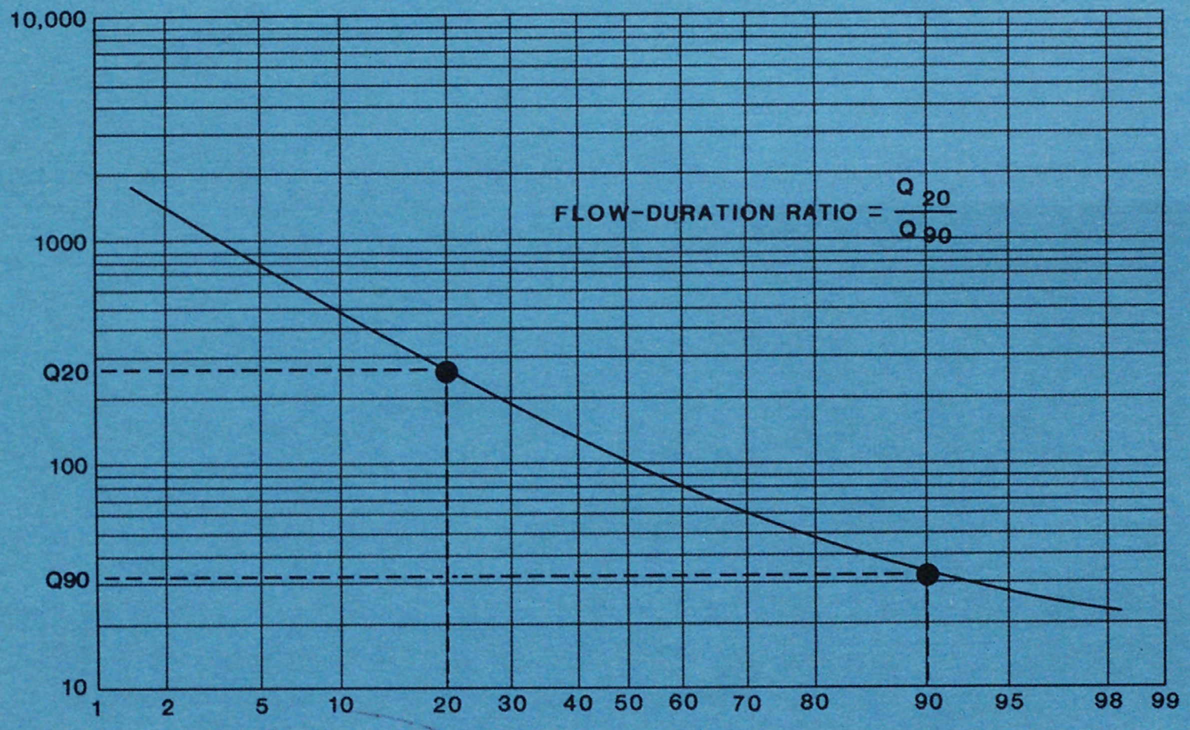
METHOD FOR ESTIMATING LOW-FLOW CHARACTERISTICS OF UNGAGED STREAMS IN INDIANA

U.S. GEOLOGICAL SURVEY

Open-File Report 86-323



Prepared in cooperation with the

INDIANA STATE BOARD OF HEALTH

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By Leslie D. Arihood and Dale R. Glatfelter

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Indianapolis, Indiana

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UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

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Multiply inch-pound units	By	To obtain Metric units
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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By Leslie D. Arihood and Dale R. Glatfelter

ABSTRACT

Equations for estimating the 7-day, 2-year and 7-day, 10-year low flows at sites on ungaged streams are presented. Regression analysis was used to develop equations relating basin characteristics and low-flow characteristics at 82 gaging stations. Significant basin characteristics in the equations are contributing drainage area and flow-duration ratio, which is the 20-percent flow duration divided by the 90-percent flow duration. Flow-duration ratio has been regionalized for Indiana on a plate in this report. Ratios for use in the equations are obtained from this plate. Drainage areas are determined from maps or are obtained from reports.

The predictive capability of the method was determined by tests of the equations and of the flow-duration ratios on the plate. The accuracy of the equations alone was tested by estimating the low-flow characteristics at 82 gaging stations where flow-duration ratio is already known. In this case, the standard errors of estimate for 7-day, 2-year and 7-day, 10-year low flows are 19 and 28 percent. When flow-duration ratios for the 82 gaging stations are obtained from the map, the standard errors are 46 and 61 percent. However, when stations with drainage areas less than 10 square miles are excluded from the test, the standard errors reduce to 38 and 49 percent. Standard errors increase when stations with small basins are included, probably because some of the flow-duration ratios obtained for these small basins are incorrect. Local geology and its effect on the ratio are not adequately reflected on the plate, which shows the regional variation in flow-duration ratio. In all the tests, no bias is apparent areally, with increasing drainage area or with increasing ratio.

Guidelines and limitations should be considered when using the method. The method can be applied only at sites in the northern and the central physiographic zones of the State. Low-flow characteristics can not be estimated for regulated streams unless the amount of regulation is known so that the estimated low-flow characteristic can be adjusted. The method is most accurate for sites with drainage areas ranging from 10 to 1,000 square miles and for predictions of 7-day, 10-year low flows ranging from 0.5 to 340 cubic feet per second.

INTRODUCTION

Background

Low-flow data are essential to proper management of water resources. A common use of low-flow data is for determining the permissible rate of disposing waste into a stream. For example, the Indiana State Board of Health uses the 7-day, 10-year low flow as a criterion for wasteload allocation. Low-flow data also aid in determining availability of water for municipal and industrial supplies, irrigation, recreation, and protection of the aquatic environment.

The U.S. Geological Survey has determined several low-flow characteristics at stream sites in Indiana where streamflow has been measured (Stewart, 1983). Characteristics investigated in this report are 7Q2 (7-day, 2-year low-flow) and 7Q10 (7-day, 10-year low-flow). The 7Q2 and 7Q10 are the average discharges for 7 consecutive days below which streamflow recedes on the average once every 2 and 10 years. Stewart (1983) presents 7Q2 and 7Q10 for 208 continuous-record gaging stations and 258 partial-record stations in Indiana. However, many stream sites for which low-flow data are required do not have any streamflow measurements on which to base estimates of 7Q2 and 7Q10. Therefore, in 1983 the U.S. Geological Survey began a study in cooperation with the Indiana State Board of Health to develop a method for estimating 7Q2 and 7Q10 for sites on ungaged streams.

Purpose and Scope

The purpose of this report is to present equations for use in estimating low-flow characteristics 7Q2 and 7Q10 for sites on ungaged streams in Indiana. Regression analysis was used to develop equations that describe the relation between basin and low-flow characteristics at 82 gaging stations. The same relation is used to estimate low-flow characteristics at ungaged sites. The equations for estimating 7Q2 and 7Q10 can be applied to all sites on unregulated streams in northern and central Indiana with (1) drainage areas less than 1,000 mi^2 and (2) 7Q10's greater than zero.

Climate and Physiography

Climate and the geology are the major factors controlling the low-flow characteristics at any point on a stream. Climate controls the input to and some of the loss from the hydrologic system; geology controls the transmissivity and storage. Together they determine the magnitude of the low-flow characteristics. The geographic variation of these factors, plus the size of the drainage area, accounts for most of the variation in low-flow characteristics among streams. Other factors such as the percent of drainage area covered by forest, slope of the channel, and percent of drainage area covered by lakes have a lesser effect.

The two climatic factors affecting low flow are precipitation and evapotranspiration. Average annual precipitation ranges from 34 inches in the northeast part of the State to 44 inches in the south-central part (Stewart, 1983, p. 7). Potential evapotranspiration generally increases from 34 inches in the northeast to 38 inches in the southwest (Farnsworth and others, 1982, map 3).

Indiana can be divided into three general physiographic zones (Schneider, 1966, p. 42). Streamflow characteristics in each zone are discussed here along with the physiography. For convenience, the zones are called the northern, central, and southern zones (fig. 1). The central zone, a depositional plain of low relief, is underlain by thick till that has been modified by post-glacial stream erosion. In general, relief in the northern and the southern zones is greater than that in the central zone. However, they also include some areas of plains having low relief. The following discussion of the three zones is based on Schneider (1966).

Northern Zone

The northern zone, or the Northern Moraine and Lake Region, consists of the Calumet lacustrine plain, the Valparaiso morainal area, the Kankakee outwash and lacustrine plain, the Steuben morainal lake area, and the Maumee lacustrine plain. The Calumet lacustrine plain consists of a stair-stepping progression of ancient beaches representing successive stages of glacial Lake Chicago. These beaches range from 590 to 640 ft in altitude. The highest one is 60 ft above Lake Michigan. Industrialization of the area makes determination of natural low-flow characteristics difficult.

The Valparaiso morainal area, whose topography ranges from hilly to an undulating till plain, is 150 ft higher than the neighboring Calumet lacustrine plain. Ice-block and peat-filled lakes are common in the entire morainal area but are more common in the knob-and-kettle topography of the northeast-southwest-trending part of the area (fig. 1). Low-flow data are sparse, except in the southern part where sustained flow is high.

The Kankakee outwash and lacustrine plain is a low and poorly drained area underlain mostly by sand from valley train and outwash deposits. These features give this area a high sustained flow.

The topography of the Steuben morainal lake area is rugged, owing to an abundance of glacial features such as moraines and morainal lakes, kames, eskers, melt-water channels, and ice-block lakes. The diverse valleys may contain streams, clay beds, or swamps, or may have internal drainage. Sustained base flow in the area is as diverse as the geology.

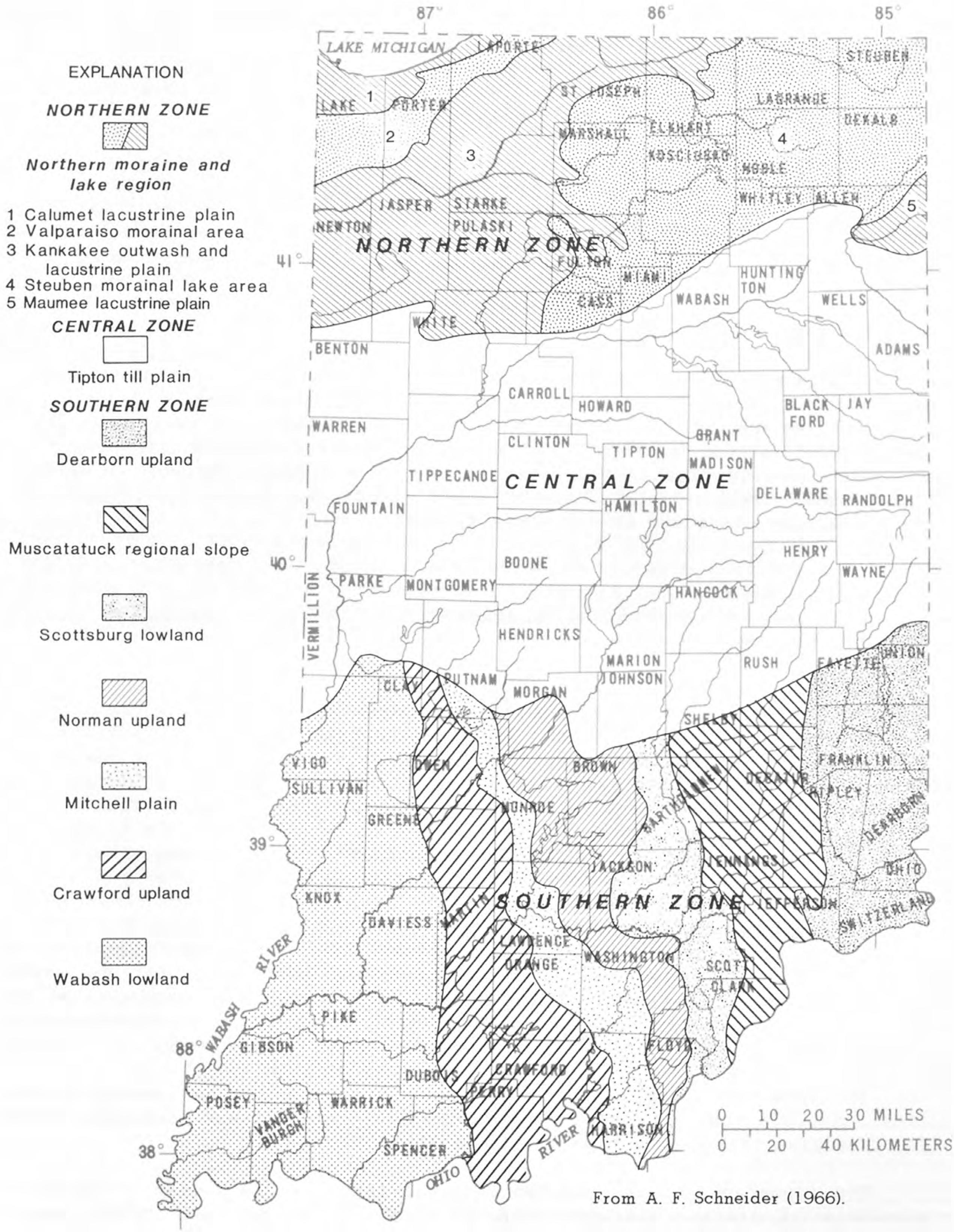


Figure 1.-- Physiography of Indiana.

The Maumee lacustrine plain is a nearly level plain formed by glacial Lake Maumee. Low-flow characteristics of this small area are controlled by a combination of features of the central zone and the Steuben morainal lake area of the northern zone.

Central Zone

The central zone consists of one major physiographic region, the nearly flat to rolling Tipton till plain. This plain is broken by only a few eskers and erosional valleys formed by melt water. The zone also contains several poorly developed end moraines of low relief. Because the surficial geology is nearly uniform, variability in base flow is probably due to the distribution of aquifer material in the zone.

Southern Zone

Physiography of the southern zone, probably the most diverse of the three zones, consists of seven units: the Dearborn upland, the Muscatatuck regional slope, the Scottsburg lowland, the Norman upland, the Mitchell plain, the Crawford upland, and the Wabash lowland. Streams having drainage areas as large as 250 mi^2 may not support year-round flow. However, smaller streams in outwash aquifers, at spring sites, and in karst areas commonly have continuous flow.

The Dearborn upland, a dissected plateau formed by flat-lying limestone of Ordovician age, is overlain by 15 ft of drift in the south to 50 ft in the north. This unit is dissected by deeply entrenched streams forming rugged V-shaped valleys.

Altitude of the Muscatatuck regional slope ranges from 725 ft at its west edge to 1,100 ft at the north end, and from 500 to 875 ft along the south end. Carbonate rock is overlain by drift generally ranging in thickness from 5 to 10 ft in the Pleistocene glaciated area of the south to 150 ft in the buried (Wisconsin) valleys of the north edge of the slope.

The Scottsburg lowland is a valley formed by erosion of nonresistant shales along the strike of bedrock. The north part of this valley is covered with drift as thick as 150 ft that makes the unit hard to detect.

The Norman upland is characterized by great relief consisting of steep slopes and narrow divides. However, many of the valley floors have been flattened by outwash. The area is underlain by siltstone that is generally erosion resistant and by soft interbedded shale. The great relief provides good drainage of the area.

The Mitchell plain is characterized by karst topography, the result of solution weathering. Numerous solution features and sinkholes are evident. Runoff is rapid, but the drainage areas are difficult to determine because much of the runoff flows into sinkholes and, thus, into numerous underground passages. At times, flow may leave the channel only to return to the streambed at a downstream location. In extreme cases, flow may be diverted to completely different streambeds.

West of the Mitchell plain lies the Crawford upland, a deeply dissected area of narrow but flat river valleys, like those in the Norman Upland. The east part contains numerous springs and caverns in the Mississippian Limestone. In general, the area is well drained.

The broad Wabash lowland, west of the Crawford upland, is the largest physiographic feature in the southern zone. Underlain by nearly nonresistant siltstone and shale of Pennsylvanian age, it had been eroded to a lowland flat tract by the beginning of the Pleistocene time. The lowland is covered by till and, in addition, is underlain by widespread lacustrine, outwash, and alluvial sediments. Drainage, which is poor in some parts of the lowland, has been largely modified by man.

DESCRIPTION OF DATA BASE

The data used in the regression analysis consist of low-flow characteristics and basin characteristics. The low-flow characteristics used as dependent variables in the regression analysis are from 82 of the 208 gaging stations. Low-flow characteristics were determined by a mathematical procedure that fitted a Pearson type III distribution to the logarithms of the flow data. The analysis for low-flow characteristics at each station used data from the beginning of record through the 1982 water year.

The 82 stations are distributed uniformly throughout the northern and central physiographic zones of the State (fig. 2). No stations from the southern zone were used in the analysis because in that area 7Q2 and 7Q10 are almost always zero. Stations where low-flow characteristics are zero were not included in the regression analysis because the data were transformed into base 10 logarithmic (log) units before analysis. Basins where 7Q10 is zero are shown in figure 3. The few stations in the southern physiographic zone where 7Q10 is greater than zero are listed in Stewart (1983).

The number of gaging stations used in the analysis was only 82 because of drainage area and regulation criteria. Stations were not used if their drainage area was greater than 1,000 mi^2 or if the stream was regulated. Basins larger than 1,000 mi^2 either have low-flow characteristic data available or contain some streams that are regulated.

Basin characteristics were used as independent variables in the regression analysis. The characteristics tested for their usefulness in estimating 7Q2 and 7Q10 are given in the following list:

1. Recession index: the number of days required for streamflow to decrease by one log unit during the low-flow period of a recession.

2. Total drainage area: the area contributing directly to surface runoff.

3. Contributing drainage area: the total drainage area minus the area of internal drainages.

4. Soil-runoff coefficient: a coefficient that relates storm runoff to the soil permeability of the five hydrologic soil groups as defined by Davis (1974, fig. 5).

5. Mean annual precipitation: the 1941-70 average annual precipitation (U.S. Department of Commerce, 1973).

6. Channel slope: the slope of the streambed between points that are 10 and 85 percent of the distance from the location on the stream to the basin divide.

7. Channel length: the distance measured along the main channel from the location on the stream to the basin divide.

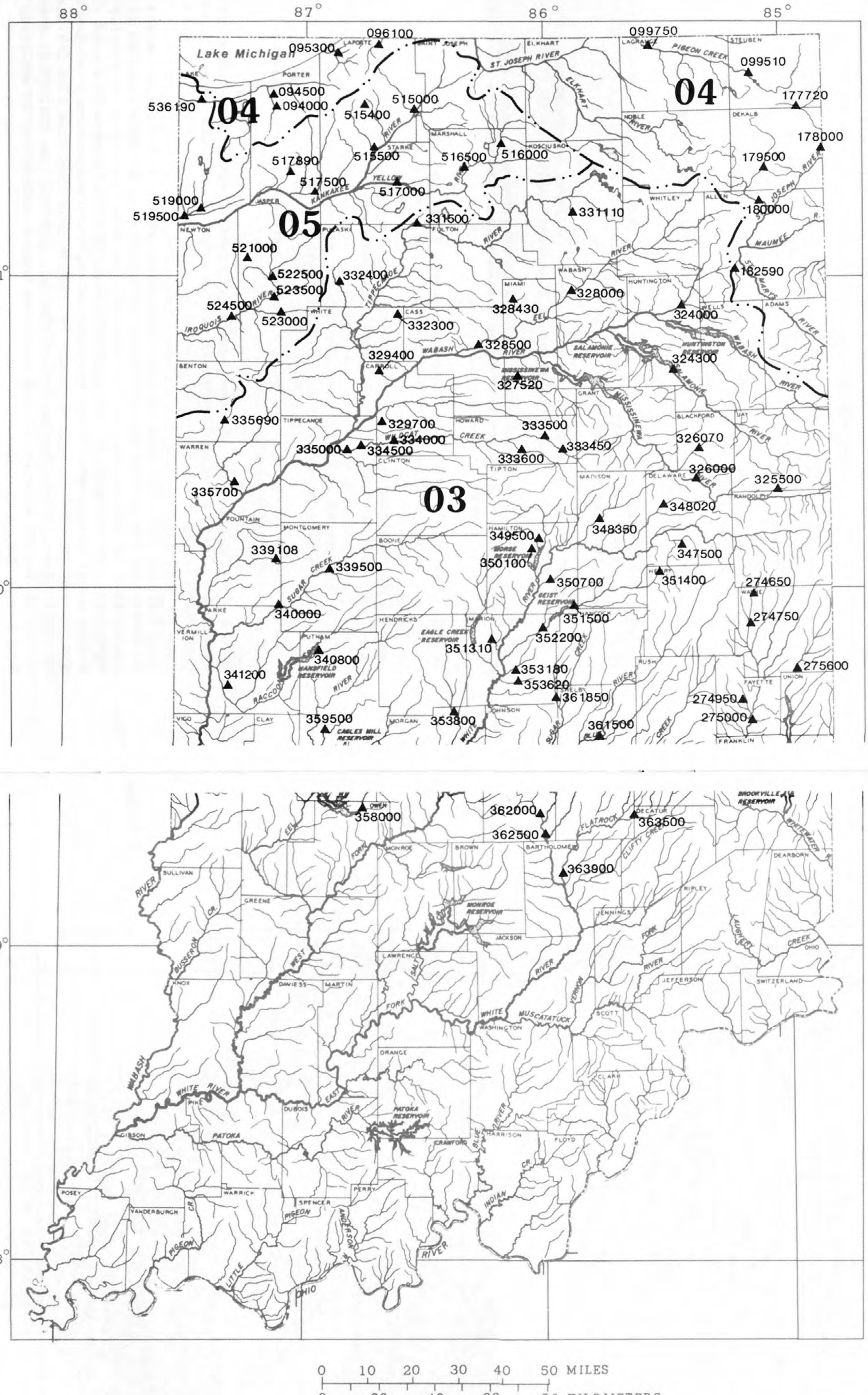
8. Surface storage: the percentage of the contributing drainage area covered by lakes, ponds, and wetlands.

9. Flow-duration ratio: the flow at the 20-percent flow duration divided by the flow at the 90-percent duration.

10. Forest cover: the percentage of the contributing drainage area covered by forest.

Except for total drainage area, recession index, and flow-duration ratio, values for these basin characteristics at the 82 stations are listed in Glatfelter (1984, table 3).

The data base of basin and low-flow characteristics was assembled for use in developing the estimating equations. The equations are more accurate if the independent variables are in the range of the data base used to develop the equations. For example, if the equations were developed from a data base where all drainage areas were about the same size, then the estimate of low-flow characteristics will be more accurate for basins near that size than for basins of other sizes. The distribution of the data and what the distribution means to the potential accuracy of the equations can be determined by analyzing the data in the next two tables.



EXPLANATION

361650 Continuous-record station and number. Complete number includes part number.

04 Part number

—·· — Boundary of basin

Figure 2.-- Locations of continuous-record gaging stations used in the analysis of low flow.

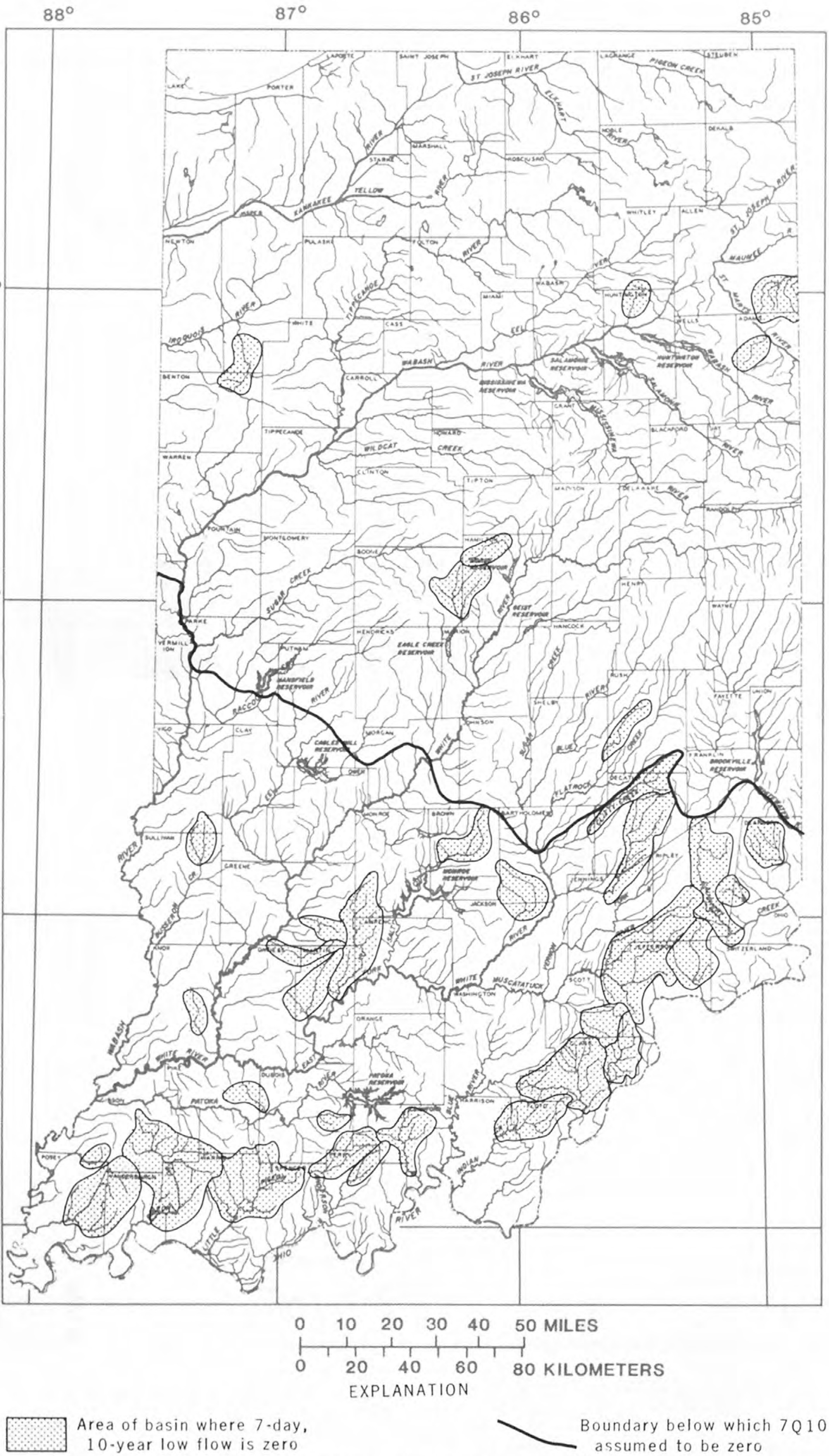


Figure 3.-- Basins where 7-day, 10-year low flow is zero.

Two patterns can be seen from the data in table 1. First, the number of gaging stations is about the same for each subdivision even though the drainage area limits and the range of those limits increase. In other words, data from fewer stations on streams with larger drainage areas were used to develop the estimating equations. Second, the average years of record is longer for stations having larger drainage areas. Thus, greater confidence can be placed on low-flow data from stations having larger drainage basins.

Table 1.--Summary of drainage areas and years of record for the 82 gaging stations used in the regression analysis

[mi^2, square mile]

Drainage area (mi^2)	Range	Number of gaging stations in range	Average years of record for stations in range
<25	25	16	13
25-75	50	17	18
75-150	75	16	23
150-325	175	16	27
325-1,000	675	17	35

Low-flow data in table 2 follow the same pattern as the drainage-area data in table 1. The number of gaging stations is about the same for each subdivision even though the 7Q10 limits and the range of those limits increase. Thus, data from fewer stations having larger values of 7Q10 were used in the regression analysis. However, the larger values of 7Q10 are generally associated with stations having larger drainage areas and longer periods of record.

Table 2.--Summary of low-flow data used in the regression analysis

[ft^3/s, cubic feet per second]

7Q10 (ft^3/s)	Range	Number of gaging stations
<0.8	0.8	17
0.8-2.75	1.95	16
2.75-7.0	4.25	15
7.0-20	13.0	16
20-340	320	18

Tables 1 and 2 are summaries of the data used in the regression analysis. Table 4, which follows the references, is a complete listing of the data from the 82 gaging stations used in the regression analysis to develop the final equations.

DEVELOPMENT OF METHOD FOR ESTIMATING LOW-FLOW CHARACTERISTICS

Regression Analysis

Regression analysis was used to develop the relation between 7Q2 and 7Q10 and basin characteristics for 82 gaging stations in Indiana. Independent variables (basin characteristics) and dependent variables (low-flow characteristics) were transformed to logarithmic units before regression analysis and the equations were developed in logarithmic form. The equations, which relate the most significant basin characteristics to 7Q2 and 7Q10, are of the form:

$$\log 7Q(2,10) = \log a + b \log A + c \log B + \ldots + n \log N$$

or

$$7Q(2,10) = a\, A^{b}\, B^{c} \ldots N^{n}$$

where

a is the regression constant,

A,B,...N the basin characteristics,

and

b,c,...n the regression coefficients.

After the equations are developed, they can be used to estimate low-flow charcteristics for ungaged sites by inputting the associated basin characteristics from the ungaged sites into the equations.

Stepwise regression procedures were used to determine the equations for 7Q2 and 7Q10. Backward elimination and maximum R^2 improvement procedures (SAS Institute, Inc.[1], 1979, p. 391) were used to determine the basin characteristics most useful in determining low-flow characteristics. The backward elimination procedure indicates which basin characteristics produce F-statistics that are significant at the 10-percent level in estimating 7Q2 and 7Q10. The maximum R^2 improvement procedure gives the equation having the highest R^2 (coefficient of determination) for a specific number of basin characteristics in the equation.

In the beginning of the analysis, equations were developed by stepwise regression procedures for different areas of the State. Developing equations for each area should more accurately estimate low-flow characteristics for that area. The State was divided into areas on the basis of a particular

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[1]Use of brand and firm trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

hydrologic or physiographic property. Several divisions of the State were done: surficial geology, major river basins, ground-water availability, thickness of drift, glaciation, hydrologic soil groups, and physiography. Data for the gaging stations were grouped into each area on the basis of station and basin location. Regression analysis of the data grouped by area was then used to develop equations for estimating 7Q2 and 7Q10 for each area. Standard errors of estimate were compared to determine the most accurate equations and best division of the State.

After testing various regionalizations, it was found only one equation for estimating 7Q2 and one for 7Q10 were necessary for the northern and the central physiographic zones. Dividing the State into areas of similar hydrology or physiography is not necessary when flow-duration ratio and contributing drainage area are used in the estimating equations. The standard error of estimate for equations that estimate 7Q10 without flow-duration ratio is about 100 percent in the central part of the State, regardless of the method of regionalization. However, with flow-duration ratio and drainage area calculated at the gaging stations, the standard error is only 28 percent for the equation estimating 7Q10. The final equations are:

$$7Q2 = 1.69(DA)(RATIO^{-1.20})$$

and

$$7Q10 = 1.66(DA^{1.03})(RATIO^{-1.51})$$

where

DA is contributing drainage area in square miles,

and

RATIO is flow-duration ratio, the 20-percent flow duration divided by the 90-percent duration.

The exponents on each independent variable are logical considering the variables' relation to low flow. As DA increases, the low-flow characteristic increases, but as RATIO increases, the low flow characteristic decreases. The inverse relation between the low-flow characteristic and RATIO is logical because of the definition of RATIO: the 20-percent flow duration divided by the 90-percent flow duration. A large RATIO is an indicator of a rapid decrease in streamflow during the recession period, and, consequently, a small low-flow characteristic. The negative exponent on RATIO results in a smaller low-flow characteristic given a larger RATIO.

A correction factor is incorporated into the preceding equations to account for the bias generated by detransforming the linear form of the equations into the exponential form presented in this report. The regression analysis involved use of the logs of the data and development of a log equation that expressed a linear relation between low-flow and basin characteristics. When the linear equations were detransformed, the resulting exponential equations estimated the median low-flow characteristic instead of the mean. Because the mean is desired, the exponential equations must be multiplied by:

$$\exp\left[\frac{(SE \times 2.303)^2}{2}\right]$$

where

SE is standard error in log units.

This term can be considered a correction factor, which for 7Q2 is 1.016 and for 7Q10 is 1.04. These factors are incorporated into the coefficients of the final equations presented earlier in this report.

The correction factors were warranted because they increased the means for 7Q2 and 7Q10 closer to the actual means. The following table demonstrates the improvement generated by the correction factors.

Source of low-flow characteristic	Mean 7Q2 (ft^3/s)	Mean 7Q10 (ft^3/s)
Actual quantity	29.79	19.54
Uncorrected estimate	27.85	18.43
Corrected estimate	28.30	19.16

Other forms of the flow-duration ratio, such as the 20-percent flow duration divided by the 99-percent duration, also were tested as independent variables in regression analysis. However, the original ratio, the 20-percent flow duration divided by the 90-percent duration, was the most significant in estimating 7Q2 and 7Q10.

The authors determined that contributing drainage area and flow-duration ratio are not highly correlated. The correlation coefficient between the two variables is only 0.20, indicating they provide separate information about low-flow characteristics.

Some bias may be present in the estimating equations because flow-duration ratio is derived from the same data set used to determine the observed 7Q10. Any error in the streamflow data influences 7Q10 as well as flow-duration ratio. However, the streamflow record for Indiana is good, and the bias should not generate significant error in the estimating equations.

Two basin characteristics, contributing drainage area and flow-duration ratio, were the most effective in estimating low-flow characteristics. Contributing drainage area is effective because streamflow generally increases as contributing drainage area increases. Total drainage area should not be used to estimate low-flow characteristics because the standard error increases slightly above the error resulting from using contributing drainage area. The noncontributing drainage area apparently does not often contribute to groundwater runoff. Use of flow-duration ratio is effective in estimating low-flow characteristics because the ratio integrates several factors affecting low flow into one variable. The combined effect of geology, climate, land use, soils, and other factors is reflected in flow-duration ratio. The ratio integrates the important factors because it approximates the slope of the straight-line part of the flow-duration curve. A shallow slope reflects the slowly changing discharge of a stream which maintains high base flows. A steep slope reflects a flashy stream that loses flow quickly in low-flow conditions. Even though the 20-percent flow duration represents some surface runoff, it still lies on the straight part of the duration curve and measures the same slope as would a higher percent duration.

Mapping of Flow-Duration Ratio

The two independent variables that are required to solve the estimating equations are drainage area and flow-duration ratio. Drainage areas for basins can easily be obtained from sources such as topographic maps. Hoggatt (1975) compiled the drainage areas for all streams in Indiana greater than 5 mi^2. Plate 1 can be used to approximate the drainage area. However, flow-duration ratios for sites on ungaged streams were not available. Therefore, plate 1 was constructed for use in estimating flow-duration ratio for the northern and the central physiographic zones.

Flow-duration ratio was delineated by using information from several sources. Ratios associated with the drainage areas of the 82 gaging stations were used to delineate most of the State. Those data were extended by using maps of surficial geology (Indiana Geological Survey, 1979) and ground-water availability (Indiana Department of Natural Resources, 1980). The map of surficial geology was used because the geology correlated with areas of known flow-duration ratio. For example, geology consisting mostly of sand and gravel is associated with areas having low ratios. Therefore, areas without a known ratio, but containing mostly sand and gravel, were given a low ratio. Similarly, areas of high ground-water availability, or areas having large aquifers of sand and gravel, had a low ratio. Therefore, areas of high ground-water availability without a known flow-duration ratio were given a low ratio. The last aid in delineating ratios was data from low-flow partial-record stations listed in Stewart (1983). In this case, correlation of unit 7Q10 (7Q10/mi^2) with ratio was used to extend the data base. For example, the ratio for an area of low unit 7Q10 was noted so that the same ratio could be used in an area of similar unit 7Q10.

Three comments about the plate should be made. First, the ratios were usually rounded to the nearest five units because the amount of data available justified this level of accuracy. The exception was in the northwestern part of the State where the ratio was designated as three. Flow-duration ratio at all the gaging stations in that area is always about three, which was taken as a justification for delineating the area similarly. Second, flow-duration ratio is not given for the southern part of the State because 7Q10 at nearly all gaging stations in that area is zero. However, Stewart (1983) should always be checked to determine if 7Q10 for any stream in the southern zone is greater than zero. The 7Q10's of a few streams in the northern and the central zones are also zero. Basins greater than 50 mi^2 drained by streams whose 7Q10 are zero are delineated on plate 1. Third, significant alterations of the surface geology can result in a flow-duration ratio that is different from that shown on the plate. For example, the 7Q10 of surface-mined areas in the southern physiographic zone of the State may be greater than zero.

APPLICATION OF METHOD

Low-flow characteristics 7Q2 and 7Q10 for an ungaged site can be estimated by inputting the drainage area and flow-duration ratio of the ungaged location into the equations developed from regression analysis. All the data needed to solve the equation for 7Q2 or 7Q10 can be derived from plate 1. After calculating 7Q2 or 7Q10, the answer is rounded to two significant figures. If the answer is less than 0.05 ft^3/s, the low-flow characteristic is assumed to be zero. An example is given to explain how the data are obtained from the plate and are used in the equation for 7Q10. The example is followed by some special conditions faced in solving for a low-flow characteristic.

The example is to determine 7Q10 for Pipe Creek at Alexandria in Madison County, Indiana. First, the site is located on plate 1, which normally should not be difficult because roads, cities, county boundaries, and streams are shown on the plate. The drainage area is determined from plate 1 by planimeter to be 58.5 mi^2. Flow-duration ratio also is obtained from plate 1 by observing its value inside the inscribed area, which for Pipe Creek at Alexandria is 10. The equation for estimating 7Q10 at any ungaged site is:

$$7Q10 = 1.66(DA^{1.03})(RATIO^{-1.51}).$$

Substitution of the previously determined drainage area and the flow-duration ratio for Pipe Creek at Alexandria results in the following equation:

$$7Q10 = 1.66(58.5^{1.03})(10^{-1.51}) = 3.4 \text{ ft}^3/\text{s}.$$

Most determinations of low flow will be similar to the preceding example; however, special cases can occur. For instance, if the drainage area for the site of interest extends into two or more areas whose flow-duration ratios differ, then an area-weighted average of the flows calculated by using each of the ratios over the basin is used. For example, for one-fourth of a 100-square mile basin the ratio is 10, and for three-fourths of the basin the ratio is 20. The 7Q10 is calculated first by using the ratio of 10 and drainage area of 100 mi^2, from which 7Q10 is 5.9 ft^3/s. Then 7Q10 is calculated by using the ratio of 20 and drainage area of 100 mi^2, from which 7Q10 is 2.1 ft^3/s. The area-weighted average of the two flows is (1/4 x 5.9) + (3/4 x 2.1) or 3.1 ft^3/s. In another special case, a site location and part of the basin are in the southern physiographic zone where 7Q10 is assumed to be zero, and part of the basin is in the central zone where 7Q10 is greater than zero. Low-flow characteristics are calculated by using the drainage area and the ratio for the part of the basin that lies above the line dividing the two zones and proceeding as in the original example (see plate 1 for location of the line.) If a basin extends into another State, the flow-duration ratio is assumed to be the same in the adjoining state as in Indiana. However, if most of the basin lies outside of Indiana, the ratio is not sufficiently defined to make a confident estimate of low flow.

The preceding method is one way for determining low-flow characteristics at ungaged sites but may not always be the best. Other sources of low-flow data are available. One should determine from Stewart (1983) if low-flow characteristics are available for gaging stations or partial-record stations on a given stream. If a gaging station is near the site for which low-flow data is required, then low-flow data from the station could provide a more accurate estimate of the low-flow characteristic than the method of this report. In particular, a more accurate estimate is possible if the method yields a significantly different flow than that from the gaging station. Low-flow data from partial-record stations at or near the site are useful as well because they reflect geology in the local area. Low-flow characteristics determined by the method in this report are based on equations influenced by conditions across the State. Therefore, low-flow data from a partial-record station close to an ungaged site in a similar hydrologic setting should be considered strongly in the determination of low-flow characteristics at an ungaged site.

ACCURACY OF METHOD

Accuracy of Equations Developed from Regression Analysis

Accuracy of low flows estimated by use of equations can be investigated in several ways. For example, is the degree of accuracy equal throughout the northern and the central physiographic zones? Are the smaller quantities of the low-flow characteristics estimated as accurately as the larger ones? How much error is associated with the equations, the plate, and a combination of both? How much accuracy is lost in the estimate of low-flow for a given loss in accuracy of drainage area and of ratio data? These questions are addressed in the sections that follow. First, error in the estimating equations is examined.

The accuracy of a regression equation can be evaluated by its standard error of estimate, coefficient of determination, and residuals. The standard error for the equations estimating 7Q2 and 7Q10 using station values of flow-duration ratio and drainage area are 19 and 28 percent and the coefficients of determination are 0.99 and 0.98. The residuals from applying the equation to estimate 7Q2 and 7Q10 at the 82 stations used to develop the equation are shown in figure 4.

The accuracy of estimates for low-flow at the 82 gaging stations obtained by use of the equation for 7Q10 is shown in figure 4. Patterns of the residuals from the equation for 7Q2 are similar, but smaller in magnitude. Because the regression analysis was done by using the logs of the data, the logs of the residuals are shown. In the upper-left corner, the residuals are plotted areally to detect a geographical trend in the accuracy of the equation. Owing to limitations of space, not all of the 82 residuals were plotted, but the ones plotted are representative. Postive and negative residuals are distributed evenly throughout the northern and central zones. The only slight trend is that most residuals are less than 0.1 in the northern zone and many are greater than 0.1 in the central zone.

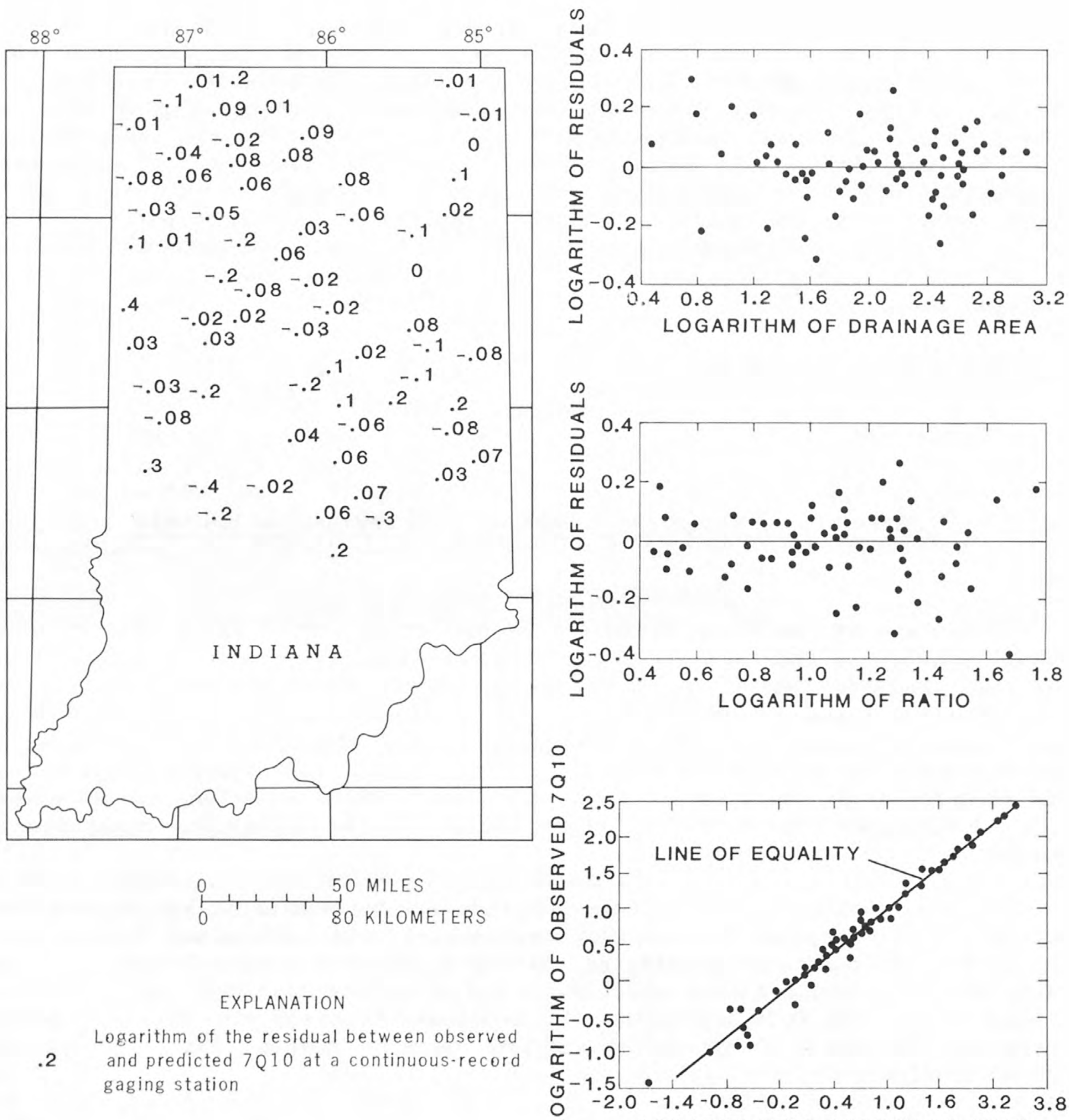

Figure 4.-- Plots of the observed and predicted 7Q10 and the residuals when the equation is applied at the 82 gaging stations used to develop the equation.

This trend also was observed in the residuals from all regression analyses of data regionalized by hydrologic and geologic properties. Unlike the residuals from the regionalized equations, residuals from the final equations given in this report are small and do not indicate any problem area. There is no trend in the accuracy of predictions with increasing drainage area (upper-right plot) and no trend in the accuracy of predictions with increasing flow-duration ratio (middle-right plot). Observed 7Q10 is plotted against 7Q10 predicted by the equation in the lower-right graph. The scatter of the points about the line of equality is slightly greater for smaller quantities of 7Q10, those less than 0.5 ft^3/s, but the decrease in accuracy is not significant. In summary, on the basis of the standard errors of estimate, coefficients of determination, and residuals, the equations predict low-flow characteristics with an acceptable amount of error for the 82 gaging stations.

Although the equations estimate 7Q2 and 7Q10 accurately for the 82 gaging stations used in developing them, they also must estimate accurately for independent stations, namely stations not used in the development of the equations. This condition can be tested by a procedure called data splitting. Basically, this consists of dividing the 82 stations into two groups. One group is used to develop estimating equations by regression analysis as before. Drainage areas and flow-duration ratios from the second group are then used in the equations developed from the first group to test how well they predict low-flow characteristics for the second group. The procedure begins by ranking the 82 stations from smallest to largest drainage area. The first station is put into group 1 (the estimating data set), the second station into group 2 (the prediction data set), the third into group 1, and so forth. Dividing the data in this manner creates an even distribution of drainage areas in both groups. An even distribution of flow-duration ratio also resulted from this data-splitting procedure. The actual distributions of drainage area and flow-duration ratio in both groups are shown in figure 5. The distributions for the estimation and prediction sets are similar, and, therefore, the equations are developed and are tested by similar distributions of data.

The equations derived from the estimating data set of 41 stations and from the original data set of 82 stations are listed in the following table:

Equations based on data at 41 stations	Equations based on data at 82 stations
$7Q2 = 1.69(DA^{0.993})(RATIO^{-1.17})$	$7Q2 = 1.69(DA)(RATIO^{-1.20})$
$7Q10 = 1.62(DA^{1.03})(RATIO^{-1.48})$	$7Q10 = 1.66(DA^{1.03})(RATIO^{-1.51})$

The two sets of equations are similar. Therefore, if the equations derived from the estimating set of stations in group 1 adequately predict low-flow characteristics for independent stations in group 2, then the final equations can be assumed to predict low-flow characteristics adequately for independent stations, if RATIO is adequately defined.

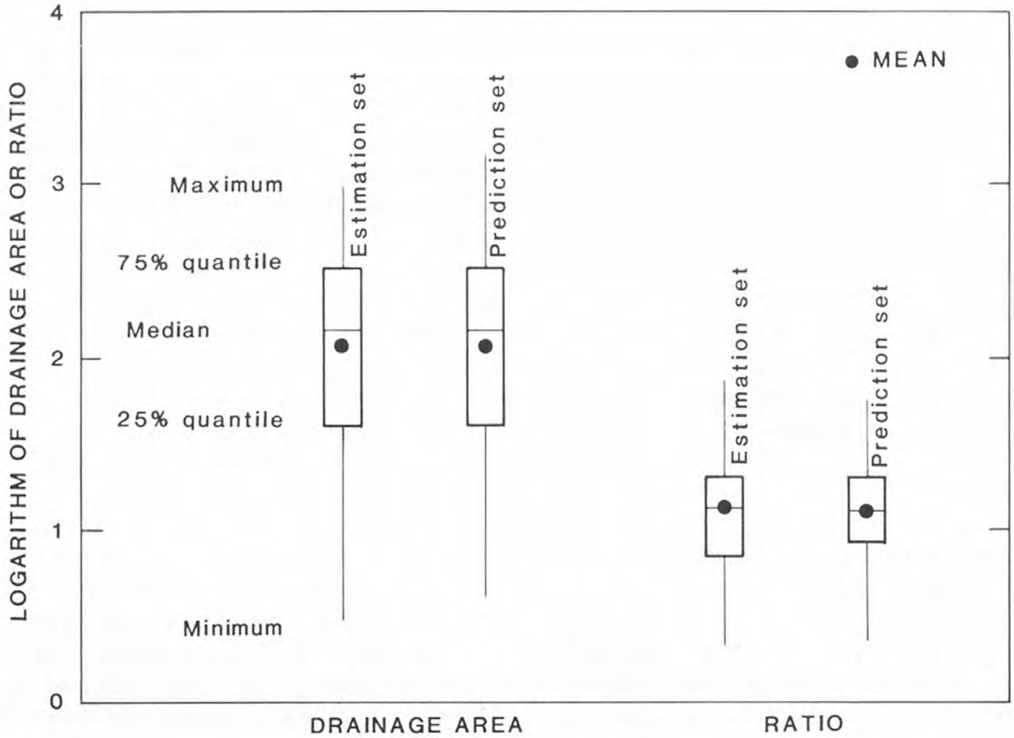

Figure 5.-- Box and whisker plots of estimation and prediction data used in data splitting.

The estimating equations appear to predict low-flow characteristics for group 2 adequately. The standard error of prediction for 7Q2 and 7Q10 using station values of flow-duration ratio and drainage area are 21 and 35 percent. The residuals, shown in figure 6, are similar to, though not as small as, those for the final equations. The postive and the negative quantities of the residuals are distributed uniformly by area and are evenly distributed with increasing drainage area and flow-duration ratio. The plot of observed 7Q10 and predicted 7Q10 is minimally scattered about the line of equality.

A final test for the estimating equations is to observe how well they estimate low-flow characteristics for stations whose drainage areas extend beyond the boundary of the State. None of the drainage basins of the 82 stations used to develop the equations cross the State boundary. A test of the equations was done on 10 available stations whose drainage basins lie completely outside Indiana. The equations adequately estimated low-flow characteristics on the basis of standard errors of estimate of 14 percent for 7Q2 and 30 percent for 7Q10. There was no indication of a significant trend in the residuals. Therefore, the equations can be inferred to estimate well for stations whose drainage basins lie partially within Indiana. Data for the 10 stations used in the analysis are presented in table 3.

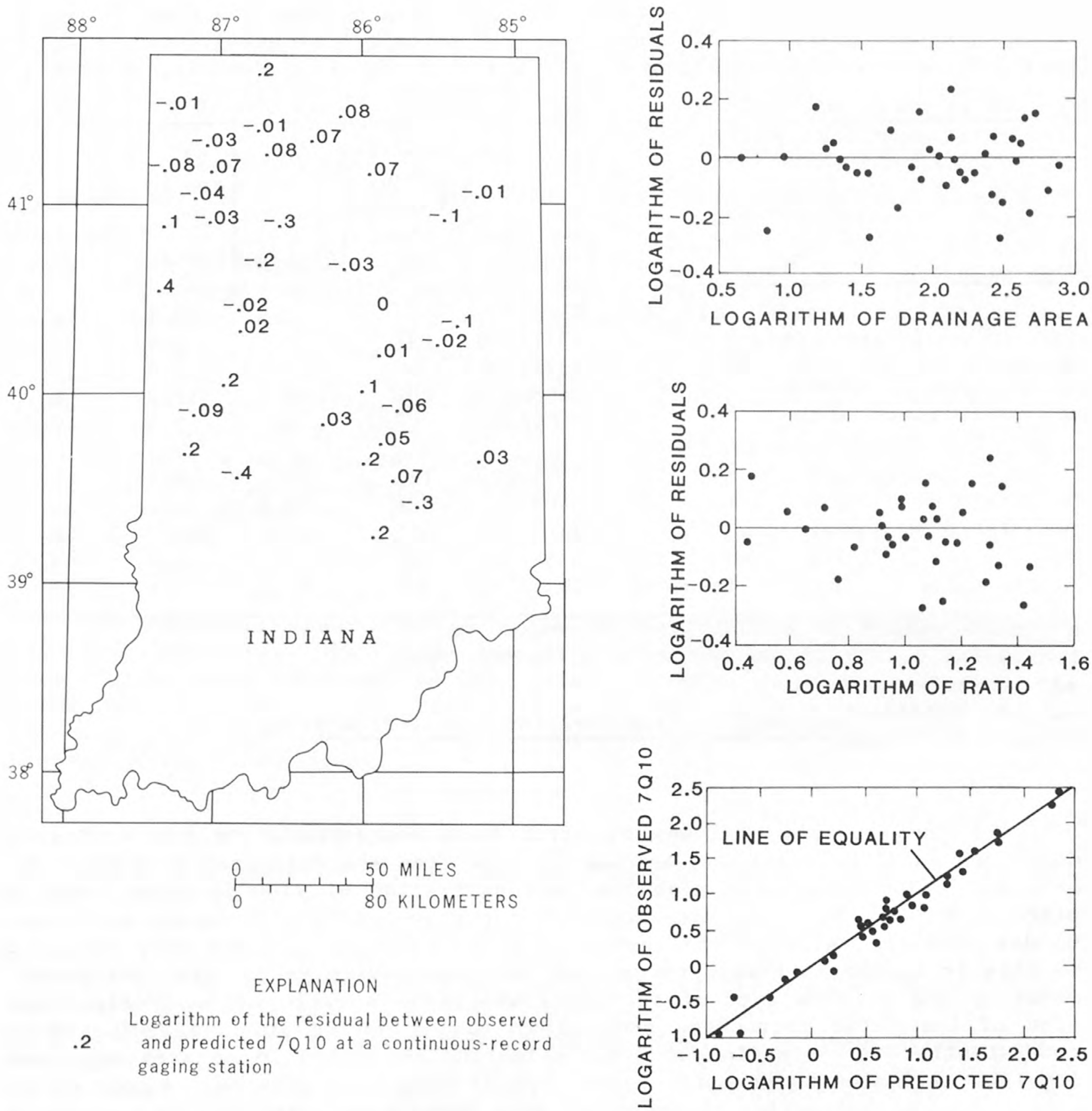

Figure 6.-- Plots of the observed and predicted 7Q10 and the residuals when the 41-station equation is applied at 41 gaging stations not used to develop the equation.

Table 3.--List of stations and data from adjacent states used to test equation

[7Q2, 7-day, 2-year low flow; 7Q10, 7-day, 10-year low flow; mi^2, square miles; ft^3/s, cubic feet per second; Branch(Br), Creek(Cr), Fork(Fk), near(nr), River(R), North(N), South(S), East(E), West(W), Saint(St.)]

Station name	Station number	Contributing drainage area (mi^2)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Flow-duration ratio
Stillwater R at Pleasant Hill, Ohio	03265000	503	25.6	12.3	15
Twin Cr nr Ingomar, Ohio	03271800	197	8.4	3.8	20
Sevenmile Cr at Camden, Ohio	03272700	69	3.1	1.6	21
St Joseph R nr Burlington, Mich.	04096400	201	44.4	17.3	6
Hog Cr nr Allen, Mich.	04096515	48.7	6.1	2.3	10
Nottawa Cr nr Athens, Mich.	04096900	162	52	29.8	4
Prairie R nr Nottawa, Mich.	04097540	106	29.4	16.7	4
Dowagiac R at Sumnerville, Mich.	04101800	255	140	104	2
Sugar Cr at Milford, Ill.	05525500	446	8.2	3.8	43
Little Calumet R at S Holland, Ill.	05536290	208	31.2	20.1	7

Accuracy of Flow-Duration Ratios from Plate 1

All the previous analyses of error have concentrated on the estimating equations only; no error was assumed to come from the data used as input. Now only the error associated with the regionalization of flow-duration ratio on plate 1 is investigated. Data coverage for flow-duration ratio was sufficient to describe the ratio to the nearest 5 units on plate 1. The only exception to this is in the northwestern part of the State where ratios are consistently about 3, and so this part of the State was given a ratio of 3. Regionalization of the ratio introduces some error in estimating 7Q2 and 7Q10. Also, consistently overestimating or underestimating the ratio in an area may cause low-flow estimates to be consistently low or high in that area. A test of the effect of regionalization of ratio was done because of these factors.

The test for the effect of regionalization is similar to that done on the estimating equations to determine their standard error and the residuals. The difference is that in this case flow-duration ratio is determined for each station from plate 1 instead of calculating ratio from flow-duration data. Inputting flow-duration ratio obtained from plate 1 and drainage area obtained from Stewart (1983) resulted in standard errors of estimate of 46 and 61 percent for the equations estimating 7Q2 and 7Q10. When estimating equations were redeveloped using values of ratio from the plate instead of from station data, the standard errors are similar: 44 and 60 percent. The coefficients and exponents of these equations are also similar to those of the final equations. Standard errors using ratios from the plate are significantly higher than those for the original estimating equations (19 and 28 percent). A large part of the increase is due to the error in estimating the ratio from plate 1 for some small drainage areas, areas less than 10 mi^2.

Flow-duration ratio from plate 1 for some small drainage areas is greatly in error. The reason for this error is related to the data base. Few data were available for streams with small drainage areas. Ratios for these small basins were not shown on the plate because they would have indicated an accuracy that the plate does not have everywhere. Usually the small drainage basins were given the ratio of the surrounding area, but in so doing, the resulting error sometimes becomes large, which also causes the error in calculating low-flow characteristics to be large. For example, the flow-duration ratio calculated for Sugar Creek near Middletown, Indiana, is 62. The ratio from the plate for the same basin is 10. The residuals in log units using the ratio from the plate in the equations to estimate 7Q2 and 7Q10 are 0.55 and 1.00. The large differences between the local ratio and the general-area ratio usually is due to large differences in local and general-area geology. When stations with drainage areas less than 10 mi^2 were excluded from the analysis, the standard errors of estimate were reduced to 38 and 49 percent for the equations for 7Q2 and 7Q10. The significant reduction in the standard error indicates that the method should be used with caution for sites whose drainage areas are 10 mi^2 or less.

The residuals associated with the regionalization of ratio, shown in figure 7, are larger than those resulting from the use of ratios calculated from station data. However, no bias areally or with increasing values of the input data is evident. The plot of observed 7Q10 against predicted 7Q10 is generally along the line of equality. The greatest scatter around the line is associated with 7Q10 less than 0.5 ft^3/s.

Accuracy of Equations and Flow-Duration Ratios

The errors from the individual components of the method (the equations and the plate) have been described, and now the cumulative error from using both components on a set of semi-independent stations is investigated. Data for partial-record stations are used so that the method can be applied to basins other than those of the 82 stations used to develop the equations. The limitation of the test is that the estimate calculated by the method is being compared to an estimate determined by correlation with gaged data. Because an estimate is being compared to an estimate, only a general agreement between the two numbers can be expected.

The two analyses of error presented from the test are the plot of observed 7Q10 and predicted 7Q10 (fig. 8) and the standard errors of estimate. The 7Q10 for the partial-record station is considered to be the observed low flow, and the 7Q10 from the method is considered to be the predicted. Scatter is large along the line of equality compared to other similar plots, but the data points are uniformly distributed about the line down to about 5 ft^3/s.

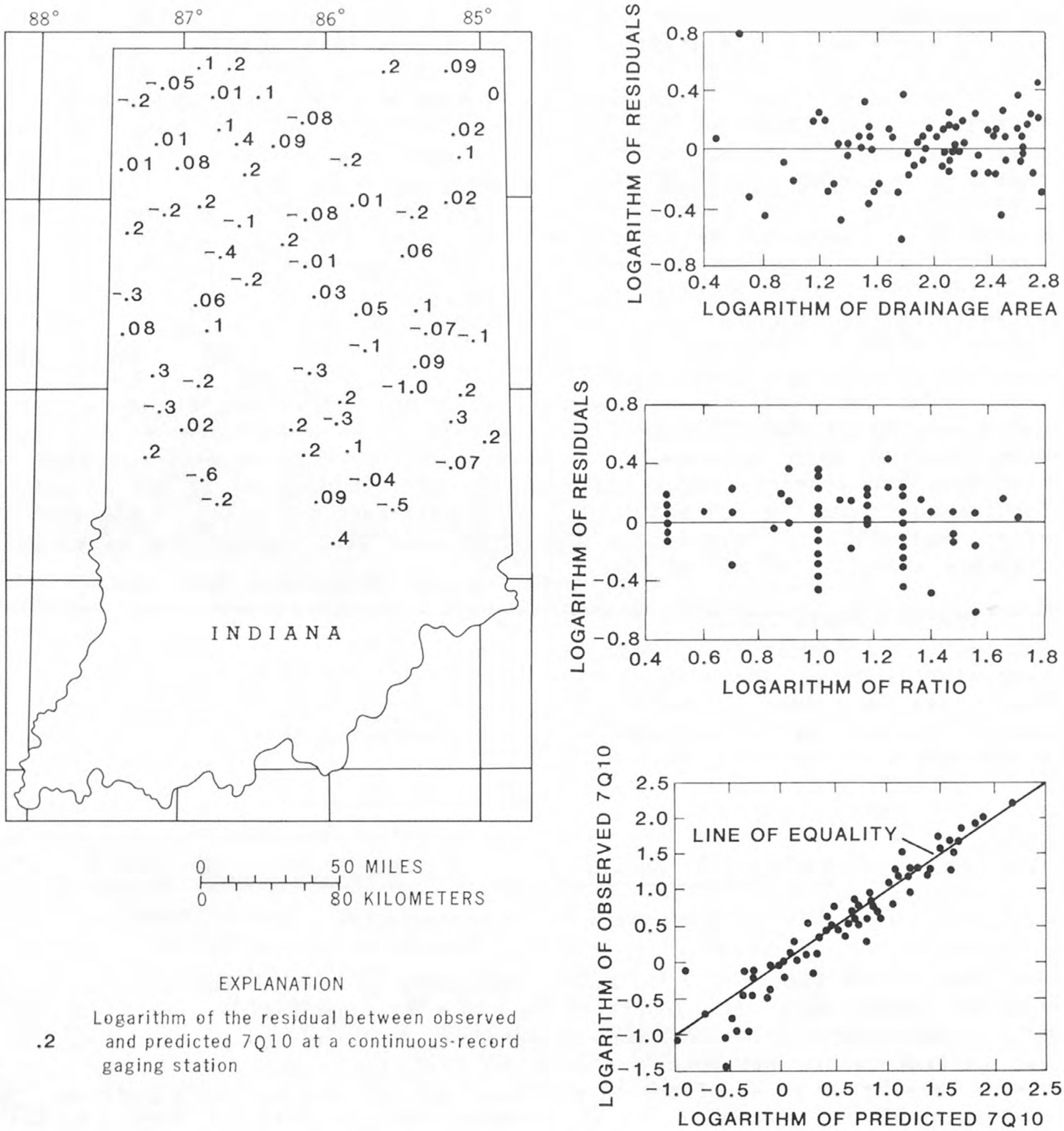

Figure 7.-- Plots of the observed and predicted 7Q10 and the residuals when flow-duration ratios obtained from plate 1 are used in the estimating equation.

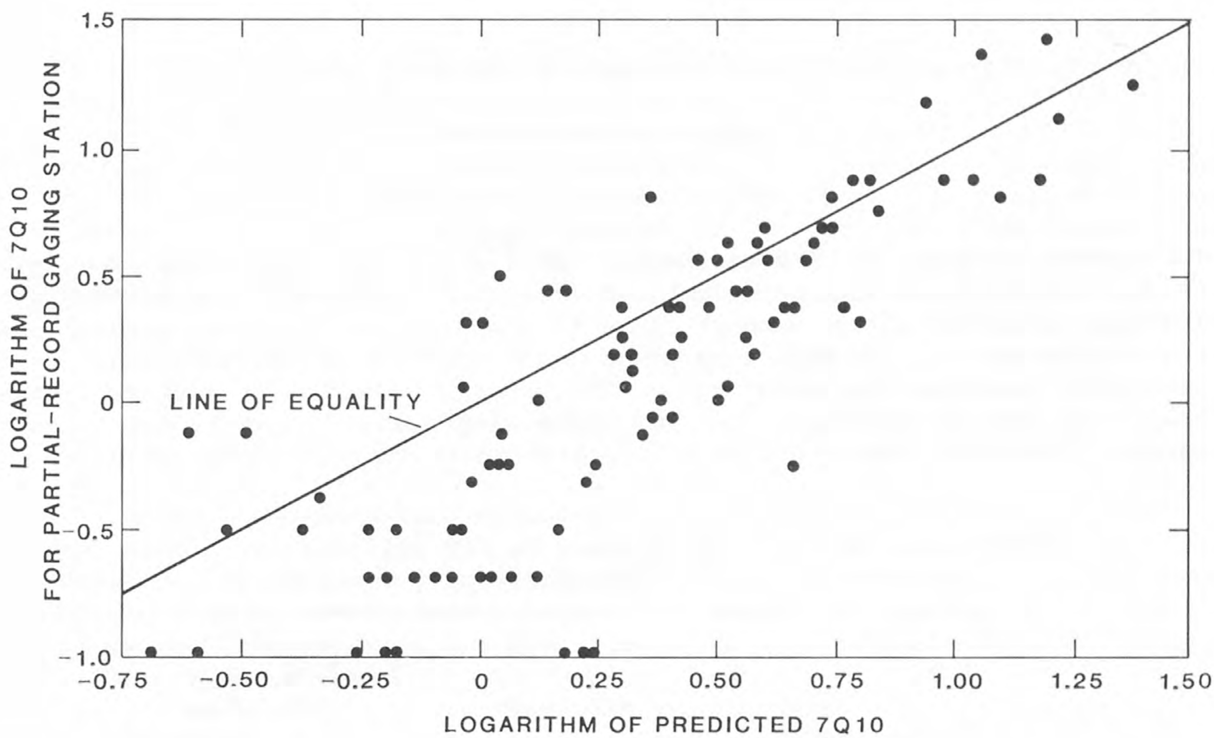

Figure 8.-- Comparison of estimate for 7Q10 at partial-record stations with 7Q10 predicted by the method.

Less than 5 ft^3/s, more points are below the line than above, which means that the method is generally overpredicting 7Q10 relative to the estimates for the partial-record stations. Overprediction does not necessarily imply that the method overestimates the actual 7Q10. That determination should be made by comparing the estimated low-flow characteristics with those for continuous-record stations. From the plot, one can conclude that low-flow characteristics can be estimated somewhat similarly to those for partial-record stations.

As before, the greatest error of prediction appears to be in the smaller quantities of 7Q2 and 7Q10. The standard errors of estimate for 7Q2 and 7Q10 are 108 and 132 percent. The errors should not be used to infer the accuracy of the method for ungaged sites because of the stated limitations of the test.

Sensitivity Analysis

Another aspect of accuracy involves sensitivity analysis. That is, how much error in the estimated low-flow characteristic results from a specific error in one of the independent variables, drainage area and flow-duration ratio? To address this, the equations are presented again.

$$7Q2 = 1.69(DA)(RATIO^{-1.20})$$

$$7Q10 = 1.66(DA^{1.03})(RATIO^{-1.51})$$

The amount of error in the estimated low-flow characteristic due to an error in drainage area is easily calculated from the equations. The exponents for drainage area are either one or close to one. Therefore, a 10 percent error in calculation of drainage area results in about a 10 percent error in the estimated low-flow characteristic. The error in the low-flow characteristic resulting from a specific error in determining ratio is not as easily calculated. Therefore, the error data is presented in the following table:

Difference in ratio (percent)	Difference in 7Q2 (percent)	Difference in 7Q10 (percent)
±10	-11, +13	-14, +17
±20	-20, +31	-24, +40
±50	-38, +130	-46, +184

The table gives percent error in estimated 7Q2 and 7Q10 for a given percent error in ratio. The first line indicates that a ±10 percent error in ratio results in a -11 to +13 percent error in 7Q2 and a -14 to +17 percent error in 7Q10. Note that errors in an estimated low-flow characteristic for a given error in ratio are constant for all quantities of drainage area and ratio. For example, assume that a site has a drainage area of 30 mi^2, a ratio of 10, and a ±10 percent error in ratio. The table indicates a -14 to +17 percent error in 7Q10. If the site had a drainage area of 300 mi^2, a ratio of 20, and a ±10 percent error in ratio, the error in 7Q10 would still be -14 to +17 percent. In other words, the error of the equations is a constant for all values of drainage area and flow-duration ratio, given a specific percent error in either variable.

LIMITATIONS OF METHOD

The method has been explained, applied, and analyzed for error, but the limits of the method have not been completely explained in one section. All limitations and additional details about use of the method are given here. The drainage areas and low-flow characteristics used to develop the equations define the limits for which this method can properly be applied. Using the method for locations with drainage areas or low-flow characteristics beyond these limits should be done with caution because the error in estimating low-flow characteristics for those cases is unknown. The 82-station data base has drainage areas ranging from 3 to 1160 mi^2, 7Q2 ranging from 0.1 to 458 ft^3/s, and 7Q10 ranging from 0.03 to 340 ft^3/s. A low-flow characteristic calculated to be less than 0.05 ft^3/s should be rounded off to 0. The method can be used on unregulated streams in the northern and central physiographic zones as defined by plate 1. The 7Q10 in the southern zone is assumed to be zero unless data from Stewart (1983) indicate otherwise. Analysis of the equations using data from partial-record stations indicates that estimates of 7Q10 greater than 5 ft^3/s have the greatest accuracy. Other analyses indicate that estimates of low flows less than 0.5 ft^3/s have the least accuracy. Estimates for sites with drainage areas less than 10 mi^2 are often not as accurate as those for larger drainage areas. The accuracy of the method is unknown for basins having more than 20 percent of its area in lakes or wetlands.

SUMMARY

One equation estimating 7Q2 and one estimating 7Q10 for Indiana streams were developed by stepwise regression analysis. Regression analysis tested the significance of several basin characteristics in determining 7Q2 and 7Q10, but the two most significant are contributing drainage area and flow-duration ratio. Drainage area and flow-duration ratio can be obtained from a 1:500,000 plate and input to either of the following equations:

$$7Q2 = 1.69(DA)(RATIO^{-1.20})$$

$$7Q10 = 1.66(DA^{1.03})(RATIO^{-1.51})$$

The error in the equations and the plate was investigated to determine the overall reliability and specific problem areas of the method. The standard errors of estimate for the equations derived from station data to estimate 7Q2 and 7Q10 are 19 and 28 percent and the coefficients of determination are 0.99 and 0.98. When flow-duration ratios for the 82 gaging stations are obtained from the plate, the standard errors are 46 and 61 percent. However, when stations with drainage areas less than 10 square miles are excluded from the test, the standard errors reduce to 38 and 49 percent. Residuals from application of the equations indicate that no bias is apparent areally or with increasing values of drainage area or flow-duration ratio. A test using a data-splitting technique indicated that the equation estimates low-flow characteristics well for stations not used in the development of the equations. The equations also estimate well for basins that cross the State boundary. Regionalization of flow-duration ratio on the plate creates significantly less error if the method is used at a site with drainage areas greater than 10 mi^2. When the method is tested by calculating low-flow characteristics for partial-record stations, the estimated values compare adequately to the station data above 5 ft^3/s.

Limitations should be considered when using the method. The method can be applied only to locations in the northern and central physiographic zones. Streams in the southern zone are assumed to have a 7Q10 of zero unless data from Stewart (1983) indicate otherwise. The method should not be used on regulated streams unless the amount of regulation is known so adjustment can be made to the estimated low-flow characteristic. Predictions probably will be more accurate if a basin has less than 20 percent of its drainage area in lakes and wetlands. The method is applicable for streams having drainage areas from 3 to 1160 mi^2, and for estimates of 7Q2 from 0.1 to 458 ft^3/s and

7Q10 from 0.1 to 340 ft^3/s. Using the equations beyond these limits should be done with caution because the error in prediction is unknown. The method is least accurate for drainage areas less than 10 mi^2 and for estimates of low- flow characteristics less than 0.5 ft^3/s. The error in an estimated low-flow characteristic will be the same as the error in a calculated drainage area and will be exponentially related to the error in an estimated flow-duration ratio. The error of the equations is a constant for all quantities of drainage area and ratio, given a constant error in either. Finally, any estimate of a low-flow characteristic by the method should be compared to low-flow data from continuous-record and partial-record gaging stations in the area,if available. The estimate probably should be adjusted according to available low-flow data, unless personal knowledge of geologic or hydrologic conditions indicate otherwise.

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Table 4.--Basic data

[7Q2, 7-day, 2-year low flow; 7Q10, 7-day, 10-year low flow; mi^2, square miles; ft^3/s, cubic feet per second; Branch(Br), Creek(Cr), Fork(Fk), near(nr), River(R), North(N), South(S), East(E), West(W), Saint(St.)]

Station name	Station number	Contributing drainage area (mi^2)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Flow-duration ratio
Whitewater R nr Economy	03274650	10.4	0.6	0.4	18
Whitewater R nr Hagerstown	03274750	58.7	13	7.2	5
Little Williams Cr at Connersville	03274950	9.16	0.9	0.4	12
Whitewater R nr Alpine	03275000	529	82	49	8
E Fk Whitewater R at Abington	03275600	200	31	20	8
Little R nr Huntington	03324000	263	9.8	3.8	22
Salamonie R nr Warren	03324300	425	14	7.2	23
Mississinewa R nr Ridgeville	03325500	133	3.3	1.1	32
Mississinewa R nr Eaton	03326000	310	6.6	2.9	28
Big Lick Cr nr Hartford City	03326070	29.2	1.2	0.7	20
Pipe Cr nr Bunker Hill	03327520	159	9.1	4.9	15
Eel R at North Manchester	03328000	417	55	35	7
Weesau Cr nr Deedsville	03328430	8.87	0.8	0.4	12
Eel R nr Logansport	03328500	789	140	97	7
Rattlesnake Cr nr Patton	03329400	6.83	0.5	0.1	14
Deer Cr nr Delphi	03329700	274	21	11	12
Walnut Cr nr Warsaw	03331110	19.6	1.2	0.6	16
Tippecanoe R nr Ora	03331500	856	187	126	6
Little Indian Cr nr Royal Center	03332300	35.0	2.5	0.8	12
Big Monon Cr nr Francesville	03332400	152	19	9.8	9
Wildcat Cr nr Jerome	03333450	146	4.0	1.4	34
Wildcat Cr nr Greentown	03333500	168	3.6	1.6	33
Kokomo Cr nr Kokomo	03333600	24.7	0.6	0.2	31
Wildcat Cr at Owasco	03334000	396	32	19	12
S Fk Wildcat Cr nr Lafayette	03334500	243	29	19	9
Wildcat Cr nr Lafayette	03335000	794	92	55	9
Mud Pine Cr nr Oxford	03335690	39.4	0.8	0.4	54
Big Pine Cr nr Williamsport	03335700	323	16	8.0	19
E Fk Coal Cr nr Hillsboro	03339108	33.4	5.4	3.8	6
Sugar Cr at Crawfordsville	03339500	509	23	7.4	20
Sugar Cr nr Byron	03340000	670	45	22	13
Big Raccoon Cr nr Fincastle	03340800	139	6.8	2.9	21
Little Raccoon Cr nr Catlin	03341200	133	7.1	4.6	21
Buck Cr nr Muncie	03347500	35.5	11	6.9	4
Killbuck Cr nr Gaston	03348020	25.5	3.1	1.3	10

Table 4.--Basic data--Continued

Station name	Station number	Contributing drainage area (mi^2)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Flow-duration ratio
Pipe Cr at Frankton	03348350	113	7.8	4.7	13
Cicero Cr nr Arcadia	03349500	131	2.6	1.1	45
Hinkle Cr nr Cicero	03350100	18.5	0.6	0.2	23
Stony Cr nr Noblesville	03350700	50.8	6.7	3.7	10
Crooked Cr at Indianapolis	03351310	17.9	1.6	0.8	12
Sugar Cr nr Middletown	03351400	5.80	0.1	0.03	62
Fall Cr nr Fortville	03351500	169	27	16	7
Mud Cr at Indianapolis	03352200	42.4	2.0	0.5	19
Bean Cr at Indianapolis	03353180	5.6	1.2	0.8	4
Lick Cr at Indianapolis	03353620	14.40	1.8	0.8	11
White Lick Cr at Mooresville	03353800	212	13	4.1	20
Mill Cr nr Cataract	03358000	245	7.1	1.4	36
Deer Cr nr Putnamville	03359500	59	0.6	0.1	49
Big Blue R at Shelbyville	03361500	421	62	39	8
Sugar Cr at New Palestine	03361650	93.9	7.9	3.9	14
Buck Cr at Acton	03361850	78.8	4.4	2.8	18
Youngs Cr nr Edinburgh	03362000	107	3.2	1.4	29
Sugar Cr nr Edinburgh	03362500	474	40	20	14
Flatrock R at St Paul	03363500	303	10	2.2	28
Flatrock R at Columbus	03363900	534	67	35	12
Little Calument R at Porter	04094000	66.2	24	20	3
Salt Cr nr McCool	04094500	74.6	25	20	3
Trail Cr at Michigan City	04095300	54.1	28	23	3
Galena R nr LaPorte	04096100	14.9	9	8	3
Pigeon Cr nr Angola	04099510	83.5	12	6	9
Pigeon R nr Scott	04099750	307	125	86	4
Fish Cr at Hamilton	04177720	37.5	2	1	15
St. Joseph R nr Newville	04178000	610	35	19	17
Cedar Cr at Auburn	04179500	87.3	3.8	1.8	20
Cedar Cr nr Cedarville	04180000	270	28	20	10
Harber ditch at Fort Wayne	04182590	21.9	0.3	0.1	50
Kankakee R nr North Liberty	05515000	116	69	56	2
Kingsbury Cr nr LaPorte	05515400	3.01	1.7	1.1	3
Kankakee R at Davis	05515500	400	252	186	2
Yellow R nr Breman	05516000	131	9.0	6.3	13

Table 4.--Basic data--Continued

Station name	Station number	Contributing drainage area (mi^2)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Flow-duration ratio
Yellow R at Plymouth	05516500	272	31	19	10
Yellow R at Knox	05517000	384	101	72	5
Kankakee R at Dunns Bridge	05517500	1160	458	341	4
Cobb ditch nr Kouts	05517890	30.3	13	10	3
Singleton ditch at Schneider	05519000	123	15	7.2	9
West Cr nr Schneider	05519500	54.7	6.9	4.6	6
Iroquois R at Rosebud	05521000	35.6	4.1	2.0	10
Iroquois R at Rennsselaer	05522500	203	13	5.5	16
Bice ditch nr South Marion	05523000	21.8	0.3	0.1	53
Slough Cr nr Collegeville	05523500	83.7	3.6	1.4	21
Iroquois R nr Foresman	05524500	449	24	11	23
Hart ditch at Munster	05536190	70.7	4.4	2.7	13

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