**National Water Availability and Use Pilot Program**

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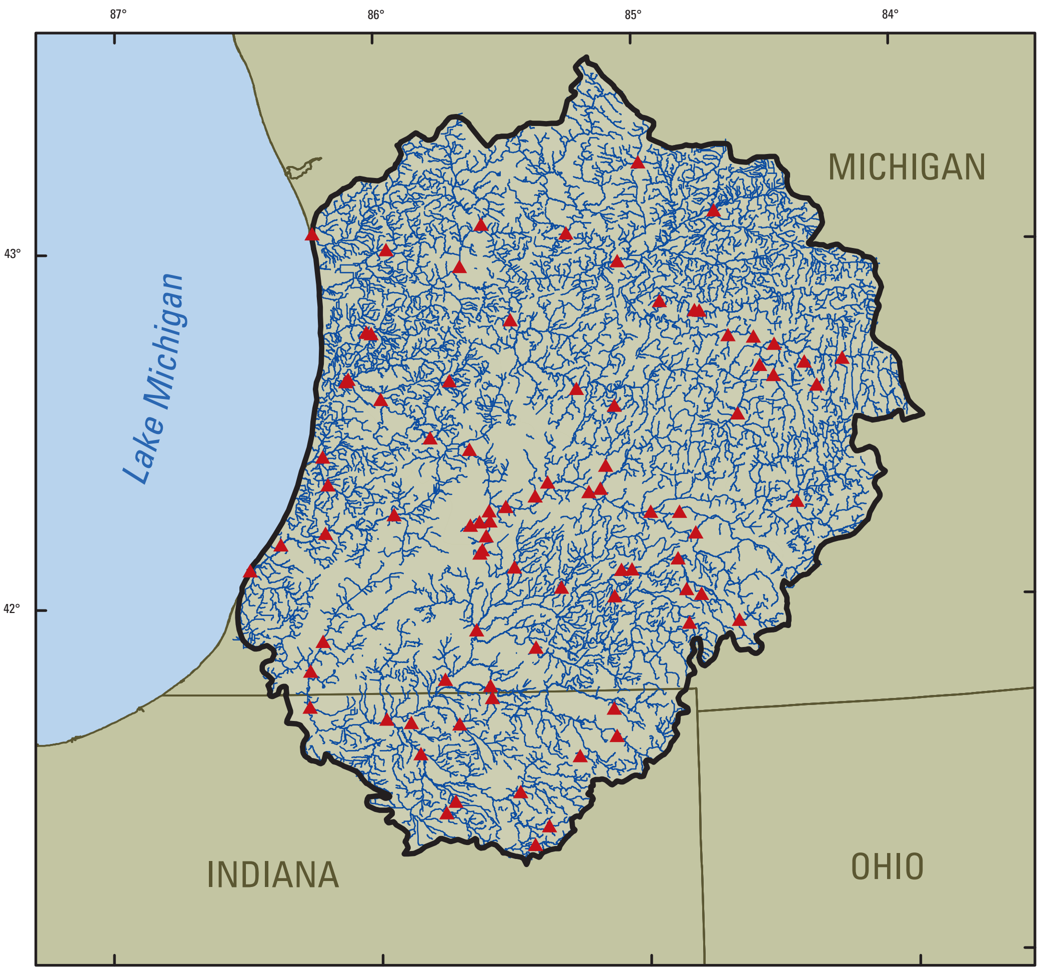


Scientific Investigations Report 2010–5020


**U.S. Department of the Interior**
**U.S. Geological Survey**

# Application of AFINCH as a Tool for Evaluating the Effects of Streamflow-Gaging-Network Size and Composition on the Accuracy and Precision of Streamflow Estimates at Ungaged Locations in the Southeast Lake Michigan Hydrologic Subregion

By G.F. Koltun and David J. Holtschlag

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U.S. Geological Survey, Reston, Virginia: 2010

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Suggested citation:
Koltun, G.F., and Holtschlag, D.J., 2010, Application of AFINCH as a tool for evaluating the effects of streamflow-gaging-network size and composition on the accuracy and precision of streamflow estimates at ungaged locations in the Southeast Lake Michigan Hydrologic Subregion: U.S. Geological Survey Scientific Investigations Report 2010–5020, 14 p.

Cover: Illustration of the network of gages operated between 1971 and 2003 in the Southeast Lake Michigan hydrologic subregion.

# Contents



## Figures



## Table

## Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| kilometer (km) | 0.6214 | mile (mi) |
| | Area | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Flow rate | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

## Abbreviations

Water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. For example, the year ending September 30, 1992 is called the "1992 water year."

| | |
|---|---|
| AFINCH | Analysis of Flows in Networks of Channels |
| APE | apparent percent error |
| CDF | cumulative distribution function |
| $CV_p$ | pseudo coefficient of variation |
| NHDPlus | National Hydrography Dataset Plus |
| USGS | U.S. Geological Survey |

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## Abstract

Bootstrapping techniques employing random subsampling were used with the AFINCH (Analysis of Flows In Networks of CHannels) model to gain insights into the effects of variation in streamflow-gaging-network size and composition on the accuracy and precision of streamflow estimates at ungaged locations in the 0405 (Southeast Lake Michigan) hydrologic subregion. AFINCH uses stepwise-regression techniques to estimate monthly water yields from catchments based on geospatial-climate and land-cover data in combination with available streamflow and water-use data. Calculations are performed on a hydrologic-subregion scale for each catchment and stream reach contained in a National Hydrography Dataset Plus (NHDPlus) subregion. Water yields from contributing catchments are multiplied by catchment areas and resulting flow values are accumulated to compute streamflows in stream reaches which are referred to as flow lines. AFINCH imposes constraints on water yields to ensure that observed streamflows are conserved at gaged locations.

Data from the 0405 hydrologic subregion (referred to as Southeast Lake Michigan) were used for the analyses. Daily streamflow data were measured in the subregion for 1 or more years at a total of 75 streamflow-gaging stations during the analysis period which spanned water years 1971–2003. The number of streamflow gages in operation each year during the analysis period ranged from 42 to 56 and averaged 47. Six sets (one set for each censoring level), each composed of 30 random subsets of the 75 streamflow gages, were created by censoring (removing) approximately 10, 20, 30, 40, 50, and 75 percent of the streamflow gages (the actual percentage of operating streamflow gages censored for each set varied from year to year, and within the year from subset to subset, but averaged approximately the indicated percentages).

Streamflow estimates for six flow lines each were aggregated by censoring level, and results were analyzed to assess (a) how the size and composition of the streamflow-gaging network affected the average apparent errors and variability of the estimated flows and (b) whether results for certain months were more variable than for others. The six flow lines were categorized into one of three types depending upon their network topology and position relative to operating streamflow-gaging stations.

Statistical analysis of the model results indicates that (1) less precise (that is, more variable) estimates resulted from smaller streamflow-gaging networks as compared to larger streamflow-gaging networks, (2) precision of AFINCH flow estimates at an ungaged flow line is improved by operation of one or more streamflow gages upstream and (or) downstream in the enclosing basin, (3) no consistent seasonal trend in estimate variability was evident, and (4) flow lines from ungaged basins appeared to exhibit the smallest absolute apparent percent errors (APEs) and smallest changes in average APE as a function of increasing censoring level. The counterintuitive results described in item (4) above likely reflect both the nature of the base-streamflow estimate from which the errors were computed and insensitivity in the average model-derived estimates to changes in the streamflow-gaging-network size and composition. Another analysis demonstrated that errors for flow lines in ungaged basins have the potential to be much larger than indicated by their APEs if measured relative to their true (but unknown) flows.

“Missing gage” analyses, based on examination of censoring subset results where the streamflow gage of interest was omitted from the calibration data set, were done to better understand the true error characteristics for ungaged flow lines as a function of network size. Results examined for 2 water years indicated that the probability of computing a monthly streamflow estimate within 10 percent of the true value with AFINCH decreased from greater than 0.9 at about a 10-percent network-censoring level to less than 0.6 as the censoring level approached 75 percent. In addition, estimates for typically dry months tended to be characterized by larger percent errors than typically wetter months.

# Introduction

The U.S. Geological Survey (USGS) streamflow-gaging network changes over time as gages are added or removed. Although there are several streamflow-gaging stations that are fully funded by the USGS, the vast majority of streamflow gages operated by the USGS are funded, in part or in whole, by other Federal, State, local, or tribal agencies. The streamflow-gaging network has continually changed (both in size and in composition), over time, to meet the data needs and fiscal realities of its supporters owing to the diverse and distributed nature of streamflow-gage funding. At times, those changes have resulted in appreciable reductions in the numbers of streamflow gages operated (Mason and Yorke, 1997).

A computer application called AFINCH (Analysis of Flows In Networks of CHannels) (Holtschlag, 2009) was developed recently (2009) by the USGS as part of the National Water Availability and Use Program—Great Lakes Basin Pilot. In short, AFINCH was designed to make use of, and extend, the limited available site-specific streamflow and water-use information to estimate streamflows and water yields throughout large regions.

AFINCH uses geospatial-climate and land-cover data sets along with available streamflow and water-use data to develop stepwise-regression models for estimating water yields and streamflows on a monthly basis. Calculations are performed on a hydrologic-subregion scale and water yields and streamflows are estimated for each catchment and stream reach in the hydrologic subregion that is defined in the National Hydrography Dataset Plus (NHDPlus) data set (Horizon Systems, 2009). Water yields from contributing catchments are multiplied by catchment areas, and resulting flow values are accumulated to compute streamflows in downstream stream reaches, which are referred to as flow lines in the NHDPlus data set. AFINCH makes use of the NHDPlus stream topology and value-added attributes to adjust and constrain estimated water yields and streamflows based on observed streamflows and water uses (withdrawals, augmentations, and diversions) so that observed streamflows are conserved at gaged locations.

Although AFINCH was developed primarily as a tool for estimating streamflows, it will be used herein to gain insights into the effects of variation in streamflow-gaging-network size and composition on the accuracy and precision of streamflow estimates from AFINCH.

## Purpose and Scope

The purpose of this report is to present the methods and results of a study in which the AFINCH model was used with bootstrapping techniques employing random subsampling to compute selected statistical characteristics of monthly flow estimates as a function of streamflow-gaging-network size and composition. This was done to gain insights into the effects of variation in streamflow-gaging-network size and composition on the accuracy and precision of streamflow estimates from AFINCH. Analyses were limited to the 0405 hydrologic subregion (fig. 1) and are based on streamflow data collected in the subregion for 33 water years ranging from 1971 to 2003.

The analyses and results primarily are intended to illustrate the effects of varying streamflow-gaging-network size and composition on the accuracy and precision of AFINCH streamflow estimates for stream reaches with varying stream- and gage-network topological characteristics. The analyses and results are not intended to be exhaustive in scope, nor are they intended necessarily to be representative of all flow lines in the 0405 hydrologic subregion or other hydrologic subregions.

# Analytical Approach

The AFINCH model is written in the MATLAB programming language (MathWorks, 2009) and makes use of the MATLAB Statistics Toolbox. The AFINCH code was modified for this study to facilitate repetitive unattended runs with a predefined set of potential explanatory variables. The potential explanatory variables used for all runs were monthly total precipitation (in inches) and monthly mean temperature (in degrees Celsius). Precipitation and temperature data were derived from geospatial climate data sets prepared by the PRISM Group (*http://www.prism.oregonstate.edu/*). A p-value criterion of 0.01 was used for variable selection and retention in the monthly stepwise regressions. Data were analyzed for water years 1971–2003. No water uses were specified for any locations during the analysis period owing to a lack of detailed water-use data.

Data from the 0405 (Southeast Lake Michigan) hydrologic subregion, which covers an area of approximately 12,800 $mi^2$, were used for the analyses, primarily because they already had been compiled during the development of the AFINCH model. Daily streamflow data were measured in the subregion for 1 or more years during the analysis period at a total of 75 streamflow-gaging stations (hereafter referred to as gages). The number of gages in operation each year during the analysis period ranged from 42 to 56 and averaged 47. A program was developed to create 30 random subsets of the 75 gages, each with a specified number of gages removed from the full-station complement. Each subset was created starting with the full complement of 75 gages; consequently, there is the potential (albeit unlikely) of having 2 or more identical subsets in a group of 30 subsets. There also is the potential that different subsets result in what effectively are identical gage networks for certain years. This can occur if omitted gages were not operated in the given year (and so the omission does not affect the model-calibration data set relative to other potential subsets where the gage was not omitted). Thirty subsets each, for 6 censoring levels, were created in a bootstrapping fashion (Davidson and Hinkley, 1997) by removing approximately 10, 20, 30, 40, 50, and 75 percent of the gages. The various percent removals henceforth will be referred to as censoring levels. For example, analyses with approximately 10 percent of the gages removed will be referred to as those corresponding to the 10-percent censoring level.

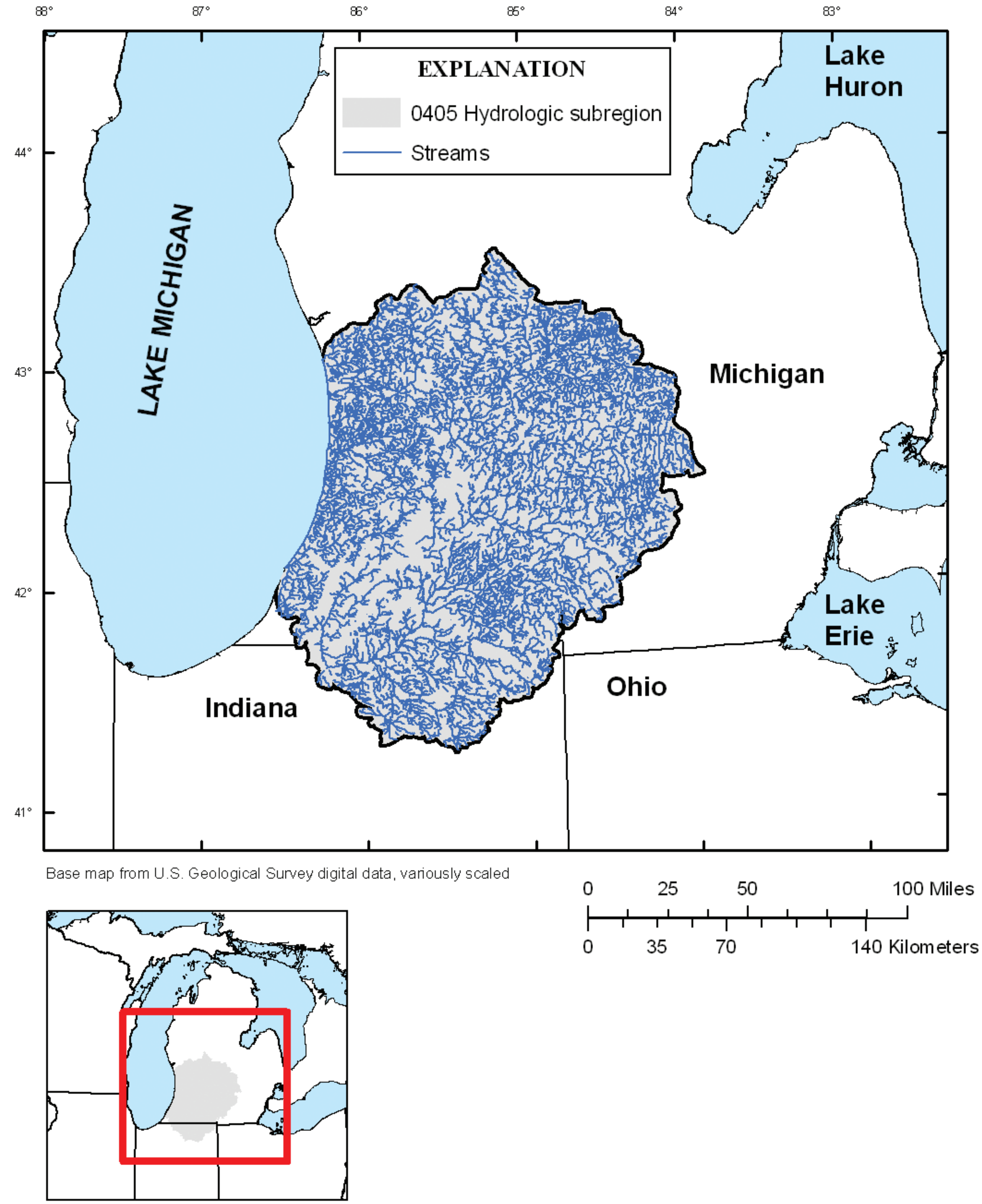


**Figure 1.** The 0405 (Southeast Lake Michigan) hydrologic subregion and National Hydrography Dataset Plus (NHDPlus) stream network.

All AFINCH processing steps (except plotting of trends and duration curves) were run, first using the full complement of gages and then for each censored gage subset. Each run resulted in monthly accumulated flow estimates (hereafter referred to as flow estimates) for all of the more than 113,000 flow lines contained in the NHDPlus data set for the 0405 hydrologic subregion. These flow lines represent stream reaches of varying length ranging from 0.001 to 17.896 km. Flow lines are uniquely identified in NHDPlus by a numeric code referred to as a COMID. In all, AFINCH was run first using all 75 gages and then using 180 subsets (30 subsets each for 6 censoring levels) of the 75 gages, resulting in a total of 5,973 water-year sets of flow estimates for each flow line. Estimates were aggregated by censoring level, and results for selected flow lines were extracted for statistical analysis.

Three types of flow lines were examined. Figure 2 shows a hypothetical basin with 4 gaging stations (identified as A–D) and 17 flow lines numbered 1–17 and color coded by type. The first type (type 1) of flow line corresponds to one in basins where no gages had been operated during the analysis period either upstream or downstream from the given flow line. Flow lines 2 and 5 in figure 2 are type 1 flow lines. Flow estimates for type 1 flow lines are free of gage-based constraints and vary solely as a function of explanatory variables in the regression models developed from the calibration-gage network.

A type 2 flow line corresponds to one in basins where one or more gages are operated upstream and (or) downstream from the given flow line. Type 2 flow lines can be located upstream from a gage (shown as “Type 2 up” in fig. 2), downstream from a gage (shown as “Type 2 down” in fig. 2), or between an upstream and downstream gage (shown as “Type 2 up/down” in fig. 2). Flow estimates for type 2 flow lines are constrained by streamflow data from the closest downstream gage (if present) and (or) partially constrained by streamflow data from upstream gages (if present). For example, flow lines 13 and 14 are constrained by gage D on flow line 12; if the summation of predicted flows from flow lines 13 and 14 and the flow contributing directly to flow line 12 were 10-percent larger than the actual flow measured at gage D, then the predicted flows for flow lines 13 and 14 and the contribution to flow line 12 would be reduced proportionally so that the flows sum to the flow measured at the gage.

The third type of flow line (type 3) corresponds to one that contains a gage (that is, a gage is located on the flow line). Flow lines 6, 7, 10, and 12 in figure 2 are type 3 flow lines. Flow estimates for type 3 flow lines are constrained to match the flows reported for the gage during periods that the gage is operated. If the gage is not operated during a particular period, then a type 3 flow line, in effect, will revert to a type 1 or type 2 flow line, depending upon the presence and relative location of other gages in the basin. For example, if gage A (fig. 2) was not operated in a given year, then flow line 6 would revert to type 1 because there would be no upstream or downstream gages with flow data that can be used to constrain estimates at the flow line.

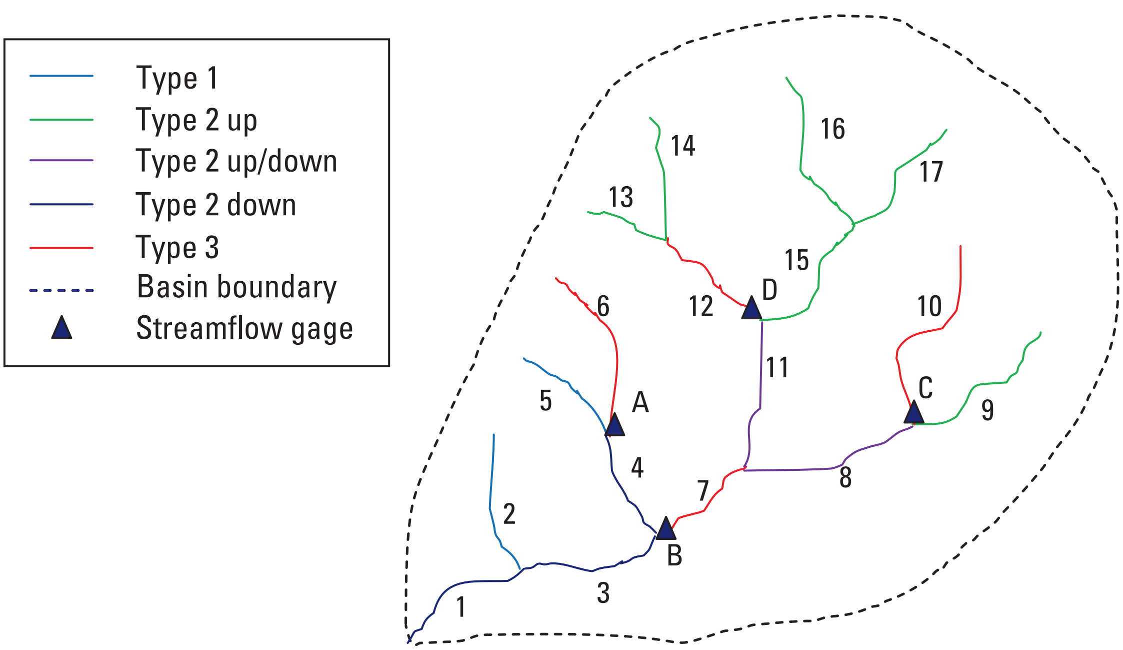


**Figure 2.** Hypothetical basin illustrating flow-line types.

The flow estimates for selected flow lines were analyzed to assess (a) how the size (a function of the censoring level) and composition of the gage network affected the average errors and variability of the estimated monthly flows and (b) whether estimates for certain months were more variable than for others.

AFINCH computes estimates of average flow, in cubic feet per second, for all flow lines for each month of each water year in the specified analysis period. The monthly flow estimates subsequently were used to compute water-year average flow estimates[1], also in cubic feet per second. For a given flow line and censoring level, the variance and mean of the flow estimates were computed for each month of each year in the analysis period and for each water year based on AFINCH output from the 30 gage subsets. Two additional statistics, a pseudo coefficient of variation ($CV_p$) and an apparent percent error (APE), also were computed from the variances and means of the flow estimates. A schematic of the analysis steps leading to the computation of these statistics is shown in figure 3.

The pseudo $CV_p$ for a given month (or year) was calculated as

$$CV_p = 100 * \sqrt{S^2} / Q_f \qquad (1)$$

where

- $S^2$ is the variance of the monthly (or annual) AFINCH flow estimates for a given water year determined from the 30 gage subsets for a given censoring level, and
- $Q_f$ is the monthly (or annual) flow estimate for the same water year determined from an AFINCH analysis using the full-gage complement.

The APE for a given water year was calculated as

$$APE = 100 * (\overline{Q}_s - Q_f) / Q_f \qquad (2)$$

where

- $\overline{Q}_s$ generally is the mean of the annual AFINCH flow estimates for the water year based on the 30 gage subsets for the given censoring level, and
- $Q_f$ is the annual flow estimate for the same water year determined from an AFINCH analysis using the full-gage complement.

[1] Water-year average flow estimates were computed by determining a weighted sum of the monthly flow estimates, where each month's weight was set to the number of days in the month divided by the number of days in the year.

This statistic is referred to as the "pseudo" coefficient of variation because, in most cases, the $CV_p$s are not computed relative to the true monthly (or annual) flows at the flow line, which frequently are not known. Instead, the $CV_p$s are computed relative to a base "best estimate" of streamflow as determined with AFINCH using the full-gage complement for model development. That "best estimate" of streamflow for a given water year is certain to be the true streamflow only when a gage is operated in the flow line during that year because AFINCH constrains the estimate to equal the gaged flow. In other cases, the "best estimate" of streamflow will vary in accuracy depending upon the quality of the regression model and on the numbers and locations of other gages operated in the basin whose streamflow data partially can constrain the estimate.

Additional analyses were done by examining AFINCH estimates for all flow lines that contained a gage to better examine the true error characteristics for ungaged flow lines (flow lines corresponding to a stream reaches that do not contain a stream gage) as a function of network size. These analyses were done by examining only those monthly flow estimates for each gaged flow line that resulted from censoring subsets for which the given gage was omitted from the network. These analyses will be referred to as the "missing gage" analyses because they are based on flow estimates derived from network subsets where the gage is missing from the calibration network. The difference between the estimated and observed monthly streamflows were computed and expressed as a percentage of the observed streamflows based on the following equation:

$$PE_{m_i} = 100 * (Q_{m_i} - \hat{Q}_{m_i}) / Q_{m_i} \qquad (3)$$

where, for a given gage and year,

- $PE_{m_i}$ is the percent error in monthly streamflow for month $i$ (where $i$=1 to 12),
- $Q_{m_i}$ is the observed monthly streamflow for month $i$, and
- $\hat{Q}_{m_i}$ is the estimated monthly streamflow for month $i$ based on a network that excludes the gage in the flow line.

The monthly percent errors for all of the gaged flow lines were aggregated by censoring level and were rank ordered; then, nonexceedance probabilities were estimated by means of the Cunnane (1978) plotting-position formula and used to construct empirical cumulative distribution functions (CDFs). The CDFs were then used to compute the probabilities that the estimated monthly flows were within plus or minus 10 percent of the observed flows as a function of censoring level. A schematic of the "missing gage" analysis steps is shown in figure 4.

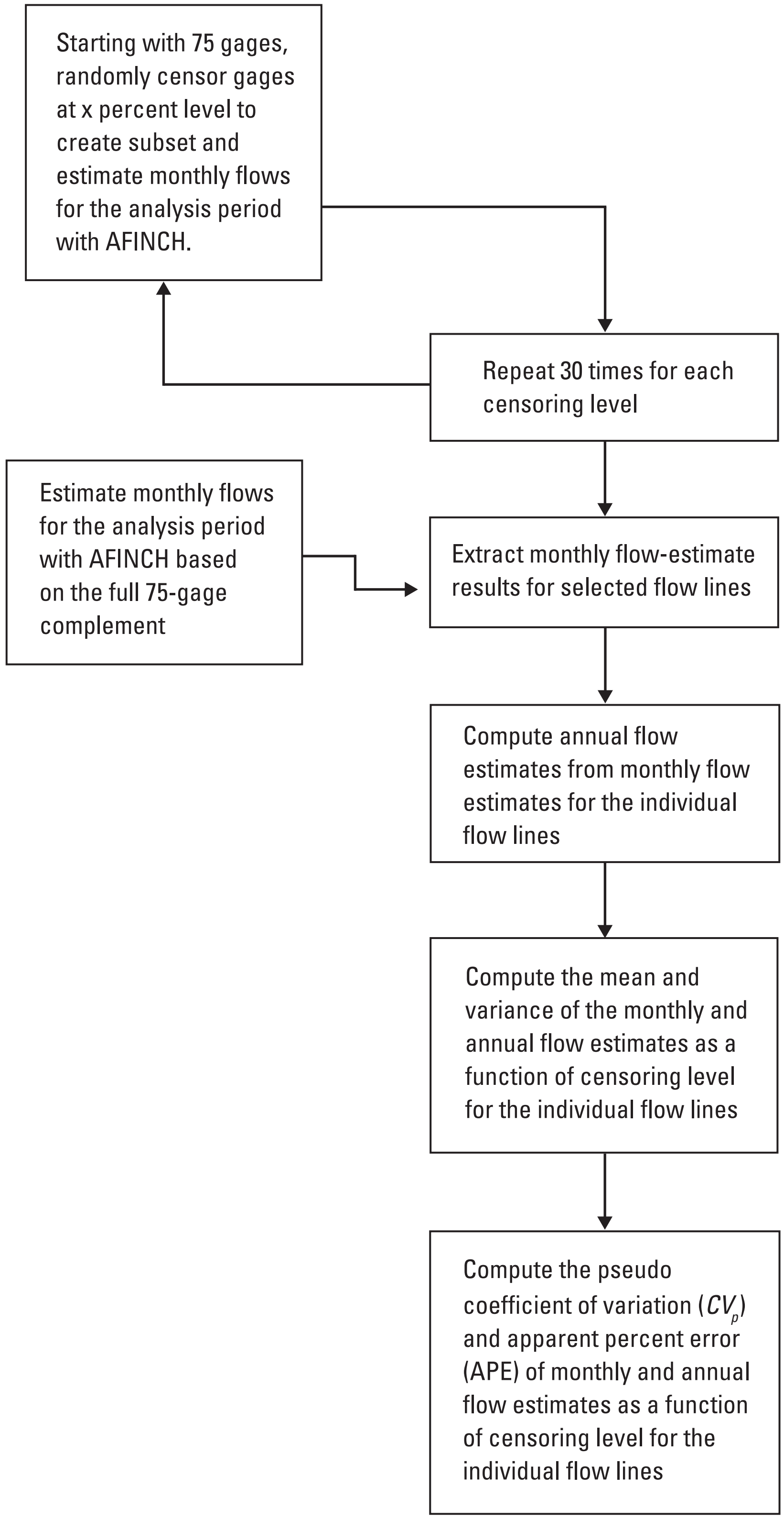


**Figure 3.** Schematic of steps leading to computation of the pseudo coefficients of variation and apparent percent errors.

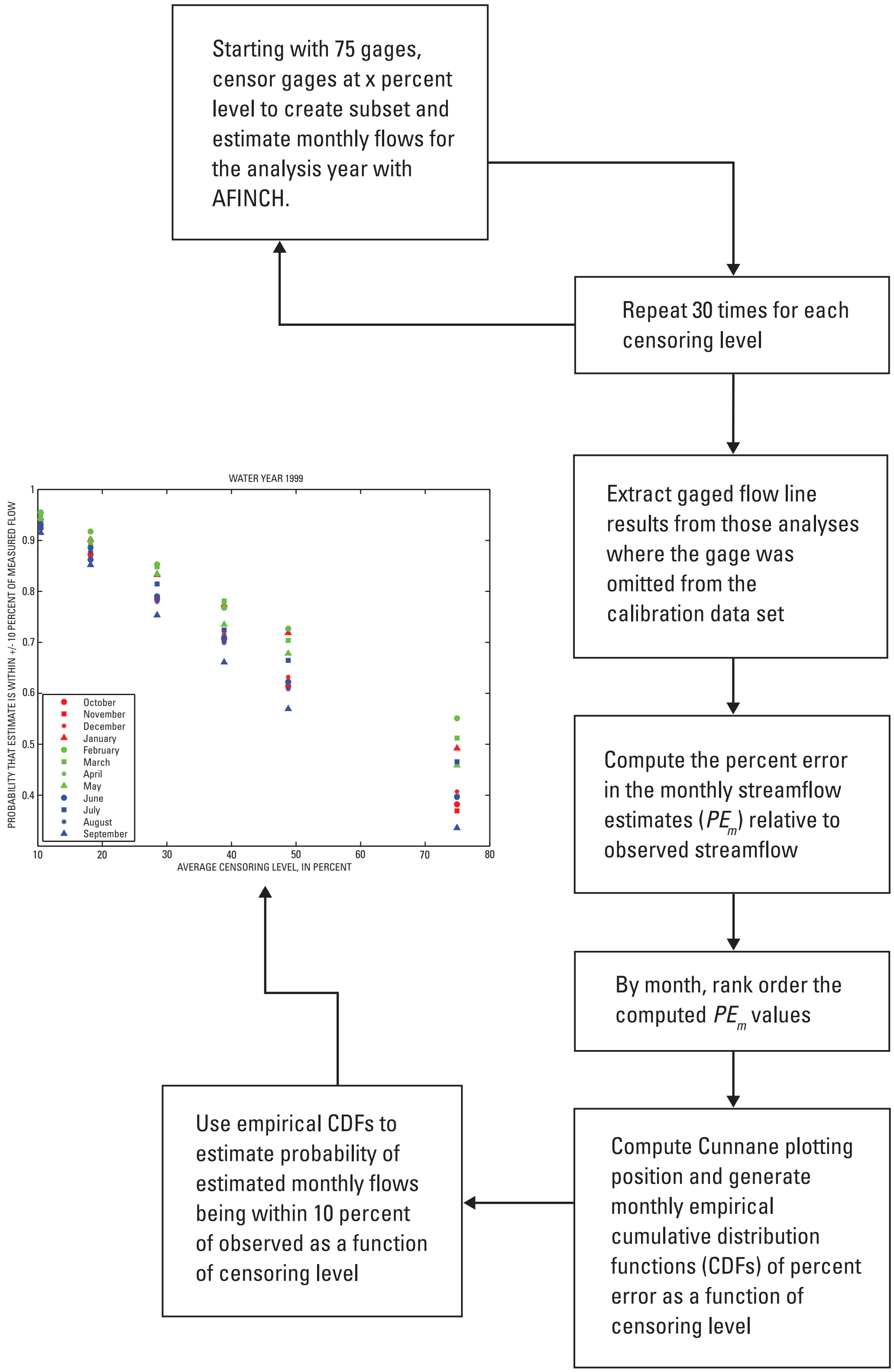


**Figure 4.** Schematic of “missing gage” analysis steps.

# Results

Data from six flow lines initially will be used to discuss and illustrate the results. The flow lines were chosen to represent a variety of types (as discussed earlier) and drainage areas (table 1). The results are interpreted based on the assumption that the AFINCH model produces the most accurate flow estimates when all available gage data are used in the model, an assumption that may or may not be true. Based on that assumption, (in most cases) variance and error measures initially are scaled relative to flow estimates obtained when the full complement of gages is used. The flow line for COMID 9019553 had a gage located on it, and as such was treated as a special case, as discussed below.

A pseudo coefficient of variation ($CV_p$) was computed for each flow line and censoring level. To facilitate comparisons of results between flow lines, each $CV_p$ for a given flow line was divided by the $CV_p$ for the 10-percent censoring level to compute a pseudo coefficient of variation ratio ($CV_p$ ratio). Consequently, the $CV_p$ ratios for the various censoring levels represent multiples of the $CV_p$ for the 10-percent censoring level.

Average $CV_p$ ratios for water-year flows (determined by summing the annual $CV_p$ ratios for each water year and dividing by 33 (the number of water years)) are plotted as a function of censoring level in figure 5. COMID 9019553 received special treatment (as mentioned previously), and data for that flow line were computed two ways. As discussed earlier, when a gage is operated in a reach corresponding to a flow line (as was true for COMID 9019553), AFINCH constrains the flow estimates to be equal to the flows observed at the gage. Consequently, whenever the gage was included in the network for a given run, the estimated flow for the coincident flow line was constrained to equal the observed (gaged) flow. Because it is statistically likely that the gage will be retained in several, but not all, of the subsets at a given censoring level, the result is a reduction in the apparent pseudo coefficient of variation relative to a comparable flow line without a gage. To account for this, the pseudo coefficients of variation were computed based upon results from all 30 subsets for a given censoring level (reported as 9019553A) and based upon only those results for which the gage data were omitted from the calibration data set (reported as 9019553).

Figure 5 shows that average $CV_p$ ratios for water-year flows tended to increase as the network size decreased. For example, the average $CV_p$ ratio corresponding to a 75-percent censoring level ranged from about 2 to 5 times the $CV_p$ ratio at the 10-percent censoring level. This indicates that less precise (more variable) estimates resulted from smaller networks as compared to larger networks. In fact, for flow lines 9005805, 9019381, and 9019553, estimate variability was about 5 times greater at the 75-percent censoring level than at the 10-percent censoring level. Each of these flow lines effectively represents reaches in basins without gages (that is, type 1 flow lines). The remaining four flow lines (3468071, 3470628, 9019203, and 9019553A) also show a tendency toward increasing average $CV_p$ ratios for annual flows with increasing censoring; however, the $CV_p$ ratios tended to be smaller than comparable $CV_p$ ratios for the type 1 flow lines. This phenomenon likely is due to variance-stabilizing effects resulting from model constraints associated with having one or more gages operated in those basins. This result indicates that the precision of AFINCH flow estimates at ungaged given flow lines is improved by operation of one or more gages upstream and (or) downstream in the enclosing basin.

**Table 1.** Flow-line characteristics.

[NHDPlus, National Hydrography Dataset Plus; mi², square mile]

| COMID of flow line | Site type | Stream name | NHDPlus contributing drainage area (mi²) | Comment |
|---|---|---|---|---|
| 3468071 | 2 | Kalamazoo River | 1,533 | Several gages operated upstream and downstream. |
| 3470629 | 2 | South Branch Kalamazoo River | 86 | Several gages operated downstream, none upstream. |
| 9005805 | 1 | Crockery Creek | 161 | Ungaged. |
| 9019203 | 2 | South Branch Black River | 136 | One gage operated upstream during entire analysis period. |
| 9019381 | 1 | Brandywine Creek | 16 | Ungaged. |
| [a]9019553 | 3 | South Branch Black River | 87 | One gage in flow line operated during entire analysis period, no other constraining gages upstream or downstream. |

[a] Flow line referred to as 9019553A when computations were based on results from all 30 subsets for a given censoring level. Flow line referred to as 9019553 when computations were based on results for which the gage data were omitted from the calibration data set.

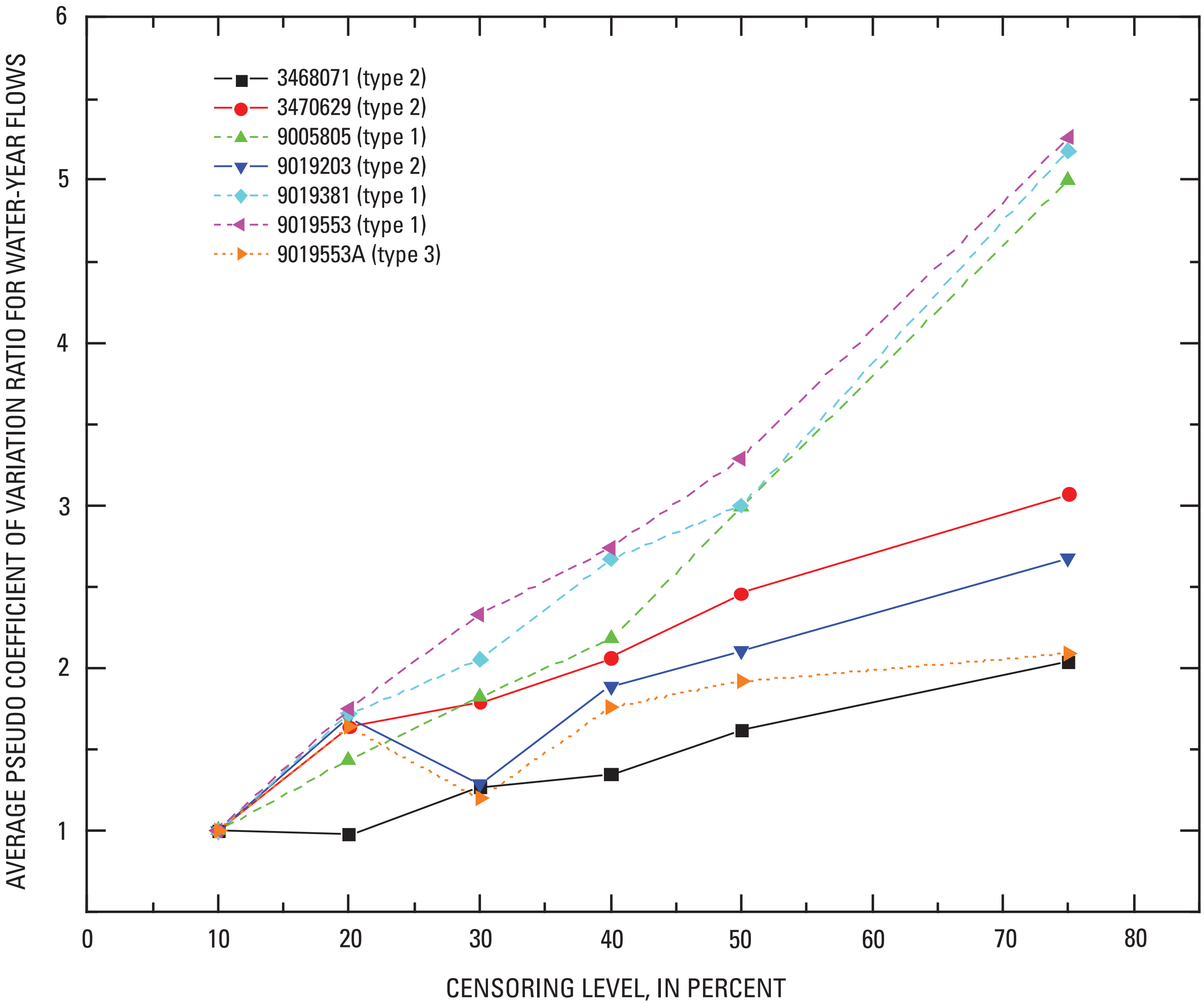


**Figure 5.** Average pseudo coefficient of variation ratios for water-year flows as a function of censoring level for selected flow lines in the 0405 (Southeast Lake Michigan) hydrologic subregion.

Monthly average $CV_p$ values corresponding to a 30-percent censoring level are plotted in figure 6 for the flow lines listed in table 1. Although it is reasonable to expect that more variable estimates might be associated with certain months or seasons of the year, figure 6 shows no clear-cut indication of seasonal trend in variability that is universal across all of the flow lines. A 30-percent censoring level was chosen for this illustration; however, other censoring levels yielded similar results. The three flow lines generally exhibiting the highest monthly average $CV_p$ values effectively represent type 1 flow lines. Again, the lower variability associated with the remaining flow lines from gaged basins likely is due to the variance-stabilizing effects of flow constraints imposed by the AFINCH model.

Average APEs for water-year flows (determined by summing the annual APEs for each water year and dividing by 33 (the number of water years)) are plotted as a function of censoring level in figure 7. COMID 9019553 received special treatment (as was true with the average $CV_p$ ratio analyses), and data for that flow line were computed two ways. Average APEs for annual streamflows were computed based upon results from all 30 subsets for a given censoring level (reported as 9019553A) and based on only those results for which the gage data were omitted from the model (reported as 9019553).

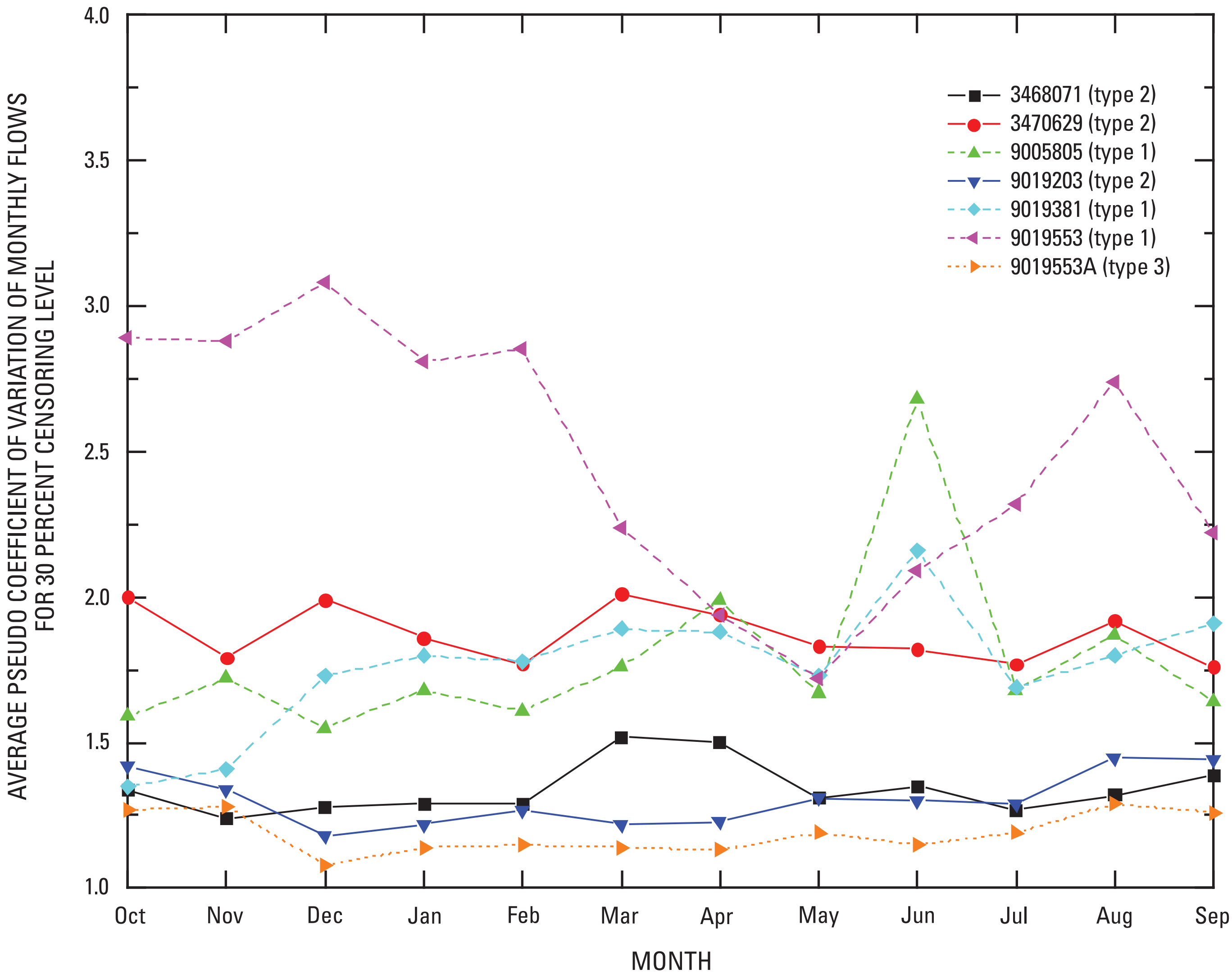


**Figure 6.** Average pseudo coefficients of variation of monthly flows for 30-percent censoring level as a function of calendar month for selected flow lines in the 0405 (Southeast Lake Michigan) hydrologic subregion.

Average APEs for annual flows tended to increase in absolute value with increasing censoring level (fig. 7). For most of the flow lines listed in table 1, average APEs for annual flows tended to become increasingly negative as the censoring level increased. The two flow lines (9005805 and 9019381) that exhibited the smallest absolute average APEs and smallest changes in average APEs as a function of increasing censoring level were both in ungaged basins (that is, type 1 flow lines). This counterintuitive result likely reflects both the nature of the base-streamflow estimate from which the APEs were computed and an insensitivity in the average estimates to changes in the gage-network size and composition (rather than the unlikely alternate hypothesis that lower estimate errors can be achieved in sparse gage networks by not operating gages in a basin). The larger APEs and increases in absolute average APEs with increased censoring observed for flow lines in gaged basins likely reflects a bias in the estimate (relative to the observed streamflow) resulting from relaxation of streamflow constraints when one or more gages in the basins were omitted from the network.

Flow line 9019553, which represents only those results where the gage that is located on that flow line (the only gage in the basin) was omitted from the analysis, has an average APE curve with gentle-slope characteristics similar to those for flow lines in ungaged basins (fig. 7); however, the average APE curve lies much farther from the zero error line than those of other basins. Unlike the other flow lines in figure 7, error results for flow-line 9019553 are reported as a

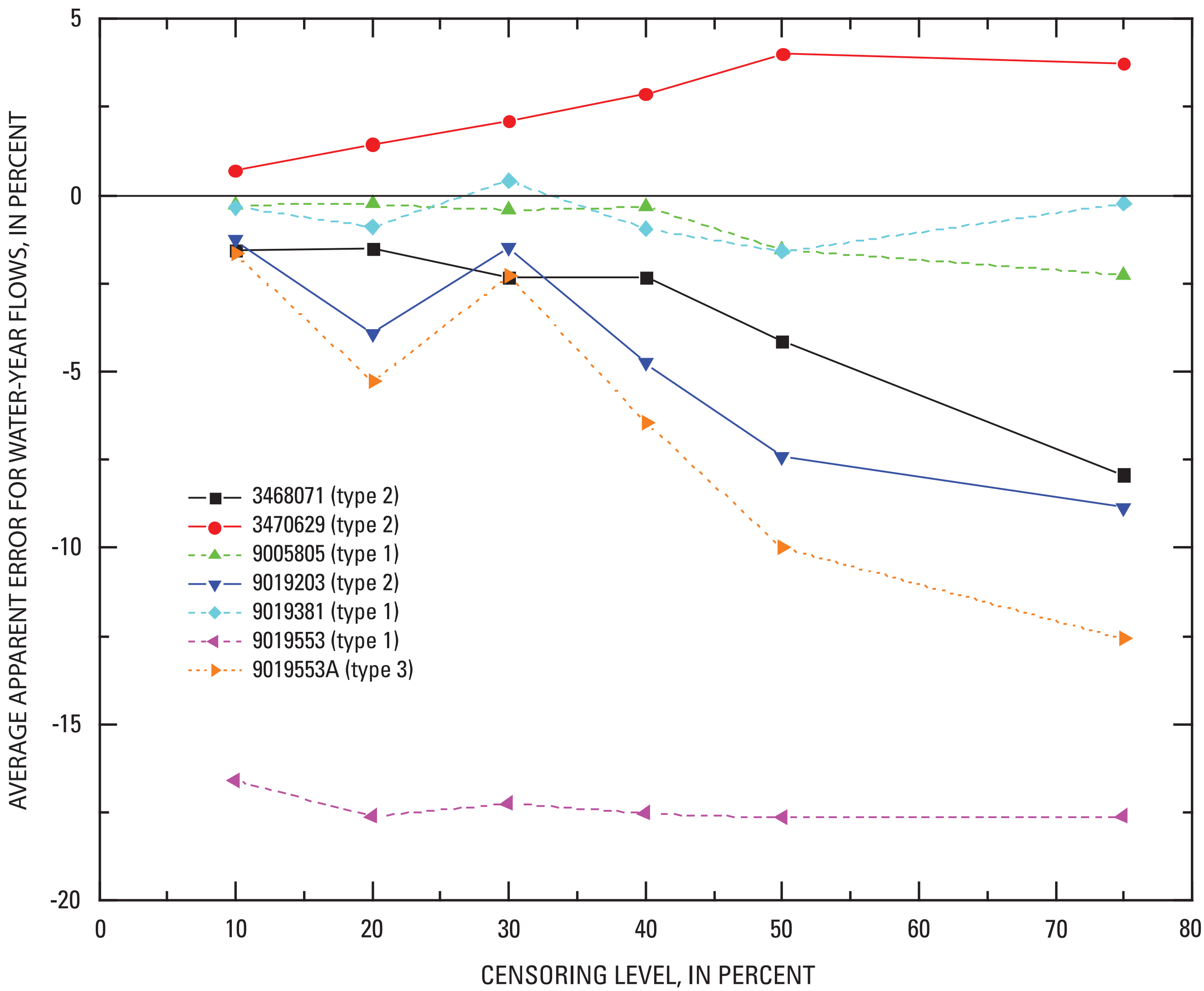


**Figure 7.** Average apparent percent errors in water-year flows as a function of censoring level for selected flow lines in the 0405 (Southeast Lake Michigan) hydrologic subregion.

percentage of the gaged flow and therefore represent the true average error in the AFINCH estimates (as opposed to other error estimates that are dependent upon the assumption that the AFINCH flow estimate for the full-gage complement is accurate). This result illustrates that the true average percent errors for the other flow lines have the potential to be much larger than presently indicated by the APEs when computed relative to the true, but unknown, flows.

Results of the “missing gage” analyses are shown in figures 8 and 9 for water years 1999 and 2000, respectively. The nominal censoring levels shown in these figures differ somewhat from each other and from those reported for the flow-line analyses because they were computed based only on data for the indicated water year. It is evident from figures 8 and 9 that the likelihood of AFINCH computing a monthly streamflow estimate within 10 percent of the measured value decreased appreciably as the network size was reduced. For example, in both 1999 and 2000, the probability of computing a monthly streamflow estimate within 10 percent of the true (observed) value was greater than 0.9 at about a 10-percent network-censoring level; however, that probability dropped to less than 0.6 as the censoring level approached 75 percent. The data shown in figures 8 and 9 also indicate that estimates for typically dry months (October and November) tended to be characterized by larger percent errors (as evidenced by the fact that those months exhibited smaller probabilities that the estimate was within plus or minus 10 percent of the observed value) than typically wetter months.

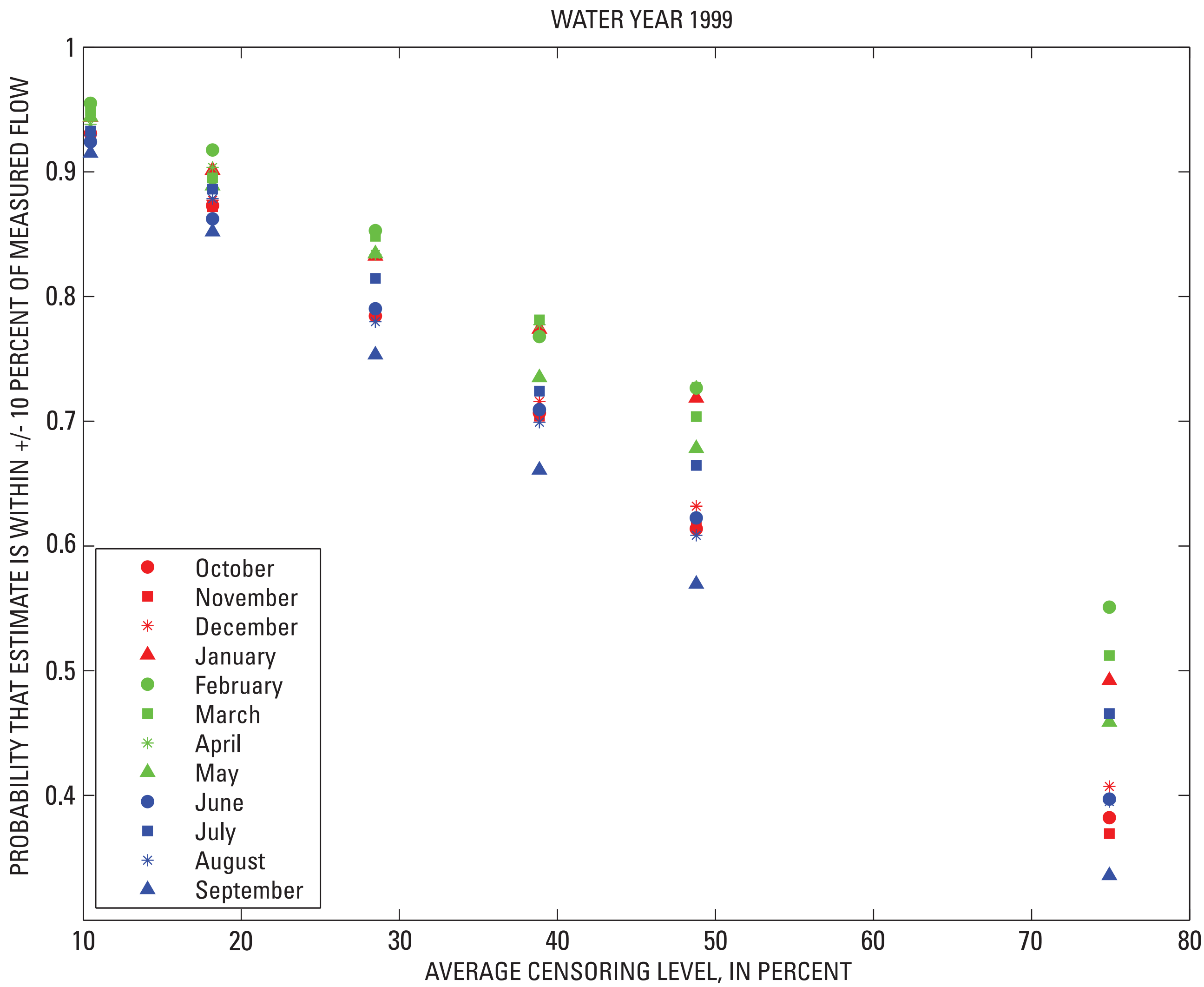


**Figure 8.** Relation between censoring level and probability of estimating monthly flow within 10 percent of measured value for the water year 1999.

# Summary and Conclusions

A computer application called AFINCH (Analysis of Flows In Networks of CHannels) was developed by the U.S. Geological Survey (USGS) to facilitate the estimation of monthly water yields and streamflows at multiple locations throughout large regions. AFINCH uses stepwise-regression techniques to estimate monthly water yields from catchments based on geospatial-climate and land-cover data in combination with available streamflow and water-use data. Water yields from contributing catchments are multiplied by their contributing areas to compute streamflows, which are accumulated to compute streamflows in stream reaches referred to as flow lines. Water yields and flow estimates are constrained by AFINCH to ensure that observed streamflows are conserved at gaged locations.

Bootstrapping techniques employing random subsampling were used with AFINCH to facilitate computation of selected statistical characteristics of monthly flow estimates at flow lines within the 0405 hydrologic subregion. This was done to gain insights into the effects of variation in streamflow-gaging-network size and composition on the accuracy and precision of streamflow estimates. Analyses were based on data for streamflow gages in the subregion that were operated in 1 or more water years from 1971 to 2003. Although AFINCH is capable of accounting for water uses, none were specified or considered in the analyses.

A program was developed and used to create 30 streamflow-gaging-network subsets for each of several censoring levels. Thirty subsets each were created by randomly censoring (that is, removing) streamflow gages corresponding to removals of approximately

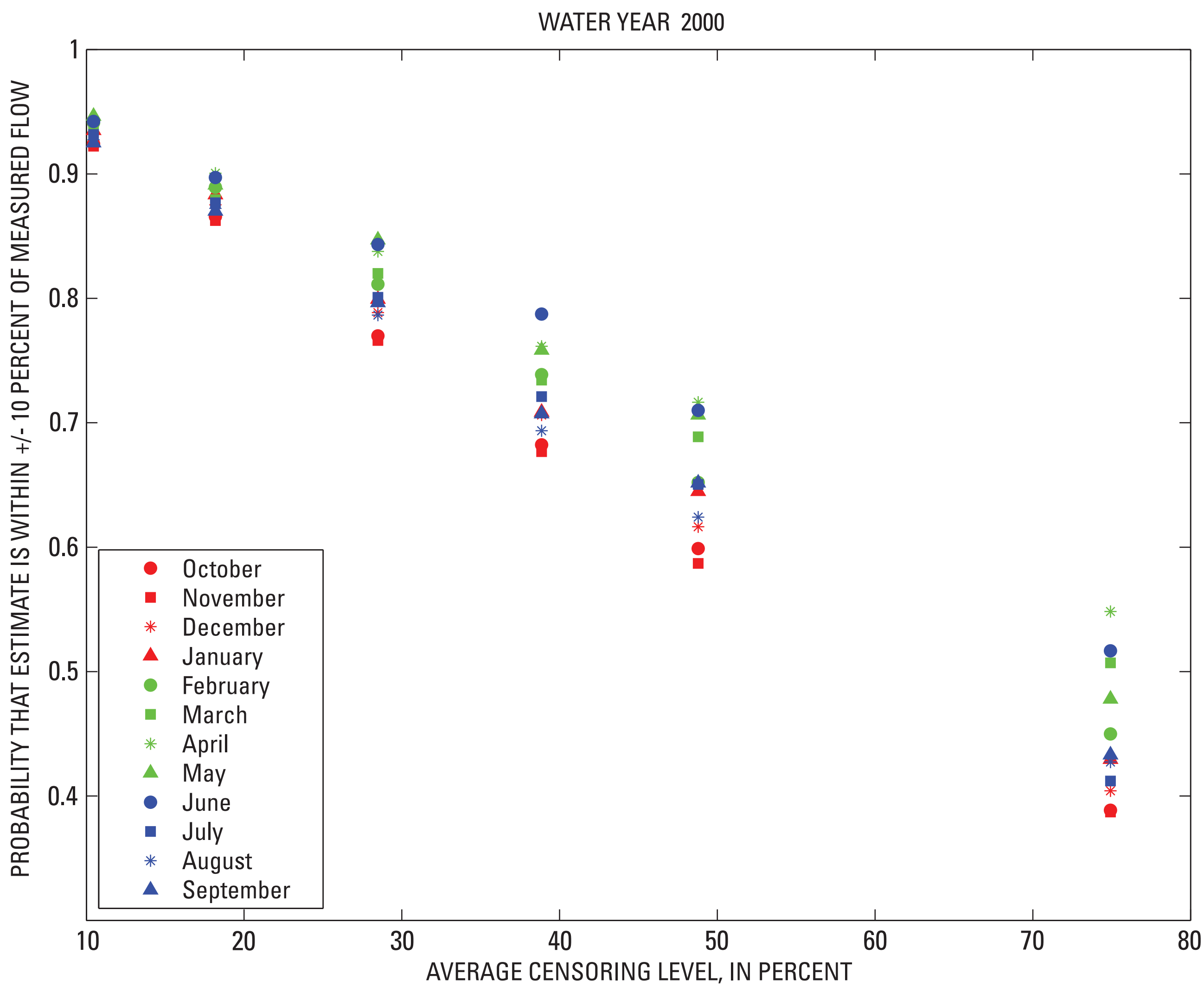


**Figure 9.** Relation between censoring level and probability of estimating monthly flow within 10 percent of measured value for the water year 2000.

10, 20, 30, 40, 50, and 75 percent of the 75 streamflow gages that were operated in 1 or more years during the analysis period. AFINCH was then used to compute flow estimates based on each subset streamflow-gaging-network and a preselected set of potential explanatory variables (monthly total precipitation and monthly mean temperature). Estimates were aggregated by censoring level and results for six flow lines were analyzed to assess (a) how the size and composition of the streamflow-gaging network affected the average apparent errors and variability of the estimated flows and (b) whether results for certain months were more variable than for others.

Average pseudo coefficient of variation ($CV_p$) ratios for water-year flows tended to increase as the network size decreased. For example, $CV_p$ ratios corresponding to a 75-percent censoring level ranged from about 2 to 5 times the $CV_p$ ratio at the 10-percent censoring level. Results such as these indicate that less precise (that is, more variable) estimates resulted from smaller networks as compared to larger networks. When streamflow gages are present in the basin, $CV_p$ ratios tended to be smaller than comparable $CV_p$ ratios for flow lines in ungaged basins, probably due to variance-stabilizing effects resulting from flow constraints imposed by AFINCH. Not surprisingly, this result indicates that the precision of AFINCH flow estimates at a given flow line will be improved by operation of one or more streamflow gages upstream and (or) downstream in the enclosing basin.

Monthly average $CV_p$ values were examined to assess whether streamflow estimates at flow lines typically were more variable in particular months or seasons of the year. No clear-cut indication of a seasonal trend in variability was evident.

Average apparent percent errors (APEs) for annual flows tended to increase in absolute value with increasing censoring level. The flow lines that exhibited the smallest absolute average APEs and smallest changes in average APE as a function of increasing censoring level were both in ungaged basins. These counterintuitive results likely reflect both the base-streamflow estimate from which the APEs were determined and insensitivity in the average estimates to changes in the streamflow-gaging-network size and composition. The larger average APEs and increases in average APE with increased censoring observed for flow lines in gaged basins likely reflects a bias in the estimate (relative to the measured streamflow) resulting from relaxation of streamflow constraints when one or more streamflow gages in the basins were omitted from the network.

Data for a flow line (9019553) that contained a streamflow gage were analyzed in a special fashion to assess the accuracy and precision of estimates produced only when the streamflow gage on the flow line was omitted from the calibration network. Precision characteristics of water-year flow estimates associated with the flow line when the streamflow gage was omitted from the calibration network were similar to those of flow lines in ungaged basins in that the overall slope of the relation between censoring level and average APE for water-year flows was relatively gentle. However, the magnitudes of the errors, in this case measured relative to the observed flows, was much larger than for other flow lines examined where the errors were measured relative to estimates produced using the full-gage complement. This last result indicates that the average percent errors for the other flow lines have the potential to be much larger than indicated by the average APEs were they reported relative to their true (but unknown) flows.

“Missing gage” analyses, based on examination of censored-subset results where the streamflow gage of interest was omitted from the calibration data set, were performed for all flow lines that contained a streamflow gage. Those analyses were done by examining only those monthly flow estimates for each gaged flow line that resulted from censoring subsets for which the given streamflow gage was omitted from the network. The percentage differences between the estimated and observed monthly streamflows (relative to the observed streamflows) for all of the flow lines gaged in a given water year were aggregated by censoring level and used to compute probabilities that the estimated monthly flows were within plus or minus 10 percent of the observed flows. Results examined for water years 1999 and 2000 indicated that the probability of AFINCH computing monthly streamflow estimates within 10 percent of the true (measured) value decreased from greater than 0.9 at about a 10-percent network-censoring level to less than 0.6 as the censoring level approached 75 percent. In addition, estimates for typically dry months tended to be characterized by larger percent errors than typically wetter months.

It is cost prohibitive to operate streamflow gages at all locations where data are desired; consequently, models like AFINCH are useful for extending the limited site-specific streamflow data that are available. Given that models like AFINCH will be used, it is important to understand the implications of streamflow-gaging-network size and composition on the accuracy and precision of flow estimates. The results described in this report are specific to both the AFINCH model and the hydrologic subregion analyzed; however, similar patterns in the accuracy and precision of flow estimates might be expected from any regression-based model that likewise constrains flow estimates on the basis of streamflow-gage data. In basins that contain one or more streamflow gages, the flow and water-use constraint features of AFINCH should frequently result in flow estimates that are more accurate than would be expected from a more traditional regression-based model without flow constraints. Although not tested, AFINCH’s ability to account for water uses may facilitate more accurate estimates and (or) the use of more streamflow-gage data for model calibration than more traditional regression-based models without water-use constraints.

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