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Estimating Mean Annual Streamflow of Rural Streams in Kentucky

Water-Resources Investigations Report 02-4206

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

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By Gary R. Martin

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Department of Highways

Louisville, Kentucky
2002

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CONVERSION FACTORS

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

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

$$°C = (°F - 32) / 1.8$$

VERTICAL DATUM

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

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Abstract

Mean annual streamflow (Q_a), defined as the mean of the series of annual mean streamflow values, was determined for selected rural stream sites in Kentucky. Streamflow data for the available period of record through the 1999 water year (October 1, 1998–September 30, 1999) at 235 continuous-record streamflow-gaging stations with at least 5 years of record located in and adjacent to Kentucky were used in the analysis. Record-extension procedures were applied for selected gaging stations to reduce time-sampling error and, thus, improve estimates of the long-term Q_a.

Techniques to estimate the Q_a at ungaged stream sites in Kentucky were developed. One-, two-, and three-variable regression equations that included total drainage area, station latitude minus 36 degrees, and mean basin elevation as explanatory variables were developed by use of ordinary- and generalized-least-squares regression. The three-variable regression equation has an approximate average standard error of prediction of 13.7 percent. The one- and two-variable equations exhibit geographical biases, and the indicated standard errors of prediction may poorly estimate the true prediction errors, depending upon the location in the State. Therefore, the three-variable equation should be used for estimating mean annual streamflow of rural streams in Kentucky whenever possible.

INTRODUCTION

The U.S. Geological Survey (USGS) has collected continuous-record streamflow-gaging data in Kentucky since 1907 (Beaber, 1970); other agencies collected such data in Kentucky as early as 1890. Statistical characteristics of the streamflow data, such as the mean annual streamflow, are needed by water-resource managers and engineers for design of hydraulic structures constructed in the riverine environment.

Resource limitations make it unfeasible for the collection of data on every stream and at every stream site where streamflow characteristics may be needed; therefore, techniques for estimating the needed streamflow characteristics at ungaged stream sites have been developed. The USGS, in cooperation with the Kentucky Transportation Cabinet—Department of Highways, compiled the available continuous-record streamflow-gaging station data, computed the Q_a for these gaged stream sites, and developed regional equations for estimating Q_a at ungaged rural stream sites on the basis of selected drainage-basin characteristics.

Purpose and Scope

The purpose of this report is to provide (1) Q_a values at continuous-record streamflow-gaging stations having 5 or more years of record through the 1999 water year and (2) procedures for estimating the Q_a at rural ungaged stream sites where flows are not appreciably affected by local diversions. This report presents Q_a values for 235 continuous-record streamflow-gaging stations in the study area. Procedures for estimating the Q_a at ungaged stream sites are described and illustrated with example computations.

Previous Studies

Mean annual streamflows in Kentucky have been investigated in various previous studies. Beaber (1970) analyzed streamflow-data needs and applications in Kentucky. Statistical multiple-regression analyses were done to define relations between selected streamflow characteristics and drainage-basin characteristics. Various regression models to estimate mean annual streamflows at ungaged stream sites statewide were developed, including

$$Q_a = 1.19A^{1.02} \quad (1)$$

$$Q_a = 1.22A^{1.01}E^{0.10} \quad (2)$$

$$Q_a = 0.290A^{1.01}E^{0.25}I^{1.27} \quad (3)$$

$$Q_a = 0.270A^{1.01}E^{0.23}I^{1.36}St^{-0.14} \quad (4)$$

where,

- Q_a is the mean annual streamflow, in ft^3/s;
- A is the drainage area in mi^2;
- E is the mean elevation of the basin, in thousands of feet above sea level;
- I is the maximum 24-hour, 2-year rainfall intensity, in inches; and
- St is the area of lakes and ponds in percent of drainage area (plus 1).

The regression analyses provided estimates of the accuracy of the relations, which improved as the number of explanatory (regressor) variables and model complexity increased. The average standard error of estimate ranged from 14.8 percent for equation 1 to 12.1 percent for equation 4.

Melcher and Ruhl (1984) computed mean annual streamflows for the available period of record through the 1982 water year. Results presented were for combined regulated and unregulated periods of record at those sites with regulated flows.

Wetzel and Bettandorff (1986) developed regression models for estimating streamflow characteristics, including Q_a, based on data for 629 streamflow-gaging stations in coal provinces covering parts of 11 States in the eastern United States, including the Eastern and Western Kentucky Coal Field physiographic regions. The basin characteristics used as explanatory variables in these regression models for estimation of Q_a included drainage area, mean annual precipitation, and mean basin elevation. The average standard error of estimate ranged from 35.7 percent for the drainage-area-only model to 17.1 percent for the model that included all three of these basin characteristics as explanatory variables. The model coefficients of determination (R^2) in log space ranged from 0.96 to 0.99.

Acknowledgments

The author would like to thank the Kentucky Transportation Cabinet for its support of this work. The author also wishes to thank the many local, State, and Federal agencies that have cooperated in the operation and maintenance of streamflow-gaging stations in Kentucky and surrounding States that were used as part of this study. The author wishes to express appreciation to the many other USGS employees who assisted with collection and analysis of streamflow data, measurement of basin characteristics, and preparation of this report.

DESCRIPTION OF STUDY AREA

The Commonwealth of Kentucky encompasses an area of 40,395 mi^2 in the east-central United States. The major drainage basins in Kentucky—Big Sandy, Licking, Kentucky, Salt, Cumberland, Green, and Tennessee Rivers—are tributaries of the Ohio and Mississippi Rivers (fig. 1). In a generalized water balance for Kentucky, approximately 60 percent of precipitation leaves drainage basins as evapotranspiration, and approximately 40 percent of precipitation leaves as direct runoff or shallow ground-water flow into the streams and rivers. Variations in climate, physiography, and geology cause localized variations in streamflow characteristics in Kentucky.

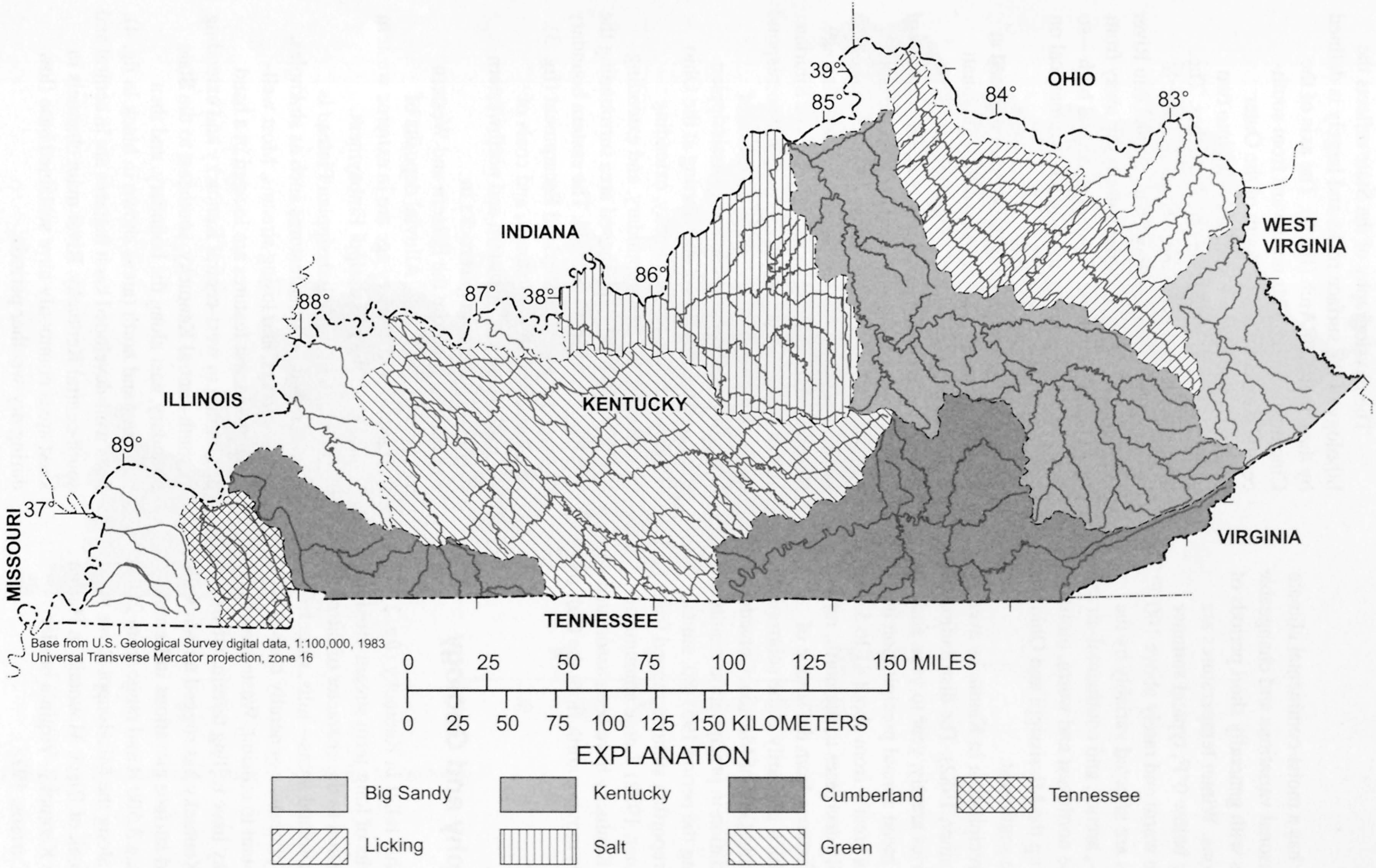


Figure 1. Major drainage basins in Kentucky.

Climate

Kentucky has a moist-continental climate with distinct seasonal variations and changeable weather patterns with generally short periods of extreme conditions. Winter temperatures are moderate, rarely below 0°F; typical summer temperatures are warm and rarely above 100°F. The weather patterns are affected variably by the meeting of cold-, arctic-, and continental-air masses arriving from the northwest and warm, moist-air masses moving up the Mississippi and Ohio River Valleys from the southwest.

Annual precipitation in Kentucky averages about 47 in. (Conner, 1982). The distribution of precipitation varies areally, year to year, and seasonally. The mean annual precipitation in Kentucky ranges areally from about 41 to 53 in. Rainfall generally decreases to the north, reflecting the increase in distance from the source of precipitation, which primarily is the subtropical Atlantic Ocean and Gulf of Mexico. Considerable year-to-year variation in precipitation results in Kentucky. During the period 1951-80, annual precipitation at reporting stations ranged from 14.5 to 78.6 in. (Conner, 1982). Large amounts of precipitation in Kentucky have been associated with tropical cyclones moving north from the Gulf of Mexico.

Physiography and Geology

Topographic relief in Kentucky (fig. 2) reflects the results of long-term stream-erosional processes in relation to the character of the rock formations. The upland areas—hills, ridges, mountains, and plateaus—generally consist of formations resistant to erosion. Western and central parts of Kentucky have rolling terrain, whereas the eastern part of Kentucky has rugged terrain with high relief. Land-surface elevations in Kentucky vary by more than 3,500 ft and range from 260 ft above sea level along the Mississippi River to 4,145 ft at the peak of Black Mountain in Harlan County near the Kentucky–Virginia border (McGrain and Currens, 1978).

The physiography of the State reflects the lithology of the surface rocks and largely is defined by the Cincinnati Arch (fig. 3). The axis of the Cincinnati Arch trends northward from south-central Kentucky to just south of the Outer Bluegrass boundary where it divides into two branches—Kankakee and Findlay Arches. The branches approximately are parallel but are separated by approximately 25 mi at the Ohio River (McFarland, 1950). Lithologic units dip away from the axis of the arch—a regional structural high—so that geologic features generally are symmetrical on each side of the arch.

Progressively younger rocks are exposed at the surface both east and west of the Cincinnati Arch. The oldest exposed rocks are part of the Jessamine Dome and adjacent areas; the location of this area corresponds approximately to the Inner Bluegrass region (fig. 3). These rocks consist of limestone, shale, and sandstone of Ordovician age. Narrow bands of shales and limestones of Silurian and Devonian age surround this area and correspond to The Knobs region. An expansive area of limestone of Mississippian age (Mississippian Plateaus Region) is exposed starting at the Ohio River in northeastern Kentucky, extending southwest to the State boundary, and extending northwest in a crescent-shaped area surrounding the Western Kentucky Coal Field. The eastern boundary of this area is the Cumberland Escarpment (fig. 3). Sandstones, shales, siltstones, and coals of Pennsylvanian age in eastern and northwestern Kentucky—the youngest rocks in Kentucky—compose the Eastern and Western Kentucky Coal Fields. Alluvial deposits of Cretaceous and Tertiary age are in extreme western Kentucky in the Mississippi Embayment.

Much of the Mississippian Plateau is characterized by karst features such as sinkholes, caves, springs, and losing streams. Most well-developed karst features are located in a band originating in west-central Kentucky and extending to south-central Kentucky, southeast to the State boundary, east along the boundary, and then northeast and north (areas shown in black in fig. 4). Less well-developed karst features are in central and south-central Kentucky. River main channels in karst areas commonly have sustained base flow during dry-weather periods.

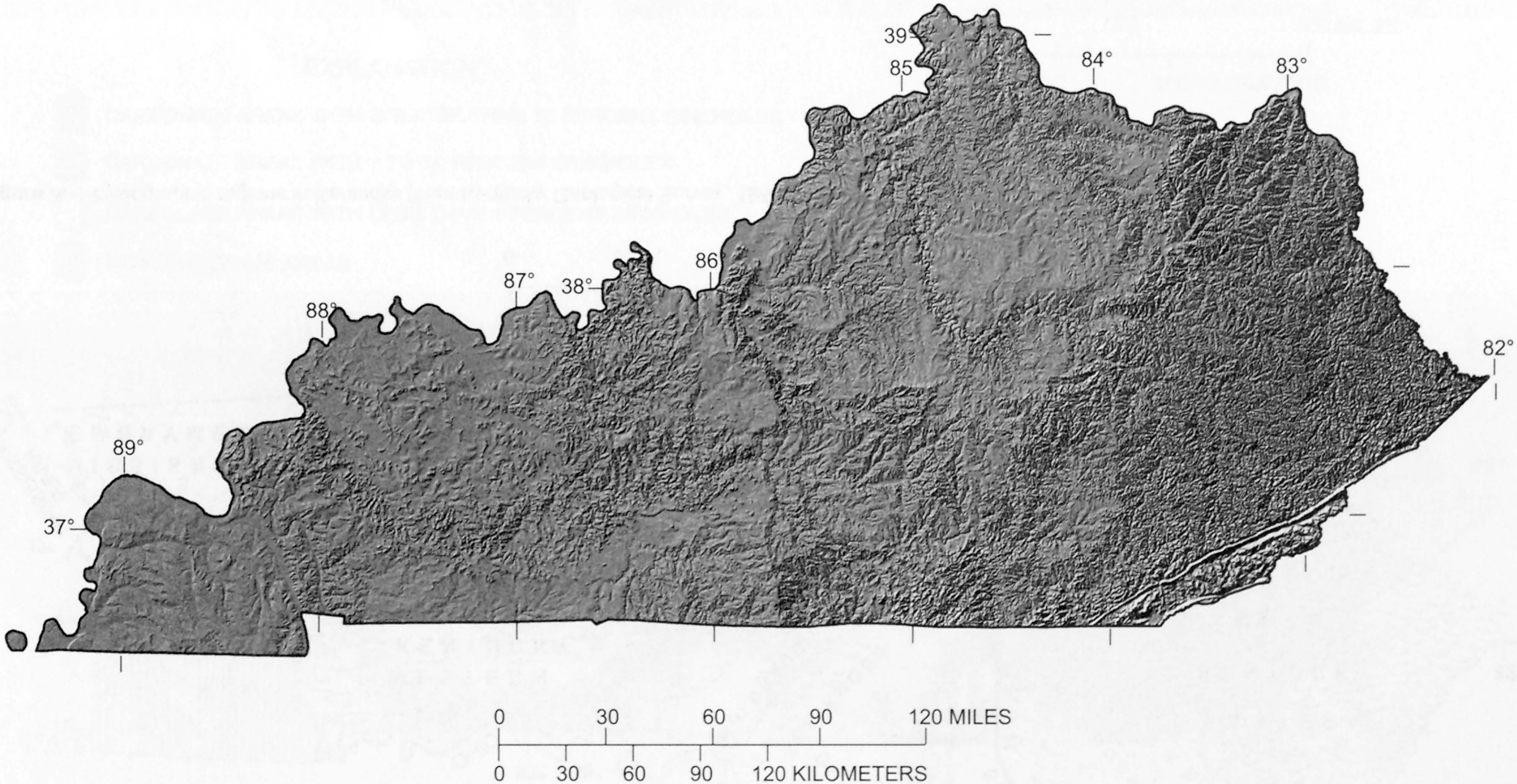


Figure 2. Shaded-relief image of landforms in Kentucky.

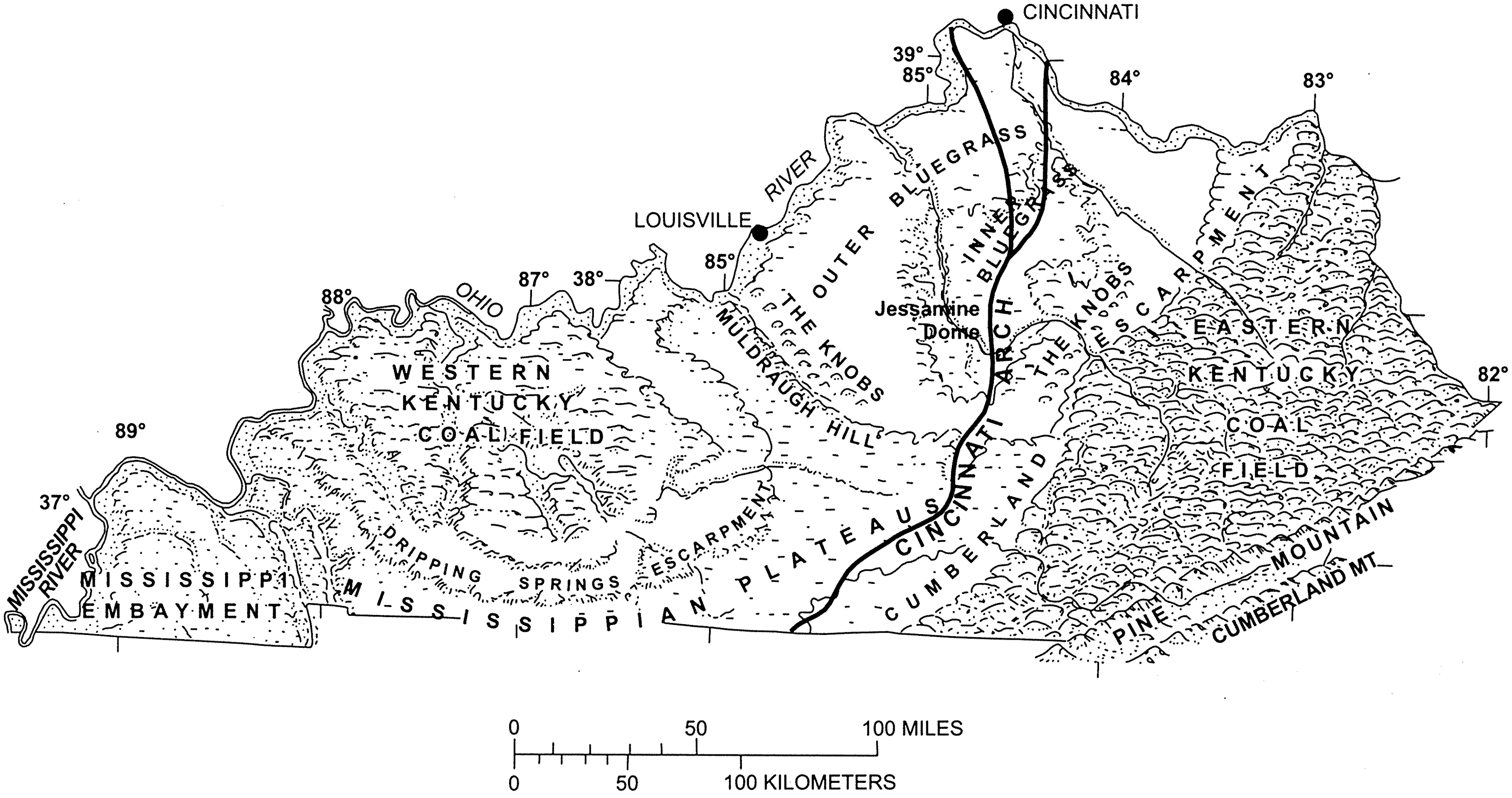


Figure 3. Physiographic regions in Kentucky [from Kentucky Geological Survey, 1980].

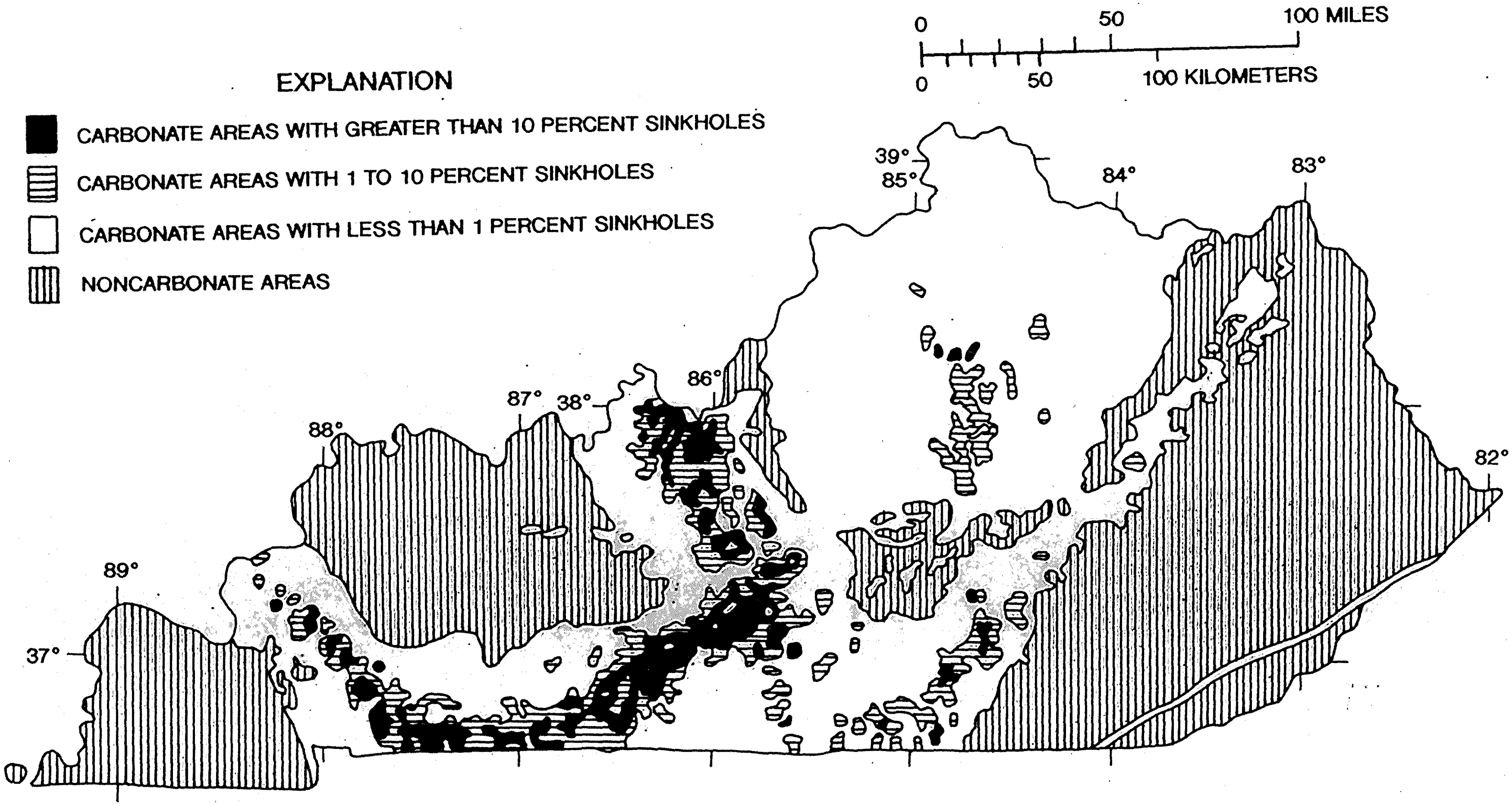


Figure 4. Generalized carbonate areas and surficial karst development in Kentucky [from Crawford and Webster, 1986].

COMPILATION AND REVIEW OF STREAMFLOW DATA

Daily mean streamflow data for 235 continuous-record streamflow-gaging stations located in Kentucky and adjacent states were retrieved by use of the USGS Automated Data Processing System (Bartholoma, 1997). The streamflow data in surrounding States were retrieved to provide additional information for use in the regionalization of Q_a values. The data were checked and verified by comparing computed yearly and monthly summary statistics of the daily mean streamflows to published values (U.S. Geological Survey, 1958a, 1958b, 1964a, 1964b, 1962-65, 1966-75, and 1976-2000).

Annual mean streamflows at 235 stations (198 in Kentucky and 37 in surrounding States) were tested for trends ($p <= 0.10$) by use of the Kendall's Tau test, which indicated that 27 stations had an increasing trend in streamflow and 3 had a decreasing trend in streamflow. These trends appeared climate-related and consistent with reported trends for mid-range (median) flows in this region (Lins and Slack,1999). Precipitation-adjusted annual mean streamflows were approximated roughly as the residuals from regressions of annual mean streamflow with annual precipitation data (by water year; see Glossary for definition) at Louisville, Ky., which is centrally located in relation to the gaging stations in the data set. Kendall's Tau tests of these residuals indicated that 28 had trend: 19 with increasing trend and 9 with decreasing trend.

Daily mean streamflows at many gaging stations in Kentucky are affected by regulation and (or) local diversions. Regulation by multipurpose or flood-control reservoirs reduce peak flows and generally augment low flows on a seasonal time scale; however, when streamflows are averaged over an annual time step, as in the case of the annual mean streamflow statistic, regulation generally has no effect on this statistic when the volume of water stored is released during the same water year. Two-sample statistical comparisons (Mathsoft, Inc., 1999a and 1999b) of pre- and post-regulation, precipitation-adjusted annual mean streamflow values (the residuals of the regression of annual mean streamflow with annual precipitation) downstream from some of the major reservoirs in Kentucky failed to indicate a significant difference in the sample means ($p = 0.05$).

Local diversions—localized transfers of water such as water-supply withdrawals or wastewater discharges—artificially decrease or increase streamflows within a reach. Local diversions are common near municipalities and in urban areas. The extent of alterations in natural streamflows caused by local diversions was reviewed based on available water-withdrawal and permitted-wastewater-discharge data. (A.C. Downs, U.S. Geological Survey, written commun., 2002; and S. Bolssen, Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, written commun., 2002). Localized diversions were deemed minor in relation to Q_a where available data indicated the flows diverted annually probably would not exceed 10 percent of Q_a.

MEAN ANNUAL STREAMFLOW ESTIMATES FOR GAGED STREAM SITES

Annual mean streamflows were computed from daily mean streamflows by use of the National Water Information System program DVMAS (Daily Values Monthly and Annual Statistics) (Bartholoma, 1997). The mean annual streamflow (Q_a) is defined as

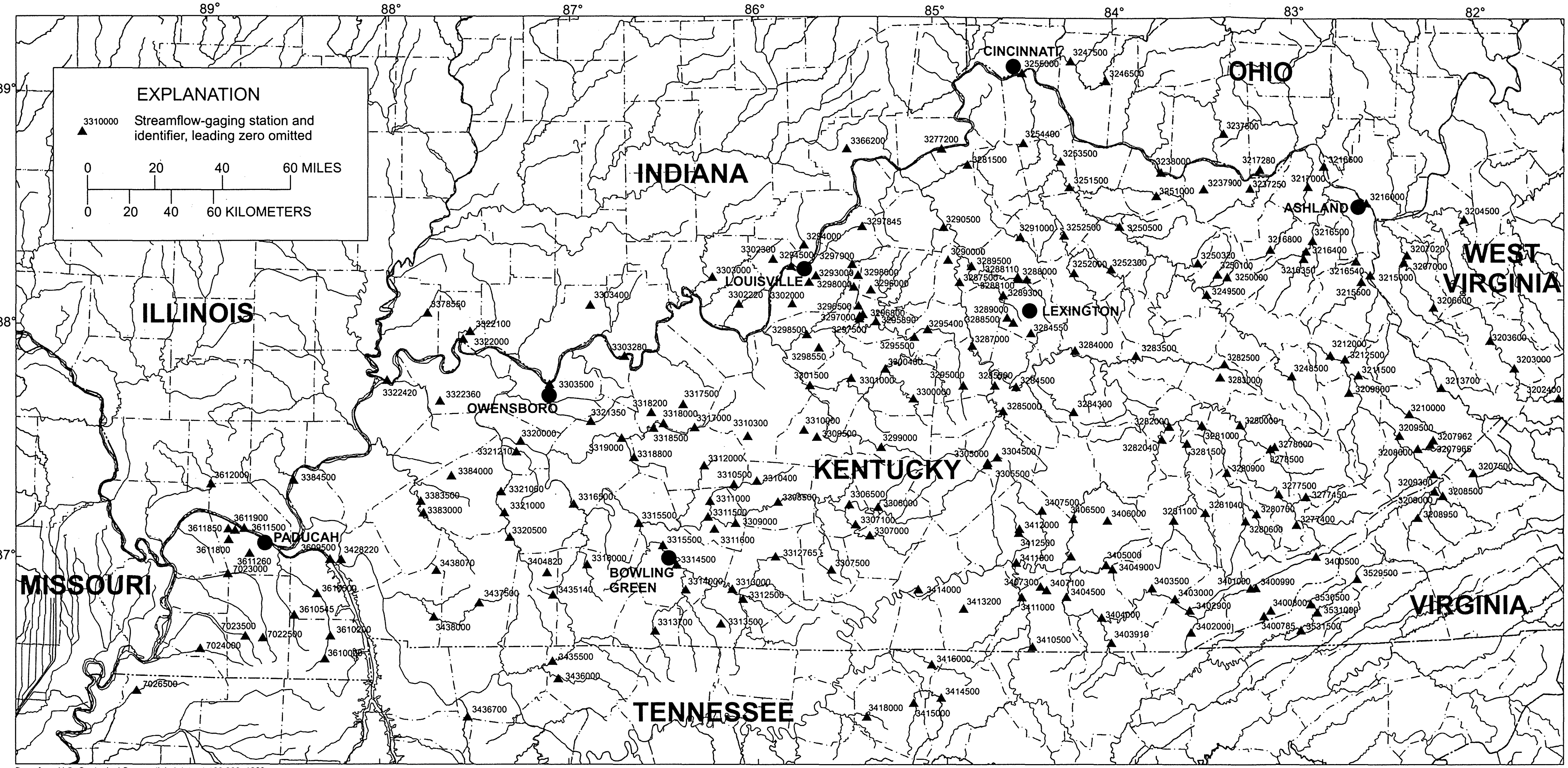
$$Q_a = \left(\sum_{i=1}^{N_a} Q_{ai} \right) / N_a , \qquad (5)$$

where

Q_{ai} is annual mean streamflow for the ith year and

N_a is the number of annual mean streamflows in the gaging station period of record.

The computed values of Q_a at streamflow-gaging stations having at least 5 years of record are shown in table 1 (back of report). Locations of these gaging stations are shown in figure 5.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Figure 5. Locations of continuous-record streamflow-gaging stations in Kentucky and surrounding States for which data are presented in this report. (See table 1.)

Streamflow statistics are subject to error associated with the particular time period sampled (time-sampling error). Gaged record may occur during either an abnormally wet or dry period, thus making it unrepresentative of long-term average climatic conditions. Time-sampling error decreases as record length increases. An example of the effects of time-sampling error is reflected in the 100 ft^3/s difference (reduction) of the computed Q_a value at Barren River at Lock 1 at Greencastle (station 0331500) compared to the computed Q_a value upstream at Barren River at Bowling Green (station 03314500) as shown in table 1.

Record-extension (augmentation) techniques may be used to reduce time-sampling error in streamflow values and statistics. Record extension is achieved by relating concurrent streamflows (and streamflow statistics) at a short-term and a nearby long-term (index) station that is hydrologically similar. The Q_a at the index station and the relation between the concurrent daily mean streamflows at both stations may be used to provide an estimate of the long-term Q_a at the short-term station. A mathematical record-extension technique, Maintenance of Variance Extension Type 1 (MOVE.1) as described by Hirsch (1982), was used in this study. The estimate was computed by use of log-transformed values of the concurrent nonzero daily mean streamflows as

$$Log\ Q_{a(s)} = M_s + \left(\frac{S_s}{S_l}\right) x\ (Log\ Q_{a(l)} - M_l)\,, \quad (6)$$

where

$Q_{a(s)}$ is the estimated long-term Q_a for the short-term station;

$Q_{a(l)}$ is the Q_a for the long-term station;

M_s, M_l are the mean of the log-transformed daily mean streamflows for the concurrent period at the short- and long-term stations, respectively; and

S_s, S_l are the standard deviations of the log-transformed daily mean streamflows for the concurrent period at the short- and long-term stations, respectively.

MOVE.1 was applied to improve Q_a estimates for Ohio River main-stem stations only (table 1). The two long-term index stations on the Ohio River at Louisville, Ky. (03294500) and at Metropolis, Ill. (03611500) each had 71 full water years of record (1929-99). Stations designated "short-term" in equation 6 had fewer than 71 years of record. The adjustments reduced time-sampling errors and improved consistency in Q_a and drainage-area-standardized values of Q_a along the river.

DEVELOPMENT OF THE TECHNIQUE FOR ESTIMATING MEAN ANNUAL STREAMFLOW FOR UNGAGED, RURAL STREAM SITES

A regression was used to develop regional equations for estimating Q_a at ungaged, rural sites. Drainage-basin characteristics, including climate, affect streamflow patterns. Relations among selected basin characteristics and computed Q_a were investigated by methods of linear correlation and multiple-linear regression.

Basin Characteristics

Various drainage-basin characteristics were tested for applicability in the regionalization of Q_a. Selection of basin characteristics for inclusion in exploratory scatter plots, linear correlation analysis, and subsequent multiple-linear-regression analysis was based on (1) the possible hydrologic importance of the characteristic in relation to the Q_a statistic, (2) the availability of previously determined basin characteristics for the study basins, and (3) results of previous regionalization studies of other streamflow statistics (Beaber, 1970; Wetzel and Bettandorff, 1986; Choquette, 1988; Ruhl and Martin, 1991; and Martin and Ruhl, 1993).

Basin characteristics tested for significance in the regression analysis included the following:

total drainage area (A), in square miles, the area measured in a horizontal plane that is enclosed by a drainage divide, measured by planimeter, digitized, or grid method from USGS 7.5-minute topographic quadrangle maps;

contributing drainage area, in square miles, is the total drainage area excluding any parts characterized by internal drainage, such as by way of sinkholes in karst terrain;
main-channel length, in miles, the length measured along the main stream channel from the station to the basin divide, following the longest tributary as determined from USGS 7.5-minute topographic quadrangle maps;
main-channel slope, in feet per mile, computed as the difference in elevation between points located at 10 and 85 percent of the main-channel length from the gage, divided by the stream length between these two points, as determined from USGS 7.5-minute topographic quadrangle maps;
basin length, in miles, the straight-line distance from the streamflow-gaging station to the basin divide (defined by the main-channel length);
mean basin width, in miles, calculated by dividing the total drainage area by basin length;
basin shape, the ratio of basin length, in miles, squared to total drainage area, in square miles;
main-channel sinuosity, the ratio of main-channel length, in miles, to basin length, in miles;
mean basin elevation (E), in thousands of feet above sea level, computed as the average elevation of the basin from a 1:250,000-scale digital elevation model converted to a grid coverage in ARC/INFO;
average basin elevation index, in thousands of feet above sea level, determined by averaging main-channel elevations at points 10 and 85 percent of the distance from a specified location on the main channel to the topographic divide, as determined from USGS 7.5-minute topographic quadrangle maps;
storage area, in percent, plus 1.00 percent, that part of the contributing drainage area occupied by lakes, ponds, and swamps, as shown on USGS 7.5-minute topographic quadrangle maps, not including temporary storage as a result of detention basins or ponding at roadway embankments;
mean annual precipitation, in inches, minus 30 in., estimated from Kentucky Department for Natural Resources and Environmental Protection (1979) and Conner (1982);
maximum 24-hour precipitation intensity, in inches, with recurrence intervals of 2 and 10 years (Hershfield, 1961);
maximum 24-hour precipitation intensity, in inches, occurring during the 30-year interval of 1951-80 (Glenn Conner, Kentucky Climate Center, written commun., 1986);
soils index, in inches ("S"; U.S. Department of Agriculture, 1969), is a measure of potential infiltration based on basin vegetative cover, soil infiltration rate, and soil water storage;
soil infiltration index, in inches per hour, is based on minimum infiltration rates for the U.S. Soil Conservation Service hydrologic soil groups (Musgrave, 1955) for soil series in Kentucky (U.S. Department of Agriculture, 1975 and 1984);
forested area, as a percentage of the contributing drainage area, plus 1.00 percent, measured from USGS 7.5-minute topographic quadrangle maps by use of the transparent-grid sampling method;
streamflow-recession index, defined as the number of days it takes base streamflow to decrease one log cycle, or one order of magnitude, as determined graphically from hydrograph plots of daily mean streamflow during representative periods of streamflow recession (Riggs, 1964; Bingham, 1982; and Ruhl and Martin, 1991);
streamflow-variability index, (Lane and Lei, 1950) at a station ("station" value) is computed as the standard deviation of the logarithms of the 19 discharges at 5-percent class intervals from 5 to 95 percent on the

flow-duration (cumulative-frequency) curve (Searcy, 1959; and Dempster, 1990) of daily mean streamflow for the entire period of record; "mapped" values of variability index tested in the regression were computed as areally weighted average values from the regionalized variability index (Ruhl and Martin, 1991);

azimuth, measured in degrees from north of line defining basin length;

gaging-station latitude (Lat_g), in decimal degrees, minus 36.0°, commonly determined from USGS 7.5-minute topographic quadrangle maps;

gaging-station longitude, in decimal degrees, minus 81.0°, commonly determined from USGS 7.5-minute topographic quadrangle maps;

drainage-basin centroid latitude, in decimal degrees minus 36.0°, determined in geographical information system (GIS) by means of the "centrallabels" command as applied to the basin-boundary polygons in ARC/INFO; and

drainage-basin centroid longitude, in decimal degrees, minus 81.0°, determined in a GIS as described for centroid latitude.

Regression Analysis

A multiple-linear-regression model was developed to relate Q_a (dependent variable) to selected basin characteristics ("independent" or explanatory variables). Included in the regression analysis were 170 streamflow-gaging stations with at least 10 years of record where Q_a was deemed not significantly affected by local diversions (identified as "minor" local diversions in table 1). The regression analysis included an exploratory phase using ordinary-least-squares (OLS) regression to select appropriate explanatory variables and a final phase using generalized-least-squares (GLS) regression. GLS regression compensates for differences in the variability and reliability of, and correlation among, the Q_a estimates at stations included in the analysis.

Inspection of scatter plots showing relations among dependent and explanatory variables and plots of residuals from initial linear regressions indicated that logarithmic (base 10) transformation of the dependent and most of the explanatory variables would be appropriate. This transformation generally helped make the relations more linear and the residuals more uniform in variance about the regression line than before transformation. The relations between dependent and explanatory variables after transformation were consistent with the assumed linear form of the model.

The general form of the regression models developed in this study is

$$\log(Q_a) = b_o + b_1 \log X_1 + b_2 \log X_2 + \dots + b_n \log X_n + \varepsilon, \quad (7)$$

where

Q_a is mean annual streamflow,

b_o is a constant,

b_i (i=1 to n) is the regression coefficient for the ith explanatory variable,

X_i (i=1 to n) is the ith explanatory variable,

ε is a random error component, and

n is the total number of explanatory variables.

The algebraically equivalent form when the log (base 10) transformation is used and when the equation is re-transformed to the original units is

$$Q_a = 10^{bo} X_1^{\ b1} X_2^{\ b2} \dots X_n^{\ bn}. \quad (8)$$

The alternative OLS regression models were generated by all-possible-regression and stepwise-regression procedures (Statistical Analysis System Institute, Inc., 1985) using the prospective explanatory variables listed in "Basin Characteristics." Various factors were considered in evaluating alternative regression models, including (1) the coefficient of determination, the proportion of the variation in the response variable explained by the regression equation; (2) the standard error of the estimate, a measure of model-fitting error; (3) the prediction sum of squares (PRESS) statistic, a measure of model-prediction error; (4) the statistical significance of each alternative explanatory variable; (5) potential multicollinearity as indicated by the correlation of explanatory variables and the value of the variance inflation factor (Montgomery and Peck, 1982); (6) the effort and modeling benefit of determining the values of each additional explanatory variable; and (7) the hydrologic validity of the signs and magnitudes of the regression exponents.

The best one-, two-, and three-variable OLS regression models included total drainage area (A), latitude of the gaging station minus 36° (Lat_g-36), and mean basin elevation (E) in thousands of feet above sea level as explanatory variables. The drainage-area-only model accounts for a large part of the variability of Q_a; however, the drainage-area-only model exhibits geographical bias, which was reduced progressively by adding the second and third explanatory variables to the regression models. The locational variable, Lat_g, may serve to integrate and index statewide variations in precipitation and evapotranspiration. Mean basin elevation also may serve as an index to a combination of other factors that are difficult to evaluate, such as radiation, temperature, wind, vegetation, and basin relief, which can cause streamflow variations (Thomas and Benson, 1970).

The OLS regression coefficients all are statistically different from zero (p-value less than 0.01). Regression residuals were analyzed to (1) identify outliers and high-leverage stations for examination, (2) confirm normality and homogeneity of variance, and (3) identify and remedy geographic bias.

The regression models (table 2) were finalized by use of GLS regression techniques (Stedinger and Tasker, 1985; and Tasker and Stedinger, 1989), which were implemented in the computer program GLSNET (G.D. Tasker, K.M. Flynn, A.M. Lumb, and W.O. Thomas, U.S. Geological Survey, written commun., 1995). Two major assumptions of OLS regression commonly are violated in regression of streamflow statistics: (1) the errors of the streamflow statistic are homogeneous among the observations and (2) the observations statistically are independent. Error in streamflow statistics vary with the length of record, which differs among the gaging stations, and streamflows at the set of gaging stations are correlated because the same climatic conditions and weather events generally affect most of the streams within a hydrologic region.

Stedinger and Tasker (1985, 1986) have shown that where streamflow records are of widely varying length and concurrent flows at different sites are highly correlated, GLS regression provides more accurate estimates of the regression coefficients, better estimates of the accuracy of the regression coefficients, and almost unbiased estimates of the model error when compared to OLS regression. GLS regression gives more weight to long-term gaging stations (with less time-sampling error) than short-term gaging stations and more weight to stations where flows are least correlated to flows at other gaging stations. GLS regression procedures use weighting matrices to proportionately account for the cross-correlation of streamflows and for the variations in time-sampling error of the streamflow statistic among the gaging stations.

Table 2. Equations (derived by generalized-least-squares regression) for estimating mean annual streamflow in Kentucky

[Q_a, mean annual streamflow in cubic feet per second; A, total drainage area, in square miles; Lat_g, latitude of the gage, or basin outfall, in decimal degrees; E, mean basin elevation, in thousands of feet above sea level; --, not applicable]

Equations	Range of explanatory variable: A	Range of explanatory variable: Lat_g	Range of explanatory variable: E	Approximate average standard error of prediction (percent)	Average equivalent years of record
$Q_a = 1.38\,A^{1.01}$	0.67–2,762	--	--	15.8	10.9
$Q_a = 1.42\,A^{1.01}(Lat_g\text{-}36)^{-0.18}$	.67–2,762	36.341–39.140	--	14.2	14.9
$Q_a = 1.39\,A^{1.00}(Lat_g\text{-}36)^{-0.15}E^{0.12}$	.67–2,762	36.341–39.140	0.391–2.414	13.7	15.4

The cross-correlations were estimated as an empirical, best-graphical-fit function of the distance between pairs of long-term gaging stations having at least 50 years of concurrent record. GLS regression required matrices of the mean, standard deviation, and skew of the annual mean streamflows associated with the matrix of the Q_a. A regional estimate of the standard deviations of annual mean streamflows independent of the Q_a estimating equation was developed within GLSNET by use of regression of the standard deviation against drainage area and mean basin elevation. A skew matrix was estimated by use of the observed skew of the series of annual mean streamflows at the gaging stations. The length of record at each gaging station was used as a measure of the reliability of the Q_a estimates. GLSNET enables partitioning of total regression-model error into model error and sampling error, which consists of both time- and space-sampling error. Model error arises from limitations of the model formulation, and it cannot be reduced by additional data collection. Time- and space-sampling error, however, are reduced through additional data collection by extending the period of data collection and by expanding the variety of basin characteristics of the sites where data are collected, respectively.

Limitations and Accuracy

The one-, two-, and three-variable regional regression models for estimating Q_a at ungaged stream sites have varying limitations and accuracies (table 2). As indicated previously, the one- and two-variable equations exhibit geographical biases, and the indicated standard errors of prediction may poorly estimate the true prediction errors, depending on the location in the State. The one- and two-variable models are suitable for initial approximate Q_a estimates; however, the three-variable equation should be used whenever possible.

The regional regression models are applicable to rural streams in Kentucky that are not appreciably affected by local diversions, which commonly are associated with urban development. Caution is warranted when applying the regression models in areas where streamflows are affected by hydrologic discontinuities such as large springs and sinks common to karst terrain in areas underlain by limestone (see fig. 4). Streamflows in these areas may vary unpredictably in karst drainageways. It may be difficult (if not impossible) to determine an accurate basin drainage area in karst terrain solely on the basis of topographic divides.

The regression model was developed by use of basin characteristics within a certain range of values. Drainage areas (A) of stations used in the regression analysis ranged from 0.67 to 2,762 mi^2, gage latitudes (Lat_g) ranged from 36.341 to 39.140°, and mean basin elevations (E) ranged from 0.391 to 2.414 in thousands of feet above sea level. Application of the regression models for Q_a estimates in basins outside these ranges is an extrapolation; therefore, these models probably should not be applied for this situation.

The standard error of prediction (of log Q_a) of the three-variable model—a measure of the accuracy of the regression estimates compared to observed data for stations excluded from the regression—is 13.7 percent. Standard error of prediction was estimated as the square root of the PRESS divided by the error degrees of freedom (Statistical Analysis System Institute, Inc., 1985; Montgomery and Peck, 1982; and Choquette, 1988). The procedure used for computing PRESS is considered a form of data splitting and can be applied as a model-validation tool. The accuracy of the three-variable model predictions for ungaged sites similar to those used in the regression could be expected to compare favorably to the standard error of prediction. A scatter plot of the values of Q_a computed from the streamflow-gaging station data and values computed using the regression model are shown in figure 6.

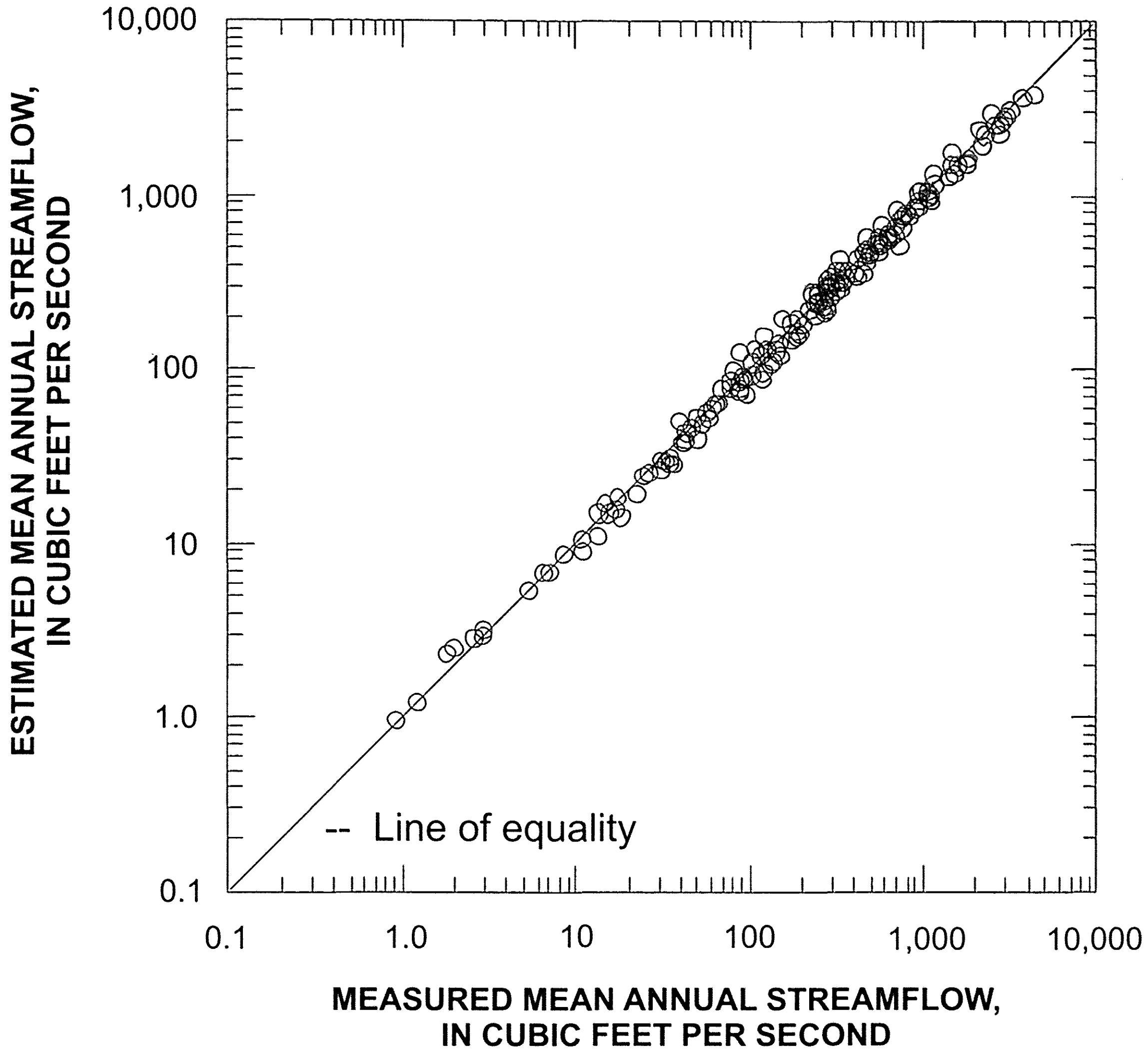


Figure 6. Comparison of measured mean annual streamflow and mean annual streamflow estimated by use of the three-variable regression equation for the 170 continuous-record streamflow-gaging stations in Kentucky and surrounding States used in the regression.

PROCEDURES FOR ESTIMATING MEAN ANNUAL STREAMFLOW AT STREAM SITES IN KENTUCKY

Procedures for obtaining Q_a estimates differ depending on the location of the stream site in relation to streamflow-gaging (gage) locations where Q_a has been determined. The appropriate procedures and examples are presented in the following sections.

Stream Sites With Gage Information

When streamflow-gaging information is available on the reach where an estimate of Q_a is desired, the gage information is used where appropriate in making the estimate, as discussed below.

Sites at Gage Locations

Estimates of Q_a values for 235 continuous-record streamflow-gaging stations are presented in table 1. When an estimate of Q_a is required at a stream site, refer to table 1 to determine whether values previously have been estimated for the site. At gage locations where the period of record is less than the equivalent years of record reported for the regression models (table 2), except on the Ohio River and where local diversions are significant, an improved estimate of Q_a may be obtained from a weighted average of the gaging-station estimate and regression-model estimate. The equivalent years of record can be used to weight the regression-model estimate, and the years of gaged record can be used to weight the gaging-station estimate.

Sites Near Gage Locations

If information is available for a stream reach where an estimate is desired, but not at the specific location, a weighting procedure can be used (Carpenter, 1983; and G.F. Koltun, U.S. Geological Survey, written commun., 2001). The drainage area of the ungaged site should differ by no more than 50 percent from that of the gaged site (ranging from 50 to 150 percent of the drainage area of the gaged site) to minimize the potential for hydrologic dissimilarity between the sites.

A weighted estimate of Q_a can be computed as

$$Q_{a_{uw}} = Q_{a_{ur}}\left[R - \left(\frac{2(|\Delta A|)(R-1)}{A_g}\right)\right], \qquad (9)$$

where R = $Q_{a_{gm}} / Q_{a_{gr}}$

and $Q_{a_{uw}}$ is the weighted mean annual flow, Q_a, for the ungaged site;

$Q_{a_{ur}}$ is the regression estimate of the Q_a for the ungaged site;

$Q_{a_{gm}}$ is the Q_a determined for the gaged site from measured streamflow data;

$Q_{a_{gr}}$ is the regression estimate of the Q_a for the gaged site;

$|\Delta A|$ is the absolute value of the difference between the drainage areas of the gaged site and the ungaged site; and

A_g is the drainage area of the gaged site.

As the difference in drainage area between the gaged and ungaged site approaches 50 percent, the value of the weighting factor in brackets in equation 9 approaches 1 and no longer has an effect on the regression estimate at the ungaged site.

Sites Between Gage Locations

If a Q_a estimate is desired between two gage locations on the same stream, the value can be estimated by linear interpolation by use of the Q_a values and corresponding drainage areas at the two gaged sites.

Stream Sites With No Gage Information

If no streamflow information is available at a stream site, or at a nearby stream site on the same stream reach so that the estimating methods in the previous section cannot be used, then the regional regression models (table 2) can be used directly to estimate Q_a.

Total drainage area of the site of interest should be determined from USGS 7.5-minute topographic maps or from other maps or GIS coverages of equivalent or improved accuracy. The drainage areas for many locations along streams in Kentucky are listed in Bower and Jackson (1981).

EXAMPLE APPLICATIONS OF ESTIMATING EQUATIONS

The estimating equations presented in this report can be applied to rural, ungaged streams with flows not appreciably affected by local diversions by (1) determining the basin characteristics required for the appropriate equation, (2) checking to ensure that the basin characteristics fall within the range of characteristics values used to develop the equation, and (3) use of the measured basin characteristics values with the appropriate equation to compute the estimate.

For example, assume that an estimate of Q_a is needed for an ungaged rural stream site with a drainage area of 80 mi^2, at a latitude of 37.525°, and a mean basin elevation of 900 ft above sea level. A comparison of basin characteristics with those listed in table 2 indicates that the characteristics for this basin are within the range of characteristics of gaging stations used to develop the estimating equations. Estimates of Q_a are computed as

$$Q_a = 1.39\,A^{1.00}(Lat_g\text{-}36)^{-0.15}E^{\,0.12}.$$

Substituting the measured basin characteristics into the above equation yields

$$Q_a = 1.39(80)^{1.00}(37.525\text{-}36)^{-0.15}(0.900)^{0.12}$$
$$= 103 \text{ ft}^3/\text{s}.$$

If it is desired to quickly obtain an approximate estimate by use of the drainage-area-only equation, then the first equation in table 2 is applied:

$$Q_a = 1.38\,A^{1.01}.$$

Substituting the measured basin characteristics into the above equation yields

$$Q_a = 1.38(80)^{1.01} = 115 \text{ ft}^3/\text{s}.$$

In situations where an estimate of Q_a is needed at a stream site on a reach near a gage location and the drainage area at the point of interest is between 50 and 150 percent of the drainage area of the gaged site, then equation 9 can be applied to obtain a Q_a estimate weighted by use of gaging-station information as shown in the following example.

Assume there is a streamflow-gaging station located downstream on the same stream reach used in the previous example with a drainage area of 85.9 mi^2, a latitude of 37.704°, and a mean basin elevation of 866 ft above sea level. The Q_a at the gaged site as computed from the long-term streamflow data is 104 ft^3/s. The regression estimate of Q_a at the gaged site is

$$Q_a = 1.39(85.9)^{1.00}(37.704\text{-}36)^{-0.15}(0.866)^{0.12}$$
$$= 108 \text{ ft}^3/\text{s}.$$

The coefficient R is determined as

$$R = Q_{a_{gm}} / Q_{a_{gr}} = \frac{104}{108} = 0.963.$$

The gage-weighted Q_a estimate for the ungaged site is computed as

$$Q_{a_{uw}} = Q_{a_{ur}}\left[R - \left(\frac{2(|\Delta A|)(R-1)}{A_g}\right)\right]$$

$$Q_{a_{uw}} =$$

$$103\left[0.963 - \left(\frac{2(|85.9 - 80.01|)(0.963 - 1)}{85.9}\right)\right]$$

$$Q_{a_{uw}} = 99.7 \text{ ft}^3/\text{s}.$$

This adjusted Q_a estimate for the ungaged upstream site, 99.7 ft^3/s, is 96 percent of the measured long-term Q_a (104) at the gaged site. This result is consistent with the ratio of the drainage areas of these two sites, 0.93, and is reasonable.

SUMMARY

Mean annual streamflow data are needed by water-resource managers and engineers for design of structures in streams and rivers. Techniques for estimating streamflow characteristics at ungaged sites are part of this need; therefore, the U.S. Geological Survey, in cooperation with the Kentucky Transportation Cabinet—Department of Highways, began a study in 1999 to compile available continuous-record streamflow-gaging data, compute mean annual flow at streamflow-gaging stations, and develop equations for estimating mean annual streamflow at ungaged rural stream sites.

The values of mean annual streamflow, Q_a, were determined at selected streamflow-gaging stations in Kentucky and surrounding States. Streamflow data for the available period of record through the 1999 water year at 235 continuous-record streamflow-gaging stations with at least 5 years of record were used in the analysis. Record extension at selected stations was accomplished by use of the MOVE.1 technique to reduce time-sampling error and, thus, improve estimates of long-term Q_a values.

Techniques to estimate Q_a at ungaged stream sites in Kentucky were developed. A multiple-linear-regression analysis was used to relate Q_a values to drainage-basin characteristics. One-, two-, and three-variable regression equations that included total drainage area, streamflow-gaging station latitude minus 36 degrees, and mean basin elevation as explanatory variables were developed by use of generalized-least-squares regression, which compensated for differences in the variability and reliability of, and correlation among, the Q_a estimates at the 170 gaging stations with 10 or more years of record included in the regression analysis. The three-variable regression equation has an approximate average standard error of prediction of 13.7 percent. The one- and two-variable equations exhibit geographical biases, and the indicated standard errors of prediction may estimate poorly the true prediction errors, depending on the location in the State. The one- and two-variable models are suitable for initial approximate Q_a estimates; however, the three-variable equation should be used whenever possible for estimating mean annual streamflow of rural streams in Kentucky. Estimating equations can be applied by (1) determining the basin characteristics required for the appropriate equation, (2) checking to ensure that the basin characteristics are within the range of values used to develop the equation, and (3) substituting the basin-characteristic values for the variables in the estimating equations as described in the example applications presented.

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GLOSSARY

COEFFICIENT OF MULTIPLE DETERMINATION.—The proportion of the variation in the dependent variable explained by the variables in a fitted regression model. Reported values are adjusted for error degrees of freedom.

LEVEL OF SIGNIFICANCE.—The selected maximum probability of making a Type I error, or rejecting a true null hypothesis. Hypothesis tests were used to determine if statistically significant relations existed between dependent and explanatory variables of regression models.

LOCAL DIVERSION.—A localized transfer of water, such as a water-supply withdrawal or wastewater releases, that artificially increase or decrease streamflow in a reach.

MULTICOLLINEARITY.—The presence of a high correlation (near linear dependencies) between two or more explanatory variables of a regression. Multicollinearity causes instability in the estimates of the least-squares regression coefficients.

MULTIPLE-LINEAR REGRESSION.—A method of regression wherein a linear relation between a dependent variable and more than one explanatory variable is defined.

ORDINARY-LEAST-SQUARES REGRESSION.—A method of fitting a regression model in which the sum of squared residuals (see Residual) is minimized.

PREDICTION SUM OF SQUARES (PRESS) STATISTIC.—A measure of model-prediction error useful in regression-model selection. It is computed by summing the square of the prediction residuals resulting from the series of predictions of each observation by regressions defined using all other observations. Thus, each observation is in turn excluded from the regression data set and is not used in prediction of itself. This process simulates prediction using new data and is a form of data splitting useful for model validation (Allen 1971, 1974; and Montgomery and Peck, 1982).

REGULATED STREAMFLOW.—Streamflow controlled by upstream hydraulic structures such as dams.

RESIDUAL.—The difference between values of mean annual streamflow computed by use of streamflow-gaging data and values estimated by use of a regression model.

STANDARD ERROR OF ESTIMATE.—A measure of model-fitting error; it is the standard deviation of the residuals of a regression adjusted for error degrees of freedom. Percentage values in this report were estimated by use of model root-mean-square error, or the square root of the sum of the squares of the residuals divided by the error degrees of freedom—n-k-1, where n is the number of observations and k is the number of explanatory variables in the regression—(Statistical Analysis System Institute, Inc., 1985) and information from Hardison (1971).

STANDARD ERROR OF PREDICTION.—A measure of model-prediction error; it was estimated as the square root of the PRESS divided by the degrees of freedom for error (Statistical Analysis System Institute, Inc., 1985; Montgomery and Peck, 1982; and Choquette, 1988). (See Prediction Sum of Squares (PRESS) Statistic.)

STREAMFLOW.—Discharge, measured as the volume of water that passes a given point within a given period of time (cubic feet per second), that occurs in a natural channel whether or not it is affected by diversion or regulation.

STREAMFLOW-GAGING STATION.—An installation that provides systematic observations of stage from which streamflow is computed.

VARIANCE INFLATION FACTOR (VIF).—An indicator of multicollinearity; it is a measure of the combined effect of the dependencies among explanatory variables on the variance of each term in a regression model (Marquardt, 1970; and Montgomery and Peck, 1982).

WATER YEAR.—The 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends.

Table 1. Continuous-record streamflow-gaging stations used in the study, selected basin characteristics, periods of record used in the analysis, corresponding mean annual flows, and selected reservoirs and diversions in the basin for Kentucky and surrounding States

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; --, not applicable; LD, local diversion; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Total drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimal degrees)	Mean basin elevation (feet above sea level)	Period of record used in the analysis (water years[1])	Number of years	Mean annual flow (ft^3/s)	Standardized mean annual flow ($ft^3/s/mi^2$)	Selected reservoirs in basin and start date or type of local diversion and location
03202400	Guyandotte River near Baileysville, West Virginia	306	37.600	81.650	2,106	1969-98	30	424	1.39	--
03203000	Guyandotte River at Man, West Virginia	758	37.740	81.880	1,878	1930-62	33	984	1.30	--
03203600	Guyandotte River at Logan, West Virginia	833	37.840	82.000	1,827	1963-98	36	1,170	1.40	--
03204500	Mud River near Milton, West Virginia	256	38.390	82.110	909	1939-80	42	290	1.13	--
03206600	East Fork Twelvepole Creek near Dunlow, West Virginia	38.5	38.020	82.300	1,081	1965-98	34	53.5	1.39	--
03207000	Twelvepole Creek at Wayne, West Virginia	291	38.220	82.450	986	1916-17, 1928-31, 1947-54, 1956-66	25	320	1.10	--
03207020	Twelvepole Creek below Wayne, West Virginia	300	38.250	82.430	980	1916-17, 1928-31, 1947-54, 1956-82	40	349	1.16	--
03207500	Levisa Fork near Grundy, Virginia	235	37.300	82.130	2,036	1942-74, 1986-87	34	290	1.23	--
03207962	Dicks Fork at Phyllis	.82	37.449	82.338	1,500	1976-84	9	.94	1.15	--
03207965	Grapevine Creek near Phyllis	6.20	37.432	82.354	1,429	1974-82, 1990-92, 1995-99	17	8.46	1.36	--
03208000	Levisa Fork below Fishtrap Dam, near Millard	392	37.416	82.421	1,810	1939-92	54	475	1.21	Fishtrap Lake, 10/68
03208500	Russel Fork at Haysi, Virginia	286	37.210	82.300	1,996	1927-99	73	336	1.18	--
03208950	Cranes Nest River near Clintwood, Virginia	66.5	37.120	82.440	2,074	1964-99	36	79.9	1.20	--
03209000	Pound River below Flannagan Dam near Haysi, Virginia	221	37.229	82.343	1,965	1927-99	72	277	1.26	Flannagan Lake, 12/63
03209300	Russell Fork at Elkhorn City	554	37.304	82.343	1,950	1961-92	32	708	1.28	Flannagan Lake, 12/63; North Fork Pound Lake, 08/66

Table 1. Continuous-record streamflow-gaging stations used in the study, selected basin characteristics, periods of record used in the analysis, corresponding mean annual flows, and selected reservoirs and diversions in the basin for Kentucky and surrounding States—*Continued*

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; --, not applicable; LD, local diversion; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Total drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimal degrees)	Mean basin elevation (feet above sea level)	Period of record used in the analysis (water years[1])	Number of years	Mean annual flow (ft^3/s)	Standardized mean annual flow ($ft^3/s/mi^2$)	Selected reservoirs in basin and start date or type of local diversion and location
03209500	Levisa Fork at Pikeville	1,232	37.476	82.518	1,789	1938-99	62	1,470	1.19	Flannagan Lake, 12/63; North Fork Pound Lake, 08/66 Fishtrap Lake, 10/68
03209800	Levisa Fork at Prestonsburg	1,702	37.671	82.777	1,628	1964-81	18	2,130	1.25	Flannagan Lake, 12/63; North Fork Pound Lake, 08/66 Fishtrap Lake, 10/68
03210000	Johns Creek near Meta	56.3	37.567	82.458	1,384	1942-93, 1995-99	57	68.9	1.22	--
03211500	Johns Creek near Van Lear	206	37.744	82.724	1,154	1940-92	53	232	1.12	Dewey Lake, 05/50
03212000	Paint Creek at Staffordsville	103	37.835	82.871	965	1951-75	25	128	1.25	--
03212500	Levisa Fork at Paintsville	2,144	37.815	82.792	1,485	1916, 1929-99	72	2,480	1.16	Dewey Lake, 05/50; Flannagan Lake, 12/63; North Fork Pound Lake, 08/66 Fishtrap Lake, 10/68 Paintsville Lake, 09/83
03213700	Tug Fork at Williamson, West Virginia	936	37.673	82.280	1,731	1968-98	31	1,140	1.22	--
03215000	Big Sandy River at Louisa	3,897	38.171	82.635	--	1940-47, 1949-76	36	4,440	1.14	Dewey Lake, 05/50; Flannagan Lake, 12/63; North Fork Pound Lake, 08/66 Fishtrap Lake, 10/68 Paintsville Lake, 09/83
03215500	Blaine Creek at Yatesville	217	38.144	82.685	862	1916-18, 1939-75	40	247	1.14	--
03216000	Ohio River at Ashland	60,750	38.481	82.637	--	1940-52	13	[2]84,000	1.38	Various
03216350	Little Sandy River below Grayson Dam near Leon	196	38.254	82.991	912	1967-92	26	241	1.23	Grayson Lake, 03/68
03216400	Little Sandy River at Leon	255	38.286	82.977	905	1962-80	19	314	1.23	Grayson Lake, 03/68
03216500	Little Sandy River at Grayson	400	38.330	82.939	875	1939-99	61	479	1.20	Grayson Lake, 03/68
03216540	East Fork Little Sandy River near Fallsburg	12.2	38.234	82.709	855	1973-91	19	15.6	1.28	--

Table 1. Continuous-record streamflow-gaging stations used in the study, selected basin characteristics, periods of record used in the analysis, corresponding mean annual flows, and selected reservoirs and diversions in the basin for Kentucky and surrounding States—*Continued*

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; --, not applicable; LD, local diversion; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Total drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimal degrees)	Mean basin elevation (feet above sea level)	Period of record used in the analysis (water years[1])	Number of years	Mean annual flow (ft^3/s)	Standardized mean annual flow ($ft^3/s/mi^2$)	Selected reservoirs in basin and start date or type of local diversion and location
03251500	Licking River at McKinneysburg	2,326	38.598	84.267	921	1925, 1939-94	57	3,030	1.30	Cave Run Lake, 12/73
03252000	Stoner Creek at Paris	239	38.229	84.256	929	1954-91	38	294	1.23	LD — waste disposal, Paris (minor)
03252300	Hinkston Creek at Carlisle	154	38.242	84.053	936	1992-99	8	208	1.35	--
03252500	South Fork Licking River at Cynthiana	621	38.391	84.303	907	1939-94	56	766	1.23	LD — water supply, Cynthiana (minor)
03253500	Licking River at Catawba	3,300	38.710	84.311	--	1916-17, 1929-99	73	4,140	1.26	Cave Run Lake, 12/73
03254400	North Fork Grassy Creek near Piner	13.6	38.792	84.514	816	1968-83	16	17.0	1.25	--
03255000	Ohio River at Cincinnati, Ohio	76,580	39.094	84.511	--	1940-62	23	[2]99,700	1.30	Various
03277200	Ohio River at Markland Dam	83,170	38.775	84.964	--	1971-99	29	[2]108,000	1.30	Various
03277400	Leatherwood Creek at Daisy	40.9	37.113	83.092	1,668	1965-74, 1992-98	17	60.4	1.48	--
03277450	Carr Fork near Sassafras	60.6	37.231	83.036	1,439	1964-94	31	77.6	1.28	Carr Fork Lake, 01/76
03277500	North Fork Kentucky River at Hazard	466	37.247	83.182	1,544	1941-93	53	576	1.24	Carr Fork Lake, 01/76
03278000	Bear Branch near Noble	2.21	37.451	83.195	1,167	1956-73	18	2.88	1.30	--
03278500	Troublesome Creek at Noble	177	37.443	83.218	1,273	1951-81	31	251	1.42	--
03280000	North Fork Kentucky River at Jackson	1,101	37.551	83.385	1,333	1929-31, 1938-99	65	1,460	1.32	Carr Fork Lake, 01/76
03280600	Middle Fork Kentucky River near Hyden	202	37.137	83.371	1,686	1958-92	35	296	1.47	LD — water supply, Hyden (minor)
03280700	Cutshin Creek at Wooton	61.3	37.165	83.308	1,530	1958-99	42	93.6	1.53	--
03280900	Middle Fork Kentucky River at Buckhorn	420	37.346	83.469	1,498	1957-75	19	632	1.50	Buckhorn Lake, 12/60
03281000	Middle Fork Kentucky River at Tallega	537	37.555	83.594	1,382	1931, 1940-99	61	751	1.40	Buckhorn Lake, 12/60
03281040	Red Bird River near Big Creek	155	37.179	83.593	1,407	1973-99	27	280	1.81	--
03281100	Goose Creek at Manchester	163	37.152	83.760	1,225	1965-99	35	266	1.63	--
03281500	South Fork Kentucky River at Booneville	722	37.479	83.677	1,188	1926-31, 1940-99	66	1,060	1.47	--

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03282000	Kentucky River at Lock 14 at Heidelberg	2,657	37.555	83.768	1,264	1926-31, 1939-99	67	3,750	1.41	Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03282040	Sturgeon Creek at Cressmont	77.3	37.501	83.810	1,098	1993-99	7	125	1.62	--
03282500	Red River near Hazel Green	65.8	37.812	83.464	1,106	1955-99	45	87.7	1.33	--
03283000	Stillwater Creek at Stillwater	24.0	37.757	83.487	1,090	1955-73	19	34.9	1.45	--
03283500	Red River at Clay City	362	37.864	83.933	1,040	1931, 1939-99	62	498	1.38	LD — waste disposal, Stanton (minor); water supply, Clay City (minor)
03284000	Kentucky River at Lock 10 near Winchester	3,955	37.895	84.262	--	1908-99	92	5,350	1.35	Buckhorn Lake, 12/60 Carr Fork Lake, 01/76 LD — water supply, Lexington (minor)
03284300	Silver Creek near Kingston	28.6	37.631	84.280	1,064	1968-83	16	42.1	1.47	LD — water supply, waste disposal, Berea (minor)
03284500	Kentucky River at Lock 8 near Camp Nelson	4,414	37.745	84.587	--	1940-71	32	5,530	1.25	Buckhorn Lake, 12/60 Carr Fork Lake, 01/76
03284550	West Hickman Creek at Jonestown	11.0	37.975	84.498	999	1975-84	10	16.8	1.52	LD — waste disposal, urban drainage, Lexington
03285000	Dix River near Danville	318	37.642	84.661	1,023	1943-99	57	475	1.49	--
03285500	Dix River near Burgin	395	37.753	84.703	997	1912-13, 1915-22	10	733	1.86	--
03287000	Kentucky River at Lock 6 near Salvisa	5,102	37.926	84.821	--	1926-99	74	6,790	1.33	Herrington Lake, 11/25; Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03287500	Kentucky River at Lock 4 at Frankfort	5,411	38.202	84.882	--	1926-30, 1933-99	72	7,220	1.33	Herrington Lake, 11/25; Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03288000	North Elkhorn Creek near Georgetown	119	38.206	84.514	944	1951-83, 1989-98	43	175	1.47	--
03288100	North Elkhorn Creek at Georgetown	147	38.219	84.563	933	1993-99	7	252	1.71	--

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03288110	Royal Spring at Georgetown	--	38.209	84.562	890	1993-99	7	25.2	--	LD — water supply, Georgetown
03288500	Cave Creek near Fort Spring	2.53	38.021	84.594	968	1953-72	20	2.94	1.16	--
03289000	South Elkhorn Creek at Fort Spring	24	38.043	84.626	965	1950-92	44	33.0	1.38	--
03289300	South Elkhorn Creek near Midway	105	38.141	84.645	928	1983-99	17	174	1.65	LD — waste disposal, urban drainage, Lexington
03289500	Elkhorn Creek near Frankfort	473	38.269	84.815	889	1919-20, 1941-83, 1988-99	58	644	1.36	LD — waste disposal, urban drainage, Lexington
03290000	Flat Creek near Frankfort	5.63	38.298	84.942	800	1952-71	20	6.48	1.15	--
03290500	Kentucky River at Lock 2 at Lockport	6,180	38.439	84.963	--	1927-30, 1933-37, 1939-99	70	8,410	1.36	Herrington Lake, 11/25; Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03291000	Eagle Creek at Sadieville	42.9	38.389	84.543	915	1942-75	34	58.2	1.36	--
03291500	Eagle Creek at Glencoe	437	38.705	84.824	830	1916-18, 1929-31, 1939-77, 1990-99	55	576	1.32	--
03292460	Harrods Creek near LaGrange	24.1	38.447	85.409	796	1969-94	26	36.9	1.53	--
03292500	South Fork Beargrass Creek at Louisville	17.2	38.211	85.702	543	1945-53, 1955-62, 1971-83, 1989-99	41	22.9	1.33	LD — waste disposal, urban drainage, Louisville
03293000	Middle Fork Beargrass Creek at Louisville	18.9	38.237	85.665	621	1945-99	55	25.4	1.34	LD — waste disposal, urban drainage, Louisville
03294000	Silver Creek near Sellersburg, Indiana	189	38.371	85.726	597	1955-99	45	223	1.18	--
03294500	Ohio River at Louisville	91,170	38.280	85.799	--	1929-99	71	116,000	1.27	Various
03295000	Salt River near Harrodsburg	41.4	37.757	84.873	944	1953-73	21	49.6	1.20	--
03295400	Salt River at Glensboro	172	38.002	85.061	850	1990-99	10	273	1.59	--
03295500	Salt River near Van Buren	196	37.968	85.134	839	1939-82	44	250	1.28	--

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03295890	Brashears Creek at Taylorsville	259	38.037	85.341	772	1982-99	18	342	1.32	--
03296000	Plum Creek Subwatershed number 4 near Simpsonville	1.55	38.174	85.368	765	1956-64	9	1.68	1.08	--
03296500	Plum Creek near Wilsonville	19.1	38.106	85.437	719	1955-61	7	23.6	1.23	--
03297000	Little Plum Creek near Waterford	5.15	38.062	85.429	679	1955-61	7	6.97	1.35	--
03297500	Plum Creek at Waterford	31.8	38.051	85.432	692	1955-74	20	41.4	1.30	--
03297845	Floyds Fork near Crestwood	46.7	38.300	85.427	768	1980-91	12	56.7	1.21	--
03297900	Floyds Fork near Pewee Valley	79.9	38.285	85.468	764	1992-99	8	113	1.41	--
03298000	Floyds Fork at Fisherville	138	38.188	85.460	737	1945-99	55	182	1.32	LD — waste disposal, irrigation water supply
03298500	Salt River at Shepherdsville	1,197	37.985	85.717	722	1939-99	61	1,590	1.33	Taylorsville Lake, 01/83
03298550	Long Lick near Clermont	7.91	37.928	85.654	683	1993-99	7	11.7	1.48	--
03299000	Rolling Fork near Lebanon	239	37.497	85.324	932	1939-92	54	349	1.46	--
03300000	Beech Fork near Springfield	85.9	37.704	85.146	866	1953-72	20	104	1.21	--
03300400	Beech Fork at Maud	436	37.833	85.296	820	1973-99	27	638	1.46	--
03301000	Beech Fork at Bardstown	669	37.797	85.481	786	1941-74, 1998-99	36	911	1.36	--
03301500	Rolling Fork near Boston	1,299	37.767	85.704	775	1938-99	61	1,820	1.40	--
03301580	Wilson Creek near Deatsville	12.3	37.864	85.611	697	1992-96	5	18.9	1.54	--
03302000	Pond Creek near Louisville	64.0	38.120	85.796	542	1945-99	55	90.7	1.42	LD — waste disposal, urban drainage, Louisville
03302220	Buck Creek near New Middletown, Indiana	65.2	38.119	86.086	750	1970-99	30	78.2	1.20	--
03302300	Little Indian Creek near Galena, Indiana	16.1	38.312	85.898	814	1969-99	31	22.7	1.41	--
03303000	Blue River near White Cloud, Indiana	476	38.237	86.228	754	1932-99	68	657	1.38	--
03303280	Ohio River at Cannelton Dam	97,000	37.899	86.706	--	1976-99	24	[2]123,000	1.27	Various

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03303400	Crooked Creek near Santa Claus, Indiana	7.86	38.118	86.890	495	1970-99	30	11.1	1.42	--
03303500	Ohio River at Owensboro	97,200	37.778	87.109	--	1941-52	12	[2]125,000	1.29	Various
03304500	McGills Creek near McKinney	2.14	37.444	84.698	1,194	1952-71	20	2.58	1.20	--
03305000	Green River near McKinney	22.4	37.422	84.750	1,150	1952-73	22	31.5	1.41	--
03305500	Green River near Mount Salem	36.3	37.411	84.753	1,151	1954-61	8	54.0	1.49	--
03306000	Green River near Campbellsville	682	37.240	85.347	951	1931, 1964-94	32	1,120	1.64	Green River Lake, 02/69
03306500	Green River at Greensburg	736	37.254	85.503	933	1940-75	36	1,120	1.53	Green River Lake, 02/69
03307000	Russell Creek near Columbia	188	37.119	85.394	876	1940-99	60	292	1.55	--
03307100	Russell Creek near Gresham	265	37.168	85.470	842	1965-75	11	451	1.70	--
03307500	South Fork Little Barren River at Edmonton	18.3	36.974	85.603	899	1942-72	31	26.3	1.44	--
03308500	Green River at Munfordville	1,673	37.268	85.886	855	1916-22, 1928-31, 1938-99	73	2,740	1.64	Green River Lake, 02/69
03309000	Green River at Mammoth Cave	1,983	37.179	86.113	835	1939-50	12	2,880	1.45	--
03309500	McDougal Creek near Hodgenville	5.34	37.544	85.672	883	1954-71	18	7.00	1.31	--
03310000	North Fork Nolin River at Hodgenville	36.4	37.576	85.740	844	1942-73	32	46.9	1.29	--
03310300	Nolin River at White Mills	357	37.551	86.045	769	1960-99	40	492	1.38	--
03310400	Bacon Creek near Priceville	85.4	37.359	85.998	775	1960-94	35	58.4	.68	--
03310500	Nolin River at Wax	600	37.345	86.122	749	1937-62	26	793	1.32	--
03311000	Nolin River at Kyrock	703	37.274	86.251	736	1931, 1940-50, 1961-99	51	942	1.34	Nolin Lake, 03/63
03311500	Green River at Lock 6 at Brownsville	2,762	37.207	86.261	805	1925-31, 1939-92	61	4,370	1.58	Nolin Lake, 03/63; Green River Lake, 02/69
03311600	Beaverdam Creek at Rhoda	10.9	37.155	86.226	673	1973-94	22	18.2	1.66	--

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03312000	Bear Creek near Leitchfield	30.8	37.427	86.279	677	1950-71	22	42.7	1.39	--
03312500	Barren River near Pageville	531	36.852	86.077	827	1940-63	24	844	1.59	--
03312765	Beaver Creek at Highway 31 East near Glasgow	49.6	37.035	85.904	838	1992-99	8	97.5	1.96	--
03313000	Barren River near Finney	942	36.895	86.134	804	1942-50, 1961-94	43	1,500	1.59	Barren River Lake, 03/64
03313500	West Bays Fork at Scottsville	7.47	36.748	86.196	785	1951-72	22	10.8	1.45	--
03313700	West Fork Drakes Creek near Franklin	110	36.719	86.546	783	1969-99	31	194	1.77	--
03314000	Drakes Creek near Alvaton	478	36.895	86.381	724	1941-71	31	697	1.46	--
03314500	Barren River at Bowling Green	1,849	37.001	86.431	743	1939-94	56	2,600	1.41	Barren River Lake, 03/64
03315000	Barren River at Lock 1 at Greencastle	1,966	37.086	86.503	733	1925-31	7	2,500	1.27	--
03315500	Green River at Lock 4 at Woodbury	5,404	37.182	86.630	--	1938-92	55	8,460	1.57	Nolin Lake, 03/63; Barren River Lake, 03/64; Green River Lake, 02/69
03316000	Mud River near Lewisburg	90.5	37.004	86.907	599	1940-72	33	151	1.67	--
03316500	Green River at Paradise	6,183	37.265	86.979	--	1940-50, 1961-81, 1992-99	40	9,360	1.51	Nolin Lake, 03/63; Barren River Lake, 03/64; Green River Lake, 02/69
03317000	Rough River near Madrid	225	37.592	86.329	711	1939-59	21	318	1.41	--
03317500	North Fork Rough River near Westview	42.0	37.692	86.391	711	1955-73	19	36.7	.87	--
03318000	Rough River near Falls of Rough	454	37.609	86.496	685	1940-51	12	627	1.38	--
03318200	Rock Lick Creek near Glen Dean	20.1	37.657	86.562	617	1957-71	15	24.9	1.24	--
03318500	Rough River at Falls of Rough	504	37.589	86.551	676	1949-94	46	759	1.51	Rough River Lake, 10/59
03318800	Caney Creek near Horse Branch	124	37.464	86.656	606	1957-92	36	188	1.52	--

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03319000	Rough River near Dundee	757	37.547	86.722	647	1941-92	52	1,080	1.43	Rough River Lake, 10/59
03320000	Green River at Lock 2 at Calhoun	7,566	37.534	87.264	--	1931-99	69	11,200	1.48	Rough River Lake, 10/59; Nolin Lake, 03/63; Barren River Lake, 03/64; Green River Lake, 02/69
03320500	Pond River near Apex	194	37.122	87.319	599	1941-99	59	274	1.41	--
03321000	Pond River near White Plains	343	37.227	87.349	562	1929-31, 1938-40	6	370	1.08	--
03321060	Pond River near Madisonville	469	37.317	87.369	535	1992-96	5	381	.81	--
03321210	Cypress Creek near Madisonville	14.2	37.489	87.286	437	1980-81, 1991-94	6	160	1.13	--
03321350	South Fork Panther Creek near Whitesville	58.2	37.619	86.887	556	1969-83	15	96.9	1.66	--
03322000	Ohio River at Evansville, Indiana	107,000	37.972	87.576	--	1941-74	34	133,000	1.24	Various
03322100	Pigeon Creek at Evansville, Indiana	323	38.004	87.539	443	1961-84	24	369	1.14	--
03322360	Beaverdam Creek near Corydon	14.3	37.704	87.698	446	1973-82, 1984-86, 1989-94	19	14.8	1.04	--
03322420	Ohio River at Uniontown Dam	108,000	37.792	87.986	--	1985-93	9	[2]138,000	1.28	Various
03366200	Herberts Creek near Madison, Indiana	9.31	38.782	85.486	826	1969-99	31	13.5	1.45	--
03378550	Big Creek near Wadesville, Indiana	104	38.082	87.769	456	1966-99	34	116	1.11	--
03383000	Tradewater River at Olney	255	37.224	87.781	532	1941-83, 1986-99	57	334	1.31	--
03383500	Tradewater River near Dalton	283	37.274	87.797	526	1929-31, 1938-40	6	284	1.00	--
03384000	Rose Creek at Nebo	2.10	37.383	87.633	423	1953-70	18	1.99	.95	--
03384500	Ohio River at Dam 51, at Golconda, Illinois	143,900	37.358	88.482	--	1941-52	12	[3]173,000	1.20	Various
03400500	Poor Fork at Cumberland	82.3	36.974	82.993	2,399	1941-93	53	143	1.73	--

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03400785	Martins Fork above Smith	23.8	36.726	83.288	2,185	1986-90	5	47.0	1.98	--
03400800	Martins Fork near Smith	55.8	36.749	83.248	2,077	1972-99	28	119	2.12	Martins Fork Lake, 11/78
03400990	Clover Fork at Harlan	222	36.848	83.326	2,181	1979-92	14	403	1.81	Martins Fork Lake, 11/78
03401000	Cumberland River near Harlan	374	36.847	83.356	2,219	1941-99	59	695	1.86	Martins Fork Lake, 11/78
03402000	Yellow Creek near Middlesboro	60.6	36.668	83.689	1,815	1941-99	59	120	1.98	LD — water supply, waste disposal, Middlesboro (minor)
03402900	Cumberland River at Pine Street Bridge at Pineville	770	36.763	83.692	1,971	1992-99	8	1,480	1.92	Martins Fork Lake, 11/78
03403000	Cumberland River near Pineville	809	36.813	83.766	1,943	1939-75, 1980-91	49	1,400	1.73	Martins Fork Lake, 11/78; LD — power plant (minor)
03403500	Cumberland River at Barbourville	960	36.862	83.887	1,850	1923-31, 1949-92, 1996-99	57	1,770	1.84	Martins Fork Lake, 11/78; LD — water supply, Barbourville (minor)
03403910	Clear Fork at Saxton	331	36.634	84.112	1,633	1969-90, 1996-99	26	557	1.68	--
03404000	Cumberland River at Williamsburg	1,607	36.744	84.158	1,679	1951-99	49	2,730	1.70	Martins Fork Lake, 11/78
03404500	Cumberland River at Cumberland Falls	1,977	36.837	84.343	1,603	1908-11, 1916-31, 1933-94	82	3,190	1.61	Martins Fork Lake, 11/78
03404820	Laurel River at Municipal Dam near Corbin	140	36.970	87.120	1,204	1974-92	19	238	1.70	LD — water supply, Corbin (minor)
03404900	Lynn Camp Creek at Corbin	53.8	36.951	84.094	1,218	1974-99	26	88.9	1.65	--
03405000	Laurel River at Corbin	201	36.969	84.127	1,206	1923-24, 1943-73	33	338	1.68	LD — water supply, Corbin (minor)
03406000	Wood Creek near London	3.89	37.161	84.112	1,238	1954-71	18	5.34	1.37	--

Table 1. Continuous-record streamflow-gaging stations used in the study, selected basin characteristics, periods of record used in the analysis, corresponding mean annual flows, and selected reservoirs and diversions in the basin for Kentucky and surrounding States—*Continued*

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; --, not applicable; LD, local diversion; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Total drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimal degrees)	Mean basin elevation (feet above sea level)	Period of record used in the analysis (water years[1])	Number of years	Mean annual flow (ft^3/s)	Standardized mean annual flow ($ft^3/s/mi^2$)	Selected reservoirs in basin and start date or type of local diversion and location
03406500	Rockcastle River at Billows	604	37.171	84.296	1,178	1937-99	63	945	1.57	--
03407000	Rockcastle River at Rockcastle Springs	745	37.010	84.315	1,163	1923-31	9	1,090	1.47	--
03407100	Cane Branch near Parkers Lake	.67	36.868	84.449	1,216	1957-66, 1974	11	.92	1.37	--
03407300	Helton Branch near Greenwood	.85	36.885	84.482	1,217	1957-74	18	1.22	1.43	--
03407500	Buck Creek near Shopville	165	37.211	84.464	1,116	1953-91	39	277	1.68	--
03410500	South Fork Cumberland River near Sterns	954	36.627	84.533	1,605	1943-99	57	1,790	1.88	--
03411000	South Fork Cumberland River at Nevelsville	1,271	36.840	84.583	1,501	1916-31, 1933-50	34	2,200	1.73	--
03411500	Cumberland River at Burnside	4,865	36.989	84.610	--	1915-50	36	7,630	1.57	Laurel River Lake, 10/73; Martins Fork Lake, 11/78
03412000	Pitman Creek near Somerset	26.3	37.135	84.588	1,082	1951-53	3	47.9	1.82	--
03413200	Beaver Creek near Monticello	43.4	36.797	84.896	1,212	1969-83, 1990-99	25	64.1	1.48	--
03414000	Cumberland River near Rowena	5,790	36.884	85.139	--	1940-92	53	9,010	1.56	Cumberland Lake, 12/50; Laurel River Lake, 10/73; Martins Fork Lake, 11/78
03414500	East Fork Obey River near Jamestown, Tennessee	202	36.416	85.026	1,645	1943-91	49	418	2.07	--
03415000	West Fork Obey River near Alpine, Tennessee	115	36.397	85.174	1,391	1943-71, 1980-81	31	157	1.37	--
03416000	Wolf River near Byrdstown, Tennessee	106	36.560	85.073	1,319	1943-91	49	189	1.78	--
03418000	Roaring River near Hilham, Tennessee	78.7	36.341	85.426	1,112	1932-74	43	109	1.39	--
03435140	Whippoorwill Creek near Claymour	20.8	36.875	87.089	719	1974-91	18	34.7	1.67	--
03435500	Red River near Adams, Tennessee	706	36.589	87.089	652	1921-69	49	937	1.33	--

Table 1. Continuous-record streamflow-gaging stations used in the study, selected basin characteristics, periods of record used in the analysis, corresponding mean annual flows, and selected reservoirs and diversions in the basin for Kentucky and surrounding States—*Continued*

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; --, not applicable; LD, local diversion; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Total drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimal degrees)	Mean basin elevation (feet above sea level)	Period of record used in the analysis (water years[1])	Number of years	Mean annual flow (ft^3/s)	Standardized mean annual flow ($ft^3/s/mi^2$)	Selected reservoirs in basin and start date or type of local diversion and location
03436000	Sulfur Fork Red River near Adams, Tennessee	186	36.515	87.059	682	1940-91	52	252	1.35	--
03436700	Yellow Creek near Shiloh, Tennessee	124	36.349	87.539	677	1958-80	23	191	1.54	--
03437500	South Fork Little River at Hopkinsville	46.5	36.839	87.481	618	1950-73	24	65.8	1.42	--
03438000	Little River near Cadiz	244	36.778	87.722	578	1941-99	59	356	1.46	--
03438070	Muddy Fork Little River near Cerulean	30.5	36.978	87.710	569	1969-83	15	50.2	1.65	--
03438220	Cumberland River near Grand Rivers	17,600	37.021	88.221	--	1967-97	31	[4]38,200	2.17	Dale Hollow Lake, 08/43; Lake Barkley, 08/44; Cumberland Lake, 12/50; various others
03529500	Powell River at Big Stone Gap, Virginia	112	36.870	82.780	2,414	1945-59, 1979-81	18	202	1.80	--
03530500	North Fork Powell River at Pennington Gap, Virginia	70	36.770	83.030	2,109	1946-51, 1979-81, 1994-95	11	137	1.95	--
03531000	Powell River near Pennington Gap, Virginia	290	36.734	82.999	2,161	1921-31	11	553	1.91	--
03531500	Powell River near Jonesville, Virginia	319	36.660	83.090	2,101	1932-99	68	543	1.70	--
03609500	Tennessee River near Paducah	40,200	37.020	88.281	--	1967-84	18	[4]66,900	1.66	Kentucky Lake, 01/36; various others
03610000	Clarks River at Murray	89.7	36.593	88.300	553	1952-71	20	88.6	.99	--
03610200	Clarks River at Almo	134	36.692	88.274	540	1983-99	17	181	1.35	LD — waste-disposal, Murray
03610500	Clarks River near Benton	227	36.873	88.347	515	1939-73	35	278	1.22	LD — waste-disposal, Murray (minor)
03610545	West Fork Clarks River near Brewers	68.7	36.780	88.467	513	1969-83, 1990-94	20	91.5	1.33	--
03611260	Massac Creek near Paducah	14.6	37.041	88.711	436	1972-99	28	17.4	1.19	--
03611500	Ohio River at Metropolis, Illinois	203,000	37.148	88.741	--	1929-99	71	278,000	1.37	Various

Table 1. Continuous-record streamflow-gaging stations used in the study, selected basin characteristics, periods of record used in the analysis, corresponding mean annual flows, and selected reservoirs and diversions in the basin for Kentucky and surrounding States—*Continued*

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; --, not applicable; LD, local diversion; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Total drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimal degrees)	Mean basin elevation (feet above sea level)	Period of record used in the analysis (water years[1])	Number of years	Mean annual flow (ft^3/s)	Standardized mean annual flow ($ft^3/s/mi^2$)	Selected reservoirs in basin and start date or type of local diversion and location
03611800	Bayou Creek at Heath	6.55	37.099	88.824	422	1991, 1994-99	7	6.42	.98	--
03611850	Bayou Creek near Grahamville	14.9	37.145	88.827	405	1991, 1994-99	7	20.8	1.40	--
03611900	Little Bayou Creek near Grahamville	5.78	37.139	88.791	365	1991, 1994-99	7	6.59	1.14	--
03612000	Cache River at Forman, Illinois	244	37.336	88.924	491	1925-99	75	297	1.22	--
07022500	Perry Creek near Mayfield	1.72	36.679	88.632	517	1953-65, 1968-72	18	1.78	1.03	--
07023000	Mayfield Creek at Lovelaceville	212	36.952	88.825	481	1939-72	34	231	1.09	--
07023500	Obion Creek at Pryorsburg	36.8	36.686	88.726	496	1952-73	22	40.1	1.09	--
07024000	Bayou De Chien near Clinton	68.7	36.629	88.964	422	1940-78, 1985-99	54	103	1.50	--
07026500	Reelfoot Creek near Samburg, Tennessee	110	36.442	89.296	391	1952-73	22	120	1.09	--

[1]Water year refers to the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends.

[2]Value adjusted based on correlation of concurrent record with Ohio River at Louisville (03294500).

[3]Value adjusted based on correlation of concurrent record with Ohio River at Metropolis, Ill. (03611500).

[4]Values in the table are for the period after 1966 only—after the Kentucky Lake-Lake Barkley Canal was opened in May 1966.

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