REGIONALIZATION OF HARMONIC-MEAN STREAMFLOWS IN KENTUCKY

By Gary R. Martin and Kevin J. Ruhl

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Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($(ft^3/s)/mi^2$)	0.0109	cubic meter per second per square kilometer

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ABSTRACT

Harmonic-mean streamflow (Q_h), defined as the reciprocal of the arithmetic mean of the reciprocal daily streamflow values, was determined for selected stream sites in Kentucky. Daily mean discharges for the available period of record through the 1989 water year at 230 continuous-record streamflow-gaging stations located in and adjacent to Kentucky were used in the analysis. Periods of record affected by regulation were identified and analyzed separately from periods of record unaffected by regulation. Record-extension procedures were applied to short-term stations to reduce time-sampling error and, thus, improve estimates of the long-term Q_h.

Techniques to estimate the Q_h at ungaged stream sites in Kentucky were developed. A regression model relating Q_h to total drainage area and streamflow-variability index was presented with example applications. The regression model has a standard error of estimate of 76 percent and a standard error of prediction of 78 percent.

INTRODUCTION

Streamflow information pertaining to the quality and quantity of water is critical for the protection and wise management of surface-water resources in Kentucky. Harmonic-mean streamflow, the reciprocal of the arithmetic mean of the reciprocal daily streamflow values, is useful for assessing the availability of water for assimilation of certain types of wastes. Kentucky water-quality standards for protection of human health from exposure to selected toxic substances incorporate the Q_h. The U.S. Geological Survey (USGS), in cooperation with the Kentucky Natural Resources and Environmental Protection Cabinet (KNREPC), analyzed available data from the streamflow-gaging network, located in and adjacent to Kentucky, to estimate the long-term Q_h and to develop a regional relation to estimate Q_h values at ungaged stream sites in Kentucky.

Discharge of contaminants can interfere with surface-water uses. The health of aquatic communities and humans can be adversely affected by exposure to elevated concentrations of contaminants. Consumption of toxic substances in fish and water can be detrimental to human health, and any adverse effects on health can be cumulative. Concentrations of such toxic substances in streams, when discharged at a constant rate, are inversely proportional to streamflow. Procedures for defining pertinent streamflow characteristics in Kentucky are, therefore, needed to set contaminant-discharge limits.

Pursuant to the 1987 amendments to the Clean Water Act, States are required to establish concentration limits for toxic substances that interfere with surface-water use. The KNREPC has established allowable concentration limits for selected toxic substances for protection of human health based on numerical criteria and associated risk factors published in 'Quality Criteria for Water 1986' (U.S. Environmental Protection Agency, 1986a). The Q_h was adopted as the governing "design" flow for setting waste-load-discharge limits for selected cancer-linked substances. It was determined that Q_h can provide the most representative estimate of long-term average instream exposure concentrations of these substances (Kentucky Natural Resources and Environmental Protection Cabinet, 1990).

Purpose and Scope

The purpose of this report is to provide (1) Q_h values at streamflow-gaging stations, considering periods of record affected by regulation and periods of record unaffected by regulation separately, and (2) a procedure for estimating the Q_h at ungaged stream sites unaffected by regulation or local diversions. This report presents Q_h values for 230 continuous-record streamflow-gaging stations in the study area. Procedures for estimating the Q_h at ungaged stream sites are described and illustrated with example computations.

Physiography and Geology

The physiography of the State reflects the lithology of the surface rocks and is largely defined by the Cincinnati Arch (fig. 1). The axis of the Cincinnati Arch trends northward from south-central Kentucky to just south of the Inner and Outer Bluegrass boundary where it divides into two branches. The branches are approximately parallel but are separated by approximately 25 mi at the Ohio River (McFarland, 1950). Lithologic units dip from the arch, a structural high, so that geologic features are generally symmetrical on each side of the axis of the arch.

East and west from the Cincinnati Arch, progressively younger rocks are exposed at the surface. The oldest exposed rocks are part of the Jessamine Dome and the areas adjacent to it. The location of this area corresponds approximately to the Inner Bluegrass region (fig. 1). 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 Outer Bluegrass region. An expansive area of limestone of Mississippian age (Mississippian Plateaus Region) is exposed starting at the Ohio River in northeastern Kentucky and extending southwest to the State boundary and northwest in a crescent-shaped area surrounding the Western Kentucky Coal Field. The eastern boundary of this area is the Cumberland Escarpment (fig. 1). 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 occur in extreme western Kentucky in the Mississippi Embayment.

Much of the Mississippian Plateau is characterized by karst features such as sinkholes, caves, springs, and gaining 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. 2). Less well-developed karst features are in central and south-central Kentucky. The streams in karst areas commonly have sustained base flow during dry-weather periods.

Climate

Annual precipitation in Kentucky averages about 47 inches (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 inches. Rainfall generally decreases to the north, reflecting the increase in distance from the source of precipitation, which is primarily the subtropical Atlantic Ocean and Gulf of Mexico. Considerable year-to-year variation in precipitation has occurred in Kentucky. During the period 1951-80, annual precipitation at reporting stations ranged from 14.5 to 78.6 in. (Conner, 1982).

Seasonally, the greatest amount of precipitation occurs during late winter and early spring in all areas except in north-central Kentucky, which receives the largest monthly precipitation in July. Winter precipitation is associated with frontal activity; however, in summer, convective thunderstorms produce most

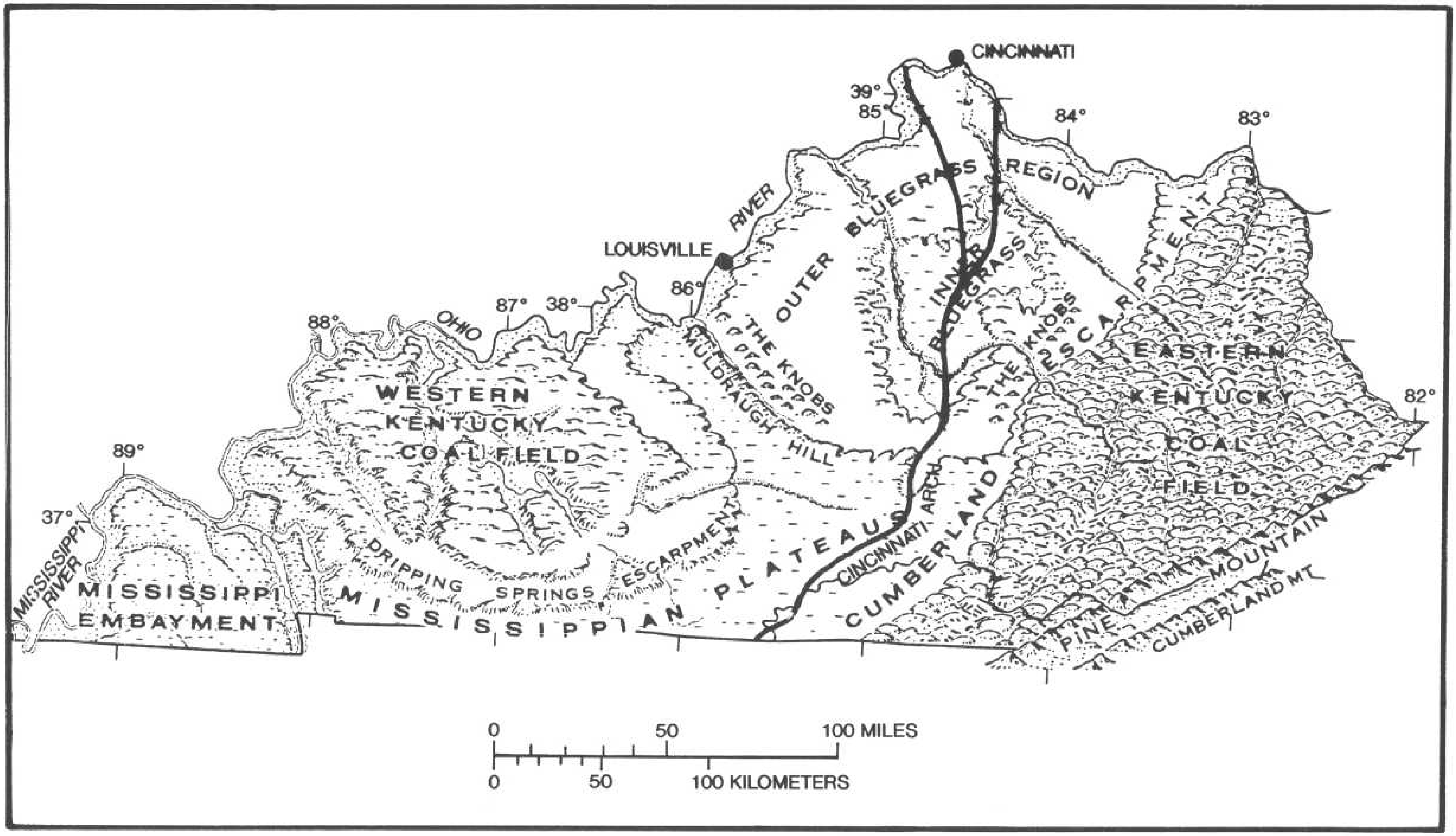

Figure 1.--Physiographic regions in Kentucky [From Kentucky Geological Survey, 1980].

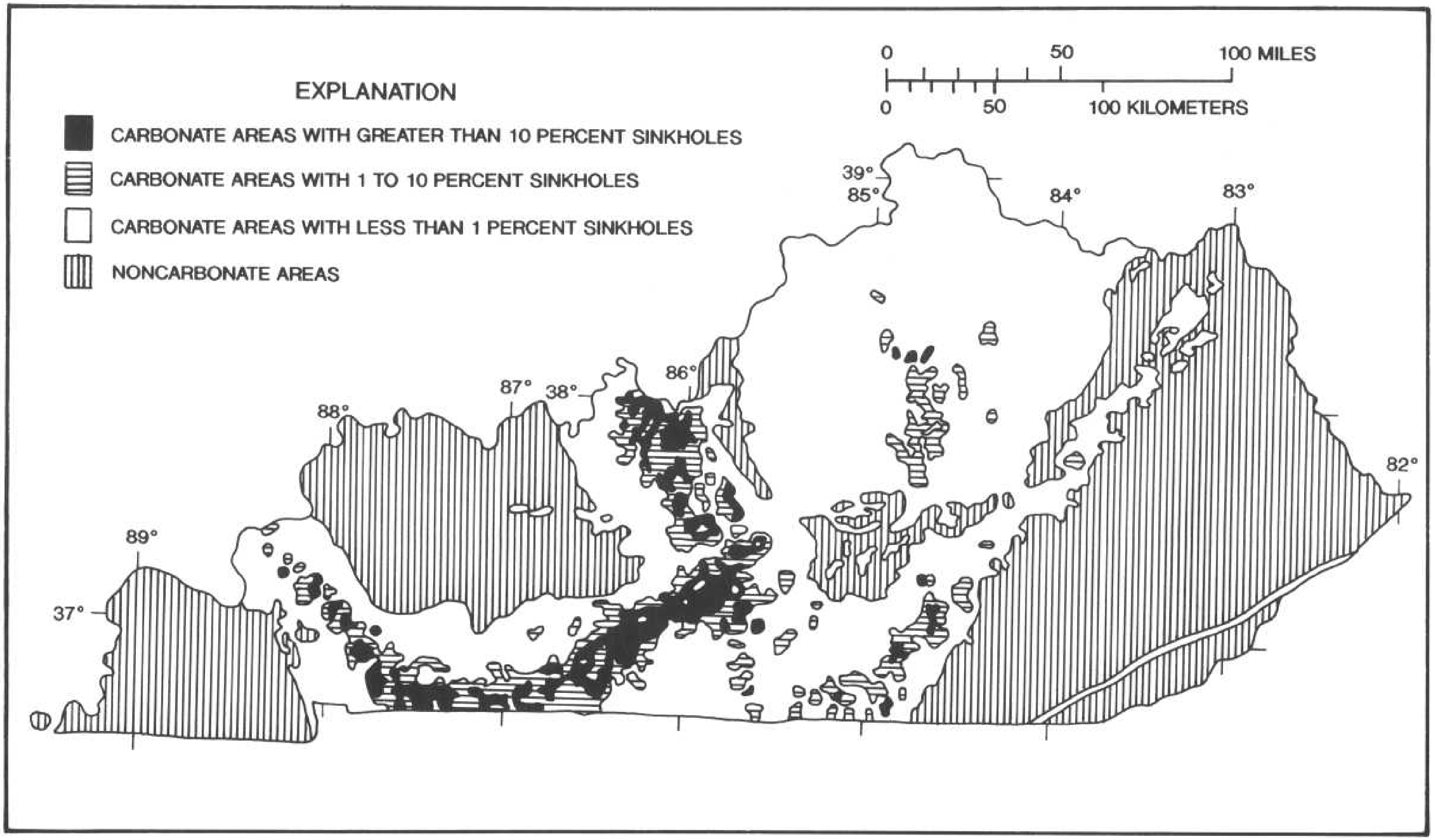

Figure 2.--Generalized carbonate areas and surficial karst development in Kentucky [From Crawford and Webster, 1986].

of the precipitation. Large amounts of rainfall in Kentucky have been associated with tropical cyclones originating in the Gulf of Mexico. Kentucky's dry season occurs during the fall, and October is the driest month. The Bermuda High, which normally resides off the coast of the southeastern United States during summer, moves inland in the fall. In October, the normal position of the Bermuda High is over Kentucky and Tennessee. The High suppresses convective activity and inhibits the movement of fronts (Conner, 1982). As a result, streamflow depends primarily on the discharge of ground water during late summer and early fall.

THEORETICAL BASIS FOR, AND COMPUTATION OF, HARMONIC-MEAN STREAMFLOW

The Q_h is one of several streamflow statistics that have been adopted by Federal and State water-quality-management agencies as design flows for use in waste-load allocation. Design flows are stream discharges that are used to set waste-load-discharge limits on the basis of permissible instream concentrations of contaminants.

Two general types of design flows are now in use--hydrologically based and biologically based (U.S. Environmental Protection Agency, 1986b). Hydrologically based design flows are derived from standard extreme-value statistical analysis of daily mean streamflow data that include only a single extreme value per year (lowest or highest). In a given year, however, several occurrences of streamflow may be more severe than the extreme value in other years during the period of record, and these occurrences are excluded in extreme-value analysis. Extreme-value analysis does, however, permit assignment of annual exceedence (or nonexceedence) probabilities. The 7-day, 10-year low flow ($7Q_{10}$), computed using the lowest arithmetic mean of discharge over 7 consecutive days during each year of record, is an example of a commonly used hydrologically based design flow. Biologically based design flows, in contrast, are intended to be closely associated with observed biological, toxicological, and ecological effects of contaminants. To that end, all of the annual streamflow record is considered to account for the cumulative adverse effects of multiple within-year extreme values on organisms. Water-quality criteria for protection of aquatic life and human health can be implemented using biologically based design flows.

Currently (1993), Kentucky uses hydrologically based design flows for protection of aquatic life and human health from toxic substances that are not linked to cancer. Biologically based design flows are used for purposes of protecting human health from cancer-linked substances. Water-quality standards for purposes of protecting human health from cancer-linked substances were established based on the health risks of long-term (lifetime) exposures through (1) consumption of water and (2) consumption of water and fish tissue.

Biologically based design flows are computed using the harmonic mean of a streamflow time series, typically daily mean streamflow. Estimates of long-term (lifetime) average exposure concentrations of contaminants in streams can be made using Q_h computed from the long-term, period-of-record daily mean streamflows. The average exposure concentration, C_{avg}, during N days can be computed (L.A. Rossman, U.S. Environmental Protection Agency, written commun., 1988; Rossman, 1990b) as

$$C_{avg} = \frac{\sum_{t=1}^{N} C_t}{N} = \frac{\sum_{t=1}^{N} \frac{W}{Q_t}}{N} = \frac{W \sum_{t=1}^{N} \frac{1}{Q_t}}{N} = \frac{W}{\frac{N}{\sum_{t=1}^{N} \frac{1}{Q_t}}} = \frac{W}{Q_h}, \tag{1}$$

where

C_t is the average exposure concentration for a given day (mass/volume);
W is constant instream contaminant loading rate (mass/time);
Q_t is the average streamflow for a given day (volume/time); and
Q_h is harmonic-mean streamflow (volume/time).

Given an allowable long-term average exposure concentration for a contaminant specified by a water-quality standard, together with the computed Q_h at a site, the allowable instream contaminant loading rate (W) can be determined from equation 1.

Thus, Q_h is the reciprocal of the arithmetic mean of the reciprocal of the daily mean streamflows, or

$$Q_h = \frac{N}{\sum_{t=1}^{N} \frac{1}{Q_t}} = \frac{N}{\frac{1}{Q_1} + \frac{1}{Q_2} + \ldots + \frac{1}{Q_N}}. \qquad (2)$$

Low streamflows within the period of record analyzed are weighted more heavily than moderate or high streamflows. For example, the harmonic mean of the integers from 1 through 10 (i.e., Q_t = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) is 3.4, compared to the arithmetic mean of 5.5. Thus, Q_h is biased toward the low end of the range of streamflows during a given period of record, and therefore, Q_h may correlate with other low-flow statistics.

A value of zero for daily mean streamflow cannot be handled directly in the above formulation because division by zero yields an undefined value. To adjust for zero flows, the harmonic mean of the nonzero daily mean streamflows was multiplied by the ratio of the number of nonzero daily mean streamflows to the total number of daily mean streamflows in the period of record analyzed. This proportional adjustment for zero flows is consistent with current U.S. Environmental Protection Agency design-flow methodology (Rossman, 1990a).

The above proportional adjustment for zeros can sometimes yield illogical results. For example, revising the above numerical example by changing the one to a zero (i.e., Q_t = 0, 2, 3, 4, 5, 6, 7, 8, 9, 10), the computed Q_h using the proportional adjustment, (9/10)(9/(1/2+1/3+ ... +1/10)), is 4.2. This result is larger than when the one is included instead of the zero.

Alternate methods of treating zero flows were explored. One alternate method is the substitution of some small value, such as 0.01 or 0.001, for zero. Values of Q_h computed using such substitutions can differ significantly from values computed using the proportional adjustment discussed above (even for stations with few days of zero flow in the streamflow record). For example, substituting 0.01 for zero in the previous example (i.e., Q_t = 0.01, 2, 3, 4, 5, 6, 7, 8, 9, 10) yields a harmonic mean of approximately 0.1, a value significantly lower than Q_h computed using the proportional adjustment. Substituting 0.001 for zero (i.e., Q_t = 0.001, 2, 3, 4, 5, 6, 7, 8, 9, 10) yields a harmonic mean of approximately 0.01, an order of magnitude lower than when 0.01 is substituted for zero. Thus, the results are sensitive to the number substituted for zero, and the results may be significantly affected by one or a few observations of zero flow in the streamflow record. Research concerning alternate methods for treating zero flows is needed, given the sensitivity of the results to the treatment applied. This research is beyond the scope of this investigation.

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.

Record-extension (augmentation) techniques may be used to reduce time-sampling error. 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_h at the index station and the relation between the concurrent streamflows at both stations may be used to provide an estimate of the long-term Q_h 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 using log-transformed values of the concurrent nonzero daily mean streamflows as

$$Q_{h(s)} = M_s + \left(\frac{S_s}{S_l}\right) \times (Q_{h(l)} - M_l) \,, \tag{3}$$

where

$Q_{h(s)}$ is the estimated long-term Q_h for the short-term station;
$Q_{h(l)}$ is Q_h for the long-term station;
M_s, M_l are the mean of the 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 daily mean streamflows for the concurrent period at the short- and long-term stations, respectively.

For example, this method was used to provide an improved estimate of long-term Q_h at the South Fork Licking River at Hayes, Kentucky (station 03253000) by relating concurrent flows at the Licking River at Catawba, Kentucky (station 03253500) during the 1929-31 water years. A graphical representation of the MOVE.1 line relating the concurrent nonzero flows is shown in figure 3. A Q_h of 184 ft^3/s at the station at Catawba corresponds to an estimated long-term Q_h of 21.4 ft^3/s at the station at Hayes. Without using the MOVE.1 record-extension procedure and instead computing directly from the streamflow data for 1929-31, the short-term Q_h at the station at Hayes would be 3.57 ft^3/s. Nearly an order of magnitude less than the estimated long-term Q_h at the station at Hayes, the short-term Q_h reflects the severe drought conditions that occurred during the 1929-31 period. This difference is unusually large, and it illustrates the need for record-extension procedures to reduce potentially large time-sampling errors at short-term stations.

DETERMINATION OF HARMONIC-MEAN STREAMFLOWS AT STREAMFLOW-GAGING STATIONS IN THE STUDY AREA

Available data through the 1989 water year from continuous-record streamflow-gaging stations were used to determine the values of Q_h. The streamflow data were first compiled and reviewed to define appropriate periods of record for analysis. Separate computations were made for regulated and unregulated periods of record at the stations affected by regulation.

Streamflow-Data Compilation

Daily mean streamflows for the available period of record were retrieved from the USGS National Water Data Storage and Retrieval System (Hutchison and others, 1975). The data were checked and verified by comparing computed yearly and monthly summary statistics of the daily mean streamflows to published values

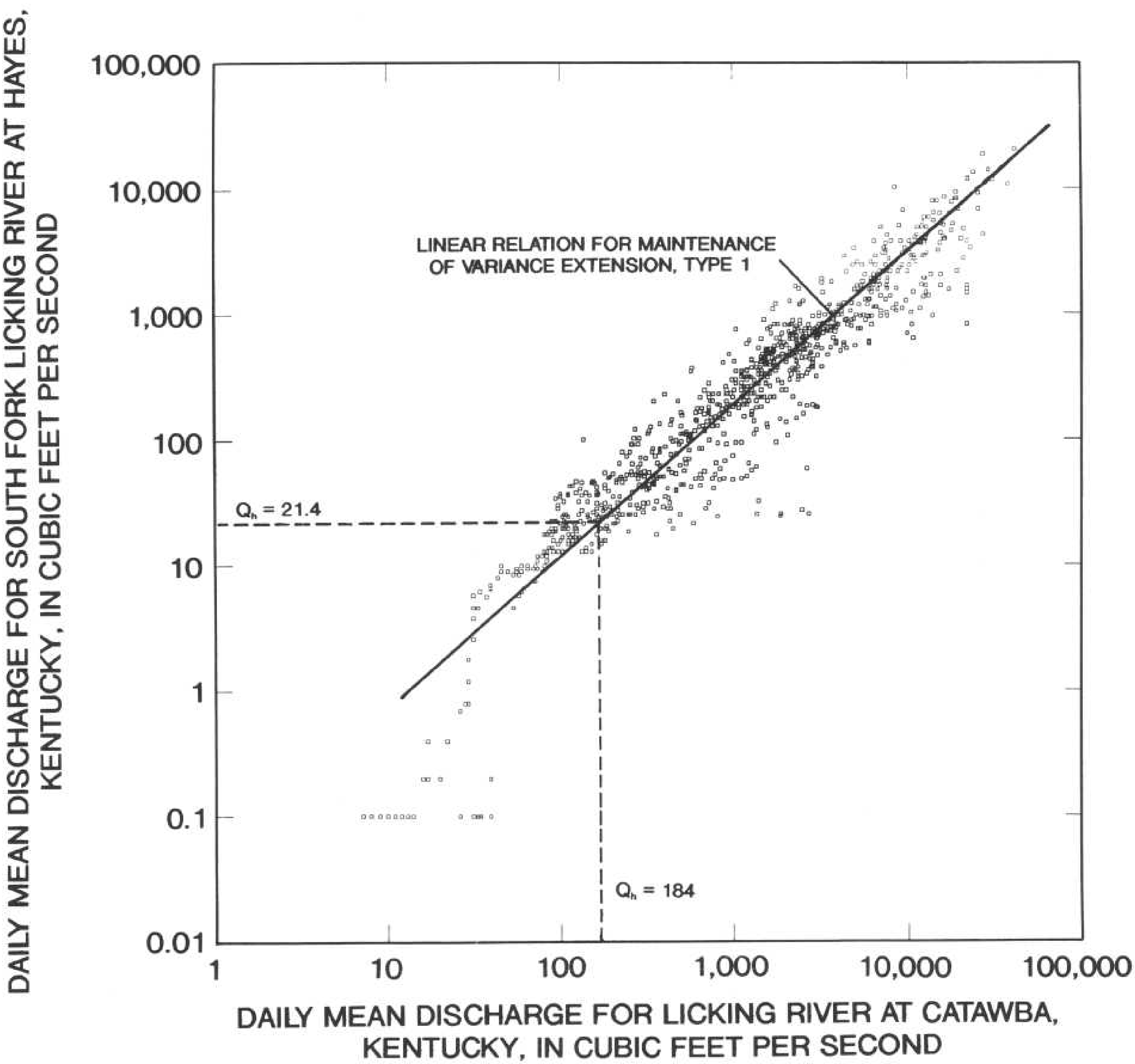

Figure 3.--Relation between concurrent daily mean flows for South Fork Licking River at Hayes, Kentucky and Licking River at Catawba, Kentucky, 1929-31 water years.

(U.S. Geological Survey, 1958a, 1958b, 1964a, 1964b, 1962-65, 1966-75, and 1976-90). Many of the stations in Kentucky are affected by regulation and (or) local diversions. Regulation by multipurpose or flood-control reservoirs reduces peak flows and generally augments low flows. Local diversions--localized transfers of water such as water supply withdrawals or wastewater discharges--artificially increase or decrease streamflows within a reach. Local diversions are common near municipalities and in urbanized areas. The extent of alterations in natural streamflows caused by regulation and local diversions is variable and difficult to quantify accurately. Periods of streamflow record affected by regulation and local diversions were considered separately from periods unaffected by regulation. Therefore, each continuous-record gaging station was screened to identify any periods of record affected by regulation (Melcher and Ruhl, 1984; Ruhl and Martin, 1991).

The retrievals included a total of 230 continuous-record streamflow-gaging stations (pl. 1), of which 54 also have regulated periods of record. Included with the stations located in Kentucky were several unregulated stations located nearby in adjacent States. The streamflow data in bordering States were retrieved to provide additional information for use in the regionalization of Q_h values. The period of record at the streamflow-gaging stations ranged from 1 to 78 years.

Unregulated Streamflow-Gaging Stations

Daily mean streamflow at unregulated stations and for unregulated periods at subsequently regulated stations were used to compute values of Q_h . To compare station values of Q_h, these values were standardized to basin drainage area (reported in units of $(ft^3/s)/mi^2$) at each unregulated station. Where nearby hydrologically similar index stations were available and suitable relations were obtained, the MOVE.1 record extension techniques were applied.

Record-extension adjustments to Q_h values were attempted at all unregulated stations with less than 10 years of record. The accuracy of results depend on the availability of a well-correlated index station in a hydrologically similar setting. Adjusted Q_h values that were not consistent with other nearby long-term stations were not used. The correlation coefficient (r) for the concurrent flows, though not used in the MOVE.1 calculation, is a measure of the strength of the linear relation; and r exceeded 0.80 for each station where the record extensions were used. Extensions were used at all the unregulated stations not affected by local diversion that had less than 6 years of record.

The extensions, while reducing time-sampling error at the station, generally improved consistency in Q_h and drainage-area-standardized Q_h values along stream reaches and among neighboring streams. A generalized depiction of the values of Q_h standardized to drainage area for unregulated stations not affected by local diversions is shown in figure 4. The largest values of drainage-area-standardized Q_h occur in karst areas (fig. 2) and also near Kentucky's eastern border with Virginia and West Virginia (an area roughly straddling the boundary between the Appalachian Plateaus and Valley and Ridge physiographic provinces). Sustained base flows are characteristic of streams in these areas (Ruhl and Martin, 1991; Hayes, 1991; and Friel and others, 1988) that have relatively high drainage-area-standardized Q_h .

Values of Q_h , drainage-area-standardized Q_h , total drainage area, and periods of record for stations not affected by regulation are listed in table 1 (back of report). The stations affected by local diversions and stations where the MOVE.1 record extensions were applied are identified by footnote in table 1.

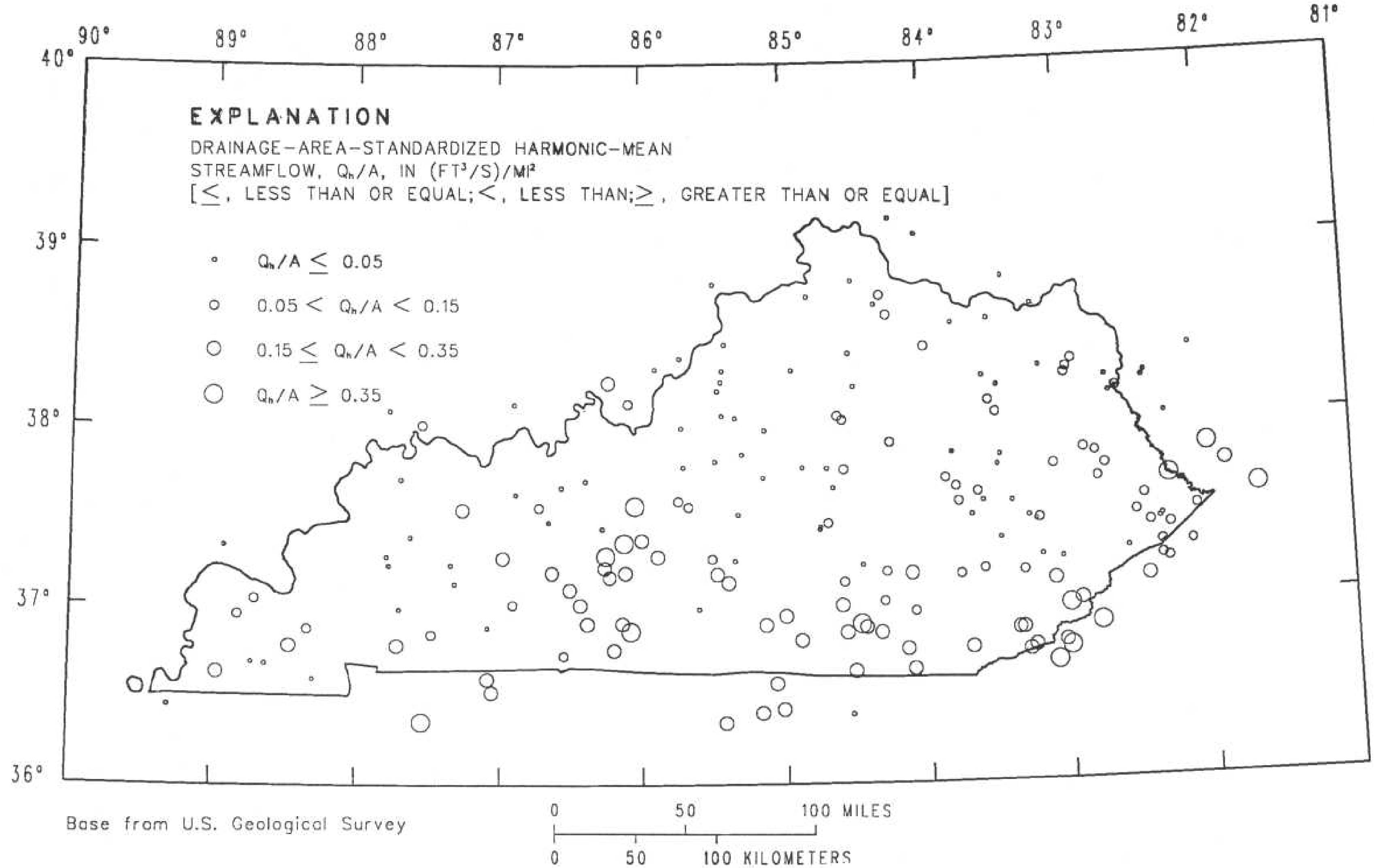

Figure 4.--Generalized drainage-area-standardized harmonic-mean streamflow at selected unregulated continuous-record streamflow-gaging stations in the study area.

At stations on the main stem of the Cumberland River, downstream of Harlan, Kentucky (station 03401000), the entire period of record was used for computation of Q_h. The effect of Martins Fork Lake, constructed in the basin headwaters in 1978, on the long-term Q_h at these downstream locations was considered to be insignificant. Streamflow at several of these stations is affected to varying degrees by local diversions.

Regulated Streamflow-Gaging Stations

Most major drainage basins in Kentucky are affected to some degree by regulation from reservoirs (lakes). All of the major reservoirs in Kentucky, except Herrington Lake on the Dix River and Kentucky Lake on the Tennessee River, are operated by the U.S. Army Corps of Engineers (COE). Herrington Lake is operated by Kentucky Utilities Company, and Kentucky Lake is operated by the Tennessee Valley Authority. The major reservoirs affecting streamflows in Kentucky are shown in figure 5. Continuous-record streamflow-gaging stations affected by these reservoirs are also shown in figure 5.

Values of Q_h were determined for both the regulated and, if applicable, unregulated periods at streamflow-gaging stations located downstream of these reservoirs. The Q_h values for periods of natural flow prior to regulation presented previously (table 1) are useful for regionalization of Q_h, but they do not reflect current streamflow conditions downstream of the reservoirs. Therefore, the values of Q_h have also been determined for the regulated record at each of the streamflow-gaging stations affected by a major reservoir. The Q_h values obtained for the regulated record and the period of regulation analyzed are given in table 2 at the back of the report.

The periods of regulated record analyzed were defined so as to reflect current operating conditions. A survey was made of each of the COE Districts operating reservoirs in Kentucky to determine the date when reservoir filling and normal release patterns were initiated. The end of the unregulated period coincides with the date that reservoir filling was initiated. The beginning of the regulated period, as used in this report, corresponds to that time when normal reservoir release patterns were initiated. Thus, the period of time when the reservoir was being filled has been excluded in computation of the Q_h.

Alterations of operating policy of the hydraulic structures at large reservoirs can significantly change streamflow characteristics downstream. Each of the COE Districts was surveyed regarding changes in operating policy and the consistency of low-flow releases from the reservoirs, because values of Q_h are likely to be sensitive to changes in low-flow release practices. Each reservoir has a target minimum release flow that may be different in summer and winter. Occasionally, the target release cannot be achieved because outlet gates must be closed either when repairs are needed or when reservoir inflow is not adequate to maintain the desired pool elevation. To analyze the streamflow-gaging stations where streamflow is affected by one or more major reservoirs, the annual 1-day, 3-day, and 7-day low-flow time series for the regulated periods of record were plotted. These annual low-flow values are the lowest mean flow for the specified number of consecutive days in each climatic year (April 1 through March 31). These lowest mean annual flows for station 03311000, Barren River near Finney, Kentucky, are shown in figure 6. This station is located just downstream from the outlet works at Barren River Lake. As indicated by the upper plot, the minimum 1-day releases were generally greater than or equal to 20 ft^3/s, except for climatic years 1977 and 1986. The minimum target release at this site is 20 ft^3/s (Paul Roberson, U.S. Army Corps of Engineers, oral commun., 1992). This was achieved during most years, and the low-flow release tends not to vary much over longer periods as indicated by the 3-day and 7-day low-flow plots (fig. 6). A review of the daily mean streamflow data (U.S. Geological Survey, 1978) indicated that the gates at Barren River Lake were closed from October through mid-December 1976 because of repairs on the outlet works. The only flow was leakage through the gates, and the flow ranged from 0 to 4.9 ft^3/s. During the period August 12-15, 1985, the flows ranged from

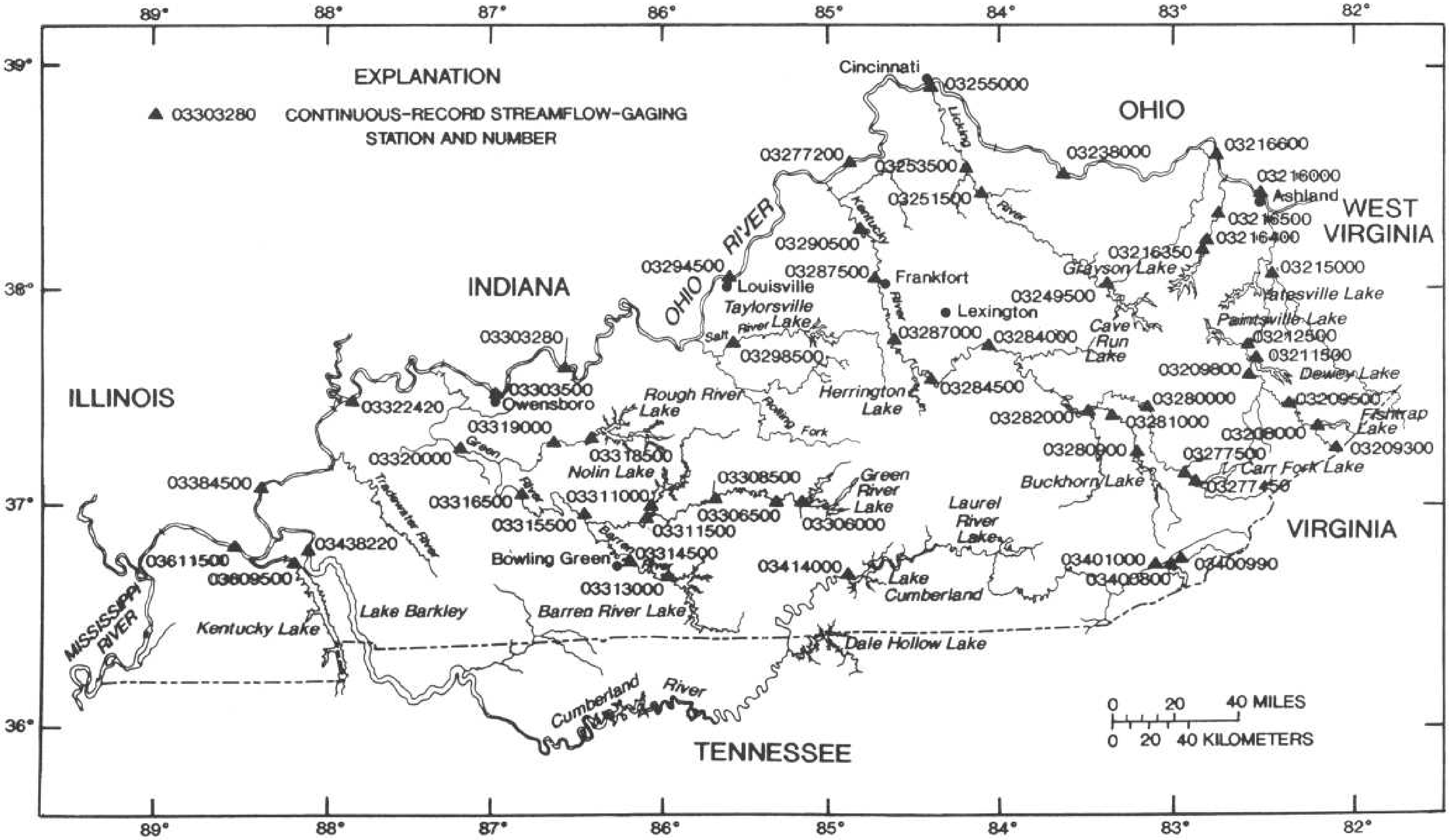

Figure 5.--Location of major reservoirs and selected regulated continuous-record streamflow-gaging stations in the study area [Adapted from U.S. Army Corps of Engineers, 1981].

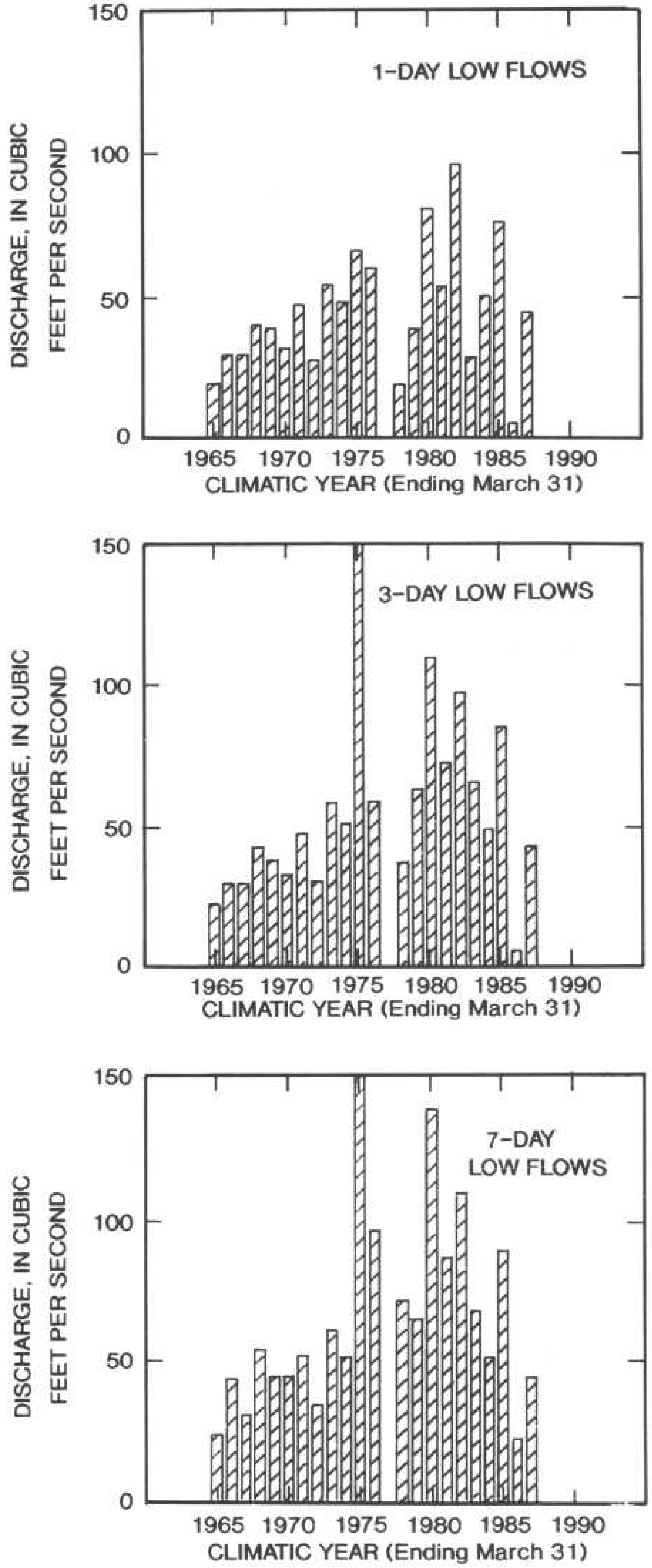

Figure 6.--The annual 1-day, 3-day, and 7-day lowest mean flows for the period of record affected by regulation at Barren River near Finney, Kentucky.

4.9 to 6.6 ft^3/s during minor maintenance activities. An upward trend in the releases occurs in the 1970's and early 1980's. This upward trend is climatic in nature, and it occurs in the flows at unregulated sites as well (Ruhl and Martin, 1991).

Zero- or near-zero-flow periods have occurred at almost all stations located directly below major reserviors, indicating gate closure. These gate closures were generally because of repair and (or) maintenance activities at the reservoirs. Some other low-release periods were the result of maintaining target pool elevations. For the stations displaying these random restrictions in reservoir releases, which are likely to continue to occur in the future, the entire period of regulated record was used in computing Q_h.

Only one station indicated a change in the release pattern over time. The plots of annual low flows for Cumberland River near Rowena (station 03414000), located just downstream of the outlet works at Lake Cumberland, indicated increased minimum releases starting around 1984. COE officials confirmed that the current power-operating policy was implemented in July, 1984. Because only 5 years of record (1984-89) are available for the current operating policy, a determination of Q_h was made using the entire regulated period 1951-89 (table 2).

The effects of regulation are most pronounced immediately below reservoir control structures and are gradually dampened with increasing distance downstream. At streamflow-gaging stations located downstream of more than one reservoir that were used in the study, it was unnecessary to delineate values of Q_h for different periods of regulation because the reservoirs most influencing streamflows were constructed first. Only a few of the stations are downstream of multiple reservoirs. Flows at the main-stem Kentucky River stations at Lock 14 (03282000) and Lock 10 (03284000) are regulated by both Buckhorn Lake, completed in 1960, and are affected to a lesser degree by Carr Fork Lake, completed in 1976 (fig. 5). Therefore, the entire period of record after 1960 was used to compute Q_h. Farther downstream, flows at the main-stem Kentucky River stations at Lock 6 (03287000), Lock 4 (03287500), and Lock 2 (03290500) are regulated by Herrington Lake, completed in 1925 (fig. 5). Buckhorn Lake and Carr Fork Lake have little effect on flows at these stations. Therefore, the entire period of record starting in 1925 was used for these three stations. For the main-stem Green River stations at Lock 6 (03311500), Lock 4 (03315500), and Lock 2 (03320000), the earliest date of regulation was used as the starting date in the determination of the Q_h. Streamflow at Lock 6 is regulated by Nolin Lake starting in 1963 and by Green River Lake starting in 1968. The addition of the Green River Lake outflows probably have had a minimal effect on low flows at Lock 6 (fig. 5). The same is true farther downstream at the Lock 4 station, which receives flows from Barren River Lake, Nolin Lake, and Green River Lake. Barren River Lake came into operation in 1964, just after Nolin Lake was completed. The next downstream station, at Lock 2, is also regulated by Rough River Lake, which was completed in 1959. For each station, the reservoir that would probably have the most effect on flows, especially low flows, was also the first to be completed. For this reason, the reservoir with the earliest completion date was used to determine the starting date of the period of regulated record at each station downstream of multiple reservoirs.

The Ohio River main-stem stations (fig. 5) were treated somewhat differently. Because reservoirs having different start dates and degrees of regulation are located throughout the Ohio River basin and the locks and dams in the main stem affect the flow in the Ohio River, the entire period of record was used for determining the Q_h. Two stations on the Ohio River have long-term, continuous streamflow record: Ohio River at Louisville, Kentucky (03294500), and Ohio River at Metropolis, Illinois (03611500). The stations at Louisville and Metropolis have daily flow record available from April 1928 through September 1989. Other stations on the Ohio River have been operated periodically, but for shorter periods of time. The Q_h was determined for the period of record at each of the Ohio River main-stem stations. Because of climatic variations in the different periods of record and different degrees of regulation, Q_h values varied considerably between stations. In an effort to make these values more consistent with the long-term record available at the Louisville and Metropolis gages (index stations), the MOVE.1 record-extension procedure was used to estimate long-term Q_h. The estimated long-term Q_h values are given in table 2. Streamflow record at the Ohio River at Louisville index station was used to provide an adjusted Q_h at

Ohio River at Ashland, Ky. (03216000),
Ohio River at Greenup Dam, Ky. (03216600),
Ohio River at Maysville, Ky. (03238000),
Ohio River at Cincinnati, Ohio (03255000),
Ohio River at Markland Dam, Ky. (03277200),
Ohio River at Cannelton Dam, Ky. (03303280),
Ohio River at Owensboro, Ky. (03303500), and
Ohio River at Uniontown, Ky. (03322420).

Streamflow record at the Ohio River at Metropolis, Illinois index station was used to provide an adjusted Q_h at Ohio River at Lock and Dam 51 at Golconda, Illinois (03384500).

Table 3 shows the Q_h for various periods, including the periods of record, at the Ohio River at Louisville and Metropolis gages. The periods chosen approximate the periods of record for the other main-stem stations (table 2). The records for stations at Ashland, Maysville, Cincinnati, and Owensboro were collected mainly in the period 1939-64. As shown in table 3, the Q_h for the period 1939-64 at Louisville is approximately equal to the Q_h for the entire period of record. Similarly, the Q_h at Metropolis for the period 1940-52 (which corresponds to the period of record at Golconda) is approximately equal to the Q_h for the entire period of record at Metropolis. However, later periods at the two index stations show a marked increase in Q_h values. The period 1970-89 corresponds closely to periods of record at Greenup, Markland, and Cannelton Dams. The period 1975-89 corresponds to the period of record at the Uniontown station. The increased values of Q_h observed at the index stations during these later periods is probably climatic in nature.

Table 3.--Harmonic-mean streamflows for selected periods for Ohio River at Louisville, Kentucky and Ohio River at Metropolis, Illinois

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

Station	Start date (month/year)	End date (month/year)	Harmonic-mean flow (ft^3/s)
Ohio River at Louisville, Ky.	04/1928	09/1989	39,700
(03294500)	10/1939	05/1964	38,100
	05/1970	09/1989	54,800
Ohio River at Metropolis, Ill.	04/1928	09/1989	135,000
(03611500)	10/1940	09/1952	134,100
	10/1975	09/1989	164,500

Annual precipitation records for this period show a similar increase (Conner, 1982; Conner, written commun., 1991). Record extensions at the short-term stations helped to minimize this time-sampling error caused by such climatic variation and resulted in a consistent downstream increase in the values of Q_h (table 2).

Flows at Cumberland River at Grand Rivers (03438220) and Tennessee River at Paducah (03609500) are affected by releases from Lake Barkley and Kentucky Lake, respectively (fig. 5). Since June 1966, the flows at these stations have also been affected by interbasin transfer. A canal connecting the two lakes was constructed to facilitate barge traffic. Values of Q_h (table 2) for the regulated period at these two stations were computed using streamflow record after June 1966 only.

DEVELOPMENT OF PROCEDURE FOR ESTIMATING HARMONIC-MEAN STREAMFLOW AT UNGAGED STREAMFLOW SITES

Drainage-basin characteristics, including climate, influence streamflow patterns. Relations among selected basin characteristics and computed Q_h were investigated by methods of linear correlation and multiple-linear regression. A regional relation to estimate Q_h at ungaged sites was defined by regression analysis.

Selected Drainage-Basin Characteristics

Several drainage-basin characteristics were tested for applicability in the regionalization of Q_h. 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 significance of the characteristic in relation to the Q_h 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).

Basin characteristics obtained from the basin and streamflow characteristics file of the National Water Data Storage and Retrieval System (Dempster, U.S. Geological Survey, written commun., 1983) and tested for significance in the regression analysis included the following:

1. Total drainage area, in square miles, is the area measured in a horizontal plane that is enclosed by a drainage divide.

2. Contributing drainage area, in square miles, is the total drainage area excluding any parts characterized by internal drainage.

3. Main-channel length, in miles, is the length measured along the main stream channel from the gage to the basin divide, following the longest tributary.

4. Main-channel slope, in feet per mile, is 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.

5. Basin length, in miles, is the straight-line distance from the gage to the basin divide (defined by the main-channel length).

6. Mean basin width, in miles, is calculated by dividing the total drainage area by basin length.

7. Main-channel sinuosity is the ratio of main-channel length, in miles, to basin length, in miles.

8. Mean basin elevation, in feet, is measured as the average elevation of 20 to 80 points per basin using the transparent grid sampling method.

9. Mean annual precipitation, in inches, is estimated from Conner (1982).

10. 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.

11. 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).

12. Forested area, as a percentage of contributing drainage area, is measured from topographic maps using the transparent grid sampling method.

13. Streamflow-recession index at a station is 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, Ruhl and Martin, 1991).

14. 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; Dempster, 1990) of daily mean streamflow for the entire period of record. Like the streamflow-recession index, this streamflow index is a measure of basin capacity to sustain base flow in a stream. In Kentucky, streamflow-variability indexes have been mapped by delineating areas of similar station streamflow-variability index and similar geologic features (Ruhl and Martin, 1991). The "map" values of streamflow-variability index for stations in Kentucky were computed as an area-weighted mean of the basin streamflow-variability indexes for use in the regression analysis. For the stations located outside Kentucky, station values of streamflow-variability index were used. The values of streamflow-variability index for the stations used in the regression are listed in table 1.

Regression Analysis

A multiple-linear-regression model was developed to relate Q_h (dependent variable) to selected basin characteristics ("independent" or explanatory variables). Only stations with streamflow data collected during unregulated periods with streamflows not significantly modified by local diversions were included in the analysis (table 1). The station located at Cumberland River at Williamsburg, Kentucky (03404000), only minimally affected by regulation at Martins Fork Lake in the basin headwaters, was also included in the regression.

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.

Several factors were considered in evaluating alternative regression models including (1) the coefficient of determination, the proportion of the variation in the dependent variable explained by the regression equation, (2) the standard error of the estimate, a measure of model-fitting error, (3) the PRESS statistic, a measure of model-prediction error, (4) the statistical significance of each alternative explanatory variable, (5) potential multicollinearity as indicated by correlation of explanatory variables and the value of the variance inflation factor (Montgomery and Peck, 1982), and (6) the effort and modeling benefit of determining the values of each additional explanatory variable.

Ordinary-least-squares regression techniques were used to fit the linear model. The alternative models were generated by all-possible-regression and stepwise-regression procedures (Statistical Analysis System Institute, 1985) using the prospective explanatory variables listed previously.

Weighted-least-squares (WLS) regression procedures could be used to compensate for differences in the reliability of estimates of Q_h (because of time-sampling error) based on station record length. However, WLS was not applied because of (1) the relatively large number of daily mean streamflow observations used to compute Q_h , and (2) record-extension procedures were applied to short-term stations to provide improved estimates of long-term values of Q_h . Of the stations included in the regression analysis, 6 years was the shortest station record length that was not extended using the MOVE.1 procedure.

Review of residual plots from regressions that included mapped values of streamflow-variability index (Ruhl and Martin, 1991) as an explanatory variable revealed a group of outliers located in the south central portion of the Mississippi Embayment in southern Calloway and Graves counties. The models significantly overpredicted harmonic-mean streamflow at the stations on Clarks River at Murray, Kentucky (0361000), Perry Creek near Mayfield, Kentucky (07022500), and Obion Creek at Pryorsburg, Kentucky (07023500). Geologic maps and information relating to ground-water/surface-water interactions in the area were reviewed for indications that the mapped values of variability index assigned for this area might be too low. Ground-water levels (Davis and others, 1983) and modeling simulations (Grubb and Arthur, 1991) indicate that significant net aquifer recharge is occurring in drainage basins in this area, particularly in Graves County. Also, a thin, shallow aquifer underlain by an aquitard (Porters Creek Clay) is present in the upper Clarks River basin (Murray, Kentucky vicinity), providing minimal ground-water discharge to streams. Perennial flow of streams in the Mississippi Embayment occurs only downstream of the intersection of stream channels with the water table. This intersection and resulting perennial streamflow occurs downstream of these three stations (Davis and others, 1983). Based on this information and the station values of streamflow-variability index computed for these three stations (1.34, 1.08, and 1.50), map variability-index boundaries from Ruhl and Martin (1991) were redefined, and a region of mapped streamflow-variability index of 1.25 was delineated (pl. 1).

The best group of two-variable models (in terms of predictive accuracy) included (1) total drainage area, or alternatively, drainage-area-related variables such as main-channel length, contributing drainage area, mean basin width, and basin length and (2) streamflow-variability index as the explanatory variables. Following this top group of models was a set of two-variable models that included streamflow-recession index coupled with various drainage-area-related basin characteristics. Thus, streamflow-variability index and streamflow-recession index, characteristics relating to basin hydrogeology and low-flow regime, are apparently closely associated with the Q_h, as they are associated with other low-flow statistics such as $7Q_{10}$ (Ruhl and Martin, 1991).

A two-variable model containing total drainage area and streamflow-variability index as explanatory variables was judged superior to alternative models including more than two variables based on comparisons of PRESS values, multicollinearity diagnostics, tests of significance of additional explanatory variables, and the extent of improvement in model predictive ability. A sensitivity analysis of the model indicated that sensitivity to the streamflow-variability index, which can vary significantly over short distances (pl. 1), would generally be reduced by including variability index without log transformation. Though model error is increased somewhat without the log transformation of the streamflow-variability index, potential model-application errors may be reduced.

The regression model selected is

$$Q_h = 1.65A^{1.02}10^{-1.85V}, \tag{4}$$

where

Q_h is the estimated harmonic-mean streamflow, in ft^3/s;
A is the total drainage area, in mi^2; and
V is the mapped streamflow-variability index on plate 1.

Noting the sign of the exponents, the estimated Q_h increases with increasing drainage area and decreasing streamflow-variability index. The estimate is a near-linear relation to drainage area because the exponent is approximately one. The estimate is more sensitive to a percentage change in the value of the streamflow-variability index than to a like change in total drainage area. The drainage area and the value of streamflow-variability index for each unregulated streamflow-gaging station not affected by local diversion that was used in the regression are listed in table 1.

Equation 4 can be solved graphically using the nomograph shown in figure 7. Example calculations are presented in the section "Estimating Harmonic-Mean Streamflow at Stream Sites in Kentucky."

Limitations and Accuracy

The regional regression model for estimating Q_h at ungaged sites is applicable to unregulated streams in Kentucky that are not significantly affected by local diversions. Caution is warranted when applying the regression model in areas where streamflows are affected by hydrologic discontinuities such as large springs and sinks common to karstic terrain in areas underlain by limestone. Streamflows in these areas may vary unpredictably over short reaches.

The regression model was developed using basin characteristics within a certain range of values. Drainage areas of stations used in the regression analysis ranged from 3.89 to 1,607 mi^2. Values of streamflow-variability index ranged from 0.40 to 1.35. Application of the regression model for a basin outside these ranges is an extrapolation and is, therefore, not recommended. Estimates of Q_h for stream sites with basin characteristics not in these ranges should be based on streamflow data collected at the site. A scatter plot showing the sampling space for drainage areas and variability indexes for the regression model is shown in figure 8. Note the absence of observations having a combination of low streamflow-variability index and low drainage area (V less than 0.50 and A less than about 65 mi^2). Application of the model in this region falls outside the sampling space, and this extrapolation is, likewise, not recommended.

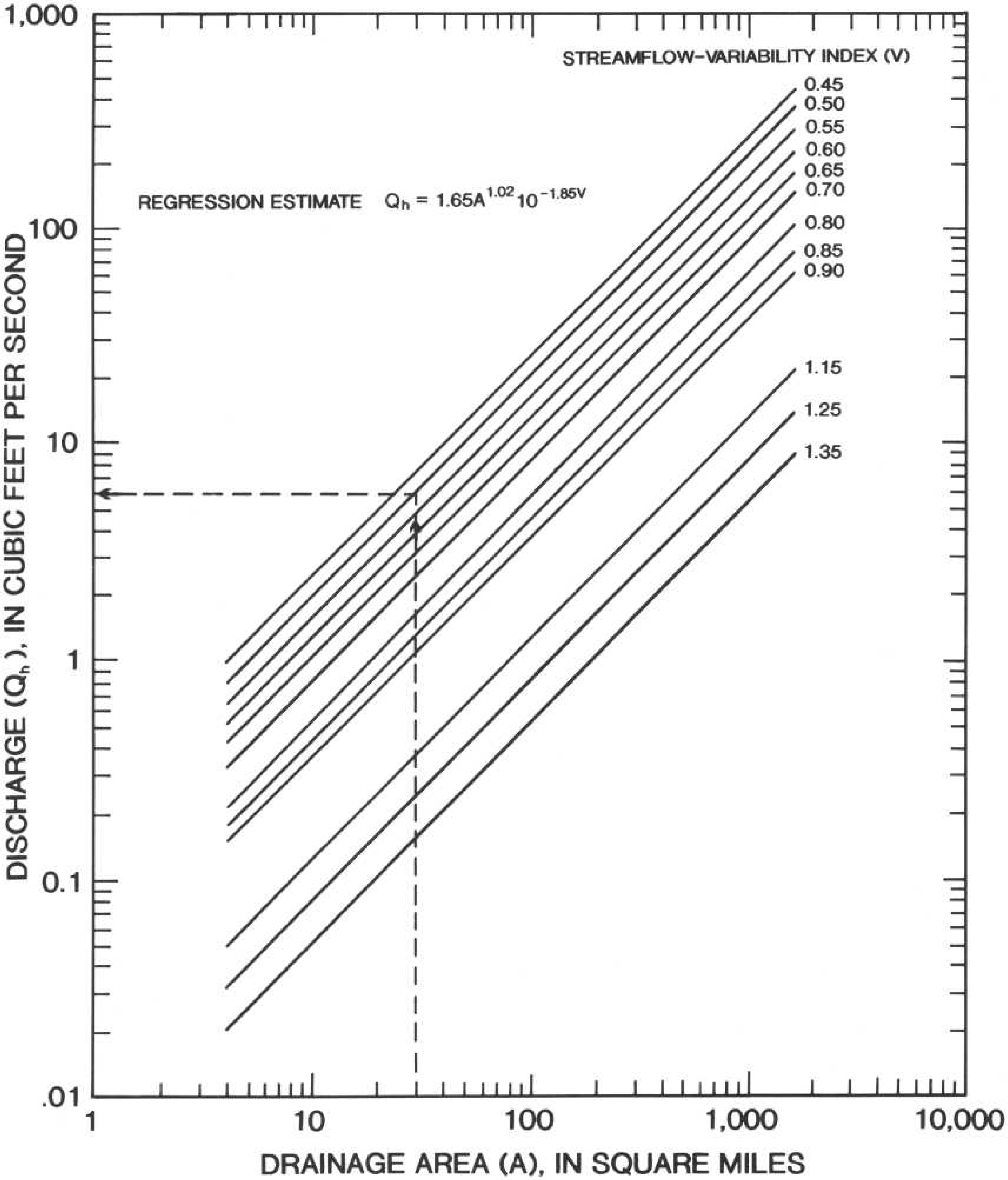

Figure 7.--Graphical solution of the regression equation for estimating harmonic-mean streamflow in Kentucky.

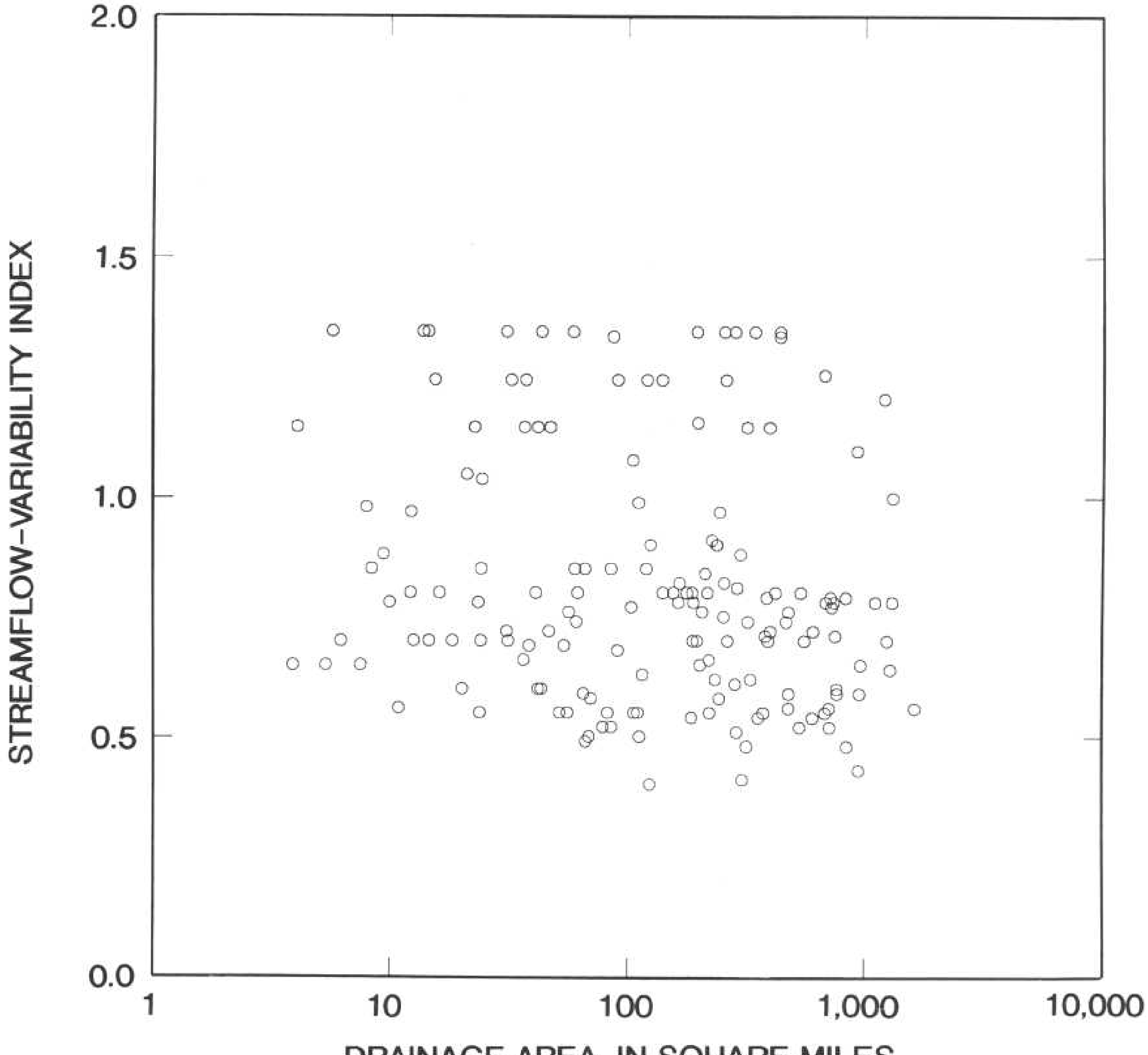

Figure 8.--Drainage area and streamflow-variability-index sampling space for the regression model.

The coefficient of multiple determination (R^2) for the regression model is 0.90. The standard error of estimate (of log Q_h)--a measure of the accuracy of the regression-model estimates compared to the observed values used in the regression--is 76 percent. The standard error of estimate was computed using the model root-mean-square error (Statistical Analysis System Institute, 1982) and information from Hardison (1971). The standard error of prediction (of log Q_h)--a measure of the accuracy of the regression estimates compared to observed data for stations excluded from the regression--is 78 percent, which is slightly higher than the standard error of estimate. Standard error of prediction was estimated as the square root of the PRESS divided by the error degrees of freedom (Statistical Analysis System Institute, 1982; Montgomery and Peck, 1982; 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 model predictions for ungaged sites similar to those used in the regression could be expected to compare favorably to the standard error of prediction. If all the assumptions for applying regression are met, two-thirds of the observations lie within one standard error of a regression line. For this regression, a 0.293 log units standard error, when untransformed, would place two-thirds of the observations within plus 96 percent and minus 49 percent of the regression line.

A scatter plot of the values of Q_h computed from the streamflow-gaging station data and values computed using the regression model (fig. 9) shows reduced residuals and a slight tendency of the model to underpredict the values of Q_h above about 50 ft^3/s. The underprediction tendency may be associated with increased error and bias in the values of mapped streamflow-variability index for large basins. The reduced residuals are probably related to generally reduced time-sampling error (long periods of record) for the stations having large values of Q_h. Also, less variability in the streamflow response would be expected for large basins as compared to small basins.

ESTIMATING HARMONIC-MEAN STREAMFLOW AT STREAM SITES IN KENTUCKY

Procedures for obtaining Q_h estimates differ depending on the location of the stream site in relation to stream gage locations where Q_h 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_h is desired, the gage information is used where appropriate in making the estimate, as discussed below.

Sites at Gage Locations

Estimates of Q_h values for 230 continuous-record streamflow-gaging stations are presented in tables 1 and 2. When an estimate of Q_h is required at a stream site, refer to table 1 (if the site is unregulated), or to table 2 (if the site is regulated), to determine whether values have previously been estimated for the site.

Sites Near Gage Locations

If information is available for an unregulated stream where an estimate is desired, but not at the specific location, a weighting procedure can be employed (Carpenter, 1983). The first constraint to the use of this method is that the drainage area of the ungaged site differ by no more than 50 percent from that of the gaged

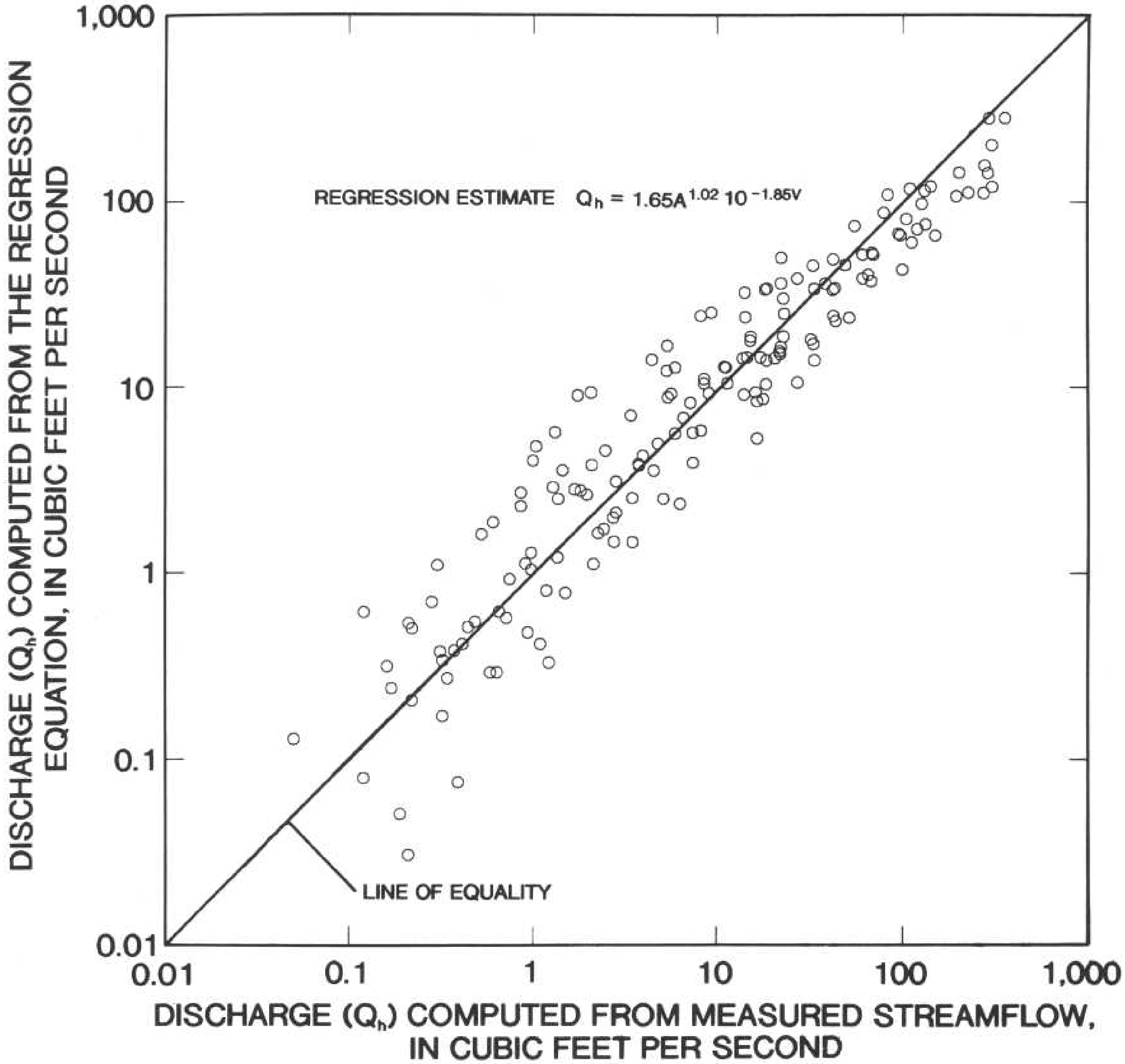

Figure 9.--Scatter plot of harmonic-mean streamflow computed from measured streamflow and from the regression equation for selected continuous-record streamflow-gaging stations in the study area.

site (to minimize the potential for hydrologic dissimilarity between the sites). The second constraint to the use of this method is that the entire drainage basin of the ungaged and gaged sites be within the same variability-index area (pl. 1), because the method assumes a linear relation between the flow values at the gaged and ungaged sites. This is not a valid assumption if the gaged and ungaged sites are affected by different basin geologic characteristics.

The first step in using the weighting procedure is to verify that the above two constraints are satisfied. If so, obtain the value of Q_h computed using streamflow-gaging data at the gage site, $Q_{h\,g(d)}$, from table 1. Also, obtain the regression estimate at the gaged site, $Q_{h\,g(r)}$, using equation 4 or figure 7. Compute the correction factor at the gaged site (C_g) as the ratio of $Q_{h\,g(d)}$ divided by $Q_{h\,g(r)}$. A correction factor at the ungaged site, C_u, is computed based on C_g and the difference in drainage area between the gaged and ungaged site as

$$C_u = C_g - \frac{2\Delta A}{A_g}(C_g - 1), \tag{5}$$

where

C_u is the correction factor for the ungaged site;
C_g is the correction factor for the gaged site;
ΔA is the absolute value of the difference in drainage area between the gaged and ungaged site, in mi^2; and
A_g is the drainage area of the gaged site, in mi^2.

Compute the regression estimate of discharge at the ungaged site, $Q_{h\,u(r)}$, using equation 4 (or fig. 7) and multiply this value by the correction factor, C_u from equation 5, to obtain the stream-gage-weighted value of the Q_h estimate at the ungaged site. The equation is

$$Q_{hw} = C_u Q_{hu(r)},\ if\ \Delta A < 0.5 A_g \tag{6}$$

where

Q_{hw} is the stream-gage-weighted Q_h determined at the ungaged site, in ft^3/s;
C_u is the correction factor for the ungaged site (from eq. 5);
$Q_{hu(r)}$ is the regression estimate of Q_h (from eq. 4), in ft^3/s.
ΔA is the absolute value of the difference in drainage area between the gaged and ungaged site, in mi^2; and
A_g is the drainage area of the gaged site, in mi^2.

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

Sites Between Gage Locations

If a Q_h estimate is desired between two gage locations on the same stream, the value can be estimated by linear interpolation, using the Q_h values and corresponding drainage areas at the two gaged sites. As with the previous method, the technique should not be used where the reach extends over, or is drained by more than one variability-index area. When this condition exists, the relation between the two gaged sites is not linear. The method described previously for unregulated sites near gage locations can, however, be used, if the basin of the stream site where Q_h is desired is in the same variability-index area as one of the two gages.

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 equation 4 can be used directly to estimate Q_h. This equation, or the nomograph shown in figure 7, can be used to estimate values of Q_h at ungaged, unregulated stream sites in Kentucky.

Total drainage area of the site of interest should be determined from USGS 7.5-minute topographic maps. The drainage areas for many locations along streams in Kentucky are listed in Bower and Jackson (1981). A map value of streamflow-variability index is obtained from plate 1. The percentage of total drainage area within each streamflow-variability-index area will also need to be determined. Examples of numerical and graphical procedures for obtaining the estimated Q_h values from basins lying entirely within one index area and those in two or more index areas are given in the following sections.

Sites With Drainage Basins in One Index Area

Estimates of Q_h at an ungaged site that is entirely within the same streamflow-variability index area is computed using the following method. Determine the total drainage area of the site from USGS 7.5-minute topographic maps and the streamflow-variability index from plate 1. Substitute the values into equation 4 as shown below. The example assumes the site has a total drainage area of 155 mi^2 and is entirely within the variability-index area of 0.70.

$$Q_h = 1.65 A^{1.02} 10^{-1.85V} \qquad \text{(eq. 4)}$$

$$Q_h = 1.65\,(155)^{1.02}\,10^{-1.85\,(0.70)}$$

$$Q_h = 14 \ \text{ft}^3/\text{s} \ \text{(rounded to the nearest tenth or two significant figures)}$$

A graphical solution can be obtained from the nomograph shown in figure 7. Enter the plot on the abscissa scale at 155 mi^2 and proceed upward to the 0.70 streamflow-variability-index curve. From there, proceed across to the ordinate scale to obtain the estimated Q_h value.

Sites With Drainage Basins in More Than One Index Area

If the drainage area for a desired site location includes more than one variability-index area, the following method is used to estimate values of Q_h. Determine the total drainage area of the site and the percentage of the drainage basin located within each of the streamflow-variability-index areas. For this example, assume that an estimate of Q_h is desired for a 300 mi^2 basin having 65 percent of the drainage area within a variability-index area of 0.70. The remaining 35 percent is contained in an area having a variability index of 0.90. The numerical solution is as follows. First, obtain a value for Q_h as if all of the basin were contained in the 0.70 variability-index area.

$$Q_h = 1.65A^{1.02}10^{-1.85V} \qquad \text{(eq. 4)}$$

$$Q_h = 1.65\,(300)^{1.02}10^{-1.85\,(0.70)}$$

$$Q_h = 28 \quad \text{ft}^3/\text{s}$$

Next, assume the entire area lies within the 0.90 variability-index area and compute the flow.

$$Q_h = 1.65A^{1.02}10^{-1.85V} \qquad \text{(eq. 4)}$$

$$Q_h = 1.65\,(300)^{1.02}10^{-1.85\,(0.90)}$$

$$Q_h = 12 \quad \text{ft}^3/\text{s}$$

Each of these Q_h estimates can also be obtained graphically using figure 7.

To obtain a solution, multiply each flow value computed above by the corresponding percentage of basin drainage area and sum the resulting values to determine the weighted average Q_h estimate.

$$\begin{aligned} 28\ \text{ft}^3/\text{s}\ (0.65) &= 18\ \text{ft}^3/\text{s} \\ 12\ \text{ft}^3/\text{s}\ (0.35) &= \underline{\ 4\ }\ \text{ft}^3/\text{s} \\ \text{weighted average } Q_h &= 22\ \text{ft}^3/\text{s} \end{aligned}$$

SUMMARY

The values of harmonic-mean streamflow, Q_h, were determined at selected streamflow-gaging stations in Kentucky. Daily mean streamflows for the available period of record through the 1989 water year at 230 continuous-record streamflow-gaging stations in Kentucky and just outside Kentucky in bordering States were used in the analysis. Periods of streamflow record affected by regulation were analyzed separately from periods unaffected by regulation. Record extension at short-term stations was accomplished using the MOVE.1 technique to reduce time-sampling error and, thus, improve estimates of long-term Q_h values.

Techniques to estimate Q_h streamflow at ungaged stream sites in Kentucky were developed. A multiple-linear-regression analysis was used to relate Q_h values to drainage-basin characteristics. A regression model that included total drainage area and streamflow-variability index as explanatory variables was defined. Example applications of the model are presented. The regression model has a standard error of estimate of 76 percent and a standard error of prediction of 78 percent.

REFERENCES CITED

Allen, D.M., 1971, Mean square error of prediction as a criterion for selecting prediction variables: Technometrics, v. 13, p. 469-475.

_____1974, The relationship between variable selection and data augmentation and a method for prediction: Technometrics, v. 16, no. 1, p. 125-127.

Beaber, H.C., 1970, A proposed streamflow data program for Kentucky: U.S. Geological Survey Open-File Report (unnumbered), 48 p.

Bingham, R.H., 1982, Low-flow characteristics of Alabama streams: U.S. Geological Survey Water-Supply Paper 2083, 27 p.

Bower, D.E., and Jackson, W.H., 1981, Drainage areas of streams at selected locations in Kentucky: U.S. Geological Survey Open-File Report 81-61, 118 p.

Carpenter, D.H., 1983, Characteristics of streamflow in Maryland: Maryland Geological Survey Report of Investigations No. 35, 237 p.

Choquette, A.F., 1988, Regionalization of peak discharges for streams in Kentucky: U.S. Geological Survey Water-Resources Investigations Report 87-4209, 105 p.

Conner, Glen, 1982, Monthly, seasonal, and annual precipitation in Kentucky 1951-1980: Kentucky Climate Center Publication Number 25, Bowling Green, Ky., Western Kentucky University, 30 p.

Crawford, N., and Webster, J., 1986, Karst hazard assessment of Kentucky: Sinkhole flooding and collapse: Bowling Green, Ky., Western Kentucky University, Center for Cave and Karst Studies, prepared for the U.S. Environmental Protection Agency, Region IV, Atlanta, Ga., scale 1:1,000,000.

Davis, R.W., Lambert, T.W., and Hansen, A.J., 1983, Surface geology and ground-water resources of the Jackson Purchase region, Kentucky: U.S. Geological Survey Water-Supply Paper 1987, 66 p., 11 pls.

Dempster, G.R., Jr., 1990, National water information user's manual, v. 2, chap. 3; Automated data processing system: U.S. Geological Survey Open-File Report 90-116, 321 p.

Friel, E.A., Embree, W.N., Jack, A.R., and Atkins, J.T., Jr., 1988, Low-flow characteristics of streams in West Virginia: U.S. Geological Survey Water-Resources Investigations Report 88-4072, 34 p.

Grubb, H.F., and Arthur, J.K., 1991, Gulf coast regional aquifer-system analysis--A Kentucky perspective: U.S. Geological Survey Water-Resources Investigations Report 90-4138, 28 p.

Hardison, C.H., 1971, Prediction error of regression estimates of streamflow characteristics at ungaged sites: U.S. Geological Survey Professional Paper 750-C, 9 p.

Hayes, D.C., 1991, Low-flow characteristics of streams in Virginia: U.S. Geological Survey Water-Supply Paper 2374, 69 p.

Hirsh, R.M., 1982, A comparison of four streamflow record extension techniques: Water Resources Research, v. 18, no. 4, p. 1082-1088.

Hutchison, N.E., Shope, W.G., Jr., Morgan, C.O., Williams, O.O., Wilson, T.A., Stuthmann, N.G., Booker, R.E., Price, W.E., Jr., and Meeks, W.C., 1975, WATSTORE--National Water Data Storage and Retrieval System of the U.S. Geological Survey--User's Guide: U.S. Geological Survey Open-File Report 75-426, 7 v., 791 p.

Kentucky Geological Survey, 1980, Physiographic diagram of Kentucky: Lexington, Ky., University of Kentucky, 1 map, scale not specified.

Kentucky Natural Resources and Environmental Protection Cabinet, 1990, Kentucky water quality standards: Kentucky Administrative Regulations title 401, chap. 5.

Lane, E.W., and Lei, Kai, 1950, Streamflow variability: Proceedings of the American Society of Civil Engineers, Transactions, v. 115, p. 1084-1134.

Marquardt, D.W., 1970, Generalized inverses, ridge regression, biased linear estimation, and nonlinear estimation: Technometrics, v. 12, p. 591-612.

McDowell, R.C., Grabowski, G.J., Jr., and Moore, S.L., 1981, Geologic map of Kentucky: U.S. Geological Survey, 4 sheets, scale 1:250,000.

McFarland, A.C., 1950, Geology of Kentucky: Lexington, Ky., University of Kentucky, 531 p.

Melcher, N.B., and Ruhl, K.J., 1984, Streamflow and basin characteristics at selected sites in Kentucky: U.S. Geological Survey Open-File Report 84-704, 80 p.

Montgomery, D.C., and Peck, E.A., 1982, Introduction to linear regression analysis: New York, N.Y., Wiley and Sons, 504 p.

Musgrave, G.W., 1955, How much of the rain enters the soil?: U.S. Department of Agriculture, Yearbook of Agriculture: Water, p. 151-159.

Riggs, H.C., 1964, The base-flow recession curve as an indicator of groundwater: International Association of Scientific Hydrology Publication 63, Berkeley, Ca., p. 352-363.

Rossman, L.A., 1990a, DFLOW user's manual: U.S. Environmental Protection Agency, 26 p.

_____1990b, Design stream flows based on harmonic means: American Society of Civil Engineers Journal of Hydraulic Engineering, v. 116, no. 7, p. 946-950.

Ruhl, K.J., and Martin, G.R., 1991, Low-flow characteristics of Kentucky streams: U.S. Geological Survey Water-Resources Investigations Report 91-4097, 50 p.

Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Statistical Analysis System Institute, Inc., 1985, SAS User's Guide: Statistics: Cary, N.C., Statistical Analysis System Institute, Inc., 956 p.

U.S. Army Corps of Engineers, 1981, Water resources development in Kentucky 1981: Louisville District Corps of Engineers, 119 p.

U.S. Department of Agriculture, 1969, National engineering handbook: Soil Conservation Service, Section 4, Hydrology, chap. 9-10.

_____1975, General soil map of Kentucky: Soil Conservation Service Map No. 4-R-34874, scale 1:750,000.

_____1984, Predicting soil loss in Kentucky: Soil Conservation Service Tech. Paper No. 4, Lexington, Kentucky, 152 p.

U.S. Environmental Protection Agency, 1986a, Quality criteria for water - 1986: Office of Water Regulations and Standards, EPA 440/5-86-001, variously paged.

_____1986b, Technical guidance manual for performing wasteload allocations: Book VI, Design conditions: Chapter 1 - Stream design flow for steady-state modeling, Office of Water Regulations and Standards, variously paged.

U.S. Geological Survey, 1958a, Compilation of records of surface waters of the United States through 1950, Part 3-A. Ohio River basin except Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1305, 652 p.

_____1958b, Compilation of records of surface waters of the United States through 1950, Part 3-B. Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1306, 353 p.

_____1964a, Compilation of records of surface waters of the United States, October 1950 to September 1960, Part 3-A. Ohio River basin except Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1725, 560 p.

_____1964b, Compilation of records of surface waters of the United States, October 1950 to September 1960, Part 3-B. Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1726, 269 p.

_____1962-65, Surface water records of Kentucky, 1961-64: U.S. Geological Survey (published annually).

_____1966-75, Water resources data for Kentucky, 1965-74--part 1. Surface-water records: U.S. Geological Survey Water-Data Reports (published annually).

_____1976-90, Water resources data for Kentucky, water years 1975-89: U.S. Geological Survey Water-Data Reports KY-75-1 to KY-89-1 (published annually).

Wetzel, K.L., and Bettandorff, J.M., 1986, Techniques for estimating streamflow characteristics in the Eastern and Interior Coal Provinces of the United States: U.S. Geological Survey Water-Supply Paper 2276, 80 p.

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.

HARMONIC-MEAN STREAMFLOW.--The reciprocal of the arithmetic mean of the reciprocals of a series of streamflows, or $Q_h = N/1/(Q_1 + 1/Q_2 + ... + 1/Q_N)$, where N is the number of observations of daily mean streamflow.

LEVEL OF SIGNIFICANCE.-- The selected maximum probability of making a Type I error, or rejecting a true null hypothesis (0.05 for this report). 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; Montgomery and Peck, 1982).

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

RESIDUAL.--The difference between values of harmonic-mean streamflow computed using streamflow-gaging data and values estimated using a regression model.

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

STREAMFLOW.--Discharge, measured as the volume of water that passes a given point within a given period of time (ft^3/s), that occurs in a natural channel whether or not it is affected by diversion or regulation.

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 using 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, 1982) 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, 1982; Montgomery and Peck, 1982; Choquette, 1988). See Prediction Sum of Squares (PRESS) Statistic.

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; Montgomery and Peck, 1982).

WATER YEAR.--The 12-month period beginning October 1 and ending September 30. It is designated by the calendar year in which it ends.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03202400	Guyandotte River near Baileysville, WV	07/68-09/89	21.3	306	0.41	[1]126	0.412
03203000	Guyandotte River at Man, WV	01/29-09/62	33.8	758	.59	131	.173
03203600	Guyandotte River at Logan, WV	10/62-01/80	17.3	833	.48	301	.361
03204500	Mud River near Milton, WV	11/24-12/24	42.8	256	.82	4.34	.0170
		03/38-10/80					
03206600	East Fork Twelvepole Creek near Dunlow, WV	10/64-09/89	25.0	38.5	.69	1.43	.0371
03207000	Twelvepole Creek at Wayne, WV	07/15-09/17	26.0	291	.81	5.29	.0182
		02/27-09/31					
		09/46-09/54					
		10/55-09/66					
03207020	Twelvepole Creek below Wayne, WV	07/15-09/17	31.3	300	.88	5.81	.0194
		02/27-09/31					
		09/46-09/54					
		10/55-02/72					
03207500	Levisa Fork near Grundy, VA	10/41-09/74	35.0	235	.62	22.5	.0957
		10/85-09/87					
03207915	Elkfoot Branch near Nigh	10/80-09/84	4.0	.70	--	[1].04	.0571
03207962	Dicks Fork at Phyllis	07/75-09/84	9.3	.82	--	[1].02	.0244
03207965	Grapevine Creek near Phyllis	10/73-09/82	9.4	6.20	.70	[1].21	.0339
		04/89-09/89					
03208000	Levisa Fork below Fishtrap Dam	04/38-09/68	30.5	392	.70	[1]37.9	.0967
03208500	Russell Fork at Haysi, VA	10/26-09/89	63.0	286	.61	26.8	.0937
03208950	Cranes Nest River near Clintwood, VA	10/63-09/89	26.0	66.5	.49	16.9	.254
03209000	Pound River below Flannagan Dam near Haysi, VA	10/26-09/38	37.2	221	.66	14.0	.0634
		10/39-02/65					
03209300	Russell Fork at Elkhorn City	10/60-02/65	4.4	554	.70	[1]68.7	.124

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03209440	Shelby Creek at Dorton	11/71-09/76	4.9	12.6	0.70	[1]0.30	0.0238
03209500	Levisa Fork at Pikeville	10/37-02/65	27.4	1,232	.70	109	.0885
03209800	Levisa Fork at Prestonsburg	10/63-02/65	1.4	1,702	--	[1]130	.0764
03210000	Johns Creek near Meta	04/41-09/89	48.5	56.3	.76	3.68	.0654
03211500	Johns Creek near Van Lear	10/39-04/50	10.6	206	.76	[1]14.3	.0694
03212000	Paint Creek at Staffordsville	04/50-09/75	25.5	103	.77	6.46	.0627
03212500	Levisa Fork at Paintsville	10/15-09/16 10/28-04/50	22.6	2,144	--	210	.0979
03213630	Right Fork Hurricane Creek near Stopover	10/80-09/83	3.0	.82	--	[1].06	.0732
03213700	Tug Fork at Williamson, WV	10/67-09/89	22.0	936	.43	355	.379
03215000	Big Sandy River at Louisa	10/38-09/47 10/48-04/50	10.6	3,897	--	546	.140
03215500	Blaine Creek at Yatesville	10/15-09/18 04/38-09/75	40.5	217	.80	10.8	.0498
03216350	Little Sandy River below Grayson Dam at Leon	10/66-02/68	1.4	196	.70	[1]14.9	.0760
03216400	Little Sandy River at Leon	10/61-02/68	6.4	255	.75	[1]22.5	.0882
03216500	Little Sandy River at Grayson	04/38-02/68	29.9	400	.72	33.1	.0828
03216540	East Fork Little Sandy River at Fallsburg	10/72-09/89	17.0	12.2	.80	.28	.0230
03216800	Tygarts Creek at Olive Hill	01/57-09/89	32.8	59.6	.85	[1]1.66	.0279
03217000	Tygarts Creek near Greenup[2]	10/40-09/89	49.0	242	--	10.5	.0434
03237280	Upper Twin Creek at McGaw, OH	07/63-09/89	26.3	12.2	.97	.32	.0262
03237500	Ohio Brush Creek near West Union, OH	10/26-09/35 10/40-09/89	58.0	387	.79	8.05	.0208
03237900	Cabin Creek near Tollesboro	04/72-09/89	17.5	22.4	1.15	.58	.0259
03246500	East Fork Little Miami River at Williamsburg, OH	03/49-09/53 10/60-09/74	18.6	237	.90	5.55	.0234

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03247500	East Fork Little Miami River near	10/15-09/17	54.5	476	0.76	18.3	0.0385
	Perrintown, OH	04/25-09/77					
03248500	Licking River near Salyersville	10/38-09/89	51.0	140	.80	7.06	.0504
03249000	Licking River at Yale	10/38-09/42	4.0	714	.79	[1]48.6	.0681
03249500	Licking River at Farmers	04/28-09/31	39.2	827	.79	[1]67.6	.0817
		04/38-11/73					
03250000	Triplett Creek at Morehead[2]	10/41-09/80	40.0	47.5	--	1.90	.0400
		10/88-09/89					
03250100	North Fork Triplett Creek near Morehead	10/67-09/89	22.0	84.7	.85	.99	.0117
03250320	Rock Lick Creek at Sharkey	07/73-11/83	10.3	4.01	1.15	.19	.0474
03250500	Licking River near Blue Lick Spring	04/38-09/59	21.5	1,785	--	111	.0622
03251000	North Fork Licking River near Lewisburg	10/46-09/89	43.0	119	1.25	.97	.0082
03251500	Licking River at McKinneysburg	10/24-03/26	36.7	2,326	--	162	.0696
		10/38-11/73					
03252000	Stoner Creek at Paris[2]	04/53-09/89	36.5	239	--	9.33	.0390
03252500	South Fork Licking River at Cynthiana[2]	04/38-09/89	51.5	621	--	16.1	.0259
03253000	South Fork Licking River at Hayes	10/28-09/31	3.0	920	1.10	[1]21.4	.0233
03253500	Licking River at Catawba	10/15-09/17	47.2	3,300	--	184	.0558
		10/28-11/73					
03254400	North Fork Grassy Creek near Piner	10/67-09/83	16.0	13.6	1.35	.39	.0287
03277400	Leatherwood Creek at Daisy	10/64-09/74	10.0	40.9	.80	6.22	.152
03277450	Carr Fork near Sassafras	10/63-12/75	12.3	60.6	.74	2.43	.0401
03277500	North Fork Kentucky River at Hazard	04/40-12/75	35.8	466	.74	[1]21.8	.0468
03278000	Bear Branch near Noble	04/55-09/73	18.5	2.21	--	.16	.0724
03278500	Troublesome Creek near Noble	04/50-09/81	31.5	177	.80	8.36	.0472
03279000	Troublesome Creek near Clayhole	10/29-09/31	2.0	187	.80	[1]8.36	.0447

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03280000	North Fork Kentucky River at Jackson	10/28-09/31	40.8	1,101	0.78	54.5	0.0495
		04/38-12/75					
03280500	North Fork Kentucky River near Airdale	10/29-09/31	4.5	1,294	.78	[1]78.3	.0605
		04/40-09/42					
03280600	Middle Fork Kentucky River near Hyden[2]	10/57-09/89	32.0	202	--	11.1	.0550
03280700	Cutshin Creek at Wooton	10/57-09/89	32.0	61.3	.80	4.45	.0726
03280900	Middle Fork Kentucky River at Buckhorn	10/56-11/60	4.1	420	.80	[1]9.19	.0219
03281000	Middle Fork Kentucky River at Tallega	10/30-03/32	22.7	537	.80	13.9	.0259
		10/39-11/60					
03281040	Red Bird River near Big Creek	08/72-09/89	17.2	155	.80	13.8	.0890
03281100	Goose Creek at Manchester	10/64-09/89	25.0	163	.78	11.2	.0687
03281500	South Fork Kentucky River at Booneville	04/25-09/31	56.5	722	.77	21.9	.0303
		10/39-09/89					
03282000	Kentucky River at Lock 14 at Heidelberg	10/25-09/31	28.2	2,657	--	212	.0794
		10/38-11/60					
03282075	Big Sinking Creek near Crystal	03/87-03/89	2.1	23.4	.78	[1]3.41	.146
03282100	Furnace Fork near Crystal	03/87-03/89	2.1	9.94	.78	[1].65	.0654
03282500	Red River at Hazel Green	04/54-09/89	35.5	65.8	.85	2.77	.0421
03283000	Stillwater Creek at Stillwater	04/54-09/73	19.5	24.0	.85	.90	.0375
03283370	Cat creek near Stanton	03/87-03/89	2.1	8.30	.85	[1].37	.0446
03283500	Red River at Clay City[2]	10/30-03/32	53.0	362	--	51.5	.142
		04/38-09/89					
03284000	Kentucky River Lock 10 near Winchester	10/07-11/60	53.2	3,955	--	454	.115
03284300	Silver Creek near Kingston[2]	10/67-09/83	16.0	28.6	--	3.39	.119
03284500	Kentucky River Lock 8 near Camp Nelson	10/39-11/60	21.2	4,414	--	507	.115
03284550	West Hickman Creek at Jonestown[2]	08/74-09/84	10.2	11.0	--	4.13	.376

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

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Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03285000	Dix River at Danville	10/42-09/89	47.0	318	1.15	3.88	0.0122
03285500	Dix River near Burgin	10/10-03/11	11.0	395	1.15	16.2	.0410
		10/11-09/13					
		04/14-09/22					
03288000	North Elkhorn Creek near Georgetown	04/50-09/83	34.5	119	.85	5.83	.0490
		10/88-09/89					
03288500	Cave Creek near Fort Spring	10/52-09/72	20.0	2.53	--	.20	.0791
03289000	South Elkhorn Creek at Fort Spring	04/50-09/89	39.5	24	.70	2.78	.1158
03289300	South Elkhorn Creek near Midway[2]	09/82-09/89	7.1	105	--	64.0	.6095
03289500	Elkhorn Creek near Frankfort[2]	10/15-09/18	48.5	473	--	70.5	.149
		04/40-09/83					
		10/87-09/89					
03290000	Flat Creek near Frankfort	10/51-09/71	20.0	5.63	1.35	.21	.0373
03291000	Eagle Creek at Sadieville	10/41-09/75	34.0	42.9	1.35	[1].17	.0040
03291500	Eagle Creek at Glencoe	10/15-09/18	45.9	437	1.35	3.40	.0078
		10/28-09/31					
		10/38-09/77					
		12/88-09/89					
03292460	Harrods Creek near LaGrange	12/67-09/89	21.8	24.1	1.04	[1].22	.0091
03292500	South Fork Beargrass Creek at Louisville[2]	04/40-09/40	32.2	17.2	--	1.99	.116
		10/44-09/53					
		10/54-09/62					
		10/69-09/83					
		06/88-09/89					
03293000	Middle Fork Beargrass Creek at Louisville[2]	10/44-09/89	45.0	18.9	--	3.84	.203
03294000	Silver Creek near Sellersburg, IN	10/54-09/89	35.0	189	.78	5.24	.0277

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03295000	Salt River near Harrodsburg	10/52-09/73	21.0	41.4	1.15	[1]0.48	0.0116
03295500	Salt River near Van Buren	10/38-09/82	44.0	196	1.16	5.03	.0257
03295890	Brashears Creek at Taylorsville	06/81-09/89	8.3	259	1.25	[1].85	.0033
03297500	Plum Creek at Waterford	04/54-09/74	20.5	31.8	1.25	.34	.0107
03297845	Floyds Fork at Crestwood	10/79-09/89	10.0	46.7	1.15	[1].12	.0026
03297970	Long Run near Eastwood	06/74-09/77	3.3	15.2	1.25	[1].05	.0033
03298000	Floyds Fork at Fisherville	10/44-09/89	45.0	138	1.25	1.34	.0097
03298500	Salt River at Sheperdsville	10/38-12/82	44.3	1,197	1.21	11.0	.0092
03299000	Rolling Fork near Lebanon	04/38-09/89	51.5	239	.90	2.03	.0085
03300000	Beech Fork near Springfield	10/52-09/72	20.0	85.9	1.34	[1].44	.0051
03300400	Beech Fork at Maud	08/72-08/89	17.1	436	1.34	[1]1.93	.0044
03301000	Beech Fork at Bardstown	04/40-09/74	34.5	669	1.26	7.26	.0109
03301500	Rolling Fork near Boston	10/38-09/89	51.0	1,299	1.00	42.7	.0329
03301940	Northern Ditch at Okolona[2]	06/74-09/76	2.3	11.8	--	7.66	.649
03302000	Pond Creek near Louisville[2]	10/44-09/89	45.0	64.0	--	9.16	.143
03302220	Buck Creek near New Middletown, IN	10/69-09/89	20.0	65.2	.59	8.91	.137
03302300	Little Indian Creek near Galena, IN	10/68-09/89	21.0	16.1	.80	.74	.0459
03303000	Blue River near White Cloud, IN	04/31-09/89	58.5	476	.56	104	.219
03303400	Crooked Creek near Santa Claus, IN	10/69-09/89	20.0	7.86	.98	.22	.0280
03304500	McGills Creek near McKinney	10/51-09/71	20.0	2.14	--	.14	.0654
03305000	Green River near McKinney	10/51-09/73	22.0	22.4	1.15	.63	.0281
03305500	Green River near Mt Salem	10/53-09/61	8.0	36.3	1.15	[1].93	.0256
03306000	Green River near Campbellsville	10/30-03/32 10/63-01/69	6.8	682	.78	[1]32.6	.0478
03306500	Green River at Greensburg	10/39-01/69	29.4	736	.78	41.8	.0568
03307000	Russell Creek near Columbia	10/39-09/89	50.0	188	.70	32.6	.173

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03307100	Russell Creek near Gresham	10/64-09/75	11.0	265	0.70	[1]41.8	0.158
03307500	South Fork Little Barren River at Edmonton	10/41-09/72	31.0	18.3	.70	.52	.0284
03308500	Green River at Munfordville	04/15-09/22	42.9	1,673	--	441	.264
		10/27-09/31					
		10/37-01/69					
03309000	Green River at Mammoth Cave	10/38-09/50	12.0	1,983	--	[1]545	.275
03309500	McDougal Creek near Hodgenville	10/53-09/71	18.0	5.34	.65	.71	.133
03310000	North Fork Nolin River at Hodgenville	10/41-09/73	32.0	36.4	.66	2.05	.0563
03310300	Nolin River at White Mills	10/59-09/89	30.0	357	.54	149	.417
03310400	Bacon Creek near Priceville	10/59-09/89	30.0	85.4	.52	21.7	.254
03310500	Nolin River at Wax	10/36-09/62	26.0	600	.54	[1]273	.455
03311000	Nolin River at Kyrock	10/30-03/32	14.9	703	.56	[1]302	.430
		10/39-09/50					
		10/60-02/63					
03311500	Green River at Lock 6 at Brownsville	10/24-09/31	31.4	2,762	--	874	.316
		10/38-02/63					
03311600	Beaverdam Creek at Rhoda	10/72-09/89	17.0	10.9	.56	2.39	.219
03312000	Bear Branch near Leitchfield	10/49-09/71	22.0	30.8	.72	1.35	.0438
03312500	Barren River near Pageville	04/39-09/63	24.5	531	.52	194	.365
03313000	Barren River near Finney	10/41-09/50	12.4	942	.59	[1]287	.305
		10/60-02/64					
03313500	West Bays Fork at Scottsville	10/50-09/72	22.0	7.47	.65	1.17	.157
03313700	West Fork Drakes Creek near Franklin[2]	10/68-09/89	21.0	110	.55	15.0	.136
03314000	Drakes Creek near Alvaton	10/39-09/71	32.0	478	.59	119	.249
03314500	Barren River at Bowling Green	10/38-02/64	25.4	1,849	--	433	.234
03315000	Barren River at Lock 1 at Greencastle	10/24-09/31	7.0	1,966	--	[1]568	.289

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03315500	Green River at Lock 4 Woodbury	10/37-02/63	25.4	5,404	--	1,570	0.291
03316000	Mud River near Lewisburg	10/39-09/72	33.0	90.5	0.68	5.33	.0589
03316500	Green River at Paradise	10/39-09/50	14.1	6,183	--	1,720	.278
		10/59-11/59					
		04/60-02/63					
03317000	Rough River near Madrid	10/38-09/59	21.0	225	--	49.6	.220
03317500	North Fork Rough River near Westview	04/54-09/73	19.5	42.0	.60	1.30	.0310
03318000	Rough River near Falls of Rough[2]	10/39-09/51	12.0	454	--	66.9	.147
03318200	Rock Lick Creek near Glenn Dean	10/56-09/71	15.0	20.1	.60	.85	.0423
03318500	Rough River at Falls of Rough[2]	10/48-09/59	11.0	504	--	68.4	.136
03318800	Caney Creek near Horse Branch	10/56-09/89	33.0	124	.90	1.03	.0083
03319000	Rough River near Dundee	04/40-09/59	19.5	757	.60	82.4	.109
03320000	Green River at Lock 2 at Calhoun	04/30-09/59	29.5	7,566	--	1,840	.243
03320500	Pond River near Apex	11/40-09/89	48.9	194	1.35	2.10	.0108
03321000	Pond River near White Plains	10/28-09/31	6.0	343	1.35	2.68	.0078
		10/37-09/40					
03321350	South Fork Panther Creek near Whitesville	04/68-09/83	15.5	58.2	1.35	1.21	.0208
03322100	Pigeon Creek at Evansville, IN	10/60-07/85	24.8	323	.74	22.7	.0703
03322360	Beaverdam Creek near Corydon	07/72-09/82	15.4	14.3	1.35	.12	.0084
		10/83-02/87					
		02/88-09/89					
03366200	Herberts Creek near Madison, IN	08/68-09/89	21.2	9.31	.88	.31	.0333
03378550	Big Creek near Wadesville, IN	07/65-09/89	24.3	104	1.08	.60	.0058
03383000	Tradewater River at Olney	10/40-05/84	48.3	255	1.35	2.71	.0106
		03/85-09/89					
03383500	Tradewater River at Dalton	10/28-09/31	6.0	283	1.35	2.22	.0078
		10/37-09/40					

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03384000	Rose Creek at Nebo	04/52-09/70	18.5	2.10	--	0.08	0.0381
03400000	Poor Fork at Harlan Letcher County Line	04/40-09/43	3.5	51.7	0.55	[1]17.5	.339
03400500	Poor Fork at Cumberland	04/40-09/89	49.5	82.3	.55	33.0	.401
03400785	Martins Fork above Smith	05/85-09/89	4.4	23.8	.55	[1]7.27	.306
03400800	Martins Fork near Smith	04/71-10/78	7.5	55.8	.55	[1]15.9	.285
03400990	Clover Fork at Harlan	10/77-10/78	1.1	222	.55	[1]60.3	.272
03401000	Cumberland River near Harlan	04/40-10/78	38.5	374	.55	[1]96.6	.258
03402000	Yellow Creek near Middlesboro[2]	10/40-09/89	49.0	60.6	--	19.1	.315
03402500	Cumberland River at Pineville	10/29-09/31	2.0	676	.55	[1]141	.209
03403000	Cumberland River near Pineville[2]	10/38-09/75 10/79-09/89	47.0	809	--	[1]175	.216
03403500	Cumberland River at Barbourville[2]	10/22-09/31 04/48-09/89	50.5	960	--	[1]190	.198
03403910	Clear Fork at Saxton	07/68-09/89	21.3	331	.62	99.0	.299
03404000	Cumberland River at Williamsburg	10/50-09/89	39.0	1,607	.56	[1]291	.181
03404500	Cumberland River at Cumberland Falls	10/07-09/11 04/15-09/31 10/32-09/89	77.6	1,977	--	351	.178
03404820	Laurel River at Municipal Dam near Corbin[2]	10/73-09/89	16.0	140	--	9.06	.0647
03404900	Lynn Camp Creek at Corbin	10/73-09/89	16.0	53.8	.69	4.69	.0872
03405000	Laurel River at Corbin[2]	10/22-09/24 10/42-09/73	33.0	201	--	9.50	.0473
03406000	Wood Creek near London	10/53-09/71	18.0	3.89	.65	1.09	.280
03406500	Rockcastle at Billows	10/36-09/89	53.0	604	.72	60.2	.0997
03407000	Rockcastle River at Rockcastle Springs	10/22-09/31	9.0	745	.71	[1]94.2	.126
03407100	Cane Branch near Parkers Lake	02/56-09/66 05/73-09/74	12.1	.67	--	.13	.194

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow (ft^3/s/mi^2)
03407300	Helton Branch near Greenwood	01/56-09/74	18.8	0.85	--	0.32	0.376
03407500	Buck Creek near Shopville	10/52-09/89	37.0	165	0.82	1.72	.0104
03408500	New River at New River, TN	09/34-09/89	55.1	382	.81	17.9	.0469
03410500	South Fork Cumberland River near Sterns	10/42-09/89	47.0	954	.65	225	.236
03411000	South Fork Cumberland River near Nevelsville	04/15-09/31 10/32-09/50	34.5	1,271	.64	[1]276	.217
03411500	Cumberland River at Burnside	10/14-09/50	36.0	4,865	--	[1]963	.198
03412500	Pitman Creek at Somerset	10/53-09/72	19.0	31.3	.70	1.79	.0572
03413000	Cumberland River near Jamestown	10/38-09/40	2.0	5,331	--	[1]1,090	.205
03413200	Beaver Creek near Monticello	10/68-09/83	15.0	43.4	.60	8.06	.186
03414000	Cumberland River near Rowena	10/39-07/50	10.8	5,790	--	[1]1,140	.197
03414500	East Fork Obey River near Jamestown, TN	10/42-09/89	47.0	202	.65	42.9	.212
03415000	West Fork Obey River near Alpine, TN	10/42-09/71 10/79-11/81	31.2	115	.63	[1]18.2	.158
03416000	Wolf River near Byrdstown, TN	10/42-09/89	47.0	106	.55	31.6	.298
03418000	Roaring River near Hilham, TN	10/31-08/75	43.9	78.7	.52	21.5	.273
03435140	Whippoorwill Creek near Claymour	05/73-09/89	16.4	20.8	1.05	.41	.0197
03435500	Red River near Adams, TN	07/20-10/69	49.3	706	.52	201	.285
03436000	Sulfer Fork Red River near Adams, TN	01/39-09/89	50.8	186	.54	41.6	.224
03436700	Yellow Creek near Shiloh, TN	10/57-11/80	23.2	124	.40	64.7	.522
03437500	South Fork Little River at Hopkinsville	10/49-09/73	24.0	46.5	.72	3.69	.0794
03438000	Little River near Cadiz	04/40-09/89	49.5	244	.58	67.0	.275
03438070	Muddy Fork Little River near Cerulean	05/68-09/83	15.4	30.5	1.35	.32	.0105
03529500	Powell River at Big Stone Gap, VA	10/44-09/59 10/78-09/81	18.0	112	.50	[1]50.9	.455
03530500	North Fork Powell River at Pennington, VA	10/44-09/51 10/78-09/81	10.0	70.0	.58	[1]18.1	.259

See footnotes at the end of the table.

Table 1.--Harmonic-mean streamflows and drainage-basin characteristics for selected unregulated continuous-record streamflow-gaging stations in the study area--Continued

[mo/yr, month/year; mi^2, square miles; ft^3/s, cubic feet per second; WV, West Virginia; VA, Virginia, --, not applicable; OH, Ohio; IN, Indiana; TN, Tennessee; IL, Illinois; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Period of unregulated record (mo/yr-mo/yr)	Years of unregulated record	Drainage area (mi^2)	Streamflow-variability index	Unregulated harmonic-mean flow (ft^3/s)	Standardized unregulated harmonic-mean flow ($ft^3/s/mi^2$)
03531000	Powell River near Pennington Gap, VA	10/20-09/31	11.0	290	0.51	111	0.383
03531500	Powell River near Jonesville, VA	10/31-09/89	58.0	319	.48	132	.414
03609500	Tennessee River near Paducah	10/1889-09/35	46.0	40,200	--	31,100	.774
03610000	Clarks River at Murray	10/51-09/71	20.0	89.7	1.25	1.48	.0165
03610200	Clarks River at Almo	10/82-09/89	7.0	134	--	12.1	.0903
03610500	Clarks River near Benton	10/38-09/73	35.0	227	.91	16.2	.0714
03610545	West Fork Clarks River near Brewers	10/68-09/83 12/88-09/89	15.8	68.7	.50	13.6	.198
03611260	Massac Creek near Paducah	10/71-09/89	18.0	14.6	.70	.97	.0664
03612000	Cache River at Forman, IL	04/23-09/89	66.0	244	.97	3.33	.0137
07022500	Perry Creek near Mayfield	10/52-09/65 10/67-09/72	18.0	1.72	--	.04	.0233
07023000	Mayfield Creek at Lovelaceville	10/38-09/72	34.0	212	.84	26.7	.126
07023500	Obion Creek at Pryorsburg	10/51-09/73	22.0	36.8	1.25	.16	.0044
07024000	Bayou De Chien near Clinton	10/39-09/78 09/84-09/89	44.1	68.7	.50	20.2	.294
07026500	Reelfoot Creek near Samburg, TN	01/51-10/73	22.7	110	.99	1.27	.0115

[1] Value adjusted based on correlation of concurrent record with a nearby gaging station.
[2] Flows at this site are subject to local diversion.

Table 2.--Harmonic-mean streamflows and drainage-basin characteristics for selected regulated continuous-record streamflow-gaging stations in the study area

[mi^2, square miles; mo/yr, month/year; ft^3/s, cubic feet per second; --, not applicable; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Drainage area (mi^2)	Period of unregulated record (mo/yr-mo/yr)	Unregulated harmonic-mean flow (ft^3/s)	Period of regulated record analyzed (mo/yr-mo/yr)	Regulated harmonic-mean flow (ft^3/s)	Source of regulation and start date
03208000	Levisa Fork below Fishtrap Dam	392	04/38-09/68	[1]37.9	08/69-09/89	138	Fishtrap Lake, 10/68
03209300	Russell Fork at Elkhorn City	554	10/60-02/65	[1]68.7	04/69-09/89	258	Flannagan Lake, 03/65; North Fork Pound Lake, 07/66
03209500	Levisa Fork at Pikeville	1,232	10/37-02/65	109	05/66-09/89	507	Flannagan Lake, 03/65; Fishtrap Lake, 10/68
03209800	Levisa Fork at Prestonsburg	1,702	10/63-02/65	[1]130	05/66-09/81	632	Flannagan Lake, 03/65; Fishtrap Lake, 10/68
03211500	Johns Creek near Van Lear	206	10/39-04/50	[1]14.3	07/50-09/89	30.9	Dewey Lake, 05/50
03212500	Levisa Fork at Paintsville	2,144	10/15-09/16 10/28-04/50	210	07/50-09/89	439	Dewey Lake, 05/50; Fishtrap Lake, 10/68
03215000	Big Sandy River at Louisa	3,897	10/38-09/47 10/48-04/50	546	07/50-09/76	841	Dewey Lake, 05/50; Fishtrap Lake, 10/68
03216000	Ohio River at Ashland	60,750	--	--	10/39-09/52	[2]30,100	Various
03216350	Little Sandy River below Grayson Dam near Leon	196	10/66-02/68	[1]14.9	05/69-09/89	57.0	Grayson Lake, 03/68
03216400	Little Sandy River at Leon	255	10/61-02/68	[1]22.5	05/69-09/80	84.1	Grayson Lake, 03/68
03216500	Little Sandy River at Grayson	400	04/38-02/68	33.1	05/69-09/89	110	Grayson Lake, 03/68
03216600	Ohio River at Greenup Dam	62,000	--	--	10/68-09/89	[2]30,600	Various
03238000	Ohio River at Maysville	70,130	--	--	10/40-05/64	[2]33,300	Various
03249500	Licking River at Farmers	827	04/28-09/31 04/38-11/73	[1]67.6	06/74-09/89	165	Cave Run Lake, 12/73
03251500	Licking River at McKinneysburg	2,326	10/24-03/26 10/38-11/73	162	06/74-09/89	463	Cave Run Lake, 12/73
03253500	Licking River at Catawba	3,300	10/15-09/17 10/28-11/73	184	06/74-09/89	579	Cave Run Lake, 12/73
03255000	Ohio River at Cincinnati, Ohio	76,580	--	--	10/39-06/63	[2]34,900	Various
03277200	Ohio River at Markland Dam	83,170	--	--	05/70-09/89	[2]37,900	Various
03277450	Carr Fork near Sassafras	60.6	10/63-12/75	2.43	08/76-09/89	12.0	Carr Fork Lake, 01/76

See footnotes at the end of the table.

Table 2.--Harmonic-mean streamflows and drainage-basin characteristics for selected regulated continuous-record streamflow-gaging stations in the study area--Continued

[mi^2, square miles; mo/yr, month/year; ft^3/s, cubic feet per second; --, not applicable; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Drainage area (mi^2)	Period of unregulated record (mo/yr-mo/yr)	Unregulated harmonic-mean flow (ft^3/s)	Period of regulated record analyzed (mo/yr-mo/yr)	Regulated harmonic-mean flow (ft^3/s)	Source of regulation and start date
03277500	North Fork Kentucky River at Hazard	466	04/40-12/75	[1]21.8	08/76-09/89	112	Carr Fork Lake, 01/76
03280000	North Fork Kentucky River at Jackson	1,101	10/28-09/31 04/38-12/75	54.5	08/76-09/89	279	Carr Fork Lake, 01/76
03280900	Middle Fork Kentucky River at Buckhorn	420	10/56-11/60	[1]9.19	01/62-09/75	76.0	Buckhorn Lake, 12/60
03281000	Middle Fork Kentucky River at Tallega	537	10/30-03/32 10/39-11/60	13.9	01/62-09/89	159	Buckhorn Lake, 12/60
03282000	Kentucky River at Lock 14 at Heidelberg	2,657	10/25-09/31 10/39-11/60	211	01/62-09/89	687	Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03284000	Kentucky River at Lock 10 at Winchester	3,955	10/07-11/60	454	01/62-09/89	907	Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03284500	Kentucky River at Lock 8 near Camp Nelson	4,414	10/39-11/60	507	01/62-09/71	961	Buckhorn Lake, 12/60
03287000	Kentucky River at Lock 6 near Salvisa	5,102	--	--	07/26/09/89	971	Herrington Lake, 11/25; Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03287500	Kentucky River at Lock 4 at Frankfort	5,411	--	--	07/26-09/89	1,130	Herrington Lake, 11/25; Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03290500	Kentucky River at Lock 2 at Lockport	6,180	--	--	07/26-09/89	1,470	Herrington Lake, 11/25; Buckhorn Lake, 12/60; Carr Fork Lake, 01/76
03294500	Ohio River at Louisville	91,170	--	--	04/28-09/89	39,700	Various
03298500	Salt River at Sheperdsville	1,197	10/38-12/82	11.0	05/83-09/89	112	Taylorsville Lake, 01/83
03303280	Ohio River at Cannelton Dam	97,000	--	--	10/75-09/89	[2]42,000	Various
03303500	Ohio River at Owensboro	97,200	--	--	10/40-09/52	[2]43,000	Various
03306000	Green River near Campbellsville	682	10/30-03/32 10/63-01/69	[1]32.6	05/69-09/89	66.2	Green River Lake, 02/69

See footnotes at the end of the table.

Table 2.--Harmonic-mean streamflows and drainage-basin characteristics for selected regulated continuous-record streamflow-gaging stations in the study area--Continued

[mi^2, square miles; mo/yr, month/year; ft^3/s, cubic feet per second; --, not applicable; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Drainage area (mi^2)	Period of unregulated record (mo/yr-mo/yr)	Unregulated harmonic-mean flow (ft^3/s)	Period of regulated record analyzed (mo/yr-mo/yr)	Regulated harmonic-mean flow (ft^3/s)	Source of regulation and start date
03306500	Green River at Greensburg	736	10/39-01/69	41.8	05/69-09/75	[3]--	Green River Lake, 02/69
03308500	Green River at Munfordville	1,673	04/15-09/22 10/27-09/31 10/37-01/69	44.0	05/69-09/89	811	Green River Lake, 02/69
03311000	Nolin River at Kyrock	703	10/30-03/32 10/39-09/50 10/60-02/63	[1]302	06/63-09/89	92.3	Nolin Lake, 03/63
03311500	Green River at Lock 6 at Brownsville	2,762	10/24-09/31 10/38-02/63	874	06/63-09/89	1,430	Nolin lake, 03/63; Green River Lake, 02/69
03313000	Barren River near Finney	942	10/41-09/50 10/60-02/64	[1]287	06/64-09/89	155	Barren River Lake, 03/64
03314500	Barren River at Bowling Green	1,849	10/38-02/64	433	06/64-09/89	733	Barren River Lake, 03/64
03315500	Green River at Lock 4 Woodbury	5,404	10/37-02/63	1,570	06/63-09/89	2,860	Nolin Lake, 03/63; Barren River Lake, 03/64; Green River Lake, 02/69
03316500	Green River at Paradise	6,183	10/39-09/50 10/59-11/59 04/60-02/63	1,720	06/63-12/81	3,140	Nolin Lake, 03/63; Barren River Lake, 03/64; Green River Lake, 02/69
03318500	Rough River at Falls of Rough	504	10/48-09/59	68.4	01/61-09/89	159	Rough River Lake, 10/59
03319000	Rough River near Dundee	757	04/40-09/59	82.4	01/61-09/89	231	Rough River Lake, 10/59
03320000	Green River at Lock 2 at Calhoun	7,566	04/30-09/59	1,840	01/61-09/89	3,570	Rough River Lake, 10/59; Nolin Lake, 03/63; Barren River Lake, 03/64; Green River Lake, 02/69
03322420	Ohio River near Uniontown	108,000	--	--	10/84-09/89	[2]49,000	Various
03384500	Ohio River at Dam 51, at Golconda, Illinois	143,900	--	--	10/40-09/52	[4]72,800	Various
03400800	Martins Fork near Smith	55.8	04/71-10/78	[1]15.9	01/79-09/89	25.9	Martins Fork Lake, 11/78

See footnotes at the end of the table.

Table 2.--Harmonic-mean streamflows and drainage-basin characteristics for selected regulated continuous-record streamflow-gaging stations in the study area--Continued

[mi^2, square miles; mo/yr, month/year; ft^3/s, cubic feet per second; --, not applicable; all stations are in Kentucky unless otherwise noted]

Station number	Station name	Drainage area (mi^2)	Period of unregulated record (mo/yr-mo/yr)	Unregulated harmonic-mean flow (ft^3/s)	Period of regulated record analyzed (mo/yr-mo/yr)	Regulated harmonic-mean flow (ft^3/s)	Source of regulation and start date
03400990	Clover Fork at Harlan	222	10/77-10/78	[1]60.3	01/79-09/89	109	Martins Fork Lake, 11/78
03401000	Cumberland River near Harlan	374	04/40-10/78	[1]96.6	01/79-09/89	168	Martins Fork Lake, 11/78
03414000	Cumberland River near Rowena	5,790	10/39-07/50	[1]1,140	03/51-09/89	[5]1,300	Cumberland Lake, 08/50
03438220	Cumberland River at Grand Rivers	17,600	--	--	06/66-09/89	[6]17,800	Lake Barkley, 08/44
03609500	Tennessee River near Paducah	40,200	10/1889-09/35	31,100	06/66-09/84	[6]43,800	Kentucky Lake, 01/36
03611500	Ohio River at Metropolis, Illinois	203,000	--	--	04/28-09/89	135,000	Various

[1] Value adjusted based on correlation of concurrent record with a nearby gaging station.
[2] Value adjusted based on correlation of concurrent record with Ohio River at Louisville (03294500).
[3] Less than 10 years of continuous record.
[4] Value adjusted based on correlation of concurrent record with Ohio River at Metropolis, IL (03611500).
[5] Value is for the entire regulated period. A change in the release schedule was implemented in July 1984, but no separate analysis was performed (less than 10 years of continuous record).
[6] Value represents only that period after the Kentucky Lake-Lake Barkley Canal was opened.

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