot;</td>
<td>61 111 149 202 244 287</td>
<td>77 140 187 247 283 337</td>
<td>15 1907-21</td>
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<td>03274100</td>
<td>Blake Run near Reily</td>
<td>39°27'59&quot;</td>
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<td>97 168 220 290 345 401</td>
<td>146 251 329 427 501 572</td>
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<td>Green Fork Tributary near Lynn, Ind.</td>
<td>40°01'14&quot;</td>
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<td>72 175 231 275 317</td>
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<td>39°48'24&quot;</td>
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<td>6220 8610 10100 11900 13100 14300</td>
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<td>West Run near Liberty, Ind.</td>
<td>39°38'24&quot;</td>
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<td>77 124 158 205 242 281</td>
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<td>39°31'20&quot;</td>
<td>84°56'51&quot;</td>
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<td>East Fork Whitewater River at Brookville, Ind.</td>
<td>39°26'02&quot;</td>
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<td>39°24'24&quot;</td>
<td>85°00'46&quot;</td>
<td>28700 43400 53300 66000 75400 84800</td>
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<td>57 1916-20</td>
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<tr>
<td>03322500</td>
<td>Wabash River near New Corydon, Ind.</td>
<td>40°33'50&quot;</td>
<td>84°48'10&quot;</td>
<td>4190 5560 6310 7110 7620 8080</td>
<td>3290 4680 5630 6860 7750 8670</td>
<td>35 1952-86</td>
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</table>

* Denotes stations where the weighted estimate is a calibration estimate, not a regression estimate.
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates.]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Number of water years Period</th>
<th>Largest recorded discharge Cal.-Magnitude (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03325500</td>
<td>Mississinewa River near Ridgeville, Ind.</td>
<td>40°16'49&quot;</td>
<td>84°59'44&quot;</td>
<td>3650 5760 7100 8960 10400 11800 40 1947-86 1958 13900</td>
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<tr>
<td>04098515</td>
<td>Hog Creek near Allen, Mich.</td>
<td>41°56'55&quot;</td>
<td>84°49'40&quot;</td>
<td>244 300 446 566 664 768 17 1970-86 1985 664</td>
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<td>04098060</td>
<td>Pigeon Creek Tributary near Ellis, Ind.</td>
<td>41°37'43&quot;</td>
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<td>46 77 99 130 154 178 10 1973-82 1981 110</td>
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<td>0417500</td>
<td>River Raisin near Tecumseh, Mich.</td>
<td>41°56'35&quot;</td>
<td>83°56'45&quot;</td>
<td>1130 1490 1740 2070 2330 2600 24 1957-80 1968 2920</td>
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<td>04176000</td>
<td>River Raisin near Adrian, Mich.</td>
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<td>83°58'50&quot;</td>
<td>2780 4000 4810 5830 6590 7340 33 1954-86 1982 6660</td>
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<td>04176500</td>
<td>River Raisin near Monroe, Mich.</td>
<td>41°57'38&quot;</td>
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<td>04176000</td>
<td>Hill Ditch near Richards</td>
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<td>81 181 230 334 425 527 35 1947-81 1972 340</td>
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<td>04177400</td>
<td>Eagle Creek Tributary near Montpelier</td>
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<td>84°40'50&quot;</td>
<td>71 111 138 175 202 230 26 1950-75 1956 195</td>
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<td>04177720</td>
<td>Fish Creek at Hamilton, Ind.</td>
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<td>84°54'12&quot;</td>
<td>324 448 527 625 696 766 17 1970-86 1985 654</td>
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<td>04178000</td>
<td>Saint Joseph River near Newville, Ind.</td>
<td>41°23'08&quot;</td>
<td>84°48'06&quot;</td>
<td>4250 6090 7350 8990 10200 11500 40 1947-86 1950 9710</td>
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<td>04181500</td>
<td>Saint Marys River at I Decatur, Ind.</td>
<td>40°50'55&quot;</td>
<td>85°56'16&quot;</td>
<td>5580 8090 9650 11500 12800 14000 55 1932-86 1943 12000</td>
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Table 3.—Flood-frequency data for streamflow-gaging stations—Continued

For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates.

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Number of water years</th>
<th>Period</th>
<th>Largest recorded discharge (ft³/s)</th>
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</thead>
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<tr>
<td>04183500</td>
<td>Maumee River at Antwerp</td>
<td>41°11'56&quot;</td>
<td>84°44'40&quot;</td>
<td>14000 15000 21000 24600 27200 29800</td>
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<td>1913</td>
<td>40000</td>
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<td>15300 18300 24700 27300 29900</td>
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<td>Racetrack Run at Hicksville</td>
<td>41°18'58&quot;</td>
<td>84°46'00&quot;</td>
<td>50 93 126 173 211 251</td>
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<td>1982</td>
<td>4900</td>
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<tr>
<td>04184500</td>
<td>Bean Creek at Powers</td>
<td>41°40'39&quot;</td>
<td>84°13'56&quot;</td>
<td>2150 3080 3650 4340 4820 5280</td>
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<td>04184750</td>
<td>Spring Creek at Fayette</td>
<td>41°40'32&quot;</td>
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<td>258 325 357 380 412 432</td>
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<td>58 73 82 92 99 105</td>
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<td>Tiffin River at Stryker</td>
<td>41°30'16&quot;</td>
<td>84°25'47&quot;</td>
<td>3410 4900 5830 6940 7730 8480</td>
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<td>1982</td>
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<td>Beaver Creek Tributary near Montpelier</td>
<td>41°34'19&quot;</td>
<td>84°31'03&quot;</td>
<td>96 25 143 164 179 194</td>
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<td>1980</td>
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<tr>
<td>04185945</td>
<td>Auglaize River Tributary near Spencerville</td>
<td>40°42'27&quot;</td>
<td>84°19'06&quot;</td>
<td>87 35 168 210 241 272</td>
<td>10 1978-87</td>
<td>1986</td>
<td>180</td>
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<td>Auglaize River near Fort Jennings</td>
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<td>5050 7210 8510 9990 11000 11900</td>
<td>62 1922-36</td>
<td>1959</td>
<td>12000</td>
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<td>04186800</td>
<td>King Run near Harrod</td>
<td>40°43'56&quot;</td>
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<td>94 26 145 168 184 199</td>
<td>21 1966-86</td>
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<td>04187500</td>
<td>Ottawa River at Allentown</td>
<td>40°45'18&quot;</td>
<td>84°11'41&quot;</td>
<td>3110 4470 5310 6290 6970 7620</td>
<td>52 1924-35</td>
<td>1959</td>
<td>7740</td>
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</table>
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft^3/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft^3/s, for indicated recurrence interval, in years</th>
<th>Record</th>
<th>Largest recorded discharge</th>
<th>Calendar Magnitude</th>
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<tbody>
<tr>
<td>04187945</td>
<td>Rattlesnake Creek near Cairo</td>
<td>40°49'20&quot;</td>
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<td>100 262 165 245 273 300</td>
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<tr>
<td>04188500</td>
<td>Eagle Creek near Findlay</td>
<td>40°59'35&quot;</td>
<td>83°39'05&quot;</td>
<td>100 273 206 245 273 300</td>
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<td>04189000</td>
<td>Blanchard River near Findlay</td>
<td>41°03'21&quot;</td>
<td>83°41'17&quot;</td>
<td>100 311 310 311 351 389</td>
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<td>04189100</td>
<td>Tiderishi Creek near Jenera</td>
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<td>100 379 417 452 458 460</td>
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<td>04189500</td>
<td>Blanchard River near Glandorf</td>
<td>41°02'40&quot;</td>
<td>84°04'55&quot;</td>
<td>100 326 397 490 557 621</td>
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<td>Little Auglaize River Tributary at Ottoville</td>
<td>40°55'05&quot;</td>
<td>84°20'47&quot;</td>
<td>100 378 455 509 558 650</td>
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<td>04190500</td>
<td>Roller Creek at Ohio City</td>
<td>40°46'16&quot;</td>
<td>84°38'15&quot;</td>
<td>100 470 538 607 650 700</td>
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<td>04191480</td>
<td>Beetree Run near Junction</td>
<td>41°13'21&quot;</td>
<td>84°24'33&quot;</td>
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<td>04191500</td>
<td>Auglaize River near Defiance</td>
<td>41°14'15&quot;</td>
<td>84°23'57&quot;</td>
<td>100 607 650 700 750 800</td>
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<td>04192500</td>
<td>Maumee River near Defiance</td>
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<td>84°16'50&quot;</td>
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<td>04192900</td>
<td>Reitz Run at Waterville</td>
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<td>83°42'35&quot;</td>
<td>100 700 800 900 1000 1100</td>
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</table>
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

(ft^3/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates)

<table>
<thead>
<tr>
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</thead>
<tbody>
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<td>04193500</td>
<td>Maumee River at Waterville</td>
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<td>04195500</td>
<td>Portage River at Woodville</td>
<td>41°26’58”</td>
<td>83°21’41”</td>
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<td>04196000</td>
<td>Sandusky River near Bucyrus</td>
<td>40°48’13”</td>
<td>83°00’21”</td>
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<tr>
<td>04196500</td>
<td>Sandusky River near Upper Sandusky</td>
<td>40°51’02”</td>
<td>83°15’23”</td>
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<tr>
<td>04196700</td>
<td>Saint James Run near Upper Sandusky</td>
<td>40°46’51”</td>
<td>83°18’12”</td>
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<td>04196800</td>
<td>Tymochtee Creek at Crawford</td>
<td>40°55’22”</td>
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<td>04197000</td>
<td>Sandusky River near Mexico</td>
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<td>83°11’42”</td>
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<td>Honey Creek at Melmore</td>
<td>41°01’20”</td>
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<td>Wolf Creek at Bettsville</td>
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<td>04197400</td>
<td>East Branch Wolf Creek at Fort Seneca</td>
<td>41°12’40”</td>
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</table>
Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

[ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

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<tr>
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<th>Longitude</th>
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<th>Record Period</th>
<th>Largest recorded discharge (ft³/s)</th>
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<tbody>
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<td>04197500</td>
<td>Havens Creek at</td>
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<td>142 213 259 316 356 394</td>
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<td>Sandusky River</td>
<td>41°18'28&quot;</td>
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<td>15700 21500 25000 29000 31800 34400 62 1924-36 1978 36500</td>
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<td>13500 19100 22600 26800 29600 32500 1939-87</td>
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<td>346 607 810 1100 1320 1580 36 1947-82 1969 1680</td>
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<td>4620 7550 9900 13300 16300 19600 14 1923-35 1969 23100</td>
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<td>295 491 635 830 982 1140</td>
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<td>Black River at</td>
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<td>7260 11000 14100 18600 22500 26700</td>
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<td>7820 10800 12900 15600 17700 19900</td>
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Table 3.--Flood-frequency data for streamflow-gaging stations—Continued

[ft$^3$/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates]

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft$^3$/s, for indicated recurrence interval, in years</th>
</tr>
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<tbody>
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<tr>
<td>04202000</td>
<td>Cuyahoga River at Hiram Rapids</td>
<td>41°20'26&quot;</td>
<td>81°10'01&quot;</td>
<td>1580</td>
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<tr>
<td>04207200</td>
<td>Tinkers Creek at Bedford</td>
<td>41°23'04&quot;</td>
<td>81°31'39&quot;</td>
<td>2430</td>
</tr>
<tr>
<td>04208000</td>
<td>Cuyahoga River at Independence</td>
<td>41°23'43&quot;</td>
<td>81°37'48&quot;</td>
<td>8560</td>
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<tr>
<td>04209000</td>
<td>Chagrin River at Willoughby</td>
<td>41°37'51&quot;</td>
<td>81°24'13&quot;</td>
<td>2430</td>
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<tr>
<td>04210000</td>
<td>Phelps Creek near Windsor</td>
<td>41°30'56&quot;</td>
<td>80°56'07&quot;</td>
<td>1860</td>
</tr>
<tr>
<td>04210090</td>
<td>Montville Ditch at Montville</td>
<td>41°36'04&quot;</td>
<td>81°03'03&quot;</td>
<td>8560</td>
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<td>Hoskins Creek at Hartsgrove</td>
<td>41°36'00&quot;</td>
<td>80°57'12&quot;</td>
<td>201</td>
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<tr>
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<td>Rock Creek near Rock Creek</td>
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<td>80°48'00&quot;</td>
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<td>Mill Creek near Jefferson</td>
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<td>80°48'03&quot;</td>
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<td>Grand River near Madison</td>
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<td>80°02'48&quot;</td>
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<td>04212500</td>
<td>Ashtabula River near Ashtabula</td>
<td>41°51'20&quot;</td>
<td>80°45'44&quot;</td>
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Record Number of water years Period Calendar Magnitude Largest recorded discharge (ft$^3$/s)

|                |                        |          |           | 4520   | 6570   | 7960   | 9750   | 11100  | 12500  | 51    | 1925-36 | 1959 | 11600 |
|----------------|-------------------------|----------|-----------| 4520   | 6570   | 7960   | 9750   | 11100  | 12500  | 51    | 1925-36 | 1959 | 11600 |

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Table 3.--Flood-frequency data for streamflow-gaging stations--Continued

(ft³/s, cubic feet per second. For each station the upper numbers are log-Pearson Type III estimates, the middle numbers are regression estimates, and the lower numbers are weighted estimates)

<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flood-peak discharge in ft³/s, for indicated recurrence interval, in years</th>
<th>Record</th>
<th>Largest recorded discharge during 95% confidence interval</th>
<th>Calender date year (ft³/s)</th>
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<td>Hubbard Run Tributary at Ashtabula</td>
<td>41°50'38&quot; 80°46'42&quot;</td>
<td>104</td>
<td>143 117 206 238 269</td>
<td>17</td>
<td>1966-82</td>
<td>1969 270</td>
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<td>04213000</td>
<td>Conneaut Creek at Conneaut</td>
<td>41°55'37&quot; 80°36'15&quot;</td>
<td>6360</td>
<td>9270 11200 13600 15400 17100</td>
<td>52</td>
<td>1923-36</td>
<td>1959 17000</td>
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<tr>
<td>04213040</td>
<td>Raccoon Creek near West Springfield, Pa.</td>
<td>41°56'42&quot; 80°26'51&quot;</td>
<td>149</td>
<td>234 294 374 434 486</td>
<td>26</td>
<td>1961-86</td>
<td>1966 406</td>
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* Streamflow at the station location is now regulated. Only un regulated annual flood-peak discharges were used to compute the discharges shown in the table.
[ ] Station not used in regression analysis. Compared to the station Maumee River at Waterville (04193500), that was used in the regression analysis, contributing drainage area is less than 25 percent different and length of record is shorter.
<table>
<thead>
<tr>
<th>Station number</th>
<th>Station name</th>
<th>Region</th>
<th>Contributing drainage area ((\text{mi}^2))</th>
<th>Main-channel slope ((\text{ft/mi}))</th>
<th>Storage area ((\text{percent}))</th>
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<td>French Creek at Saegerstown, Pa.</td>
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<td>.5</td>
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<td>Big Seewickley Creek near Ambridge, Pa.</td>
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<tr>
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<td>Mahoning River at Alliance</td>
<td>A</td>
<td>89.2</td>
<td>10.4</td>
<td>.9</td>
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<tr>
<td>03087000</td>
<td>Beech Creek near Bolton</td>
<td>A</td>
<td>17.4</td>
<td>27.0</td>
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<tr>
<td>03088000</td>
<td>Deer Creek at Limaville</td>
<td>A</td>
<td>33.2</td>
<td>6.8</td>
<td>.5</td>
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<tr>
<td>03089500</td>
<td>Mill Creek near Berlin Center</td>
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<td>19.1</td>
<td>11.1</td>
<td>2.0</td>
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<tr>
<td>03090500</td>
<td>Mahoning River near Berlin Center</td>
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<td>248</td>
<td>28.2</td>
<td>2.4</td>
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<tr>
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<td>Kale Creek near Pricetown</td>
<td>A</td>
<td>21.9</td>
<td>11.4</td>
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</tr>
<tr>
<td>03092090</td>
<td>West Branch Mahoning River near Ravenna</td>
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<tr>
<td>03092100</td>
<td>Hinkley Creek near Charlestown</td>
<td>A</td>
<td>10.6</td>
<td>20.5</td>
<td>1.0</td>
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<tr>
<td>03092500</td>
<td>West Branch Mahoning River near Newton Falls</td>
<td>A</td>
<td>96.3</td>
<td>11.7</td>
<td>3.7</td>
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<tr>
<td>03092600</td>
<td>Ordinance Creek near Newton Falls</td>
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<tr>
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<td>Walnut Creek at Cortland</td>
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<td>15.8</td>
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<td>Mosquito Creek at Niles</td>
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<tr>
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<td>Little Shenango River at Greenville, Pa.</td>
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<td>4.0</td>
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<tr>
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<td>6.19</td>
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<td>Branson Run at Georgetown</td>
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<td>37.9</td>
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<td>Little Piney Fork at Parlett</td>
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<td>Short Creek near Dillonvale</td>
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<td>Main-channel slope (ft/mi)</td>
<td>Storage area (percent)</td>
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<tr>
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Table 4.--Selected basin characteristics of streamflow-gaging stations--Continued

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<tr>
<th>Station number</th>
<th>Station name</th>
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<th>Contributing drainage area (mi²)</th>
<th>Main-channel slope (ft/ft)</th>
<th>Storage area (percent)</th>
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Table 4. --Selected basin characteristics of streamflow-gaging stations--Continued

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Table 4.--Selected basin characteristics of streamflow-gaging stations--Continued

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<th>Station name</th>
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<th>Contributing drainage area ( \text{(mi}^2 )</th>
<th>Main-channel slope ( \text{ft/mi} )</th>
<th>Storage area ( % )</th>
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Table 4. Selected basin characteristics of streamflow-gaging stations—Continued

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APPENDIX A

Statistical Techniques for Determining Confidence Intervals and Testing for Extrapolation

This appendix provides an outline and example of the steps that must be followed to determine confidence intervals for the true t-year peak discharge and perform a more rigorous test for extrapolation than is covered in the body of the report.

Steps for Determining Confidence Intervals and Testing for Extrapolation

(1) Compute the regression estimate of the at-site population standard deviation:

\[ \hat{\sigma} = \exp[\hat{\ln}(s)] \],

where \( \hat{\ln}(s) = -1.564 - 0.076(\log_{10}(\text{CONTDA})) + 0.153(\log_{10}(\text{SLOPE})) \).

\( \hat{\sigma} \) is regression estimate of the at-site population standard deviation, and \( \hat{s} \) is regression estimate of the at-site sample standard deviation.

(2) Compute the estimated model error variance for the site of interest:

\[ \hat{\gamma}^2 = \hat{\gamma}_m^2 + 2\hat{\rho}_{\mu0}k\Delta\hat{\gamma}_m + k^2\Delta^2, \]

where \( \hat{\Delta} = [\hat{\sigma}^2 (\exp(\hat{\gamma}^2) - 1)]^{-0.5} \).

\( \hat{\gamma}^2 \) is estimated model error variance for the regression of peak discharge on basin characteristics at the site of interest,
\( \gamma_m^2 \) is estimated model error variance for the regression of sample mean on basin characteristics (in this analysis, \( \gamma_m^2 \) has been determined to have the numerical value 2.867x10^{-2}),

\( \rho_{\mu \sigma} \) is estimated correlation between the errors in the regressions for the mean and standard deviation (in this analysis, \( \rho_{\mu \sigma} \) has been determined to have the numerical values shown in table 5 for the tabulated recurrence intervals),

\( k \) is Pearson Type III frequency factor for the desired recurrence interval and skewness (the numerical values of \( k \) can be determined from tables published by Interagency Advisory Committee on Water Data, 1982), and

\( \gamma_s^2 \) is estimated model error variance for the regression of \( \ln(s) \) on basin characteristics (in this analysis, \( \gamma_s^2 \) has been determined to have the numerical value 4.324x10^{-2}).

(3) Compute the estimated sampling error variance for the site of interest:

\[
\hat{\Sigma} = x U x^T,
\]

where \( \hat{\Sigma} \) is estimated sampling error variance for the site of interest,

\( x \) is a row vector of basin characteristics for the site of interest (table 6), and

\( U \) is the variance-covariance matrix, which was determined as follows:
\[ U = (X^T \hat{\Theta}^{-1} X)^{-1}, \]

where \( X \) is an \( n \) by \( p \) matrix of \( p-1 \) basin characteristics augmented on the left by a column of ones,

\( \hat{\Theta} \) is the \( n \) by \( n \) GLS estimate of the covariance matrix, and

\( n \) is number of observations in the regression data set.

(4) Test for extrapolation:

If \( \hat{\Sigma} \) is greater than \( \Sigma_{\text{max}} \), then an estimate at the site of interest would constitute an extrapolation and consequently may suffer in accuracy. \( \Sigma_{\text{max}} \) is the maximum sampling error observed in the regression for the \( t \)-year peak discharge (table 5).

(5) Compute the regression estimate of the \( t \)-year peak discharge for the site of interest.

The regression equation for the desired region and recurrence interval should be selected from table 1 in the main body of the report.

(6) Compute the estimated variance of prediction at the site of interest:

where \( \hat{\Sigma}_p \), the estimated variance of prediction at the site of interest, is defined as:

\[ \hat{\Sigma}_p = \hat{\gamma}^2 + \hat{\Sigma}. \]
(7) Compute the $100(1-\alpha)$ percent confidence interval for the true $t$-year peak discharge:

\[
\hat{y}_u = (C)\hat{y}
\]

\[
\hat{y}_l = \left(\frac{1}{C}\right)\hat{y}
\]

\[
C = 10^{\left[t_{(\alpha/2,n-p)} (\hat{y}_p)^{-5}\right]},
\]

where $\hat{y}_u$ is upper confidence limit,

$\hat{y}_l$ is lower confidence limit, and

$t_{(\alpha/2,n-p)}$ is critical value of the Student's $t$ distribution for $n-p$ degrees of freedom.

**Example**

Estimate the 100-year peak discharge and the 90-percent confidence interval for an ungauged site with the following basin characteristics:

- Contributing drainage area (CONTDA) = 123 mi$^2$
- Main-channel slope (SLOPE) = 14.4 ft/mi
- Storage area (STORAGE) = 0.0 percent
- Region = B
(1) Compute $\sigma$:

$$\ln(s) = -1.564 - 0.076\log_{10}(\text{CONTDA}) + 0.153\log_{10}(\text{SLOPE})$$

$$= -1.564 - 0.076\log_{10}(123) + 0.153\log_{10}(14.4)$$

$$= -1.546$$

$$\sigma = \exp[\ln(s)]$$

$$= \exp[-1.546]$$

$$= 0.213.$$  

(2) Compute $\gamma^2$:

$$\Delta = [\sigma^2 (\exp^{\gamma^2} - 1)]^{0.5}$$

$$= [(0.213)^2(\exp(4.324\times10^{-2}) - 1)]^{0.5}$$

$$= 4.48\times10^{-2}.$$  

$$\gamma^2 = \gamma_m^2 + 2\rho\mu\kappa\Delta\gamma_m^2 + k^2\Delta^2$$

$$= 2.867\times10^{-2} + (2)(-0.52)(2.326)(4.48\times10^{-2})(2.867\times10^{-2})^{0.5} + (2.326)^2(4.48\times10^{-2})^2$$

$$= 2.118\times10^{-2},$$  

where $k$ is determined from a table of published values and is based on a 100-year recurrence interval and $\theta$ skew coefficient.
(3) Compute $\hat{\Sigma}$:

$$\hat{\Sigma} = xUx^T$$

$$= 1.280 \times 10^{-3},$$

where $x = [x(1) \ x(2) \ x(3) \ x(4) \ x(5) \ x(6)]$

$$= [1 \ \log_{10}(\text{CONTDA}) \ \log_{10}(\text{SLOPE}) \ \log_{10}(\text{STORAGE}+1) \ x(5) \ x(6)]$$

$$= [1 \ \log_{10}(123) \ \log_{10}(14.4) \ \log_{10}(0+1) \ 0 \ 1].$$

$U$ is the variance-covariance matrix for the 100-year recurrence interval from table 7.

Note that the form of the $x$-vector for Region B is obtained from table 6.

(4) Test for extrapolation:

$$\hat{\Sigma}_{\text{max}} = 3.881 \times 10^{-3} \text{ (from table 5 for the 100-year recurrence interval).}$$

Because $\hat{\Sigma}$ is not greater than $\hat{\Sigma}_{\text{max}}$, the estimate will not be an extrapolation.

(5) Compute the regression estimate of the 100-year peak discharge. The equation for the 100-year peak discharge for region B is:

$$\hat{y} = 99.7(\text{CONTDA})^{0.756}(\text{SLOPE})^{0.285}(\text{STORAGE}+1)^{-0.363}$$

$$= 99.7(123)^{0.756}(14.4)^{0.285}(0+1)^{-0.363}$$

$$= 8,110 \text{ cubic feet per second.}$$
(6) Compute the estimated variance of prediction:

\[ \hat{\sigma}_p^2 = \hat{\gamma}^2 + \hat{\Sigma} \]

\[ = 2.118 \times 10^{-2} + 1.280 \times 10^{-3} \]

\[ = 2.246 \times 10^{-2}. \]

(7) Compute the 90-percent confidence interval:

\[ C = 10^\left[ t\_{\alpha/2, n-p} \left( \hat{\sigma}_p^2 \right)^{0.5} \right] \]

\[ = 10^\left[ (1.65)(2.246 \times 10^{-2})^{0.5} \right] \]

\[ = 1.767. \]

\[ \hat{y}_u = (C)\hat{y} \]

\[ = 1.767(8110) \]

\[ = 14,300 \text{ cubic feet per second}. \]

\[ \hat{y}_l = \left( \frac{1}{C} \right)\hat{y} \]

\[ = \frac{1}{1.767}(8110) \]

\[ = 4,590 \text{ cubic feet per second}. \]

The 90-percent confidence interval for \( \hat{y} = 8,110 \) is (14,300, 4,590).
Table 5.—$\hat{\rho}_{\mu \sigma}$ and $\hat{\Sigma}_{max}$ values, by recurrence interval

<table>
<thead>
<tr>
<th>Recurrence interval (years)</th>
<th>$\hat{\rho}_{\mu \sigma}$</th>
<th>$\hat{\Sigma}_{max}$</th>
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<td>5</td>
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<td>2.719x10^{-3}</td>
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<td>2.820x10^{-3}</td>
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<td>3.126x10^{-3}</td>
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<td>3.489x10^{-3}</td>
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<tr>
<td>100</td>
<td>-0.52</td>
<td>3.881x10^{-3}</td>
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Table 6.—Regions and x-vectors

[The row vector is augmented on the left by a 1 and on the right by two numbers which depend on the region in which the site of interest is located]

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<tr>
<th>Region</th>
<th>x(1)</th>
<th>x(2)</th>
<th>x(3)</th>
<th>x(4)</th>
<th>x(5)</th>
<th>x(6)</th>
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<td>log_{10}(SLOPE)</td>
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<td>log_{10}(STORAGE+1)</td>
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<td>log_{10}(SLOPE)</td>
<td>log_{10}(STORAGE+1)</td>
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APPENDIX B

Independent Variables Tested as Potential Regressor Variables

The following independent variables, which provide measures of basin characteristics, were tested as potential regressor variables. These variables were determined from U.S. Geological Survey 7.5-minute topographic quadrangle maps unless stated otherwise.

Contributing drainage area (in square miles).—the area, measured in a horizontal plane, that contributes surface runoff to a specified location on a stream. This area may be located inside or outside of the natural topographic divides of the basin.

Main-channel slope (in feet per mile).—computed as the difference in elevation at points 10 and 85 percent of the distance along the main channel from a specified location on the channel to the topographic divide, divided by the channel distance between the two points.

Main-channel length (in miles).—determined by measuring the distance along the main channel from a specified location to the topographic divide.

Mean basin elevation (in feet above sea level).—average of 20 to 80 ground-point elevations evenly distributed throughout the basin.

Basin elevation index (in thousands of feet above sea level).—determined by averaging main-channel elevations at points 10 and 85 percent of the distance from a specified location on the main channel to the topographic divide.

Basin shape index.—a dimensionless number computed by dividing the square of the main-channel length by the contributing drainage area.

Storage area.—the percentage of the contributing drainage area occupied by lakes, ponds, and swamps as explicitly shown on U.S. Geological Survey 7.5-minute topographic quadrangle maps. For the regression analysis, 1 was added to the storage-area percentage.

Forested area.—the percentage of the contributing drainage area occupied by forest cover. For the regression analysis, 1 was added to the forested-area percentage.
Surface-mined area.—the percentage of the contributing drainage area occupied by disturbed earth resulting from surface mining. For the regression analysis, 1 was added to the surface-mined-area percentage.

Mean annual precipitation (in inches).—determined from Ohio Department of Natural Resources, Ohio Water Plan Inventory Report 13 (Ohio Division of Water, 1962). For the regression analysis, 27 was subtracted from mean annual precipitation to account for annual evapotranspiration.

24-hour, 2-year rainfall (in inches).—the 24-hour rainfall expected to be equalled or exceeded an average of one time in a 2-year period, determined from Weather Bureau Technical Paper no. 40 (U.S. Department of Commerce, 1961).

Mean minimum January temperature (in degrees Fahrenheit).—determined from Weather Bureau, Climatography of the United States, no. 60-33 (U.S. Department of Commerce, 1959). Mean minimum January temperature was subtracted from 32 for the regression analysis to represent the number of degrees below freezing.