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Scientific Investigations Report 2010–5217

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

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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

°C=(°F-32)/1.8

Elevation, as used in this report, refers to the distance in feet above the National Geodetic Vertical Datum of 1929 (NGVD 1929).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Methods for Estimating Selected Low-Flow Frequency Statistics for Unregulated Streams in Kentucky

By Gary R. Martin and Leslie D. Arihood

Abstract

This report provides estimates of, and presents methods for estimating, selected low-flow frequency statistics for unregulated streams in Kentucky including the 30-day mean low flows for recurrence intervals of 2 and 5 years ($30Q_2$ and $30Q_5$) and the 7-day mean low flows for recurrence intervals of 5, 10, and 20 years ($7Q_2$, $7Q_{10}$, and $7Q_{20}$). Estimates of these statistics are provided for 121 U.S. Geological Survey streamflow-gaging stations with data through the 2006 climate year, which is the 12-month period ending March 31 of each year. Data were screened to identify the periods of homogeneous, unregulated flows for use in the analyses.

Logistic-regression equations are presented for estimating the annual probability of the selected low-flow frequency statistics being equal to zero. Weighted-least-squares regression equations were developed for estimating the magnitude of the nonzero $30Q_2$, $30Q_5$, $7Q_2$, $7Q_{10}$, and $7Q_{20}$ low flows. Three low-flow regions were defined for estimating the 7-day low-flow frequency statistics.

The explicit explanatory variables in the regression equations include total drainage area and the mapped streamflow-variability index measured from a revised statewide coverage of this characteristic. The percentage of the station low-flow statistics correctly classified as zero or nonzero by use of the logistic-regression equations ranged from 87.5 to 93.8 percent. The average standard errors of prediction of the weighted-least-squares regression equations ranged from 108 to 226 percent. The $30Q_2$ regression equations have the smallest standard errors of prediction, and the $7Q_{20}$ regression equations have the largest standard errors of prediction.

The regression equations are applicable only to stream sites with low flows unaffected by regulation from reservoirs and local diversions of flow and to drainage basins in specified ranges of basin characteristics. Caution is advised when applying the equations for basins with characteristics near the applicable limits and for basins with karst drainage features.

Introduction

Information on streamflow characteristics, such as low-flow frequency statistics, is needed for effective management of water resources. Decisions related to waste-load allocations, discharge and withdrawal permits, water-supply planning, and in-stream flow requirements depend on estimates of low-flow frequency statistics; and methods for estimating these statistics at gaged stream sites are part of this need. The U.S. Geological Survey (USGS), in cooperation with the Kentucky Division of Water (KDOW), made estimates of the $30Q_2$, $30Q_5$, $7Q_2$, $7Q_{10}$, $7Q_{20}$ low flows at 121 streamflow-gaging stations with data through the 2006 climate year (the 12-month period ending March 31 of each year) and developed regional regression equations for estimating these low-flow frequency statistics for unregulated streams in Kentucky.

Frequency analysis in water-resource studies associates an estimate of flow magnitude to a frequency of occurrence. The more extreme the flow (flood or drought), the smaller the estimated frequency of occurrence (and annual probability, p) and the larger the recurrence interval (T). A low-flow frequency statistic, such as the 7-day, 10-year low flow (abbreviated as $7Q_{10}$), is estimated from the series of annual minimum mean flows for a specific number of consecutive days—7 days for $7Q_{10}$. The 7-day mean flows are computed for the entire daily mean flow record, and the minimum value determined for each year. The series of annual minimum mean 7-day flows are fit to a theoretical frequency distribution, and the flow magnitude that is expected to not be exceeded, on average, once in 10 years is the $7Q_{10}$ low-flow statistic. The annual nonexceedance probability, p, of the low-flow statistic is the inverse of the expected recurrence interval, 1/T, or 1/10 = 0.1, for $7Q_{10}$. The recurrence interval is an estimated period, averaged over a very long period of time, and it is not a prediction of when a particular flow will happen. For example, the $7Q_{10}$ flow could happen 3 years in a row, and it may not recur during any given 20-year period.

Resources limit the routine collection of flow data on every stream reach and at every stream site where such information eventually may be needed. Therefore, methods of estimating low-flow frequency statistics by use of regional-regression equations have been developed, and these methods effectively transfer information from gaged to ungaged stream sites. The estimating methods presented in this report apply only to stream sites where low flows are not appreciably affected by drainage-basin modifications such as regulation by reservoirs, interbasin transfers, withdrawals, and discharges.

Purpose and Scope

This report presents estimates of, and methods for estimating, selected low-flow frequency statistics ($30Q_2$, $30Q_5$, $7Q_2$, $7Q_{10}$, and $7Q_{20}$) for streams in Kentucky. The report describes the methods used for estimating these statistics at 121 gaged stream sites where a range of streamflow information has been collected through climate year 2006. The report also describes the development, accuracy, limitations, and application of methods to estimate these statistics at ungaged, unregulated stream sites where flows are not appreciably affected by local diversions.

Previous Studies

Previous studies have presented selected low-flow frequency statistics estimated from USGS streamflow-gaging data in tabular and map formats including Speer and others, 1965; Swisshelm, 1974; Davis, 1979; Sullavan, 1980, 1984; Melcher and Ruhl, 1984; and the Ohio River Valley Water Sanitation Commission, 2006. Ruhl and Martin, 1991, presented statewide regression equations for estimating selected low-flow frequency statistics.

Description of Study Area

The Commonwealth of Kentucky is an area of 40,395 mi^2 in the east-central United States. The major drainage basins in Kentucky—Big Sandy, Licking, Kentucky, Lower Ohio-Salt, Upper and Lower Cumberland, Green, and Lower Tennessee Rivers—are tributaries to the Ohio River, the northern border of Kentucky adjacent to Ohio, Indiana, and Illinois and the Mississippi River on the western border of Kentucky adjacent to Missouri (fig. 1). In a generalized annual water balance for Kentucky, about 60 percent of precipitation leaves drainage basins as evapotranspiration and about 40 percent leaves as direct runoff and (or) the shallow groundwater flow that produces the seasonal low flows in late summer and early autumn (September—October). The hydrologic conditions that determine low-flow characteristics vary widely across geographic and time scales in Kentucky as described in this report.

Geology and Physiography

Topographic relief in Kentucky reflects the results of long-term stream-erosional processes in relation to the rock formations. The upland areas—hills, ridges, mountains, and plateaus—generally consist of formations resistant to erosion. Western and central parts of Kentucky have rolling terrain, whereas, the eastern part of Kentucky has rugged terrain with high relief. Land-surface elevations (the distance above the vertical datum) in Kentucky vary by more than 3,500 ft and range from 260 ft above the National Geodetic Vertical Datum of 1929 (NGVD 1929) along the Mississippi River to 4,145 ft at the peak of Black Mountain in Harlan County near the Kentucky–Virginia border (McGrain and Currens, 1978).

The physiography of the State reflects the lithology of the surface rocks and largely is defined by the Cincinnati Arch (fig. 2). The axis of the Cincinnati Arch trends northward from south-central Kentucky to just south of the Outer Bluegrass boundary where the axis divides into two branches—Kankakee (the northwestward branch) and Findlay Arches. The branches are almost parallel but are separated by about 25 mi at the Ohio River (McFarland, 1950). Lithologic units dip away from the axis of the arch—a regional structural high—so that geologic features generally are symmetrical on each side of the arch.

Progressively younger rocks are exposed at the surface east and west of the Cincinnati Arch (fig. 2). The oldest exposed rocks are part of the Jessamine Dome and adjacent areas; this area corresponds approximately to the Inner Bluegrass region. These rocks consist of limestone, shale, and sandstone of Ordovician age (fig. 3). Narrow bands of shales and limestones of Silurian and Devonian age surround this area and correspond to The Knobs region. An expansive area of limestone of Mississippian age (Mississippian Plateaus Region) is exposed starting at the Ohio River in northeastern Kentucky, extending southwest to the State boundary, and extending northwest in a crescent-shaped area surrounding the Western Kentucky Coal Field. The eastern boundary of this area is the Cumberland Escarpment. Sandstones, shales, siltstones, and coals of Pennsylvanian age in eastern and northwestern Kentucky—the youngest rocks in Kentucky—compose the Eastern and Western Kentucky Coal Fields. Alluvial deposits of Cretaceous and Tertiary age are in extreme western Kentucky in the Mississippi Embayment.

Much of the Mississippian Plateaus is characterized by carbonate rock and karst features such as sinkholes, caves, springs, and losing streams. Most well-developed karst features are 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. Less-well-developed karst features are in central and south-central Kentucky. Detailed descriptions and maps illustrating the geology and physiography of Kentucky are presented in The Geology of Kentucky (McDowell, 1986).

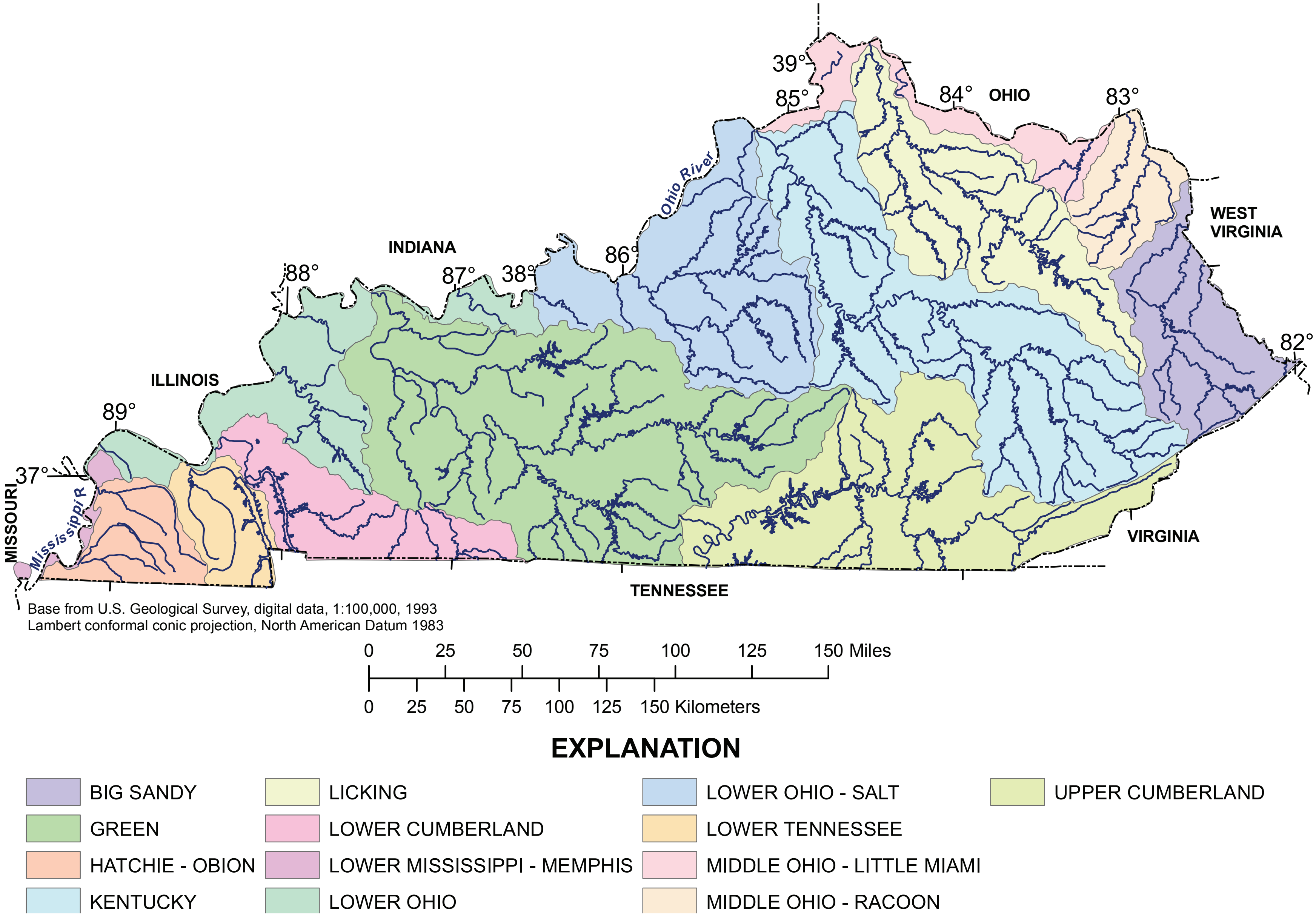


Figure 1. Major drainage basins in Kentucky.

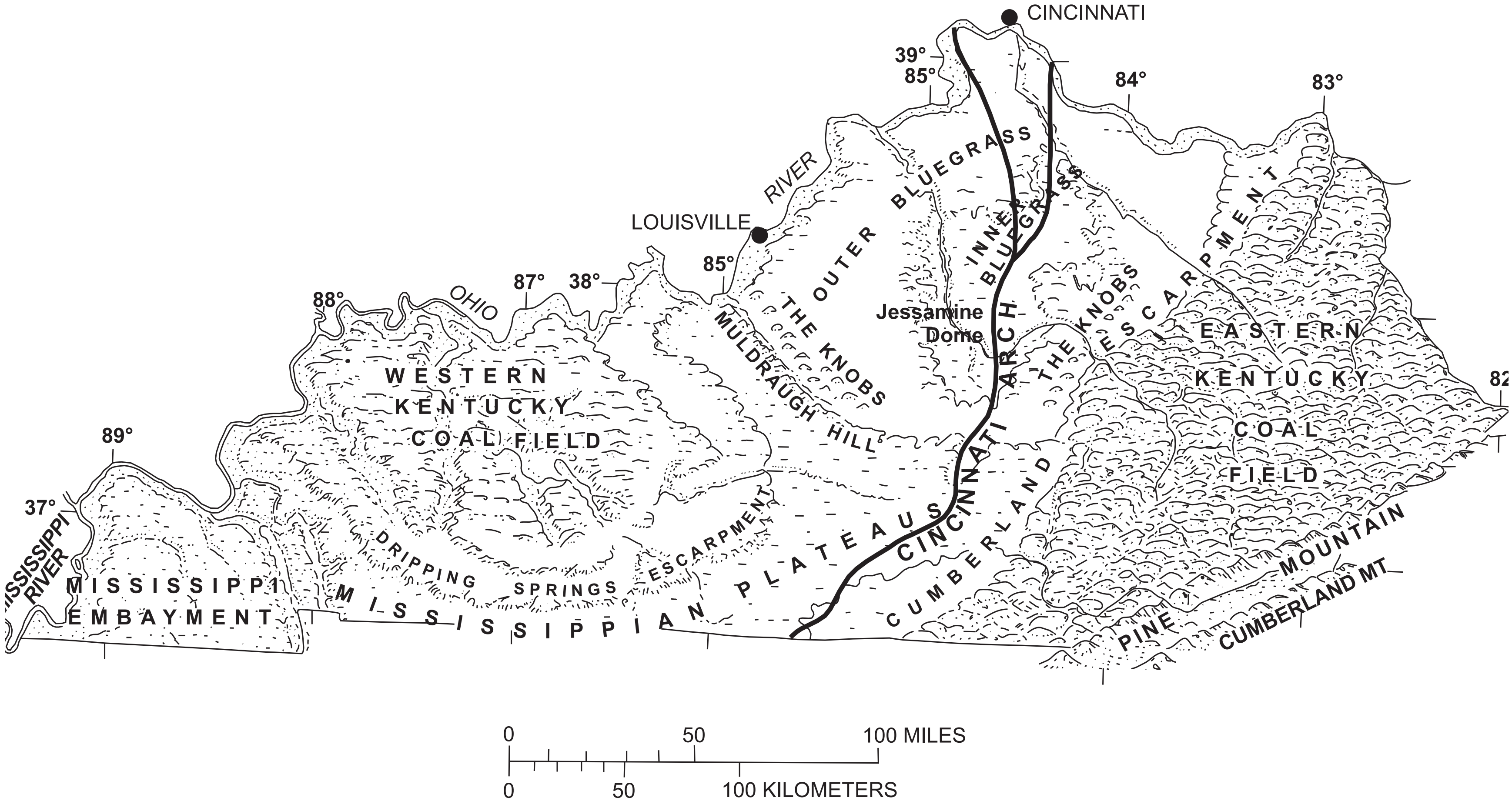


Figure 2. Physiographic regions in Kentucky [from Kentucky Geological Survey, 1980].

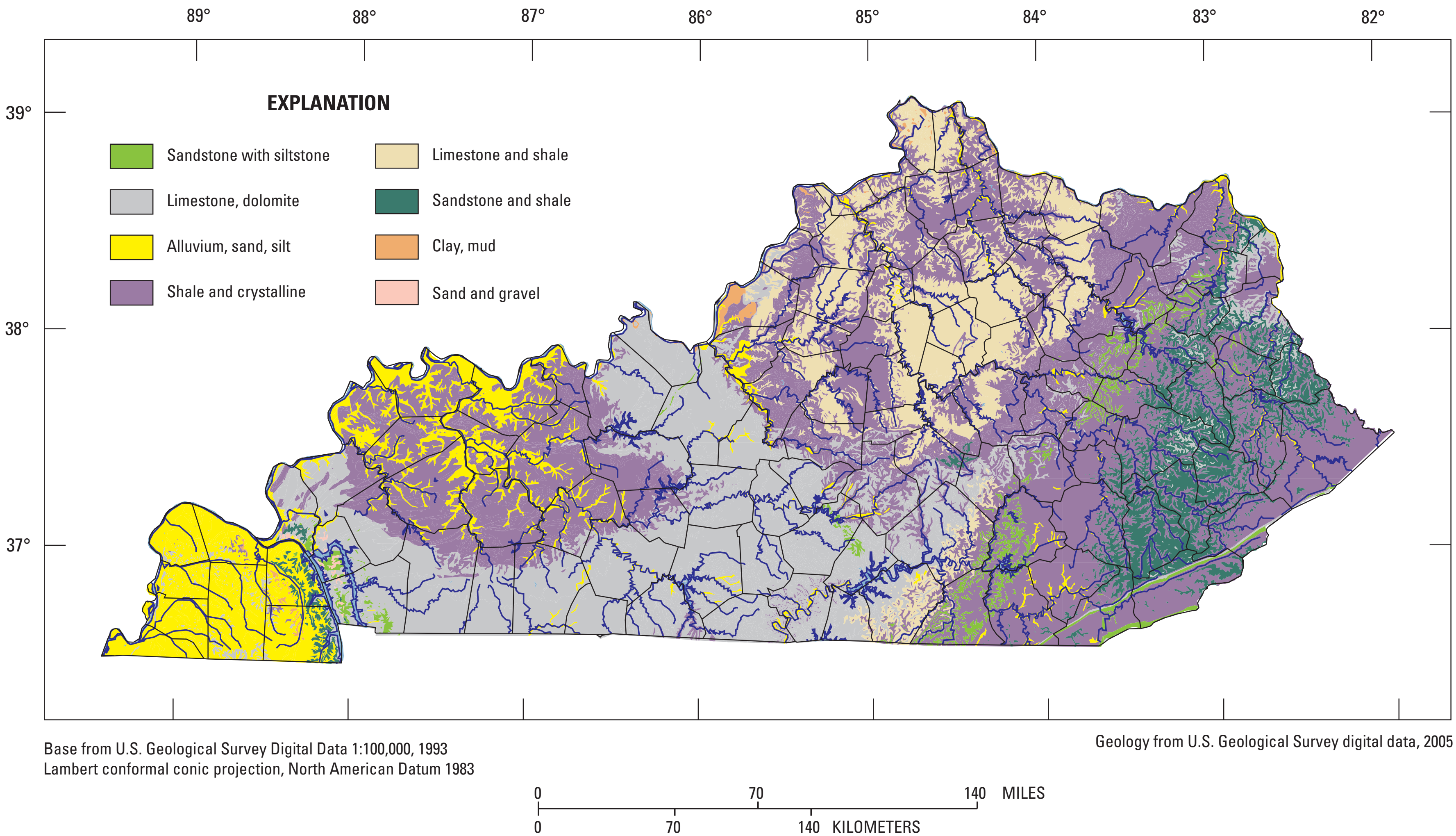


Figure 3. Generalized geology of Kentucky.

Climate

Kentucky has a moist-continental climate with distinct seasonal variations and highly changeable weather patterns. Weather patterns in Kentucky are affected variably by the meeting of cold, continental air masses arriving from the northwest and warm, moist air masses moving up the Mississippi and Ohio River Valleys from the southwest (Conner, 1982). Temperatures and precipitation vary from southwest to northeast under the influence of latitude and elevation (Hill, 2005).

Winter temperatures are moderate, rarely below 0°F; typical summer temperatures are warm, humid, and occasionally more than 100°F. Average annual snowfall varies from about 10 in. in the southwest to about 20 in. in the northeast. Snow cover rarely persists longer than 1 week in the southwest and 2 weeks in the northeast. Normal mean annual temperature (1971–2000) varies from 59°F. in the southwest to 53°F. in the northeast. Most areas of Kentucky receive about 40 percent of available sunshine in winter and about 60 percent of available sunshine in summer because of clouds (Kentucky Climate Center at Western Kentucky University, 2010).

Annual precipitation in Kentucky averaged about 50 in. at 29 long-term reporting stations for the period 1971–2000. The distribution of precipitation varies areally, annually, and seasonally. The normal mean annual precipitation in Kentucky ranges areally from about 55 in. in the southwest to 43 in. in the northeast (Hill, 2005). Rainfall generally decreases to the north, reflecting the increase in distance from the source of moisture, which primarily is the subtropical Atlantic Ocean and Gulf of Mexico. Kentucky has considerable year-to-year variation in precipitation. For example, during the period 1951–80, annual precipitation at reporting stations ranged from 14.5 to 78.6 in. Large amounts of precipitation in Kentucky have been associated with tropical cyclones moving north from the Gulf of Mexico (Conner, 1982).

Precipitation falls throughout the year but the sources and amounts of precipitation vary seasonally. Although March generally is the wettest month of the year, averaging from 4 to 6 in., the precipitation pattern is bimodal with a second peak, averaging from 3.3 to 5.5 in., in July. October generally is the driest month when precipitation averages from 2 to 3 in. Mean seasonal precipitation in Kentucky is about 13.5 in. in spring (March through May), 12.4 in. in summer (June through August), 9.8 in. in autumn (September through November), and 11.5 in. in winter (December through February) (Conner, 1982).

Winter precipitation is characterized by frontal storms. Summer precipitation generally results from thunderstorms. Precipitation intensity generally is higher in summer than during other seasons, but the number of days having precipitation is similar in winter and summer. The Bermuda high-pressure system has a strong effect on seasonal precipitation patterns in Kentucky. In the autumn, this high-pressure system generally moves inland from the southeastern coast of the United States and is centered over Kentucky and Tennessee, where this system inhibits convective activity and frontal storm movement and produces a dry season (Conner, 1982).

Daily average temperature and total precipitation data for the 110-year period January 1895–December 2004 (Kentucky Climate Center at Western Kentucky University, 2008a, 2008b), aggregated to monthly and annual values, were examined to assess how seasonal weather and long-term climate patterns (the climate signal) may have affected low-flow characteristics in Kentucky. These annual data were plotted with locally weighted scatterplot smooth (LOWESS) curves (Cleveland 1979, 1984; Helsel and Hirsch, 2002) fitted to identify general patterns in the data over time (fig. 4). The LOWESS curve shows temperatures generally increased from around 1900 until 1945, then decreased until about 1975, then increased to the end of the available record in 2004. These temperature patterns are consistent with those patterns reported for global mean surface temperature for these periods (National Research Council, 2006). Precipitation in Kentucky has generally had an positive trend during the period 1895–2004, except during a flat to declining period from the 1930s into the 1950s. This overall precipitation increase in Kentucky from 1895–2004 is consistent with reported increases over land areas north of 30 degrees north latitude (Karl and others, 1996; Karl and Knight, 1998; Solomon and others, 2007).

Multiple statistical trend tests were made by use of the daily temperature and precipitation data aggregated to monthly and annual values (appendix 1). The results were, in general, consistent with the patterns observed in the LOWESS curves (fig. 4), though no full-year trend in temperature during the entire 1895–2004 period was detected. A notable positive trend in the statewide monthly cold-season (November–March) temperatures and negative trend in warm-season (April–October) temperatures was observed from 1895–2004. The warm-season precipitation can be intense (as is typical in the summer months) and generally contributes proportionately more to direct-runoff surface-water flows and less to groundwater recharge than happens during other periods of the year. The warm-season precipitation had positive trend from 1895–2004. However, only one of the tests indicated a positive trend for full-year monthly precipitation for the period 1895–2004. The historical relations of temperature, precipitation, and low-flow characteristics in Kentucky are explored further in the section “Assessment of the Annual Low-Flow Time-Series Data.”

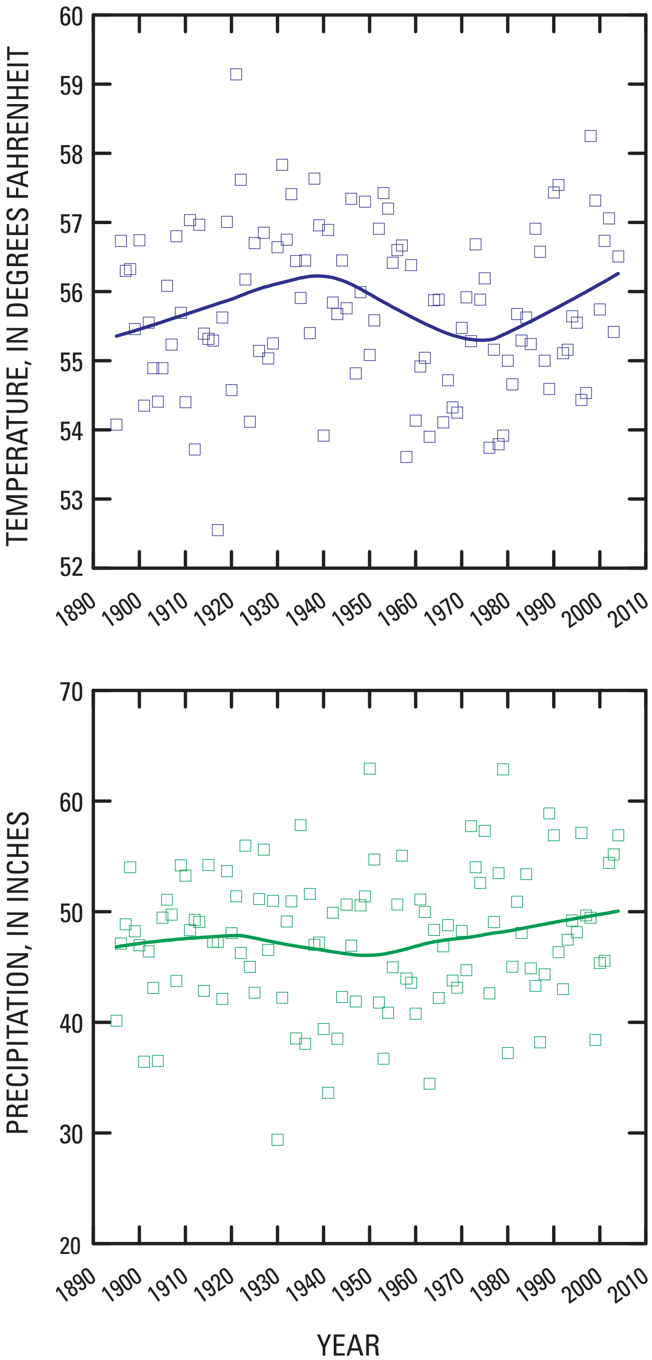


Figure 4. Annual temperature and precipitation with a LOWESS curve fit to the data for the period 1890–2004 in Kentucky.

Methods for Data-Collection Stations

Low-flow frequency statistics were estimated at streamflow-gaging stations by methods that varied with the type and amount of streamflow data that were available. The statistics were estimated by fit of the annual low-flow time series to a theoretical frequency distribution at the long-term, continuous-record (LTCR) streamflow-gaging stations, which typically by definition have daily mean discharge records available for 10 or more years. The statistics were estimated by methods of correlation to the LTCR (index) stations at the low-flow, partial-record (LFPR) streamflow-gaging stations, which typically have a few instantaneous streamflow measurements during representative base-flow periods. LTCR stations having less than 10 years of data also were treated as LFPR stations.

Long-Term Continuous-Record Streamflow-Gaging Stations

Available daily mean streamflow data were retrieved by use of the USGS National Water Information System (NWIS) Automated Data Processing System (U.S. Geological Survey, 2003) and the NWIS online database (*http://waterdata.usgs.gov/nwis*). The USGS has collected continuous-record streamflow-gaging information in Kentucky since 1907 (Beaber, 1970); other agencies have collected such data in Kentucky beginning in 1890. The data were checked and verified by comparison of summary statistics for the published data (Wells, 1957, 1958; Hendricks, 1964; U.S. Geological Survey, 1964, 1962–65, 1966–75, and 1976–2007). Low-flow frequencies were estimated for LTCR stations by use of annual-minimum-mean flows for D consecutive days (D-day low flows where D=1–365). The D-day mean flows (for 7 and 30 consecutive days in this study) were computed for the entire period of record and the minimum value was selected for each year. The annual period used was the climate year, which extends from April 1–March 31, because this period typically encompasses the late summer and early autumn period when most streams in the United States reach an annual minimum flow. In this report, the climate year is referenced by the year in which the 12-month period ends. The base-10 logarithm of the annual D-day low flows were fit to the widely used Pearson Type III theoretical three-parameter frequency distribution and plotted along with the "graphical fit" defined by the Weibull plotting-position formula

$$p = m/n + 1 \tag{1}$$

where

- p is the nonexceedance probability,
- m is the order number of the D-day annual low-flow value after ranking from smallest to the largest magnitude, and
- n is the number of climate years of record.

The graphical fit is considered the basic frequency curve for annual low flows; however, a purely statistical analysis may provide misleading results and final interpretation on the adequacy of the frequency curves is based on the professional judgment of the hydrologist (Riggs, 1972). The log-Pearson Type III frequency distribution fit is a function of the mean, standard deviation, and skew of the log-transformed annual D-day low-flow series. Other frequency distributions also have been found to perform adequately (Tasker, 1987; Vogel and Kroll, 1989).

Several of the LTCR stations in Kentucky have one or more annual D-day low-flow time-series values equal to zero, which cannot be log-transformed. (Occasionally, all the annual D-day low flows were zero; therefore, the statistic was zero for all recurrence intervals.) A conditional probability adjustment was made for the time series having some zeros on the basis of the mean, standard deviation, and skewness of the nonzero annual values (Interagency Advisory Committee on Water Data, 1982; Tasker, 1987).

The frequency analysis was done for 102 unregulated LTCR stations in Kentucky (those stations where annual lows were suitable for frequency analysis and were used in the regression analysis) with data through the 2006 climate year by use of the USGS program, SWSTAT (Lumb and others, 1990). Descriptions of these stations are in table 1 (at back of report), and the estimated low-flow frequencies are in table 2 (at back of report). Station locations used in the analyses are shown in plate 1.

Details concerning the review, analysis, and screening of the annual low-flow time-series data at the LTCR stations prior to frequency analysis, the treatment of trended annual low-flow data, and combining data at nearby LTCR stations are in the following sections of this report.

Assessment of the Annual Low-Flow Time-Series Data

The results of frequency analysis may be adversely affected if the annual low-flow time-series data are not random, independent, and stationary over time, as is assumed. A homogeneous, systematic annual low-flow time series that has unchanging statistical properties and is representative of the same population of annual low flows is ideal. Therefore, the annual 7- and 30-day low-flow data (and in addition 1- and 90-day lows) were closely examined for possible trends and any indications of regulation, local diversions of flow (discharges and withdrawals), and possible sustained changes in streamflows because of changes in the prevailing climate (Lins and Slack, 1999; McCabe and Wolock, 2002). The data-screening procedures required consideration of multiple lines of information to make a judgment as to the suitability of specific periods of the annual low-flow data for frequency analysis. The components of the data-screening procedures included (1) careful visual screening and comparison of time-series and other plots of the data, (2) analysis of available water withdrawal and discharge permit information, and (3) statistical trend tests.

Variations in meteorological and climate conditions were indicated in selected short-term periods of record (for less than about 4-5 decades) (see “Climate” section). For example, the LOWESS curves and trend tests indicated temperatures increased for the period 1895–1945, decreased 1946–75, and increased again 1976–2004 (appendix 1). However, a statistically significant year-round temperature trend with long-term persistence was not demonstrated. The warm-season (April–October) precipitation did have a positive trend from 1895–2004, which might tend to divert potential groundwater recharge water to direct runoff in surface waters, thus possibly diminishing base flows. However, only one of the tests (seasonal-Kendall of monthly data) indicated a positive trend (p-value 0.0835) for full-year precipitation for the period 1895–2004. Given these inconclusive results of trend tests for the precipitation data and the lack of a demonstrated long-term trend in the temperature, the periods of annual low-flow record having short-term fluctuations or trends were retained and provided data representative of the full range of climate conditions observed during the period of record. The data were not detrended to address such fluctuations in climate conditions absent a long-term, persistent trend in the annual low flows (Julie Kiang, U.S. Geological Survey, oral commun., 2008).

The potential effects of local diversions of flow on low-flow characteristics at each gaging station also were assessed by analysis of available statewide permit information for local diversions of flow. A geographic information system (GIS) to compile and account for withdrawals and discharges in basins upstream from the low-flow stations was developed. KDOW wastewater-discharge-permit data (Kentucky Pollution Discharge Elimination System (KPDES), Vickie Prather, written commun., 2007) for 1989–2004 and water-withdrawal data for 2002–05 (Downs and Caldwell, 2007) were compiled and analyzed. The KPDES data include 2,770 discharge sources (after excluding the “stormwater” waste code). An inventory of withdrawals and discharges was made for each low-flow station along with a statewide GIS. A full, rigorous statewide mathematical water balance of the cumulative water withdrawals and discharges data was not feasible because of data limitations, and the need to address these data needs was beyond the scope of this study. Instead, a simple accounting of the numbers of permitted withdrawals and discharges by gaging station was prepared (table 1) and considered in screening the annual low-flow times-series data for the possible effects of local diversions. About 50 percent of LTCR and LFPR stations had at least one local diversion upstream according to the GIS inventory developed from the permit data.

The annual 7-day low-flow time series was examined for various periods for each station record by use of two trend-screening tests, one of which compensated for serial correlation of the data, as described in appendix 2. These two trend tests were used as data-screening tools and were considered along with the other information on permitted withdrawals and discharges and indications in extensive data plots as to the suitability of the annual low-flow data for frequency analysis as described.

The annual low-flow times-series plots for all LTCR stations in Kentucky were examined and compared to each other and to plots of selected LTCR stations in the Hydro-Climate Data Network (HCDN) (Slack and Landwehr, 1992) and Hydrologic Benchmark Network (HBN) (Mast and Turk, 1999) in Kentucky and nearby States. Many, but not all, of the HCDN and HBN stations have a low-flow regime unaffected by regulation and (or) local diversions of flows. Time-series plots and LOWESS curves fit to annual low flows at Twin Creek near Germantown, Ohio, (03272000); Little Wabash River below Clay City, Illinois, (03379500,); French Broad River at Ashville, North Carolina, (03451500,); Clinch River above Tazewell, Tennessee, (03528000); Tellico River at Tellico Plains, Tennessee, (03518500); Greenbrier River at Alderson, West Virginia, (03183500); Nolichucky River at Embreeville, Tennessee, (03465500); Powell River near Jonesville, Virginia, (03531500) in (or subbasins of) the HCDN, and Holiday Creek near Andersonville, Virginia, (02038850); Upper Twin Creek at McGaw, Ohio, (03237280); Cataloochee Creek near Cataloochee, North Carolina, (03460000); Little River above Townsend, Tennessee, (03497300); North Sylamore Creek near Fifty Six, Arkansas, (07060710) in (or subbasins of) the HBN, among other stations, were reviewed (appendix 3).

Unusually large annual low flows were observed at several gaging stations in Kentucky in selected years, including the 1916, 1929, 1943, 1951, 1959, 1961, 1972, 1975, 1980, 1986, 1990, and 1997 climate years. A comparison of the annual low flows among nearby gaging stations confirmed the magnitude of the unusually large low flows, and these flows were attributed to unusually wet conditions in certain parts of the State at that time. These occasional, unusually large annual low flows were considered part of the variations in regional meteorological conditions, and all such data were retained in the frequency analysis.

The annual low-flow time-series plots and LOWESS curves for most of the HCDN and HBN stations with unregulated, unmodified drainage basins in Kentucky and surrounding States showed common patterns of increasing and decreasing annual low flows. These flow patterns include the apparently climate-related decrease (or ‘dip’) in low flows for the 1920–1950s period, which was concurrent with a period of increasing temperature and generally steady to declining precipitation; a step-trend increase—a concave-downward ‘bump’ in low flow during the wet, cool 1970s; and generally a negative trend in low flows since then (fig. 5). Only a few stations had LOWESS curves of the low-flow time-series data that remained almost constant during the 1980–2006 period. This pattern of decreasing then increasing and then again decreasing annual low flows during the 1920–2006 period, a sinusoidal-wave form, was deemed the characteristic shape (an “s-curve”) representative of changes in the annual low-flow time series that resulted only from the changes in meteorological and climate conditions in Kentucky during this period. This characteristic s-curve shape of the annual low flows was judged representative of the regional ‘climate signal,’ and indicative of stationary, homogeneous, streamflow in basins having no substantial anthropogenic basin modifications (regulation or local diversions). Even several highly trended annual low-flow time series LOWESS curves showed the same s-curve, climate-signal pattern superimposed in the overall trend.

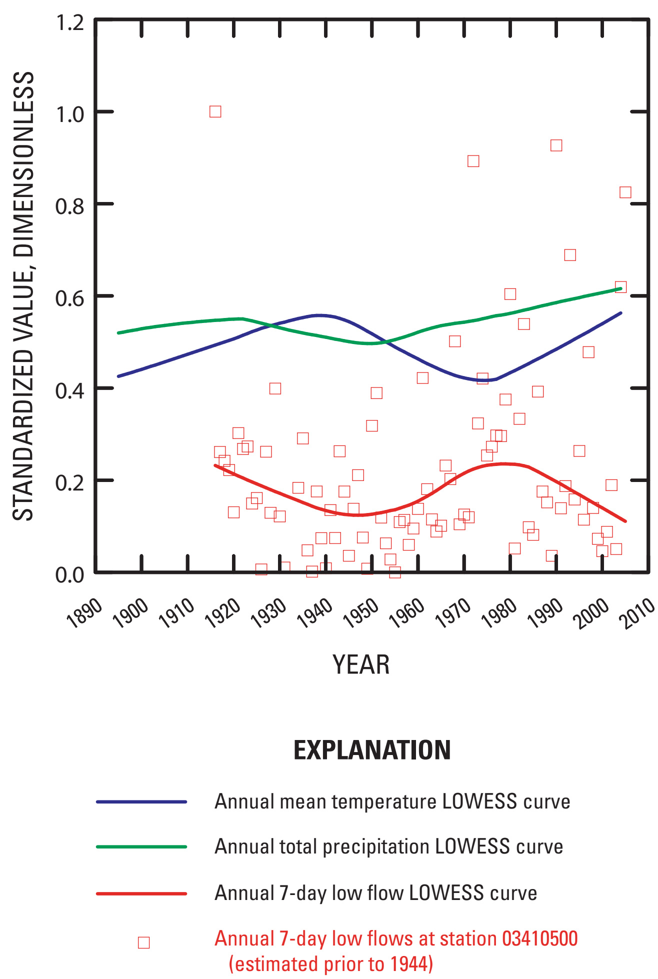


Figure 5. LOWESS curves fit to the standardized Kentucky annual mean temperature, total precipitation, and 7-day low flows at South Fork Cumberland River near Stearns, Kentucky (station number 03410500).

The curves for station South Fork Cumberland River near Stearns, Kentucky, (number 03410500, table 1, fig. 5) had the characteristic s-curve pattern in the annual low flows that was considered representative of homogeneous, unmodified basins only affected by meteorological and climatic patterns (the climate signal) during the entire period of record. The station near Stearns, with a sparsely populated drainage area of 954 mi^2 in mountainous northeastern Tennessee and southeastern Kentucky and about 94 percent forested, appeared largely unaffected by the other potential anthropogenic basin modifications such as land and water-use changes (4.4 percent pasture and other grasses, 0.6 percent residential and commercial, 0.1 percent quarries and strip mines, and 0.1 percent open water) (Tennessee Department of Environment and Conservation, 2007) that could potentially alter the low-flow regime. This station was selected as a reference station for comparison to the annual low-flow data at all LTCR stations in Kentucky.

Double-mass curves (Searcy and others, 1960; fig. 6) were developed for comparison of cumulative annual 1-, 7-, 30-, and 90-day low flows at each LTCR station in Kentucky and at the reference station at Stearns, Ky., station number 03410500. A uniform, constant slope in a double-mass curve indicates no change in the relation between the paired time series. A change or ‘break’ in the slope of the double-mass curve indicates that the relation between the time series has changed for some reason. The most common cause for a change of slope of double-mass curves of the annual D-day low flows is a basin modification such as regulation or local diversions—water withdrawals and discharges—that have changed the low-flow regime in one (or both) of the basins.

The homogeneous periods of annual low-flow record (table 1), generally in the early part of record before basin modifications, were identified primarily from the uniform, linear periods of record of constant slope on the double-mass curves—by a visual examination of the annual low-flow time-series plot with the LOWESS curve and the double-mass curve paired with the reference station at Stearns, Ky.—while also considering the inventory of permitted local diversions upstream from each station and results of the trend-screening tests (appendix 2).

Use and interpretation of the double-mass curves are not without limitations. Some deviations or breaks in double-mass curves were observed when comparing the reference station to other LTCR stations in Kentucky having small basins (less than 100 mi^2) where localized meteorological and climate conditions likely contributed to the difference, because other nearby stations, when available, generally had a pattern of annual low flows similar to that observed for the small drainage basin.

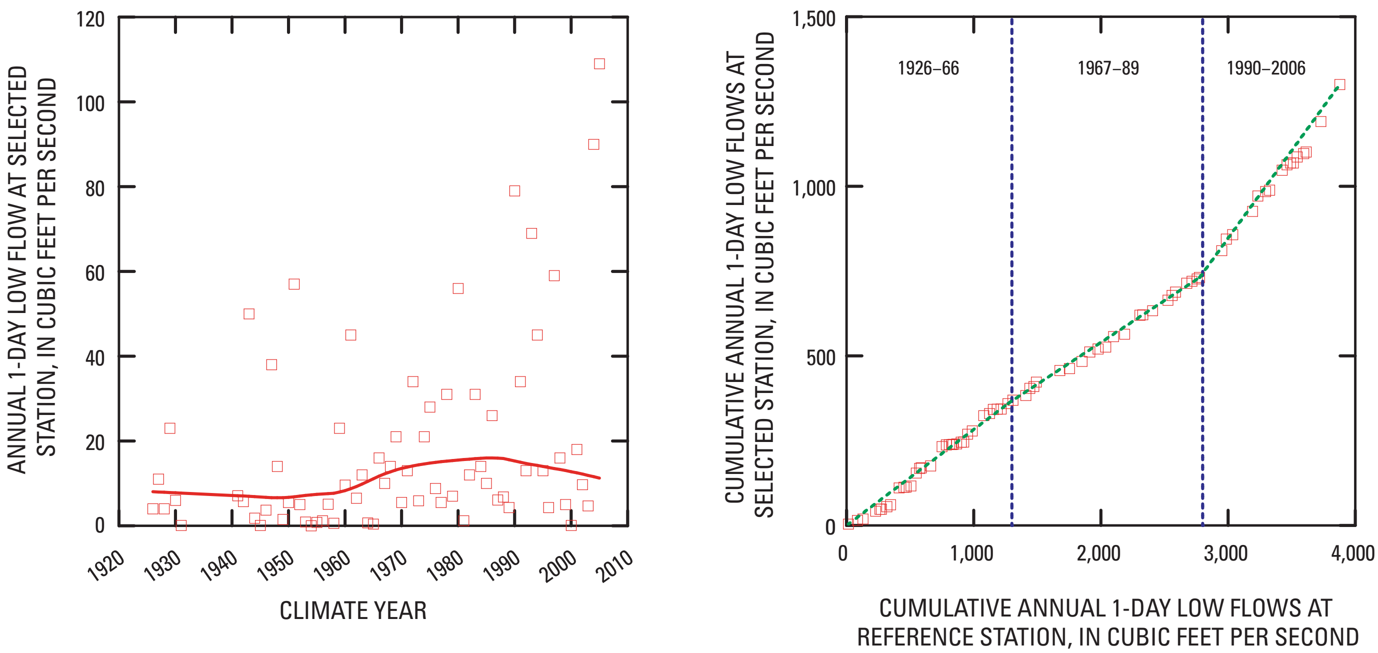


Figure 6. Annual mean 1-day low flows, LOWESS curve fit to low flows at station South Fork Kentucky River at Booneville, Kentucky (03281500), and double-mass curve comparing cumulative annual 1-day mean low flows at the selected station and the reference station South Fork Cumberland River near Stearns, Kentucky (03410500), showing three periods of homogeneous low flows during 1926–60, 1967–89, and 1990–2006.

Similarly, but at a larger regional scale, some breaks in slope around 1960 (and occasionally around 1970 for stations to the south of Kentucky), possibly related to a shift in the regional climate, was noted in many but not all double-mass curves created for the HCDN and HBN stations that used the selected reference station at Stearns, Ky. Double-mass curves of annual low flows at selected HCDN and HBN stations are described further in appendix 3. The double-mass curves of annual low flows at the HCDN and HBN stations listed previously with homogeneous records and unmodified basins when paired with the annual low flows at the reference station at Stearns, Ky., generally had a uniform linear pattern, which was indicative of little, if any, change in the relation of the concurrent annual low flows. Generally a uniform slope was evident before and after the break when the change in slope occurred around 1960. These changes in slope of the double-mass curves were judged a regional phenomenon, possibly climate-related, that caused little if any effect on the definitions of the homogeneous periods of low-flow record suitable for frequency analysis (table 1 and appendix 3).

The local diversion records also had limitations in completeness and accuracy in some cases. For example, agricultural water withdrawals in Kentucky are commonly needed in dry periods and were not subject to withdrawal-permit requirements. Therefore, some low-flow data possibly affected by local diversions of flow may be included in periods identified as having homogeneous, stationary, unregulated-flow conditions; however, such effects were likely minor during these periods identified as homogeneous.

Selected stations with pronounced trends in annual low flows likely caused by local diversions of flow and (or) basin modifications were identified also (table 1 and appendix 2). An approach for detrending such annual low-flow time series is presented in appendix 4. However, no low-flow frequency statistics derived from detrended annual low-flow series were used in the final regressions because of the uncertain error characteristics for these stations with trended annual low flows. Further investigation is warranted concerning (1) estimation low-flow frequency statistics for trended annual low flows by use of a detrending procedure, such as described in appendix 4, and (2) identification of homogeneous, post-basin-modification or regulated periods of record suitable for frequency analysis by use of double-mass curves.

Combining Low-Flow Streamflow-Gaging-Station Records

The daily mean discharge records at two pairs of LTCR stations located near each other on the same stream were combined to provide extended periods of record. The simple drainage-area-ratio method was used to estimate discharge at one of the paired stations because the drainage areas of these two pairs of stations differed by about 5 percent. The estimated and combined records were treated as single discharge records representative of long-term flows at one of the paired adjacent gages. Records at stations Kinniconick Creek near Tannery, Kentucky, (03237250) and Kinniconick Creek below Trace Creek at Tannery, Kentucky, (03237255), (tables 1 and 2) were combined by adjusting the discharge record for the period October 1, 1991, until December 7, 2000, at upstream station 03237250 by the ratio of the drainage areas at the two stations (1.065), which provided a combined record spanning water years (the 12-month period ending September 30 of each year) 1992–2006 (climate years 1993–2006) for station 03237255. Records at station Cumberland River at Pine Street Bridge at Pineville, Kentucky, (03402900) and Cumberland River near Pineville, Kentucky (03403000) were combined by multiplying the discharge record for the period October 1, 1991–September 30, 2005, at upstream station 03402900 by the ratio of the drainage areas at the two stations (1.051), which provided a combined record spanning water years 1939–2005 (climate years 1940–2005) for station 03403000.

Low-Flow Partial-Record Streamflow-Gaging Stations

Estimates of low-flow frequencies at LFPR stations can be made by use of either graphical or mathematical correlation methods. Estimates in this report were made by use of the mathematical correlation method of Stedinger and Thomas (1985). Estimates for the LFPR stations included in the weighted-least squares (WLS) regressions are shown in table 2.

Methods for Ungaged Stream Sites

The collection data for all streams where low-flow-frequency estimates may be needed is not feasible. Therefore, low-flow regionalization methods to transfer information from gaged to ungaged sites have been developed as described in following sections.

Regional-Regression Method

Regionalization of the low-flow statistics was accomplished by development of statistical regression models of two types—logistic regression and multiple-linear regression. These regressions relate low-flow characteristics (dependent or response variable) to selected basin characteristics (independent or explanatory variables), which are shown in table 3 (at back of report). Many streams in Kentucky have an annual minimum low flow of zero. The annual probabilities of the 7- and 30-day low flows being equal to zero were regionalized by use of logistic regression. The nonzero values of the low-flow statistics ($30Q_2$, $30Q_5$, $7Q_2$, $7Q_{10}$, and $7Q_{20}$) were regionalized by use of multiple linear regression, including ordinary-least-squares (OLS) and WLS regressions. Application of these regression models is a sequential process that begins with estimation of the probability of the selected low-flow statistic being equal to zero by use of the logistic-regression equations. Nonzero low-flow statistics are estimated by use of the final WLS-regression equations. Development and application of these regression equations is described in the following sections of this report.

Basin Characteristics

Various drainage-basin characteristics were tested for applicability in the regionalization process. Selection of basin characteristics for inclusion in exploratory scatterplots, linear-correlation analysis, the logistic-regression analysis, and the subsequent multiple-linear-regression analysis was based on (1) the possible hydrologic importance of the characteristic in relation to the low-flow frequencies, (2) the ability to measure the characteristics, and (3) results of previous regionalization studies of the same and other similar streamflow statistics (Beaber, 1970; Thomas and Benson, 1970; Wetzel and Bettandorff, 1986; Choquette, 1988; Ruhl and Martin, 1991; Martin and Ruhl, 1993; and Martin, 2002).

All low-flow frequencies (dependent variable) and the basin characteristics (independent or explanatory variables) were log-10 transformed to a linear relation. Basin characteristics expressed as a percentage had a one added to allow the log transform.

All map-based basin characteristics (table 3) were measured from digital coverages by use of ARC/INFO, ArcGIS, and ArcHydro Tools available in ArcGIS version 9.0 . The name, units, method of measurement, and source data for the basin characteristics tested in the regression analyses are in table 3. Values of the basin characteristics used to develop the final regional regression equations, the total drainage area and mapped streamflow-variability index, are listed in table 2.

The streamflow-variability index (V) (Lane and Lei, 1950) at a streamflow-gaging station ("station" value) is computed as the standard deviation of the base-10 logarithms of the 19 flow values at 5-percent class intervals from 5 to 95 percent on the flow-duration (cumulative-frequency) curve (Searcy, 1959; SAS Institute, Inc., 2004) of daily mean streamflow for the identified homogeneous periods of record (table 2). The V values used in this study were updated from the values used in the previous study (Ruhl and Martin, 1991; Martin and Ruhl, 1993) on the basis of (1) the defined homogeneous periods of flow and (2) computation by use of the 19 designated 5-percentile-point increments selected from the flow-duration curve defined by a continuous ranking of the daily mean streamflow values for the complete water years of data in the homogeneous period of record. Initial values of V in this study were computed by excluding the zero-flow points (which cannot be log-transformed) on the low-flow end of the flow-duration curves. (For example, the 95-percent duration flow, at which 95 percent of all daily mean streamflow is greater than or equal to the indicated flow, is at the low-flow end of the flow-duration curve.) However, these initial V values differed substantially from the values computed previously when comparing the same station and period of record (Ruhl and Martin, 1991). When, instead of excluding the zero-flow points, a value of 0.005 was substituted for the zeros allowing all 19 5-percentile points to be included, results closely compared with previously computed values. This substitution captures the full range of the flow-duration curve, which was missed when the zero points on the curve were excluded. The substitution of 0.005 ft^3/s for zeros approximates the shape of the flow-duration curve as developed in the algorithm used in the previous Kentucky low-flow study (Searcy, 1959; Dempster, 1990), which defined 20 to 30 class intervals along the flow-duration curve and generated a series of small, nonzero flows at the low end of the flow-duration curve.

A characteristic related to V is the flow-duration ratio, which is computed as the ratio of selected values on the flow-duration curve. The ratio of the 20-percent flow duration to the 90-percent flow duration (R2090) was computed for comparison to the V.

The V and R2090 are measures of the slope of the flow-duration curve, and these measurements are indicators of basin capacity to sustain base flow in a stream. Smaller values of V and R2090 indicate a flatter slope of the flow-duration curve, which represents sustained base flows, while the larger values of V and R2090 indicate a steeper slope of the flow-duration curve, which may go to zero at the low end. The V was mapped in previous low-flow studies in Kentucky (Ruhl and Martin, 1991; Martin and Ruhl, 1993) by delineating areas of similar station value of V and similar geologic features. The "map" values of V for stations in Kentucky were computed as an area-weighted mean of the mapped V for use in the regression analysis. For those stations with drainage basins that extend outside Kentucky, the station values of streamflow-variability index were used in the previous study.

Reviews of mapped residuals from initial regressions based on the mapped values of V in the previous studies (Ruhl and Martin, 1991; Martin and Ruhl, 1993) and the updated low-flow frequencies indicated geographic patterns or bias could be addressed by modification of the map by using R2090 instead of V and (or) by defining subregions where changes in the geologic setting were indicated. Initial regressions that used the new and updated station values of V and R2090 showed that these were significant explanatory variables, with the station R2090 having slightly lower errors than the station V. Therefore, new maps of V and R2090 were developed, and the possibility of creating separate low-flow subregions was investigated.

Mapping of areas with equal values of V and R2090 was based on information from four sources: (1) LTCR gaging-station flow data (collected for 10 or more years), (2) short-term gaging-station flow data (collected for less than 10 years), (3) LFPR station data, and (4) lithologic characteristics of surficial geology (U.S. Geological Survey, 2005). All these data helped to provide areal information on low-flow characteristics; therefore, these data were plotted on a map covering Kentucky and parts of adjoining States, and these data were then used collectively to define boundary lines for V and R2090.

New maps of V and R2090 were developed concurrently by use of similar procedures. The main source for mapping areas of equal V (and R2090) were the station values calculated from the LTCR station flow data. The calculated station values were plotted at each gaging station along with the drainage area boundary associated with the gaging station to visualize the extent over which the values applied. The areas of equal V were usually delineated along drainage basin boundaries where V values differed by 0.05 units or more. Although many unique values of V were calculated for LTCR stations, mapped values were reduced to 15 most common values and rounded to the nearest 0.05 increment (0.45, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 1.05, 1.15, 1.20, 1.25, 1.30, 1.35). The other three sources of information were used to confirm or extend boundary decisions based on LTCR station values of V. At least one V value based on flow data from a LTCR station was required to define an area of equal V; no area was defined by relying only on the other three sources of information for defining V. Often, multiple LTCR gaging stations were in large basins, and the V values differed by more than 0.05 units between the overall basin value and the values for subbasins. An example of this situation would be a large basin with one value for V and one or more subbasins in the large basin with a different value for V. A V value outside of the subbasin was required so that the combination of V for the subbasin and the estimated map V value for the area outside the subbasin approximates the V value for the entire basin. The combination was based on the proportion of area associated with each V value. For example, if a large basin had a V of 1.0 and half of the same basin (the subbasin) had a V value defined by another LTCR station to be 1.2, then the remaining half of the basin would be assigned 0.8 so that the composite value for the entire basin of 1.0 would be achieved.

Data from 93 short-term gaging stations (less than 10 years of continuous daily mean flow data) in and near Kentucky and 188 of the LFPR stations presented in Ruhl and Martin (1991, table 2) were used to obtain approximate V values to assist in mapping. The approximate V values for the short-term gaging stations were calculated from the flow data by using the regression equations (equation 3 from Ruhl and Martin, 1991, to estimate $7Q_{10}$), just as was done for the LTCR stations. The approximate V values derived from data at the LFPR stations were based on the values for $7Q_{10}$ low flow. A relation was established between $7Q_{10}$ low flow and the V for the same flow record by using the data from the LTCR stations. First, the $7Q_{10}$ low flows at LTCR gaging stations were divided by the drainage area to obtain a $7Q_{10}$ low-flow yield. Then, a power relation between V and low-flow yield was developed (fig. 7). The linear relation between log-transformed V and log-transformed $7Q_{10}$ low-flow yield had a coefficient of determination of 0.741, which indicates a reasonable relation between the two variables. The power form of the resulting equation to estimate V from $7Q_{10}(x)$ follows:

$$V = 0.405x^{-0.08} \qquad (2)$$

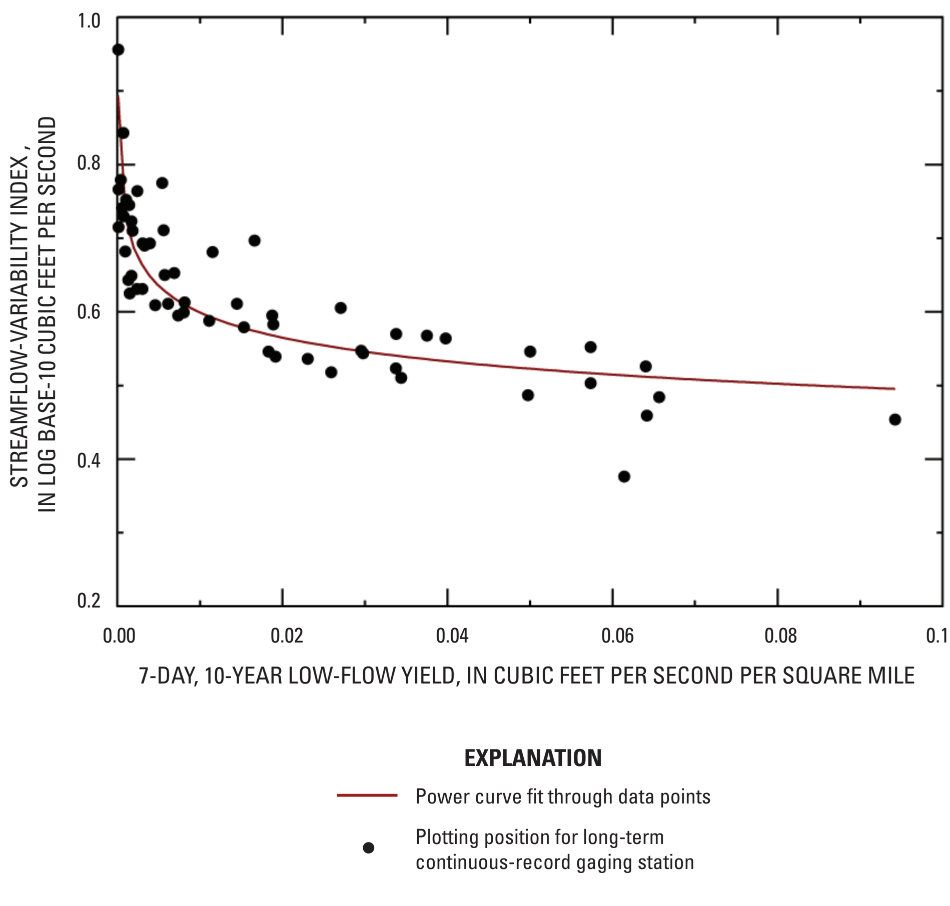


Figure 7. Relation between 7-day, 10-year low-flow yield and streamflow-variability index.

Equation 2 was then used to estimate V values at LFPR stations by using the $7Q_{10}$ low flow data for the LFPR stations. The $7Q_{10}$ low flows at LFPR stations were divided by the drainage areas in square miles to obtain low-flow yields. Then V values at LFPR stations were calculated by inputting the yields for the LFPR station data into equation 2 and solving for V. Finally, the V values from all three sources were plotted on a map of Kentucky along with the surficial geology to guide in the mapping of areas of equal V.

Boundary lines shown on the map for V (plate 2) are sometimes related to boundary lines for lithologic changes in surficial geology (fig. 3), and sometimes are not related. The Mississippian limestone in the western half of Kentucky does appear to have consistent effects on the well-sustained low flows because the V values in those areas were consistently near a value of 0.55. As a result of the consistency, a polygon was defined around almost the entire area of limestone and given the V value of 0.55. The LTCR station data often indicated a change in V values even though the lithologic characteristics of surface geology did not change. A specific lithology does not necessarily result in a consistent effect on groundwater discharge and low flow because other factors, such as basin slope or the degree of rock fracturing or modification, also can influence low-flow characteristics. Regardless of fine-scale changes in surficial geology or V values for small basins, areas smaller than 50 mi^2 were usually not defined because of the lack of gaging stations with drainage areas of such size. Such detailed mapping (polygons less than 50 mi^2) would infer a greater accuracy to the map than justified by the coverage of gaging station data. Because the map of V values had additional sources of information to define V, such as low-flow yields from LFPR stations, the current (2010) map of V has been updated in several areas from the map presented in Martin and Ruhl (1993, plate 1). The updated V at ungaged locations can be obtained from a map of V for the entire State and parts of adjoining States that drain into Kentucky (plate 2).

Low-Flow Regions

Review of maps of the regression residuals (the observed minus the estimated low-flow statistic) indicated geographic patterns in the residuals centered in the Cumberland and the Mississippian Plateaus. Three low-flow regions (fig. 8) were created on the basis of the geographic patterns of the residuals and the geology. The need for area indicator variables in the regression equations for the lowest flow statistics ($7Q_{10}$ and $7Q_{20}$) may be related to groundwater discharge during the lowest flows. The amount and distribution of groundwater discharge is reflected in the upper end of the flow-duration curve. Characteristics of the curves were observed from flow-duration curves in appendix 2 of Ruhl and others (1995). The flow-duration curves were observed for several typical stations in the areas of positive, negative, and mixed residuals. The flow-duration curves flattened out in the area of positive residuals during lowest flows; whereas, the curves usually steepened in the area of negative residuals. The difference in the curves is likely the result of the differences in geology between the two areas (fig. 3). The area of positive residuals (fig. 8) is karsted limestone and the area of negative residuals is shale and sandstone. The flow-duration curves were fairly straight or at least did not indicate consistent breaks in slope during lowest flows in the area of mixed residuals. The V-flow variable measures the overall slope of the flow-duration curve and, based on that slope, is used to estimate all the low-flow statistics. If the slope of the flow-duration curve breaks from the average at the lowest flows, the V variable is not well-suited to express that break, and the regression equation will either underestimate (for curve flattening) or overestimate (for curve steepening). The region-indicator variable helps to compensate for breaks in the slope during lowest flows and makes little or no correction for the higher low-flow statistics ($30Q_2$ and $30Q_5$).

Logistic-Regression Analysis

Logistic-regression equations were developed to estimate the probability of the annual minimum 7- and 30-day mean low flows being equal to zero by use of data for 112 long-term, continuous-record streamflow-gaging stations in Kentucky (tables 1 and 2). Procedures and assumptions of logistic regression are described in detail elsewhere (Tasker, 1989; Ludwig and Tasker, 1993; SAS Institute, Inc., 1995; Allison, 1999; Hosmer and Lemeshow, 2000; Helsel and Hirsch, 2002; Hortness, 2006; Bent and Steeves, 2006). Trial explanatory (independent) variables in the logistic regressions included numerous physical and climatic characteristics of each gaged basin (table 3). The dependent variables were the empirical probabilities, or observed frequencies, of zero values for the 7- and 30-day annual low flows at each of the long-term stations, expressed as a decimal value ranging from zero and one. The observed frequencies of zero flows at a given station were computed as the number of climate years in which the 7- and 30-day low flows were zero, divided by the total number of climate years of record at the station (table 2). The final logistic-regression model is expressed in the following form:

$$PZERO_D = \frac{1}{1+e^{(-b_0 - b_1 \log_{10}(x_1) - b_2 \log_{10}(x_2) \ldots - b_n \log_{10}(x_n))}} \quad (3)$$

where

$PZERO_D$ is the probability of the annual *D*-day low flow being zero,

e is the exponential constant, approximately equal to 2.71828,

n is the number of basin-characteristic explanatory variables in the regression,

x_i is the value of the i^{th} basin characteristic, and

b_0, b_1, and b_n are the coefficients determined by maximizing the log-likelihood function.

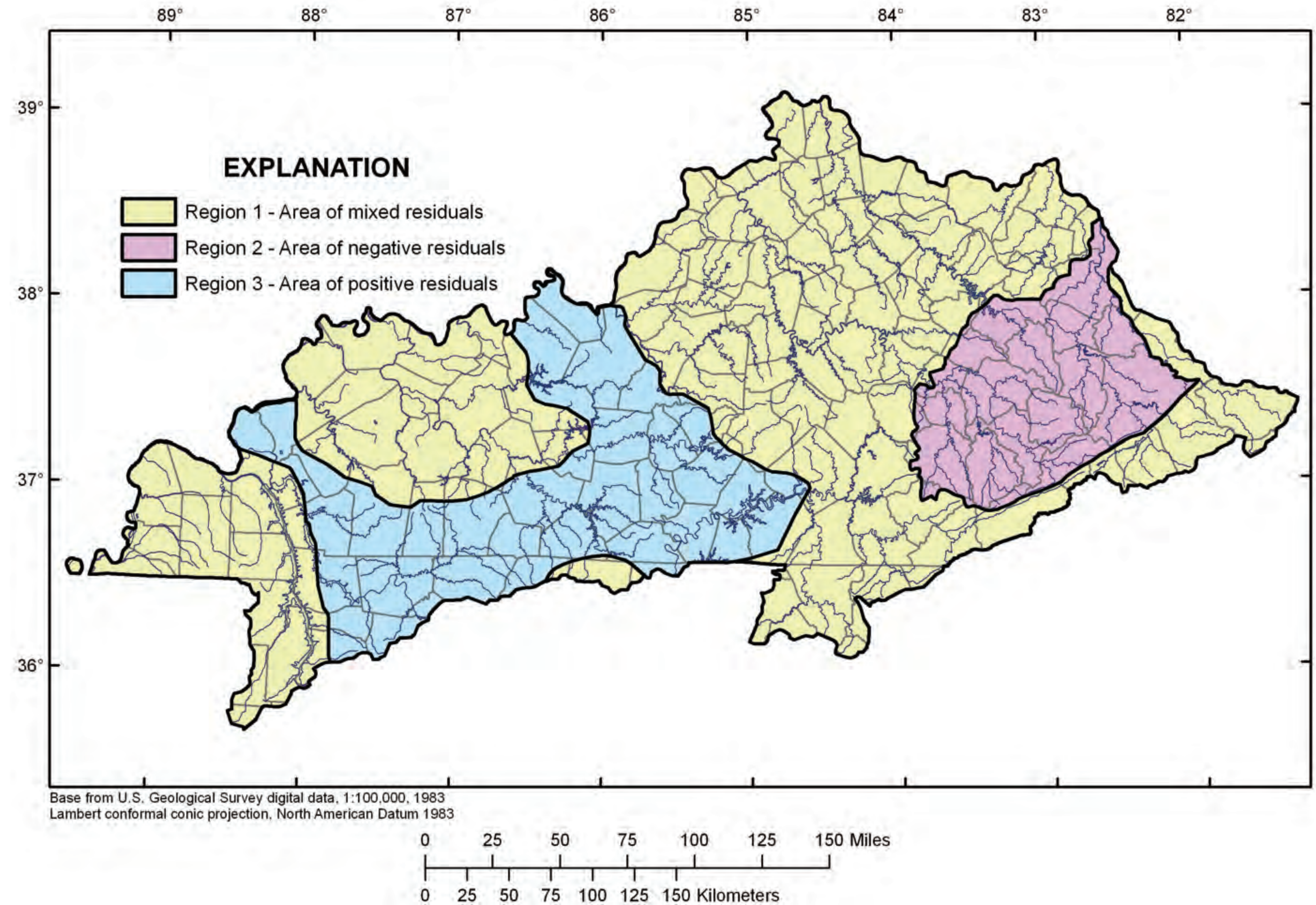


Figure 8*A*. Locations of the low-flow regions in Kentucky: Regions 1, 2, and 3.

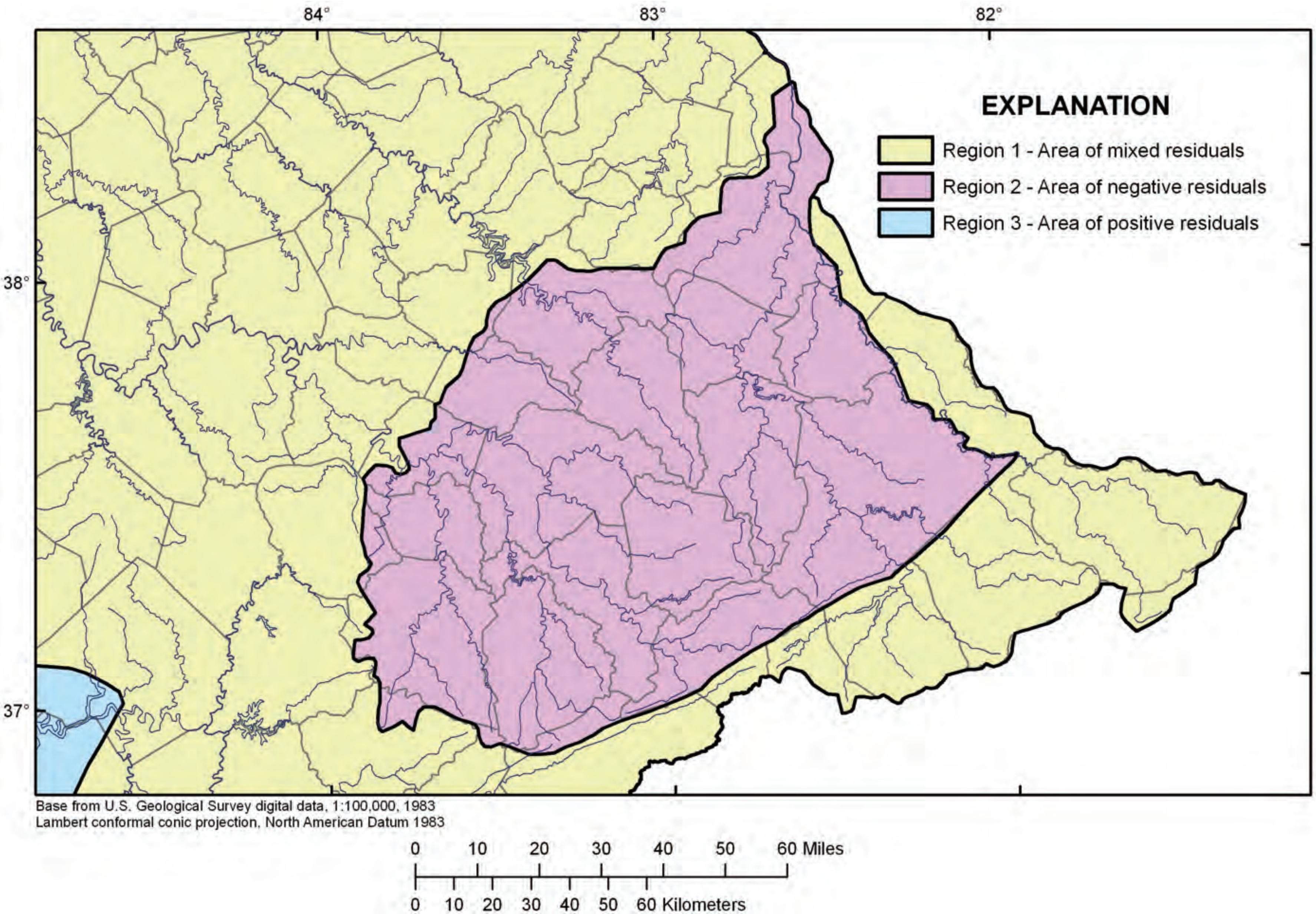


Figure 8*B*. Locations of the low-flow regions in Kentucky: Region 2 enlarged view (Cumberland Plateau vicinity).

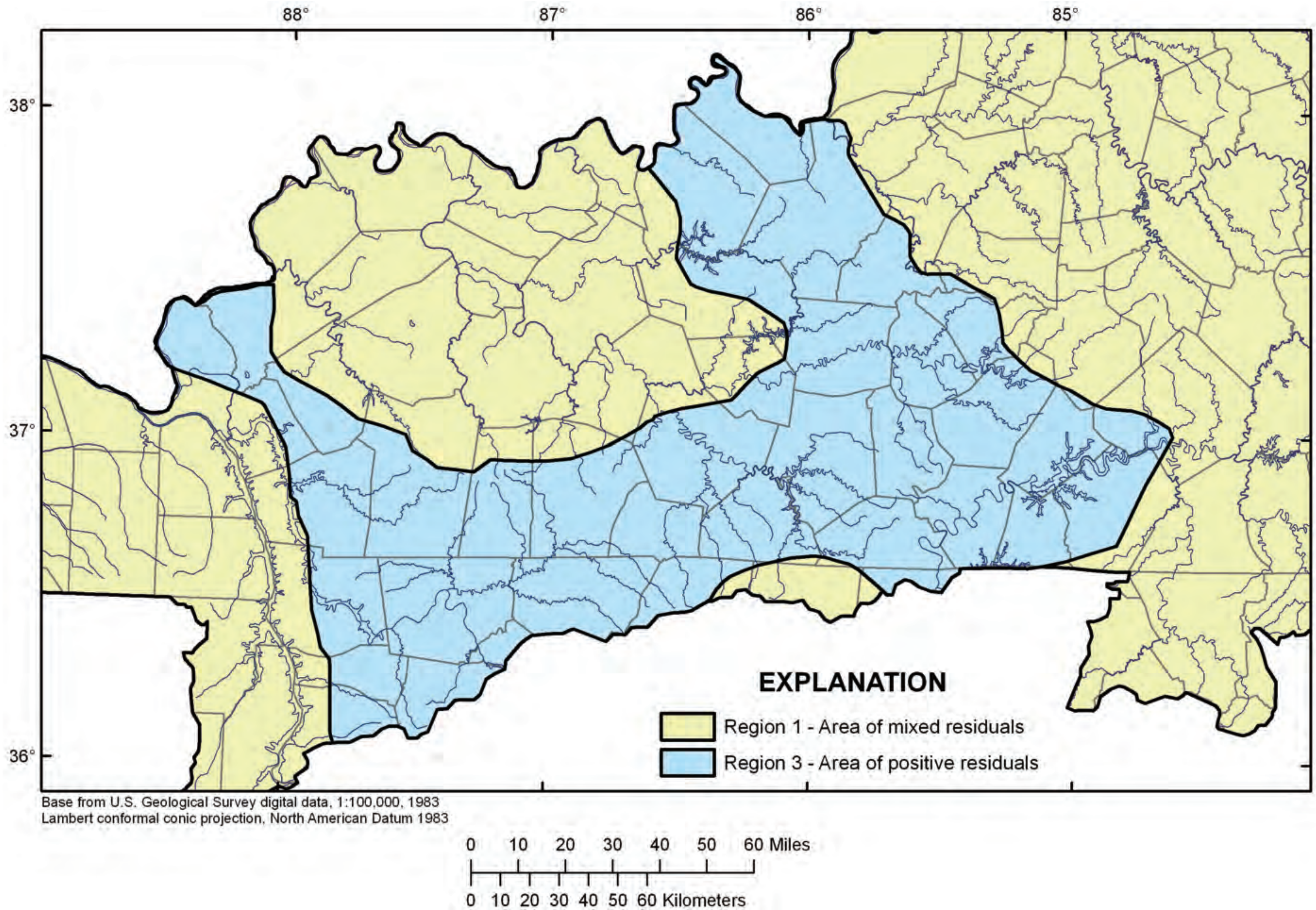


Figure 8*C*. Locations of the low-flow regions in Kentucky: Region 3 enlarged view (Mississippian Plateau vicinity).

The logistic-regression equations, applicable statewide, were developed by use of SAS statistical software (SAS Institute, Inc., 1995 and 2004). Weights were applied to each of the 112 gaging stations included in the regressions. The period of record at each gaging station, which is the total number of climate years, was used as the weight because the number of climate years is a measure of the reliability of the estimated low-flow characteristic, in this case, the annual probability of zero flow. The weights were centered, or standardized, by dividing each station period of record by the average period of record (22.8 years) for the 112 stations included in the logistic regression (table 2). The mean value of these standardized weights was, therefore, one (Stuckey, 2006).

Model selections were done by iterative step-forward, backward-elimination, stepwise, and score procedures to evaluate numerous alternative combinations of the explanatory variables. A significance level of 0.05 for the p-values of explanatory variables was used as the criteria for inclusion in these models. The final logistic-regression equations (table 4) included total drainage area and V, mapped streamflow-variability index (table 2, plate 2), as the explanatory variables.

Analysis of the estimates provided by the logistic-regression estimating equations indicated optimal performance in terms of the percentage of gaging stations correctly classified as zero or nonzero flow for each low-flow statistic ($30Q_2$, $30Q_5$, $7Q_2$, $7Q_{10}$, $7Q_{20}$) varied depending on the particular 'cutpoint' probability used. Classification tables (SAS Institute, Inc., 1995; Hosmer and Lemeshow, 2000) (appendix 5) were developed by determining the numbers of correct and incorrect classifications of events (zero flow) and nonevents (nonzero flow) by comparison of the estimated probabilities to the zero and nonzero status of each low-flow statistic at the various probability cutpoints. The optimal cutpoints are shown in bold numbers in the classification tables. The logistic-regression equations were adjusted to operate at the optimal cutpoints by multiplying the probabilities computed from the logistic regression equation by the ratio of the standard cutpoints to the optimal cutpoints. For example, the standard cutpoint for $7Q_2$ is 0.5 (inverse of the return period, 1/T or 1/2), at which 73.2 percent of stations were classified correctly. The optimal cutpoint is 0.985, at which 93.8 percent of the stations were classified correctly. To get optimal results at the standard cutpoint for $7Q_2$, a conversion factor (C, in table 4) of 0.508 (0.5 divided by 0.985) was applied to the final logistic-regression equation. The percentage of the station low-flow frequencies correctly classified as zero or nonzero by use of the logistic-regression equations ranged from 87.5 to 93.8 percent after the conversion factors were applied.

The logistic-regression equations are applied to determine if the statistic of interest is either zero or nonzero. The estimated probabilities of zero flows are compared to the standard probability cutpoints that equal the probability of the statistics of interest (inverse of the return period, 1/T). If the estimated probability of zero flow is greater than the nonexceedance probability of the low-flow statistic of interest, then the low-flow statistic is estimated to be zero. For example, taking the $7Q_{10}$ statistic, if the estimated probability of zero flow exceeds 0.1, then the $7Q_{10}$ is estimated to be zero. Alternatively, for the $7Q_{10}$ statistic, if the probability of zero flow is less than or equal to 0.1, then the $7Q_{10}$ should be estimated by using the multiple-linear-regression equations for estimating nonzero low-flow statistics described in the next section.

Table 4. Logistic-regression equations for estimating the annual probability of zero flow for selected low-flow frequencies for unregulated streams in Kentucky.

[*C*, coefficient to adjust to the optimal cutpoint probability; $PZERO_{30}$, annual probability the 30-day low flow equals zero; $PZERO_7$, annual probability the 7-day low flow equals zero; *e*, exponential constant, approximately equal to 2.71828; *A*, total drainage area in square miles; *V*, mapped streamflow-variability index (plate 2)]

Low-flow statistic	Annual-zero-flow probability equation	C	Percentage correctly classified
30Q2	$PZERO_{30} = \dfrac{C}{1+e^{(5.67+1.72\log_{10} A - 10.6V)}}$	0.505	98.2
30Q5		.242	93.8
7Q2	$PZERO_7 = \dfrac{C}{1+e^{(4.95+2.25\log_{10} A - 12.6V)}}$	0.508	93.8
7Q10		.182	87.5
7Q20		.111	89.3

Multiple-Linear-Regression Analysis

Multiple-linear-regression equations were developed by use of a total of 114 gaging stations, including 102 LTCR streamflow-gaging stations with at least 10 years of record not substantially affected by local diversions (table 2) and 12 LFPR stations. The regression analysis included exploratory use of OLS and WLS regressions to identify appropriate explanatory variables to include. WLS regression was used to compensate by weighting for differences in the length of record and the variance (time-sampling error) of annual low flows at the gaging stations included in the analysis.

Inspection of scatterplots 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. Only stations with nonzero low-flow statistics were included in the multiple linear regressions because the logarithmic transformation is not possible for stations with low-flow statistics equaling zero.

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

$$Log(DQ_T) = b_0 + b_1 logX_1 + b_2\, logX_2 + \ldots + b_n logX_n + \varepsilon \quad (4)$$

where

DQ_T is a low-flow statistic of D-days annual duration and T-years average return interval,

b_0 is a constant (y-intercept),

b_i (i=1 to n) is the regression coefficient for the i^{th} explanatory variable,

X_i (i=1 to n) is the i^{th} explanatory variable,

ε is a random error component equal to model plus time-sampling error, and

n is the total number of explanatory variables.

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

$$DQ_T = 10^{b0} X_1^{\ b1} X_2^{b2} \ldots X_n^{bn} \quad (5)$$

WLS regression is the most appropriate when stations in the network have differing periods of record, when the regression model has reduced r-square indicating that not a large proportion of variability is explained by the regression (when errors are elevated), and when the cross-correlation of station data is not strongly correlated to the distance separating the stations. Weights were estimated for each station included in the regression (Tasker, 1980). A regression model was developed for each of the low-flow statistics by using WLS regression. WLS regression solves for regression coefficients in the same manner as OLS regression, except that in WLS regression weights are assigned to each of the gages in the analysis depending on how accurate the estimates of hydrologic statistics are thought to be at each gage. Gages with long record length will generally produce estimates of low-flow statistics that have less uncertainty, or lower variance. The gages with longer record lengths are given greater weight in the WLS regression than stations with short record length that have estimates of the flow statistics with increased uncertainty.

Tasker (1980) developed a WLS regression scheme specifically for use with hydrologic frequency statistics such as $30Q_2$ or $7Q_{10}$. The weights are dependent on estimated model-error variance and average time-sampling-error variance for the station, and the weights are calculated as

$$W_i = \frac{1}{\sigma_\delta^2 + c_1\left(\dfrac{1}{POR_i}\right)} \quad (6)$$

where

σ_δ^2 is the model-error variance,

$$c_1 = \max\left[0, \bar{s}^2\left(1 + \frac{\bar{K}^2}{2}(1 + 0.75\bar{G}^2) + \bar{K}\,\bar{G}\right)\right] \quad (7)$$

POR_i is the number of years of record at gage i

$\bar{s}$ is average standard deviation of the log base-10 of annual low-flow time series at all gages, which is estimated by an independent ‘sigma regression,’ (Tasker and Stedinger, 1989),

$\bar{G}$ is average skew of the annual log base-10 low-flow time series at all gages, and

$\bar{K}$ is average K-factor of Log-Pearson Type III distribution fitted to the gages used in the regression.

The model-error variance is a measure of the variance inherent in the imperfect model resulting from the fact that not all of the variability in the observed data is explained in the model. The total-error variance also includes a component caused by time-sampling-error variance, which is a measure of the variance caused by imperfect estimates of the true, but unknown, population low-flow statistic at each gage. The model-error variance is estimated from an initial OLS regression as:

$$\sigma_\delta^2 = \max\left[0,\ \sigma_{OLS}^2 - c_1\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{POR_i}\right)\right] \quad (8)$$

where

σ_{OLS}^2 is the standard error of the estimate from the OLS regression fitting of the flow statistic to the basin characteristics, total drainage area and mapped streamflow-variability index (plate 1), and

n is the number of gages included in the regression.

The WLS regression included 12 selected LFPR stations among the 114 stations used (table 2). These stations also were weighted by use of the Tasker method. However, the period of record used was 1 year for each climate year during which low-flow measurements were made, as much as a maximum of 10 years to avoid overweighting the LFPR stations. Other factors in the weighting for the LFPR stations were as estimated in the Stedinger and Thomas (1985) correlation to the LTCR index stations.

These estimates of the sampling-error and model-error variance are a benefit of the WLS method developed by Tasker (1980). This method provides a way to partition total-error variance into model-error and sampling-error variance. The model-error variance includes only the variance caused by the imperfect model. About 90 percent of the total-error variance in the regional low-flow equations developed in this study was model-error variance.

The alternative regression models were generated by use of several model-selection methods including all-possible-regression, forward-selection, backward-elimination, and stepwise-regression procedures (SAS Institute, Inc., 2004,) by using the prospective explanatory variables (table 3). Various factors were considered in evaluating alternative regression models, including (1) the coefficient of determination, the proportion of the variation in the response variable explained by the regression equation; (2) the standard error of the estimate, a measure of model-fitting error; (3) the prediction sum of squares (PRESS) statistic, a measure of model-prediction error; (4) the statistical significance of each alternative explanatory variable; (5) potential multicollinearity as indicated by the correlation of explanatory variables and the value of the variance-inflation factor (Montgomery and Peck, 1982); (6) the effort and modeling benefit of determining the values of each additional explanatory variable; and (7) the hydrologic validity of the signs and magnitudes of the regression exponents.

The best WLS-regression models included total drainage area (A), the mapped streamflow-variability index (V), and, for the 7-day low-flow frequencies, the subregion-indicator variables, as explanatory variables (table 5, fig. 8). In the final regression models for all the 7-day low-flow-frequency statistics, the same three variables were retained, even though in the equation for the largest of the 7-day low-flow frequencies, $7Q_2$, the location variables were not significant at a p-value of 0.05. These three variables were retained to keep the same model form and avoid inconsistent estimates for the different frequencies (for example, having $7Q_{10}$ exceed $7Q_2$). The p-value for the $7Q_{10}$ low-flow estimating equation for region 3 was 0.06. The remaining explanatory variables in these regression models were significant at a p-value of less than 0.05.

The subregion-indicator variable was used in a combined regression that grouped stations from all three regions rather than developing a separate set of regression equations for each of the three regions. This grouping allowed pooling the information to provide one estimate of the common error variance and more residual degrees of freedom than would be possible otherwise. The addition of the region-indicator variables also reduced the V exponent somewhat in comparison to the value of the V exponent seen in the two-variable model, though V remains the most sensitive variable in the model. Note the region in which the stream site was located determined which regional estimating equation to use—upstream parts of the basin may drain from a different low-flow region.

Applying the Tasker weights did not change selection of the best two-variable models, which included A and V or flow-duration ratio, R2090. Applying the weights did affect selection of the third and fourth explanatory variables, none of which were used in the final equations. Flow-duration ratio worked satisfactorily as the second variable in combination with the karst-area coverage of percentage of basin not drained by sinkholes (Taylor and Nelson, 2008) as the third variable. Soil depth (U.S. Department of Agriculture–Natural Resources Conservation Service, 2007) and main-channel slope were other (third) explanatory variables that provided only small improvement in error (less than a 3-percentage-point decrease in error).

Limitations and Accuracy of the Estimating Equations

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

The regression equations were developed by use of basin characteristics in a certain range of values. Drainage areas (A) of stations used in the regression analysis ranged from 0.04 to 1,984 mi^2, and mapped streamflow-variability index values ranged from 0.45 to 1.35 (figs. 9 and 10, table 6). Applications of the regression equations for estimates in basins with combinations of drainage area and mapped streamflow-variability index outside these two-dimensional sample spaces, the explanatory-variable hull, are extrapolations. Therefore, these equations should not be applied in basins with characteristics beyond these sample spaces represented by the characteristics of basins used to develop the regression equations.

Table 5. Weighted-least-squares regression equations for estimating selected nonzero low-flow frequencies for unregulated streams statewide and in each low-flow region in Kentucky.

[$30Q_2$, 30-day, 2-year low flow; A, total drainage area; V, mapped streamflow-variability index (plate 2); $30Q_5$, 30-day, 5-year low flow; $7Q_2$, 7-day, 2-year low flow; $7Q_{10}$, 7-day, 10-year low flow; $7Q_{20}$, 7-day, 20-year low flow]

Equation	Standard error of estimate			Standard error of prediction		
	Average		Range	Average		Range
	$\log_{10}$	Percent	Percent	$\log_{10}$	Percent	Percent
Statewide						
$30Q_2 = 0.0141\,A^{0.885}\,V^{-3.91}$	0.367	102	+133 to -57.0	0.38	108	+140 to -58.4
$30Q_5 = 0.00302\,A^{0.835}\,V^{-6.25}$	.454	141	+184 to -64.8	.49	161	+210 to -67.8
Region 1						
$7Q_2 = 0.00490\,A^{0.847}\,V^{-5.54}$	0.452	140	+183 to -64.7	0.48	157	+205 to -67.2
$7Q_{10} = 0.00692\,A^{0.774}\,V^{-3.75}$	.499	166	+216 to -68.3	.56	208	+265 to -72.6
$7Q_{20} = 0.00759\,A^{0.732}\,V^{-3.40}$	.518	177	+230 to -69.3	.58	226	+284 to -73.4
Region 2						
$7Q_2 = 0.00383\,A^{0.847}\,V^{-5.54}$	0.452	140	+183 to -64.7	0.48	157	+205 to -67.2
$7Q_{10} = 0.00177\,A^{0.774}\,V^{-3.75}$	.499	166	+216 to -68.3	.56	208	+265 to -72.6
$7Q_{20} = 0.00136\,A^{0.732}\,V^{-3.40}$	.518	177	+230 to -69.3	.58	226	+284 to -73.4
Region 3						
$7Q_2 = 0.00556\,A^{0.847}\,V^{-5.54}$	0.452	140	+183 to -64.7	0.48	157	+205 to -67.2
$7Q_{10} = 0.0129\,A^{0.774}\,V^{-3.75}$	.499	166	+216 to -68.3	.56	208	+265 to -72.6
$7Q_{20} = 0.0201\,A^{0.732}\,V^{-3.40}$	.518	177	+230 to -69.3	.58	226	+284 to -73.4

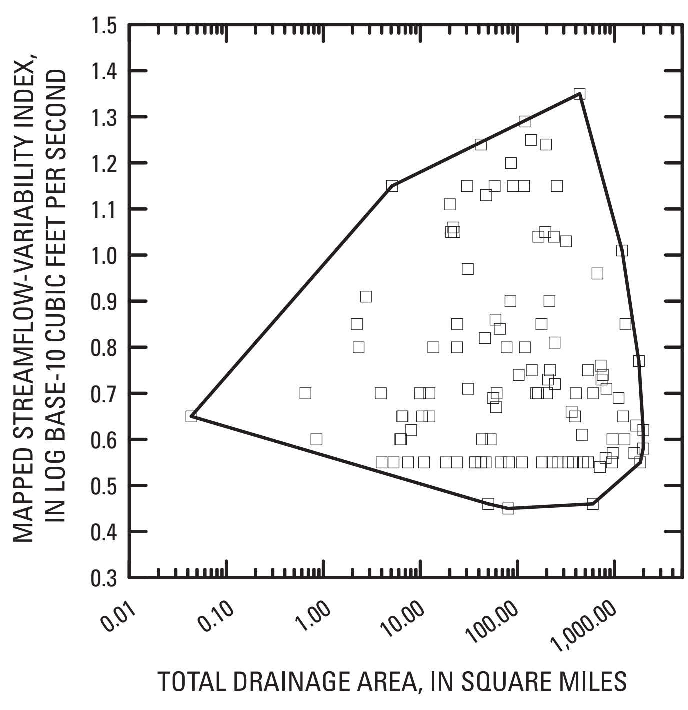


Figure 9. Total-drainage-area and mapped streamflow-variability-index sample space for the logistic-regression equations for estimating the probability of zero flow for unregulated streams in Kentucky.

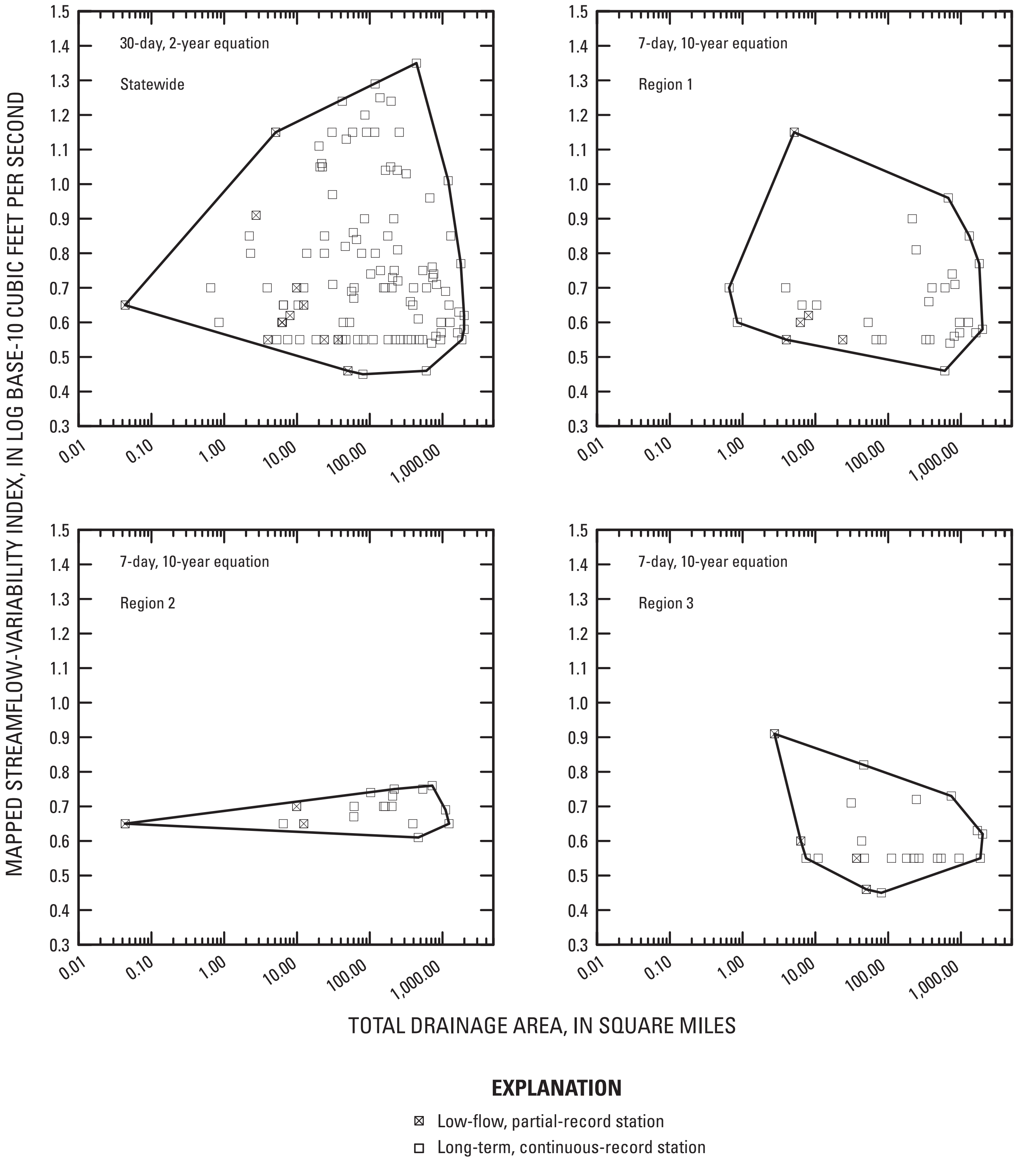


Figure 10. Total-drainage-area and mapped streamflow-variability-index sample spaces for 30-day, 2-year and 7-day, 10-year low-flow-frequency estimating equations for unregulated streams in Kentucky.

Table 6. Basin-characteristic ranges for the logistic-regression equations for estimating the annual probability of zero flow for selected low-flow frequencies and the weighted-least-squares regression equations for estimating selected nonzero low-flow frequencies for unregulated streams statewide and in each low-flow region in Kentucky.

[*A*, total drainage area; *V*, mapped streamflow-variability index (plate 2); $PZERO_7$, annual probability the 7-day low flow equals zero; $PZERO_{30}$, annual probability the 30-day low flow equals zero; $30Q_2$, 30-day, 2-year low flow; $30Q_5$, 30-day, 5-year low flow; $7Q_2$, 7-day, 2-year low flow; $7Q_{10}$, 7-day, 10-year low flow; $7Q_{20}$, 7-day, 20-year low flow]

Low-flow charactertistic	Number of stations	A (square miles)		V (base-10 logarithms of cubic feet per second)	
		Minimum	Maximum	Minimum	Maximum
Statewide					
$PZERO_7$, $PZERO_{30}$	112	0.04	1,984	0.45	1.35
$30Q_2$	114	.04	1,984	.45	1.35
$30Q_5$	107	.04	1,984	.45	1.35
Region 1					
$7Q_2$	52	0.65	1,976	0.46	1.35
$7Q_{10}$	33	.65	1,976	.46	1.15
$7Q_{20}$	32	.65	1,976	.46	1.15
Region 2					
$7Q_2$	25	0.04	1,230	0.61	0.85
$7Q_{10}$	18	.04	1,230	.61	.76
$7Q_{20}$	17	.04	1,230	.61	.76
Region 3					
$7Q_2$	26	2.74	1,984	0.45	0.91
$7Q_{10}$	23	2.74	1,984	.45	.91
$7Q_{20}$	21	2.74	1,984	.45	.91

Application of the equations near or outside the boundaries of the regression sample spaces may produce unexpected results, such as estimates of $7Q_{10}$ exceeding $7Q_2$ (though this result is uncommon and generally the differences are expected to be minimal) or estimates of $7Q_{20}$ exceeding $7Q_{10}$, which may be more common. Inconsistent results also may be caused by differing number and characteristics of basins used to develop the multiple-linear WLS regression for the different low-flow frequencies considered (table 5). Only the gaging stations with nonzero low-flow statistics can be included in these WLS regressions—so, for example, a station with a nonzero $7Q_2$ and a zero $7Q_{10}$ was included in the $7Q_2$ regression but was not included in the $7Q_{10}$ regression. Consequently, the applicable sample spaces differ somewhat for each low-flow frequency. The more extreme low-flow frequencies have progressively fewer gaging stations included in these regressions than the less extreme low-flow frequencies. Caution is warranted in applying the equations for basins with characteristics approaching the maximum and minimum limits (table 6) and the periphery of the sample spaces (fig. 10). If conflicting results may be obtained (such as $7Q_{20}$ exceeding $7Q_{10}$ and $7Q_{10}$ exceeding $7Q_2$), the results for the larger recurrence interval can be designated as less than (<) the results for the smaller recurrence interval.

The average standard error of prediction of the final multiple-linear regression model—a measure of the accuracy of the regression estimates compared to observed data for stations excluded from the regression—ranged from 108 to 226 percent (table 5). The $30Q_2$ regression equations have the smallest standard errors of prediction, and the $7Q_{20}$ regression equations have the largest standard errors of prediction. Average standard error of prediction was estimated as the square root of the PRESS divided by the error degrees of freedom (Montgomery and Peck, 1982; SAS Institute, Inc., 1985; and Choquette, 1988). The procedure used for computing PRESS is considered a form of data splitting and can be applied as a model-validation tool. The accuracy of the three-variable model predictions for ungaged sites similar to those predictions used in the regression could be expected to compare favorably to the standard error of prediction.

A scatterplot of the $7Q_{10}$ computed from the streamflow-gaging-station data and the values estimated from the regression equations (fig. 11) shows reduced residuals and a slight tendency to underestimate the $7Q_{10}$ above 20 ft^3/s.

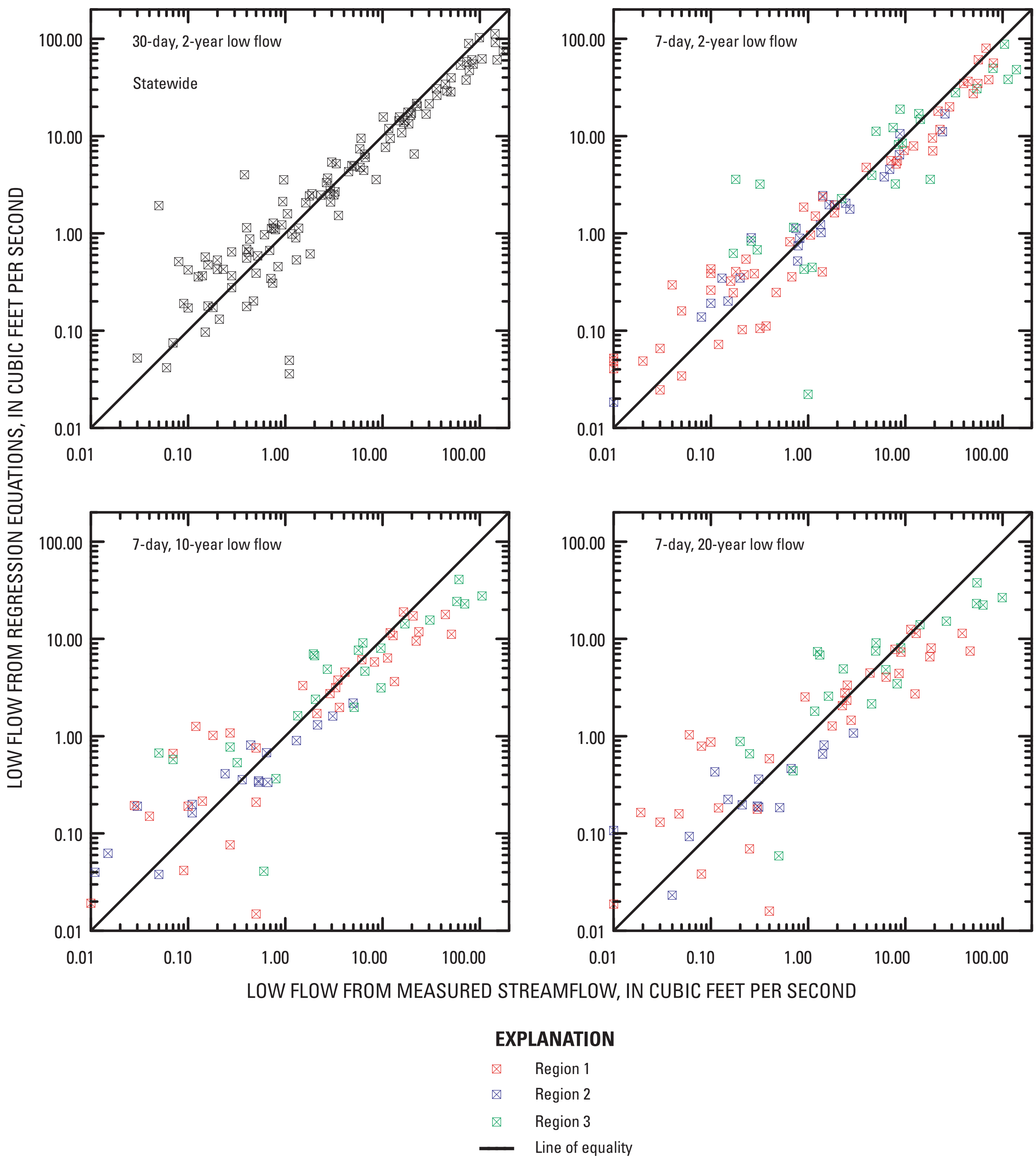
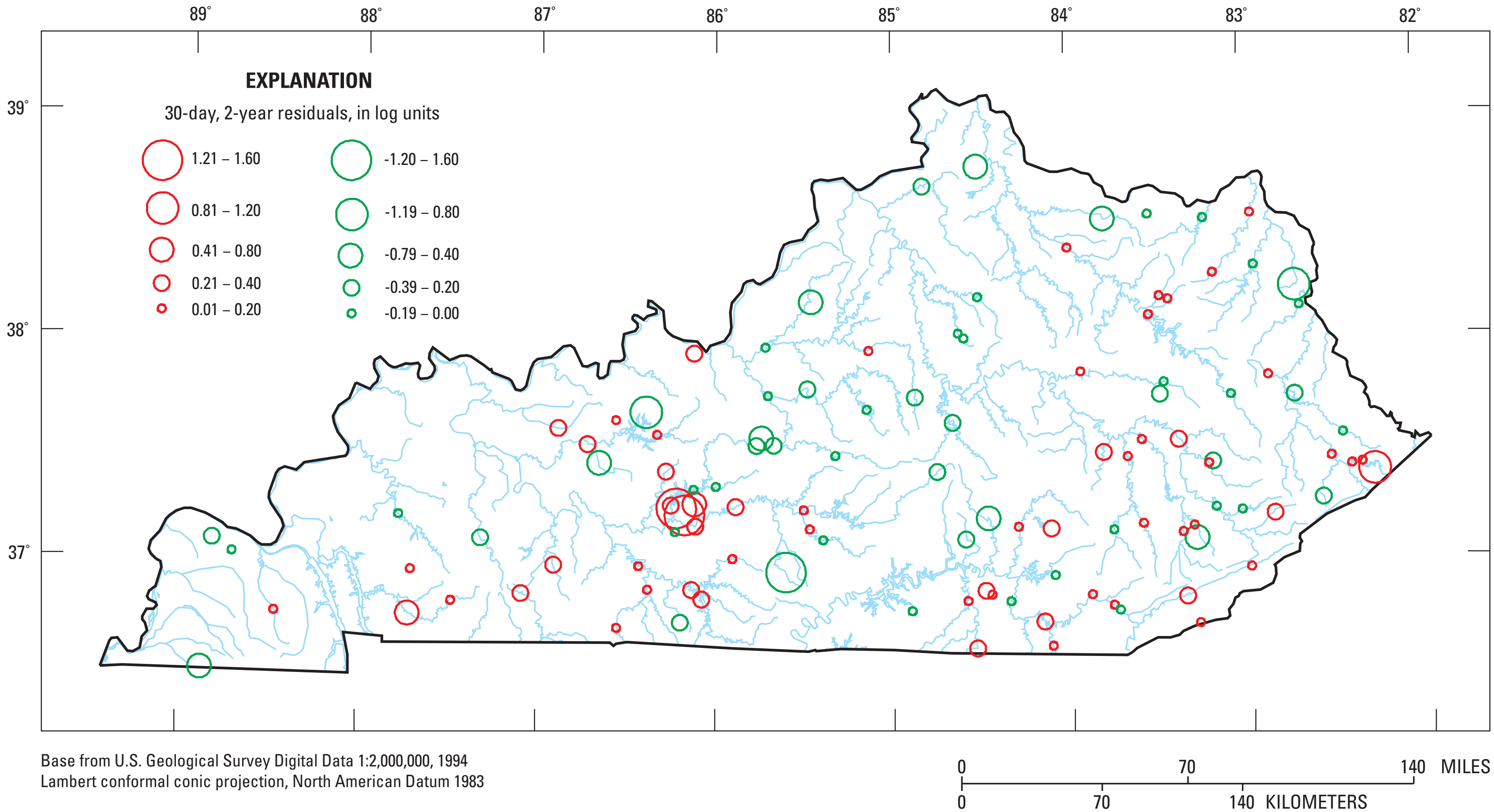


Figure 11. Comparison of selected low-flow frequencies estimated from measured streamflow and from regression equations for unregulated streams in Kentucky.

The underestimation 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 the low-flow frequency statistic. Less variability in the streamflow response would be expected for large basins as compared to small basins. Maps showing the magnitude and distribution of residuals in the final regressions for $30Q_2$ and $7Q_{10}$ are shown in figures 12 and 13, respectively.



Base from U.S. Geological Survey Digital Data 1:2,000,000, 1994
Lambert conformal conic projection, North American Datum 1983

Figure 12. Residuals for the 30-day, 2-year low-flow regressions in Kentucky.

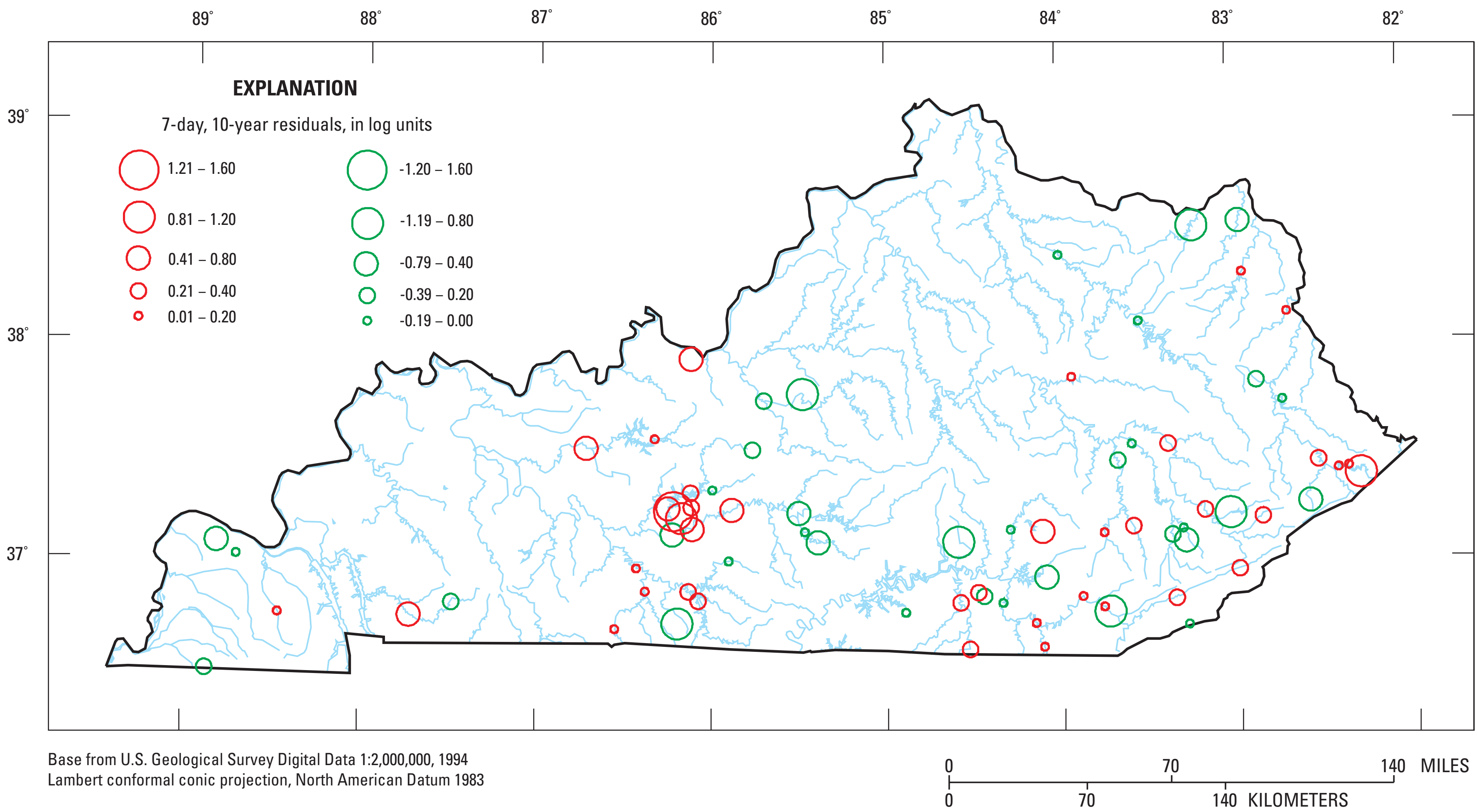


Figure 13. Residuals for the 7-day, 10-year low-flow regressions in Kentucky.

The elevated percentage errors (> 100) result, in part, from the increased scatter in estimates for small basins and from the zero-bounded low-flow frequency statistics. Also, the large percentage errors may not correspond to large flow magnitudes. For example, a $7Q_{10}$ estimate of 1 ft^3/s that has a standard error of prediction ranging from −72.6 to 265 percent (table 5), results in a standard error flow range of 0.27 to 3.65 ft^3/s, though this error range does exceed one order of magnitude. Typically, low-flow statistics have the largest percentage errors, followed by peak-flow statistics (Hodgkins and Martin, 2003), and then mean annual flow statistics (Martin, 2002), which have the smallest percentage errors.

Example Applications of the Estimating Equations

Procedures for using the estimating equations are described in the following examples:

Example 1

An estimate of the $7Q_{10}$ low flow is needed for an ungaged stream site in Region 1. The site has the following drainage-basin characteristics: A, 400 mi^2; and V, 1.15. First, confirm that the basin characteristics are in the acceptable ranges defined for this statistic and Region 1 (table 6 and figs. 9 and 10), which is correct.

Next, the probability of the annual low flow being zero is computed from the logistic regression equation (table 4):

$$PZERO7 = \frac{C}{1+e^{4.95+2.25\log_{10}A-12.6V}}$$

$$PZERO7 = \frac{0.182}{1+e^{4.95+2.25\log_{10}400-12.6(1.15)}}$$

$$PZERO7 = \frac{0.182}{1+e^{-4.363}}$$

$$PZERO7 = 0.18 > 0.10$$

Therefore, $7Q_{10}$ is zero.

Example 2

An estimate of the $7Q_{10}$ low flow and the standard error of prediction are needed for an ungaged stream site in Region 3. The site has the following drainage-basin characteristics: A, 200 mi^2; and V, 0.55. First, confirm that the basin characteristics are in the acceptable ranges defined for this statistic and Region 3 (table 6 and figs. 9 and 10), which is the case.

$$PZERO7 = \frac{C}{1+e^{4.95+2.25\log_{10}A-12.6V}}$$

$$PZERO7 = \frac{0.182}{1+e^{4.95+2.25\log_{10}200-12.6\bullet(0.55)}}$$

$$PZERO7 = \frac{0.182}{1+e^{3.197}}$$

$$PZERO7 = 0.007 < 0.10$$

Therefore, $7Q_{10}$ is nonzero and should be computed by using the WLS regional estimating equation for the 7-day, 10-year low flow in Region 3 (table 5),

$$7Q_{10} = 0.0129\, A^{\,0.774}\, V^{-3.75}$$

$$7Q_{10} = 0.0129\,(200)^{0.774}\,(0.55)^{-3.75}$$

$$7Q_{10} = 7.33\ ft^3/s$$

The standard errors of prediction for the $7Q_{10}$ ranges from -72.6 percent to + 265 percent (table 5), and values are computed as

$$7.33 - 0.726(7.33) = 2.01\ ft^3/s$$

and

$$7.33 + 2.65(7.33) = 26.7\ ft^3/s$$

Example 3

An estimate of the $30Q_2$ low flow is needed for a stream site having drainage areas of 40 and 160 mi^2 and streamflow-variability index zones of 0.65 and 0.75, respectively. First, confirm that the basin characteristics are in the acceptable ranges defined for this statistic (table 6 and figs. 9 and 10), which is true. The next step is to determine if the $30Q_2$ is zero by using the logistic regression equation (table 4).

When a drainage basin includes contributing drainage area from more than one streamflow-variability index zone, the estimating equations should be applied as though the entire basin is in each specific streamflow-variability index zone, then a final estimate is obtained by area-weighting each estimate to provide a composite result.

Begin by applying the estimating equation as though the entire drainage basin is in streamflow-variability index zone 0.65:

$$PZERO30 = \frac{C}{1+e^{5.67+1.72\log_{10}A-10.6V}}$$

$$PZERO30_{0.65} = \frac{0.505}{1+e^{5.67+1.72\log_{10}(200)-10.6(0.65)}}$$

$$PZERO30_{0.65} = \frac{0.505}{1+e^{2.74}}$$

$$PZERO30_{0.65} = 0.03$$

Next, apply the estimating equation as though the entire drainage basin is in streamflow-variability index zone 0.75:

$$PZERO30_{0.75} = \frac{0.505}{1+e^{5.67+1.72\log_{10}(200)-10.6(0.75)}}$$

$$PZERO30_{0.75} = \frac{0.505}{1+e^{1.68}}$$

$$PZERO30_{0.75} = 0.08$$

Finally, multiply each of the estimates by the proportion of the total drainage area represented by each estimate to obtain the area-weighted composite estimate:

$$PZERO30 = 0.2\times 0.03 + 0.8\times 0.08$$

$$PZERO30 = 0.07 < 0.50$$

Therefore, the PZERO30 is less than the annual nonexceedance probability, the reciprocal of the return period, 1/T, or ½=0.50, the $30Q_2$ is nonzero and should be estimated by use of the regional estimating equation for the $30Q_2$ (table 5). These estimating equations also should be applied as though the entire basin is in each specific streamflow-variability-index zone, and a final estimate is obtained by area-weighting each estimate to provide a composite result:

$$30Q_2 = 0.0141\, A^{0.885}\, V^{-3.91}$$

$$30Q_2 = 0.0141\times 200^{0.885}\times 0.65^{-3.91}$$

$$30Q_2 = 8.26\ ft^3/s$$

Next, compute an estimate as though the entire basin is in streamflow-variability-index area 0.75:

$$30Q_2 = 0.0141\times 200^{0.885}\times 0.75^{-3.91}$$

$$30Q_2 = 4.72\ ft^3/s$$

Finally, multiply each of the estimates by the proportion of the total drainage area represented by each estimate to obtain the area-weighted composite estimate:

$$30Q_2 = 0.20\times 8.26 + 0.80\times 4.72$$

$$30Q_2 = 5.43\ ft^3/s$$

Weighted Drainage-Area-Ratio Method

If a low-flow frequency is available for a gaged location of a stream reach and an estimate is needed at an ungaged point on the same stream, then a weighting procedure can be used (Carpenter, 1983; and Koltun and Whitehead, 2002). Two conditions must be met to use this method: (1) the drainage area of the ungaged site should differ by no more than 50 percent from that of the gaged site (ranging from 50 to 150 percent of the drainage area of the gaged site), and (2) the entire drainage basin of the ungaged site must be in the same streamflow-variability index area (plate 2). These conditions limit the possibility of hydrologic dissimilarity between the gaged and ungaged sites. The second condition is necessary because a linear relation between the low-flow-frequency values at the gaged and ungaged sites is assumed.

A weighted estimate can be computed as

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

where

$$R = \frac{DQ_{T_{gm}}}{DQ_{T_{gr}}}$$

and

$DQ_{T_{uw}}$ is the weighted low-flow frequency, DQ_T, for the ungaged site;

$DQ_{T_{ur}}$ is the regression estimate of the DQ_T for the ungaged site;

$DQ_{T_{gm}}$ is the DQ_T determined for the gaged site from measured streamflow data;

$DQ_{T_{gr}}$ is the regression estimate of the DQ_T for the gaged site;

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

A_g is the drainage area of the gaged site.

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

Summary

Low-flow frequencies are needed for effective management of water resources. Decisions related to waste-load allocations, discharge and withdrawal permits, water-supply planning, and in-stream flow requirements depend on estimates of low-flow frequencies, and methods for estimating low-flow frequencies at ungaged stream sites are part of this need. The U.S. Geological Survey, in cooperation with the Kentucky Division of Water, made estimates of the 7-day mean low flows for recurrence intervals of 5, 10, and 20 years ($7Q_2$, $7Q_{10}$, and $7Q_{20}$) and 30-day mean low flows for recurrence intervals of 2 and 5 years ($30Q_2$ and $30Q_5$) at 121 streamflow-gaging stations in Kentucky with data through the 2006 climate year and developed regional regression equations for estimating low-flow characteristics of unregulated streams in Kentucky. Data were screened to identify the periods of homogeneous, unregulated flows by use of annual low-flow time-series plots, trend tests, available information on permitted water discharges and withdrawals, and double-mass curves for comparing annual low flows at each gaging station to flows at a reference gaging station.

Logistic-regression equations were developed for estimating the probability of the annual 7- and 30-day low flows being zero. Weighted-least-squares regression equations were developed for estimating the magnitude of the nonzero $7Q_2$, $7Q_{10}$, $7Q_{20}$, $30Q_2$, and $30Q_5$ low flows. Three low-flow regions were defined for applying the equations used for estimating the 7-day low-flow frequencies, while separate regions for estimating the 30-day low-flow frequencies were not necessary.

The explicit explanatory variables in the regression equations include total drainage area and the mapped streamflow-variability index measured from a revised statewide coverage of this characteristic. The percentage of the station low-flow frequencies correctly classified as zero or nonzero by use of the logistic-regression equations ranged from 87.5 to 93.8 percent. The average standard errors of prediction of the weighted-least-squares regression equations ranged from 108 to 226 percent.

The estimating equations can be applied by (1) determining the basin characteristics required for the appropriate equation, (2) checking to ensure that the basin characteristics are in the range of values used to develop the equation, and (3) substituting the basin-characteristic values for the variables in the estimating equations. The user first determines the probability of the low-flow frequency having a value of zero by use of the logistic-regression equation, and if a nonzero value is likely, the low-flow frequency value is estimated by use of the weighted-least-squares regression equations as described in the example applications presented in this report.

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Table 1. Description of streamflow-gaging stations evaluated for use in the low-flow regressions in Kentucky.

[Type, type of streamflow-gaging stations; --, not applicable; climate year, the 12-month period April 1–March 31 is identified by the year in which it ends; LD, local diversions; major STP, major sewage-treatment plants upstream (major defined as 1 million gallons per day or more; P, low-flow, partial-record station; KY, Kentucky; W, withdrawal; D, discharge; W1,D1, one withdrawal and one discharge in basin--zero and up are the number of withdrawals and discharges; C, long-term, continuous-record station; period of record for partial-record stations indicates years in which low-flow measurements were made]

Station number	Type	Station name	Total drainage area	Period of record (climate years)	
				Unregulated	Homogeneous unregulated
03207915[1]	C	Elkfoot Branch, Levisa Fork, KY	0.04	1981-85	1981-85
03207965	C	Grapevine Creek near Phyllis, KY	6.49	1975-82, 1991-92, 1996-2006	1975-82, 1991-92
03208000	C	Levisa Fork below Fishtrap Dam near Millard, KY	391	1939-68	1939-68
03209440[1]	C	Shelby Creek at Dorton, KY	12.4	1973-77	1973-77
03209500	C	Levisa Fork at Pikeville, KY	1,230	1939-63	1939-63
03210000	C	Johns Creek near Meta, KY	56.4	1942-93, 1996-2006	1942-75
03211500	C	Johns Creek near Van Lear, KY	206	1941-50	1941-50
03212000	C	Paint Creek at Staffordville, KY	103	1951-75	1951-68
03215500	C	Blaine Creek at Yatesville, KY	217	1917-18, 1939-75	1917-18, 1939-75
03216500	C	Little Sandy River at Grayson, KY	400	1939-68	1939-68
03216540	C	East Fork Little Sandy River near Fallsburg, KY	12.4	1974-91	1974-91
03216800	C	Tygarts Creek at Olive Hill, KY	59.4	1958-94	1958-67
03217000	C	Tygarts Creek near Greenup, KY	242	1942-2006	1942-67
03237255[2]	C	Kinniconick Creek below Trace Creek at Tannery, KY	214	1993-2006	1993-2003
03237900	C	Cabin Creek at Tollesboro, KY	21.9	1973-92	1973-92
03248500	C	Licking River near Salyersville, KY	140	1940-92, 1996-97	1940-75
03249500	C	Licking River at Farmers, KY	827	1929-73	1929-73
03250000	C	Triplett Creek at Morehead, KY	47.7	1943-80, 1990-92	1943-59
03250100	C	North Fork Triplett Creek near Morehead, KY	84.7	1969-94	1969-94
03250500	C	Licking River Near Blue Lick Springs, KY	1,785	1939-59	1939-59
03251000	C	North Fork Licking River near Lewisburg, KY	119	1948-91	1948-63
03252500	C	South Fork Licking River at Cynthiana, KY	621	1939-94	--
03254400	C	North Fork Grassy Creek near Piner, KY	13.6	1969-83	1969-83
03277355[1]	P	Camp Creek near Polly, Ky	6.3	1988, 1992, 2005	1988, 1992, 2005
03277400	C	Leatherwood Creek at Daisy, KY	40.9	1966-74, 1993-98	1966-74
03277450	C	Carr Fork near Sassafras, KY	60.5	1965-75	1965-75
03277500	C	North Fork Kentucky River at Hazard, KY	465	1941-75	1941-75
03278000	C	Bear Branch near Noble, KY	2.21	1956-73	1956-73
03278500	C	Troublesome Creek at Noble, KY	177	1951-81	1951-65

Period of record (climate years) Regulated	Local diversions	Number of major STPs	Source of regulation and start date	Remarks
--	W0,D0	0	--	--
--	W0,D2	0	--	--
1970-92	W2,D7	0	Fishtrap Lake, 10/68	--
--	W0, D3	0	--	--
1970-2006	W20,D59	0	Flannagan Lake, 12/63; North Fork Pound Lake, 08/66; Fishtrap Lake, 10/68	--
--	W4, D7	0	--	Highly trended after 1975
1952-92	W4, D7	0	Dewey Lake, 05/50	--
--	W0,D3	0	--	--
--	W0,D4	0	Yatesville Lake, 05/1992	--
1969-2006	W3,D14	0	Grayson Lake, 03/68	--
--	W0,D0	0	--	--
--	W2,D1	0	--	--
--	W3,D9	0	--	--
--	W0,D0	0	--	--
--	W0,D2	0	--	--
--	W1,D5	0	--	--
1975-1994	W5,D24	0	Cave Run Lake, 12/73	Highly trended after 1973
--	W1,D0	0	--	--
--	W0,D2	0	--	--
2003-06	W16,D61	2	Cave Run Lake, 12/73	--
--	W0,D4	0	--	--
--	W7,D43	4	--	Not used; LD
--	W0,D0	0	--	--
--	W0,D0	0	--	--
--	W5,D1	0	--	Not used, under 10 years
1977-94	W0,D3	0	Carr Fork Lake, 01/76	Highly trended after 1975
1977-92	W29,D33	0	Carr Fork Lake, 01/76	--
--	W0,D0	0	--	--
--	W2,D10	0	--	--

Table 1. Description of streamflow-gaging stations evaluated for use in the low-flow regressions in Kentucky. —Continued

[Type, type of streamflow-gaging stations; --, not applicable; climate year, the 12-month period April 1–March 31 is identified by the year in which it ends; LD, local diversions; major STP, major sewage-treatment plants upstream (major defined as 1 million gallons per day or more; P, low-flow, partial-record station; KY, Kentucky; W, withdrawal; D, discharge; W1,D1, one withdrawal and one discharge in basin--zero and up are the number of withdrawals and discharges; C, long-term, continuous-record station; period of record for partial-record stations indicates years in which low-flow measurements were made]

Station number	Type	Station name	Total drainage area	Period of record (climate years)	
				Unregulated	Homogeneous unregulated
03280000	C	North Fork Kentucky River at Jackson, KY	1,101	1930-31, 1939-75	1930-31, 1939-75
03280600	C	Middle Fork Kentucky River near Hyden, KY	202	1959-92	1959-68
03280680[1]	P	Wolf Creek at Cinda, Ky	9.89	1988-89, 1992, 2006	1988-89, 1992, 2006
03280700	C	Cutshin Creek at Wooton, KY	61.1	1959-2006	1959-89
03280900	C	Middle Fork Kentucky River at Buckhorn, KY	420	1958-60	1958-60
03281000	C	Middle Fork Kentucky River at Tallega, KY	536	1932, 1941-60	1932, 1941-60
03281040	C	Red Bird River near Big Creek, KY	155	1974-2000	1974-89
03281100	C	Goose Creek at Manchester, KY	163	1966-2006	1966-89
03281500	C	South Fork Kentucky River at Booneville, KY	722	1926-31, 1941-2006	1926-31, 1941-66
03282040	C	Sturgeon Creek at Cressmmont, KY	77.4	1994-2006	1994-2006
03282500	C	Red River near Hazel Green, KY	65.9	1955-2006	1955-71
03283000	C	Stillwater Creek at Stillwater, KY	24.0	1955-73	1955-73
03283500	C	Red River at Clay City, KY	362	1932, 1939-2006	1932, 1939-60
03285000	C	Dix River at Danville, KY	317	1944-2006	1944-71
03288000	C	North Elkhorn Creek near Georgetown, KY	119	1951-84, 1990-1999	1951-74
03288500	C	Cave Creek near Fort Spring, KY	2.31	1954-72	1954-72
03289000	C	South Elkhorn Creek at Fort Spring, KY	23.9	1951-92, 1999-2006	1951-74
03289500	C	Elkhorn Creek near Frankfort, KY	473	1917-18, 1941-84, 1989-2006	--
03290000	C	Flat Creek near Frankfort, KY	5.65	1953-71	1953-71
03291000	C	Eagle Creek at Sadieville, KY	41.5	1943-75	1943-75
03291500	C	Eagle Creek at Glencoe, KY	437	1917-18, 1930-31, 1940-77, 1990-2006	1917-18, 1930-31, 1940-71
03292500	C	South Fork Beargrass Creek at Louisville, KY	17.2	1946-53, 1956-62, 1972-83, 1990-2006	--
03293000	C	Middle Fork Beargrass Creek at Old Cannons Lane, Louisville, KY	18.9	1946-2006	--
03295000	C	Salt River near Harrodsburg, KY	41.9	1954-73	1954-73
03295500	C	Salt River near Van Buren, KY	196	1940-82	1940-67
03298000	C	Floyds Fork at Fisherville, KY	138	1946-2006	1946-75
03298500	C	Salt River at Shepherdsville, KY	1,196	1940-82	1940-67
03299000	C	Rolling Fork near Lebanon, KY	239	1939-92	1939-65
03300000	C	Beech Fork near Springfield, KY	86.0	1954-72	1954-72
03300400	C	Beech Fork at Maud, KY	436	1974-2006	1974-80

Period of record (climate years)	Local diversions	Number of major STPs	Source of regulation and start date	Remarks
Regulated				
1977-2006	W37, D63	1	Carr Fork Lake, 01/76	--
--	W7,D5	0	--	--
--	W0,D0	0	--	--
--	W0,D1	0	--	--
1962-75	W8,D17	0	Buckhorn Lake, 12/60	--
1962-2006	W8,D22	0	Buckhorn Lake, 12/60	--
--	W0,D4	0	--	--
--	W0,D1	0	--	--
--	W5,D20	1	--	--
--	W0,D0	0	--	--
--	W0,D4	0	--	--
--	W0,D0	0	--	--
--	W3,D29	0	--	--
--	W1,D9	1	--	--
--	W0,D5	0	--	--
--	W0,D0	0	--	--
--	W0,D4	0	--	--
--	W14,D60	3	--	Not used, LD
--	W0,D0	0	--	--
--	W0,D2	0	--	--
--	W2,D20	0	--	--
--	W0,D6	0	--	Not used, urban
--	W2,D5	0	--	Not used, urban
--	W0,D3	0	--	--
--	W2, D15	2	--	--
--	W7, D30	1	--	--
1984-2006	W18, D114	6	Taylorsville Lake, 01/83	--
--	W3, D8	0	--	--
--	W0,D0	0	--	--
--	W1, D4	0	--	--

Table 1. Description of streamflow-gaging stations evaluated for use in the low-flow regressions in Kentucky. —Continued

[Type, type of streamflow-gaging stations; --, not applicable; climate year, the 12-month period April 1–March 31 is identified by the year in which it ends; LD, local diversions; major STP, major sewage-treatment plants upstream (major defined as 1 million gallons per day or more; P, low-flow, partial-record station; KY, Kentucky; W, withdrawal; D, discharge; W1,D1, one withdrawal and one discharge in basin--zero and up are the number of withdrawals and discharges; C, long-term, continuous-record station; period of record for partial-record stations indicates years in which low-flow measurements were made]

Station number	Type	Station name	Total drainage area	Period of record (climate years)	
				Unregulated	Homogeneous unregulated
03301000	C	Beech Fork at Bardstown, KY	669	1941-74, 1999, 2002-2006	1941-62
03301500	C	Rolling Fork near Boston, KY	1,300	1940-2006	1940-65
03302150[1]	P	Doe Run near Brandenburg Station, KY	36.9	1960, 1963-65, 1969-73	1960, 1963-65, 1969-73
03304500	C	McGills Creek near McKinney, KY	2.16	1953-71	1953-71
03305000	C	Green River near McKinney, KY	22.4	1953-73	1953-73
03306000	C	Green River near Campbellsville, KY	682	1932, 1965-68	1932, 1965-68
03306500	C	Green River at Greensburg, KY	736	1941-68	1941-68
03307000	C	Russell Creek near Columbia, KY	179	1941-2006	1941-80
03307100	C	Russell Creek near Gresham, KY	265	1966-75	1966-75
03307500	C	South Fork Little Barren River at Edmonton, KY	18.3	1943-72	1943-72
03308500	C	Green River at Munfordville, KY	1,681	1916-22, 1929-31, 1939-68	1916-22, 1929-31, 1939-68
03309000	C	Green River at Mammoth Cave, KY	1,984	1940-50	1940-50
03309100[1]	P	Wet Prong Buffalo Creek near Mammoth Cave, KY	2.74	1963-75	1963-75
03309500	C	McDougal Creek near Hodgenville, KY	5.28	1955-71	1955-71
03310000	C	North Fork Nolin River at Hodgenville, KY	36.7	1943-73	1943-73
03310078[1]	P	South Fork Nolin River at Mathers Mill,	50.1	1975-79, 1981-82, 1989	1975-79, 1981-82, 1989
03310300	C	Nolin River at White Mills, KY	360	1961-2006	--
03310400	C	Bacon Creek near Priceville, KY	80.6	1961-94	1961-94
03310500	C	Nolin River at Wax, KY	599	1938-62	1938-47
03310600[1]	P	Dog Creek near Mammoth Cave, Ky	8.04	1962-75	1962-75
03311000	C	Nolin River at Kyrock, KY	707	1932, 1941-50, 1962	1932, 1941-50
03311100[1]	P	Bylew Creek Near Mammoth Cave, Ky	5.11	1962-75	1962-75
03311600	C	Beaverdam Creek at Rhoda, KY	10.9	1974-94	1974-94
03312000	C	Bear Creek near Leitchfield, KY	30.8	1951-71	1951-71
03312500	C	Barren River near Pageville, KY	532	1940-63	1940-63
03312765	C	Beaver Creek at Highway 31 East near Glasgow, KY	47.1	1993-2002	1993-2002
03313000	C	Barren River near Finney, KY	942	1943-50, 1962-63	1943-50, 1962-63
03313500	C	West Bays Fork at Scottsville, KY	7.46	1952-1972	1952-67
03313700[3]	C	West Fork Drakes Creek near Franklin, KY	111	1970-89	1970-79
03314000	C	Drakes Creek near Alvaton, KY	475	1942-71	1942-71

Period of record (climate years)	Local diversions	Number of major STPs	Source of regulation and start date	Remarks
Regulated				
--	W5, D25	2	--	--
--	W9, D44	3	--	--
--	W0,D0	0	--	--
--	W0,D0	0	--	--
--	W1, D0	0	--	--
1970-94	W5, D9	0	Green River Lake, 02/69	--
1970-75, 2006	W6, D10	0	--	--
--	W3, D6	0	--	--
--	W3, D7	0	--	--
--	W0,D0	0	--	--
1970-2006	W13, D40	1	Green River Lake, 02/69	--
2005-06	W14, D50	1	--	--
--	W0,D0	0	--	--
--	W0,D0	0	--	--
--	W2, D1	0	--	--
--	W0,D0	0	--	--
--	W14, D23	1	--	Not used; LD
--	W1, D1	0	--	--
--	W15, D24	1	--	--
--	W0,D0	0	--	--
1964-2004	W17, D28	1	Nolin Lake, 03/63	--
--	W0,D0	0	--	--
--	W0,D0	0	--	--
--	W0, D3	1	--	--
--	W2, D8	0	--	--
--	W0, D1	0	--	--
1965-94	W7, D20	1	Barren River Lake, 03/64	--
--	W0,D0	0	--	--
1990-2004	W1, D1	0	Concrete dam, raised and modified 1989	--
--	W2, D3	1	--	--

Table 1. Description of streamflow-gaging stations evaluated for use in the low-flow regressions in Kentucky. —Continued

[Type, type of streamflow-gaging stations; --, not applicable; climate year, the 12-month period April 1–March 31 is identified by the year in which it ends; LD, local diversions; major STP, major sewage-treatment plants upstream (major defined as 1 million gallons per day or more; P, low-flow, partial-record station; KY, Kentucky; W, withdrawal; D, discharge; W1,D1, one withdrawal and one discharge in basin--zero and up are the number of withdrawals and discharges; C, long-term, continuous-record station; period of record for partial-record stations indicates years in which low-flow measurements were made]

Station number	Type	Station name	Total drainage area	Period of record (climate years)	
				Unregulated	Homogeneous unregulated
03314500	C	Barren River at Bowling Green, KY	1,846	1940-63	1940-63
03316000	C	Mud River near Lewisburg, KY	90.7	1941-72	1941-61
03317000	C	Rough River near Madrid, KY	225	1940-59	1940-59
03317500	C	North Fork Rough River near Westview, KY	42.0	1955-73	1955-73
03318000	C	Rough River near Falls of Rough, KY	454	1941-51	--
03318200	C	Rock Lick Creek near Glen Dean, KY	20.1	1958-71	1958-71
03318500	C	Rough River at Falls of Rough, KY	504	1950-59	--
03318800	C	Caney Creek near Horse Branch, KY	117	1958-92	1958-92
03319000	C	Rough River near Dundee, KY	757	1941-59	1941-59
03320500	C	Pond River near Apex, KY	194	1942-2006	1942-2006
03321350	C	South Fork Panther Creek near Whitesville, KY	58.2	1969-83	1969-83
03322360	C	Beaverdam Creek near Corydon, KY	10.7	1974-82, 1985-86, 1989-94	1974-82, 1985-86, 1989-94
03383000	C	Tradewater River at Olney, KY	255	1942-84, 1986-2006	1942-75
03384000	C	Rose Creek at Nebo, KY	2.10	1953-70	1953-70
03400500	C	Poor Fork at Cumberland, KY	82.1	1941-92	1941-60
03400785[1]	C	Martins Fork above Smith, KY	23.7	1986-91	1986-91
03400800	C	Martins Fork near Smith, KY	55.8	1972-78	1972-78
03401000	C	Cumberland River near Harlan, KY	373	1941-78	1941-78
03402000	C	Yellow Creek near Middlesboro, KY	60.6	1942-2005	--
03402930[1]	P	Fourmile Creek at Fourmile, Ky	6.20	1988-89, 1991-92, 2006	1988-89, 1991-92, 2006
03403000[4]	C	Cumberland River near Pineville, KY	809	1940-75	1940-71
03403500	C	Cumberland River at Barbourville, KY	960	1924-31, 1949-78	1924-31, 1949-71
03403910	C	Clear Fork at Saxton, KY	331	1970-90, 1997-2004	1970-90, 1997-2004
03404000	C	Cumberland River at Williamsburg, KY	1,607	1952-78	1952-78
03404500	C	Cumberland River at Cumberland Falls, KY	1,976	1909-11, 1916-31, 1934-78	1909-11, 1916-31, 1934-60
03404900	C	Lynn Camp Creek at Corbin, KY	53.0	1975-2005	1975-89
03405000	C	Laurel River at Corbin, KY	201	1924, 1944-73	--
03406000	C	Wood Creek near London, KY	3.90	1955-71	1955-71
03406500	C	Rockcastle River at Billows, KY	604	1938-2006	1938-90
03407100	C	Cane Branch near Parkers Lake, KY	0.65	1957-66	1957-66
03407300	C	Helton Branch at Greenwood, KY	0.85	1957-74	1957-74

Period of record (climate years) Regulated	Local diversions	Number of major STPs	Source of regulation and start date	Remarks
1965-94, 2003-06	W17, D45	3	Barren River Lake, 03/64	--
--	W3, D9	3	--	--
--	W2, D0	0	--	--
--	W0,D0	0	--	--
--	W4, D13	0	--	Not used; mill present
--	W0,D0	0	--	--
1961-94	W4, D16	0	Rough River Lake, 10/59	Not used; mill present
--	W0, D3	0	--	--
1961-92, 2003-04	W5, D20	0	Rough River Lake, 10/59	--
--	W1, D3	0	--	--
--	W0, D7	0	--	--
--	W0, D2	0	--	--
--	W3, D7	0	--	--
--	W0,D0	0	--	--
--	W5, D8	0	--	--
--	W0,D0	0	--	--
1980-2004	W0,D0	0	Martins Fork Lake, 11/78	Not used, under 10 years
1980-2005	W20, D22	0	Martins Fork Lake, 11/78	--
1942-2005	W5, D4	1	Fern Lake, 1890	Not used, regulated
--	W0,D0	0	--	--
1981-2005	W28, D41	2	Martins Fork Lake, 11/78; Fern Lake	--
1980-93, 1997-2005	W33, D60	4	Martins Fork Lake, 11/78; Fern Lake	--
--	W0, D2	0	--	--
1980-2006	W35, D70	5	Martins Fork Lake, 11/78; Fern Lake	--
1980-94, 2004-05	W38, D89	5	Martins Fork Lake, 11/78; Fern Lake	--
--	W0, D5	0	--	--
--	W4, D21	2	--	Not used, LD
--	W0,D0	0	--	--
--	W4, D24	0	--	--
--	W0,D0	0	--	--
--	W0,D0	0	--	--

Table 1. Description of streamflow-gaging stations evaluated for use in the low-flow regressions in Kentucky. —Continued

[Type, type of streamflow-gaging stations; --, not applicable; climate year, the 12-month period April 1–March 31 is identified by the year in which it ends; LD, local diversions; major STP, major sewage-treatment plants upstream (major defined as 1 million gallons per day or more; P, low-flow, partial-record station; KY, Kentucky; W, withdrawal; D, discharge; W1,D1, one withdrawal and one discharge in basin--zero and up are the number of withdrawals and discharges; C, long-term, continuous-record station; period of record for partial-record stations indicates years in which low-flow measurements were made]

Station number	Type	Station name	Total drainage area	Period of record (climate years)	
				Unregulated	Homogeneous unregulated
03407500	C	Buck Creek near Shopville, KY	165	1954-91	1954-70
03410500	C	South Fork Cumberland River near Stearns, KY	954	1944-2005	1944-2005
03411000	C	South Fork Cumberland River at Nevelsville, KY	1,267	1916-31, 1934-50	1916-31, 1934-50
03412500	C	Pitman Creek at Somerset, KY	31.0	1955-72	1955-72
03413200	C	Beaver Creek near Monticello, KY	43.2	1970-83, 1991-2006	1970-83, 1991-95
03435140	C	Whippoorwill Creek near Claymour, KY	20.7	1975-91	1975-91
03437500	C	South Fork Little River at Hopkinsville, KY	46.1	1951-73	1951-60
03438000	C	Little River near Cadiz, KY	244	1941-2006	1941-62
03438070	C	Muddy Fork Little River near Cerulean, KY	30.3	1970-83	1970-83
03610000	C	Clarks River at Murray, KY	89.7	1953-71	--
03610200	C	Clarks River at Almo, KY	134	1984-2006	--
03610500	C	Clarks River near Benton, KY	227	1940-73	--
03610545	C	West Fork Clarks River near Brewers, KY	68.3	1970-83, 1990-94	1970-83, 1990-94
03611260	C	Massac Creek near Paducah, KY	10.4	1973-2006	1973-93
03611800	C	Bayou Creek near Heath, KY	6.55	1995-2006	1995-2006
03611850	C	Bayou Creek near Grahamville, KY	14.9	1995-2006	--
07022500	C	Perry Creek near Mayfield, KY	1.72	1954-66, 1969-72	1954-66, 1969-72
07023000	C	Mayfield Creek at Lovelaceville, KY	212	1940-72	--
07023500	C	Obion Creek at Pryorsburg, KY	37.0	1953-73	1953-73
07024000	C	Bayou De Chien near Clinton, KY	68.7	1941-78, 1986-2006	--
07025440[1]	P	Harris Fork Creek near Fulton, KY	3.99	1988, 1992, 2006	1988, 1992, 2006

[1] Low-flow, partial-record streamflow-gaging stations; or a long-term-continuous-record, streamflow-gaging station having less than 10 years record, which was treated as a low-flow, partial-record station..

[2] Combined records for stations 03237250 and 03237255.

[3] Station 03313700 had estimated 3 cubic feet per second withdrawal for water supply for the period 1977-79, which was added to the measured low flows prior to the frequency analysis.

[4] Combined records for stations 03402900 and 03403000.

Period of record (climate years)	Local diversions	Number of major STPs	Source of regulation and start date	Remarks
Regulated				
--	W0, D5	0	--	--
--	W1, D0	0	--	--
--	W2, D1	0	--	--
--	W1, D2	0	--	--
--	W0,D0	0	--	--
--	W0, D1	0	--	--
--	W1, D1	0	--	--
--	W6, D6	2	--	--
--	W0,D0	0	--	--
--	W0, D2	0	--	Not used; urbanized
--	W2, D8	1	--	Not used; highly trended
--	W3, D11	2	--	--
--	W0,D0	0	--	--
--	W0,D0	0	--	--
--	W0,D0	0	--	--
--	W0,D13	0	--	Not used; highly trended
--	W0,D0	0	--	--
--	W8, D28	1	--	Not used; highly trended
--	W2, D1	0	--	--
--	W0, D4	0	--	Not used; highly trended
--	W0,D0	0	--	--

Table 2. Low-flow frequencies for streamflow-gaging stations used in the low-flow regressions in Kentucky.

[mi², square mile; ft³/s, cubic foot per second; climate years, the 12-month period April 1--March 31 is identified by the year in which it ends; Regression: B, both the logistic regression and weighted-least-squares regression; KY, Kentucky; W, weighted-least-squares regression only; L, logistic regression only; period of record for the low-flow, partial-record stations indicates years in which low-flow measurements were made; --, not applicable]

Station number	Regression	Station name	Total drainage area (mi²)	Streamflow-variability index (log base-10 ft³/s) Station value	Map value	Homogeneous unregulated period of record (climate years)	Number of years
03207915[1]	B	Elkfoot Branch, Levisa Fork, KY	0.04	0.567	0.65	1981-85	5
03207965	B	Grapevine Creek near Phyllis, KY	6.49	0.611	0.65	1975-82, 1991-92	10
03208000	B	Levisa Fork below Fishtrap Dam near Millard, KY	391.00	0.649	0.65	1939-68	30
03209440[1]	B	Shelby Creek at Dorton, KY	12.40	0.711	0.65	1973-77	5
03209500	B	Levisa Fork at Pikeville, KY	1,230.00	0.631	0.65	1939-63	25
03210000	B	Johns Creek near Meta, KY	56.40	0.775	0.69	1942-75	34
03211500	B	Johns Creek near Van Lear, KY	206.00	0.752	0.73	1941-50	10
03212000	B	Paint Creek at Staffordville, KY	103.00	0.747	0.74	1951-68	18
03215500	B	Blaine Creek at Yatesville, KY	217.00	0.745	0.75	1917-18, 1939-75	39
03216500	B	Little Sandy River at Grayson, KY	400.00	0.711	0.7	1939-68	30
03216540	B	East Fork Little Sandy River near Fallsburg, KY	12.40	1.079	0.7	1974-91	18
03216800	B	Tygarts Creek at Olive Hill, KY	59.40	0.789	0.86	1958-67	10
03217000	B	Tygarts Creek near Greenup, KY	242.00	0.779	0.81	1942-67	26
03237255[2]	B	Kinniconick Creek below Trace Creek at Tannery, KY	214.00	0.904	0.9	1993-2003	11
03237900	B	Cabin Creek at Tollesboro, KY	21.90	1.045	1.06	1973-92	20
03248500	B	Licking River near Salyersville, KY	140.00	0.75	0.75	1940-75	36
03249500	B	Licking River at Farmers, KY	827.00	0.693	0.71	1929-73	38
03250000	B	Triplett Creek at Morehead, KY	47.70	1.149	1.13	1943-59	17
03250100	B	North Fork Triplett Creek near Morehead, KY	84.70	0.882	0.9	1969-94	26
03250500	B	Licking River Near Blue Lick Springs, KY	1,785.00	0.764	0.77	1939-59	21
03251000	B	North Fork Licking River near Lewisburg, KY	119.00	1.304	1.29	1948-63	16
03254400	B	North Fork Grassy Creek near Piner, KY	13.60	0.984	0.8	1969-83	15
03277355[1]	W	Camp Creek near Polly, Ky	6.30	--	0.6	1988, 1992, 2005	3
03277450	B	Carr Fork near Sassafras, KY	60.50	0.715	0.67	1965-75	11
03277500	B	North Fork Kentucky River at Hazard, KY	465.00	0.631	0.61	1941-75	35
03278000	B	Bear Branch near Noble, KY	2.21	0.891	0.85	1956-73	18
03278500	B	Troublesome Creek at Noble, KY	177.00	0.834	0.85	1951-65	15
03280000	B	North Fork Kentucky River at Jackson, KY	1,101.00	0.643	0.69	1930-31, 1939-75	39
03280600	B	Middle Fork Kentucky River near Hyden, KY	202.00	0.73	0.7	1959-68	10
03280680[1]	W	Wolf Creek At Cinda, Ky	9.89	--	0.7	1988-89, 1992, 2006	4
03280700	B	Cutshin Creek at Wooton, KY	61.10	0.682	0.7	1959-89	31

Magnitude of low-flow frequency (ft³/s)					Annual 7-day low flow equal to zero[5]		Annual 30-day low flow equal to zero[5]	
30-day, 2-year	30-day, 5-year	7-day, 2-year	7-day, 10-year	7-day, 20-year	Number	Frequency	Number	Frequency
0.053	0.02	0.039	0.009	0.006	0	0.00	0	0.00
0.5	0.26	0.15	0.05	0.04	0	0.00	0	0.00
17	5.49	8.71	1.3	0.67	0	0.00	0	0.00
0.4	0.1	0.2	0.015	0.006	0	0.00	0	0.00
50.8	18.7	25.6	4.97	2.93	0	0.00	0	0.00
1.62	0.21	0.26	0	0	8	0.24	3	0.09
3.34	1.1	1.65	0.36	0.21	0	0.00	0	0.00
3.25	1.3	1.36	0.11	0	1	0.06	0	0.00
5.09	2.22	2.69	0.53	0.31	0	0.00	0	0.00
11.6	6.19	7.13	2.88	2.25	0	0.00	0	0.00
0.08	0	0	0	0	9	0.50	3	0.17
1.17	0.22	0.68	0	0	1	0.10	0	0.00
4.47	1.58	1.87	0.27	0.1	1	0.04	0	0.00
1.88	0.56	0.65	0.07	0	1	0.09	1	0.09
0.16	0.02	0.01	0	0	9	0.45	2	0.10
2.65	0.69	1.34	0	0	5	0.14	0	0.00
30.2	11.8	19	4.1	2.53	0	0.00	0	0.00
0.28	0.02	0.03	0	0	8	0.47	1	0.06
1.37	0.15	0.22	0	0	3	0.12	0	0.00
35.8	15	22.8	6.12	4.33	0	0.00	0	0.00
0.14	0.01	0	0	0	10	0.63	3	0.19
0.127	0.028	0	0	0	8	0.53	1	0.07
1.3	1	1.1	0.8	0.7	--	--	--	--
2.33	0.72	0.75	0.03	0.01	0	0.00	0	0.00
22.3	10.5	8.8	2.14	1.41	0	0.00	0	0.00
0.03	0.01	0.01	0	0	8	0.44	3	0.17
3.16	0.47	0.79	0	0	2	0.13	1	0.07
50.4	17.6	24.1	3.07	1.46	0	0.00	0	0.00
6.65	2.26	1.42	0.24	0.15	0	0.00	0	0.00
0.1	0.035	0.1	0.011	0.007	--	--	--	--
2.92	1.2	0.82	0.11	0.06	0	0.00	0	0.00

Table 2. Low-flow frequencies for streamflow-gaging stations used in the low-flow regressions in Kentucky.—Continued

[mi², square mile; ft³/s, cubic foot per second; climate years, the 12-month period April 1--March 31 is identified by the year in which it ends; Regression: B, both the logistic regression and weighted-least-squares regression; KY, Kentucky; W, weighted-least-squares regression only; L, logistic regression only; period of record for the low-flow, partial-record stations indicates years in which low-flow measurements were made; --, not applicable]

Station number	Regression	Station name	Total drainage area (mi²)	Streamflow-variability index (log base-10 ft³/s)		Homogeneous unregulated period of record (climate years)	Number of years
				Station value	Map value		
03281000	B	Middle Fork Kentucky River at Tallega, KY	536.00	0.741	0.75	1932, 1941-60	21
03281040	B	Red Bird River near Big Creek, KY	155.00	0.69	0.7	1974-89	16
03281100	B	Goose Creek at Manchester, KY	163.00	0.71	0.7	1966-89	24
03281500	B	South Fork Kentucky River at Booneville, KY	722.00	0.766	0.76	1926-31, 1941-66	32
03282040	B	Sturgeon Creek at Cressmmont, KY	77.40	0.778	0.8	1994-2006	13
03282500	B	Red River near Hazel Green, KY	65.90	0.811	0.84	1955-71	17
03283000	B	Stillwater Creek at Stillwater, KY	24.00	0.854	0.85	1955-73	19
03283500	B	Red River at Clay City, KY	362.00	0.653	0.66	1932, 1939-60	23
03285000	B	Dix River at Danville, KY	317.00	1.021	1.03	1944-71	28
03288000	B	North Elkhorn Creek near Georgetown, KY	119.00	0.816	0.8	1951-74	24
03288500	B	Cave Creek near Fort Spring, KY	2.31	0.741	0.8	1954-72	19
03289000	B	South Elkhorn Creek at Fort Spring, KY	23.90	0.799	0.8	1951-74	24
03290000	L	Flat Creek near Frankfort, KY	5.65	1.22	1.25	1953-71	19
03291000	L	Eagle Creek at Sadieville, KY	41.50	1.47	1.34	1943-75	33
03291500	B	Eagle Creek at Glencoe, KY	437.00	1.335	1.35	1917-18, 1930-31, 1940-71	36
03295000	B	Salt River near Harrodsburg, KY	41.90	1.152	1.24	1954-73	20
03295500	B	Salt River near Van Buren, KY	196.00	1.248	1.24	1940-67	28
03298000	B	Floyds Fork at Fisherville, KY	138.00	1.312	1.25	1946-75	30
03298500	B	Salt River at Shepherdsville, KY	1,197.00	0.967	1.01	1940-67	28
03299000	B	Rolling Fork near Lebanon, KY	239.00	1.046	1.04	1939-65	27
03300000	B	Beech Fork near Springfield, KY	86.00	1.202	1.2	1954-72	19
03301000	B	Beech Fork at Bardstown, KY	669.00	0.956	0.96	1941-62	22
03301500	B	Rolling Fork near Boston, KY	1,300.00	0.843	0.85	1940-65	26
03302150[1]	W	Doe Run Near Brandenburg Station, Ky	36.90	--	0.55	1960, 1963-65, 1969-73	9
03304500	L	McGills Creek near McKinney, KY	2.16	1.077	1.05	1953-71	19
03305000	B	Green River near McKinney, KY	22.40	1.121	1.05	1953-73	21
03306500	B	Green River at Greensburg, KY	736.00	0.723	0.73	1941-68	28
03307000	B	Russell Creek near Columbia, KY	179.00	0.595	0.55	1941-80	40
03307100	B	Russell Creek near Gresham, KY	265.00	0.583	0.55	1966-75	10
03307500	B	South Fork Little Barren River at Edmonton, KY	18.30	1.245	0.55	1943-72	30
03308500	B	Green River at Munfordville, KY	1,681.00	0.568	0.63	1916-22, 1929-31, 1939-68	40
03309000	B	Green River at Mammoth Cave, KY	1,984.00	0.546	0.62	1940-50	11

Magnitude of low-flow frequency (ft^3/s)					Annual 7-day low flow equal to zero[5]		Annual 30-day low flow equal to zero[5]	
30-day, 2-year	30-day, 5-year	7-day, 2-year	7-day, 10-year	7-day, 20-year	Number	Frequency	Number	Frequency
15.7	4.18	6.07	0.64	0.31	0	0.00	0	0.00
5.86	2.6	1.86	0.66	0.51	0	0.00	0	0.00
4.84	2.41	2.44	0.53	0.3	0	0.00	0	0.00
18.6	3.25	6.91	0.44	0.11	1	0.03	0	0.00
3.52	0.15	0.78	0	0	2	0.15	1	0.08
0.79	0.3	0.13	0	0	4	0.24	0	0.00
0.23	0.09	0.08	0	0	6	0.32	0	0.00
16.4	8.56	9.73	3.29	2.5	0	0.00	0	0.00
0.94	0.14	0.23	0	0	5	0.18	2	0.07
1.77	0.58	1.06	0	0	3	0.13	1	0.04
0.07	0.03	0.05	0	0	4	0.21	0	0.00
0.52	0.06	0.47	0	0	9	0.38	1	0.04
0	0	0	0	0	19	1.00	13	0.68
0	0	0	0	0	27	0.82	18	0.55
0.61	0.03	0.05	0	0	16	0.44	5	0.14
0.1	0.03	0	0	0	10	0.50	2	0.10
0.69	0	0	0	0	16	0.57	6	0.21
0.16	0	0	0	0	16	0.53	8	0.27
5.82	1.04	0.9	0	0	3	0.11	1	0.04
1.05	0.12	0.18	0	0	8	0.30	3	0.11
0.28	0.04	0	0	0	10	0.53	2	0.11
3	0.77	1.19	0.12	0.06	0	0.00	0	0.00
15	4.5	8.04	1.51	0.93	0	0.00	0	0.00
8.6	6.4	7.9	5.1	4.5	--	--	--	--
0	0	0	0	0	16	0.84	13	0.68
0.09	0	0.01	0	0	10	0.48	5	0.24
19.4	6.51	9.31	1.94	1.25	0	0.00	0	0.00
14.7	6.68	7.48	2	1.32	0	0.00	0	0.00
22.8	13.4	13.8	6.27	5	0	0.00	0	0.00
0.05	0	0	0	0	23	0.77	12	0.40
151	101	114	69.9	63	0	0.00	0	0.00
174	137	139	105	99.2	0	0.00	0	0.00

Table 2. Low-flow frequencies for streamflow-gaging stations used in the low-flow regressions in Kentucky.—Continued

[mi², square mile; ft³/s, cubic foot per second; climate years, the 12-month period April 1--March 31 is identified by the year in which it ends; Regression: B, both the logistic regression and weighted-least-squares regression; KY, Kentucky; W, weighted-least-squares regression only; L, logistic regression only; period of record for the low-flow, partial-record stations indicates years in which low-flow measurements were made; --, not applicable]

Station number	Regression	Station name	Total drainage area (mi²)	Streamflow-variability index (log base-10 ft³/s)		Homogeneous unregulated period of record (climate years)	Number of years
				Station value	Map value		
03309100[1]	W	Wet Prong Buffalo Creek Nr Mammoth Cave,	2.74	--	0.91	1963-75	13
03309500	B	McDougal Creek near Hodgenville, KY	5.28	0.584	0.55	1955-71	17
03310000	B	North Fork Nolin River at Hodgenville, KY	36.70	0.777	0.55	1943-73	31
03310078[1]	W	South Fork Nolin River at Mathers Mill, KY	50.10	--	0.46	1975-79, 1981-82, 1989	8
03310400	B	Bacon Creek near Priceville, KY	80.60	0.376	0.45	1961-94	34
03310500	B	Nolin River at Wax, KY	599.00	0.459	0.46	1938-47	10
03310600[1]	W	Dog Creek Near Mammoth Cave, Ky	8.04	--	0.62	1962-75	14
03311000	B	Nolin River at Kyrock, KY	707.00	0.484	0.54	1932, 1941-50	11
03311100[1]	W	Bylew Creek Near Mammoth Cave, Ky	5.11	--	1.15	1962-75	14
03311600	B	Beaverdam Creek at Rhoda, KY	10.90	0.546	0.55	1974-94	21
03312000	B	Bear Creek near Leitchfield, KY	30.80	0.839	0.97	1951-71	21
03312500	B	Barren River near Pageville, KY	532.00	0.487	0.55	1940-63	24
03312765	B	Beaver Creek at Hwy 31 East, KY	47.10	0.51	0.55	1993-2002	10
03313000	B	Barren River near Finney, KY	942.00	0.503	0.55	1943-50, 1962-63	10
03313500	B	West Bays Fork at Scottsville, KY	7.46	0.638	0.55	1952-67	16
03313700[3]	B	West Fork Drakes Creek near Franklin, KY	111.00	0.552	0.55	1970-79	10
03314000	B	Drakes Creek near Alvaton, KY	475.00	0.544	0.55	1942-71	30
03314500	B	Barren River at Bowling Green, KY	1,846.00	0.547	0.55	1940-63	24
03316000	B	Mud River near Lewisburg, KY	90.60	1.17	1.15	1941-61	21
03317000	B	Rough River near Madrid, KY	225.00	0.564	0.55	1940-59	20
03317500	B	North Fork Rough River near Westview, KY	42.00	0.788	0.55	1955-73	19
03318200	B	Rock Lick Creek near Glen Dean, KY	20.10	1.007	1.11	1958-71	14
03318800	B	Caney Creek near Horse Branch, KY	117.00	1.314	1.15	1958-92	35
03319000	B	Rough River near Dundee, KY	757.00	0.697	0.74	1941-59	19
03320500	B	Pond River near Apex, KY	194.00	1.052	1.05	1942-2006	65
03321350	B	South Fork Panther Creek near Whitesville, KY	58.20	1.091	1.15	1969-83	15
03322360	L	Beaverdam Creek near Corydon, KY	10.70	1.329	1.15	1974-82, 1985-86, 1989-94	17
03383000	B	Tradewater River at Olney, KY	255.00	1.145	1.15	1942-75	34
03384000	L	Rose Creek at Nebo, KY	2.10	1.154	1.15	1953-70	18
03400500	B	Poor Fork at Cumberland, KY	82.10	0.523	0.55	1941-60	20
03400785[1]	B	Martins Fork above Smith, KY	23.70	0.575	0.55	1986-91	6
03401000	B	Cumberland River near Harlan, KY	373.00	0.536	0.55	1941-78	38

Magnitude of low-flow frequency (ft³/s)					Annual 7-day low flow equal to zero[5]		Annual 30-day low flow equal to zero[5]	
30-day, 2-year	30-day, 5-year	7-day, 2-year	7-day, 10-year	7-day, 20-year	Number	Frequency	Number	Frequency
1.1	0.8	1	0.6	0.5	--	--	--	--
0.28	0.15	0.17	0	0	2	0.12	1	0.06
0.96	0.12	0.32	0	0	6	0.19	1	0.03
6	3.9	5	2.7	2.3	--	--	--	--
10.2	7.42	8.83	5.65	4.95	0	0.00	0	0.00
76.6	58.9	67.6	44.2	38.4	0	0.00	0	0.00
1.8	0.9	1.4	0.5	0.3	--	--	--	--
85.4	64.7	72.2	51.1	46.4	0	0.00	0	0.00
1.1	0.7	0.9	0.5	0.4	--	--	--	--
0.92	0.59	0.71	0.27	0.2	0	0.00	0	0.00
0.71	0.06	0.32	0	0	5	0.24	3	0.14
72.3	50.1	54.4	30.7	26.4	0	0.00	0	0.00
6.4	4.17	4.52	2.04	1.62	0	0.00	0	0.00
105	86.3	79.7	58.1	54	0	0.00	0	0.00
0.43	0.18	0.26	0.07	0	1	0.06	0	0.00
12	10.4	8.5	6.58	6.31	0	0.00	0	0.00
44.3	29.5	32.9	17	14.2	0	0.00	0	0.00
143	97.7	105	61.1	54.6	0	0.00	0	0.00
0.84	0.02	0.21	0	0	8	0.38	4	0.19
18.2	13.1	14.3	9.6	8.96	0	0.00	0	0.00
0.38	0.19	0.18	0	0	2	0.11	0	0.00
0.21	0.05	0	0	0	8	0.57	1	0.07
0.15	0	0	0	0	22	0.63	9	0.26
28.1	18.8	19.1	13.2	12.6	0	0.00	0	0.00
0.75	0.05	0.16	0	0	25	0.38	7	0.11
0.74	0.04	0	0	0	7	0.47	1	0.07
0	0	0	0	0	15	0.88	9	0.53
0.76	0.05	0.17	0	0	12	0.35	4	0.12
0	0	0	0	0	18	1.00	18	1.00
10.7	6.53	8.27	3.6	2.77	0	0.00	0	0.00
2.9	1.3	1.9	0.5	0.4	0	0.00	0	0.00
45.9	24.2	28.5	11.2	8.62	0	0.00	0	0.00

Table 2. Low-flow frequencies for streamflow-gaging stations used in the low-flow regressions in Kentucky.—Continued

[mi², square mile; ft³/s, cubic foot per second; climate years, the 12-month period April 1--March 31 is identified by the year in which it ends; Regression: B, both the logistic regression and weighted-least-squares regression; KY, Kentucky; W, weighted-least-squares regression only; L, logistic regression only; period of record for the low-flow, partial-record stations indicates years in which low-flow measurements were made; --, not applicable]

Station number	Regression	Station name	Total drainage area (mi²)	Streamflow-variability index (log base-10 ft³/s)		Homogeneous unregulated period of record (climate years)	Number of years
				Station value	Map value		
03402930[1]	W	Fourmile Creek At Fourmile, Ky	6.20	--	0.6	1988-89, 1991-92, 2006	5
03403000[4]	B	Cumberland River near Pineville, KY	809.00	0.588	0.56	1940-71	32
03403500	B	Cumberland River at Barbourville, KY	960.00	0.613	0.57	1924-31, 1949-71	31
03403910	B	Clear Fork at Saxton, KY	331.00	0.539	0.55	1970-90, 1997-2004	29
03404000	B	Cumberland River at Williamsburg, KY	1,607.00	0.599	0.57	1952-78	27
03404500	B	Cumberland River at Cumberland Falls, KY	1,976.00	0.65	0.58	1909-11, 1916-31, 1934-60	46
03404900	B	Lynn Camp Creek at Corbin, KY	53.00	0.625	0.6	1975-89	15
03406000	B	Wood Creek near London, KY	3.90	0.526	0.7	1955-71	17
03406500	B	Rockcastle River at Billows, KY	604.00	0.693	0.7	1938-90	53
03407100	B	Cane Branch near Parkers Lake, KY	0.65	0.579	0.7	1957-66	10
03407300	B	Helton Branch at Greenwood, KY	0.85	0.454	0.6	1957-74	18
03407500	B	Buck Creek near Shopville, KY	165.00	1.054	1.04	1954-70	17
03410500	B	South Fork Cumberland River near Stearns, KY	954.00	0.595	0.6	1944-2005	62
03411000	B	South Fork Cumberland River at Nevelsville, KY	1,267.00	0.611	0.6	1916-31, 1934-50	33
03412500	B	Pitman Creek at Somerset, KY	31.00	0.754	0.71	1955-72	18
03413200	B	Beaver Creek near Monticello, KY	43.20	0.605	0.6	1970-83, 1991-95	19
03435140	B	Whippoorwill Creek near Claymour, KY	20.70	1.046	1.05	1975-91	17
03437500	B	South Fork Little River at Hopkinsville, KY	46.10	0.775	0.82	1951-60	10
03438000	B	Little River near Cadiz, KY	244.00	0.57	0.72	1941-62	22
03438070	B	Muddy Fork Little River near Cerulean, KY	30.30	1.159	1.15	1970-83	14
03610545	B	West Fork Clarks River near Brewers, KY	68.30	0.518	0.55	1970-83, 1990-94	19
03611260	B	Massac Creek near Paducah, KY	10.40	0.681	0.65	1973-93	21
03611800	B	Bayou Creek near Heath, KY	6.55	0.609	0.65	1995-2006	12
07022500	L	Perry Creek near Mayfield, KY	1.72	1.053	1.35	1954-66, 1969-72	17
07023500	L	Obion Creek at Pryorsburg, KY	37.00	1.457	1.34	1953-73	21
07025440[1]	W	Harris Fork Creek Near Fulton, KY	3.99	--	0.55	1988, 1992, 2006	3

[1] Low-flow, partial-record streamflow-gaging stations; or a long-term-continuous-record, streamflow-gaging station having less than 10 years record, which was treated as a low-flow, partial-reacord station..

[2] Combined records for stations 03237250 and 03237255.

[3] Station 03313700 had estimated 3 cubic feet per second withdrawal for water supply for the period 1977-79, which was added to the measured low flows prior to the frequency analysis.

[4] Combined records for stations 03402900 and 03403000.

[5] Refers to the number and frequency of occurrence of annual D-day low flows equalling zero.

Magnitude of low-flow frequency (ft³/s)					Annual 7-day low flow equal to zero[5]		Annual 30-day low flow equal to zero[5]	
30-day, 2-year	30-day, 5-year	7-day, 2-year	7-day, 10-year	7-day, 20-year	Number	Frequency	Number	Frequency
0.4	0.1	0.1	0.028	0.019	--	--	--	--
63.3	32	39.9	12.8	9.01	0	0.00	0	0.00
73.3	32.6	44.2	12	7.82	0	0.00	0	0.00
36.2	18.6	21.8	8.26	6.35	0	0.00	0	0.00
145	64.4	80.6	20.6	12.9	0	0.00	0	0.00
99	42.9	56.4	16.4	11.4	0	0.00	0	0.00
2.72	1.47	1.41	0.18	0.08	0	0.00	0	0.00
0.47	0.35	0.37	0.27	0.25	0	0.00	0	0.00
19.8	9.05	12.2	3.47	2.39	0	0.00	0	0.00
0.06	0.04	0.03	0.01	0.01	0	0.00	0	0.00
0.15	0.12	0.12	0.09	0.08	0	0.00	0	0.00
0.4	0.02	0.04	0	0	8	0.47	2	0.12
78.2	43.9	49.9	22.2	17.9	0	0.00	0	0.00
82.8	45.8	55.8	23.6	18.4	0	0.00	0	0.00
0.72	0.33	0.3	0.05	0	1	0.06	0	0.00
2.9	1.97	2.21	1.34	1.17	0	0.00	0	0.00
0.4	0	0.02	0	0	8	0.47	5	0.29
1.28	0.63	0.91	0.32	0.25	0	0.00	0	0.00
21.1	14.6	18.1	9.64	8.24	0	0.00	0	0.00
0.18	0.01	0.01	0	0	6	0.43	1	0.07
6.52	4.5	3.96	2.11	1.77	0	0.00	0	0.00
0.42	0.3	0.28	0.14	0.12	0	0.00	0	0.00
0.2	0.15	0.1	0.04	0.03	0	0.00	0	0.00
0	0	0	0	0	17	1.00	15	0.88
0	0	0	0	0	18	0.86	9	0.43
0.2	0.1	0.1	0.1	0.047	--	--	--	--

Table 3. Basin characteristics tested for use in the low-flow regression analyses in Kentucky.

[ft, foot; DEM, digital elevation model; ft³/s, cubic foot per second; Ksat, permeability of saturated soil; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; KGS, Kentucky Geological Survey; SAS, Statistical Analysis System, Inc. (a registered trademark of SAS Institute, Inc., Cary, N.C.); PRISM, Parameter-elevation Regressions on Independent Slopes Model; µm/s, micrometer per second; SSURGO, Soil Survey Geographic (Database); USDA, U.S. Department of Agriculture; ArcGIS and ArcHydro Tools are trademarks of Environmental Systems Research Institute, Inc., Redlands, Calif.]

Name	Units	Method	Source data
Physical measurements			
Total drainage area	Square miles	ArcHydro flow accumulation	Statewide Kentucky Single Zone 30-ft DEM (*http://technology.ky.gov/gis/*) conditioned to conform to the National Hydrography Dataset, 1:24,000 scale (*http://nhd/usgs/gov*).
Centroid latitude	Degrees	ArcGIS 9.0 centroid method	NAD 83
Centroid longitude	Degrees	ArcGIS 9.0 centroid method	NAD 83
Gage latitude	Degrees	ArcGIS 9.0	NAD 83
Gage longitude	Degrees	ArcGIS 9.0	NAD 83
Mean basin elevation	Feet above mean sea level	NAVD 88 and ArcGIS 9.0	National Elevation Dataset elevation grid, 10- and 30-meter resolution (*http://nhd.usgs.gov*)
Stream slope, 10/85 method	Feet per mile	ArcHydro method	National Hydrography Dataset, 1:24,000 scale (*http://nhd.usgs.gov*) and National Elevation Dataset elevation grid, 10- and 30-meter resolution (*http://nhd.usgs.gov*)
Land cover			
Cultivated crops	Percent	(Area A82/drainage area) times 100, where classes are defined at *http://www.mrlc.gov*	U.S. Geological Survey, 2007—National Land-Cover Database, 2001 (*http://www.mrlc.gov*)
Forest	Percent	(Sum of areas A42-A43/drainage area) times 100, where classes are defined at *http://www.mrlc.gov*	U.S. Geological Survey, 2007—National Land-Cover Database, 2001 (*http://www.mrlc.gov*)
Wetlands	Percent	(Sum of areas A11, A90 and A95/drainage area) times 100, where classes are defined at *http://www.mrlc.gov*	U.S. Geological Survey, 2007—National Land-Cover Database, 2001 (*http://www.mrlc.gov*)
Grasslands	Percent	(Sum of area A71/drainage area) times 100, where classes are defined at *http://www.mrlc.gov*	U.S. Geological Survey, 2007—National Land-Cover Database, 2001 (*http://www.mrlc.gov*)
Pasture/hay	Percent	(Sum of area A81/drainage area) times 100, where classes are defined at *http://www.mrlc.gov*	U.S. Geological Survey, 2007—National Land-Cover Database, 2001 (*http://www.mrlc.gov*)

Table 3. Basin characteristics tested for use in the low-flow regression analyses in Kentucky.—Continued

[ft, foot; DEM, digital elevation model; ft^3/s, cubic foot per second; Ksat, permeability of saturated soil; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; KGS, Kentucky Geological Survey; SAS, Statistical Analysis System, Inc. (a registered trademark of SAS Institute, Inc., Cary, N.C.); PRISM, Parameter-elevation Regressions on Independent Slopes Model; µm/s, micrometer per second; SSURGO, Soil Survey Geographic (Database); USDA, U.S. Department of Agriculture; ArcGIS and ArcHydro Tools are trademarks of Environmental Systems Research Institute, Inc., Redlands, Calif.]

Name	Units	Method	Source data
Geology			
Mississippian	Percent and indicator	(Selected cells/basin cells) times 100	Geology of Kentucky, simplified digital version, 2002 (*http://kgsweb.uky.edu/download/state/kygeol.ZIP*)
Ordivician	Percent and indicator	(Selected cells/basin cells) times 100	Geology of Kentucky, simplified digital version, 2002 (*http://kgsweb.uky.edu/download/state/kygeol.ZIP*)
Pennsylvanian	Percent and indicator	(Selected cells/basin cells) times 100	Geology of Kentucky, simplified digital version, 2002 (*http://kgsweb.uky.edu/download/state/kygeol.ZIP*)
Sink holes in basin	Each	Summation	Taylor and Nelson, 2008
Sink-hole drainage	Percent	(Sink cells/basin cells) times 100	Taylor and Nelson, 2008
Non-sink-hole drainage	Percent	100 – Sink-hole drainage	Taylor and Nelson, 2008
Physiography			
Physiographic regions including Eastern Coalfield, Eastern Pennyroyal, Inner Bluegrass, Outer Bluegrass, Western Pennyroyal, Western Coalfield, Purchase	Percent and indicator	(Selcted cells/basin cells) times 100	H.L. Nelson Jr., U.S. Geological Survey, written commun., 2005; adapted from Physiographic Diagram of Kentucky (Kentucky Geological Survey, 1980)
Hydrography			
Streamflow-varibility index (map value)	Log-10 ft^3/s	Area-weighted average	Plate 2
Streamflow-varibility index (station value)	Log-10 ft^3/s	SAS percentiles on continuous ranking of the daily mean streamflow values	U.S. Geological Survey National Water Information System (NWIS)
Flow-duration ratio (map value)	Unitless	Area-weighted average	Map of flow-duration ratio
Flow-duration ratio (station value)	Unitless	Ratio of the 20- and 90-percent flow-duration flows determined on SAS percentiles on continuous ranking of the daily mean streamflow values	U.S. Geological Survey National Water Information System (NWIS)
Recession index (station value)	Days to decline one log cycle	Graphical (Riggs, 1964)	U.S. Geological Survey National Water Information System (NWIS)

Table 3. Basin characteristics tested for use in the low-flow regression analyses in Kentucky.—Continued

[ft, foot; DEM, digital elevation model; ft^3/s, cubic foot per second; Ksat, permeability of saturated soil; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; KGS, Kentucky Geological Survey; SAS, Statistical Analysis System, Inc. (a registered trademark of SAS Institute, Inc., Cary, N.C.); PRISM, Parameter-elevation Regressions on Independent Slopes Model; µm/s, micrometer per second; SSURGO, Soil Survey Geographic (Database); USDA, U.S. Department of Agriculture; ArcGIS and ArcHydro Tools are trademarks of Environmental Systems Research Institute, Inc., Redlands, Calif.]

Name	Units	Method	Source data
		Meteorological	
Precipitation (mean monthly, seasonal, and annual)	Millimeters times 100	ArcGIS areal mean, centroid, and gage values	PRISM Group at Oregon State University monthly and annual values 1971–2000 (*http:\\ORION\F$\Metadata\meta_30sec\us_ppt01_30*)
Precipitation frequency (24-hour, 2-year)	Inches times 1,000	ArcGIS areal mean	National Oceanic and Atmospheric Administration Atlas 14, Volume 2 (*http://www.nws.noaa.gov/ohd/hdsc/index.html*)
Climate region (Eastern, Bluegrass, Central, Western Kentucky)	Percent and indicator	(Selected cells/basin cells) times 100	Climate Regions of Kentucky (Kentucky Climate Center at Western Kentucky University, 2008a, b)
		Soils	
Water Holding Capacity	Unitless	Averaged for depth where Ksat > 1 µm/s as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)
Conductivity Multiplier	Unitless	Averaged for depth where Ksat > 1 µm/s as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)
Soil Depth	Inches	Averaged for depth where Ksat > 1 µm/s as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)
Field Capacity	Unitless	Averaged for depth where Ksat > 1 µm/s as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)
Permeability	Inches per hour and indicator	Averaged for depth where Ksat > 1 µm/s as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)
Porosity	Unitless	Averaged for depth where Ksat > 1 µm/sec as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)
Sand, silt, clay	Percent	Averaged for depth where Ksat > 1 µm/sec as reported in SSURGO then representative values rasterized and sampled by drainage basin.	Soil Survey Geographic (SSURGO) Data for Kentucky (*http://www.soils.usda.gov/survey/geography/ssurgo/*), USDA–Natural Resources Conservation Service (2007)

Glossary

climate year The 12-month period from April 1 through March 31. The climate year is designated by the calendar year in which the period ends.

coefficient of multiple determination The proportion of the variation in the dependent variable explained by the variables in a fitted regression model. Reported values are adjusted for error degrees of freedom.

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

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

multicollinearity 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 used to model the linear relation between a dependent variable and one or more independent variables.

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. PRESS is computed by summing the square of the prediction residuals resulting from the series of predictions of each observation by regressions defined by using all other observations. Thus, each observation is left out of the regression data set and is not used in prediction of that observation. This process simulates prediction with new data and is a form of data splitting useful for model validation (Allen, 1971, 1974; and Montgomery and Peck, 1982).

regulated streamflow Streamflow controlled by upstream hydraulic structures such as dams.

residual The difference between value of the streamflow statistic computed by use of streamflow-gaging data and value estimated by use of a regression model.

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

standard error of prediction A measure of model-prediction error; it was estimated as the square root of the PRESS divided by the degrees of freedom for error (SAS Institute, Inc., 1985; Montgomery and Peck, 1982; and Choquette, 1988). (*See* Prediction Sum of Squares (PRESS) Statistic.)

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

streamflow-gaging station An installation that provides systematic observations of stage from which streamflow is computed.

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

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

Note: In the standardized USGS regional-regression nomenclature the statistics and basin characteristics used herein are designated as follows: $30Q_2$, M30D2Y; $30Q_5$, M30D5Y; $7Q_2$, M7D2Y; $7Q_{10}$, M7D10Y; $7Q_{20}$, M7D20Y; A, ABEL8K; V, STREAM_VAR, respectively.

Appendix 1. Trend Tests of Long-Term Climate Data for Kentucky During 1895–2004

Daily average temperature and total precipitation data for the 110-year period January 1895–December 2004 (Kentucky Climate Center at Western Kentucky University, 2008a, b), aggregated to monthly and annual values, were examined to assess how seasonal weather and long-term climate patterns (the climate signal) may have affected low-flow characteristics in Kentucky. Trend tests including the seasonal-Kendall (Mathsoft, Inc., 1999a, 1999b; Hirsch and others, 1982), Mann-Kendall (Helsel and Hirsch, 2002), and a modified generalized-least-squares regression on time were made by using the monthly, seasonal, and annual statewide temperature and precipitation data for Kentucky. The generalized-least-squares (GLS) regression against time compensates for possible serial correlation in the residuals of the regression. Serial correlation in time series may bias the results of the Mann-Kendall trend test (Dave Lorenz, U.S. Geological Survey, oral commun., 2007). The GLS regression against time was done by use of the AUTOREG procedure (Freund and Littell, 2000) in SAS 9 (SAS Institute, Inc., 2004).

Results of trend tests of annual and seasonal average temperatures and total precipitation for selected periods during 1895–2004 are shown in table 1–1. A p-value of 0.2 or less was indicative of possible trend. The results were, in general, consistent with the patterns observed in the LOWESS curves (fig. 4 in main report). No full-year trend in temperature during the entire 1895–2004 period was detected. A positive trend was detected in the statewide monthly cold-season (November–March) temperatures and negative trend in warm-season (April–October) temperatures from 1895–2004. Only one of the tests (seasonal-Kendall of monthly data) indicated a positive trend (p-value 0.0835) for full-year precipitation for the period 1895–2004.

Table 1–1. Summary of trends and trend-test p-values in statewide monthly and annual temperature and precipitation data for 1895–2004 in Kentucky.

[T, temperature; P, precipitation; Winter, period including November through March; Summer; period including April through October; --, no trend detected at p-value 0.20 under null hypothesis of no trend; na, not tested; ↑, positive trend; ↓, negative trend

Period	Full year		Winter 5 months		Summer 7 months	
	T	P	T	P	T	P
Summary of trends detected at a p-value of 0.20						
1895–2004	--	↑	↑	--	↓	↑
1895–1945	↑	na	↑	na	--	na
1946–1975	↓	na	--	na	↓	na
1976–2004	↑	na	↑	na	--	na
1950–2004	na	↑	↑	--	--	↑
1920–1950	na	--	na	--	na	--
Seasonal-Kendall test p-values using monthly values						
1895–2004	0.4355	0.0835	0.1007	0.3265	0.0146	0.0052
1895–1945	.2613	na	.1982	na	.7293	na
1946–1975	.0693	na	.4663	na	.0777	na
1976–2004	.0287	na	.0191	na	.2212	na
1950–2004	na	.1893	.0515	.9304	.8953	.0624
1920–1950	na	.9634	na	.6319	na	.6872
Kendall's tau test p-values using annual values						
1895–2004	0.7723	0.3187	0.1409	0.4695	0.0279	0.0035
1895–1945	.0911	na	.0484	na	.8012	na
1946–1975	.1387	na	.3177	na	.1042	na
1976–2004	.0069	na	.021	na	.2448	na
1950–2004	na	.1723	na	.5911	na	.0183
1920–1950	na	.7211	na	.5074	na	.7726
Generalized-least-squares regression-on-time test p-values using annual values						
1895–2004	0.8733	0.2106	0.1187	0.4433	0.0261	0.0042
1895–1945	.0926	na	.0317	na	.6788	na
1946–1975	.0863	na	.3002	na	.0914	na
1976–2004	.0039	na	.0285	na	.2153	na
1950–2004	na	.2874	na	.596	na	.0433
1920–1950	na	.9525	na	.4433	na	.9972

Appendix 2. Trend-Test Screening of Annual 7-Day Low Flows for Selected Long-Term Continuous-Record Streamflow-Gaging Stations in Kentucky for Various Periods of Record

The annual 7-day low-flow time series were screened by use of trend-indicator tests to examine various periods of record for each LTCR streamflow-gaging station in Kentucky. Trends were examined by use of the Mann-Kendall test (Helsel and Hirsch, 2002) (table 2–1), which may indicate monotonic increasing and decreasing values over time. However, there must be no serial correlation of the observations for the p-values from the Mann-Kendall test to be correct. Annual low-flow time series may exhibit appreciable serial correlation. Trends also were examined by use of the modified generalized-least-squares regression approach, a regression against time that compensates for possible serial correlation in the residuals of the regression. The data were examined after log base-10 transformation. The significance of the slope term in the regression of annual 7-day low flows versus time (year) by using a p-value of 0.2 was an indicator of possible trend. The Durbin-Watson statistic on the residuals from the regressions provided an indication of serial correlation. Most of the time, the results were consistent for these two trend tests. The raw computations for these two trend tests on the annual 7-day low flows for selected LTCR stations in Kentucky for various periods of the record are listed in table 2–1.

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3207965	0.389	0.0143	0.5576	2.3971	0.0319	0.0001	1975-2006	21
3207965	0.022	0.9287	0.0486	2.5621	0.0148	0.5405	1975-1992	10
3207965	-0.315	0.1830	0.0468	3.0610	-0.0120	0.5230	1993-2006	11
3208000	0.470	<.0001	0.3769	1.9566	0.0258	<.0001	1939-1992	54
3208000	0.237	0.0661	0.1238	2.2665	0.0221	0.0565	1939-1968	30
3208000	-0.036	0.8121	0.0219	0.9593	0.0062	0.5005	1970-1992	23
3209300	-0.033	0.8153	0.0652	1.0081	0.0061	0.2180	1968-1992	25
3209500	0.590	<.0001	0.5733	1.6888	0.0211	<.0001	1939-2006	68
3209500	0.033	0.8153	0.0062	2.1911	0.0054	0.7092	1939-1963	25
3209500	0.209	0.0690	0.2179	1.8244	0.0054	0.0036	1970-2006	37
3209800	0.242	0.2726	0.2757	1.4166	0.0169	0.0796	1970-1981	12
3210000	0.572	<.0001	0.4585	1.8614	0.0376	<.0001	1942-2006	63
3210000	0.220	0.0746	0.0822	1.9779	0.0301	0.1002	1942-1975	34
3210000	0.330	0.0120	0.2265	1.7792	0.0134	0.0091	1976-2006	29
3211500	0.565	<.0001	0.4425	1.2792	0.0184	<.0001	1941-1992	52
3211500	0.200	0.4208	0.1149	2.6574	0.0517	0.3379	1941-1950	10
3211500	0.358	0.0011	0.1119	1.7210	0.0047	0.0326	1952-1992	41
3212000	0.140	0.3264	0.1131	2.3665	0.0299	0.1003	1951-1975	25
3212000	0.236	0.1724	0.1170	2.5338	0.0477	0.1647	1951-1968	18
3212500	0.592	<.0001	0.6420	1.8047	0.0165	<.0001	1930-2006	77
3212500	0.200	0.2047	0.0628	2.9326	0.0144	0.2731	1930-1950	21
3212500	0.126	0.4135	0.0848	1.7633	0.0052	0.1886	1985-2006	22
3215500	0.053	0.6371	0.0049	2.0389	-0.0025	0.6714	1917-1975	39
3216000	0.152	0.4929	0.0688	2.7978	0.0102	0.4102	1941-1952	12
3216350	0.305	0.0334	0.2217	0.9073	0.0174	0.0175	1969-1992	25
3216400	0.515	0.0197	0.5774	1.3573	0.0354	0.0041	1969-1980	12
3216500	0.441	<.0001	0.4936	1.3646	0.0148	<.0001	1939-2006	68
3216500	-0.002	0.9858	0.0000	2.3471	-0.0003	0.9708	1939-1968	30
3216500	-0.122	0.2796	0.0000	1.0977	0.0000	0.9984	1969-2006	38
3216540	0.007	0.9676	0.0051	2.0879	0.0122	0.7790	1974-1991	18

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3216600	-0.156	0.1738	0.0084	1.8852	-0.0012	0.5903	1970-2006	37
3216800	-0.273	0.0179	0.1185	1.5676	-0.0268	0.0369	1958-1994	37
3216800	0.022	0.9287	0.0949	1.9041	0.0823	0.3864	1958-1967	10
3216800	-0.294	0.0317	0.1647	1.5150	-0.0434	0.0357	1968-1994	27
3217000	0.038	0.6547	0.0070	1.8080	0.0030	0.5077	1942-2006	65
3217000	0.095	0.4944	0.0200	1.9468	0.0137	0.4911	1942-1967	26
3217000	-0.131	0.2406	0.0342	1.6670	-0.0102	0.2594	1968-2006	39
3237255	0.099	0.6222	0.0136	1.9912	0.0231	0.6913	1993-2006	14
3237255	-0.091	0.6971	0.0609	2.2345	-0.0561	0.4644	1993-2003	11
3237900	-0.079	0.6504	0.0037	1.6741	-0.0074	0.7993	1973-1991	20
3238000	0.008	0.9579	0.0008	2.1152	0.0007	0.8959	1942-1964	23
3248500	0.344	0.0002	0.2039	2.1492	0.0259	0.0005	1940-1997	55
3248500	0.171	0.1443	0.0563	2.1987	0.0231	0.1634	1940-1975	36
3248500	-0.088	0.5997	0.0016	1.5526	-0.0021	0.8726	1976-1997	19
3249500	0.410	<.0001	0.2551	2.3098	0.0128	<.0001	1929-2006	59
3249500	0.140	0.2179	0.0482	2.3558	0.0087	0.1854	1929-1973	38
3249500	0.274	0.0916	0.2033	2.1450	0.0152	0.0460	1975-2006	20
3250000	0.270	0.0149	0.1658	1.8215	0.0324	0.0082	1943-1992	41
3250000	0.099	0.6001	0.0184	1.9471	0.0320	0.6038	1943-1959	17
3250100	-0.211	0.1377	0.0953	1.3226	-0.0391	0.1249	1969-1994	26
3250500	0.153	0.2827	0.1827	2.3074	0.0103	0.0331	1939-2006	25
3250500	-0.076	0.6290	0.0180	2.4439	-0.0102	0.5623	1939-1959	21
3251000	0.180	0.1015	0.0630	1.8989	0.0202	0.1002	1948-1991	44
3251000	0.306	0.1308	0.1412	2.9451	0.0767	0.1514	1948-1963	16
3251200	-0.125	0.5417	0.1126	2.6630	-0.0911	0.2408	1993-2006	14
3251500	0.459	<.0001	0.3527	1.7287	0.0139	<.0001	1926-2006	61
3251500	0.195	0.0994	0.0556	1.8593	0.0085	0.1727	1926-1973	35
3251500	-0.060	0.6742	0.0100	1.9438	-0.0029	0.6342	1975-2006	25
3252000	0.292	0.0099	0.1881	1.5037	0.0154	0.0065	1954-1991	38
3252300	-0.099	0.6222	0.0424	2.2908	-0.0447	0.4799	1993-2006	14

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3252500	0.316	0.0006	0.1208	1.8355	0.0095	0.0087	1939-1994	56
3252500	0.406	0.0002	0.2070	2.0020	0.0179	0.0025	1939-1980	42
3252500	0.222	0.0744	0.0279	2.2262	0.0076	0.3610	1939-1970	32
3253500	0.319	<.0001	0.2231	1.8681	0.0092	<.0001	1917-2006	78
3253500	0.038	0.7101	0.0040	2.1986	0.0019	0.6814	1917-1973	45
3253500	-0.149	0.2301	0.0407	1.6992	-0.0067	0.2681	1975-2006	32
3254400	-0.071	0.7355	0.0013	1.8680	0.0056	0.8990	1969-1983	15
3255000	-0.028	0.8533	0.0001	2.7356	0.0002	0.9676	1941-75	23
3277200	-0.250	0.0343	0.0536	1.9141	-0.0039	0.1807	1972-2006	35
3277400	0.448	0.0200	0.5656	1.8139	0.0172	0.0012	1966-1998	15
3277450	0.552	<.0001	0.5298	2.0017	0.0590	<.0001	1965-1994	30
3277450	0.477	0.0423	0.3392	2.1837	0.1431	0.0601	1965-1975	11
3277450	0.477	0.0057	0.5245	1.4451	0.0470	0.0007	1977-1994	18
3277500	0.433	<.0001	0.3734	2.0277	0.0195	<.0001	1941-2006	53
3277500	0.232	0.0500	0.1139	2.0312	0.0153	0.0474	1941-1975	35
3277500	0.279	0.1175	0.1336	1.9596	0.0218	0.1491	1977-2006	17
3278000	0.279	0.1368	0.1291	1.7335	0.0304	0.1431	1956-1973	18
3278500	0.350	0.0059	0.2130	2.1025	0.0465	0.0090	1951-1981	31
3278500	0.000	1.0000	0.0059	2.0709	0.0189	0.7861	1951-1965	15
3278500	0.367	0.0476	0.2146	2.4517	0.0465	0.0707	1966-1981	16
3280000	0.459	<.0001	0.4041	2.0756	0.0182	<.0001	1930-2006	68
3280000	0.225	0.0498	0.1480	2.0872	0.0195	0.0187	1930-1975	37
3280000	0.129	0.3177	0.0284	2.2396	0.0052	0.3732	1977-2006	30
3280000	0.093	0.4557	0.0673	2.1024	0.0146	0.1516	1930-1970	32
3280000	0.031	0.8186	0.0425	2.1507	0.0137	0.3024	1930-1965	27
3280000	-0.022	0.8879	0.0315	2.2407	0.0141	0.4294	1930-1960	22
3280600	0.163	0.1771	0.0016	2.5023	0.0038	0.8207	1959-1992	34
3280600	-0.092	0.7165	0.0004	1.8509	-0.0036	0.9590	1959-1968	10
3280700	0.306	0.0022	0.2016	1.9195	0.0199	0.0014	1959-2006	48
3280700	-0.004	0.9729	0.0022	2.0910	0.0030	0.8038	1959-1989	31

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3280700	-0.206	0.2487	0.0580	1.5946	-0.0178	0.3516	1990-2006	17
3280900	0.209	0.2983	0.1717	2.6751	0.0326	0.1408	1962-1975	14
3281000	0.295	0.0006	0.2557	1.4338	0.0163	<.0001	1932-2006	64
3281000	-0.076	0.6290	0.0277	2.1289	-0.0161	0.4707	1932-1960	21
3281000	-0.162	0.1319	0.0394	2.1526	-0.0042	0.2077	1962-2006	42
3281040	0.071	0.6022	0.0121	2.2398	0.0061	0.5855	1974-2000	27
3281040	-0.200	0.2799	0.0963	2.8957	-0.0251	0.2421	1974-1989	16
3281040	-0.564	0.0158	0.3654	2.5720	-0.0843	0.0489	1990-2000	11
3281100	0.170	0.1184	0.0683	1.8945	0.0095	0.0989	1966-2006	41
3281100	-0.203	0.1648	0.1193	1.7127	-0.0208	0.0983	1966-1989	24
3281100	-0.214	0.2319	0.0239	1.9931	-0.0104	0.5536	1990-2006	17
3281500	0.198	0.0141	0.0766	1.7623	0.0094	0.0186	1926-2006	72
3281500	0.004	0.9741	0.0004	1.7722	-0.0015	0.9094	1926-1966	32
3281500	0.004	0.9721	0.0014	2.0183	-0.0018	0.8203	1967-2006	40
3282000	0.298	0.0002	0.2388	1.6454	0.0097	<.0001	1927-2006	72
3282000	0.278	0.0104	0.1323	1.5768	0.0121	0.0194	1941-1960	41
3282000	-0.028	0.8304	0.0006	1.9902	0.0009	0.8954	1977-2006	30
3282040	-0.090	0.6688	0.0623	2.1975	-0.0646	0.4110	1994-2006	13
3282500	0.148	0.1267	0.0364	1.8706	0.0123	0.1753	1955-2006	52
3282500	0.256	0.1583	0.2149	3.1624	0.0797	0.0609	1955-1971	17
3282500	-0.268	0.0246	0.1386	2.1945	-0.0339	0.0276	1972-2006	35
3283000	0.185	0.2848	0.2139	2.3570	0.0608	0.0462	1955-1973	19
3283500	0.154	0.0608	0.0601	1.8501	0.0045	0.0423	1932-2006	69
3283500	-0.138	0.3553	0.0231	2.1572	-0.0084	0.4884	1932-60	23
3283500	0.121	0.2366	0.0464	1.6299	0.0055	0.1505	1961-2006	46
3284000	0.302	<.0001	0.2229	1.9792	0.0060	<.0001	1909-2006	96
3284000	-0.003	0.9748	0.0005	2.2147	0.0005	0.8754	1909-1960	52
3284000	0.013	0.9213	0.0004	1.8714	0.0007	0.9160	1977-2006	28
3284300	0.019	0.9211	0.1418	1.7444	0.0545	0.1665	1969-1983	15
3284500	0.323	0.0073	0.1246	1.9493	0.0080	0.0406	1941-2006	34

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3284500	0.084	0.6037	0.0003	2.2038	0.0011	0.9392	1941-1960	20
3285000	0.302	0.0005	0.2082	1.7620	0.0251	0.0002	1944-2006	63
3285000	0.164	0.2264	0.0677	2.0367	0.0320	0.1810	1944-1971	28
3285000	-0.050	0.6700	0.0004	1.6760	-0.0015	0.9117	1972-2006	35
3286500	-0.103	0.6255	0.0013	1.9696	-0.0031	0.9081	1994-2006	13
3287000	-0.085	0.5092	0.0002	2.1158	0.0005	0.9373	1977-2006	30
3287500	-0.094	0.4645	0.0067	1.9743	-0.0029	0.6674	1977-2006	30
3288000	0.361	0.0006	0.1959	1.7155	0.0268	0.0026	1951-1999	44
3288000	0.292	0.0469	0.2951	1.7849	0.0686	0.0050	1951-1975	24
3288000	-0.121	0.4553	0.0001	2.0609	-0.0009	0.9636	1975-1999	20
3288500	0.331	0.0525	0.2387	2.5095	0.0455	0.0338	1954-1972	19
3289000	0.421	<.0001	0.3509	1.5066	0.0365	<.0001	1951-2006	50
3289000	0.379	0.0131	0.2861	2.0097	0.0842	0.0071	1951-1974	24
3289000	-0.092	0.5084	0.0481	1.9848	-0.0076	0.2816	1975-99	26
3289300	-0.127	0.3979	0.0635	0.9467	-0.0063	0.2460	1984-2006	23
3289500	0.417	<.0001	0.2529	1.3372	0.0087	<.0001	1917-2006	64
3289500	0.236	0.0578	0.0005	1.4038	-0.0006	0.9070	1917-1970	32
3289500	0.030	0.8078	0.0031	1.7343	0.0010	0.7612	1971-2006	32
3289500	0.083	0.5792	0.0626	1.8069	0.0067	0.2495	1980-2006	23
3290500	0.017	0.8337	0.0000	1.9077	0.0001	0.9599	1927-2006	74
3290500	-0.117	0.3629	0.0113	1.9885	-0.0037	0.5755	1977-2006	30
3291000	-0.064	0.6530	0.0005	1.5365	0.0014	0.8973	1943-1975	33
3291500	0.285	0.0020	0.1550	1.4594	0.0199	0.0020	1917-2006	59
3291500	-0.104	0.3990	0.0444	1.7578	-0.0167	0.2176	1917-1971	36
3291500	-0.095	0.5260	0.0322	2.3919	-0.0124	0.4128	1972-2006	23
3292460	-0.674	<.0001	0.7174	1.8036	-0.0951	<.0001	1969-1994	26
3292500	0.551	<.0001	0.4368	1.4362	0.0270	<.0001	1946-2006	41
3292500	-0.079	0.6887	0.0132	1.7374	-0.0190	0.6831	1946-1962	15
3292500	-0.007	0.9697	0.0211	1.5332	-0.0034	0.5655	1980-2006	18
3293000	0.055	0.5460	0.0124	0.8888	0.0038	0.4044	1946-2006	58

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3294500	-0.219	0.0562	0.0354	1.9485	-0.0029	0.2649	1929-2006	37
3294500	-0.219	0.0562	0.0354	1.9485	-0.0029	0.2649	1970-2006	37
3295000	0.293	0.0934	0.1744	2.0514	0.0561	0.0669	1954-1973	20
3295400	-0.159	0.3918	0.0168	1.9003	-0.0211	0.6321	1991-2006	16
3295500	0.458	<.0001	0.3739	1.8855	0.0621	<.0001	1940-1982	43
3295500	0.109	0.4547	0.0170	2.2380	0.0178	0.5087	1940-67	28
3295500	0.230	0.2344	0.0830	1.5161	0.0351	0.2977	1968-1982	15
3295890	0.214	0.1482	0.0900	2.3528	0.0519	0.1544	1983-2006	24
3297500	0.047	0.7964	0.0001	2.2935	0.0007	0.9666	1955-1974	20
3297845	-0.130	0.6165	0.0151	2.0145	-0.0264	0.7186	1981-1991	11
3297900	0.103	0.6255	0.0063	2.4093	0.0119	0.7962	1993-2006	13
3298000	0.406	<.0001	0.2946	1.6338	0.0337	<.0001	1946-2006	58
3298000	0.353	0.0115	0.1623	2.2280	0.0422	0.0273	1946-1975	30
3298000	-0.011	0.9369	0.0012	1.2962	0.0036	0.8591	1976-2006	28
3298500	0.588	<.0001	0.5542	1.8032	0.0402	<.0001	1940-2006	67
3298500	0.489	<.0001	0.3994	1.9087	0.0540	<.0001	1940-82	43
3298500	0.189	0.1602	0.0907	1.9580	0.0375	0.1194	1940-67	28
3298500	0.178	0.2346	0.1365	2.3034	0.0148	0.0827	1984-2006	23
3298550	-0.169	0.4087	0.0072	1.1163	-0.0096	0.7726	1993-2006	14
3299000	0.221	0.0199	0.1157	1.4690	0.0247	0.0118	1939-1992	54
3299000	0.223	0.1125	0.1128	1.4109	0.0507	0.0868	1939-1965	27
3299000	-0.092	0.5044	0.0699	1.9541	-0.0314	0.1828	1966-1992	27
3300000	0.376	0.0364	0.2120	2.2938	0.0692	0.0473	1954-1972	19
3300400	-0.169	0.1676	0.0665	1.6019	-0.0268	0.1472	1974-2006	33
3300400	-0.096	0.5920	0.0164	1.9606	-0.0236	0.6244	1990-2006	17
3301000	0.341	0.0019	0.1315	1.7870	0.0138	0.0215	1941-2006	40
3301000	0.255	0.0962	0.0810	1.9719	0.0341	0.1994	1941-1962	22
3301000	0.294	0.0883	0.0300	1.5369	0.0056	0.4916	1963-2006	18
3301500	0.219	0.0088	0.1328	1.6823	0.0096	0.0024	1940-2006	67
3301500	0.154	0.2703	0.0556	1.8103	0.0173	0.2464	1940-65	26

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3301500	-0.174	0.1686	0.0010	1.7508	-0.0011	0.8429	1966-2006	31
3302000	0.329	0.0003	0.3177	0.6109	0.0139	<.0001	1946-2006	58
3302000	0.600	<.0001	0.4708	1.0728	0.0429	0.0002	1970-2006	35
3303280	0.067	0.6049	0.0147	2.1206	0.0028	0.5240	1977-2006	30
3303500	0.294	0.2115	0.1011	2.7413	0.0171	0.3406	1942-52	11
3304500	0.000	1.0000	0.0005	2.3478	-0.0013	0.9300	1953-1971	19
3305000	0.340	0.0454	0.1797	1.8744	0.0471	0.0555	1953-1973	21
3306000	-0.048	0.7627	0.0810	1.9719	0.0341	0.1994	1970-1994	21
3306500	0.352	0.0025	0.1961	1.1424	0.0201	0.0068	1941-2006	36
3306500	0.101	0.4528	0.0083	1.2778	0.0059	0.6457	1941-1968	28
3307000	0.248	0.0032	0.1165	1.7065	0.0075	0.0050	1941-2006	66
3307000	0.382	0.0005	0.2452	1.4059	0.0174	0.0012	1941-1980	40
3307000	-0.058	0.6754	0.0076	2.2924	-0.0048	0.6729	1981-2006	26
3307100	0.333	0.1797	0.2396	2.6850	0.0427	0.1511	1966-75	10
3307500	0.306	0.0374	0.0890	2.0047	0.0221	0.1093	1943-72	30
3308500	0.326	<.0001	0.2229	1.0437	0.0043	<.0001	1916-2006	76
3308500	-0.010	0.9257	0.0014	1.0981	-0.0005	0.8209	1916-1968	40
3308500	-0.277	0.0191	0.1461	1.9382	-0.0048	0.0234	1970-2006	35
3309000	0.345	0.1391	0.3292	2.3139	0.0199	0.0649	1940-1950	11
3309500	0.052	0.7725	0.1073	1.3526	0.0421	0.1994	1955-1971	17
3310000	0.173	0.1775	0.0831	1.4249	0.0292	0.1157	1943-1973	31
3310300	0.033	0.7475	0.0021	1.6718	0.0005	0.7618	1961-2006	46
3310300	0.484	0.0028	0.4149	1.9992	0.0168	0.0022	1961-1980	20
3310300	-0.040	0.7745	0.0022	1.6095	-0.0008	0.8210	1981-2006	26
3310400	-0.014	0.9056	0.0007	1.3126	-0.0004	0.8845	1961-1994	34
3310500	0.177	0.2157	0.0575	1.2579	0.0055	0.2481	1938-1962	25
3310500	-0.022	0.9287	0.0045	1.7564	0.0029	0.8532	1938-1947	10
3310500	0.115	0.5521	0.0001	1.1222	0.0004	0.9757	1948-1962	15
3311000	-0.136	0.1441	0.0051	2.1700	-0.0047	0.6061	1931-2004	55
3311000	0.236	0.3115	0.0669	2.3520	0.0062	0.4424	1931-1950	11

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3311000	0.189	0.0804	0.0672	2.4787	0.0303	0.0973	1964-2004	42
3311500	0.336	0.0002	0.2373	1.2603	0.0053	<.0001	1926-1992	59
3311500	0.099	0.4531	0.0208	1.0183	0.0025	0.4559	1926-1962	29
3311500	-0.265	0.0768	0.1658	2.7835	-0.0088	0.0538	1970-1992	23
3311600	-0.130	0.4141	0.0589	2.1655	-0.0115	0.2890	1974-1994	21
3312000	0.294	0.0676	0.2255	0.8140	0.0672	0.0296	1951-1971	21
3312000	0.277	0.2906	0.0538	0.7649	0.0779	0.5189	1951-1960	10
3312000	-0.127	0.5858	0.1337	1.9712	-0.0460	0.2687	1961-1971	11
3312500	0.091	0.5351	0.0216	1.3095	0.0043	0.4935	1940-1963	24
3312765	-0.111	0.6547	0.0253	2.7664	-0.0138	0.6607	1993-2002	10
3313000	-0.037	0.7361	0.0049	2.1052	-0.0031	0.6645	1943 - 1994	41
3313000	0.156	0.5312	0.0045	2.2480	0.0012	0.8540	1943 - 1963	10
3313000	0.237	0.0661	0.0205	2.1837	0.0128	0.4506	1965 - 1994	30
3313500	0.689	<.0001	0.5950	2.2839	0.0681	<.0001	1952 - 1972	21
3313500	0.610	0.0011	0.5052	2.3156	0.0784	0.0020	1952 - 1967	16
3313700	-0.143	0.2274	0.0166	1.5039	-0.0087	0.4610	1970-2004	35
3313700	-0.244	0.3252	0.2796	1.1628	-0.0404	0.1161	1970-1979	10
3313700	-0.257	0.1815	0.0411	2.1576	-0.0172	0.4688	1990-2004	15
3314000	0.299	0.0204	0.1635	1.0590	0.0105	0.0267	1942-1971	30
3314000	0.059	0.7263	0.0131	1.0524	0.0047	0.6414	1942-1960	19
3314000	0.418	0.0734	0.3506	1.4895	0.0345	0.0549	1961-1971	11
3314500	0.252	0.0048	0.1385	1.1852	0.0053	0.0037	1940-2006	59
3314500	0.087	0.5516	0.0133	1.0500	0.0038	0.5917	1940-1963	24
3314500	-0.112	0.3503	0.0030	1.4309	-0.0011	0.7595	1965-2006	34
3315500	0.280	0.0019	0.1357	0.9901	0.0047	0.0044	1939-1992	58
3315500	0.101	0.4874	0.0125	0.9020	0.0031	0.6036	1939-1962	24
3315500	-0.379	0.0056	0.2919	2.1099	-0.0111	0.0036	1970-1992	27
3316000	0.281	0.0272	0.1570	1.2031	0.0516	0.0247	1941-1972	32
3316000	-0.061	0.7087	0.0072	1.3861	-0.0177	0.7139	1941-1961	21
3316000	0.257	0.2743	0.2032	1.9868	0.0377	0.1640	1962-1972	11

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3316500	0.326	0.0016	0.1524	1.5161	0.0045	0.0080	1941-2006	45
3316500	0.506	0.0458	0.5533	1.8951	0.0255	0.0136	1941-1962	10
3316500	-0.206	0.1397	0.1034	2.3401	-0.0058	0.1092	1970-2006	26
3317000	0.216	0.1832	0.0239	1.1229	0.0051	0.5152	1940-1959	20
3317500	0.018	0.9154	0.0000	2.4233	0.0004	0.9896	1955-1973	19
3318000	0.294	0.2115	0.2498	1.6441	0.0394	0.1175	1941-1951	11
3318200	0.107	0.6246	0.0218	1.9139	0.0276	0.6146	1958-1971	14
3318500	0.277	0.0074	0.1977	1.9877	0.0097	0.0022	1950-1994	45
3318500	-0.111	0.6547	0.1275	1.4333	-0.0328	0.3112	1950-1959	10
3318500	0.059	0.6247	0.0232	2.5017	0.0037	0.3894	1961-1994	34
3318800	-0.013	0.9214	0.0005	2.1526	0.0021	0.8941	1958-1992	35
3319000	0.443	<.0001	0.4415	1.3955	0.0111	<.0001	1941-2004	54
3319000	0.188	0.2626	0.0305	1.1812	0.0065	0.4749	1941-1959	19
3319000	0.020	0.8705	0.0074	2.3709	0.0013	0.6275	1961-2004	34
3320000	0.221	0.0047	0.1071	1.4206	0.0034	0.0039	1931-2006	76
3320000	-0.108	0.4092	0.0013	0.9769	-0.0008	0.8517	1931-1959	29
3320000	-0.279	0.0150	0.1143	2.1683	-0.0074	0.0407	1970-2006	37
3320500	0.255	0.0042	0.1272	1.8549	0.0221	0.0035	1942-2006	65
3320500	0.043	0.8142	0.0073	1.0423	0.0172	0.7283	1942-1960	19
3320500	0.006	0.9664	0.0008	1.4099	0.0036	0.8860	1942-1970	29
3320500	0.251	0.0351	0.1255	1.4815	0.0358	0.0269	1942-1980	39
3320500	0.209	0.0476	0.0825	2.0865	0.0244	0.0529	1961-2006	46
3320500	0.049	0.6808	0.0084	2.2711	0.0095	0.5960	1971-2006	36
3320500	0.226	0.1135	0.1241	2.4729	0.0534	0.0775	1981-2006	26
3321350	0.112	0.5887	0.0254	2.6316	0.0373	0.5707	1969-1983	15
3322000	0.281	0.0218	0.1092	1.8952	0.0058	0.0603	1942-74	33
3322360	0.139	0.5035	0.0078	2.2743	0.0026	0.7365	1974-1994	17
3383000	0.261	0.0027	0.1853	1.7542	0.0240	0.0004	1942-2006	64
3383000	0.285	0.0227	0.1486	1.6070	0.0448	0.0244	1942-1975	34
3383000	-0.018	0.8865	0.0002	2.3308	0.0011	0.9447	1976-2006	30

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3384500	0.367	0.1183	0.1838	2.7231	0.0254	0.1882	1942-1952	11
3400500	0.201	0.0358	0.1252	1.8532	0.0055	0.0101	1941-1992	52
3400500	0.195	0.2297	0.0983	1.9555	0.0137	0.1784	1941-1960	20
3400500	0.141	0.2563	0.0014	2.3253	0.0012	0.8669	1971-1992	32
3400800	0.220	0.0829	0.1053	1.9566	0.0127	0.0750	1972-2004	31
3400800	-0.055	0.7115	0.0619	2.2811	-0.0030	0.2524	1980-2004	23
3400800	-0.271	0.1993	0.1874	2.1973	-0.0094	0.1395	1990-2004	13
3400990	0.282	0.1795	0.1854	2.2913	0.0168	0.1418	1980-2006	13
3401000	0.367	<.0001	0.2766	1.9550	0.0085	<.0001	1941-2005	65
3401000	0.313	0.0057	0.1846	1.9378	0.0121	0.0071	1941-1978	38
3401000	0.200	0.1206	0.0814	1.8333	0.0100	0.1264	1941-1970	30
3401000	0.021	0.8967	0.0000	2.0425	0.0004	0.9771	1941-1960	20
3401000	0.046	0.7409	0.0031	2.0476	0.0016	0.7875	1980-2005	26
3402000	0.406	<.0001	0.3418	1.5432	0.0075	<.0001	1942-2005	64
3402000	-0.129	0.4412	0.0675	1.7435	-0.0102	0.2829	1942-1960	19
3402000	0.239	0.0688	0.0770	1.4957	0.0070	0.1451	1942-1970	29
3402000	0.416	0.0002	0.2805	1.4605	0.0104	0.0005	1942-1980	39
3402000	0.044	0.7119	0.0242	1.7421	0.0027	0.3722	1971-2005	35
3402000	-0.010	0.9441	0.0168	1.5175	0.0035	0.5363	1981-2005	25
3403000	0.378	0.0002	0.3067	1.7225	0.0132	<.0001	1940-2005	47
3403000	0.291	0.0127	0.1897	1.6498	0.0151	0.0079	1940-1975	36
3403000	0.200	0.1084	0.1068	1.6342	0.0126	0.0679	1940-1971	32
3403000	0.309	0.1857	0.0755	1.9736	0.0181	0.4134	1981-2005	11
3403500	0.391	<.0001	0.2994	1.6387	0.0094	<.0001	1924-2005	62
3403500	0.344	0.0023	0.1526	1.6333	0.0094	0.0153	1924-1978	38
3403500	0.168	0.1849	0.0444	1.7388	0.0054	0.2551	1924-1971	31
3403500	0.040	0.7916	0.0050	1.6383	0.0020	0.7483	1980-2005	23
3403910	-0.106	0.4198	0.0103	1.8941	-0.0032	0.5999	1970-2004	29
3404000	0.372	<.0001	0.3364	1.4615	0.0133	<.0001	1952-2006	55
3404000	0.533	<.0001	0.5072	1.7653	0.0363	<.0001	1952-1978	27

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3404000	0.439	0.0087	0.4094	1.7129	0.0456	0.0032	1952-1970	19
3404000	-0.009	0.9501	0.0004	1.9964	0.0007	0.9166	1980-2006	27
3404500	0.349	<.0001	0.2115	1.4669	0.0078	<.0001	1909-2005	82
3404500	0.190	0.0265	0.0467	1.4767	0.0045	0.0863	1909-1978	64
3404500	0.025	0.7828	0.0000	1.6432	-0.0001	0.9781	1909-1970	56
3404500	-0.184	0.0720	0.0923	1.9803	-0.0083	0.0401	1909-1960	46
3404500	0.309	0.0836	0.2969	2.1223	0.0193	0.0237	1980-2005	17
3404820	0.140	0.4517	0.0858	1.6416	0.0821	0.2380	1975-1992	18
3404900	0.069	0.5864	0.0086	1.8553	0.0054	0.6206	1975-2005	31
3404900	-0.240	0.2149	0.0245	1.4231	0.0203	0.5481	1975-1989	15
3404900	-0.200	0.2799	0.0397	1.1155	-0.0202	0.4593	1990-2005	16
3405000	0.233	0.0663	0.2799	2.1422	0.0158	0.0022	1924-1973	31
3405000	0.180	0.1638	0.0886	2.3012	0.0090	0.1102	1944-1973	30
3406000	0.119	0.5091	0.0190	2.1019	0.0037	0.5974	1955-1971	17
3406500	0.211	0.0103	0.1015	1.5932	0.0066	0.0076	1938-2006	69
3406500	0.137	0.1493	0.0344	1.5461	0.0049	0.1837	1938-1990	53
3406500	-0.276	0.1369	0.0262	1.8984	-0.0123	0.5490	1991-2006	16
3407100	0.000	1.0000	0.0142	1.2723	0.0090	0.7430	1957-1966	10
3407300	-0.007	0.9693	0.0060	1.2691	0.0014	0.7607	1957-1974	18
3407500	0.237	0.0415	0.1056	1.5611	0.0360	0.0466	1954-1991	38
3407500	0.297	0.1158	0.1973	2.0491	0.0935	0.0741	1954-1970	17
3407500	0.529	0.0002	0.5170	2.1764	0.1115	<.0001	1954-1980	27
3407500	-0.216	0.1735	0.1133	1.8932	-0.0651	0.1358	1971-1991	21
3407500	-0.075	0.7528	0.0000	1.5536	-0.0019	0.9888	1981-1991	11
3410500	0.176	0.0437	0.0768	1.7602	0.0045	0.0292	1944-2005	62
3410500	0.392	0.0006	0.3077	1.6106	0.0142	0.0004	1944-1980	37
3410500	0.013	0.9256	0.0031	2.0039	0.0024	0.7911	1981-2005	25
3410500	0.085	0.2386	0.0259	1.6258	0.0018	0.1339	1916-2005	88
3411000	-0.311	0.0111	0.2162	2.0201	-0.0127	0.0064	1916-1950	33
3411500	-0.328	0.0056	0.1560	2.0124	-0.0109	0.0189	1916-1950	35

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3412500	0.138	0.4257	0.0012	2.5922	0.0042	0.8906	1955-1972	18
3413200	-0.067	0.6048	0.0000	2.1473	-0.0001	0.9813	1970-2006	30
3413200	0.018	0.9163	0.0005	2.4379	0.0005	0.9278	1970-1995	19
3413200	0.091	0.6971	0.0199	1.9400	0.0118	0.6789	1996-2006	11
3414000	0.478	<.0001	0.2102	1.3322	0.0331	0.0006	1941-1992	52
3414000	0.067	0.7884	0.0031	2.2960	0.0053	0.8792	1941-1950	10
3414000	0.282	0.1795	0.2069	2.4683	0.0294	0.1184	1980-1992	13
3435140	-0.174	0.3585	0.0358	2.7588	-0.0345	0.4670	1975-1991	17
3437500	0.012	0.9368	0.0121	1.2203	-0.0050	0.6167	1951-1973	23
3438000	0.352	<.0001	0.2112	1.3985	0.0049	0.0001	1941-2006	66
3438000	0.399	0.0095	0.1810	1.1750	0.0153	0.0484	1941-1962	22
3438000	0.186	0.0766	0.0701	1.6934	0.0035	0.0824	1963-2006	44
3438070	-0.297	0.1663	0.1046	2.4805	-0.0471	0.2592	1970-1983	14
3438220	0.525	<.0001	0.5527	1.0407	0.0155	<.0001	1941-1997	57
3438220	-0.057	0.6556	0.0051	2.0809	-0.0015	0.7068	1968-1997	30
3609500	0.417	<.0001	0.1900	1.5430	0.0037	<.0001	1891-1984	94
3609500	0.044	0.8048	0.0902	1.3606	0.0106	0.2416	1968-1984	17
3610000	-0.072	0.7150	0.0074	2.1271	-0.0083	0.7261	1953-1971	19
3610200	0.565	0.0002	0.4570	1.9336	0.0252	0.0004	1984-2006	23
3610500	0.407	0.0007	0.2723	1.4785	0.0138	0.0015	1940-1973	34
3610500	0.243	0.1234	0.1145	1.4412	0.0135	0.1335	1940-1960	21
3610500	0.336	0.0080	0.1605	1.5067	0.0107	0.0255	1940-1970	31
3610545	0.228	0.1724	0.0802	2.1863	0.0078	0.2402	1970-1994	19
3611260	0.355	0.0033	0.2257	1.3927	0.0111	0.0045	1973-2006	34
3611260	0.279	0.0793	0.1470	1.9789	0.0134	0.0862	1973-1993	21
3611260	-0.301	0.1577	0.4004	1.2439	-0.0302	0.0203	1994-2006	13
3611500	0.419	<.0001	0.3447	1.7407	0.0046	<.0001	1929-2006	78
3611500	-0.012	0.9167	0.0002	2.2960	0.0002	0.9303	1970-2006	37
3611500	0.020	0.8840	0.0028	2.1831	0.0011	0.7933	1980-2006	27
3611800	0.000	1.0000	0.1370	2.9221	-0.0281	0.2362	1995-2006	12

Table 2–1. Trend-test screening of annual 7-day low flows for selected long-term continuous-record streamflow-gaging stations in Kentucky for various periods of record.—Continued

[p-value, probability statistically significant if less than 0.20; n, number of data values; R^2, coefficient of determination; < less than]

Station number	Trend analysis		Regression analysis					
	Mann-Kendall value	p-value	R^2	Durbin-Watson value	Slope	Slope p-value	Period of record	n
3611850	0.515	0.0197	0.4357	1.9953	0.0193	0.0195	1995-2006	12
3611900	-0.062	0.7829	0.0109	2.5027	-0.0031	0.7467	1995-2006	12
7023000	0.672	<.0001	0.7483	0.9236	0.0139	<.0001	1940-1972	33
7023500	0.406	0.0275	0.2493	1.5523	0.0217	0.0212	1953-1973	21
7024000	0.721	<.0001	0.7564	1.5277	0.0063	<.0001	1941-2006	59

Appendix 3. Double-Mass Curves Showing Relations of Cumulative Annual 7-Day Low Flows among Selected Hydro-Climate Data Network, Hydrologic Benchmark Network, and Reference Streamflow-Gaging Stations in and surrounding Kentucky

Time-series plots of the annual low flows for all LTCR stations in Kentucky were examined and compared to each other and to the plots of selected LTCR stations in the Hydro-Climate Data Network (HCDN) (Slack and Landwehr, 1992) and Hydrologic Benchmark Network (HBN) (Mast and Turk, 1999) in Kentucky and bordering States. These stations included Twin Creek near Germantown, Ohio, (03272000); Little Wabash River below Clay City, Illinois, (03379500,); French Broad River at Ashville, North Carolina, (03451500,); Clinch River above Tazewell, Tennessee, (03528000); Tellico River at Tellico Plains, Tennessee, (03518500); Greenbrier River at Alderson, West Virginia, (03183500); Nolichucky River at Embreeville, Tennessee, (03465500); Powell River near Jonesville, Virginia, (03531500) in (or subbasins of) the HCDN and Holiday Creek near Andersonville, Virginia, (02038850); Upper Twin Creek at McGaw, Ohio, (03237280); Cataloochee Creek near Cataloochee, North Carolina, (03460000); Little River above Townsend, Tennessee, (03497300); North Sylamore Creek near Fifty Six, Arkansas, (07060710) in (or subbasins of) the HBN.

The annual low-flow data for South Fork Cumberland River near Stearns, Kentucky, (03410500) was identified as representative of basins in Kentucky largely unaffected by regulation and (or) direct anthropogenic alterations such that low flows varied only in response to climate and meteorological conditions and were suitable for low-flow frequency analysis. Double-mass curves (Searcy and others, 1960) showing relations of the cumulative annual 7-day low flows for these HCDN and HBN stations paired with the record at the Stearns, Kentucky, gage as the reference (abscissa) (figs. 3–1 and 3–2) were plotted to compare the record at Stearns with low flows at long-term benchmark stations in the region.

Many, but not all, of the HCDN and HBN stations have a low-flow regime unaffected by regulation and (or) local diversions of flows that results in a double-mass curve of uniform linear slope indicative of no change in the relation between the paired time series. A change or break in the slope of the double-mass curve signals that the relation between the time series has changed for some reason. The most common cause is a basin modification such as regulation or local diversions—water withdrawals and discharges—that have changed the low-flow regime in one of the basins. Any anthropogenic alterations of the low flows at gages in Kentucky tended to be more common in the later part of the streamflow record—after 1980, for example.

A distinct change in slope of the double-mass curves plotted for these HCDN and HBN stations with the Stearns, Kentucky, gage as the reference station was observed, however, at several but not all stations around the year 1960 and occasionally in the early 1970s (figs. 3–1 and 3–2). Typically these double-mass curves had a uniform linear slope before and after such a change in slope around 1960 and 1970. This change in slope around 1960 also was observed when plotting other selected HCDN and HBN stations surrounding Kentucky against each other (fig. 3–3), which indicates a likely regional phenomenon not unique to the selected reference gage at Stearns, Kentucky. The double-mass curves for stations at latitudes near Kentucky show this change in slope around 1960, while the double-mass curves for stations farther south of Kentucky exhibited the change in slope at a later date around 1970. A double-mass curve comparing a station near Kentucky to one farther south of Kentucky (fig. 3–3 C) also possibly indicated slope changes around both 1960 and 1970.

These changes in slope of the double-mass curves are possibly related to shifts in the hydroclimate regime characterized by a transition from around 1960 into the early 1970s from a warm-dry period to a cool-wet period as identified by other researchers (Lins and Slack, 1999; Enfield and others, 2001; Grundstein and Bentley, 2001; McCabe and Wolock, 2002; and McCabe and others, 2004). Identification of the exact nature and causes of a possible shift in the regional hydroclimate regime was beyond the scope of this study.

Seventy-four stations in Kentucky had streamflow time-series records that span the climate years 1959–60, of which 6 stations were identified as having the approximately 1960 change in slope of the double-mass curve that was used as the end point of the identified homogeneous period of record for low-flow frequency analysis (table 2 in main report). Therefore, for the large majority stations (about 90 percent), no change in slope of the double-mass curves plotted with the Stearns reference station around 1960 was identified. Some of these 6 stations with identified homogeneous periods ending in 1959 or 1960 may have been truncated prematurely as a result of this change in slope around 1960. However, a homogeneous, representative period of record of at least 10 years was identified nonetheless and used in the low-flow frequency analysis for these six stations. Use of the Stearns, Kentucky, low-flow record as the reference station in screening and identifying the homogeneous periods of record at all the LTCR stations in Kentucky was considered appropriate.

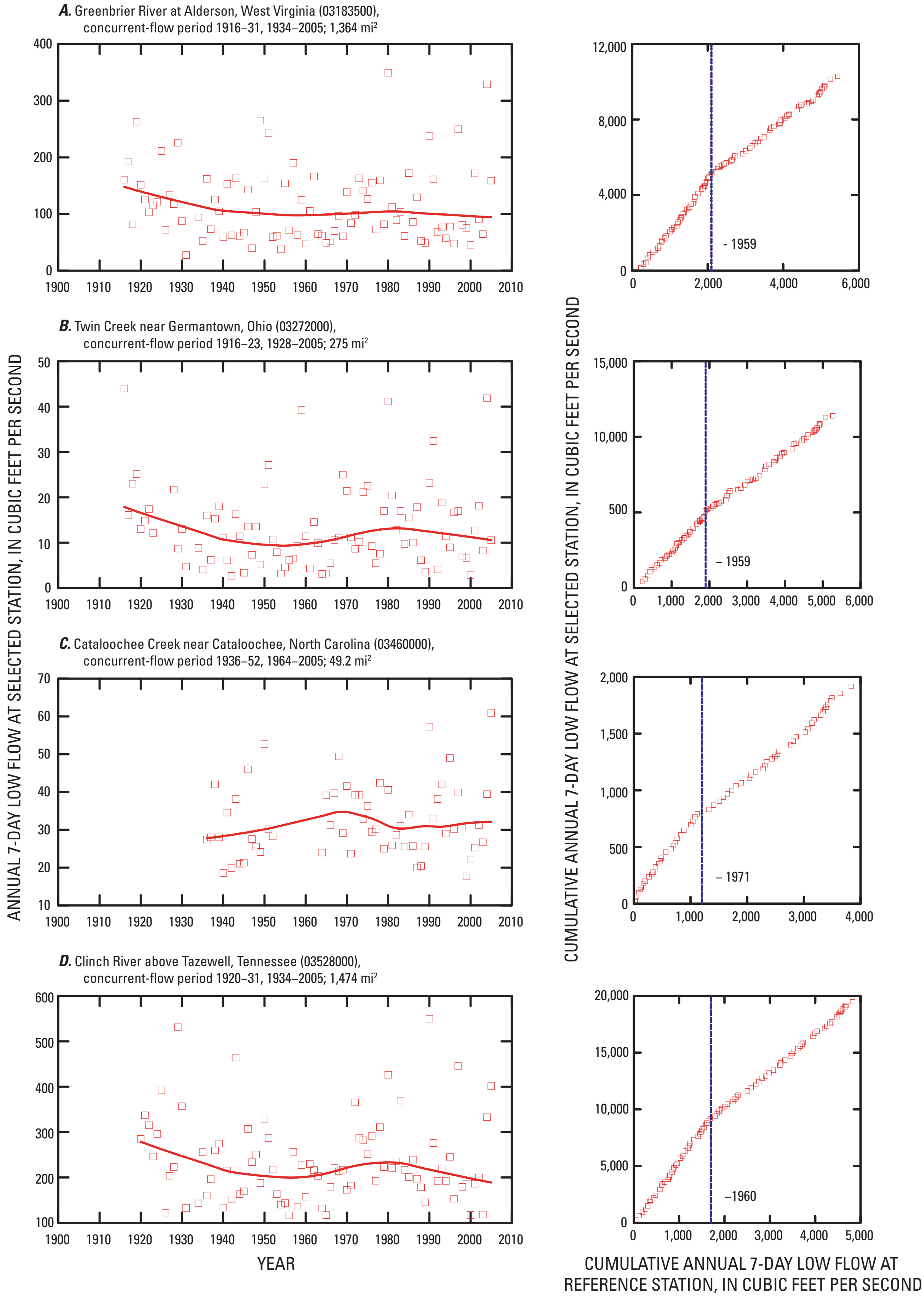

Figure 3–1. Annual 7-day low-flow time series with LOWESS curve and double-mass plots versus reference station South Fork Cumberland River near Stearns, Kentucky (03410500), for ***A***, Greenbrier River at Alderson, West Virginia; ***B***, Twin Creek near Germantown, Ohio; ***C***, Cataloochee Creek near Cataloochee, North Carolina; and ***D***, Clinch River above Tazewell, Tennessee.

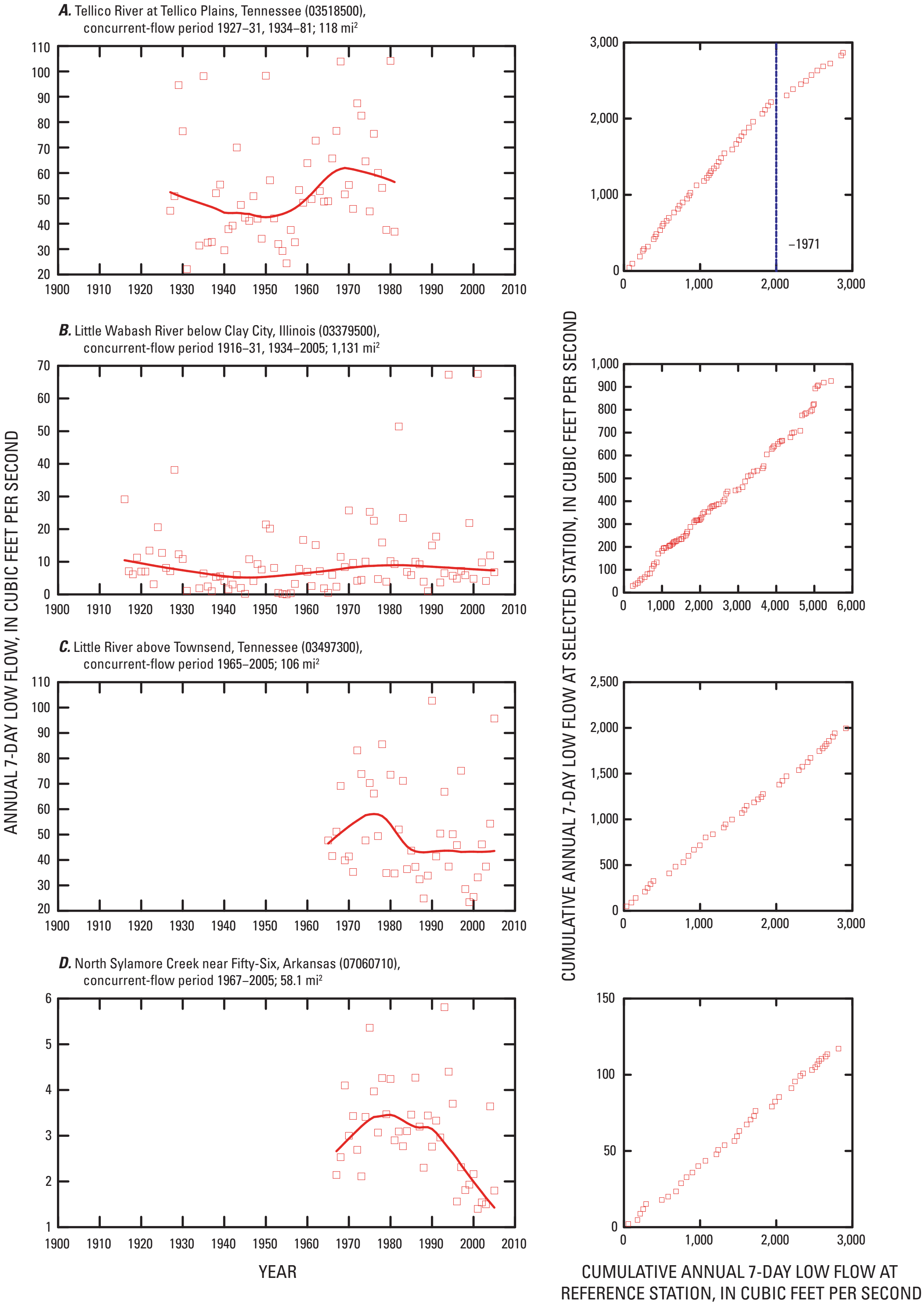

Figure 3–2. Annual 7-day low-flow time series with LOWESS curve and double-mass plots versus reference station South Fork Cumberland River near Stearns, Kentucky (03410500), for ***A***, Tellico River at Tellico Plains, Tennessee; ***B***, Little Wabash River below Clay City, Illinois (03379500); ***C***, Little River above Townsend, Tennessee; and ***D***, North Sylamore Creek near Fifty-Six, Arkansas.

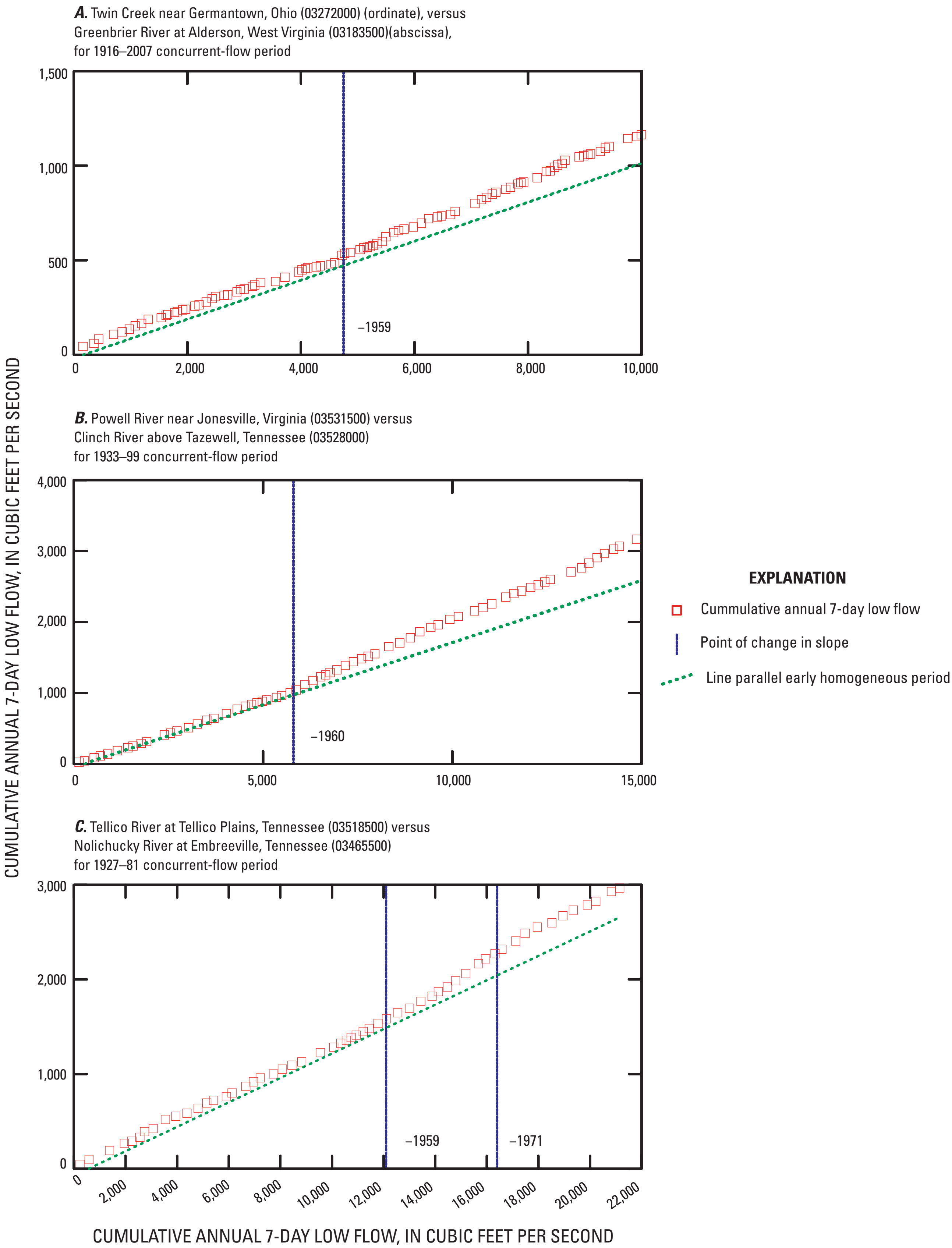

Figure 3–3. Double-mass plots of cumulative annual 7-day low flows for ***A***, Twin Creek near Germantown, Ohio, versus Greenbrier River at Alderson, West Virginia; ***B***, Powell River near Jonesville, Virginia, versus Clinch River above Tazewell, Tennessee; and ***C***, Tellico River at Tellico Plains, Tennessee, versus Nolichucky River at Embreeville, Tennessee.

Appendix 4. A Procedure for Detrending Annual Low-Flow Data for Frequency Analysis

Selected LTCR low-flow stations, including some previously used as low-flow index stations, had trended annual low-flow time series (table 1 in main report, fig. 4–1). These trends were most likely caused by various ongoing anthropogenic basin modifications including mining activities, agricultural irrigation and drainage systems, stream channelization, and local diversions of flows that have altered the low-flow regime during the station periods of record.

A procedure and example application for adjustments of trended annual low flows are described here. This procedure was based on procedures developed by Ries and Dillow (2006) to adjust for trends in annual peak flows based on time alone. The estimates were made by use of LOWESS, or Locally Weighted Scatterplot Smoothing (Cleveland 1979, 1984; Helsel and Hirsch, 2002), which defined smoothed trend lines for an annual flow time series. These adjustments for trend in effect shifted the annual low-flow values ‘forward’ in time to the most recent year of trended record and (or) the adjustments shifted the annual values ‘backward’ in time to the beginning of the trended period of record. These shifted low-flow characteristics were assumed representative of basin hydrologic conditions at the point in time to which the series was adjusted.

Estimates of low-flow frequency, in section “Long-term Continuous-Record Streamflow-Gaging Stations,” calculated by using the Pearson Type III distribution are a function of the mean, standard deviation, and skew of the logarithms of the annual low-flow series. As the first step in this low-flow detrending procedure, the mean value of the logarithms of annual low flows was taken as the LOWESS estimate in log-space flow at the beginning and (or) ending point of trended period.

The arithmetic trend-adjusted low-flow time series values were next determined by converting the log-space LOWESS values to equivalent arithmetic values of flow by detransforming from the log base-10 values. Residuals around the smoothed arithmetic trend line were then computed by subtracting each annual arithmetic trend-line flow value from the observed annual low-flow value. These arithmetic residuals were then shifted to a point higher or lower on the discharge (ordinate) scale to the smoothed arithmetic trend-line low flow (as determined from the log-space LOWESS curve) at the beginning and (or) ending year in the record, depending on the year and basin condition for which a low-flow frequency statistic was needed.

The trend-adjusted annual low-flow values were next log transformed prior to the subsequent steps in this detrending procedure. For estimation of standard deviation and skew of the trend-adjusted record, the 5-, 6-, 7-, 8-, 9-, and 10-year ‘moving periods’ of the trend-adjusted log-transformed annual-low-flow record were calculated. These series of moving-period statistics were plotted and also fitted with a LOWESS line to estimate representative values of the standard deviation and skew at the beginning and (or) ending year of the trended periods of record. The moving-period statistics and LOWESS-curve values typically followed a similar pattern in the plots and generally tended to converge toward the same proximate values at the beginning and (or) ending year of the trended periods of record.

Plots of annual 7-day low flows at station 07023000 (Mayfield Creek at Lovelaceville, Ky.) for the period 1940–72 that illustrate a trend adjustment to 1972 basin conditions are shown in fig. 3–1. The LOWESS-curve estimate for the mean of the logarithms of the annual 7-day low-flow series at station 07023000, adjusted to 1972 basin conditions, 1.325 log ft^3/s units, or 21.1 ft^3/s, is shown in fig. 4–1***A***. The arithmetic original, LOWESS curve, and detrended time series for 1972 basin conditions at gaging station 07023000 are shown in fig. 4–1***B***. Arithmetic residuals were shifted by adding to a constant LOWESS-curve value in 1972 of 21.1 ft^3/s, which was taken as the estimated mean of the detrended series. Next, the LOWESS estimates of the standard deviation of the logarithms of annual 7-day low flows at station 07023000 adjusted to 1972 for the 6-, 8-, and 10-year moving periods are shown in fig. 4–1***C***. Finally, the LOWESS-curve estimates of the skew coefficient of the logarithms of annual 7-day low flows at station 07023000 adjusted to 1972 for the 6-, 8-, and 10-year moving periods are shown in fig. 4–1***D***. For the 10 year moving period, the standard deviation and skew LOWESS-curve estimates at 1972 are 0.061 and 0.774, respectively. For these estimated mean, standard deviation, and skew values of the logarithms of annual 7-day low flows; the estimated $7Q_{10}$ of the trend-adjusted annual 7-day lows for 1972 basin conditions was 17.9 ft^3/s. When this same procedure was applied to trend-adjusted annual low flows for 1940 basin conditions, the estimated $7Q_{10}$ was 5.4 ft^3/s, about one third the estimate for 1972 basin conditions.

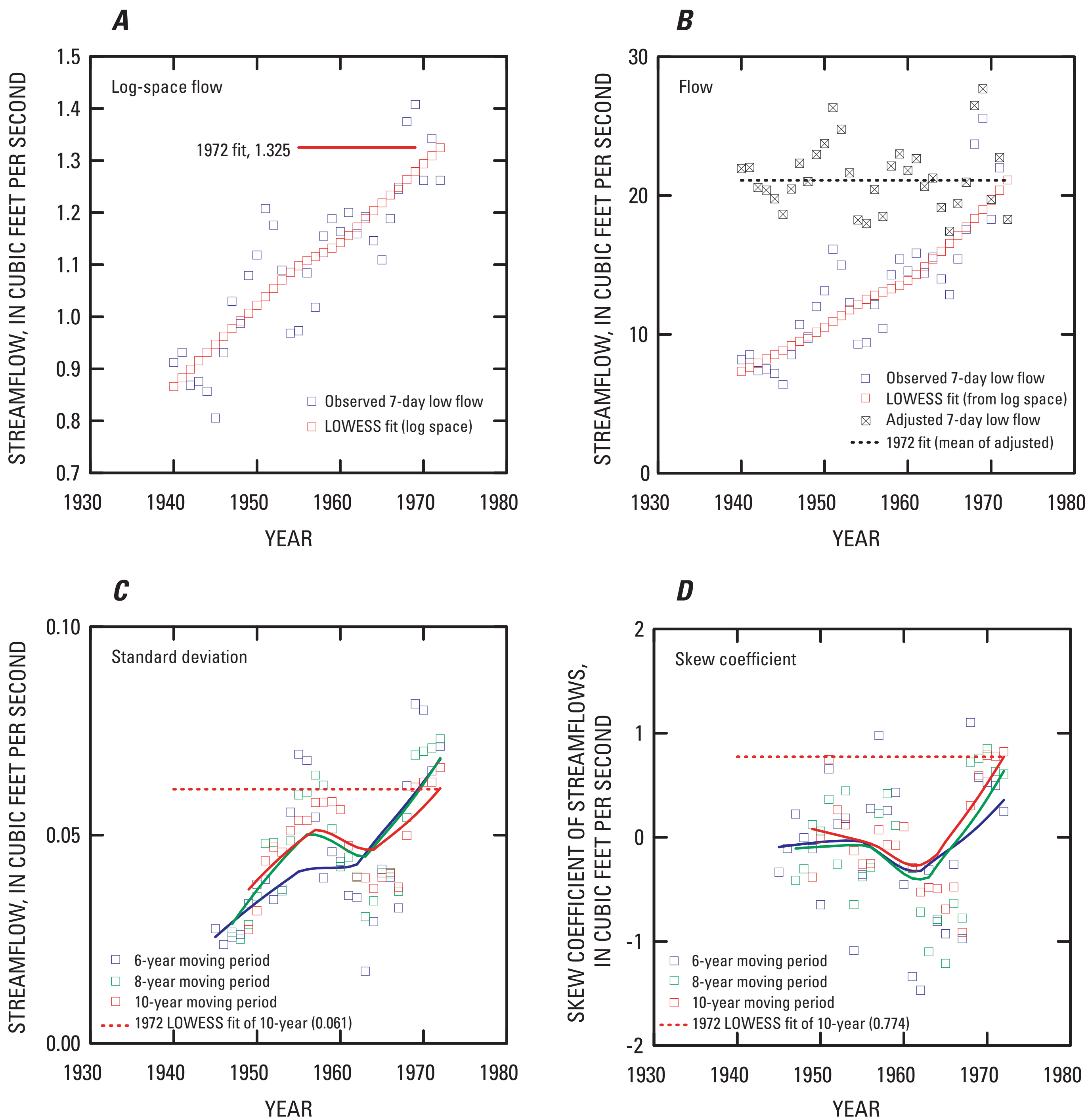

Figure 4–1. Adjustments of annual 7-day low flows and estimates of mean, standard deviation, and skew of the logarithms of annual 7-day low flows at Mayfield Creek at Lovelaceville, Kentucky (07023000) for basin conditions in 1972.

Appendix 5. Classification Tables for Logistic-Regression Equations for Estimating the Probability of Zero Flow For Selected Low-Flow Frequencies in Kentucky

Analysis of the estimates provided by the logistic-regression estimating equations indicated optimal performance in terms of the percentage of gaging stations correctly classified as zero or nonzero flow for each low-flow statistic ($30Q_2$, $30Q_5$, $7Q_2$, $7Q_{10}$, $7Q_{20}$) varied depending on the particular ‘cutpoint’ probability used. Classification tables (SAS Institute, Inc., 1995; Hosmer and Lemeshow, 2000) (tables 5–1 through 5–5) were developed by determining the numbers of correct and incorrect classifications of events (zero flow) and nonevent (nonzero flow) by comparison of the estimated probabilities to the zero and nonzero status of each low-flow statistic at the various probability cutpoints. The optimal cutpoints are shown in bold numbers in the classification tables. The logistic-regression equations were adjusted to operate at the optimal cutpoints by multiplying the probabilities computed from the logistic regression equation by the ratio of the standard cutpoints to the optimal cutpoints. For example, the standard cutpoint for $7Q_2$ is 0.5 (inverse of the return period, 1/T or 1/2), at which 73.2 percent of stations were classified correctly. The optimal cutpoint is 0.985, at which 93.8 percent of the stations were classified correctly. To get optimal results at the standard cutpoint for $7Q_2$, a conversion factor (C, in table 4 in main report) of 0.508 (0.5 divided by 0.985) was applied to the final logistic-regression equation.

The logistic-regression equations are applied to determine if the statistic of interest is either zero or nonzero. The estimated probabilities of zero flows are compared to the standard probability cutpoints that equal the probability of the statistics of interest (inverse of the return period, 1/T). If the estimated probability of zero flow is greater than the nonexceedance probability of the low-flow statistic of interest, then the low-flow statistic is estimated to be zero. For example, in the $7Q_{10}$ statistic, if the estimated probability of zero flow exceeds 0.1, then the $7Q_{10}$ is estimated to be zero. Alternatively, for the $7Q_{10}$ statistic, if the probability of zero flow is less than or equal to 0.1, then the $7Q_{10}$ should be estimated by using the multiple-linear-regression equations for estimating nonzero low-flow statistics (table 5 in main report).

Table 5–1. Classification table for the logistic-regression equation for estimating zero-flow probability for the 30-day, 2-year low flow in Kentucky.

[Correct, number of observations correctly classified; Incorrect, number of observations incorrectly classified; Event, zero flow; Nonevent, nonzero flow; Percentages: Correct, the frequency with which the equation correctly classifies the low-flow statistic for each probability cutpoint; Sensitivity, the ratio of correctly classified events to the total number of events; Specificity, the ratio of correctly classified nonevents to the total number of nonevents; False positive, the ratio of the number of nonevents incorrectly classified as events to the sum of all observations classified as events; False negative, the ratio of the number of events incorrectly classified as nonevents to the sum of all observations classified as nonevents; SAS Institute, Inc., 1995, p. 45–50]

Probability level (cutpoint)	Correct		Incorrect		Percentages				
	Event	Nonevent	Event	Nonevent	Correct	Sensitivity	Specificity	False positive	False negative
0.05	8	31	73	0	34.8	100.0	29.8	90.1	0.0
.1	8	42	62	0	44.6	100.0	40.4	88.6	.0
.2	8	53	51	0	54.5	100.0	51.0	86.4	.0
.3	8	59	45	0	59.8	100.0	56.7	84.9	.0
.4	8	65	39	0	65.2	100.0	62.5	83.0	.0
.5	8	71	33	0	70.5	100.0	68.3	80.5	.0
.6	8	74	30	0	73.2	100.0	71.2	78.9	.0
.7	8	78	26	0	76.8	100.0	75.0	76.5	.0
.8	8	82	22	0	80.4	100.0	78.8	73.3	.0
.9	8	87	17	0	84.8	100.0	83.7	68.0	.0
.985	7	102	2	1	97.3	87.5	98.1	22.2	1.0
.99	7	103	1	1	98.2	87.5	99.0	12.5	1.0
.995	5	104	0	3	97.3	62.5	100.0	.0	2.8

Table 5–2. Classification table for the logistic-regression equation for estimating zero-flow probability for the 30-day, 5-year low flow in Kentucky.

[Correct, number of observations correctly classified; Incorrect, number of observations incorrectly classified; Event, zero flow; Nonevent, nonzero flow; Percentages: Correct, the frequency with which the equation correctly classifies the low-flow statistic for each probability cutpoint; Sensitivity, the ratio of correctly classified events to the total number of events; Specificity, the ratio of correctly classified nonevents to the total number of nonevents; False positive, the ratio of the number of nonevents incorrectly classified as events to the sum of all observations classified as events; False negative, the ratio of the number of events incorrectly classified as nonevents to the sum of all observations classified as nonevents; SAS Institute, Inc., 1995, p. 45–50]

Probability level (cutpoint)	Correct		Incorrect		Percentages				
	Event	Nonevent	Event	Nonevent	Correct	Sensitivity	Specificity	False positive	False negative
0.05	29	31	52	0	53.6	100.0	37.3	64.2	0.0
.1	29	42	41	0	63.4	100.0	50.6	58.6	.0
.2	28	52	31	1	71.4	96.6	62.7	52.5	1.9
.3	28	58	25	1	76.8	96.6	69.9	47.2	1.7
.4	28	64	19	1	82.1	96.6	77.1	40.4	1.5
.5	27	69	14	2	85.7	93.1	83.1	34.1	2.8
.6	27	72	11	2	88.4	93.1	86.7	28.9	2.7
.7	27	76	7	2	92.0	93.1	91.6	20.6	2.6
.75	26	78	5	3	92.9	89.7	94.0	16.1	3.7
.8	26	79	4	3	93.8	89.7	95.2	13.3	3.7
.825	25	80	3	4	93.8	86.2	96.4	10.7	4.8
.85	25	80	3	4	93.8	86.2	96.4	10.7	4.8
.9	23	81	2	6	92.9	79.3	97.6	8.0	6.9
.95	22	82	1	7	92.9	75.9	98.8	4.3	7.9
.99	8	83	0	21	81.3	27.6	100.0	.0	20.2

Table 5–3. Classification table for the logistic-regression equation for estimating zero-flow probability for the 7-day, 2-year low flow in Kentucky.

[Correct, number of observations correctly classified; Incorrect, number of observations incorrectly classified; Event, zero flow; Nonevent, nonzero flow; Percentages: Correct, the frequency with which the equation correctly classifies the low-flow statistic for each probability cutpoint; Sensitivity, the ratio of correctly classified events to the total number of events; Specificity, the ratio of correctly classified nonevents to the total number of nonevents; False positive, the ratio of the number of nonevents incorrectly classified as events to the sum of all observations classified as events; False negative, the ratio of the number of events incorrectly classified as nonevents to the sum of all observations classified as nonevents; SAS Institute, Inc., 1995, p. 45–50]

Probability level (cutpoint)	Correct		Incorrect		Percentages				
	Event	Nonevent	Event	Nonevent	Correct	Sensitivity	Specificity	False positive	False negative
0.05	27	23	62	0	44.6	100.0	27.1	69.7	0.0
.1	27	31	54	0	51.8	100.0	36.5	66.7	.0
.2	27	39	46	0	58.9	100.0	45.9	63.0	.0
.3	26	48	37	1	66.1	96.3	56.5	58.7	2.0
.4	26	50	35	1	67.9	96.3	58.8	57.4	2.0
.5	26	56	29	1	73.2	96.3	65.9	52.7	1.8
.6	26	58	27	1	75.0	96.3	68.2	50.9	1.7
.7	26	63	22	1	79.5	96.3	74.1	45.8	1.6
.8	26	67	18	1	83.0	96.3	78.8	40.9	1.5
.9	25	74	11	2	88.4	92.6	87.1	30.6	2.6
.98	23	80	5	4	92.0	85.2	94.1	17.9	4.8
.985	23	82	3	4	93.8	85.2	96.5	11.5	4.7
.99	22	83	2	5	93.8	81.5	97.6	8.3	5.7
.995	19	84	1	8	92.0	70.4	98.8	5.0	8.7
.999	8	85	0	19	83.0	29.6	100.0	.0	18.3

Table 5–4. Classification table for the logistic-regression equation for estimating zero-flow probability for the 7-day, 10-year low flow in Kentucky.

[Correct, number of observations correctly classified; Incorrect, number of observations incorrectly classified; Event, zero flow; Nonevent, nonzero flow; Percentages: Correct, the frequency with which the equation correctly classifies the low-flow statistic for each probability cutpoint; Sensitivity, the ratio of correctly classified events to the total number of events; Specificity, the ratio of correctly classified nonevents to the total number of nonevents; False positive, the ratio of the number of nonevents incorrectly classified as events to the sum of all observations classified as events; False negative, the ratio of the number of events incorrectly classified as nonevents to the sum of all observations classified as nonevents; SAS Institute, Inc., 1995, p. 45–50]

Probability level (cutpoint)	Correct		Incorrect		Percentages				
	Event	Nonevent	Event	Nonevent	Correct	Sensitivity	Specificity	False positive	False negative
0.05	52	23	37	0	67.0	100.0	38.3	41.6	0.0
.1	52	31	29	0	74.1	100.0	51.7	35.8	.0
.2	50	37	23	2	77.7	96.2	61.7	31.5	5.1
.3	49	46	14	3	84.8	94.2	76.7	22.2	6.1
.4	48	47	13	4	84.8	92.3	78.3	21.3	7.8
.5	46	51	9	6	86.6	88.5	85.0	16.4	10.5
.55	46	52	8	6	87.5	88.5	86.7	14.8	10.3
.6	45	52	8	7	86.6	86.5	86.7	15.1	11.9
.7	42	54	6	10	85.7	80.8	90.0	12.5	15.6
.8	40	56	4	12	85.7	76.9	93.3	9.1	17.6
.9	34	58	2	18	82.1	65.4	96.7	5.6	23.7
.99	24	60	0	28	75.0	46.2	100.0	.0	31.8

Table 5–5. Classification table for the logistic-regression equation for estimating zero-flow probability for the 7-day, 20-year low flow in Kentucky.

[Correct, number of observations correctly classified; Incorrect, number of observations incorrectly classified; Event, zero flow; Nonevent, nonzero flow; Percentages: Correct, the frequency with which the equation correctly classifies the low-flow statistic for each probability cutpoint; Sensitivity, the ratio of correctly classified events to the total number of events; Specificity, the ratio of correctly classified nonevents to the total number of nonevents; False positive, the ratio of the number of nonevents incorrectly classified as events to the sum of all observations classified as events; False negative, the ratio of the number of events incorrectly classified as nonevents to the sum of all observations classified as nonevents; SAS Institute, Inc., 1995, p. 45–50]

Probability level (cutpoint)	Correct		Incorrect		Percentages				
	Event	Nonevent	Event	Nonevent	Correct	Sensitivity	Specificity	False positive	False negative
0.05	57	23	32	0	71.4	100.0	41.8	36.0	0.0
.1	57	31	24	0	78.6	100.0	56.4	29.6	.0
.2	55	37	18	2	82.1	96.5	67.3	24.7	5.1
.3	54	46	9	3	89.3	94.7	83.6	14.3	6.1
.4	53	47	8	4	89.3	93.0	85.5	13.1	7.8
.45	52	48	7	5	89.3	91.2	87.3	11.9	9.4
.5	50	50	5	7	89.3	87.7	90.9	9.1	12.3
.6	48	50	5	9	87.5	84.2	90.9	9.4	15.3
.7	44	51	4	13	84.8	77.2	92.7	8.3	20.3
.8	41	52	3	16	83.0	71.9	94.5	6.8	23.5
.9	34	53	2	23	77.7	59.6	96.4	5.6	30.3
.99	24	55	0	33	70.5	42.1	100.0	.0	37.5

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