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Evaluation of a Method of Estimating Low-Flow Frequencies from Base-Flow Measurements at Indiana Streams

Water-Resources Investigations Report 00–4063

Prepared in cooperation with the
Indiana Department of Natural Resources, Division of Water

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U.S. Geological Survey

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U.S. Department of the Interior
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Conversion Factors and Abbreviations

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

The following abbreviations are used in this report:

Abbreviation	Description
$7Q_{10}$	7-day, 10-year low flow
$7Q_2$	7-day, 2-year low flow

Evaluation of a Method of Estimating Low-Flow Frequencies from Base-Flow Measurements at Indiana Streams

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Abstract

A mathematical technique of estimating low-flow frequencies from base-flow measurements was evaluated by using data for streams in Indiana. Low-flow frequencies at low-flow partial-record stations were estimated by relating base-flow measurements to concurrent daily flows at nearby streamflow-gaging stations (index stations) for which low-flow-frequency curves had been developed. A network of long-term streamflow-gaging stations in Indiana provided a sample of sites with observed low-flow frequencies. Observed values of 7-day, 10-year low flow and 7-day, 2-year low flow were compared to predicted values to evaluate the accuracy of the method.

Five test cases were used to evaluate the method under a variety of conditions in which the location of the index station and its drainage area varied relative to the partial-record station. A total of 141 pairs of streamflow-gaging stations were used in the five test cases. Four of the test cases used one index station, the fifth test case used two index stations. The number of base-flow measurements was varied for each test case to see if the accuracy of the method was affected by the number of measurements used.

The most accurate and least variable results were produced when two index stations on the same stream or tributaries of the partial-record station were used. All but one value of the predicted 7-day, 10-year low flow were within 15 percent of the values observed for the long-term continuous record, and all of the predicted values of the 7-day, 2-year low flow were within 15 percent of the observed values. This apparent accuracy, to some extent, may be a result of the small sample set of 15.

Of the four test cases that used one index station, the most accurate and least variable results were produced in the test case where the index station and partial-record station were on the same stream or on streams tributary to each other and where the index station had a larger drainage area than the partial-record station. In that test case, the method tended to over predict, based on the median relative error. In 23 of 28 test pairs, the predicted 7-day, 10-year low flow was within 15 percent of the observed value; in 26 of 28 test pairs, the predicted 7-day, 2-year low flow was within 15 percent of the observed value.

When the index station and partial-record station were on the same stream or streams tributary to each other and the index station had a smaller drainage area than the partial-record station, the method tended

to under predict the low-flow frequencies. Nineteen of 28 predicted values of the 7-day, 10-year low flow were within 15 percent of the observed values. Twenty-five of 28 predicted values of the 7-day, 2-year low flow were within 15 percent of the observed values.

When the index station and the partial-record station were on different streams, the method tended to under predict regardless of whether the index station had a larger or smaller drainage area than that of the partial-record station. Also, the variability of the relative error of estimate was greatest for the test cases that used index stations and partial-record stations from different streams. This variability, in part, may be caused by using more streamflow-gaging stations with small low-flow frequencies in these test cases. A small difference in the predicted and observed values can equate to a large relative error when dealing with stations that have small low-flow frequencies.

In the test cases that used one index station, the method tended to predict smaller low-flow frequencies as the number of base-flow measurements was reduced from 20 to 5. Overall, the average relative error of estimate and the variability of the predicted values increased as the number of base-flow measurements was reduced.

Introduction

The management and availability of Indiana's water resources increase in importance every year with growing demands for the use and development of Indiana's waterways. Low-flow characteristics of streams are needed for management decisions by State and local officials concerned with water supplies, pollution management of wastewater, and fish and wildlife preservation. Fowler and Wilson (1996) presented low-flow characteristics for 229 continuous-record stations and 285 low-flow partial-record stations in Indiana. These characteristics included low-flow-frequency analysis and flow-duration analysis for the continuous-record sites and low-flow-frequency analysis for the partial-record stations. Continuous-record stations are streamflow-gaging stations for which daily streamflow is computed and stored. Low-flow partial-record stations are sites where discharge measurements are made at base flow. The term "partial-record station" is used in this report as a substitute for the longer term "low-flow partial-record station."

Frequency analysis for continuous-record stations is done by a standard procedure of fitting a frequency curve to observed annual minimum flows. Frequency curves relate the magnitude of a variable to the frequency of occurrence (Riggs, 1968). Low-flow-frequency curves developed by the U.S. Geological Survey (USGS) are defined by using a mathematical procedure for fitting the data to a log Pearson type III distribution (Riggs, 1972). In low-flow investigations, the frequency curve relates the minimum average discharge (Q) for a given number of consecutive days (N-day) to the recurrence interval in years (T-year). For example, the 7-day, 10-year low flow ($7Q_{10}$) is the minimum average discharge for 7 consecutive days, which has a 0.1 probability of not being exceeded in a given year. The recurrence interval is the reciprocal of the probability of recurrence.

Frequency analysis for low-flow partial-record stations cannot be done by the frequency-curve method because a partial-record station does not have a record of annual minimum flows. Instead, base-flow measurements are related to the concurrent daily mean flows of a nearby continuous-record station (index station) for which a low-flow-frequency curve has been defined. In Fowler and Wilson (1996), low-flow frequencies at partial-record stations were estimated by use of the mathematical technique described in Stedinger and Thomas (1985) (which will be referred to as the Stedinger-Thomas method) or by the graphical correlation method described in Riggs (1972). The Stedinger-Thomas method was used as the primary method for estimating low-flow frequencies because it is a mathematical method, which avoids the bias of drawing best-fit curves through the data.

Therefore, the evaluation of the accuracy of low-flow frequencies in this report was based on the Stedinger-Thomas method. As in Fowler and Wilson (1996), low-flow-frequency estimates were limited to the $7Q_{10}$ and the $7Q_2$.

For the purposes of this report, the terms “flow,” “streamflow,” and “discharge” will be considered synonymous and will be used interchangeably. All three terms refer to the volume of water that passes a given point within a given period of time; all have units of cubic feet per second (ft^3/s).

Estimates of low-flow frequencies by use of the Stedinger-Thomas method are predicted from correlation of base flows and thus are referred to as “predicted” values in this report. Estimates of low-flow frequencies by use of log Pearson type III frequency curves are values observed for long-term continuous record (annual minimum flows) at streamflow-gaging stations and are referred to as “observed” values in this report. The observed values are treated as known or “true” values in this report for making comparisons to evaluate the accuracy of the method; however, the “true” low-flow frequencies never are known.

The evaluation of the Stedinger-Thomas method of estimating low-flow frequencies presented in this report was prepared by the USGS, in cooperation with the Indiana Department of Natural Resources, Division of Water.

Purpose and Scope

This report presents an evaluation of the accuracy of estimating low-flow frequencies of Indiana streams, using base-flow measurements. The results of this study provide performance information for a variety of conditions to users of low-flow-frequency values in Indiana. The report provides a general range of the accuracy that can be expected when estimating low-flow frequencies for a given set of conditions. The accuracy of estimating low-flow frequencies is highly variable, with each site being a unique situation. The results of this study, however, may provide assistance on how to evaluate the method of relating base-flow measurements to daily mean flows at an index station.

This report also provides a detailed evaluation of the Stedinger-Thomas method of estimating low-flow frequencies from base-flow measurements (Stedinger and Thomas, 1985), which can be applied to areas other than Indiana.

Acknowledgments

The author acknowledges the contributions of three individuals from the USGS. Michael McNally wrote a computer program that was used to retrieve daily mean flows from the USGS data base to match the dates of base-flow measurements at the partial-record stations. Gary Tasker and Kirk White provided insightful comments and helpful suggestions in their technical reviews of the manuscript.

Methods of Investigation

A network of long-term streamflow-gaging stations provides a sample of sites with observed low-flow frequencies. These observed values are compared to the values predicted with the Stedinger-Thomas method to evaluate the accuracy of the method. Streamflow-gaging stations were paired for each analysis, in that one station was treated as a partial-record station with base-flow measurements and the other station was treated as the index station. This approach is similar to the test of the method presented in Stedinger and Thomas (1985). The Stedinger-Thomas method was evaluated for five situations or “test cases.” For descriptive purposes in this report, these five test cases are referred to as Test Case A through Test Case E (table 1).

Pairs of streamflow-gaging stations were selected to provide reasonable index stations for each other. Pairs of streamflow-gaging stations were selected primarily on the basis of proximity to the partial-record station, an important characteristic of a good index station. Ideally, the index station and the partial-record station should have

Table 1. Description of test cases used to evaluate the Stedinger-Thomas method of estimating low-flow frequencies at partial-record sites in Indiana

Test Case	Sample size	Index-station characteristics	
		Location relative to partial-record site	Drainage area
A	28	Same stream or tributary	Greater than partial-record station
B	28	Same stream or tributary	Less than partial-record station
C	35	Different stream or basin	Greater than partial-record station
D	35	Different stream or basin	Less than partial-record station
E[1]	15	Same stream or tributary	Greater than or less than partial-record station

[1]Test Case E uses two index stations.

similar base-flow-recession characteristics, such as similar flow-duration curves or similar hydrographs. The base-flow-recession characteristics at the partial-record station typically will be unknown, however, because there is no continuous record of streamflows. Yet similar base-flow-recession characteristics can be inferred if the watershed for the index station is of similar terrain, drainage area, and geologic characteristics as that for the partial-record station. The pairs of stations that were selected cover a wide range of drainage areas, difference in drainage area, and distance between stations to examine which characteristics, if any, affect the accuracy of the method. The stations in each pair are, for the most part, within the same physiographic region or near the boundaries of adjacent regions. A total of 141 pairs of streamflow-gaging stations were used in the five test cases.

In Case A, the partial-record station and the index station are on the same stream or the partial-record station is on a tributary of the stream where the index station is located. The drainage area at the index station is greater than at the partial-record station. In other words, the index station is downstream from the partial-record station. Case B is similar to Case A, except that the drainage area at the index station is less than at the partial-record station. In other words, the index station is upstream from the partial-record station. The same 28 pairs of streamflow-gaging stations are used in Case A and Case B; switching the position of the index station allows for an evaluation of the effect of the difference in drainage area between the index stations and partial-record stations.

In Case C, the partial-record station and the index station are on different streams, possibly in different drainage basins, and the drainage area at the index station is greater than at the partial-record station. Case D is similar to Case C, except that the drainage area at the index station is less than at the partial-record station. The same 35 pairs of streamflow-gaging stations are used in Case C and Case D; switching the position of the index station allows for an evaluation of the effect of the difference in drainage area between the index stations and partial-record stations. Cases C and D allow for an evaluation of how accuracy is affected by selecting an index station from another basin.

Case E evaluates the Stedinger-Thomas method when two index stations are used. In Case E, the partial-record station and the two index stations are on the same stream or tributaries. In 11 instances, 1 index station is upstream from the partial-record station and 1 index station is downstream from the partial-record station. In four instances, the partial-record station is downstream from two tributaries with index stations. Case E allows for an evaluation of how accuracy is affected by using two index stations, as compared to Case A and Case B that use one index station. The sample size for Case E is smaller than the other test cases because the distribution of streamflow-gaging stations within the State provided limited sets of stations suitable for use as index stations for this case.

Pairs of streamflow-gaging stations selected for the test cases had to have some period of record common to both gages because each station served as an index station and as a partial-record station (Cases A and B, C and D). Estimates of low-flow frequencies vary with length of record (Riggs, 1972), so a common period of record was used to give the method a fair chance at predicting the observed low-flow frequency. In actual low-flow investigations, the period of record at the index station would not be controlled. One would expect that the longer the period of record at the index station, the more reliable the estimates at the partial-record station. Table 2 (at the back of this report) lists the streamflow-gaging stations used in this study with their complete periods of record and most recently published values of $7Q_{10}$ and $7Q_2$. Many of the streamflow-gaging stations listed in table 2 were used multiple times, often with different periods of record that were dependent on the streamflow-gaging station with which it was paired.

Low-flow measurements, representing base flow for each streamflow-gaging station, were retrieved from the historical files and entered into the data base if needed. With the base-flow measurements in the data base, the concurrent daily flows at the index stations could be retrieved with a computer program. The base-flow measurements were plotted against the concurrent daily flows (using logarithmic scales) to determine a linear relation between the flows at the two sites. Twenty measurements, covering a range of flows, were selected for each analysis to define the linear relation. The measurements were selected to cover the shortest period of time whenever possible; however, the measurements were made for routine maintenance of rating curves, and often only a few measurements were made at low flow during a year. In some instances, the measurements cover a span of 10 years or more. Actual low-flow investigations would collect base-flow measurements in a much shorter time span; however, data collected over such a large time span does provide independent observations of base flow.

The 20 measurements used to define the relation between base-flow measurements and concurrent daily flows are more than most low-flow investigations will use. Riggs (1972) indicated that generally 8 to 10 measurements made on different streamflow recessions, and in more than 1 year, should adequately define the relation to concurrent flows at the index station. Because the Stedinger-Thomas method includes a linear regression, it is recommended that at least 10 measurements be used (W.O. Thomas, Jr., and others, U.S. Geological Survey, written commun., 1993). Twenty measurements were used in the analyses for this study primarily for three reasons: (1) the data were available because of the long-term record of the streamflow-gaging stations; (2) choosing measurements to define the linear relation with concurrent daily flows has a certain amount of bias associated with it, which probably increases as the number of measurements decreases; using 20 measurements generally provided a wider range of base flows to define the linear relation; and (3) Stedinger and Thomas (1985) indicated that the standard error of estimate is not reduced significantly when the number of observations exceeds 20.

In a later section of this report, the number of base-flow measurements used in the analyses is varied to evaluate how the accuracy of the method is affected. The number of base-flow measurements is varied for a subset of the streamflow-gaging-station pairs for each test case, and the results are compared to those obtained when the original 20 measurements were used.

Frequency Analysis at Partial-Record Stations

Low-flow frequencies at partial-record stations were estimated by use of the mathematical technique described in Stedinger and Thomas (1985). The Stedinger-Thomas method defines the relation between base-flow measurements at a partial-record station and concurrent daily flows at an index station, using least-squares-regression analysis of the logarithms of flows. The regression analysis and low-flow statistics (moments) at the index station are used to estimate the desired flow characteristics at the partial-record station. The least-squares-regression line, based on discharge measurements at the partial-record station and concurrent flows at the index station, is defined by the equation:

$$y = a + bx, \tag{1}$$

where y represents the log-transformed flows at the partial-record station, and

x represents the log-transformed flows at the index station.

From Stedinger and Thomas (1985), the logarithm of the N-day, T-year low flow at the partial-record station, Y_T, is estimated by the equation:

$$Y_T = \mu_y + K_y \sigma_y, \tag{2}$$

where μ denotes the mean,

σ denotes the standard deviation, and

K_y is the frequency factor for the value of skew coefficient at the T-year recurrence interval for the partial-record station.

Because the partial-record station has no record of N-day low flows, the logarithms of base-flow measurements at the partial-record station and concurrent daily flows at the index station are used to estimate the parameters in equation 2. One of the key assumptions of the Stedinger-Thomas method is that the frequency factor for the index station, K_x, and the frequency factor for the partial-record station, K_y, are the same. It is assumed that the frequency factors will be approximately equal if the sites are in similar hydrologic settings and have similar drainage areas. This is an important assumption of the method that must be considered when choosing index stations.

Given that the frequency factors for the index station and partial-record station are assumed to be the same, K_y in equation 2 can be estimated by K_x, which can be substituted with $\left(\frac{X_T - m_x}{s_x}\right)$. The relation in equation 2 then can be approximated by:

$$Y_T = a + bm_x + \left(\frac{X_T - m_x}{s_x}\right)\left(b^2 s_x^2 + s_e^2\left(1 - \frac{s_x^2}{(L-1)\tilde{s}_x^2}\right)\right)^{1/2}, \tag{3}$$

where m_x is the sample mean of the logarithms of the annual N-day low flows at the index station,

s_x is the sample standard deviation of the logarithms of the annual N-day low flows at the index station,

s_e is the standard error of estimate of the least-squares-regression equation (eq. 1),

L is the number of base-flow measurements and concurrent daily flows used to estimate the regression equation,

$\tilde{s}_x$ is the standard deviation of the logarithm of the concurrent daily flows at the index station used in the regression equation, and

X_T is the logarithm of the N-day, T-year low flow for the index station.

The factor $\left(1 - \frac{s_x^2}{(L-1)\tilde{s}_x^2}\right)$ was used to obtain an unbiased estimator of σ_y^2 (Stedinger and Thomas, 1985, p. 4).

Stedinger and Thomas (1985) recommend that the correlation coefficient exceed 0.70. In this study, there were 7 instances, out of 141, in which the correlation coefficient was less than 0.70. Because the method uses the logarithms of flows, zero flows cannot be used. Many small streams in southern Indiana often have zero flow (Stewart and others, 1999; Arihood and Glatfelter, 1991); therefore, many streamflow-gaging stations in southern Indiana could not be used in this study.

The Stedinger-Thomas method has been automated by the USGS and has the capability of using multiple index stations (W.O. Thomas and others, U.S. Geological Survey, written commun., 1993). The user is responsible for selecting which measurements are used in the analysis. The method will fit a least squares regression to the data, so the user must determine if the base-flow measurements have an adequate linear relation with the concurrent daily flows at the index station.

Evaluation of the Stedinger-Thomas Method

The Stedinger-Thomas method of estimating low-flow frequencies at partial-record stations was evaluated through five test cases designed to cover a variety of conditions. In these test cases the location of the index station was varied to evaluate the effects of drainage-area differences, using an index station from a different stream or drainage basin and using two index stations. A discussion of the results of each test case follows.

Test Cases A and B

Test Cases A and B are designed to evaluate the Stedinger-Thomas method when the index station and the partial-record station are on the same stream or when the upstream station is on a tributary of the downstream station. In Case A, the drainage area of the index station is greater than at the partial-record station. In Case B, the drainage area of the index station is less than at the partial-record station. The pairs of streamflow-gaging stations used in Cases A and B are shown in figure 1. The pair numbers in figure 1 correspond to those in tables 3 and 4 (at the back of this report). Cases A and B use the same 28 pairs of streamflow-gaging stations, with the positions of the index and partial-record stations reversed for Case B. Low-flow frequencies listed in the tables include one more significant figure than normally would be reported. The extra significant figure is used for comparison purposes to help in evaluating the method.

Figure 2a shows the predicted $7Q_{10}$ and the observed $7Q_{10}$ for Case A. The relative error of predicted $7Q_{10}$ over the range of observed values is shown in figure 2b. The observed values are based on log Pearson type III frequency curves of the annual 7-day minimum flows at the partial-record station for the same period of record as the index station. The relative error of estimate was determined by the equation:

$$(\textit{Observed } 7Q_T - \textit{Predicted } 7Q_T) / \textit{Predicted } 7Q_T \;, \quad (4)$$

where T is the recurrence interval (in years) of the annual 7-day minimum flows.

There were 17 instances in Case A in which the Stedinger-Thomas method predicted higher values of $7Q_{10}$ than the values observed for the continuous record. There were seven instances in which the Stedinger-Thomas method predicted lower values than the observed values. The average relative error of estimate was -1.0 percent, with a standard deviation of 16.2 (table 3). In Case A, the relative error of estimate ranged from -28.0 percent to 47.6 percent. A negative value of relative error (fig. 2b) indicates that the predicted value is greater than the observed value.

A predicted value within 15 percent of the observed value was selected arbitrarily as the criterion that represented an excellent estimate. The 15-percent error band is included in the plots of relative error. In Case A, 23 of 28 predicted values of $7Q_{10}$

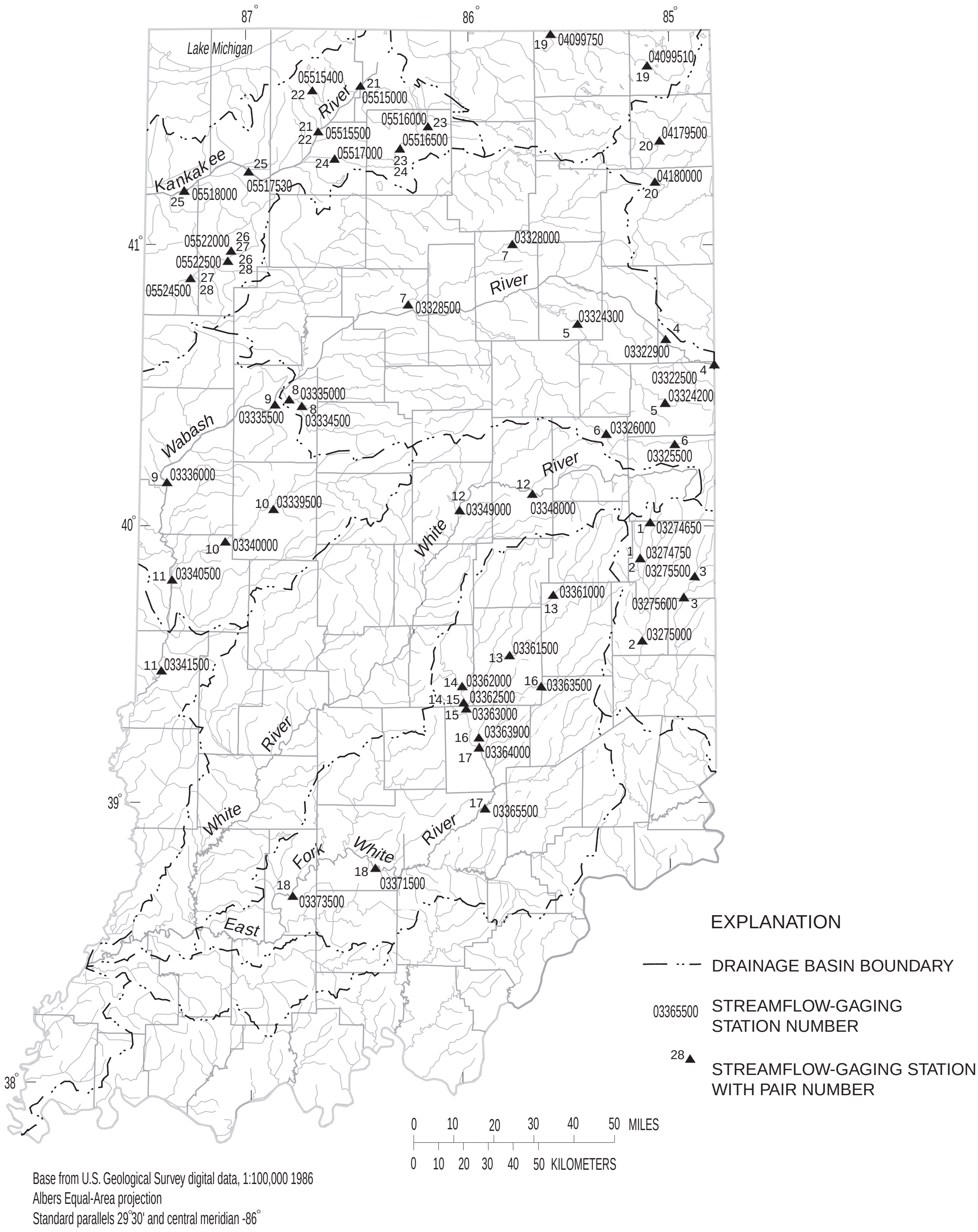


Figure 1. Map showing pairs of streamflow-gaging stations used to evaluate the Stedinger-Thomas method of estimating low-flow frequencies from base-flow measurements at Indiana streams, when the index station and partial-record station are located on the same stream or tributaries.

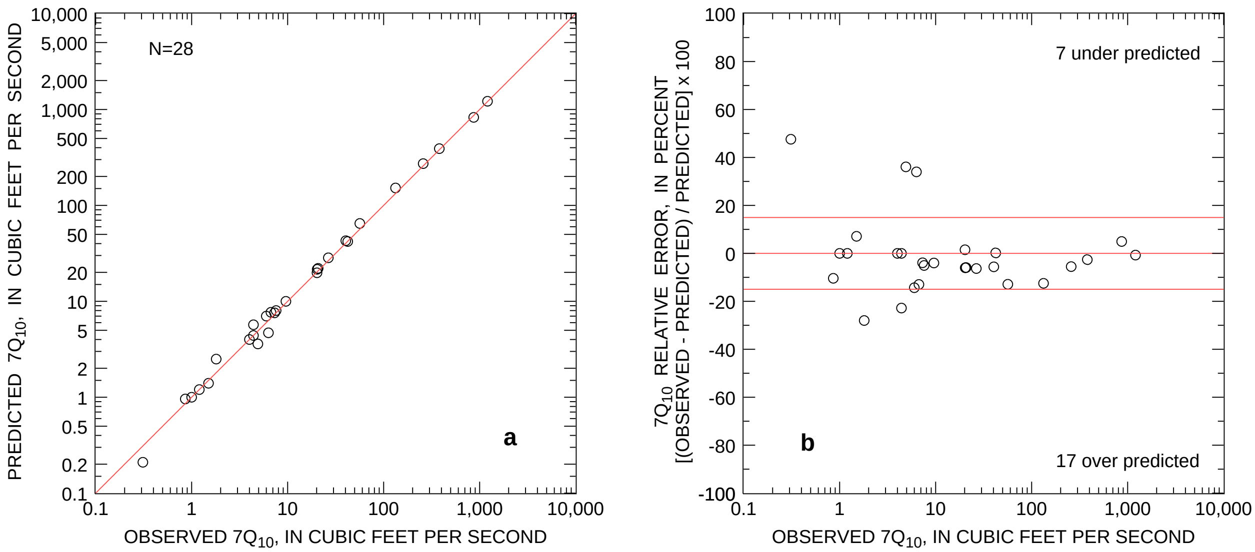


Figure 2. Predicted values of $7Q_{10}$ and observed values of $7Q_{10}$ (a) for Indiana streams in Test Case A and (b) the relative error of the predicted values of $7Q_{10}$ with the observed values of $7Q_{10}$ for Test Case A.

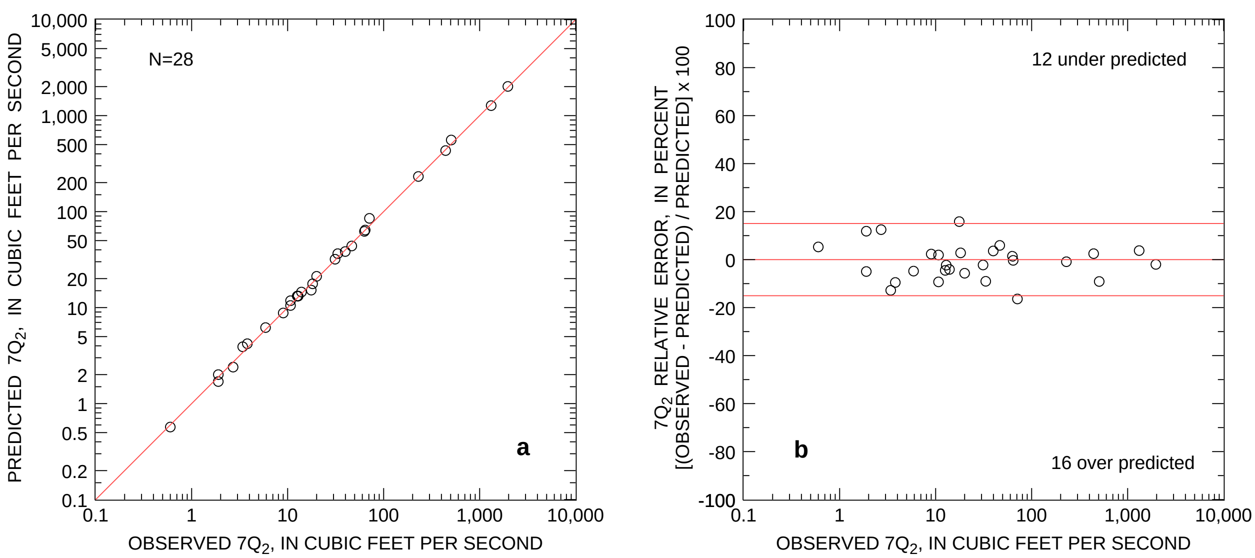


Figure 3. Predicted values of $7Q_2$ and observed values of $7Q_2$ (a) for Indiana streams in Test Case A and (b) the relative error of the predicted values of $7Q_2$ with the observed values of $7Q_2$ for Test Case A.

were within 15 percent of the observed $7Q_{10}$. The relative error of estimate shows no direct relation with the magnitude of the $7Q_{10}$; however, the largest errors are for those stations with a $7Q_{10}$ less than 10 ft^3/s (fig. 2b). At small flows, a relatively small difference equates to a large error in percent. For example, in the first pair listed in table 3, a difference of 0.1 ft^3/s equates to an error of 47.6 percent.

Overall, the predicted values of $7Q_2$ for Case A were slightly more accurate, with less variability than the predicted values of $7Q_{10}$ (fig. 3). The relative error of estimate ranged from -16.4 percent to 15.8 percent. All but two predicted values of $7Q_2$ were within 15 percent of the observed value. In Case A, there were 16 instances in which the Stedinger-Thomas method predicted higher values of $7Q_2$ than the values observed for the continuous record. There were 12 instances in which the Stedinger-Thomas method predicted lower values than the observed values (fig. 3b). The average relative error of estimate was -1.0 percent, with a standard deviation of 7.5 percent—less than half the standard deviation for the predicted values of $7Q_{10}$ (table 3).

The positions of the index and partial-record stations in Case B are reversed from the positions in Case A. In other words, the index station of Case B is the partial-record station of Case A. Figure 4 shows the predicted $7Q_{10}$ and the observed $7Q_{10}$ for Case B, and the relative error of predicted $7Q_{10}$ over the range of observed values. In Case B, the Stedinger-Thomas method tended to predict lower values of $7Q_{10}$ than the values observed for the continuous record. The $7Q_{10}$ was under predicted 19 times and over predicted 9 times. The average relative error of estimate was 9.6 percent, with a standard deviation of 16.8 percent (table 4, at the back of this report). In Case B, 19 of 28 predicted values of $7Q_{10}$ were within 15 percent of the observed $7Q_{10}$. The relative error of estimate ranged from -12.8 percent to 55.1 percent. The relative error of estimate shows no direct relation with the size of the observed $7Q_{10}$; however, all but one of the observations with greater than 15-percent error have index stations with a $7Q_{10}$ of less than 10 ft^3/s. The index stations for Case B, and their low-flow frequencies, are listed in table 3 as the partial-record stations of Case A. The pair numbers in tables 3 and 4 correspond to the same pairs of streamflow-gaging stations.

The predicted values of $7Q_2$ for Case B were slightly more accurate, with less variability than the predicted values of $7Q_{10}$ (fig. 5). The relative error of estimate ranged from -8.6 percent to 31.1 percent. All but three predicted values of $7Q_2$ were within 15 percent of the observed value, but there was a tendency to under predict (fig. 5b). The method under predicted the $7Q_2$ 17 times and over predicted 10 times. The average relative error of estimate was 4.5 percent, with a standard deviation of 8.7 percent—almost half the standard deviation of the estimates of $7Q_{10}$ (table 4).

Boxplots of the relative error were used to illustrate the performance of the Stedinger-Thomas method in Cases A and B (figs. 6 and 7). In Case A, the method tended to over predict (based on the median relative error) the $7Q_{10}$ and the $7Q_2$, but more so for the $7Q_{10}$. In Case B, the method tended to under predict the $7Q_{10}$ and the $7Q_2$, once again, more so for the $7Q_{10}$. The Case B estimates of $7Q_{10}$ also show more variability than for Case A, based on the spread of the interquartile range (fig. 6). The difference between the two cases is the location of the index station; the index station in Case B has a smaller drainage area and smaller flows than for Case A. The smaller flows probably are associated with more variability and reduced accuracy. When Cases A and B are combined, the median relative error is close to zero for both $7Q_{10}$ (fig. 6) and $7Q_2$ (fig. 7), which indicates that there is no bias to over predict or under predict. The combined average relative error of estimate is 4.3 percent for $7Q_{10}$ and 1.7 percent for $7Q_2$.

Test Cases C and D

Test Cases C and D are designed to evaluate the Stedinger-Thomas method when the index station and partial-record station are on different streams or in different basins. In Case C, the drainage area of the index station is greater than at the partial-record station. In Case D, the drainage area

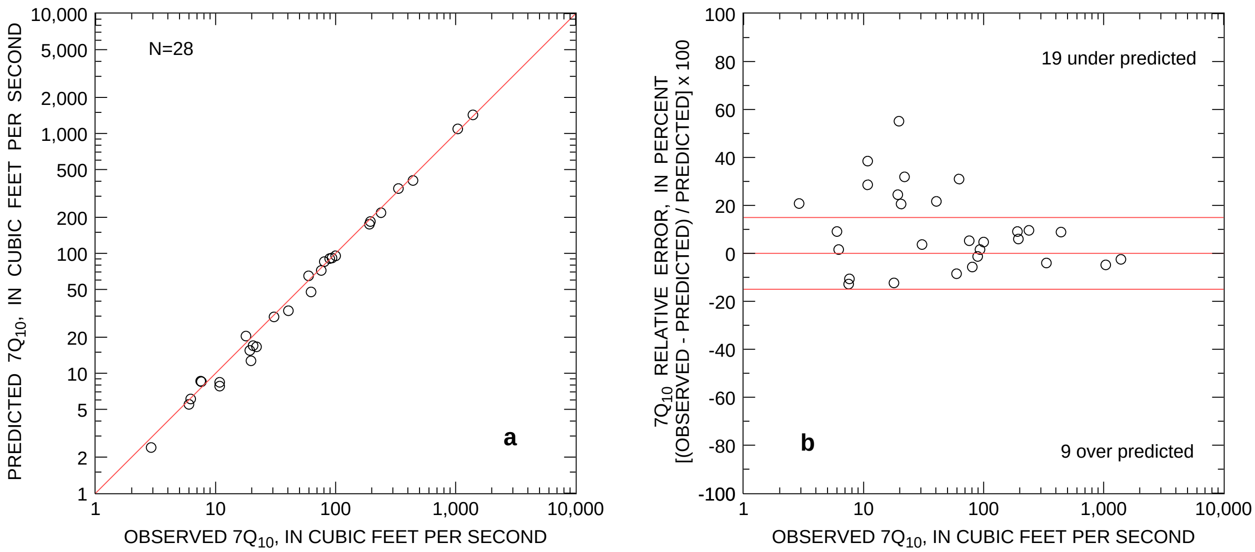


Figure 4. Predicted values of $7Q_{10}$ and observed values of $7Q_{10}$ (a) for Indiana streams in Test Case B and (b) the relative error of the predicted values of $7Q_{10}$ with the observed values of $7Q_{10}$ for Test Case B.

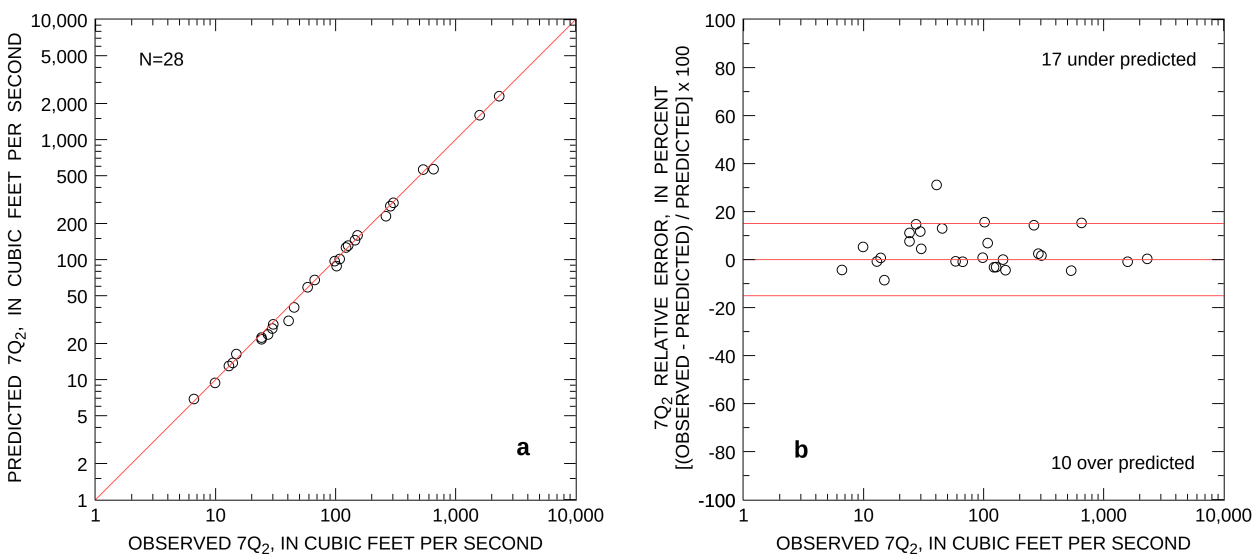


Figure 5. Predicted values of $7Q_2$ and observed values of $7Q_2$ (a) for Indiana streams in Test Case B and (b) the relative error of the predicted values of $7Q_2$ with the observed values of $7Q_2$ for Test Case B.

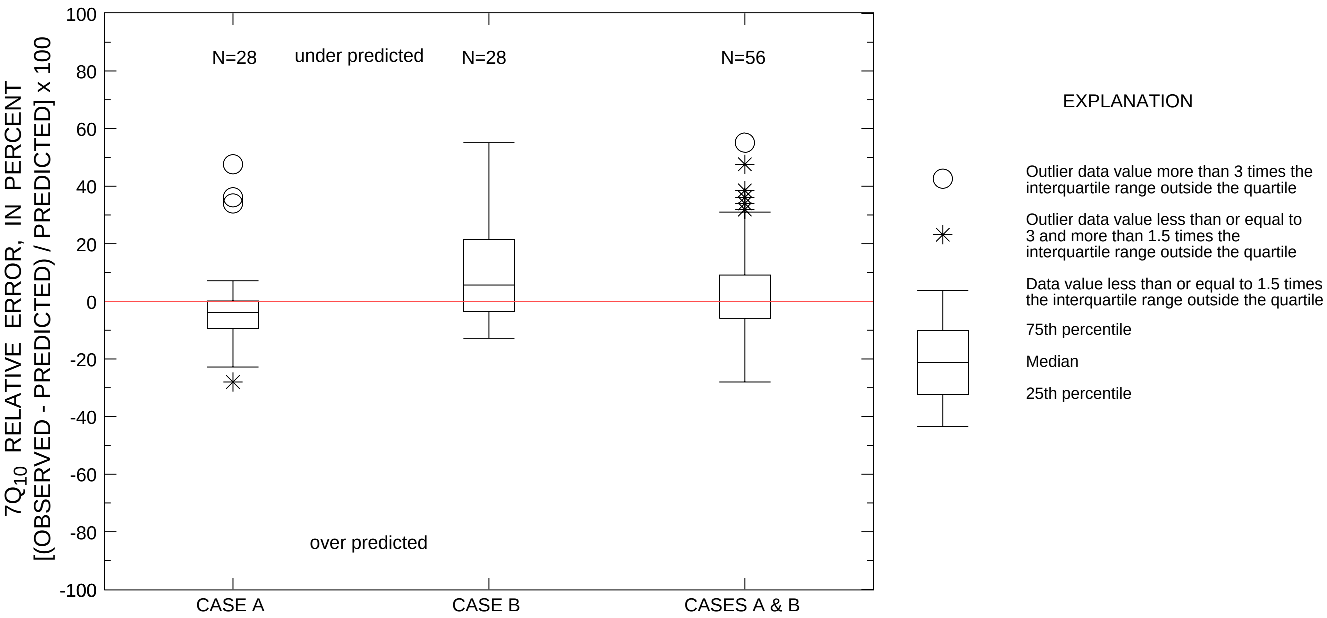


Figure 6. Relative error in predicted values of $7Q_{10}$ for Indiana streams, using the Stedinger-Thomas method, Test Cases A and B.

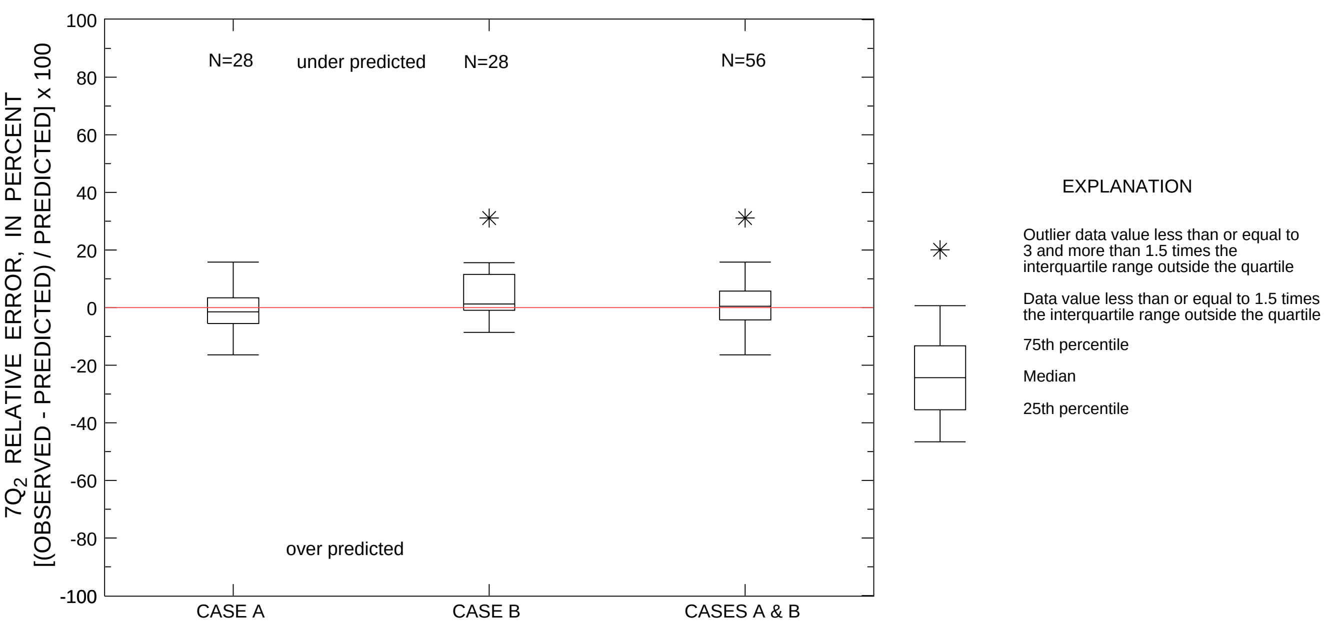


Figure 7. Relative error in predicted values of $7Q_2$ for Indiana streams, using the Stedinger-Thomas method, Test Cases A and B.

of the index station is less than at the partial-record station. The pairs of streamflow-gaging stations used in Cases C and D are shown in figure 8. The pair numbers in figure 8 correspond to those in tables 5 and 6 (at the back of this report). Cases C and D use the same 35 pairs of streamflow-gaging stations, with the positions of the index and partial-record stations reversed for Case D.

Figure 9a shows the predicted $7Q_{10}$ and the observed $7Q_{10}$ for Case C. The relative error of predicted $7Q_{10}$ over the range of observed values is shown in figure 9b. In Case C, there were 14 instances in which the Stedinger-Thomas method predicted higher values of $7Q_{10}$ than the values observed for the continuous record. There were 20 instances in which the predicted values of $7Q_{10}$ were lower than the values observed for the continuous record. The average relative error of estimate was 20.6 percent, with a standard deviation of 45.5 percent (table 5). The noticeably large average relative error, compared to Cases A and B, is a result of a few stations with small flows that have large relative errors (fig. 9b). For example, in pair number 33 listed in table 5, the difference between the observed and predicted $7Q_{10}$ is only 0.06 ft^3/s; however, this equates to a relative error of 150 percent.

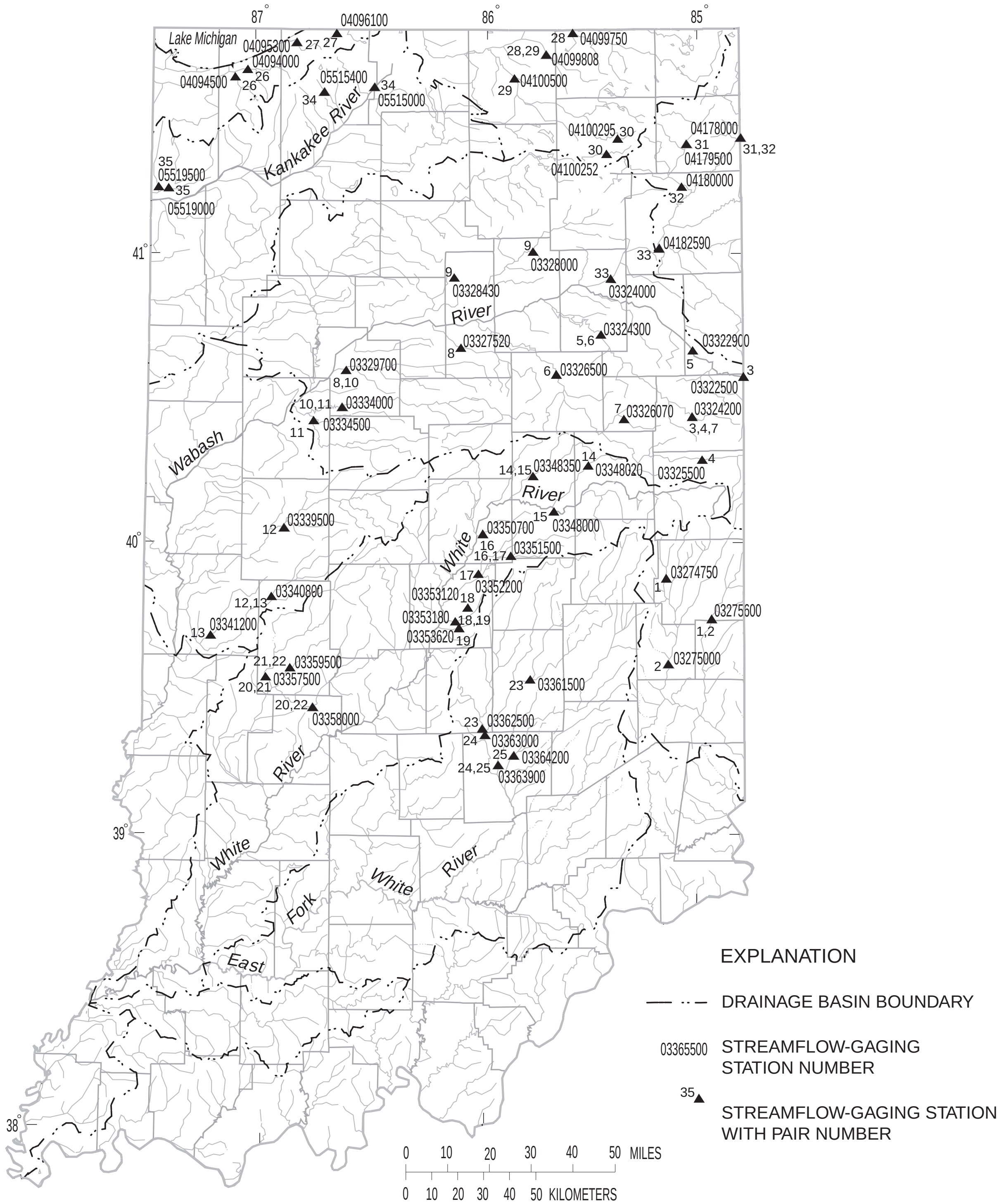
In Case C, 15 of 35 predicted values of $7Q_{10}$ were within 15 percent of the observed $7Q_{10}$. The relative error of estimate ranged from -40.0 percent to 150 percent. The relative error of estimate tends to increase as the observed $7Q_{10}$ decreases; the largest errors are for those stations with a $7Q_{10}$ less than 2 ft^3/s (fig. 9b). The large variability in relative error of Case C compared to Case A may in part be related to the increased number of stations with small values of $7Q_{10}$. At extremely low flows in natural channels, it becomes more difficult to maintain the accuracy of discharge measurements and to account for shifting controls at streamflow-gaging stations, which can result in reduced accuracy of the streamflow record.

The predicted values of $7Q_2$ for Case C were slightly more accurate with less variability than the predicted values of $7Q_{10}$. The relative error of estimate ranged from -34.1 percent to 96.1 percent (table 5). There were 23 instances in which the method predicted lower values of $7Q_2$ than the values observed for the continuous record. There were 10 instances in which the predicted values of $7Q_2$ were higher than the values observed for the continuous record (fig. 10). In Case C, 19 of 35 predicted values of $7Q_2$ were within 15 percent of the observed value. The average relative error of estimate was 14.2 percent, with a standard deviation of 27.6 percent (table 5).

The positions of the index station and partial-record station in Case D are reversed from the positions in Case C so that the drainage area of the index station is less than at the partial-record station. Figure 11 shows the predicted $7Q_{10}$ and the observed $7Q_{10}$ for Case D and the relative error of the predicted $7Q_{10}$ over the range of observed values. There were 17 instances in Case D in which the predicted value of $7Q_{10}$ was lower than the value observed for the continuous record. There were also 17 instances in which the predicted value was higher than the observed value. The average relative error of estimate was 14.6 percent, with a standard deviation of 36.6 percent (table 6). The large average relative error, compared to Cases A and B, is a result of a few stations with small flows that have large relative errors (fig. 11b).

In Case D, 18 of 35 predicted values of $7Q_{10}$ were within 15 percent of the observed $7Q_{10}$. The relative error of estimate ranged from -28.6 percent to 123 percent. Although there is no direct relation between the two, the relative error of estimate tends to increase as the observed $7Q_{10}$ decreases. As in Case B, all but one of the observations with greater than 15-percent error have index stations with a $7Q_{10}$ of less than 10 ft^3/s. The index stations for Case D, and their low-flow frequencies, are listed in table 5 as the partial-record stations of Case C.

The predicted values of $7Q_2$ for Case D were slightly more accurate, with less variability than the estimates of $7Q_{10}$. The relative error of estimate ranged from -16.6 percent to 81.8 percent (table 6). There were 20 instances in Case D in which the predicted value of $7Q_2$ was lower than the value observed for the continuous record. There were 13 instances in which the predicted value was higher than the observed value (fig. 12). In Case D, 25 of 35 predicted values of $7Q_2$ were within 15 percent



Base from U.S. Geological Survey digital data, 1:100,000 1986
Albers Equal-Area projection
Standard parallels 29°30' and central meridian -86°

Figure 8. Map showing pairs of streamflow-gaging stations used to evaluate the Stedinger-Thomas method of estimating low-flow frequencies from base-flow measurements at Indiana streams, when the index station and partial-record station are located on different streams or basins.

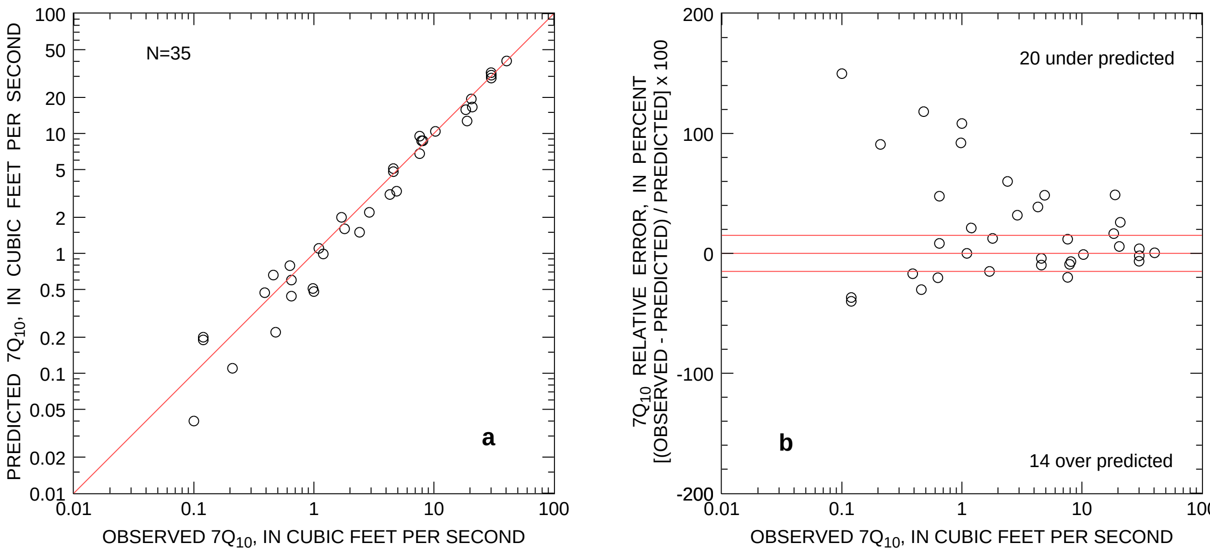


Figure 9. Predicted values of $7Q_{10}$ and observed values of $7Q_{10}$ (a) for Indiana streams in Test Case C and (b) the relative error of the predicted values of $7Q_{10}$ with the observed values of $7Q_{10}$ for Test Case C.

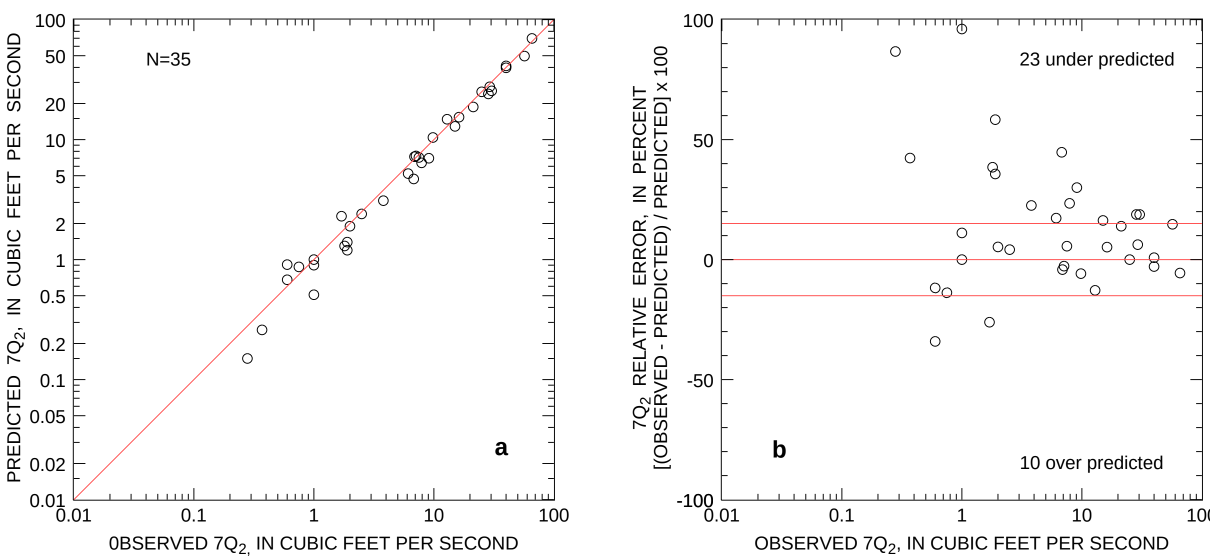


Figure 10. Predicted values of $7Q_2$ and observed values of $7Q_2$ (a) for Indiana streams in Test Case C and (b) the relative error of the predicted values of $7Q_2$ with the observed values of $7Q_2$ for Test Case C.

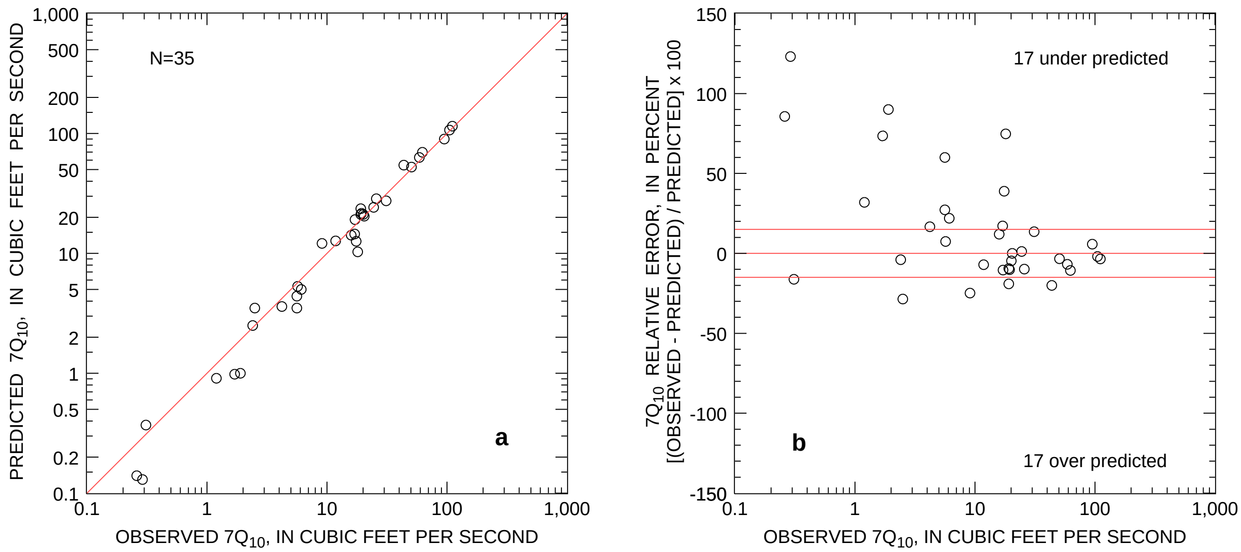


Figure 11. Predicted values of $7Q_{10}$ and observed values of $7Q_{10}$ (a) for Indiana streams in Test Case D and (b) the relative error of the predicted values of $7Q_{10}$ with the observed values of $7Q_{10}$ for Test Case D.

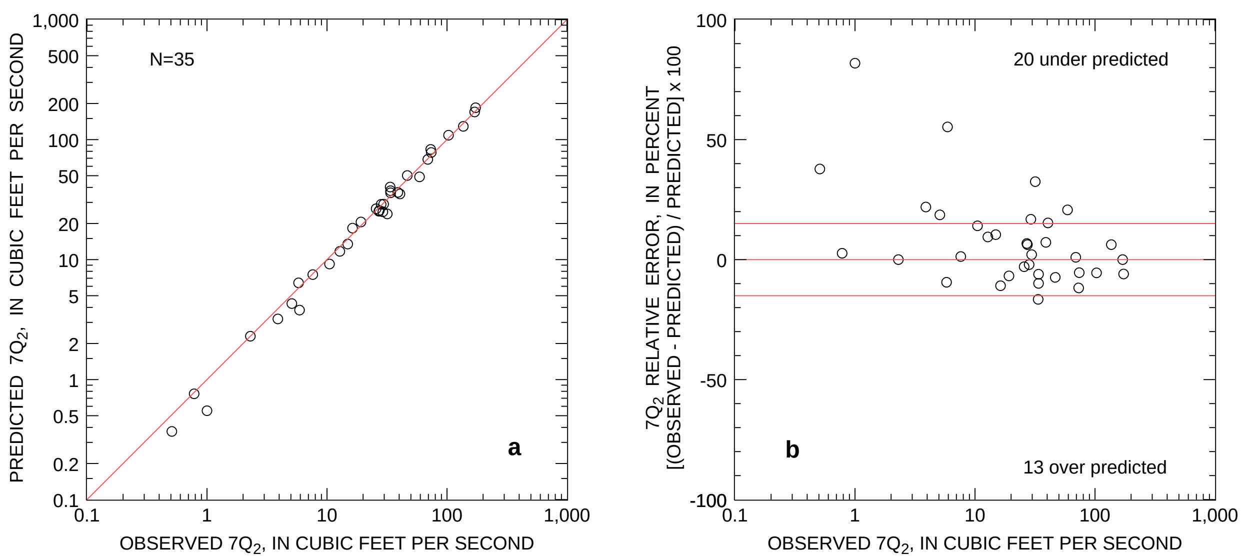


Figure 12. Predicted values of $7Q_2$ and observed values of $7Q_2$ (a) for Indiana streams in Test Case D and (b) the relative error of the predicted values of $7Q_2$ with the observed values of $7Q_2$ for Test Case D.

of the observed value. The average relative error of estimate was 7.6 percent, with a standard deviation of 19.9 percent (table 6).

Boxplots of the relative error were used to illustrate the performance of the Stedinger-Thomas method in Cases C and D (figs. 13 and 14). In Case C, the method tended to under predict (based on the median relative error) the $7Q_{10}$ and the $7Q_2$. In Case D, the method tended to under predict the $7Q_2$ but not the $7Q_{10}$. Predicted values of $7Q_{10}$ and $7Q_2$ in Case C show more variability than for Case D, based on the spread of the interquartile range and whiskers. When Cases C and D are combined, the median relative error of the estimates of $7Q_{10}$ is 2.5 percent (fig. 13) and the median relative error of the estimates of $7Q_2$ is 5.5 percent (fig. 14), which indicates that there is a slight bias to under predict. The combined average relative error of estimate is 17.6 percent for $7Q_{10}$ and 10.9 percent for $7Q_2$.

Test Case E

Test Case E is designed to evaluate the Stedinger-Thomas method when two index stations are used. In Case E, the partial-record station and the two index stations are on the same stream or tributaries. For 11 of the 15 sets of streamflow-gaging stations, one index station is upstream from the partial-record station and one index station is downstream from the partial-record station. For the remaining four sets, the partial-record station is downstream from the confluence of two tributaries with index stations. The 15 sets of streamflow-gaging stations used in Case E are shown in figure 15. The set numbers in figure 15 correspond to those in table 7 (at the back of this report). The results of Case E can be compared to the combined results of Cases A and B because each test uses stations that are on the same stream or tributaries.

Figure 16 shows the predicted values of $7Q_{10}$ and the observed values of $7Q_{10}$ for Case E and the relative error of the predicted $7Q_{10}$ over the range of observed values. In Case E, there were six instances in which the predicted value of $7Q_{10}$ was higher than the value observed for the continuous record. There were nine instances in which the predicted value was lower than the observed value. The average relative error of estimate was 2.0 percent, with a standard deviation of 7.9 percent (table 7). All but one predicted value of $7Q_{10}$ was within 15 percent of the observed value. The relative error of estimate ranged from -9.5 percent to 20.8 percent. The average relative error of estimate is similar to that for Cases A and B combined—4.3 percent, with a standard deviation of 17.2 percent.

Figure 17 shows the predicted $7Q_2$ and the observed $7Q_2$ for Case E and the relative error of the predicted $7Q_2$ over the range of observed values. The accuracies of the predicted values of $7Q_2$ for Case E were similar to those for the $7Q_{10}$. There were six instances in which the method predicted higher values of $7Q_2$ than the values observed for the continuous record. There were eight instances in which the predicted value was lower than the observed value. All of the predicted values of $7Q_2$ were within 15 percent of the observed value. The relative error of estimate ranged from -6.2 percent to 11.5 percent. The average relative error of estimate was 1.7 percent, with a standard deviation of 5.2 percent (table 7). The average relative error of estimate is similar to that for Cases A and B combined—1.7 percent, with a standard deviation of 8.5 percent.

Boxplots of the relative error of estimate were used to illustrate the performance of the Stedinger-Thomas method in Case E and to compare it to the combined results of Cases A and B (figs. 18 and 19). The median and interquartile range for Case E are comparable to those for Cases A and B combined for the $7Q_{10}$ and the $7Q_2$. The small range in relative error of estimate for Case E probably is a result of the small sample set and the high degree of correlation in the flows between the stations that were used. The apparent accuracy of the method in Case E also can be explained, in part, by the lack of small low-flow frequencies; only three of the stations have an observed $7Q_{10}$ less than10 ft^3/s (table 7). The largest relative error is associated with the smallest $7Q_{10}$ (fig. 16b). The sample size for Case E is smaller than the other

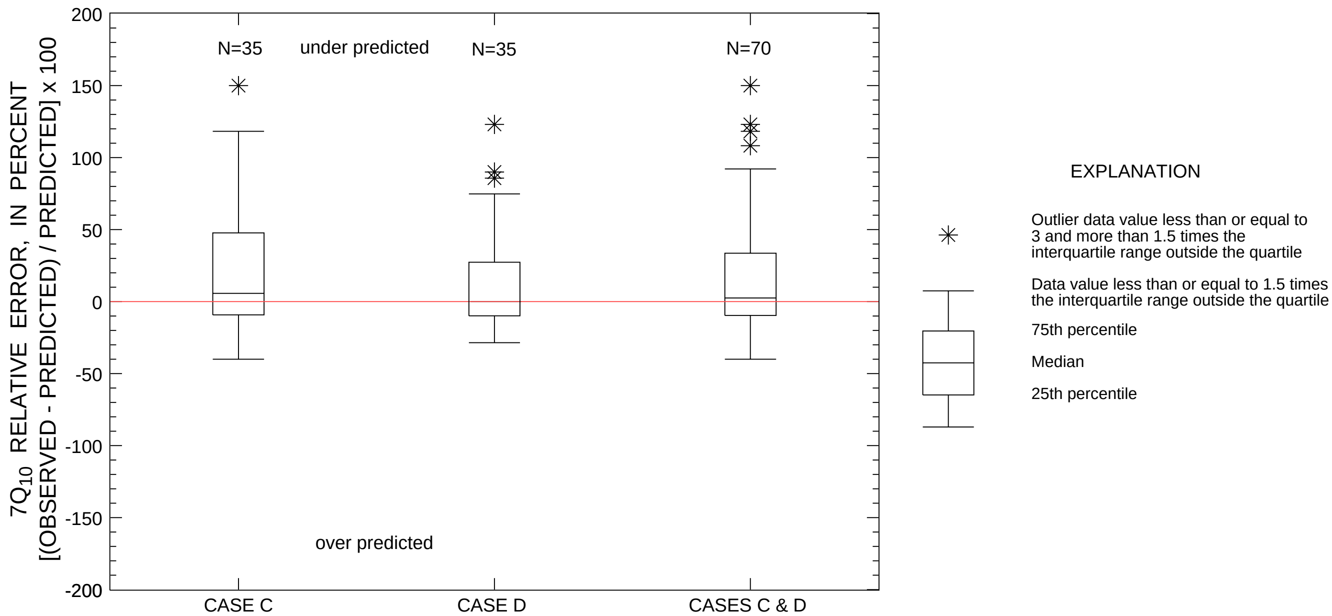


Figure13. Relative error in predicted values of $7Q_{10}$ for Indiana streams, using the Stedinger-Thomas method, Test Cases C and D.

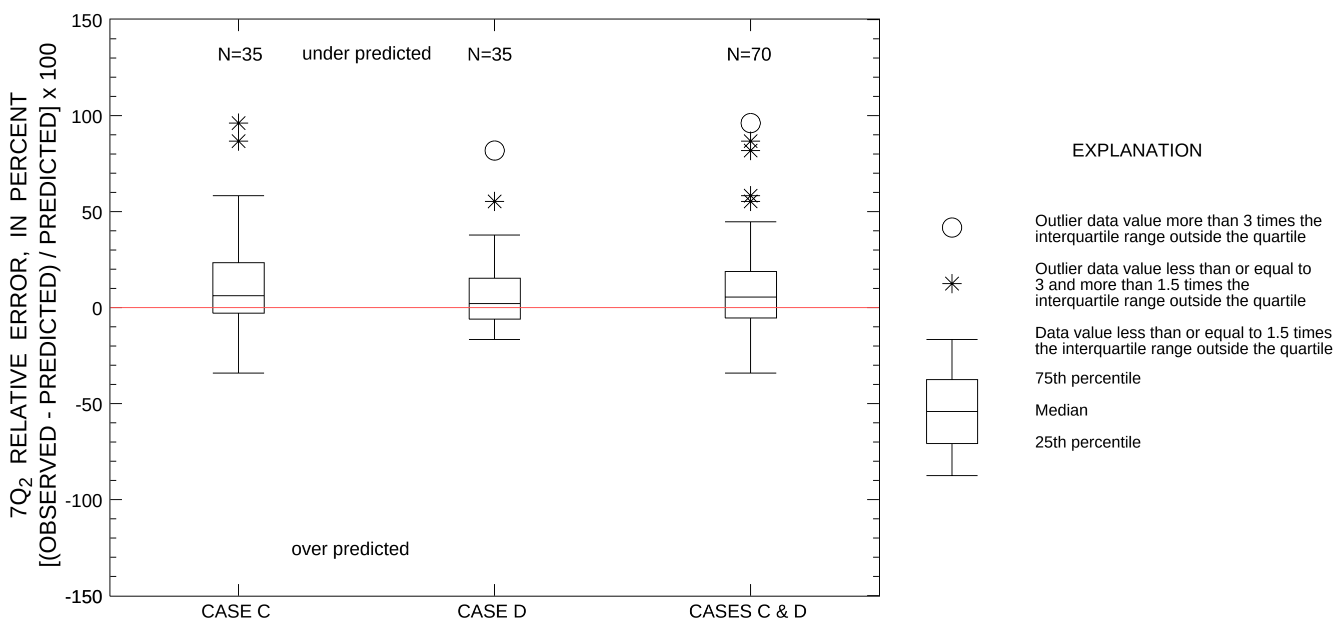


Figure 14. Relative error in predicted values of $7Q_2$ for Indiana streams, using the Stedinger-Thomas method, Test Cases C and D.

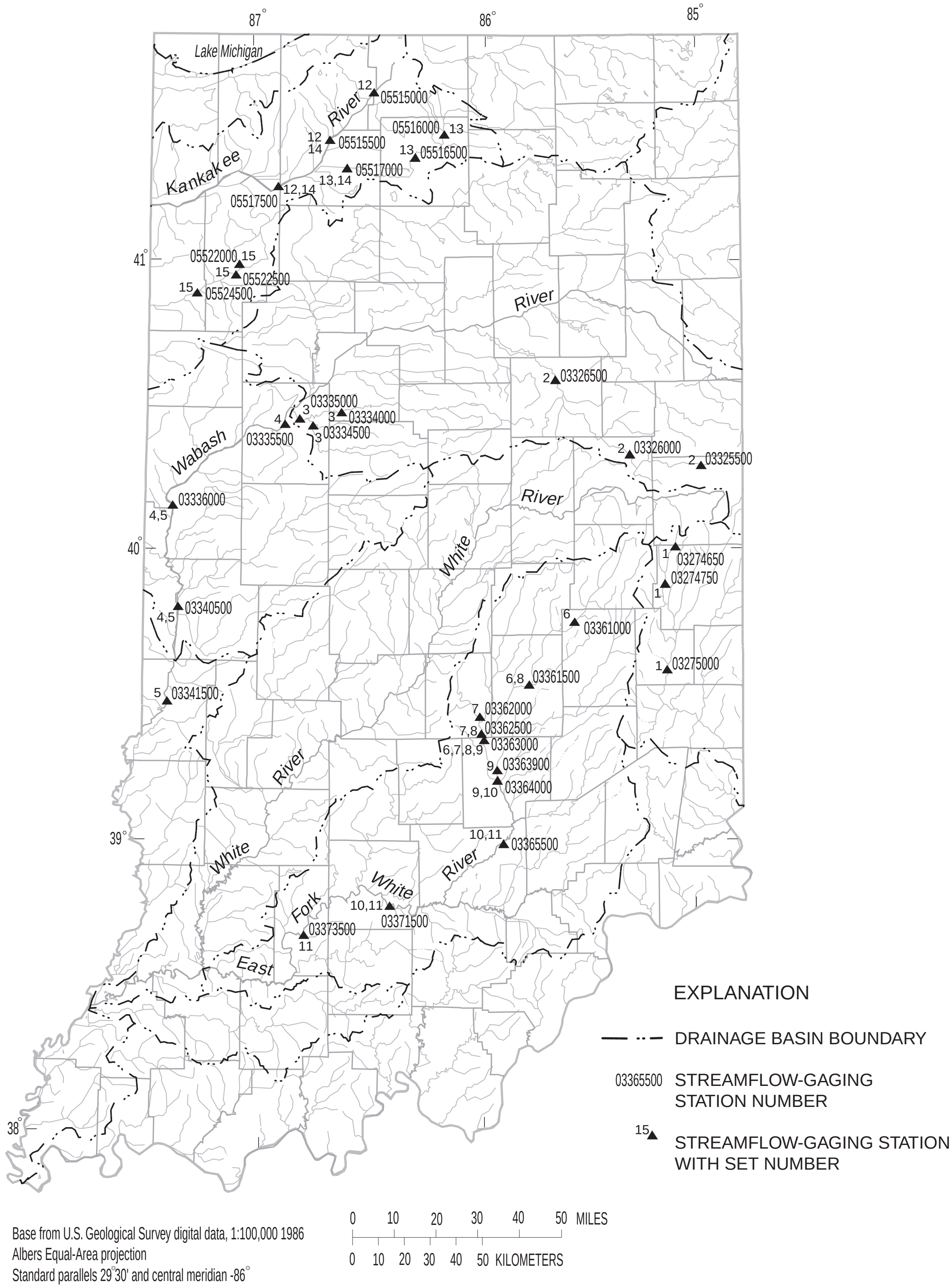


Figure 15. Map showing sets of streamflow-gaging stations used to evaluate the Stedinger-Thomas method of estimating low-flow frequencies from base-flow measurements at Indiana streams, when two index stations and the partial-record station are located on the same stream or tributaries.

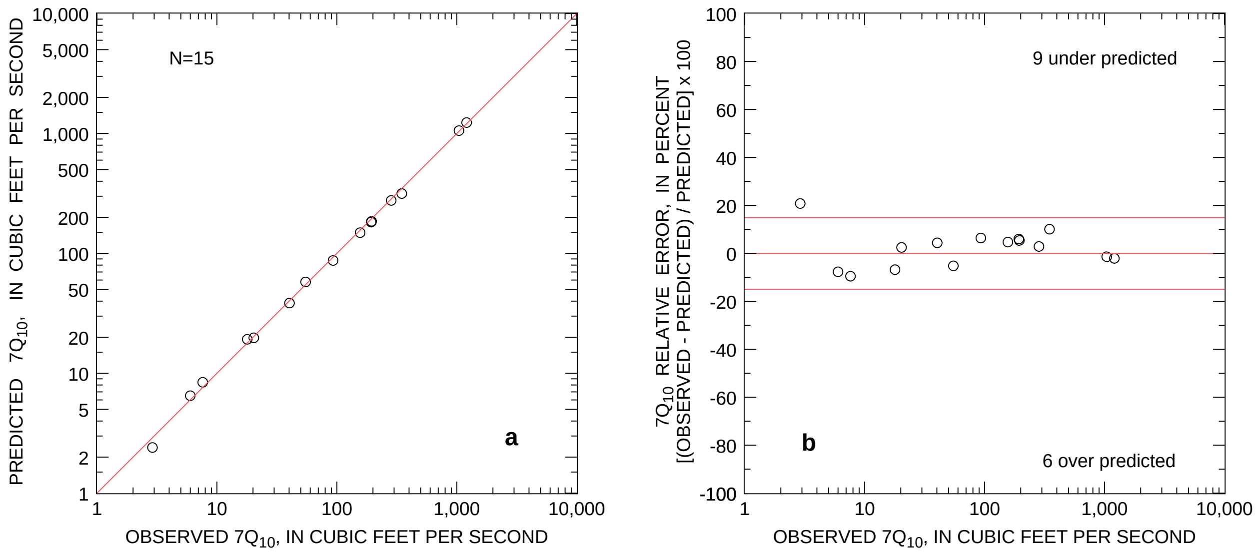


Figure 16. Predicted values of $7Q_{10}$ and observed values of $7Q_{10}$ (a) for Indiana streams in Test Case E and (b) the relative error of the predicted values of $7Q_{10}$ with the observed values of $7Q_{10}$ for Test Case E.

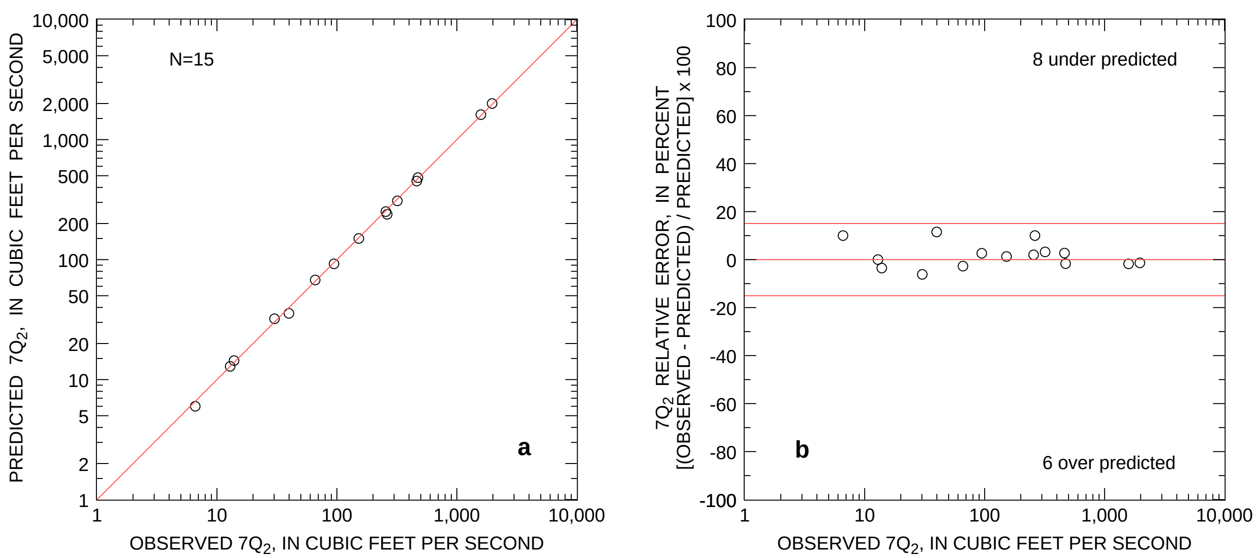


Figure 17. Predicted values of $7Q_2$ and observed values of $7Q_2$ (a) for Indiana streams in Test Case E and (b) the relative error of the predicted values of $7Q_2$ with the observed values of $7Q_2$ for Test Case E.

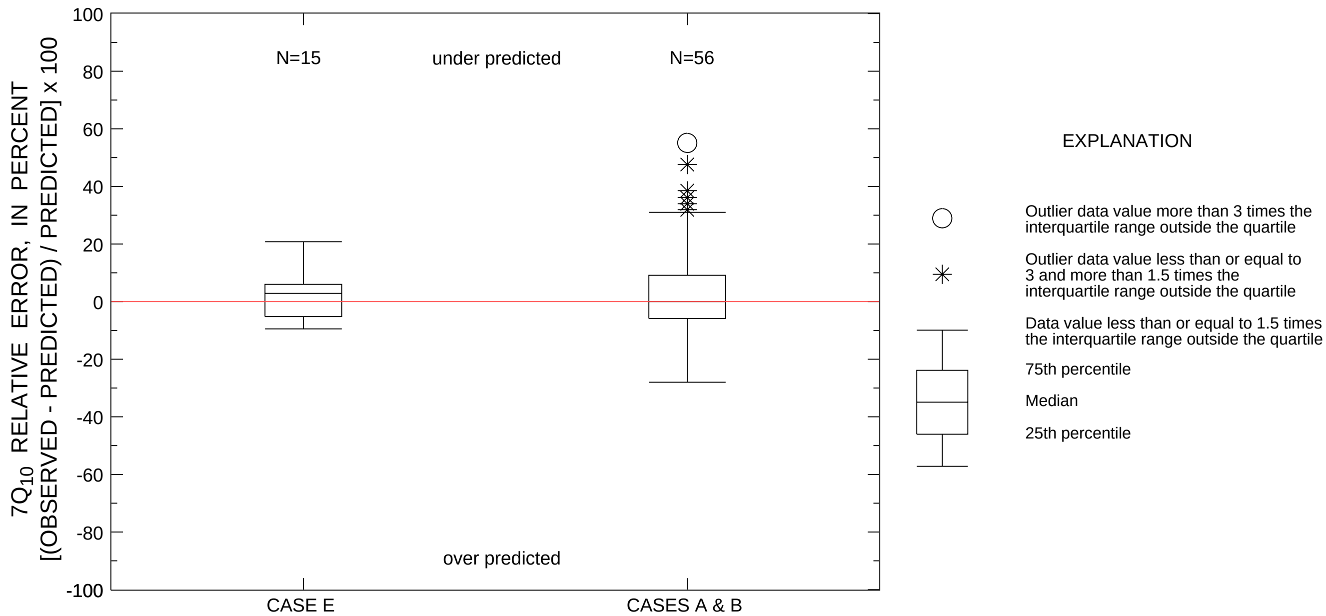


Figure 18. Relative error in predicted values of $7Q_{10}$ for Indiana streams, using the Stedinger-Thomas method, Test Case E compared with Test Cases A and B combined.

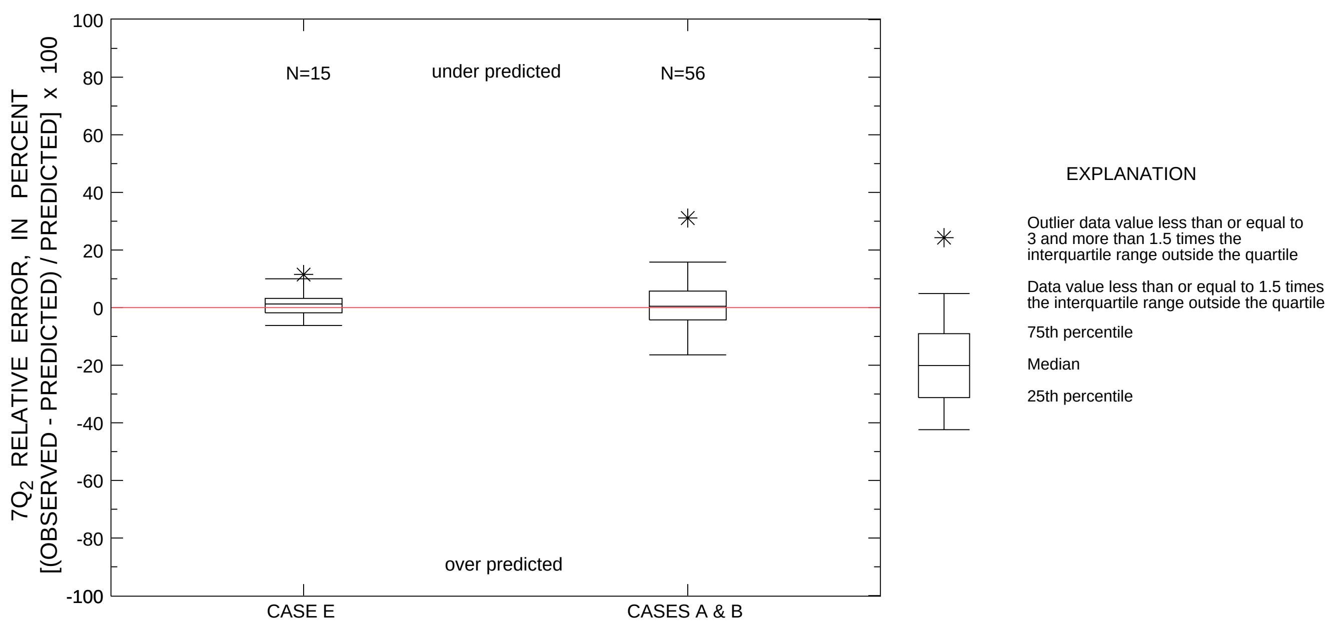


Figure 19. Relative error in predicted values of $7Q_2$ for Indiana streams, using the Stedinger-Thomas method, Test Case E compared with Test Cases A and B combined.

cases because the distribution of streamflow-gaging stations within the State provided limited sets of stations suitable for use as index stations.

Case E uses many of the same streamflow-gaging stations as Cases A and B. The results of Case E can be compared directly to the results of Case A or B when streamflow-gaging stations with a common period of record and a common index station are used. Table 8 shows the low-flow frequencies that were predicted for Test Case E and either Test Case A or B. The average percent difference between the two predicted values of $7Q_{10}$ is 7.5 percent, with a standard deviation of 6.2 percent. The average percent difference between the two predicted values of $7Q_2$ is 4.9 percent, with a standard deviation of 4.8 percent. These relatively small differences indicate that using two index stations does not produce significantly different results than using one index station under these limited and specific conditions.

Evaluation of All Test Cases

The previous sections discussing each test case indicate that the Stedinger-Thomas method provides the best estimate when the index station is on the same stream as the partial-record station or on one of its tributaries. In Case A, in which the drainage area of the index station is greater than the partial-record station, the Stedinger-Thomas method provided the best results among the four test cases that used one index station, but there was a tendency to predict higher values than observed for the continuous record (figs. 6 and 7). In Case B, in which the position of the index station and partial-record station are reversed, the Stedinger-Thomas method also performed well but not as well as in Case A—and there was a tendency to under predict. The tendency of the method to predict high or low values, relative to the observed values, would not be a concern in actual low-flow investigations if the average relative error of estimate were as small as in these test cases. The combined results of Cases A and B produced unbiased results, which indicate an equal chance of over estimating or under estimating the low-flow frequencies (figs. 6 and 7). Unbiased estimates are important for actual low-flow investigations because index stations will be upstream from some partial-record stations and downstream from others.

The results of Test Cases C and D indicate that estimates of low-flow frequencies are less accurate when the index station and the partial-record station are on different streams or in different basins. Relating flows between streams that are not tributary to each other inherently poses more uncertainty. Because droughts and low-flow conditions usually are of regional extent, however, good correlations are often possible between stations on different streams. Many of the test pairs in Cases C and D had relative errors of less than 15 percent, a criterion that was selected to indicate excellent estimates of low-flow frequency.

The large variability in relative error of Case C, as compared to Case A, may be related to the increased number of stations with small values of $7Q_{10}$. In these instances, a small difference in flow equates to a large relative error. Overall, the Stedinger-Thomas method tended to under predict in Cases C and D (figs. 13 and 14), but the median relative error was well below 10 percent (tables 5 and 6). In Cases C and D, there were 12 instances (17 percent) in which the relative error of estimate of $7Q_{10}$ was greater than 50 percent.

Of the five test cases, the Stedinger-Thomas method performed best when two index stations from the same stream or tributaries were used (Case E). The results of Test Case E were similar to the combined results of Test Cases A and B, but with much less variability (figs. 18 and 19). The small range in relative error for Case E probably is because of the small sample set and the high degree of correlation in the flows between the stations that were used.

Several factors or characteristics of the partial-record stations were evaluated in an attempt to explain and predict the variability of the errors of estimate. These characteristics include drainage area, difference in drainage area between the partial-record station and the index station, correlation coefficient of the least-squares-regression part of the method, and distance between the two sites. None of these characteristics showed a direct relation with the relative error of estimate and, therefore, could not explain the variability of the error nor be used to predict the relative error.

The only characteristic that showed some relation to the relative error of estimate was the size of the observed low-flow-frequency value at the partial-record station or the index station ("observed" refers to the value for the continuous record from the log Pearson type III frequency curves). A small low-flow-frequency value often was associated with the largest relative errors of estimate. This is partly a result of simple mathematics—a small difference between the predicted value and the observed value equates to a large relative error when the observed value is small. The quality of streamflow record also could explain why large relative errors are associated more typically with small low-flow frequencies. At extremely low flows in natural channels, it becomes more difficult to maintain the accuracy of discharge measurements and to keep track of shifting controls at streamflow-gaging stations, which can result in reduced accuracy of the streamflow record.

Estimates of low-flow frequencies at partial-record stations are most accurate when the index station and partial-record station have similar base-flow-recession characteristics. Base-flow-recession characteristics can be determined for streamflow-gaging stations from hydrographs and flow-duration curves of the daily mean flows. Because partial-record stations do not have a continuous record of the daily flows, however, base-flow-recession characteristics cannot be determined. When choosing an index station, one is left to infer the similarity in base-flow-recession characteristics through geographic proximity and the similarity in terrain, drainage area, and geologic characteristics. Because the number of continuous-record streamflow-gaging stations is limited, geographic proximity is usually the first consideration when choosing an index station.

Figure 20 shows flow-duration curves for two pairs of streamflow-gaging stations that were used in Test Cases A and B. The flow-duration curves for each pair are based on the same period of record, and the daily mean flows have been normalized to account for drainage area. These flow-duration curves may help explain the performance of the Stedinger-Thomas method. Figure 20a shows similar base-flow-recession characteristics for South Fork Wildcat Creek near Lafayette and Wildcat Creek near Lafayette. The flow-duration curves have similar values near the low-flow end—where flow is equaled or exceeded 98 to 99 percent of the time. This pair of streamflow-gaging stations produced good estimates of the $7Q_{10}$ and $7Q_2$ in Test Cases A and B (pair 8, tables 3 and 4). In Test Case A, the relative error of estimate was 1.5 percent for the $7Q_{10}$ and -2.2 percent for the $7Q_2$, with a correlation coefficient of 0.86. In Test Case B, the relative error of estimate was -8.5 percent for the $7Q_{10}$ and 0.8 percent for the $7Q_2$, with a correlation coefficient of 0.77.

Figure 20b shows flow-duration curves for Cedar Creek at Auburn and Cedar Creek near Cedarville, which indicate different base-flow-recession characteristics at the two sites. The flow-duration curves diverge from each other at the low-flow end, indicating that Cedar Creek has a more sustained supply of ground water near Cedarville during base-flow conditions than it does near Auburn. This pair of streamflow-gaging stations produced poor estimates of the $7Q_{10}$ and relatively poor estimates of the $7Q_2$ in Test Cases A and B (pair 20, tables 3 and 4). In Test Case A, the relative error of estimate was -28.0 percent for the $7Q_{10}$ and -9.5 percent for the $7Q_2$, with a correlation coefficient of 0.85. In Test Case B, the relative error of estimate was 55.1 percent for the $7Q_{10}$ and 14.7 percent for the $7Q_2$, with a correlation coefficient of 0.87.

Arihood and Glatfelter (1991) developed an equation for estimating low-flow characteristics of ungaged streams in Indiana. One of the significant basin characteristics that was used in their equation was flow-duration ratio, which is the 20-percent flow duration divided by the 90-percent flow duration (using daily mean flow, in ft^3/s). In that report, Arihood and Glatfelter (1991) subdivided the State into areas of common flow-duration ratios. The flow-duration ratios for the two stations in figure 20a are similar, 8.1 for South Fork Wildcat Creek and 8.7 for Wildcat Creek. The flow-duration ratios

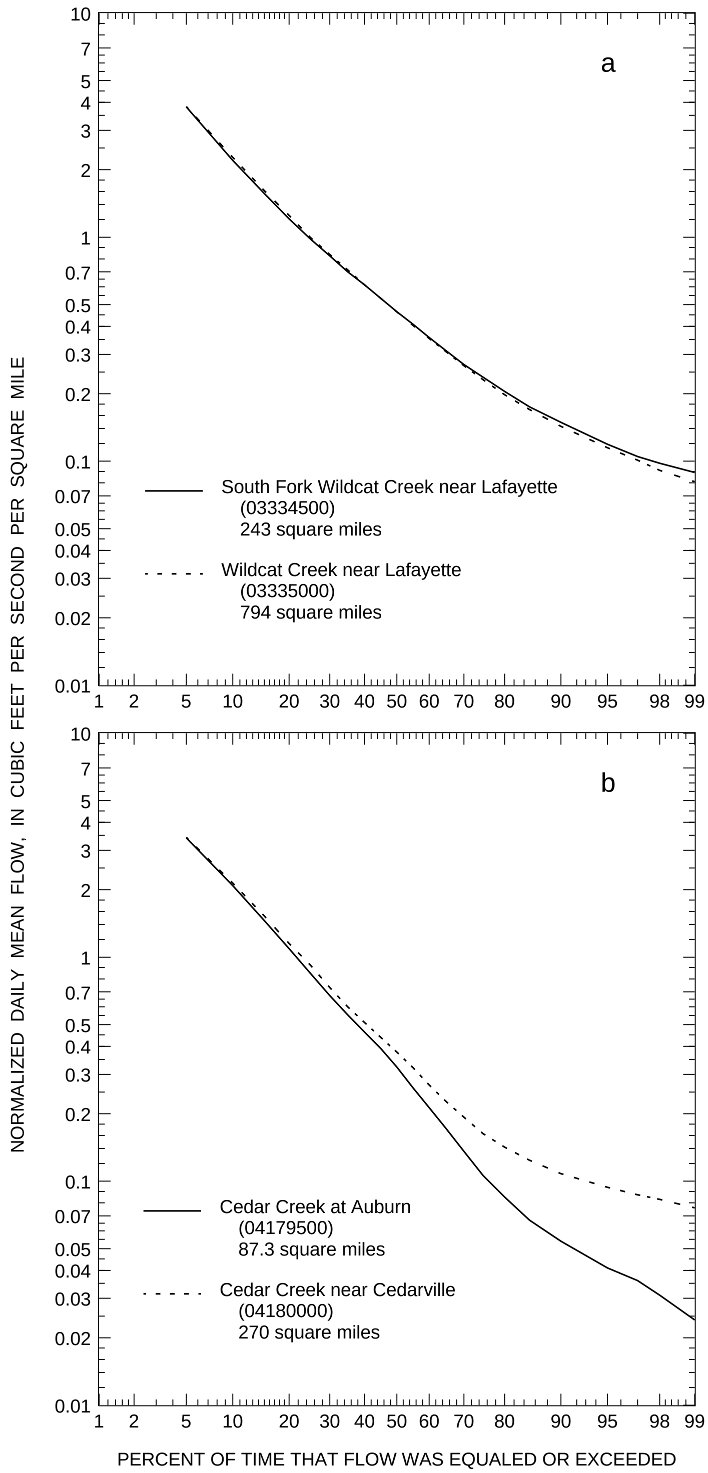


Figure 20. Flow-duration curves for (a) a pair of streamflow-gaging stations in Indiana with similar base-flow-recession characteristics and (b) a pair of streamflow-gaging stations in Indiana with different base-flow-recession characteristics.

for the two stations in figure 20b are different, 20.3 for Auburn and 10.7 for Cedarville. A map of flow-duration ratios, like that presented in Arihood and Glatfelter (1991), is helpful for selecting index stations with base-flow-recession characteristics similar to the partial-record station. By plotting the location of the partial-record station, one could look for potential index stations within the same subarea or in an adjacent subarea with a similar flow-duration ratio.

Some of the error in estimating low-flow frequencies for the sites on Cedar Creek may be attributed to the relatively small values of $7Q_{10}$ and $7Q_2$ for Cedar Creek at Auburn (pair 20, table 3). In three of the four instances ($7Q_{10}$ and $7Q_2$ for Test Cases A and B), however, the difference between the predicted and observed low-flow frequency was significantly larger for the Cedar Creek stations than for the Wildcat Creek stations. The Cedar Creek stations have a much smaller difference in drainage area (table 3), but the Wildcat Creek stations are closer to each other (fig. 1).

Correlation coefficients (coefficient of determination) for the linear regression part of the method are included in tables 3 to 7. There was no apparent relation between the relative error of estimate and the correlation coefficient; however, not many of the test pairs had correlation coefficients below 0.70. Stedinger and Thomas (1985) recommended that the correlation coefficient exceed 0.70. The average correlation coefficient for Test Cases A and B was about 0.88, with a minimum of 0.64. The average correlation coefficient for Test Cases C and D was about 0.84, with a minimum of 0.50. Test pairs with low correlation coefficients were just as likely to produce accurate estimates of the low-flow frequencies (for example, test pair 7 in table 4 and test pair 9 in table 6).

Varying the Number of Base-Flow Measurements

In previous sections of this report, the Stedinger-Thomas method is evaluated for a variety of test conditions, with the number of base-flow measurements held constant at 20. As previously mentioned, most low-flow investigations will not have 20 base-flow measurements with which to work. In this section, the number of base-flow measurements is varied to see how the accuracy of low-flow-frequency estimates is affected. Because the Stedinger-Thomas method includes a linear regression, it is recommended that at least 10 measurements be used (W.O. Thomas, Jr., and others, U.S. Geological Survey, written commun., 1993). The automated method, however, will work with less than 10 measurements. Also, for practical application of low-flow investigations, many sites may not have 10 base-flow measurements available. Riggs (1972) indicated that, generally, 8 to 10 measurements made on different streamflow recessions and in more than 1 year should define the relation to concurrent flows at the index station. A study of estimating low-flow characteristics ($7Q_{10}$) in Massachusetts and Rhode Island indicated that using more than six or eight base-flow measurements added little confidence to the estimates (Tasker, 1975).

A subset of 10 station pairs was selected from each of the five test cases. These subsets were made up of station pairs that had a low relative error for the original test cases that used 20 base-flow measurements. The low-flow frequencies then were estimated, with the number of base-flow measurements reduced to 15, then 10, and finally 5. Each test started with a scatter plot of the original 20 base-flow measurements plotted against the concurrent daily flows at the index station. Measurements then were dropped from the data set while trying to maintain a linear relation between the base-flow measurements and the daily flows. The predicted values of $7Q_{10}$ and $7Q_2$ and the relative errors of estimate for each pair of stations are listed in tables 9 to 18.

Boxplots of the relative error of estimate were used to illustrate the performance of the Stedinger-Thomas method when the number of base-flow measurements was varied (figs. 21 and 22). Figure 21 shows the relative error in predicted values of $7Q_{10}$ for all five test cases, and figure 22 shows the relative error of predicted values of $7Q_2$ (n=10 for all test cases). In Case A, the method tended to over predict the $7Q_{10}$ and the $7Q_2$ when the original 20 measurements were used (the

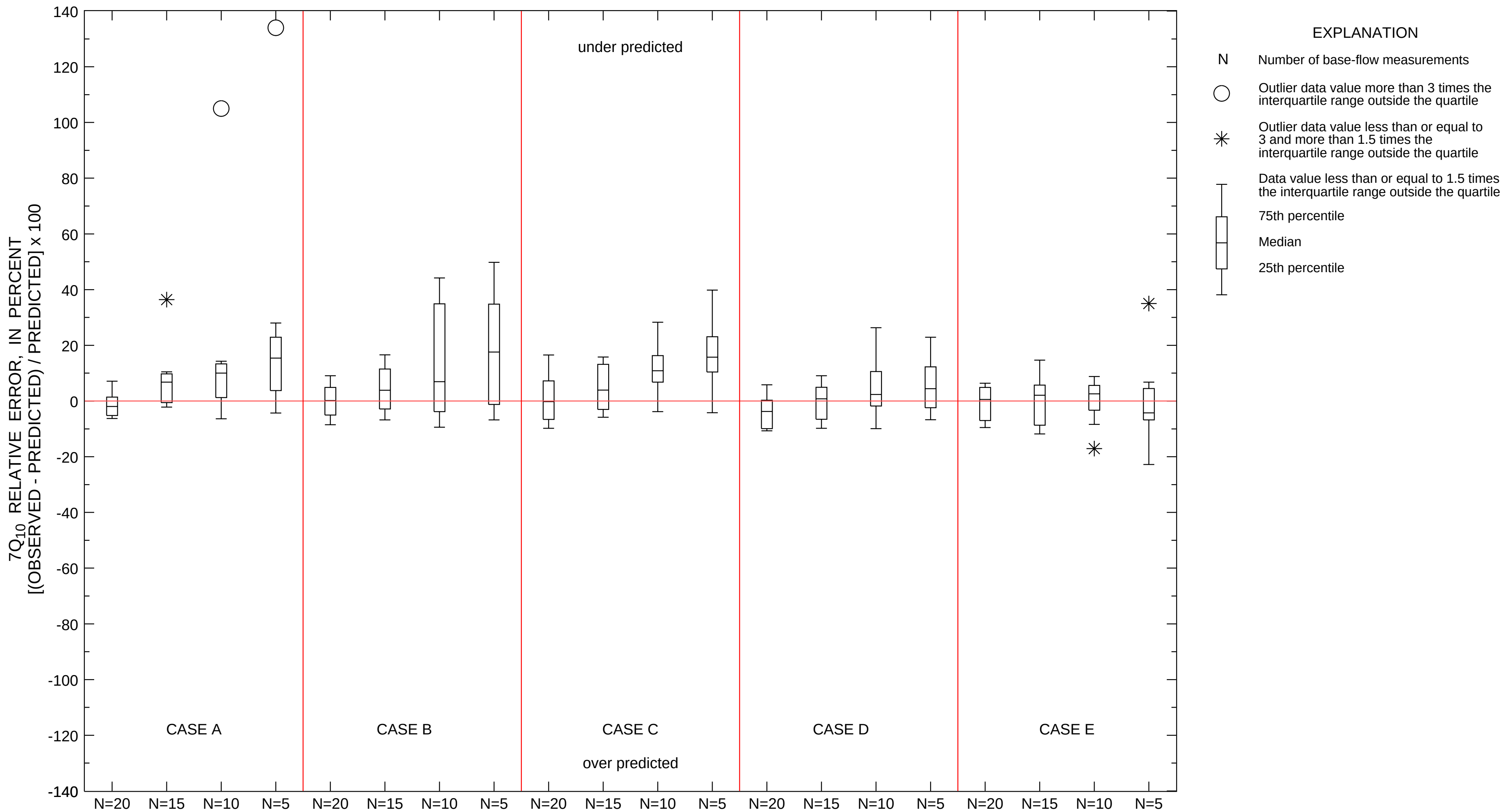


Figure 21. Relative error in predicted values of $7Q_{10}$ for Indiana streams, using the Stedinger-Thomas method, with the number of base-flow measurements varied.

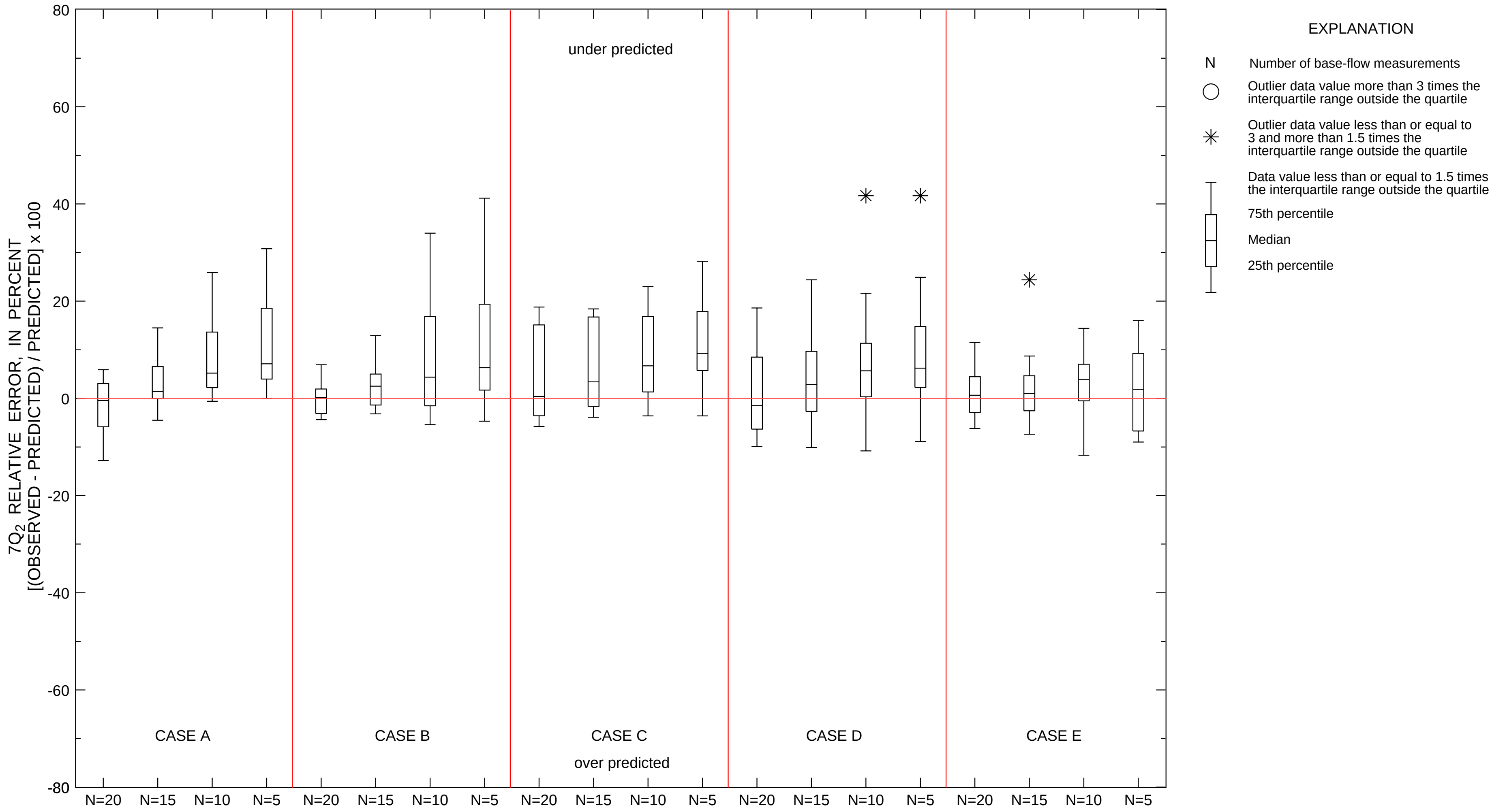


Figure 22. Relative error in predicted values of $7Q_2$ for Indiana streams, using the Stedinger-Thomas method, with the number of base-flow measurements varied.

median value in the boxplots can be used as a reference). As the number of measurements was reduced, the method predicted smaller values of $7Q_{10}$ (table 9) and $7Q_2$ (table 10). In Case B, there was the same trend to predict increasingly smaller values as the number of measurements was reduced from 20 to 5 (tables 11 and 12). As the median and average relative error increased with decreasing number of measurements in Cases A and B, so did the variability.

Case C (tables 13 and 14) and Case D (tables 15 and 16) show the same trends as Cases A and B—on average, the method tends to predict smaller values of $7Q_{10}$ and $7Q_2$ as the number of measurements decreases. This tendency is probably the result of the changing slope in the linear-regression part of the method. As more measurements are dropped from the analysis, the regression line is influenced more by each measurement. With 15 or 20 measurements, the regression line is influenced more by an averaging effect.

In Case E, the method did not consistently predict smaller low-flow frequencies as the number of measurements decreased. The method tended to under predict the $7Q_{10}$ when 20, 15, or 10 measurements were used; when 5 measurements were used, the method tended to over predict the $7Q_{10}$ (table 17). In Case E, the method tended to under predict the $7Q_2$, regardless of the number of measurements used; there was not much change in the median, average, or variability in the relative error as the number of measurements was reduced (table 18).

Summary and Conclusions

A mathematical technique of estimating low-flow frequencies at partial-record stations was evaluated, using streams in Indiana. The Stedinger-Thomas method estimates low-flow frequencies at low-flow partial-record stations by relating base-flow measurements to daily flows at a nearby streamflow-gaging station (index station) for which a low-flow-frequency curve has been developed. A least-squares-regression analysis of the logarithms of flows is used to define the relation between base-flow measurements at the partial-record station and concurrent daily flows at the index station. The regression analysis and low-flow statistics (moments) at the index station are used to predict the desired low-flow frequency at the partial-record station.

A network of long-term streamflow-gaging stations in Indiana provided a sample of sites with observed low-flow frequencies. Observed values of the 7-day, 10-year low flow ($7Q_{10}$) and 7-day, 2-year low flow ($7Q_2$) were compared to values predicted with the Stedinger-Thomas method to evaluate the accuracy of the method. Streamflow-gaging stations were paired for each analysis—one station was treated as a partial-record station with base-flow measurements, and the other station was treated as the index station. Low-flow frequencies for each pair of streamflow-gaging stations were based on a common period of record.

Five test cases were used to evaluate the Stedinger-Thomas method under a variety of conditions. In four test cases, the location of the index station was varied to evaluate the effect of differences in drainage area and the effect of using an index station on a different stream or drainage basin. The fifth test case evaluated the effectiveness of using two index stations. A total of 141 pairs of streamflow-gaging stations were used in the five test cases.

The most accurate and least variable results were produced when two index stations on the same stream or tributaries of the partial-record station were used (Test Case E). All but one value of the predicted $7Q_{10}$ were within 15 percent of the values observed for the long-term continuous record. The relative error of the predicted $7Q_{10}$ ranged from -9.5 percent to 20.8 percent, with a median of 2.9 percent (a positive value of relative error indicates that the predicted flow is lower than the observed flow). All of the predicted values of $7Q_2$ were within 15 percent of the observed values. The relative error of the predicted $7Q_2$ ranged from -6.2 percent to 11.5 percent, with a median of 1.3 percent. This apparent accuracy and small variability may be a result of the small sample set of 15 that included only a few stations with low-flow frequencies less than 10 ft^3/s.

Of the four test cases that used one index station, the most accurate and least variable results were produced when the index station and partial-record station were on the same stream or streams tributary to each other and when the index station had a larger drainage area than did the partial-record station (Test Case A). In this case, the method tended to over predict the low-flow frequencies, based on the median relative error. In 23 of 28 test pairs, the predicted $7Q_{10}$ was within 15 percent of the observed value. The relative error of the predicted $7Q_{10}$ ranged from -28.0 percent to 47.6 percent, with a median of -4.0 percent. In 26 of 28 test pairs, the predicted $7Q_2$ was within 15 percent of the observed value. The relative error of the predicted $7Q_2$ ranged from -16.4 percent to 15.8 percent, with a median of -1.4 percent.

When the index station was on the same stream or a tributary of the partial-record station and had a smaller drainage area than the partial-record station (Test Case B), the method tended to under predict the low-flow frequencies. Nineteen of 28 predicted values of $7Q_{10}$ were within 15 percent of the observed values. The relative error of estimate ranged from -12.8 percent to 55.1 percent, with a median of 5.6 percent. Twenty-five of 28 predicted values of $7Q_2$ were within 15 percent of the observed values. The relative error of estimate ranged from -8.6 percent to 31.1 percent, with a median of 1.2 percent.

When the index station and the partial-record station were on different streams (Test Cases C and D), the method tended to under predict regardless of whether the index station had a larger or smaller drainage area than that of the partial-record station. Also, the variability of the relative error of estimate was much higher for the test cases that used index stations and partial-record stations on different streams. When the index station had a larger drainage area than that of the partial-record station (Test Case C), 15 of 35 predicted values of $7Q_{10}$ were within 15 percent of the observed values. The relative error of estimate ranged from -40.0 percent to 150 percent, with a median of 5.7 percent. Nineteen of 35 predicted values of $7Q_2$ were within 15 percent of the observed values. The relative error of estimate ranged from -34.1 percent to 96.1 percent, with a median of 6.2 percent.

When the index station and partial-record station were on different streams and the index station had a smaller drainage area than that of the partial-record station (Test Case D), 18 of 35 predicted values of $7Q_{10}$ were within 15 percent of the observed values. The relative error of estimate ranged from -28.6 percent to 123 percent, with a median of 0.0 percent. In 25 of 35 test pairs, the predicted $7Q_2$ was within 15 percent of the observed value. The relative error of estimate ranged from -16.6 percent to 81.8 percent, with a median of 2.1 percent.

The only characteristic that showed some relation with the relative error of estimate was the size of the observed low-flow-frequency value at the partial-record station or the index station. There was not a direct, or linear, relation but a small low-flow-frequency value often was associated with the largest relative errors of estimate. This is partly a result of the simple mathematics of computing the relative error or of a reduced accuracy in the measurement of streamflow and computation of streamflow records at very low flows.

In the test cases that used one index station, the Stedinger-Thomas method tended to predict smaller low-flow frequencies as the number of base-flow measurements was reduced from 20 to 5. In most of these cases, the variability of the predicted values also increased as the number of base-flow measurements was reduced.

References Cited

Arihood, L.D., and Glatfelter, D.R., 1991, Method for estimating low-flow characteristics of ungaged streams in Indiana: U.S. Geological Survey Water-Supply Paper 2372, 18 p.

Fowler, K.K., and Wilson, J.T., 1996, Low-flow characteristics of Indiana streams: U.S. Geological Survey Water-Resources Investigations Report 96-4128, 313 p.

Riggs, H.C., 1968, Frequency curves: Techniques of water-resources investigations of the United States Geological Survey, book 4, chap. A2, 15 p.

_____1972, Low-flow investigations: Techniques of water-resources investigations of the United States Geological Survey, book 4, chap. B1, 18 p.

Stedinger, J.R., and Thomas, W.O., Jr., 1985, Low-flow frequency estimation using base-flow measurements: U.S. Geological Survey Open-File Report 85-95, 22 p.

Stewart, J.A., Keeton, C.R., Hammill, L.E., Nguyen, H.T., and Majors, D.K., 1999, Water resources data—Indiana—water year 1998: U.S. Geological Survey Water-Data Report IN-98-1, 452 p.

Tasker, G.D., 1975, Combining estimates of low-flow characteristics of streams in Massachusetts and Rhode Island: Journal of Research of the U.S. Geological Survey, v. 3, no. 1, p. 107–112.

Data Tables

Table 2. Streamflow-gaging stations in Indiana used to evaluate the Stedinger-Thomas method of estimating low-flow frequencies at partial-record sites, using base-flow measurements

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; $7Q_{10}$ and $7Q_2$ are for the period of record through 1993, from Fowler and Wilson, 1996; ft^3/s, cubic feet per second; c, current year as of September 1998—these stations were still active as of September 1998 (Stewart and others, 1999)]

Station number	Station name	Drainage area (square miles)	Period of record[1]	$7Q_{10}$ (ft^3/s)	$7Q_2$ (ft^3/s)
03274650	Whitewater River near Economy	10.4	1970-c	0.3	0.6
03274750	Whitewater River near Hagerstown	58.7	1970-c	7.6	13
03275000	Whitewater River near Alpine	529	1928-c	51	86
03275500	East Fork Whitewater River at Richmond	121	1949-78	4.2	10
03275600	East Fork Whitewater River at Abington	200	1965-c	18	30
03322500	Wabash River near New Corydon	262	1951-88	2.3	5.9
03322900	Wabash River at Linn Grove	453	1964-c	5.6	11
03324000	Little River near Huntington	263	1943-c	4.4	12
03324200	Salamonie River at Portland	85.6	1959-93	1.0	1.9
03324300	Salamonie River near Warren	425	1957-c	7.6	15
03325500	Mississinewa River near Ridgeville	133	1946-c	1.2	3.5
03326000	Mississinewa River near Eaton	310	1952-71	2.9	6.6
03326070	Big Lick Creek near Hartford City	29.2	1971-c	.5	1.0
03326500	Mississinewa River at Marion	682	1923-c	19	38
03327520	Pipe Creek near Bunker Hill	159	1968-c	4.9	9.1
03328000	Eel River at North Manchester	417	1929-c	37	59
03328430	Weesau Creek near Deedsville	8.87	1970-c	.4	.8
03328500	Eel River near Logansport	789	1943-c	100	145
03329700	Deer Creek near Delphi	274	1943-c	12	23
03334000	Wildcat Creek at Owasco	396	1943-73, 88-c	19	34
03334500	South Fork Wildcat Creek near Lafayette	243	1943-c	20	30
03335000	Wildcat Creek near Lafayette	794	1954-c	60	98
03335500	Wabash River at Lafayette	7,267	1969-c	868	1,320
03336000	Wabash River at Covington	8,218	1969-c	1,040	1,580
03339500	Sugar Creek at Crawfordsville	509	1938-c	8.0	24
03340000	Sugar Creek near Byron	670	1940-71	22	45
03340500	Wabash River at Montezuma	11,118	1969-c	1,210	1,970
03340800	Big Raccoon Creek near Fincastle	139	1957-c	2.4	6.8
03341200	Little Raccoon Creek near Catlin	133	1957-71	4.6	7.1
03341500	Wabash River at Terre Haute	12,263	1969-c	1,390	2,300
03348000	White River at Anderson	406	1931-93	28	58
03348020	Killbuck Creek near Gaston	25.5	1968-91	1.1	2.5
03348350	Pipe Creek at Frankton	113	1968-c	4.3	7.9
03349000	White River at Noblesville	858	1946-c	81	122
03350700	Stony Creek near Noblesville	50.8	1967-c	2.9	6.1
03351500	Fall Creek near Fortville	169	1941-c	15	28
03352200	Mud Creek at Indianapolis	42.4	1958-76	.5	2.0
03353120	Pleasant Run at Arlington Avenue at Indianapolis	7.58	1959-c	.1	.4
03353180	Bean Creek at Indianapolis	4.40	1970-93	.6	1.0
03353620	Lick Creek at Indianapolis	15.6	1970-c	.2	1.0
03357500	Big Walnut Creek near Reelsville	326	1949-c	4.5	19
03358000	Mill Creek near Cataract	245	1949-c	1.7	7.5

Table 2. Streamflow-gaging stations in Indiana used to evaluate the Stedinger-Thomas method of estimating low-flow frequencies at partial-record sites, using base-flow measurements—Continued

Station number	Station name	Drainage area (square miles)	Period of record[1]	$7Q_{10}$ (ft^3/s)	$7Q_2$ (ft^3/s)
03359500	Deer Creek near Putnamville	59.0	1954-65, 67-72	0.1	0.6
03361000	Big Blue River at Carthage	184	1950-c	27	47
03361500	Big Blue River at Shelbyville	421	1943-c	40	66
03362000	Youngs Creek near Edinburgh	107	1942-c	1.5	3.4
03362500	Sugar Creek near Edinburgh	474	1942-c	20	40
03363000	Driftwood River near Edinburgh	1,060	1940-92	94	151
03363500	Flatrock River at St. Paul	303	1930-c	2.3	11
03363900	Flatrock River at Columbus	534	1967-c	31	58
03364000	East Fork White River at Columbus	1,707	1947-c	133	230
03364200	Haw Creek near Clifford	47.5	1967-91	.6	1.7
03365500	East Fork White River at Seymour	2,341	1927-c	172	285
03371500	East Fork White River near Bedford	3,861	1939-c	258	443
03373500	East Fork White River at Shoals	4,927	1923-c	265	464
04094000	Little Calumet River at Porter	66.2	1945-c	21	25
04094500	Salt Creek near McCool	74.6	1945-91	19	26
04095300	Trail Creek at Michigan City	54.1	1969-94	24	30
04096100	Galena River near LaPorte	17.2	1969-c	8.1	9.8
04099510	Pigeon Creek near Angola	106	1945-c	7.1	15
04099750	Pigeon River near Scott	361	1968-c	89	127
04099808	Little Elkhart River at Middlebury	97.6	1979-c	30	40
04100252	Forker Creek near Burr Oak	19.2	1969-c	.2	.6
04100295	Rimmell Branch near Albion	10.7	1979-c	.2	.4
04100500	Elkhart River at Goshen	594	1931-c	85	139
04178000	St. Joseph River near Newville	610	1946-c	20	39
04179500	Cedar Creek at Auburn	87.3	1943-73	1.8	3.8
04180000	Cedar Creek near Cedarville	270	1946-c	21	29
04182590	Harber Ditch at Fort Wayne	21.9	1964-91	.1	.3
05515000	Kankakee River near North Liberty	174	1951-c	57	71
05515400	Kingsbury Creek near LaPorte	7.08	1970-86	1.2	1.9
05515500	Kankakee River at Davis	537	1924-c	189	257
05516000	Yellow River near Bremen	135	1955-73	6.3	9.0
05516500	Yellow River at Plymouth	294	1948-c	21	33
05517000	Yellow River at Knox	435	1943-c	76	106
05517500	Kankakee River at Dunns Bridge	1,352	1948-c	348	476
05517530	Kankakee River near Kouts	1,376	1974-c	381	507
05518000	Kankakee River at Shelby	1,779	1922-c	417	574
05519000	Singleton Ditch at Schneider	123	1948-c	7.4	15
05519500	West Creek near Schneider	54.7	1948-51, 54-72	4.6	6.9
05522000	Iroquois River near North Marion	144	1948-93	4.4	11
05522500	Iroquois River at Rensselaer	203	1948-c	5.9	14
05524500	Iroquois River near Foresman	449	1948-c	11	24

[1]Wabash River stations downstream from Huntington Reservoir are partially regulated by upstream reservoirs. Low-flow statistics are calculated for the regulated period, 1969–93. The period of record shown does not include the years prior to 1969.

Table 3. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case A—the paired stations are on the same stream or tributaries, and the drainage area at the index station is greater than at the partial-record station

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; ft^3/s, cubic feet per second; R^2, coefficient of determination or fraction of the variance explained by a regression of the base-flow measurements with the concurrent daily flows at the index station]

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
1	03274650	03274750	48.3	22	1972-93	0.21	0.31	47.6	0.57	0.6	5.3	0.86
2	03274750	03275000	470	22	1972-93	8.0	7.6	-5.0	13.2	12.9	-2.3	.96
3	03275500	03275600	79.0	12	1967-78	7.6	7.3	-3.9	13.2	12.6	-4.5	.87
4	03322500	03322900	191	23	1966-88	4.0	4.0	0	6.2	5.9	-4.8	.87
5	03324200	03324300	339	33	1961-93	1.0	1.0	0	2.0	1.9	-5.0	.80
6	03325500	03326000	177	19	1953-71	.96	.86	-10.4	2.4	2.7	12.5	.81
7	03328000	03328500	372	49	1945-93	42.1	42.2	.2	62.2	63.1	1.4	.69
8	03334500	03335000	551	38	1956-93	19.9	20.2	1.5	31.9	31.2	-2.2	.86
9	03335500	03336000	951	23	1971-93	827	868	5.0	1,270	1,318	3.8	.90
10	03339500	03340000	161	30	1942-71	7.7	6.7	-13.0	21.2	20.0	-5.7	.95
11	03340500	03341500	1,145	23	1971-93	1,217	1,208	-.7	2,012	1,972	-2.0	.94
12	03348000	03349000	452	46	1948-93	42.8	40.4	-5.6	64.4	64.2	-.3	.89
13	03361000	03361500	237	45	1949-93	28.4	26.6	-6.3	43.9	46.5	5.9	.88
14	03362000	03362500	367	42	1952-93	1.4	1.5	7.1	3.9	3.4	-12.8	.84
15	03362500	03363000	586	50	1944-93	21.6	20.3	-6.0	38.4	39.8	3.6	.96
16	03363500	03363900	231	49	1944-92	3.6	4.9	36.1	15.2	17.6	15.8	.80
17	03364000	03365500	634	25	1969-93	152	133	-12.5	232	230	-.9	.96
18	03371500	03373500	1,066	38	1956-93	273	258	-5.5	432	443	2.5	.95
19	04099510	04099750	255	24	1970-93	10.0	9.6	-4.0	17.7	18.2	2.8	.85
20	04179500	04180000	183	26	1948-73	2.5	1.8	-28.0	4.2	3.8	-9.5	.85

Table 3. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case A—the paired stations are on the same stream or tributaries, and the drainage area at the index station is greater than at the partial-record station—Continued

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
21	05515000	05515500	363	42	1952-93	65.0	56.6	-12.9	85.2	71.2	-16.4	0.87
22	05515400	05515500	530	15	1972-86	1.2	1.2	0	1.7	1.9	11.8	.91
23	05516000	05516500	159	17	1957-73	4.7	6.3	34.0	8.8	9.0	2.3	.91
24	05516500	05517000	141	44	1950-93	22.1	20.8	-5.9	36.5	33.2	-9.0	.94
25	05517530	05518000	403	18	1976-93	391	381	-2.6	558	507	-9.1	.94
26	05522000	05522500	59.0	44	1950-93	4.4	4.4	0	10.5	10.7	1.9	.98
27	05522000	05524500	305	44	1950-93	5.7	4.4	-22.8	11.8	10.7	-9.3	.96
28	05522500	05524500	246	44	1950-93	7.0	6.0	-14.3	14.5	13.9	-4.1	.97
Average			**382**	**32**			**112**	**-1.0**		**177**	**-1.0**	**.89**
Standard deviation			**286**	**12**			**279**	**16.2**		**442**	**7.5**	**.07**
Median			**322**	**32**			**7.45**	**-4.0**		**17.9**	**-1.4**	**.89**
Minimum			**48.3**	**12**			**.31**	**-28.0**		**.6**	**-16.4**	**.69**
Maximum			**1,145**	**50**			**1,208**	**47.6**		**1,972**	**15.8**	**.98**

[1]Predicted $7Q_{10}$ and $7Q_2$ were estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[2]Observed $7Q_{10}$ and $7Q_2$ were determined by frequency analysis of the annual 7-day low flows for the period of record shown.

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 4. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case B—the paired stations are on the same stream or tributaries, and the drainage area at the index station is less than at the partial-record station

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; ft^3/s, cubic feet per second; R^2, coefficient of determination or fraction of the variance explained by a regression of the base-flow measurements with the concurrent daily flows at the index station]

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
1	03274750	03274650	48.3	22	1972-93	8.5	7.6	-10.6	13.0	12.9	-.8	0.91
2	03275000	03274750	470	22	1972-93	47.7	62.5	31.0	88.2	102	15.6	.94
3	03275600	03275500	79.0	12	1967-78	15.5	19.3	24.5	26.6	29.7	11.7	.85
4	03322900	03322500	191	23	1966-88	6.1	6.2	1.6	9.4	9.9	5.3	.67
5	03324300	03324200	339	33	1961-93	8.6	7.5	-12.8	16.3	14.9	-8.6	.78
6	03326000	03325500	177	19	1953-71	2.4	2.9	20.8	6.9	6.6	-4.3	.77
7	03328500	03328000	372	49	1945-93	95.5	100	4.7	145	145	0	.64
8	03335000	03334500	551	38	1956-93	65.0	59.5	-8.5	97.2	98.0	.8	.77
9	03336000	03335500	951	23	1971-93	1,092	1,040	-4.8	1,598	1,584	-.9	.96
10	03340000	03339500	161	30	1942-71	16.6	21.9	31.9	40.0	45.2	13.0	.95
11	03341500	03340500	1,145	23	1971-93	1,429	1,393	-2.5	2,299	2,305	.3	.97
12	03349000	03348000	452	46	1948-93	85.4	80.5	-5.7	126	122	-3.2	.78
13	03361500	03361000	237	42	1952-93	33.2	40.4	21.7	67.6	67.0	-.9	.92
14	03362500	03362000	367	50	1944-93	17.0	20.5	20.6	30.9	40.5	31.1	.84
15	03363000	03362500	586	49	1944-92	91.7	93.2	1.6	159	152	-4.4	.95
16	03363900	03363500	231	25	1969-93	29.5	30.6	3.7	58.8	58.4	-.7	.85
17	03365500	03364000	634	45	1949-93	175	191	9.1	298	303	1.7	.94
18	03373500	03371500	1,066	38	1956-93	347	333	-4.0	562	536	-4.6	.93
19	04099750	04099510	255	24	1970-93	90.5	89.3	-1.3	131	127	-3.1	.91
20	04180000	04179500	183	26	1948-73	12.7	19.7	55.1	23.8	27.3	14.7	.87

Table 4. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case B—the paired stations are on the same stream or tributaries, and the drainage area at the index station is less than at the partial-record station—Continued

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
21	05515500	05515000	363	42	1952-93	184	195	6.0	230	263	14.3	0.92
22	05515500	05515400	530	15	1972-86	218	239	9.6	279	286	2.5	.80
23	05516500	05516000	159	17	1957-73	20.4	17.9	-12.3	28.9	30.2	4.5	.76
24	05517000	05516500	141	44	1950-93	72	75.8	5.3	101	108	6.9	.94
25	05518000	05517530	403	18	1976-93	405	441	8.9	568	655	15.3	.94
26	05522500	05522000	59.0	44	1950-93	5.5	6.0	9.1	13.8	13.9	.7	.98
27	05524500	05522000	305	44	1950-93	7.8	10.8	38.5	22.4	24.1	7.6	.96
28	05524500	05522500	246	44	1950-93	8.4	10.8	28.6	21.7	24.1	11.1	.98
Average							**165**	**9.6**		**257**	**4.5**	**.87**
Standard deviation							**319**	**16.8**		**511**	**8.7**	**.09**
Median							**50.0**	**5.6**		**82.5**	**1.2**	**.91**
Minimum							**2.9**	**-12.8**		**6.6**	**-8.6**	**.64**
Maximum							**1,393**	**55.1**		**2,305**	**31.1**	**.98**

[1]Predicted $7Q_{10}$ and $7Q_2$ were estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[2]Observed $7Q_{10}$ and $7Q_2$ were determined by frequency analysis of the annual 7-day low flows for the period of record shown.

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 5. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case C—the paired stations are on different streams or basins, and the drainage area at the index station is greater than at the partial-record station

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; ft^3/s, cubic feet per second; R^2, coefficient of determination or fraction of the variance explained by a regression of the base-flow measurements with the concurrent daily flows at the index station]

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
1	03274750	03275600	141	22	1972-93	9.5	7.6	-20.0	14.8	12.9	-12.8	0.88
2	03275600	03275000	329	27	1967-93	15.8	18.4	16.5	25.5	30.3	18.8	.95
3	03324200	03322500	176	28	1961-88	.51	.98	92.2	1.3	1.8	38.5	.86
4	03324200	03325500	47.4	33	1961-93	.48	1.0	108	1.2	1.9	58.3	.78
5	03324300	03322900	28.0	28	1966-93	8.7	7.9	-9.2	15.4	16.2	5.2	.93
6	03324300	03326500	257	36	1958-93	6.8	7.6	11.8	12.9	15.0	16.3	.86
7	03326070	03324200	56.4	21	1973-93	.22	.48	118	.51	1.0	96.1	.94
8	03327520	03329700	115	24	1970-93	3.3	4.9	48.5	7.0	9.1	30.0	.88
9	03328430	03328000	408	22	1972-93	.47	.39	-17.0	.87	.75	-13.8	.77
10	03329700	03334000	122	33	1945-77	10.4	10.3	-1.0	18.7	21.3	13.9	.91
11	03334500	03334000	153	33	1945-77	12.7	18.9	48.8	24.0	28.5	18.8	.79
12	03340800	03339500	370	35	1959-93	1.5	2.4	60.0	4.7	6.8	44.7	.91
13	03341200	03340800	6.0	13	1959-71	5.1	4.6	-9.8	7.3	7.1	-2.7	.84
14	03348020	03348350	87.5	23	1970-92	1.1	1.1	0	2.4	2.5	4.2	.79
15	03348350	03348000	293	24	1970-93	3.1	4.3	38.7	6.4	7.9	23.4	.82
16	03350700	03351500	118	25	1969-93	2.2	2.9	31.8	5.2	6.1	17.3	.93
17	03352200	03351500	127	17	1960-76	.66	.46	-30.3	1.9	2.0	5.3	.89
18	03353180	03353120	3.18	22	1972-93	.6	.65	8.3	1.0	1.0	0	.59
19	03353180	03353620	11.2	22	1972-93	.44	.65	47.7	.9	1.0	11.1	.92
20	03358000	03357500	81.0	43	1951-93	2.0	1.7	-15.0	7.1	7.5	5.6	.89

Table 5. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case C—the paired stations are on different streams or basins, and the drainage area at the index station is greater than at the partial-record station—Continued

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
21	03359500	03357500	267	14	1956-72	0.2	0.12	-40.0	0.68	0.6	-11.8	0.82
22	03359500	03358000	186	14	1956-72	.19	.12	-36.8	.91	.6	-34.1	.84
23	03361500	03362500	53.0	49	1945-93	40.2	40.4	.5	69.6	65.7	-5.6	.88
24	03363900	03363000	526	24	1969-92	32.1	30.0	-6.5	49.7	57.0	14.7	.81
25	03364200	03363900	486	23	1969-91	.79	.63	-20.3	2.3	1.7	-26.1	.90
26	04094000	04094500	8.4	45	1947-91	19.4	20.5	5.7	25.0	25.0	0	.80
27	04096100	04095300	36.9	23	1971-93	8.7	8.1	-6.9	10.4	9.8	-5.8	.91
28	04099808	04099750	263	13	1981-93	29.0	30.1	3.8	39.7	40.0	.8	.95
29	04099808	04100500	496	13	1981-93	30.7	30.1	-2.0	41.2	40.0	-2.9	.74
30	04100295	04100252	8.5	12	1982-93	.11	.21	90.9	.26	.37	42.3	.96
31	04179500	04178000	523	26	1948-73	1.6	1.8	12.5	3.1	3.8	22.6	.82
32	04180000	04178000	340	46	1948-93	16.6	20.9	25.9	27.5	29.2	6.2	.77
33	04182590	03324000	241	26	1966-91	.04	.1	150	.15	.28	86.7	.92
34	05515400	05515000	167	15	1972-86	.99	1.2	21.2	1.4	1.9	35.7	.72
35	05519500	05519000	68.3	20	1950-69	4.8	4.6	-4.2	7.2	6.9	-4.2	.79
Average			**188**	**25**			**8.2**	**20.6**		**13.2**	**14.2**	**.85**
Standard deviation			**162**	**10**			**10.9**	**45.5**		**16.7**	**27.6**	**.08**
Median			**141**	**24**			**2.9**	**5.7**		**6.9**	**6.2**	**.86**
Minimum			**3.18**	**12**			**.1**	**-40.0**		**.28**	**-34.1**	**.59**
Maximum			**526**	**49**			**40.4**	**150**		**65.7**	**96.1**	**.96**

[1]Predicted $7Q_{10}$ and $7Q_2$ were estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[2]Observed $7Q_{10}$ and $7Q_2$ were determined by frequency analysis of the annual 7-day low flows for the period of record shown.

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 6. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case D—the paired stations are on different streams or basins, and the drainage area at the index station is less than at the partial-record station

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; ft^3/s, cubic feet per second; R^2, coefficient of determination or fraction of the variance explained by a regression of the base-flow measurements with the concurrent daily flows at the index station]

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
1	03275600	03274750	141	22	1972-93	12.6	17.5	38.9	25.0	29.2	16.8	0.93
2	03275000	03275600	329	27	1967-93	69.8	62.3	-10.7	109	103	-5.5	.91
3	03322500	03324200	176	28	1961-88	3.5	2.5	-28.6	6.4	5.8	-9.4	.70
4	03325500	03324200	47.4	33	1961-93	.98	1.7	73.5	3.2	3.9	21.9	.60
5	03322900	03324300	28.0	28	1966-93	3.5	5.6	60.0	9.2	10.5	14.1	.95
6	03326500	03324300	257	36	1958-93	28.6	25.8	-9.8	50.3	46.6	-7.4	.87
7	03324200	03326070	56.4	21	1973-93	.91	1.2	31.9	2.3	2.3	0	.98
8	03329700	03327520	115	24	1970-93	14.5	17.0	17.2	25.7	27.3	6.2	.75
9	03328000	03328430	408	22	1972-93	52.4	50.6	-3.4	68.4	69.1	1.0	.50
10	03334000	03329700	122	33	1945-77	21.1	19.1	-9.5	37.5	33.8	-9.9	.91
11	03334000	03334500	153	33	1945-77	23.6	19.1	-19.1	36.0	33.8	-6.1	.81
12	03339500	03340800	370	35	1959-93	12.7	11.8	-7.1	28.9	28.3	-2.1	.54
13	03340800	03341200	6.0	13	1959-71	2.5	2.4	-4.0	4.3	5.1	18.6	.87
14	03348350	03348020	87.5	23	1970-92	3.6	4.2	16.7	7.5	7.6	1.3	.86
15	03348000	03348350	293	24	1970-93	54.5	43.6	-20.0	78.1	73.9	-5.4	.91
16	03351500	03350700	118	25	1969-93	19.1	17.1	-10.5	40.3	33.6	-16.6	.86
17	03351500	03352200	127	17	1960-76	14.2	15.9	12.0	25.3	27.0	6.7	.75
18	03353120	03353180	3.18	22	1972-93	.13	.29	123	.37	.51	37.8	.84
19	03353620	03353180	11.2	22	1972-93	.14	.26	85.7	.55	1.0	81.8	.89
20	03357500	03358000	81.0	43	1951-93	5.3	5.7	7.5	20.6	19.2	-6.8	.89

Table 6. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case D—the paired stations are on different streams or basins, and the drainage area at the index station is less than at the partial-record station—Continued

Pair	Partial-record station	Index station	Drainage-area difference (square miles)	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
21	03357500	03359500	267	14	1956-72	4.4	5.6	27.3	13.5	14.9	10.4	0.91
22	03358000	03359500	186	14	1956-72	1.0	1.9	90.0	3.8	5.9	55.3	.80
23	03362500	03361500	53.0	49	1945-93	20.4	20.4	0	35.2	40.6	15.3	.87
24	03363000	03363900	526	24	1969-92	107	105	-1.9	184	173	-6.0	.91
25	03363900	03364200	486	23	1969-91	27.4	31.1	13.5	48.9	59.0	20.7	.91
26	04094500	04094000	8.4	45	1947-91	21.6	19.4	-10.2	26.5	25.7	-3.0	.88
27	04095300	04096100	36.9	23	1971-93	24.2	24.5	1.2	29.0	29.6	2.1	.77
28	04099750	04099808	263	13	1981-93	89.8	95.0	5.8	129	137	6.2	.90
29	04100500	04099808	496	13	1981-93	115	111	-3.5	170	170	0	.93
30	04100252	04100295	8.5	12	1982-93	.37	.31	-16.2	.76	.78	2.6	.93
31	04178000	04179500	523	26	1948-73	10.3	18.0	74.8	24.0	31.8	32.5	.88
32	04178000	04180000	340	46	1948-93	21.1	20.1	-4.7	36.3	38.9	7.2	.72
33	03324000	04182590	241	26	1966-91	12.1	9.1	-24.8	18.3	16.3	-10.9	.86
34	05515000	05515400	167	15	1972-86	63.2	58.9	-6.8	82.8	73.0	-11.8	.82
35	05519000	05519500	68.3	20	1950-69	5.0	6.1	22.0	11.7	12.8	9.4	.84
Average							**24.3**	**14.6**		**39.7**	**7.6**	**.83**
Standard deviation							**29.5**	**36.6**		**44.6**	**19.9**	**.11**
Median							**17.1**	**0**		**28.3**	**2.1**	**.87**
Minimum							**.26**	**-28.6**		**.51**	**-16.6**	**.50**
Maximum							**111**	**123**		**173**	**81.8**	**.98**

[1]Predicted $7Q_{10}$ and $7Q_2$ were estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[2]Observed $7Q_{10}$ and $7Q_2$ were determined by frequency analysis of the annual 7-day low flows for the period of record shown.

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 7. Sets of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements: Case E—the grouped stations are on the same streams or tributaries, and there are two index stations

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; ft^3/s, cubic feet per second; R^2, coefficient of determination or fraction of the variance explained by a regression of the base-flow measurements with the concurrent daily flows at the index stations]

Set	Partial-record station	Index station 1	Index station 2	Years of record	Period of record	Predicted[1] $7Q_{10}$ (ft^3/s)	Observed[2] $7Q_{10}$ (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ (percent)	Predicted $7Q_2$ (ft^3/s)	Observed $7Q_2$ (ft^3/s)	Relative error of predicted $7Q_2$ (percent)	R^2
1	03274750	03274650	03275000	22	1972-93	8.4	7.6	-9.5	12.9	12.9	0	0.94
2	03326000	03325500	03326500	19	1953-71	2.4	2.9	20.8	6.0	6.6	10.0	.85
3	03335000	03334500	03334000	22	1956-93	57.8	54.8	-5.2	92.1	94.5	2.6	.96
4	03336000	03335500	03340500	23	1971-93	1,055	1,040	-1.4	1,613	1,584	-1.8	.97
5	03340500	03336000	03341500	23	1971-93	1,234	1,208	-2.1	2,001	1,972	-1.4	.96
6	03361500	03361000	03363000	41	1952-92	38.5	40.2	4.4	67.7	65.9	-2.7	.98
7	03362500	03362000	03363000	49	1944-92	19.8	20.3	2.5	35.7	39.8	11.5	.93
8	03363000	03361500	03362500	48	1945-92	87.3	92.9	6.4	150	152	1.3	.98
9	03364000	03363000	03363900	24	1969-92	149	156	4.7	251	256	2.0	.98
10	03365500	03364000	03371500	35	1959-93	182	193	6.0	309	319	3.2	.96
11	03371500	03365500	03373500	35	1959-93	276	284	2.9	451	463	2.7	.98
12	05515500	05515000	05517500	42	1952-93	185	195	5.4	239	263	10.0	.91
13	05516500	05516000	05517000	17	1957-73	19.2	17.9	-6.8	32.2	30.2	-6.2	.76
14	05517500	05515500	05517000	42	1952-93	316	348	10.1	482	474	-1.7	.90
15	05522500	05522000	05524500	44	1950-93	6.5	6.0	-7.7	14.4	13.9	-3.5	.98
Average				**32**			**244**	**2.0**		**383**	**1.7**	**.93**
Standard deviation				**11**			**374**	**7.9**		**592**	**5.2**	**.06**
Median				**35**			**92.9**	**2.9**		**152**	**1.3**	**.96**
Minimum				**17**			**2.9**	**-9.5**		**6.6**	**-6.2**	**.76**
Maximum				**49**			**1,208**	**20.8**		**1,972**	**11.5**	**.98**

[1]Predicted $7Q_{10}$ and $7Q_2$ were estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[2]Observed $7Q_{10}$ and $7Q_2$ were determined by frequency analysis of the annual 7-day low flows for the period of record shown.

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 8. Low-flow frequencies at selected streamflow-gaging stations in Indiana, estimated with two test cases of the Stedinger-Thomas method of estimating low-flow frequencies, using base-flow measurements

[$7Q_{10}$ and $7Q_2$ are the minimum average discharge for 7 consecutive days with a recurrence interval of 10 and 2 years; Case E, uses two index stations that are on the same stream or tributaries as the partial-record station; Case A and B use one index station that is on the same stream or tributary as the partial-record station; ft^3/s, cubic feet per second]

Pair	Partial-record station	Years of record	Period of record	Observed[1] $7Q_{10}$ (ft^3/s)	Case E predicted[2] $7Q_{10}$ (ft^3/s)	Case A or B predicted $7Q_{10}$ (ft^3/s)	Percent difference in $7Q_{10}$ estimates	Observed $7Q_2$ (ft^3/s)	Case E predicted $7Q_2$ (ft^3/s)	Case A or B predicted $7Q_2$ (ft^3/s)	Percent difference in $7Q_2$ estimates
1	03274750	22	1972-93	7.6	8.4	8.0	4.9	12.9	12.9	13.2	2.3
2	03326000	19	1953-71	2.9	2.4	2.0	18.2	6.6	6.0	6.9	14.0
3	03336000	23	1971-93	1,040	1,055	1,092	3.4	1,584	1,613	1,598	.9
4	03340500	23	1971-93	1,208	1,234	1,217	1.4	1,972	2,001	2,012	.5
5	03362500	49	1944-92	20.3	19.8	21.6	8.7	39.8	35.7	38.4	7.3
6	05515500	42	1952-93	195	185	184	.5	263	239	230	3.8
7	05516500	17	1957-73	17.9	19.2	20.4	6.1	30.2	32.2	28.9	10.8
8	05522500	44	1950-93	6.0	6.5	7.0	7.4	13.9	14.4	14.5	.7
9	05522500	44	1950-93	6.0	6.5	5.5	16.7	13.9	14.4	13.8	4.2
Mean		**31**					**7.5**				**4.9**
Standard deviation		**13**					**6.2**				**4.8**
Median		**23**					**6.1**				**3.8**
Minimum		**17**					**.5**				**.5**
Maximum		**49**					**18.2**				**14.0**

[1]Observed $7Q_{10}$ and $7Q_2$ were determined by frequency analysis of the annual 7-day low flows for the period of record shown.

[2]Predicted $7Q_{10}$ and $7Q_2$ were estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

Table 9. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 10-year low flows, with the number of base-flow measurements varied: Case A—the paired stations are on the same stream or tributaries, and the drainage area at the index station is greater than at the partial-record station

[$7Q_{10}$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 10 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_{10}$ (ft^3/s)	Predicted[2] $7Q_{10}$ n=20 (ft^3/s)	Predicted $7Q_{10}$ n=15 (ft^3/s)	Predicted $7Q_{10}$ n=10 (ft^3/s)	Predicted $7Q_{10}$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ n=20 (percent)	Relative error of predicted $7Q_{10}$ n=15 (percent)	Relative error of predicted $7Q_{10}$ n=10 (percent)	Relative error of predicted $7Q_{10}$ n=5 (percent)
2	03274750	03275000	7.6	8.0	7.5	7.3	6.6	-5.0	1.3	4.1	15.2
3	03275500	03275600	7.3	7.6	7.3	6.7	6.1	-3.9	0	9.0	19.7
4	03322500	03322900	4.0	4.0	3.8	3.6	3.3	0	5.3	11.1	21.2
7	03328000	03328500	42.2	42.1	38.2	37.6	36.5	.2	10.5	12.2	15.6
9	03335500	03336000	868	827	793	768	678	5.0	9.5	13.0	28.0
13	03361000	03361500	26.6	28.4	27.2	26.5	26.2	-6.3	-2.2	.4	1.5
14	03362000	03362500	1.5	1.4	1.1	.73	.64	7.1	36.4	105	134
19	04099510	04099750	9.6	10.0	8.8	8.4	8.4	-4.0	9.1	14.3	14.3
24	05516500	05517000	20.8	22.1	19.2	20.5	19.9	-5.9	8.3	1.5	4.5
26	05522000	05522500	4.4	4.4	4.5	4.7	4.6	0	-2.2	-6.4	-4.3
Mean			**99.2**					**-1.3**	**7.6**	**16.4**	**25.0**
Standard deviation			**270**					**4.6**	**11.2**	**31.8**	**39.5**
Median			**8.6**					**-2.0**	**6.8**	**10.0**	**15.4**
Minimum			**1.5**					**-6.3**	**-2.2**	**-6.4**	**-4.3**
Maximum			**868**					**7.1**	**36.4**	**105**	**134**

[1]Observed $7Q_{10}$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_{10}$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100.*

Table 10. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 2-year low flows, with the number of base-flow measurements varied: Case A—the paired stations are on the same stream or tributaries, and the drainage area at the index station is greater than at the partial-record station

[$7Q_2$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 2 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_2$ (ft^3/s)	Predicted[2] $7Q_2$ n=20 (ft^3/s)	Predicted $7Q_2$ n=15 (ft^3/s)	Predicted $7Q_2$ n=10 (ft^3/s)	Predicted $7Q_2$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_2$ n=20 (percent)	Relative error of predicted $7Q_2$ n=15 (percent)	Relative error of predicted $7Q_2$ n=10 (percent)	Relative error of predicted $7Q_2$ n=5 (percent)
2	03274750	03275000	12.9	13.2	12.8	12.6	12.4	-2.3	0.8	2.4	4.0
3	03275500	03275600	12.6	13.2	13.2	12.4	11.3	-4.5	-4.5	1.6	11.5
4	03322500	03322900	5.9	6.2	5.9	5.6	5.5	-4.8	0	5.4	7.3
7	03328000	03328500	63.1	62.2	59.7	60.1	59.0	1.4	5.7	5.0	6.9
9	03335500	03336000	1,318	1,270	1,226	1,170	1,063	3.8	7.5	12.6	24.0
13	03361000	03361500	46.5	43.9	43.8	44.0	43.6	5.9	6.2	5.7	6.7
14	03362000	03362500	3.4	3.9	3.4	2.7	2.6	-12.8	0	25.9	30.8
19	04099510	04099750	18.2	17.7	15.9	15.6	15.6	2.8	14.5	16.7	16.7
24	05516500	05517000	33.2	36.5	32.9	33.4	33.2	-9.0	.9	-.6	0
26	05522000	05522500	10.7	10.5	10.5	10.4	10.3	1.9	1.9	2.9	3.9
Mean			**152**					**-1.8**	**3.3**	**7.8**	**11.2**
Standard deviation			**410**					**6.0**	**5.3**	**8.2**	**9.8**
Median			**15.6**					**-.5**	**1.4**	**5.2**	**7.1**
Minimum			**3.4**					**-12.8**	**-4.5**	**-.6**	**0**
Maximum			**1,318**					**5.9**	**14.5**	**25.9**	**30.8**

[1]Observed $7Q_2$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_2$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100.*

Table 11. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 10-year low flows, with the number of base-flow measurements varied: Case B—the paired stations are on the same stream or tributaries, and the drainage area at the index station is less than at the partial-record station

[$7Q_{10}$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 10 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_{10}$ (ft^3/s)	Predicted[2] $7Q_{10}$ n=20 (ft^3/s)	Predicted $7Q_{10}$ n=15 (ft^3/s)	Predicted $7Q_{10}$ n=10 (ft^3/s)	Predicted $7Q_{10}$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ n=20 (percent)	Relative error of predicted $7Q_{10}$ n=15 (percent)	Relative error of predicted $7Q_{10}$ n=10 (percent)	Relative error of predicted $7Q_{10}$ n=5 (percent)
4	03322900	03322500	6.2	6.1	5.8	4.3	4.3	1.6	6.9	44.2	44.2
7	03328500	03328000	100	95.5	85.8	75.3	76.0	4.7	16.6	32.8	31.6
8	03335000	03334500	59.5	65.0	61.8	60.8	49.2	-8.5	-3.7	-2.1	20.9
9	03336000	03335500	1,040	1,092	1,068	1,033	910	-4.8	-2.6	.7	14.3
11	03341500	03340500	1,393	1,429	1,374	1,458	1,446	-2.5	1.4	-4.5	-3.7
12	03349000	03348000	80.5	85.4	86.4	88.9	86.4	-5.7	-6.8	-9.4	-6.8
15	03363000	03362500	93.2	91.7	87.7	82.3	74.6	1.6	6.3	13.2	24.9
19	04099750	04099510	89.3	90.5	90.3	92.6	89.7	-1.3	-1.1	-3.6	-.4
24	05517000	05516500	75.8	72	67.3	53.7	50.6	5.3	12.6	41.2	49.8
26	05522500	05522000	6.0	5.5	5.4	4.9	5.8	9.1	11.1	22.4	3.4
Mean			**294**					**-.1**	**4.1**	**13.5**	**17.8**
Standard deviation			**494**					**5.5**	**7.8**	**20.3**	**20.0**
Median			**84.9**					**.2**	**3.9**	**7.0**	**17.6**
Minimum			**6**					**-8.5**	**-6.8**	**-9.4**	**-6.8**
Maximum			**1,393**					**9.1**	**16.6**	**44.2**	**49.8**

[1]Observed $7Q_{10}$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_{10}$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100.*

Table 12. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 2-year low flows, with the number of base-flow measurements varied: Case B—the paired stations are on the same stream or tributaries, and the drainage area at the index station is less than at the partial-record station

[$7Q_2$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 2 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_2$ (ft^3/s)	Predicted[2] $7Q_2$ n=20 (ft^3/s)	Predicted $7Q_2$ n=15 (ft^3/s)	Predicted $7Q_2$ n=10 (ft^3/s)	Predicted $7Q_2$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_2$ n=20 (percent)	Relative error of predicted $7Q_2$ n=15 (percent)	Relative error of predicted $7Q_2$ n=10 (percent)	Relative error of predicted $7Q_2$ n=5 (percent)
4	03322900	03322500	9.9	9.4	9.5	8.3	8.2	5.3	4.2	19.3	20.7
7	03328500	03328000	145	145	135	125	122	0	7.4	16.0	18.9
8	03335000	03334500	98.0	97.2	94.4	92.7	84.0	.8	3.8	5.7	16.7
9	03336000	03335500	1,584	1,598	1,571	1,541	1,454	-.9	.8	2.8	8.9
11	03341500	03340500	2,305	2,299	2,226	2,230	2,232	.3	3.5	3.4	3.3
12	03349000	03348000	122	126	123	129	128	-3.2	-.8	-5.4	-4.7
15	03363000	03362500	152	159	157	154	149	-4.4	-3.2	-1.3	2.0
19	04099750	04099510	127	131	131	130	126	-3.1	-3.1	-2.3	.8
24	05517000	05516500	108	101	95.7	80.6	76.5	6.9	12.9	34.0	41.2
26	05522500	05522000	13.9	13.8	13.7	13.2	13.4	.7	1.5	5.3	3.7
Mean			**466**					**.2**	**2.7**	**7.8**	**11.2**
Standard deviation			**799**					**3.6**	**4.9**	**12.0**	**13.5**
Median			**124**					**.2**	**2.5**	**4.4**	**6.3**
Minimum			**9.9**					**-4.4**	**-3.2**	**-5.4**	**-4.7**
Maximum			**2,305**					**6.9**	**12.9**	**34.0**	**41.2**

[1]Observed $7Q_2$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_2$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100.*

Table 13. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 10-year low flows, with the number of base-flow measurements varied: Case C—the paired stations are on different streams or basins, and the drainage area at the index station is greater than at the partial-record station

[$7Q_{10}$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 10 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_{10}$ (ft^3/s)	Predicted[2] $7Q_{10}$ n=20 (ft^3/s)	Predicted $7Q_{10}$ n=15 (ft^3/s)	Predicted $7Q_{10}$ n=10 (ft^3/s)	Predicted $7Q_{10}$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ n=20 (percent)	Relative error of predicted $7Q_{10}$ n=15 (percent)	Relative error of predicted $7Q_{10}$ n=10 (percent)	Relative error of predicted $7Q_{10}$ n=5 (percent)
2	03275600	03275000	18.4	15.8	16.1	16.4	16.1	16.5	14.3	12.2	14.3
6	03324300	03326500	7.6	6.8	7.2	7.0	6.3	11.8	5.6	8.6	20.6
10	03329700	03334000	10.3	10.4	9.9	9.0	8.8	-1.0	4.0	14.4	17.0
13	03341200	03340800	4.6	5.1	4.8	4.1	3.9	-9.8	-4.2	12.2	17.9
23	03361500	03362500	40.4	40.2	35.8	31.5	28.9	.5	12.8	28.3	39.8
24	03363900	03363000	30.0	32.1	29.5	27.5	27.1	-6.5	1.7	9.1	10.7
26	04094000	04094500	20.5	19.4	17.7	16.8	15.7	5.7	15.8	22.0	30.6
27	04096100	04095300	8.1	8.7	8.6	8.0	7.4	-6.9	-5.8	1.3	9.5
28	04099808	04099750	30.1	29.0	28.9	27.4	26.2	3.4	3.8	9.5	14.5
29	04099808	04100500	30.1	30.7	30.8	31.2	31.3	-2.3	-2.6	-3.8	-4.2
Mean			**20.0**					**1.1**	**4.5**	**11.4**	**17.1**
Standard deviation			**12.2**					**8.4**	**7.7**	**9.2**	**11.9**
Median			**19.5**					**-.3**	**3.9**	**10.9**	**15.8**
Minimum			**4.6**					**-9.8**	**-5.8**	**-3.8**	**-4.2**
Maximum			**40.4**					**16.5**	**15.8**	**28.3**	**39.8**

[1]Observed $7Q_{10}$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_{10}$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100.*

Table 14. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 2-year low flows, with the number of base-flow measurements varied: Case C—the paired stations are on different streams or basins, and the drainage area at the index station is greater than at the partial-record station

[$7Q_2$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 2 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_2$ (ft^3/s)	Predicted[2] $7Q_2$ n=20 (ft^3/s)	Predicted $7Q_2$ n=15 (ft^3/s)	Predicted $7Q_2$ n=10 (ft^3/s)	Predicted $7Q_2$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_2$ n=20 (percent)	Relative error of predicted $7Q_2$ n=15 (percent)	Relative error of predicted $7Q_2$ n=10 (percent)	Relative error of predicted $7Q_2$ n=5 (percent)
2	03275600	03275000	30.3	25.5	25.6	26.0	25.8	18.8	18.4	16.5	17.4
6	03324300	03326500	15.0	12.9	12.9	12.2	11.7	16.3	16.3	23.0	28.2
10	03329700	03334000	21.3	18.7	18.8	18.4	18.6	13.9	13.3	15.8	14.5
13	03341200	03340800	7.1	7.3	7.2	7.0	7.2	-2.7	-1.4	1.4	-1.4
23	03361500	03362500	65.7	69.6	66.7	62.2	60.7	-5.6	-1.5	5.6	8.2
24	03363900	03363000	57.0	49.7	48.3	48.4	47.8	14.7	18.0	17.8	19.2
26	04094000	04094500	25.0	25.0	23.8	23.2	22.8	0	5.0	7.8	9.6
27	04096100	04095300	9.8	10.4	10.2	9.7	9.0	-5.8	-3.9	1.0	8.9
28	04099808	04099750	40.0	39.7	39.3	38.4	37.0	.8	1.8	4.2	8.1
29	04099808	04100500	40.0	41.2	40.9	41.5	41.5	-2.9	-2.2	-3.6	-3.6
Mean			**31.1**					**4.8**	**6.4**	**9.0**	**10.9**
Standard deviation			**19.6**					**9.9**	**9.1**	**8.8**	**9.5**
Median			**27.7**					**.4**	**3.4**	**6.7**	**9.3**
Minimum			**7.1**					**-5.8**	**-3.9**	**-3.6**	**-3.6**
Maximum			**65.7**					**18.8**	**18.4**	**23.0**	**28.2**

[1]Observed $7Q_2$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_2$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100.*

Table 15. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 10-year low flows, with the number of base-flow measurements varied: Case D—the paired stations are on different streams or basins, and the drainage area at the index station is less than at the partial-record station

[$7Q_{10}$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 10 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_{10}$ (ft^3/s)	Predicted[2] $7Q_{10}$ n=20 (ft^3/s)	Predicted $7Q_{10}$ n=15 (ft^3/s)	Predicted $7Q_{10}$ n=10 (ft^3/s)	Predicted $7Q_{10}$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ n=20 (percent)	Relative error of predicted $7Q_{10}$ n=15 (percent)	Relative error of predicted $7Q_{10}$ n=10 (percent)	Relative error of predicted $7Q_{10}$ n=5 (percent)
2	03275000	03275600	62.3	69.8	66.4	62.3	63.5	-10.7	-6.2	0	-1.9
6	03326500	03324300	25.8	28.6	25.4	25.6	21.0	-9.8	1.6	.8	22.9
10	03334000	03329700	19.1	21.1	20.7	21.2	19.9	-9.5	-7.7	-9.9	-4.0
13	03340800	03341200	2.4	2.5	2.3	1.9	2.0	-4.0	4.3	26.3	20.0
23	03362500	03361500	20.4	20.4	18.7	18.0	18.6	0	9.1	13.3	9.7
24	03363000	03363900	105	107	106	104	103	-1.9	-.9	1.0	1.9
26	04094500	04094000	19.4	21.6	21.5	20.9	20.8	-10.2	-9.8	-7.2	-6.7
27	04095300	04096100	24.5	24.2	23.6	23.6	23.3	1.2	3.8	3.8	5.2
28	04099750	04099808	95.0	89.8	88.9	86.6	88.9	5.8	6.9	9.7	6.9
29	04100500	04099808	111	115	111	107	107	-3.5	0	3.7	3.7
Mean			**48.5**					**-4.3**	**.1**	**4.2**	**5.8**
Standard deviation			**41.1**					**5.7**	**6.3**	**10.4**	**9.7**
Median			**25.2**					**-3.8**	**.8**	**2.4**	**4.5**
Minimum			**2.4**					**-10.7**	**-9.8**	**-9.9**	**-6.7**
Maximum			**111**					**5.8**	**9.1**	**26.3**	**22.9**

[1]Observed $7Q_{10}$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_{10}$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 16. Pairs of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 2-year low flows, with the number of base-flow measurements varied: Case D—the paired stations are on different streams or basins, and the drainage area at the index station is less than at the partial-record station

[$7Q_2$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 2 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station	Observed[1] $7Q_2$ (ft^3/s)	Predicted[2] $7Q_2$ n=20 (ft^3/s)	Predicted $7Q_2$ n=15 (ft^3/s)	Predicted $7Q_2$ n=10 (ft^3/s)	Predicted $7Q_2$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_2$ n=20 (percent)	Relative error of predicted $7Q_2$ n=15 (percent)	Relative error of predicted $7Q_2$ n=10 (percent)	Relative error of predicted $7Q_2$ n=5 (percent)
2	03275000	03275600	103	109	103	96.3	97.1	-5.5	0	7.0	6.1
6	03326500	03324300	46.6	50.3	45.7	46.0	41.9	-7.4	2.0	1.3	11.2
10	03334000	03329700	33.8	37.5	37.6	37.9	37.1	-9.9	-10.1	-10.8	-8.9
13	03340800	03341200	5.1	4.3	4.1	3.6	3.6	18.6	24.4	41.7	41.7
23	03362500	03361500	40.6	35.2	33.8	33.4	32.5	15.3	20.1	21.6	24.9
24	03363000	03363900	173	184	180	177	172	-6.0	-3.9	-2.3	.6
26	04094500	04094000	25.7	26.5	26.3	25.4	25.0	-3.0	-2.3	1.2	2.8
27	04095300	04096100	29.6	29.0	28.5	28.2	28.0	2.1	3.9	5.0	5.7
28	04099750	04099808	137	129	129	127	123	6.2	6.2	7.9	11.4
29	04100500	04099808	170	170	164	160	160	0	3.7	6.3	6.3
Mean			**76.4**					**1.0**	**4.4**	**7.9**	**10.2**
Standard deviation			**63.5**					**9.7**	**10.5**	**14.5**	**14.0**
Median			**43.6**					**-1.5**	**2.9**	**5.7**	**6.2**
Minimum			**5.1**					**-9.9**	**-10.1**	**-10.8**	**-8.9**
Maximum			**173**					**18.6**	**24.4**	**41.7**	**41.7**

[1]Observed $7Q_2$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_2$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 17. Sets of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 10-year low flows, with the number of base-flow measurements varied: Case E—the grouped stations are on the same streams or tributaries, and there are two index stations

[$7Q_{10}$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 10 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station 1	Index Station 2	Observed[1] $7Q_{10}$ (ft^3/s)	Predicted[2] $7Q_{10}$ n=20 (ft^3/s)	Predicted $7Q_{10}$ n=15 (ft^3/s)	Predicted $7Q_{10}$ n=10 (ft^3/s)	Predicted $7Q_{10}$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_{10}$ n=20 (percent)	Relative error of predicted $7Q_{10}$ n=15 (percent)	Relative error of predicted $7Q_{10}$ n=10 (percent)	Relative error of predicted $7Q_{10}$ n=5 (percent)
1	03274750	03274650	03275000	7.6	8.4	8.6	8.3	7.9	-9.5	-11.6	-8.4	-3.8
3	03335000	03334500	03334000	54.8	57.8	57.4	55.7	57.5	-5.2	-4.5	-1.6	-4.7
4	03336000	03335500	03340500	1,040	1,055	984	1,020	1,098	-1.4	5.7	2.0	-5.3
6	03361500	03361000	03363000	40.2	38.5	38.0	37.7	42.6	4.4	5.8	6.6	-5.6
7	03362500	03362000	03363000	20.3	19.8	17.7	19.8	19.7	2.5	14.7	2.5	3.0
8	03363000	03361500	03362500	92.9	87.3	92.1	85.4	68.8	6.4	.9	8.8	35.0
9	03364000	03363000	03363900	156	149	151	152	146	4.7	3.3	2.6	6.8
12	05515500	05515000	05517500	195	185	185	188	188	5.4	5.4	3.7	3.7
13	05516500	05516000	05517000	17.9	19.2	20.3	21.6	23.2	-6.8	-11.8	-17.1	-22.8
15	05522500	05522000	05524500	6.0	6.5	6.5	5.7	6.7	-7.7	-7.7	5.3	-10.4
Mean				**163**					**-.7**	**0**	**.4**	**-.4**
Standard deviation				**315**					**6.1**	**8.7**	**7.8**	**15.0**
Median				**47.5**					**.6**	**2.1**	**2.6**	**-4.3**
Minimum				**6.0**					**-9.5**	**-11.8**	**-17.1**	**-22.8**
Maximum				**1,040**					**6.4**	**14.7**	**8.8**	**35.0**

[1]Observed $7Q_{10}$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_{10}$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.

Table 18. Sets of streamflow-gaging stations in Indiana used to evaluate the accuracy of the Stedinger-Thomas method of estimating 7-day, 2-year low flows, with the number of base-flow measurements varied: Case E—the grouped stations are on the same streams or tributaries, and there are two index stations

[$7Q_2$ is the minimum average discharge for 7 consecutive days with a recurrence interval of 2 years; ft^3/s, cubic feet per second; n, number of base-flow measurements]

Pair	Partial-record station	Index station 1	Index Station 2	Observed[1] $7Q_2$ (ft^3/s)	Predicted[2] $7Q_2$ n=20 (ft^3/s)	Predicted $7Q_2$ n=15 (ft^3/s)	Predicted $7Q_2$ n=10 (ft^3/s)	Predicted $7Q_2$ n=5 (ft^3/s)	Relative error[3] of predicted $7Q_2$ n=20 (percent)	Relative error of predicted $7Q_2$ n=15 (percent)	Relative error of predicted $7Q_2$ n=10 (percent)	Relative error of predicted $7Q_2$ n=5 (percent)
1	03274750	03274650	03275000	12.9	12.9	13.0	12.9	12.8	0	-.8	0	.8
3	03335000	03334500	03334000	94.5	92.1	92.0	90.0	92.9	2.6	2.7	5.0	1.7
4	03336000	03335500	03340500	1,584	1,613	1533	1,584	1,698	-1.8	3.3	0	-6.7
6	03361500	03361000	03363000	65.9	67.7	67.6	67.3	70.7	-2.7	-2.5	-2.1	-6.8
7	03362500	03362000	03363000	39.8	35.7	32.0	34.8	36.5	11.5	24.4	14.4	9.0
8	03363000	03361500	03362500	152	150	153	143	131	1.3	-.7	6.3	16.0
9	03364000	03363000	03363900	256	251	249	248	251	2.0	2.8	3.2	2.0
12	05515500	05515000	05517500	263	239	242	241	239	10.0	8.7	9.1	10.0
13	05516500	05516000	05517000	30.2	32.2	32.6	34.2	33.2	-6.2	-7.4	-11.7	-9.0
15	05522500	05522000	05524500	13.9	14.4	14.3	13.3	13.6	-3.5	-2.8	4.5	2.2
Mean				**251**					**1.3**	**2.8**	**2.9**	**1.9**
Standard deviation				**477**					**5.7**	**8.8**	**7.0**	**8.1**
Median				**80.2**					**.7**	**1.0**	**3.9**	**1.9**
Minimum				**12.9**					**-6.2**	**-7.4**	**-11.7**	**-9.0**
Maximum				**1,584**					**11.5**	**24.4**	**14.4**	**16.0**

[1]Observed $7Q_2$ was determined by frequency analysis of the annual 7-day low flows.

[2]Predicted $7Q_2$ was estimated, using the Stedinger-Thomas method (Stedinger and Thomas, 1985).

[3]Relative error, in percent, is computed as: *[(observed - predicted) / predicted] x 100*.