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Methods for Estimating Selected Low-Flow Frequency Statistics and Harmonic Mean Flows for Streams in Iowa

Scientific Investigations Report 2012–5171

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

Cover. Photograph of South Fork English River at State Highway 149 crossing north of South English, Iowa. Photograph by U.S. Geological Survey.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
mile per square mile (mi/mi^2)	0.621	kilometer per square kilometer (km/km^2)
square mile per mile (mi^2/mi)	1.609	square kilometer per kilometer (km^2/km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Hydraulic conductivity	
inch per second (in/s)	25,400	micrometers per second (μm/s)

Acronyms

Adj-R^2	Adjusted coefficient of determination
AMLE	Adjusted maximum-likelihood estimation
ANNIE	USGS Interactive Hydrologic Analyses and Data Management computer program
BFI	Base-flow index
DAR	Drainage-area ratio
DEM	Digital elevation model
DRG	Digital raster graphics
DRNAREA	GIS-determined drainage area
DRNFREQ	Drainage frequency
e	Base of the natural logarithm, approximately equal to 2.7183
GIS	Geographic Information System
GLS	Generalized-least-squares regression
GRoI	Geographic space RoI
HRoI	Hybrid RoI, a combination of PRoI and GRoI
HUC	Hydrologic unit code
HYSEP	Hydrograph separation and analysis
IDNR	Iowa Department of Natural Resources
IOWDM	USGS Input and Output for a Watershed Data Management (WDM file) computer program

KSATSSUR	Average soil permeability or saturated hydraulic conductivity of soil
LOWESS	Locally-Weighted Scatter plot Smoother
M1D10Y	Annual 1-day mean low flow for a recurrence interval of 10 years
M1D10Y1012	Seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years
M7D2Y	Annual 7-day mean low flow for a recurrence interval of 2 years
M7D10Y	Annual 7-day mean low flow for a recurrence interval of 10 years
M7D10Y1012	Seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years
M30D5Y	Annual 30-day mean low flow for a recurrence interval of 5 years
M30D10Y	Annual 30-day mean low flow for a recurrence interval of 10 years
MEV	Model error variance
MLE	Maximum-likelihood estimation
MSE	Mean-square error
NED	National elevation dataset
NHD	National hydrography dataset
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
OLS	Ordinary-least-squares regression
PAM	Partitioning around medoids
PRC8	Mean August precipitation
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PRoI	Independent or predictor-variable space RoI
Pseudo-R^2	Pseudo coefficient of determination
P_{zero}	Probability of the low-flow frequency statistic being equal to zero
QAH	Harmonic mean flow
RMSE	Root mean square error, also referred to as SEE
RoI	Region of influence
RRE	Regional regression equation
RSD	Relative stream density
SEE	Average standard error of estimate, also referred to as RMSE
SEM	Standard error of model
SEP	Average standard error of prediction
SOILASSURGO	Hydrologic soil type A
SOILBSSURGO	Hydrologic soil type B

SOILCSSURGO	Hydrologic soil type C
SSURGO	NRCS Soil Survey Geographic database
StreamStats	USGS Web-based GIS tool (*http://water.usgs.gov/osw/streamstats/index.html*)
STREAM_VAR	Streamflow-variability index
SWSTAT	USGS Surface-Water Statistics computer program
TAU_ANN	Annual base-flow-recession time constant
TMDL	Total Maximum Daily Load
U	Covariance matrix
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VIF	Variance inflation factor
WBD	Watershed boundary dataset
WDAR	Weighted drainage-area ratio
WLA	Waste-load allocation
WLS	Weighted-least-squares regression
WREG	Weighted-multiple-linear regression program

Methods for Estimating Selected Low-Flow Frequency Statistics and Harmonic Mean Flows for Streams in Iowa

By David A. Eash and Kimberlee K. Barnes

Abstract

A statewide study was conducted to develop regression equations for estimating six selected low-flow frequency statistics and harmonic mean flows for ungaged stream sites in Iowa. The estimation equations developed for the six low-flow frequency statistics include: the annual 1-, 7-, and 30-day mean low flows for a recurrence interval of 10 years, the annual 30-day mean low flow for a recurrence interval of 5 years, and the seasonal (October 1 through December 31) 1- and 7-day mean low flows for a recurrence interval of 10 years. Estimation equations also were developed for the harmonic-mean-flow statistic. Estimates of these seven selected statistics are provided for 208 U.S. Geological Survey continuous-record streamgages using data through September 30, 2006. The study area comprises streamgages located within Iowa and 50 miles beyond the State's borders. Because trend analyses indicated statistically significant positive trends when considering the entire period of record for the majority of the streamgages, the longest, most recent period of record without a significant trend was determined for each streamgage for use in the study. The median number of years of record used to compute each of these seven selected statistics was 35. Geographic information system software was used to measure 54 selected basin characteristics for each streamgage. Following the removal of two streamgages from the initial data set, data collected for 206 streamgages were compiled to investigate three approaches for regionalization of the seven selected statistics. Regionalization, a process using statistical regression analysis, provides a relation for efficiently transferring information from a group of streamgages in a region to ungaged sites in the region. The three regionalization approaches tested included statewide, regional, and region-of-influence regressions. For the regional regression, the study area was divided into three low-flow regions on the basis of hydrologic characteristics, landform regions, and soil regions. A comparison of root mean square errors and average standard errors of prediction for the statewide, regional, and region-of-influence regressions determined that the regional regression provided the best estimates of the seven selected statistics at ungaged sites in Iowa.

Because a significant number of streams in Iowa reach zero flow as their minimum flow during low-flow years, four different types of regression analyses were used: left-censored, logistic, generalized-least-squares, and weighted-least-squares regression. A total of 192 streamgages were included in the development of 27 regression equations for the three low-flow regions. For the northeast and northwest regions, a censoring threshold was used to develop 12 left-censored regression equations to estimate the 6 low-flow frequency statistics for each region. For the southern region a total of 12 regression equations were developed; 6 logistic regression equations were developed to estimate the probability of zero flow for the 6 low-flow frequency statistics and 6 generalized least-squares regression equations were developed to estimate the 6 low-flow frequency statistics, if nonzero flow is estimated first by use of the logistic equations. A weighted-least-squares regression equation was developed for each region to estimate the harmonic-mean-flow statistic. Average standard errors of estimate for the left-censored equations for the northeast region range from 64.7 to 88.1 percent and for the northwest region range from 85.8 to 111.8 percent. Misclassification percentages for the logistic equations for the southern region range from 5.6 to 14.0 percent. Average standard errors of prediction for generalized least-squares equations for the southern region range from 71.7 to 98.9 percent and pseudo coefficients of determination for the generalized-least-squares equations range from 87.7 to 91.8 percent. Average standard errors of prediction for weighted-least-squares equations developed for estimating the harmonic-mean-flow statistic for each of the three regions range from 66.4 to 80.4 percent.

The regression equations are applicable only to stream sites in Iowa with low flows not significantly affected by regulation, diversion, or urbanization and with basin characteristics within the range of those used to develop the equations. If the equations are used at ungaged sites on regulated streams, or on streams affected by water-supply and agricultural withdrawals, then the estimates will need to be adjusted by the amount of regulation or withdrawal to estimate the actual flow conditions if that is of interest. Caution is advised when applying the equations for basins with characteristics near the applicable limits of the equations and for basins located in karst topography. A test of two drainage-area ratio methods

using 31 pairs of streamgages, for the annual 7-day mean low-flow statistic for a recurrence interval of 10 years, indicates a weighted drainage-area ratio method provides better estimates than regional regression equations for an ungaged site on a gaged stream in Iowa when the drainage-area ratio is between 0.5 and 1.4.

These regression equations will be implemented within the U.S. Geological Survey StreamStats web-based geographic-information-system tool. StreamStats allows users to click on any ungaged site on a river and compute estimates of the seven selected statistics; in addition, 90-percent prediction intervals and the measured basin characteristics for the ungaged sites also are provided. StreamStats also allows users to click on any streamgage in Iowa and estimates computed for these seven selected statistics are provided for the streamgage.

Introduction

Knowledge of the magnitude and frequency of low flows for streams is fundamental for water-supply planning and design, waste-load allocation, reservoir storage design, and maintenance and quantity and quality of water for irrigation, recreation, and wildlife conservation. Low-flow statistics indicate the probable availability of water in streams during times when conflicts between water supply and demand are most prevalent. Because of this, low-flow statistics are needed by Federal, State, and local agencies for water-quality regulatory activities and water-supply planning and management. These statistics can be used as thresholds when setting wastewater-treatment plant effluent limits and allowable pollutant loads to meet water-quality regulations. Low-flow statistics can be used by commercial, industrial, and hydroelectric facilities to determine availability of water for water supply, waste discharge, and power generation. Low-flow statistics also can be used in ecological research. Low-flow conditions can disturb ecosystems and create biological responses and changes in habitat such as reduced populations of aquatic species and shifts in the relative distribution of species (Miller and Golladay, 1996).

Currently (2012), 384 stream reaches in Iowa were designated as impaired (Category 5 of the State's Section 303(d) list that exceed specific water-quality and/or biological criteria) (Iowa Department of Natural Resources and the U.S. Environmental Protection Agency, 2010). These stream reaches are scheduled to have pollutant loads analyzed and maximum loading rates established by Total Maximum Daily Load (TMDL) assessments (U.S. Environmental Protection Agency, 2011). Reliable estimates of expected streamflow are needed for specific periods of the year when determining the maximum allowable load of a pollutant in a stream. Estimates of expected streamflow are especially important for low-flow periods when agencies need to determine waste-load allocations (WLAs) for National Pollution Discharge Elimination System (NPDES) discharge permits for municipalities, industries, and other entities with facilities that release treated wastewater into a stream. A WLA is the loading capacity or maximum quantity of a pollutant each point-source discharger is allowed to release into a particular stream. WLAs are used to establish water-quality-based limits for point-source discharges.

Seasonal low-flow statistics are used by Iowa Department of Natural Resources (IDNR) for setting thresholds for controlled discharges from wastewater-treatment plants during the period October through December. Controlled discharges from wastewater-treatment plants are only allowed twice a year, one in the spring and another in the fall. Because streamflows in Iowa are typically lower in the fall than in the spring, fall is the critical season used to develop discharge limits for these facilities (Connie Dou, Iowa Department of Natural Resources, written commun., 2007).

The U.S. Geological Survey (USGS) operates a network of streamgages in Iowa that provides streamflow data for a variety of purposes, and low-flow frequency statistics and harmonic-mean flows can be calculated from streamflow data collected at these locations. However, it is not possible to operate streamgages at every location; therefore, methods are needed for estimating low-flow frequency statistics and harmonic mean flows at ungaged stream sites. In response to the need to update and improve the accuracy of estimates of low-flow frequency statistics and harmonic mean flows for ungaged stream sites in Iowa, the USGS, in cooperation with the IDNR, initiated a statewide study in 2007. This study updates selected low-flow frequency and harmonic-mean-flow estimates for streams in Iowa with data collected through September 30, 2006. Major components of the study included (1) computing seven selected statistics at 208 continuous-record streamgages within Iowa and adjacent States with at least 10 years of streamflow record using the longest, most recent period of record through September 30, 2006, without a significant trend; (2) measuring 54 basin characteristics for each streamgage that include hydrologic-characteristic measurements from five kriged grids developed for the study area; (3) developing 27 regional regression equations to estimate 7 selected statistics at ungaged stream sites based on basin characteristics; and (4) testing two drainage-area ratio methods to determine if either method provides better estimates for a selected low-flow frequency statistic for ungaged sites on gaged streams in Iowa compared to regional regression estimates and to determine the appropriate range of drainage-area ratios to use with the method.

Purpose and Scope

Regression equations for estimating selected low-flow frequency statistics and harmonic-mean flows were developed for use in Iowa and are described in this report. The regression equations relate selected low-flow frequency statistics and harmonic mean flows to physical and hydrologic characteristics of drainage basins. In addition, the regression equations developed from this study also are included in the USGS StreamStats Web-based geographic information system (GIS) tool (*http://water.usgs.gov/osw/streamstats/index.html*). StreamStats allows users to obtain selected streamflow-statistic estimates, upstream drainage-basin characteristics, and other information for user-selected stream sites. Using a GIS-based interactive map of Iowa, the user can 'point and click' on a stream site and StreamStats will delineate the basin boundary upstream from the selected site. The user also can 'point and click' on USGS streamgages and receive selected streamflow statistics and other streamgage information.

This report presents 27 regional regression equations that can be used to estimate 7 selected statistics for ungaged sites on unregulated streams in Iowa. Sixteen of the equations can be used to estimate low-flow frequency statistics for annual 1-, 7-, and 30-day mean low flows for a recurrence interval of 10 years (M1D10Y, M7D10Y, and M30D10Y) and an annual 30-day mean low flow for a recurrence interval of 5 years (M30D5Y). Eight of the equations can be used to estimate low-flow frequency statistics for seasonal (October 1 through December 31) 1- and 7-day mean low flows for a recurrence interval of 10 years (M1D10Y1012 and M7D10Y1012). Three of the equations can be used to estimate the harmonic-mean-flow statistic. Low-flow frequency and harmonic-mean-flow statistical names used in this report were selected to maintain consistency with names used within StreamStats (*http://water.usgs.gov/osw/streamstats/StatisticsDefinitions.html*).

The equations were developed using selected low-flow frequency statistics and harmonic-mean flows computed for 192 continuous-record streamgages unaffected by regulation or diversion that are located in Iowa and in adjacent States within a 50-mile (mi) buffer of Iowa (all gaged drainage basins are within the buffer). Selected low-flow frequency statistics and harmonic mean flows computed for 208 streamgages are presented in this report. Low-flow frequency statistics and harmonic mean flows for these 208 streamgages were computed using streamflow data collected through September 30, 2006, and were computed using 10 or more years of record. Because significant positive trends in annual low flow were found when considering the entire period of streamflow record for the majority of the streamgages included in this study, low-flow frequency statistics and harmonic mean flows were computed for each streamgage using the longest, most-recent period of record without a significant trend in low flow. The accuracy and limitations of the regression equations and the methodology used to develop the equations are described in the report.

Description of Study Area

The study area (fig. 1) includes the entire State of Iowa and adjacent areas within a 50-mi buffer of Iowa in the neighboring states of Illinois, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin. A map of Iowa soil regions created by the National Cooperative Soil Survey and the Natural Resources Conservation Service (NRCS) is shown in figure 2 (*ftp://ftp-fc.sc.egov.usda.gov/IA/technical/IowaSoilRegionsMap.html*). There are 10 landform regions in the State, each having distinctive topography and geology (fig. 3).

The Mississippi and Missouri River Alluvial Plains and Iowa-Cedar Lowland (formerly included in the Mississippi Alluvial Plain; Prior, 1991) landform regions make up a small part of Iowa; these regions are characterized as broad flat-floored flood plains underlain by water-transported deposits (Prior and others, 2009).

The Southern Iowa Drift Plain is characteristic of an older, postglacial landscape that has eroded to form a steeply to gently rolling topography and a well-established drainage system (Prior, 1991). The region formed as a result of repeated continental glacial advances across southern Iowa, during which the bedrock surface of the uplands was smoothed and the valleys were filled with thick deposits of glacial till. Periods of glaciation were followed by interglacial periods of erosion. The sequence of repeated glacial scour and fill formed a nearly level drift plain across southern Iowa. The topography of southern Iowa developed as a result of the erosion of this drift plain; common terrain characteristics are integrated drainage networks, stepped erosional surfaces, and exposed bedrock in the deeper alluvial valleys (Prior, 1991). Nearly all of the upland soils of southern Iowa are formed from moderate deposits of wind-blown loess that subsequently covered the glacial tills. Soils in southern Iowa are generally characterized as loess over clay-loam till and clay paleosol; thickness of loess deposits in southern Iowa range from 6 to over 16 feet (ft) (Oschwald and others, 1965).

The Des Moines Lobe landform region is characteristic of a young, postglacial landscape that is unique with respect to the rest of the State (Prior, 1991). This region generally comprises low-relief terrain, accentuated by natural lakes, potholes, and marshes, where surface-water drainage typically is poorly defined and sluggish. Soils of this region generally consist of friable, calcareous loam glacial till with thick deposits of compact, uniform pebbly loam (Oschwald and others, 1965; Prior, 1991).

The Iowan Surface landform region is a low-relief plain with well-established, low-gradient drainage networks. Topography of this region appears slightly inclined to gently rolling with long slopes and open views to the horizon (Prior 1991). Soils of this region are characterized as thin, discontinuous loess or loam and clay loam over glacial drift (Prior, 1991; Oschwald and others, 1965).

The Northwest Iowa Plains landform region is similar to the Iowan Surface landform region in terms of erosional history and overall appearance. The topography of this region is a gently rolling landscape of low, uniform relief. A well-established branching network of streams covers this region, providing effective drainage and a uniformly ridged land surface (Prior, 1991). Most of the valleys are wide swales that merge gradually with long, even slopes up to broad, gently rounded basin divides. Windblown loess is abundant and

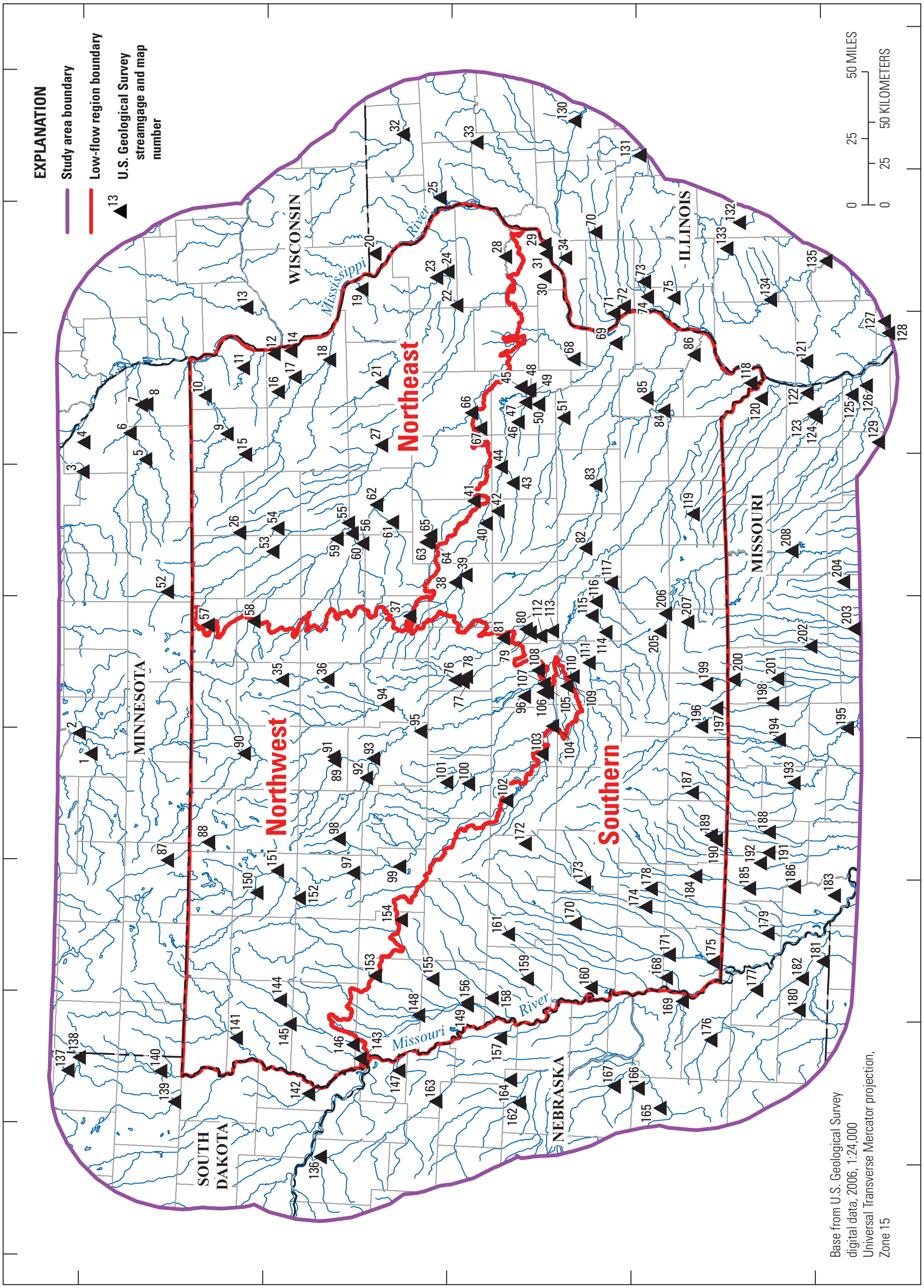

Figure 1. Location of low-flow regions and streamgages evaluated for regionalizing selected low-flow frequency statistics and harmonic mean flows in Iowa.

nearly continuous across the Northwest Iowa Plains; depth of the mantle varies generally from 16 to 4 ft in a southwest to northeast direction across the region. Soils in this region are characterized as loess over clay loam till (Oschwald and others, 1965).

The East-Central Iowa Drift Plain is similar to the Southern Iowa Drift Plain and was formerly included as part of the Southern Iowa Drift and the Iowan Surface but is now considered a separate landform because of its uniqueness (Prior and others, 2009). The East-Central Iowa Drift Plain has bedrock

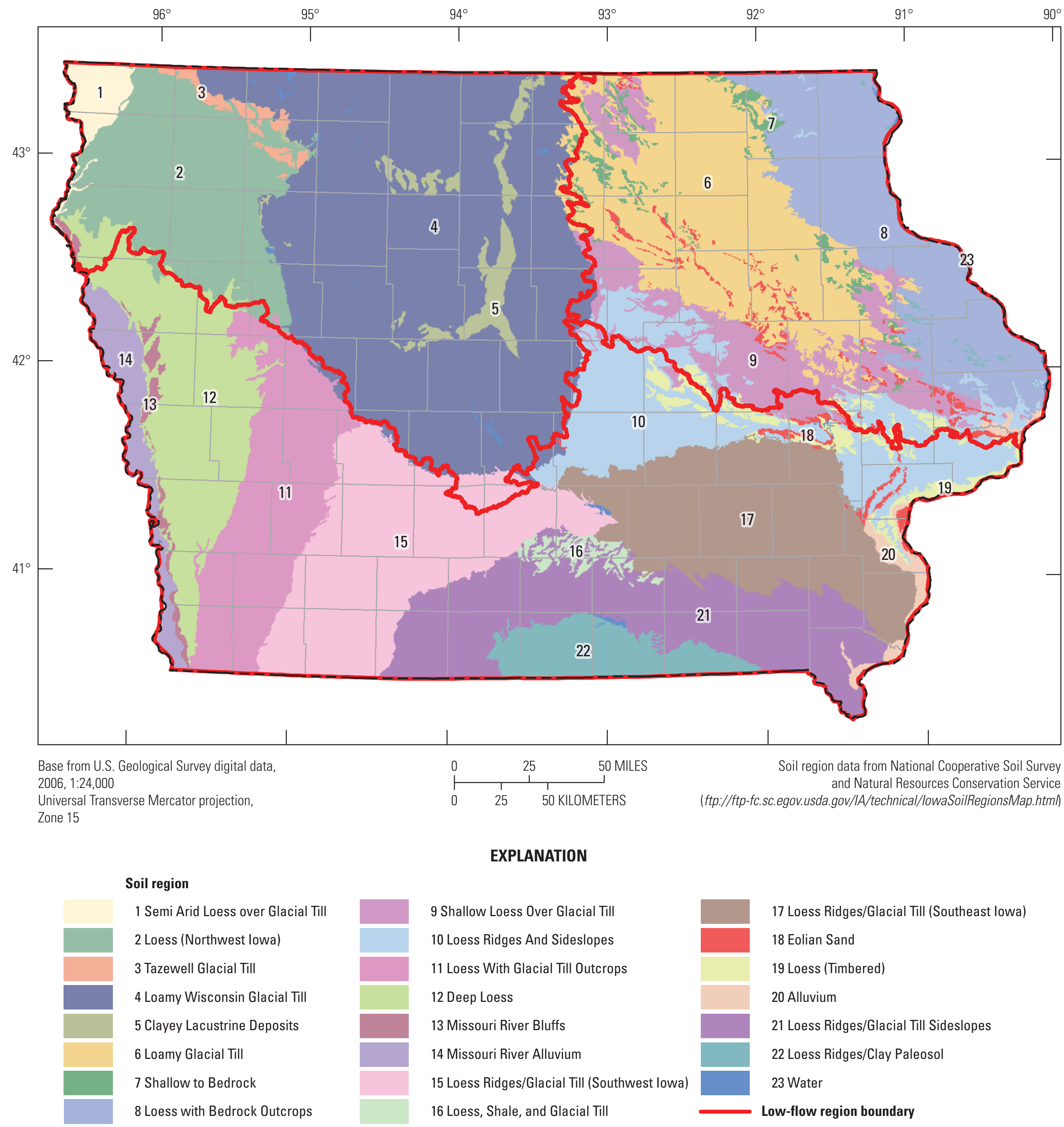

Figure 2. Soil regions in Iowa.

closer to the surface and more bedrock outcropping than does the Southern Iowa Drift Plain. Topography of the region consists of steeply rolling hills and valleys. A mantle of loess covers the uplands and upper hill slopes. Soils in this region are characterized as loess over glacial till or limestone bedrock (Oschwald and others, 1965).

The Paleozoic Plateau landform region has a bedrock-dominated, erosional topography that is characterized by plateau-like uplands, integrated drainage networks with steep gradients, and deeply entrenched valleys (Prior, 1991; Horick and Soenksen, 1989; Iowa Natural Resources Council, 1958). Stream erosion and hillslope development have stripped away glacial deposits from all but limited areas of this region. Karst topography occurs in the Paleozoic Plateau where carbonate rocks occur at depths of less than 50 ft beneath the land surface. Dissolution of these carbonate rocks (limestone and dolomite) by groundwater has enlarged cracks and crevices in the bedrock and has resulted in surface depressions, sinkholes,

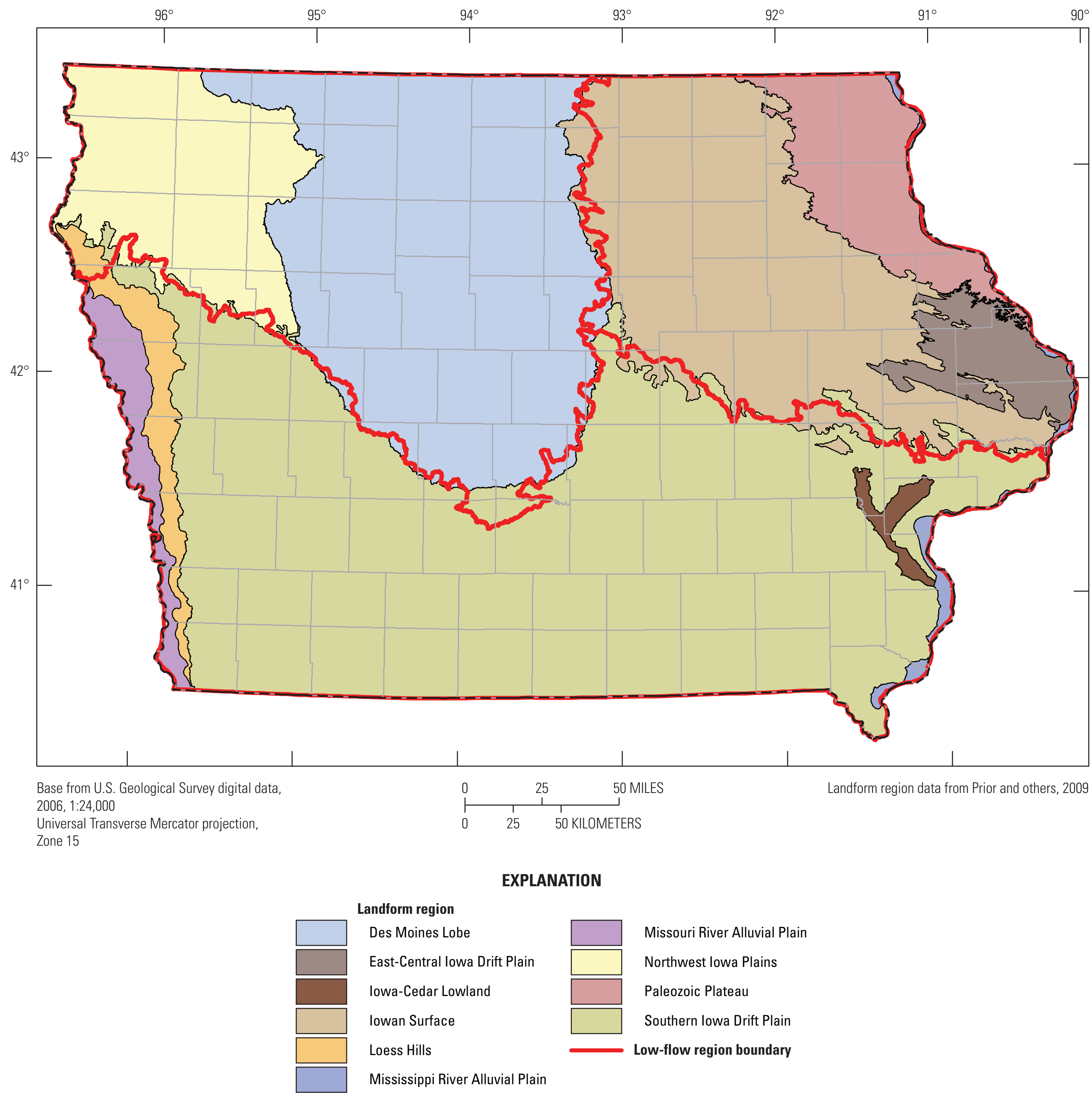

Figure 3. Landform regions in Iowa.

caves, caverns, and springs. Where sinkholes have formed in streambeds, streams can abruptly disappear as surface-water runoff is captured and redirected to groundwater flow. Soils in this region are characterized as thin loess and glacial drift over bedrock or clay loam till (Prior, 1991; Oschwald and others, 1965).

The Loess Hills landform region is one of the State’s most distinctive landscapes. The irregular Loess Hills extend as a narrow band that borders the full length of the Missouri River in western Iowa. The topography is sharp-featured, with alternating peaks and saddles that drop and climb along narrow, uneven ridge crests (Prior, 1991). A dense drainage network forming tight hollows, narrow ravines, and steep gullies distinguishes the intricately sculptured terrain. Loess is wind-deposited silt that is highly erodible and is very unstable when exposed surfaces become saturated with water. Loess depths in the Loess Hills are generally over 60 ft (Prior, 1991).

Most precipitation in the study area results from storms moving inland primarily from the Gulf of Mexico and secondarily from the Pacific Ocean (Soenksen and Eash, 1991). Annual precipitation, which is mostly rain, ranges from 26 inches (in.) in the extreme northwest to as much as 38 in. in the southeast; the statewide average is around 34 in. (National Climatic Data Center, 2012). About 75 percent of the annual precipitation is received during April through September. Typically during August through February, streamflow in most unregulated streams in the study area is base flow; during March through July, streamflow is significantly greater, primarily as a result of snowmelt during late February through early April and rainfall during May through July. Annual minimum streamflows typically occur during August through February.

Base flow in streams in Iowa has increased, and more precipitation flowed into streams as base flow than as surface flow over the second half of the 20th century (Schilling and Libra, 2003). Reasons for the observed base-flow trends are hypothesized to be as follows: improved conservation practices, added artificial drainage, increasing row crop intensity, and channel incision. Increasing base flow in streams in Iowa is significantly related to increasing row crop production; a 13- to 52-percent increase in row crop percentage in many Iowa basins has contributed to a 7- to 31-percent increase in base flow (Schilling, 2005). Analyses of streamflow trends for the United States found positive trends in minimum flows; the trends appear to have occurred around 1970 as an abrupt change rather than as a gradual change (McCabe and Wolock, 2002; Lins, 2005). Kendall’s *tau* trend analysis of annual minimum daily mean discharges for 18 streamgages in Iowa included in the McCabe and Wolock (2002) study indicated significant positive trends for all 18 streamgages (David Wolock, U.S. Geological Survey, written commun., 2007). Lins (2005) found positive trends in the Upper Mississippi region and the pattern of trends is dominated by increases in streamflow during the months of September to December. A study by Small and others (2006) found that positive trends in 7-day low flow for the upper Mississippi region during 1948–97 appear to be related to an increase in fall precipitation.

Previous Studies

This is the fourth in a series of reports that describe low-flow characteristics for Iowa streams. The first report (Schwob, 1958) contained information on low-flow frequency and flow duration for 51 continuous-record streamgages using streamflow data collected through the 1953 water year and storage requirements for critical low-flow periods for 18 of the streamgages. A water year is the period October 1 through September 30 and is designated by the year in which it ends. Schwob also presented methods for estimating low-flow frequency and flow duration for ungaged sites that required the collection of discharge measurements at the ungaged sites. The second report (Heinitz, 1970) contained information on average discharge, low-flow frequency, flow duration, and storage requirements for continuous-record streamgages using streamflow data collected through the 1966 water year. Data on flow duration were presented for 113 streamgages and on low-flow frequency for 77 streamgages. Storage requirements for draft rates, or the amount of water that can be stored during high flows and released to supplement low flows, were presented for 65 streamgages. Annual 7-day mean low flows for a recurrence interval of 2 years (M7D2Y) were presented for 431 low-flow partial-record sites, and for some of these sites, M7D10Y low-flow frequency data were presented. Heinitz also presented a regression equation for estimating average discharge for ungaged sites that required the measurement of drainage area and annual precipitation for the ungaged site, and a method for estimating draft storage requirements for ungaged sites that required the collection of a few low-flow discharge measurements at ungaged sites. The third report (Lara, 1979) contained information on annual and seasonal low-flow frequency and flow duration for 142 continuous-record streamgages using streamflow data collected through the 1976 water year. Data on the average discharge, the 84-percent exceedance discharge, and the M7D2Y and M7D10Y low-flow frequency discharges were presented for 426 low-flow partial-record sites. Lara (1979) also presented a regional regression equation for estimating average discharge for ungaged sites for three hydrologic regions identified for the State that required the measurement of drainage area and annual precipitation. Lara (1979) attempted to develop regional regression equations for low-flow frequency, but reported the equations could not be successfully applied because low flows are closely related to geologic characteristics, which at the time, could not be easily quantified or described by simple indexes. The collection of base-flow discharge measurements at ungaged sites remained the recommended procedure for estimating low-flow characteristics. Two maps (plates 3 and 4) show areal trends of M7D2Y and M7D10Y low-flow frequency discharges that could be used for very approximate estimates (Lara, 1979).

Methods for Data-Set Development for Streamgages

Data used in this report were collected for 208 active and inactive continuous-record streamgages located in Iowa and within a 50-mi buffer of Iowa in the neighboring States of Illinois, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin (fig. 1 and table 1 at end of report). Streamgages with at least 10 complete years of daily mean discharges and unaffected by regulation or diversion were initially selected for evaluation in the study, which included 133 streamgages in Iowa and 75 streamgages in neighboring States. Streamgages from neighboring States were used to improve the representativeness of selected low-flow frequency statistics and harmonic mean flows and basin characteristics found in Iowa border areas and to provide better estimates of the error of the regression equations for ungaged sites near the State border. Daily mean discharge data collected through the 2006 water year (through September 30, 2006) were retrieved for the 208 streamgages from the USGS National Water Information System (NWIS) database for use in computing selected low-flow frequency statistics and harmonic mean flows.

Streamflow data were reviewed to eliminate data affected by regulations or diversions from biasing the computation of selected low-flow frequency statistics and harmonic mean flows. Decisions on inclusion or exclusion of data for streamgages were made using hydrologic judgment according to available information regarding the occurrence, timing, and extent of regulations or diversions upstream from the streamgages. No explicit decision criteria were used. In general, all streamgages with data affected by upstream regulations or affected by upstream diversions during typical low-flow periods were deleted from the study data set. Information available about possible regulations or diversions at streamgages was not always complete and the veracity was questionable in some cases. Thus, it is possible that some data affected by regulation or diversion could have been included in the study data set. However, the overall effect on the development of regional regression equations is believed to be minimal. Streamflow statistics for 22 streamgages operated by the Iowa Water Science Center that were excluded from this study are presented in the appendix.

A standard, continuous-record streamgage records gage height (the stage or water-surface elevation) continuously from which a daily mean discharge is computed by use of a stage-discharge relation. A low-flow partial-record site is a site on a stream where base-flow discharge measurements are collected periodically for correlation to streamflows at a nearby hydrologically similar streamgage. As noted in the previous section, 426 low-flow partial-record sites located in Iowa were included in the last low-flow study (Lara, 1979). Base-flow measurements were collected at these sites during 1957 to 1976, since then, no additional measurements have been collected. Low-flow studies typically include data from partial-record sites to supplement the continuous-record streamgage data set with an expanded range and geographic coverage of basin and low-flow characteristics. On the basis of studies indicating positive trends in low flows in Iowa and the Upper Mississippi region (Schilling and Libra, 2003; Schilling, 2005; McCabe and Wolock, 2002; Lins, 2005) and on the basis of computations of M7D10Y low-flow frequency statistics for several Iowa streamgages included in this study that also indicated positive trends in annual low flow for different record lengths, data from the 426 partial-record sites were not included in this study because of the possibility that data limited to the period 1957–76 may bias the results of regional regression equations.

Low-Flow Frequency

To estimate low-flow discharges for selected recurrence intervals at continuous-record streamgages, such as the M7D10Y, a low-flow frequency analysis was performed. For this report, low-flow frequencies were estimated for annual statistics of M1D10Y, M7D10Y, M30D10Y, and M30D5Y and for seasonal statistics (October 1 through December 31) of M1D10Y1012 and M7D10Y1012 for each of the 208 streamgages (table 1). The magnitude and frequency of low flows are computed for a streamgage by relating a specific number of consecutive daily mean discharges during an annual period to annual minimum nonexceedance probability or recurrence interval. Annual nonexceedance probability is expressed as the chance that a selected low-flow magnitude will not be exceeded in any one year. Recurrence interval, which is the reciprocal of the annual nonexceedance probability, is the average number of years between nonexceedances of a selected low-flow magnitude. For example, if a theoretical 7-day mean low-flow discharge is not exceeded once on the average during any 10-year period (recurrence interval), then it has a 10-percent chance (annual nonexceedance probability equals 0.1) of not being exceeded during any one year. This low-flow discharge is referred to as the annual 7-day, mean low flow for a recurrence interval of 10 years, or M7D10Y. Likewise, if a theoretical 30-day mean low-flow discharge is not exceeded on the average during any 5-year period, then it has a 20-percent chance of not being exceeded during a specific year. This low-flow discharge is referred to as the annual 30-day, mean low flow for a recurrence interval of 5 years, or M30D5Y. Although the recurrence interval represents the long-term average period between low flows of a specific magnitude, rare low flows could occur at shorter intervals or even within the same year. Discharge values estimated for low-flow frequency statistics like M7D10Y and M30D5Y change as streamflow records become longer.

The USGS has established standard methods for estimating low-flow frequency statistics for streamgages (Riggs, 1972). In this study, the USGS computer programs IOWDM, ANNIE, and SWSTAT (*http://water.usgs.gov/software/surface_water.html*) were used to format daily mean discharge data and to compute N-day, Kendall's *tau*, flow duration, and low-flow frequency analyses (Lumb and others, 1990; Flynn and others, 1995).

N-Day Analyses

Low-flow frequency statistics are computed using the annual minimum mean discharges for any specific number of consecutive days (N-day low flows) during an annual period. The mean discharge for each N-day period throughout the annual period is calculated and the minimum value is used for that annual period. For example, the M7D10Y low-flow statistic is computed from the annual series of minimum 7-day mean flows for a streamgage. From the daily mean discharge record, the mean flow for each consecutive 7-day period is determined and the lowest mean value for each year is assigned to that year in the annual series. The series of annual minimum N-day values are then fit to a log-Pearson Type III distribution to determine the low-flow frequency (Riggs, 1972). More specific information about the log-Pearson Type III distribution can be found in Interagency Advisory Committee on Water Data (1982). Low-flow frequency statistics also can be computed on a seasonal or monthly basis by limiting the daily mean discharge data used for the annual series to just the season or month of interest. For example, M7D10Y1012 low-flow statistics for the fall season are computed by fitting a probability distribution to the annual series of minimum 7-day mean flows calculated from daily mean discharges during October 1 through December 31 of each year. Annual and seasonal N-day discharge values for some streamgages included this study were equal to zero. A conditional probability adjustment for zero flow values (Interagency Advisory Committee on Water Data, 1982, appendix 5) was used for low-flow frequency analyses for streamgages with one or more annual or seasonal N-day discharge values of zero.

The annual period used in this study for the computation of annual low-flow frequency statistics is defined as the climatic year (April 1 through March 31). The climatic year is used for low-flow frequency analyses because low-flow events in Iowa typically occur during the late summer through winter months. N-day periods analyzed in this study for each annual climatic year were 1-, 7-, and 30-day periods. A seasonal period (October 1 through December 31) also was used in this study for the computation of fall low-flow frequency statistics. N-day periods analyzed in this study for each annual fall season were 1- and 7-day periods. For streamgages included in the study, the number of climatic years of record are often one year less than the number of fall (October 1 through December 31) years of record (table 1) because many streamgages are operated on a water-year basis (October 1 to September 30), and the first half of the first water year of record is not included when analyzing the data by climate year because of incomplete data for a full climate year. As a result, seven streamgages with at least 10 years of fall record only had 9 years of annual climate-year record (table 1); five of these seven streamgages were included in the study for the development of regression equations for low-flow frequency statistics for the fall season and for the harmonic mean flow, but were not included in the study for the development of annual (climate-year) regression equations for low-flow frequency statistics.

Trend Analyses

N-day data calculated for annual climatic years and for annual fall seasons were analyzed for the entire period of record (table 1) for trends using the Kendall's *tau* hypothesis test in the SWSTAT program (Lumb and others, 1990). Trends in the N-day data could introduce a bias into the low-flow frequency analyses because a major assumption of frequency analyses is annual low flows are independent and stationary over time. The Kendall's *tau* test computes the monotonic relation between N-day values (discharge) and time (climatic years) (Helsel and Hirsch, 2002). A p-value threshold of 5 percent ($\alpha = 0.05$) was used in this study for the Kendall's *tau* test and p-values less than or equal to 5 percent were flagged as having statistically significant trends (positive or negative). Five Kendall *tau* tests, one test for each annual and fall N-day record, were performed for each streamgage included in the study. The Kendall's *tau* test was performed for the five N-day time series at each streamgage: the annual climate-year minimum 1-, 7-, and 30-day low flows and the annual fall minimum 1- and 7-day low flows. Results of the Kendall's *tau* tests indicated statistically significant positive trends for 133 of the 208 streamgages tested using the entire period of record. Annual and seasonal precipitation data for Iowa were tested for trends using Kendall's *tau* analyses. While statistically significant trends in Iowa precipitation are apparent for some areas of the State for some of the periods of record tested, the precipitation data do not appear to fully explain the low-flow trends. Changes in agricultural practices are hypothesized to be the primary cause of the positive low-flow trends in the State (Schilling and Libra, 2003: Schilling, 2005). Two approaches were considered for this study to try to minimize the bias of significant positive trends in the computation of selected low-flow frequency statistics and harmonic mean flows: (1) use a common period of record for each streamgage (for example, do not use any N-day values prior to 1970) or (2) use a variable length of record for each streamgage (use the longest, most recent period of record without a significant trend). Because the variable-length record approach allows for longer record lengths to be included for many streamgages, it was selected for use in this study. A series of Kendall's *tau* analyses were computed for each streamgage using the initial base period 1985–2006; from 1985, the length of record tested was increased by 5-year increments backwards in time until a significant positive trend was detected for any one of the five N-day annual low-flow records being tested. Trend analyses were then computed by decreasing the length of record by 1-year increments sequentially until a significant positive trend was not detected for each of the five N-day records. This procedure was used for each streamgage to determine the beginning year of the longest period of recent record without a significant trend for any of the five N-day records. Approximately 10,000 Kendall's *tau* trend analyses were computed as part of the variable-length record approach. Results of the trend analyses indicated a strong directional effect in which streamgages in the eastern and southern areas of the State have longer periods of record without significant trends compared to streamgages in the western and northern parts of the State. Streamgages with discontinued or intermittent records were evaluated with respect to other nearby streamgage records to determine an appropriate period of record to use. Table 1 lists the longest period of record without a significant trend for all five N-day records for each streamgage under the column heading of "Period of record used for low-flow study." A difference in the period of record listed in this column from the preceding column heading of "Entire period of record," indicates that a significant trend was found for the entire period of record and a shorter period of record was used for the computation of selected low-flow frequency statistics and harmonic mean flows.

The number of climatic years used for the low-flow study for the 208 streamgages ranged from 10 to 70 years with a mean of 33.3 years and a median of 35 years. The number of years of fall record used in the study ranged from 10 to 72 years with a mean of 33.0 years and a median of 35 years.

Harmonic Mean Flow

Design flows are used in water-pollution control programs to provide adequate protection against pollutant exposure periods of a given duration (Rossman, 1990a). The harmonic-mean-flow statistic (QAH) can serve as a design flow for human health criteria that are based on lifetime exposures because it can be used to calculate the average exposure concentration of a contaminant for an average contaminant loading rate (Rossman 1990b; Koltun and Whitehead, 2002). A QAH value was calculated for each of the 208 streamgages from the daily mean discharge record using the USGS BIOFLO (version 2.0) computer program (Straub, 2001), which is based on a computer program developed by the U.S. Environmental Protection Agency called DFLOW (Rossman, 1990b). The exposure concentration will be greater and more deleterious on days with low flow than on days with high flows. The QAH statistic computed from a streamflow record generally is smaller than the corresponding arithmetic mean discharge, is adjusted for the days with zero flow, and gives greater weight to low daily mean discharges than high daily mean discharges. The QAH streamflow statistic is calculated as:

$$QAH = \left(\frac{N_{nz}}{N_t}\right)\left(\frac{N_{nz}}{\sum_{i=1}^{N_{nz}}\frac{1}{Q_i}}\right) \tag{1}$$

where

Q_i is the daily mean discharge,
N_{nz} is the number of non-zero Q_i, and
N_t is the total number of Q_i.

If N_{nz} equals N_t, QAH is equal to the reciprocal of the mean of the reciprocals of all Q_i. Values of QAH computed for each of the 208 streamgages are presented in table 2 (at end of report) as observed values.

Streamflow-Variability Index

The streamflow-variability index (STREAM_VAR) initially was proposed by Lane and Lei (1950) to help produce synthetic flow-duration curves. Subsequently, a generalized STREAM_VAR has been used in the development of regression equations for estimating QAH in Kentucky (Martin and Ruhl, 1993) and Ohio (Koltun and Whitehead, 2002), and for estimating low-flow frequency statistics in Kentucky (Martin and Arihood, 2010).

A STREAM_VAR value was calculated for each of the 208 streamgages (observed value listed in table 3 at end of report) by (1) computing a flow-duration curve using daily mean discharge data to obtain discharge values at 5-percent exceedance intervals from 5 to 95 percent, and (2) calculating the standard deviation of the logarithms of the 19 discharge values corresponding to the 5-percent exceedance intervals from 5 to 95 percent (Searcy, 1959). The flow-duration curve is a cumulative frequency curve that shows the percentage of time that a specific discharge is equaled or exceeded (fig. 4). For example, the 80th percentile represents the discharge value that 80 percent of the daily mean discharges are equal to or greater than.

The STREAM_VAR statistic is calculated as:

$$STREAM\_VAR = \sqrt{\frac{\sum_{i=5,5}^{95}\left(log\left(Q_{ci}\right)-\overline{log\left(Q_c\right)}\right)^2}{18}} \tag{2}$$

where

$log\,(Q_{ci})$ is the base 10 logarithm of the i-percent duration streamflow (i=5, 10, 15, 20 … 95), and
$\overline{log\left(Q_c\right)}$ is the mean of the logs of the 19 streamflow values at 5-percent intervals from 5 to 95 percent on the flow-duration curve of daily mean discharges.

If an i-percent duration streamflow value is zero (which cannot be log-transformed), the log (Q_{ci}) value was set to zero in equation 2 to allow all nineteen 5-percent intervals to be included in the calculation of STREAM_VAR.

STREAM_VAR is a measure of the slope of the flow-duration curve and is a measure of the capacity of a watershed to sustain base flow in a stream (Martin and Arihood, 2010). Small values of STREAM_VAR (less than about 0.55) indicate a flatter slope of the flow-duration curve and represent sustained base flows. Large values of STREAM_VAR (greater than about 0.55) indicate a steeper slope of the flow-duration curve, which may go to zero flow at the low end (high percentiles); such large values represent an absence of sustained

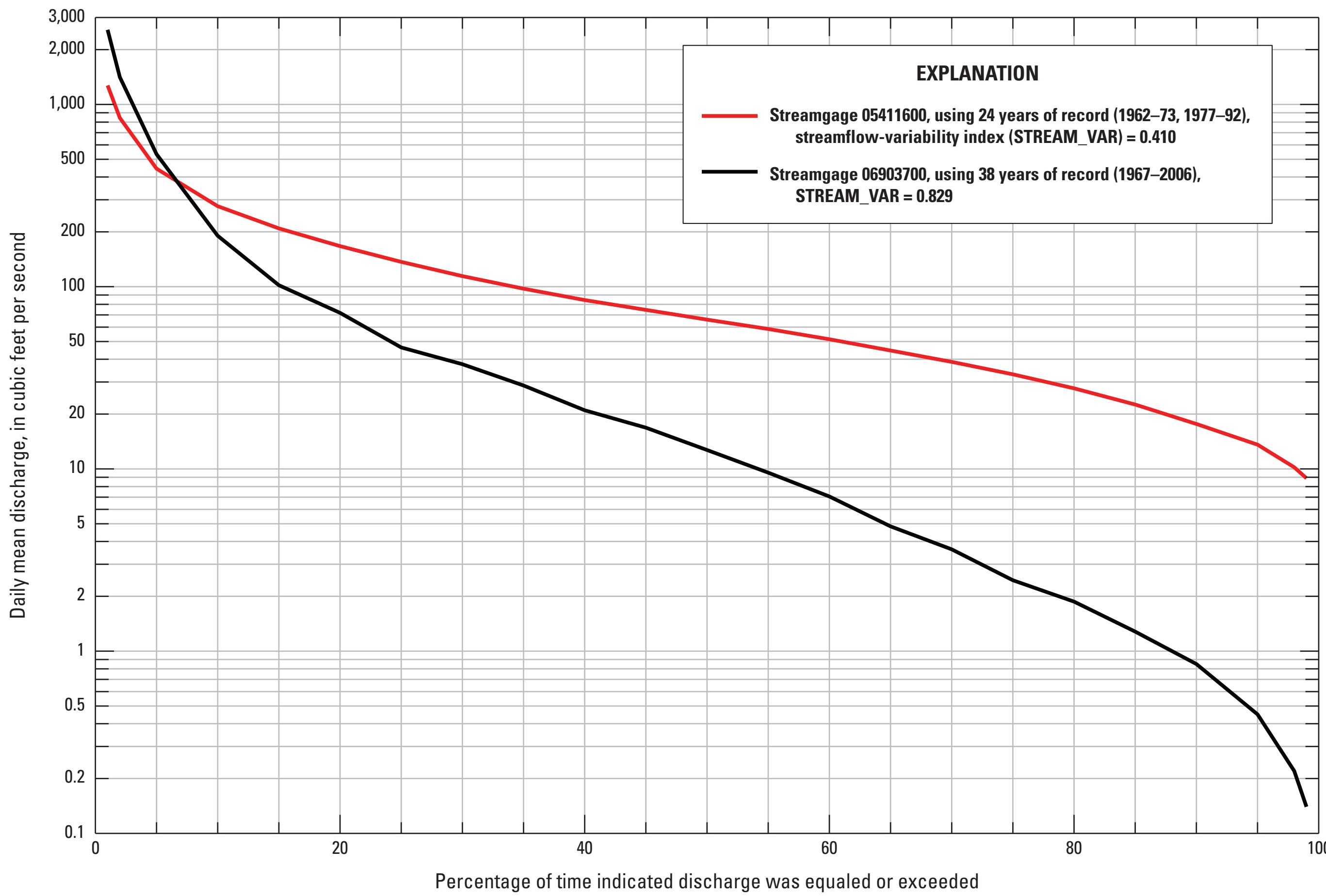

Figure 4. Examples of flow-duration curves for streamgages Turkey River at Spillville, Iowa (streamgage 05411600, map number 15), and South Fork Chariton River near Promise City, Iowa (streamgage 06903700, map number 207).

base flow. Flow-duration curves for which relatively small and large STREAM_VAR values were computed are shown in figure 4 for two streamgages in Iowa. The Turkey River at Spillville, Iowa (streamgage 05411600, map number 15), has a published drainage area of 177 mi^2 and an observed STREAM_VAR value of 0.410 calculated from 24 years of record. The South Fork Chariton River near Promise City, Iowa (streamgage 06903700, map number 207), has a similar published drainage area of 168 mi^2 and an observed STREAM_VAR value of 0.829 calculated from 38 years of record. The duration curve for the Turkey River streamgage is much flatter than the curve for the Chariton River streamgage, which indicates sustained base flow at the Turkey River streamgage; whereas the steeper duration curve for the Chariton River streamgage indicates the absence of sustained base flows.

Base-Flow-Recession Time Constant

Boussinesq (1903) advanced the refined problem of outflow from a horizontal, unconfined aquifer discharging into a fully incised stream (Funkhouser and others, 2008). Brutsaert and Nieber (1977) demonstrated that the Boussinesq problem can be calculated as:

$$\frac{dQ}{dt} = -aQ^b \quad (3)$$

where

- Q is streamflow,
- T is time, and
- a and b are constants.

For this low-flow study, only the large-time behavior was analyzed (Funkhouser and others, 2008), for which a value of 1 generally is assigned to b (Brutsaert and Lopez, 1998; Eng and Brutsaert, 1999). For the large-time solution, a is calculated as:

$$\alpha = \frac{1}{\tau} = \frac{\pi^2 KpdL_s^2}{fA^2} \quad (4)$$

where

- τ is the reciprocal of a (see equation 3),
- K is the hydraulic conductivity,

p is approximately 0.3465 (Brutsaert and Nieber, 1977),
d is the aquifer thickness,
L_s is the upstream stream length,
f is the drainable porosity, and
A is the drainage area;

and thus:

$$Q_{t+\Delta t} = Q_t e^{-\Delta t/\tau} \quad (5)$$

where

$Q_{t+\Delta t}$ is the streamflow at time $t+\Delta t$,
Q_t is the streamflow at time t, and
Δt is the change in time.

The variable τ is a long-term base-flow-recession time constant, which characterizes the rate of recession of base flow as a number of days (Brutsaert and Lopez, 1998; Eng and Brutsaert, 1999); the variable τ will hereby be referred to as the streamflow statistic TAU_ANN. Instead of using equation 4, an effective value of TAU_ANN can be calculated from daily mean discharges for continuous-record streamgages by use of equation 5 (Eng and Milly, 2007; Funkhouser and others, 2008). An empirical Monte Carlo program (EmpMC program; Ken Eng, U.S. Geological Survey, written commun., 2007) was used to identify 500 pairs of days using a peak threshold of 25 percent. The 25-percent threshold is used to limit the program analysis to hydrograph peaks below the 25th percentile duration value of the record of daily mean discharges. The program was used to compute TAU_ANN and TAU_1012 (October 1 through December 31) values for each of the 208 streamgages for six different 4-day periods. Covariances computed for the six different analyses were used to determine the best 4-day period to use for computing TAU_ANN and TAU_1012 values for this study. The time period of 6–9 days following the start of a hydrograph recession was selected as the best 4-day period to use for Iowa. The associated daily mean discharges for these days then were used to compute 500 TAU_ANN values for each of the 208 streamgages using equation 5. Observed TAU_ANN base-flow-recession time constant values, computed as the mean of the 500 values, are listed in table 3 for each streamgage.

Base Flow

Two base-flow separation programs, base-flow index and hydrograph separation and analysis, were used in this study to compute the base-flow component of streamflow. Both programs partition the streamflow hydrograph into surface-runoff and base-flow components. The surface-runoff component is associated with precipitation that enters the stream as overland runoff and the base-flow component with groundwater discharge.

Base-Flow Index

A computer program called Base-Flow Index (BFI) (Wahl and Wahl, 1988, 1995) implements a technique developed by the Institute of Hydrology (1980a, 1980b) that divides the water year into N-day increments and the minimum streamflow is determined during each N-day period. Minimum N-day streamflows are compared to adjacent N-day minimums to identify turning points on a base-flow hydrograph (Esralew and Lewis, 2010). Straight lines between the turning points designate the base-flow hydrograph, and an estimate of the volume of base flow is calculated from the area beneath the hydrograph. The BFI program computes a ratio of base flow to total streamflow for each year of record, and the mean value of the annual ratios is used for the BFI value. A BFI value was computed for each of the 208 streamgages (observed value listed in table 3).

The default N-day period used by the BFI program is 5 days. This N-day period is not appropriate for all streamgages. To identify an appropriate N value for each streamgage, BFI values were calculated for N values ranging from 1 to 10 days. A graph showing the relation of N values and BFI was used to determine an appropriate N value for each streamgage through a visual identification of a change in slope of the graph. An appropriate N value to use for BFI was selected from the graph where the slope no longer substantially changed (Wahl and Wahl, 1995). Figure 5 shows the graph for the Chariton River near Chariton, Iowa (streamgage 06903400, map number 205) for which an N value of 2 was selected from the graph and thus a BFI value of 0.182 was determined for the period of record analyzed. The default value of 0.9 for the turning point parameter (f) was used for all

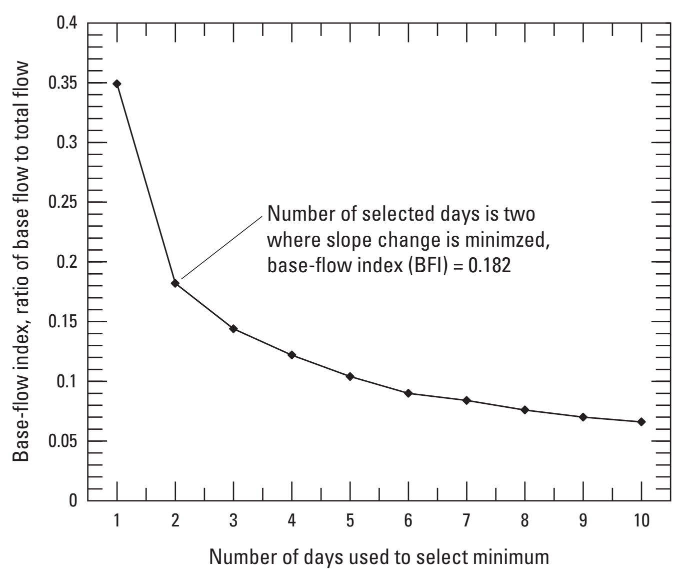

Figure 5. Relation between base-flow index (BFI) and number of days (N) used to select an appropriate N value for BFI for the streamgage Chariton River near Chariton, Iowa (streamgage 06903400, map number 205).

streamgages because BFI computations have not been shown to be highly sensitive to variations of f (Wahl and Wahl, 1995).

Hydrograph Separation and Analysis of Base Flow

A computer program for streamflow hydrograph separation and analysis called HYSEP (Sloto and Crouse, 1996) implements three techniques developed by Pettyjohn and Henning (1979). The local minimum technique was used in this study. This method checks each daily mean discharge value for a specified period of record to determine if a particular day has the lowest discharge in one-half the interval minus 1 day before and after that day. If a particular day is the lowest discharge, then it is a local minimum and a straight line is used to connect that particular day to adjacent local minimums. Linear interpolations are used to estimate base-flow values for each day between local minimums. The local minimum technique can be visualized as connecting the lowest points on the hydrograph with straight lines. The HYSEP program computes a percentage of base flow to total streamflow for each year of record, and the median value of the annual percentages is used for the HYSEP value. A HYSEP value was computed for each of the 208 streamgages (observed value listed in table 3).

Table 4 summarizes mean and median BFI and HYSEP values for all streamgages located in Iowa (excludes the 75 streamgages in adjacent States) and for each of the three low-flow regions. Seven streamgages located in Iowa, which are not assigned to low-flow regions in table 1, were included in the statewide summary but not included in the regional summaries. Mean and median summary values listed in table 4 for BFI and HYSEP indicate that the northeast region has the greatest percentage (58 to 59 percent) of base flow to annual streamflow compared to the rest of the State, and that the southern region has the smallest percentage (46 to 51 percent) of base flow to annual streamflow. Mean and median summary values for the northwest region are slightly smaller than those for the northeast region indicating that the percentage of base flow to annual streamflow is about 5 to 13 percent greater for the northern regions compared to the southern region.

Basin Characteristics

Low-flow characteristics of streams are related to the physical, geologic, and climatic properties of drainage basins (Smakhtin, 2001). In most studies, drainage area is a significant variable in explaining low-flow variability (Funkhouser and others, 2008; Kroll and others, 2004). Basin characteristics investigated in this study as potential explanatory variables in the regression analysis were selected on the basis of their theoretical relation to low flows, results of previous studies in similar hydrologic areas, and the ability to quantify the basin characteristics using GIS technology and digital data sets. The use of GIS enables the automation of the basin-characteristic measurements and solution of the regional regression equations using StreamStats.

Using GIS technology, 54 basin characteristics were measured for each of the 208 streamgages include in this study. Table 5 (at end of report) provides a brief description of each basin characteristic and the data source used to measure the characteristic. Basin-characteristic names used in this study were selected to maintain consistency with the names of explanatory variables in the USGS StreamStats Web-based GIS tool (*http://water.usgs.gov/osw/streamstats/bcdefinitions1.html*).

The basin characteristics can be separated into four categories: morphometric (physical or shape) characteristics, hydrologic characteristics, pedologic (soils)/geologic/land use characteristics, or climatic characteristics. Morphometric characteristics were measured from one to three data sources, which are described in the following section Geographic Information System Measurements. Hydrologic characteristics were initially computed for each streamgage using daily mean discharge data as previously described in the sections Streamflow-Variability Index, Base-Flow-Recession Time Constant, and Base Flow and were subsequently mapped using a kriging procedure that is described in the following section Kriged Hydrologic Characteristics. The pedologic, geologic, and land-use characteristics were computed from the NRCS Soil Survey Geographic (SSURGO) Database (Soil Survey Staff, 2012) for the seven soil characteristics, from the Iowa Geological and Water Survey Des Moines Lobe landform region boundary for the Des Moines Lobe geologic

Table 4. Summary of base-flow index (BFI) and hydrograph separation and analysis (HYSEP) of base-flow values computed from observed streamflow for streamgages in Iowa.

Region	Number of streamgages[1]	Mean BFI (percent)	Median BFI (percent)	Mean HYSEP (percent)	Median HYSEP (percent)
Statewide	[2]133	52	55	52	55
Northeast	32	59	58	59	58
Northwest	31	56	56	56	56
Southern	63	46	50	46	51

[1]Excludes 75 streamgages located in adjacent States.

[2]Includes seven streamgages in Iowa listed in table 1 that are not assigned to low-flow regions.

characteristic (Prior and others, 2009), and from the Multi-Resolution Land Characteristics Consortium 2001 National Land Cover Database for the land-use characteristic that measured percent area of row crops (*http://www.mrlc.gov/index.php*; Homer and others, 2004). The climatic characteristics were computed from Oregon State University Parameter-elevation Regressions on Independent Slopes Model (PRISM) data sets (PRISM Climate Group, 2008).

Kriged Hydrologic Characteristics

Kriging is a geostatistical method that can be used to determine optimal weights for measurements at sampled locations (streamgages) for the estimation of values at unsampled locations (ungaged sites). Values initially computed for the five hydrologic characteristics (BFI, HYSEP, TAU_ANN, TAU_1012, and STREAM_VAR; table 3 does not include TAU_1012) from daily mean discharge data were subsequently kriged to create isoline maps using Geostatistical Analyst tools in ArcGIS version 9.3 (Environmental Systems Research Institute, 2001, 2009). These five kriged grids then were used to interpolate values for each of five hydrologic characteristics for each of the 208 streamgages for use as explanatory variables in the regression analyses. Prior to kriging, semivariogram modeling was used to characterize the degree of spatial correlation in each of the hydrologic-characteristic data sets using Geostatistical Analyst tools in ArcGIS version 9.3 (Environmental Systems Research Institute, 2001, 2009). The semivariogram model defines the linear weighting function used to krige each grid of observed hydrologic-characteristic values. An informative discussion of semivariogram modeling and kriging is presented in Bossong and others (1999) and in Environmental Systems Research Institute (2001).

Each hydrologic-characteristic data set was checked for anisotropy, which indicates a directional trend in the spatial correlation of the data. Four of the five hydrologic-characteristic data sets (BFI, HYSEP, TAU_ANN, and TAU_1012) were determined to be anisotropic, and directional semivariogram modeling was used to account for the directional trends. The STREAM_VAR data set was determined to be isotropic, and directional semivariogram modeling was not required. Figure 6 shows the semivariogram model that was developed for the STREAM_VAR data plotted with a lag of 25,000 meters (m) (15.5 mi). The semivariogram shows a plot of the squared differences per pair of STREAM_VAR values as a function of distance between streamgages. The correlation between STREAM_VAR values at two streamgages is assumed to depend on the distance between the two streamgages. This dependence can be evaluated by squaring the difference between the STREAM_VAR values at each pair of streamgages and then grouping the squared differences according to the distance between the paired locations. A model that is represented by a mathematical expression is fit to the semivariogram points to pass a smooth curve through the scattered points. A number of different semivariogram models were tested for best fit of each hydrologic-characteristic data set and cross-validation estimation accuracy. Various model parameters also were tested for each hydrologic-characteristic data set, including the number of lags, lag sizes, nugget values, partial sill values, major range values, minor range values, search angles, and the maximum and minimum number of streamgages to include in the searches. The semivariogram model for STREAM_VAR (fig. 6) was developed using 204 of the initial 208 streamgages. Four outliers were removed from the data set to improve the fit of the semivariogram model to the data and to improve the estimation accuracy of the model. Three to four outliers also were removed from each of the other four hydrologic-characteristic data sets to improve the fit and accuracy of the models. A Gaussian model was determined to provide the best fit and estimation accuracy for all five of the hydrologic-characteristic data sets. The Gaussian model parameters used to fit the STREAM_VAR semivariogram (fig. 6) are listed in table 6 with the Gaussian model parameters used to fit semivariograms for the other four hydrologic-characteristic data sets.

The parameters of preliminary semivariogram models were calibrated using a kriging cross-validation technique. In this technique, the fitted semivariogram is used in a series of sequential kriging analyses in which data points are individually deleted and estimates are made for the deleted point locations. After kriged values at all data point locations have been estimated, the kriged values and standard deviations of the data are used to obtain cross-validation prediction errors. A successful calibration is based on the criteria for these prediction errors. Generally, the best model has the standardized mean nearest to zero, the smallest root-mean-squared prediction error, the average standard error nearest to the root-mean-squared prediction error, and the standardized root-mean-squared prediction error nearest to one (Environmental Systems Research Institute, 2001). Cross-validation prediction errors are listed in table 7 for the semivariogram models used to krige the five hydrologic-characteristic data sets (table 6).

Universal or ordinary kriging was used to create a grid of estimated values for the study area for each of the five hydrologic characteristics. The grids created from the kriging process were contoured using ArcGIS version 9.3 (Environmental Systems Research Institute, 2009) to create isoline maps. Several different grid sizes were tested during the kriging and contouring process to evaluate the detail and generality of isoline delineations. Grid spacings of 47,000 m (29.2 mi) for STREAM_VAR and TAU_ANN, 50,000 m (31.1 mi) for TAU_1012, 64,000 m (39.8 mi) for HYSEP, and 67,000 m (41.6 mi) for BFI were determined to provide the best balance between creating isoline maps with the lowest prediction errors and isoline delineations considered to provide the best level of detail and generality. Isoline maps created from kriged grids for three (STREAM_VAR, TAU_ANN, and BFI) of the five hydrologic characteristics that were used to develop regression equations are shown in figures 7–9.

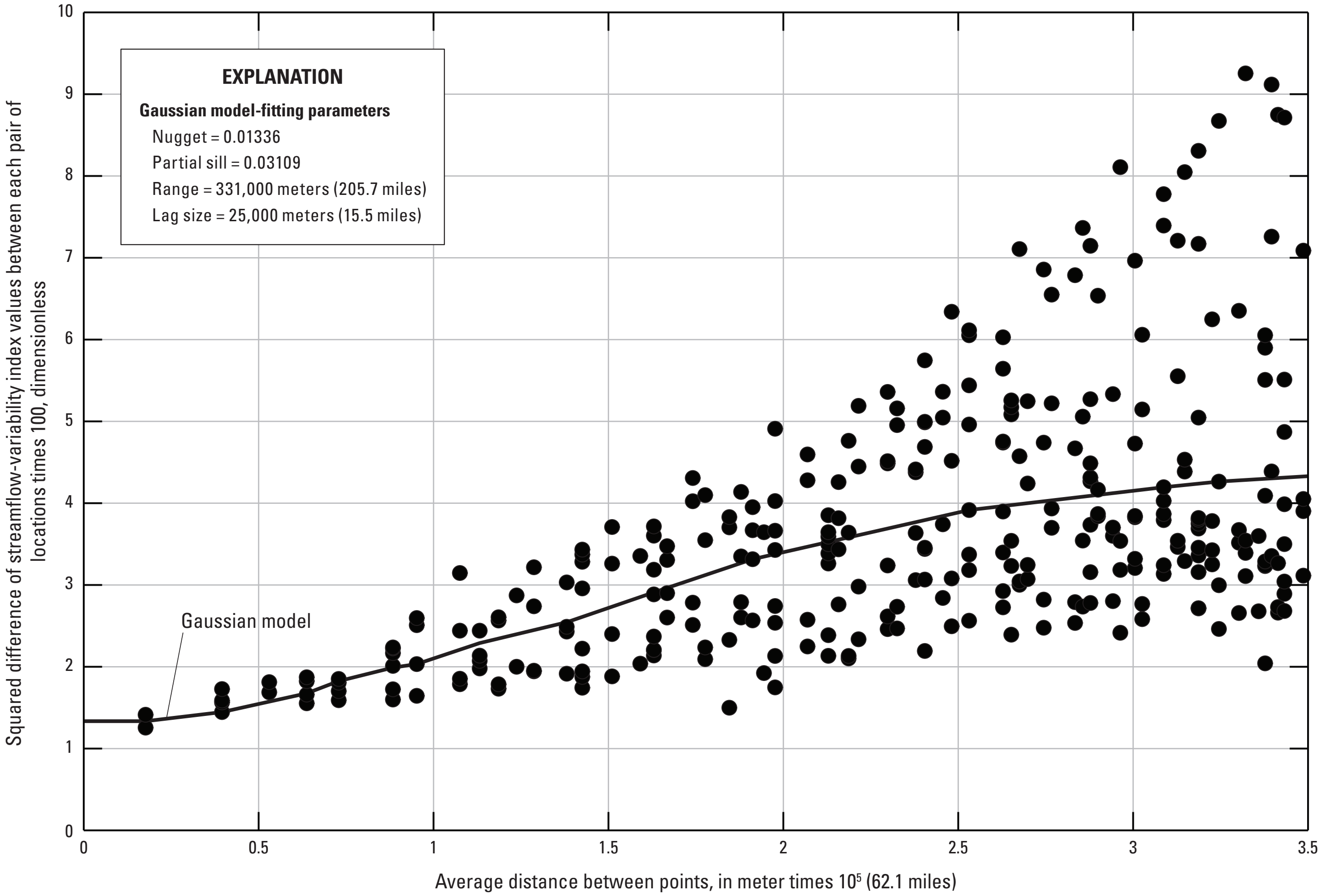

Figure 6. Semivariogram used to krige estimates of streamflow-variability index (STREAM_VAR) for Iowa.

Geographic Information System Measurements

Three primary GIS-data layers were processed to produce the Iowa StreamStats data layers. These data layers were needed to delineate accurate stream networks and basin boundaries, and the layers were used to measure 27 morphometric basin characteristics (table 5). The three primary GIS-data layers include the 1:24,000-scale USGS National Hydrography Dataset (NHD) (*http://nhd.usgs.gov/*; Simley and Carswell, 2009), the 1:24,000-scale USDA/NRCS Watershed Boundary Dataset (WBD) (*http://datagateway.nrcs.usda.gov/*; USGS and NRCS, 2009) using 12-digit hydrologic unit codes (HUCs), and the 10-m (32.81 ft) USGS National Elevation Dataset (NED) (*http://ned.usgs.gov/*; Gesch, 2007).

Several preprocessing steps were needed for each of the three data layers to facilitate rapid determination of basin characteristics. Preprocessing of the NHD included removing flowline paths that represent man-made features (a stream network that only represents natural streams is needed) and selection of the primary flow path in those areas where the NHD indicated split flow (such as might occur when flow splits around an island in a river or with a braided channel). The NHD and WBD had to be verified that the stream from the NHD only crossed the watershed boundary (from the WBD) at the outlet (unless the watershed is downstream from another watershed, in which case the main-stem stream will enter the watershed at one place); and watershed outlets should align exactly to the confluences of the streams. For the NED, downloaded blocks were mosaicked into one tile, data were extracted for a 4-kilometer (km) (2.5 mi) buffer area around each 8-digit HUC, and projected from decimal degrees to Universal Transverse Mercator (UTM) Zone 15. A hydro-corrected digital elevation model (DEM) was then developed by filling depressions or sinks, using the basin boundaries from the WBD to conserve known drainage divides, and using the streams from the NHD to create well-defined flow paths through the elevation data.

ArcHydro Tools, version 1.3, a set of utilities developed to operate in the ArcGIS, version 9.3, environment (Environmental Systems Research Institute, 2009) was used to process fifty-eight 8-digit HUCs to create StreamStats data layers for the entire State. To calculate basin characteristics to develop the Iowa low-flow frequency and harmonic-mean-flow regional regression equations, additional data layers were generated. These primary base-grid data layers include

Table 6. Model parameters used to fit semivariograms for kriged hydrologic characteristics.

[BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; TAU_1012, October to December annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; NA, not applicable]

Hydrologic characteristic	Type of kriging	Number of streamgages used in semivariogram model[1]	Model type	Number of lags	Lag size (meters)	Nugget	Partial sill	Major range (meters)	Minor range (meters)	Search angle (degrees)	Number of maximum streamgages included in search	Number of minimum streamgages included in search
BFI	Universal	204	Gaussian	14	25,000	0.006	0.026	334,000	209,000	94.4	5	2
HYSEP	Universal	204	Gaussian	14	25,000	55	252	334,000	209,000	95.6	5	2
TAU_ANN	Universal	205	Gaussian	14	25,000	33.8	97.9	334,000	209,000	127	5	2
TAU_1012	Universal	204	Gaussian	14	25,000	115	171	335,000	210,000	121	5	2
STREAM_VAR	Ordinary	204	Gaussian	14	25,000	.013	.031	331,000	NA	NA	6	2

[1]Three or four outliers were removed from the 208 streamgages.

Table 7. Cross-validation prediction errors of semivariogram models for kriged hydrologic characteristics.

[BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; TAU_1012, October to December annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index]

Hydrologic characteristic	Type of kriging	Number of streamgages used in semivariogram model	Model type	Mean	Root-mean-square error	Average standard error	Mean standardized	Root-mean-square error standardized
BFI	Universal	204	Gaussian	0.000	0.083	0.084	0.005	1
HYSEP	Universal	204	Gaussian	-.016	8.08	8.14	.000	1
TAU_ANN	Universal	205	Gaussian	-.010	6.35	6.30	.002	1
TAU_1012	Universal	204	Gaussian	.030	11.5	11.4	.004	1
STREAM_VAR	Ordinary	204	Gaussian	.000	.123	.123	-.005	1

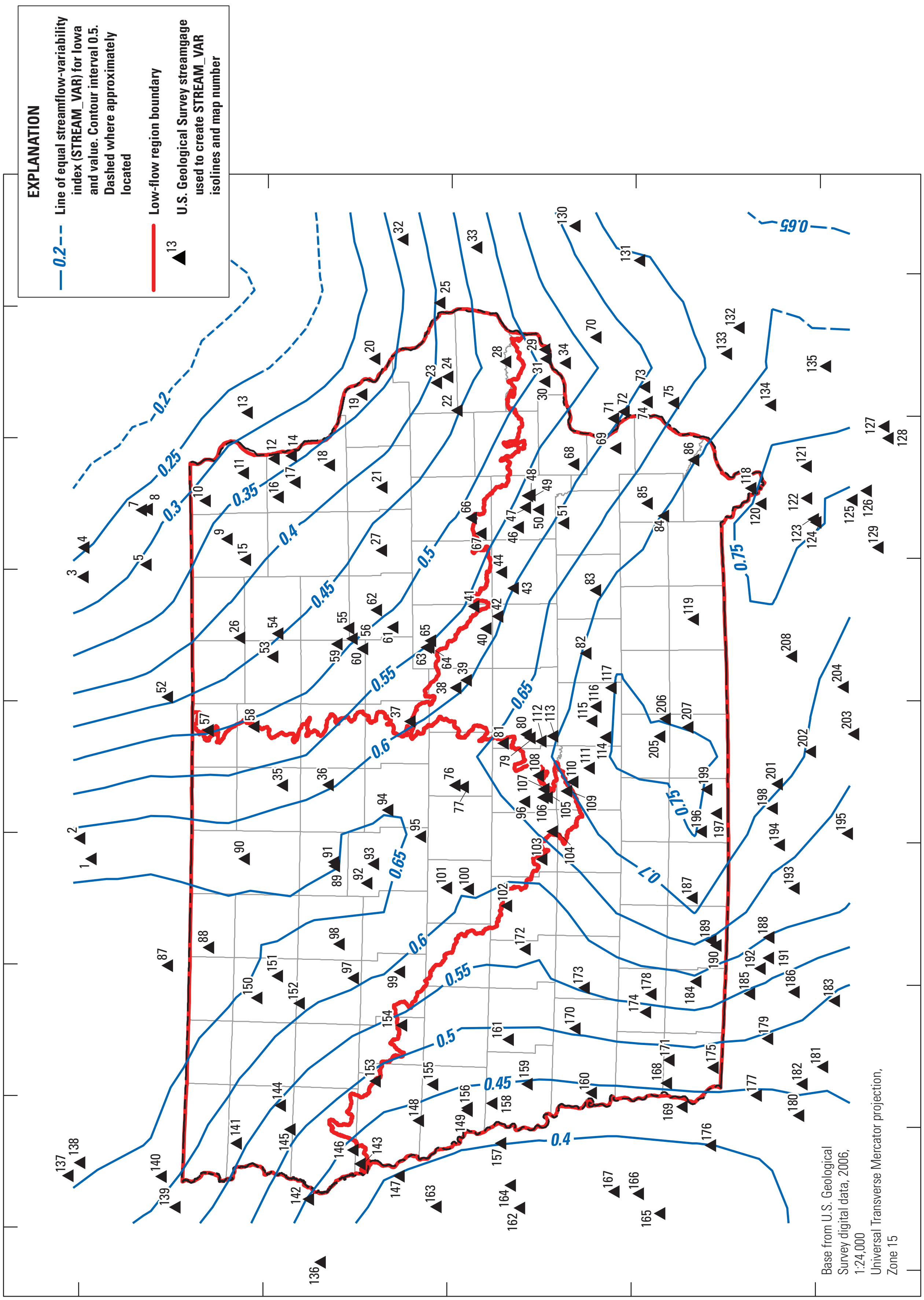

Figure 7. Streamflow-variability index (STREAM_VAR) isolines for Iowa.

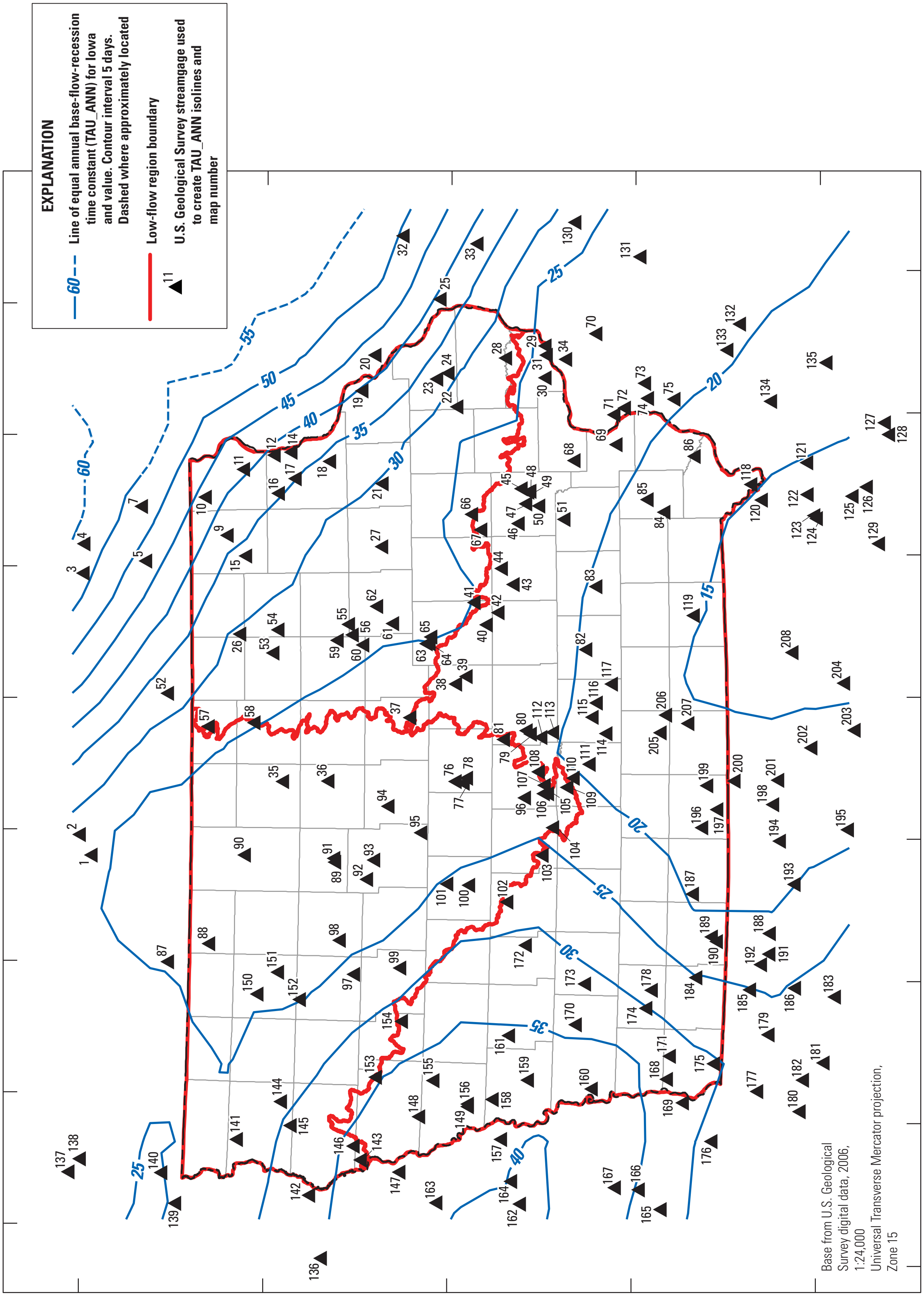

Figure 8. Annual base-flow-recession time constant (TAU_ANN) isolines for Iowa.

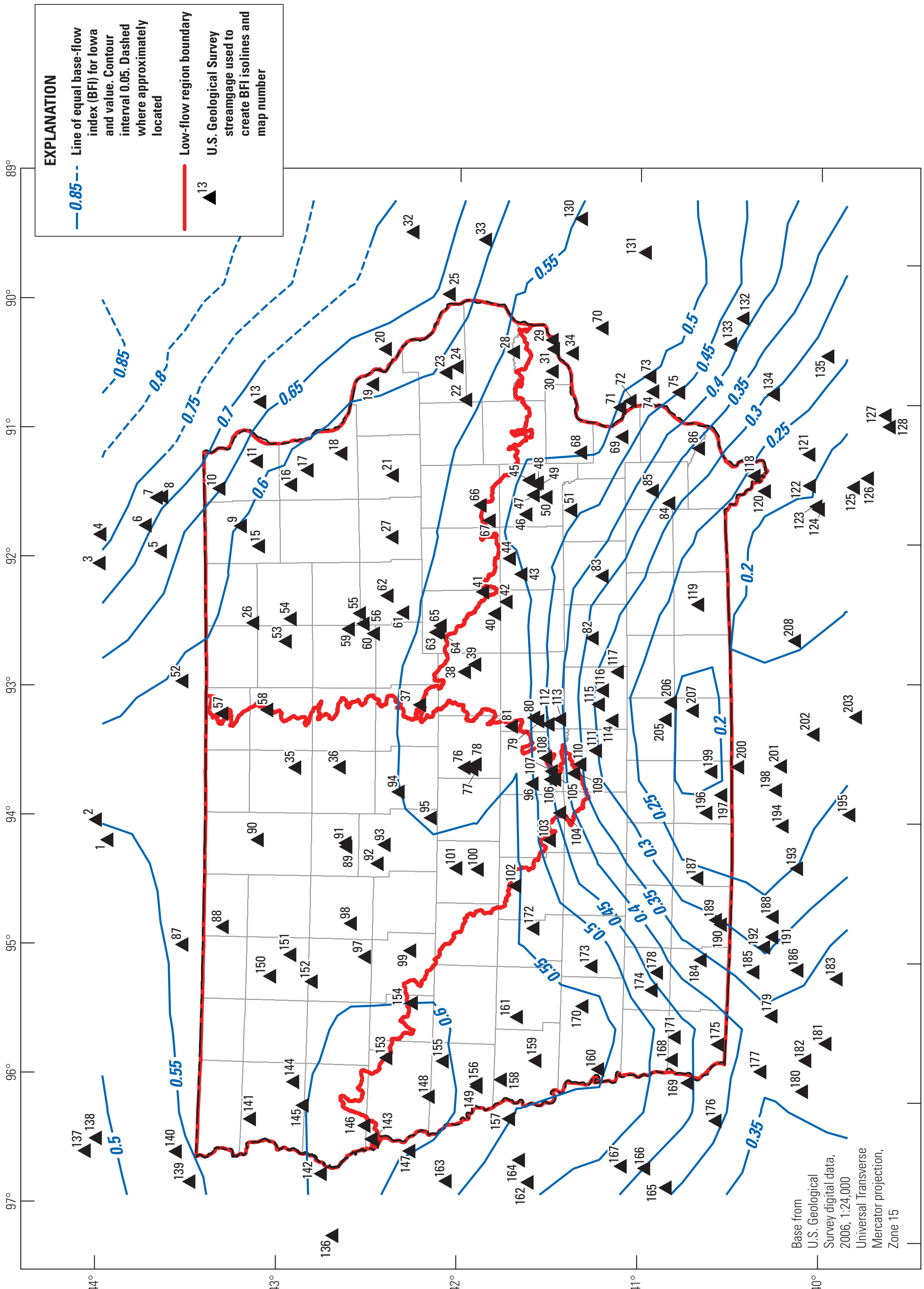

Figure 9. Base-flow index (BFI) isolines for Iowa.

catchments, flow accumulation, flow direction, and an artificial flow-path grid used to delineate drainage basins. These additional layers then were used to create layers that control the StreamStats delineation of a watershed, subwatersheds, and stream networks within these watersheds, including the created layers named AdjointCatchment, Catchment, DrainageLine, DrainagePoint, LongestFlowPathCat, and LongestFlowPathAdjCat. Once processing was complete for all 58 processing units, a global geodatabase was created to direct StreamStats to how all units relate to each other. In addition, the DEM was resampled to 150 m for use in the basin-length calculations. All 54 basin characteristics listed in table 5 were measured using ArcHydro Tools or Spatial Analyst tools in ArcGIS, version 9.3 (Environmental Systems Research Institute, 2009).

In order to measure basin characteristics for streamgages located outside of Iowa, similar preprocessing steps were performed on GIS data layers for an additional twenty-seven 8-digit HUCs located in neighboring states. These 27 HUCs are not part of the GIS data layers used by StreamStats for Iowa. Because certified WBD data were not available at the time in adjacent states, the preprocessing of these 27 HUCs did not include the “walling” of basin boundaries using WBD; preprocessing did include the “burning” of streams from the NHD into the NED. However, a global geodatabase was not created for these 27 HUCs because none of the streamgages within these HUCs accumulated flow from more than one HUC.

GIS measurements of the five hydrologic basin characteristics (table 5) were interpolated by area-weighting values for streamgage watershed boundaries from grids that were created using a kriging procedure described in the previous section, Kriged Hydrologic Characteristics. GIS measurements of seven soil characteristics (table 5) were made using a three-step process. First, the NRCS Soil Data Viewer tool, built as an extension of ArcMap, was used to create four 8-digit HUC data layers for the soil characteristics. Second, a shapefile was created for the hydrosoils data layer (includes the four hydrologic soil types A, B, C, and D), and a grid was created for each of the SAND, CLAY, and KSATSSUR data layers. Third, the ARCMAP attribute selection tool was used to calculate a percent-area value for each hydrologic soil type, and the Spatial Analyst tool was used to calculate area-weighted values for SAND, CLAY, and KSATSSUR for each streamgage watershed boundary. The geologic characteristic DESMOIN, the land-use characteristic ROWCROP, and the 14 climatic characteristics (table 5) were all measured from grids as area-weighted values for each streamgage watershed.

Table 3 lists two drainage area values for each streamgage included in the study. Each streamgage has a drainage area that is listed in the USGS NWIS data base which is referred to as the “published” drainage area. Published drainage areas were determined primarily from 1:24,000-scale topographic maps by manual planimetering or GIS digitizing methods when streamgage operation began. Drainage area values listed in table 3 as “GIS” drainage area, for the basin characteristic DRNAREA, were measured as part of this study using a two-step process within ArcHydro Tools. First, a streamgage location was selected using the point generation tool and second, one of the watershed delineation tools (such as Batch Watershed Delineation) was used to automatically delineate the watershed boundary using hydro-corrected DEM data. The watershed delineation process in the second step delineates the basin boundary from the DEM data proceeding from the streamgage location until an existing basin boundary is reached within the WBD data and then the delineation follows the WBD boundary for the remainder of the watershed delineation. For some streamgages with small drainage areas that are located completely within a 12-digit HUC, the entire watershed delineation was made from the DEM data.

GIS delineations of watershed boundaries were inspected for streamgages with drainage area differences greater than 5 percent from published values. Basin boundaries of several GIS-delineated watersheds were edited where the delineation did not match well with digital raster graphics (DRG) elevation contours. Most edits made only a small difference in the drainage area value for the watershed. If the GIS-delineated basin boundary was accurate according to the 8-digit HUC, WBD line work, and DRG contour lines, then the GIS delineation was accepted even if it exceeded a 5-percent difference from the published drainage area. GIS delineations are generally believed to be more accurate than the published drainage areas. The majority of the GIS watershed delineations are using part of the WBD boundaries, which have been certified by NRCS, and use of the WBD data accounts for some of the differences between GIS and published values of drainage areas. GIS measurements of drainage area (DRNAREA) were used to develop the regression equations because StreamStats will use the same GIS data layers and delineation methods for determining watershed boundaries and drainage areas for ungaged stream sites. Drainage areas of the 208 streamgages ranged from 1.4 to 7,783 mi^2.

Regional Regression Analyses to Estimate Selected Low-Flow Frequency Statistics and Harmonic Mean Flows for Ungaged Stream Sites

In a regional regression study, subdividing a large study area into subregions that are relatively homogeneous in terms of low-flow hydrology typically helps to reduce error in the regression equations. Because low-flow regions have not been determined for Iowa in previous studies, preliminary statewide regression equations were initially developed for each of the seven selected statistics using all streamgages with low-flow frequency and harmonic-mean-flow statistic values greater than zero flow. Because linear regression analysis assumes a continuous response of streamflow to basin characteristics, streamgages with estimates of zero flow for the seven selected statistics cannot be used to estimate parameters of a linear regression model. Table 8 lists the significant variables identified and the predictive accuracies obtained for preliminary statewide regression equations initially developed for each of the seven selected statistics using ordinary-least-squares (OLS) and subsequently finalized using weighted-least-squares (WLS) or generalized-least-squares (GLS) multiple-linear regression analyses (see following sections for further discussion of OLS, WLS, and GLS regression). The preliminary statewide low-flow frequency and harmonic-mean-flow equations provided base-level predictive accuracies that regional regression equations can be compared against to evaluate improvement in accuracy. Because regional regression equations provided improved accuracies, the statewide equations were not developed further and are not listed in this report; they are summarized in table 8 to provide a reference showing the improvement obtained through regionalization.

Definition of Low-Flow Regions

Two streamgages were removed from the initial data set of 208 streamgages during the development of the statewide equations. The Iowa River at Wapello, Iowa, (streamgage 05465500, map number 69) was removed because of regulation, and the Big Nemaha Falls at Falls City, Nebr., (streamgage 06815000, map number 181) was removed because the drainage basin upstream from the streamgage extends outside of the 50-mi buffer of Iowa delineating the study area (table 9). These two streamgages are listed in tables 1–3 because they were included in the kriging of the five hydrologic characteristics before being removed from the study; their inclusion or exclusion from the kriging data sets is not believed to significantly affect the kriging results.

Residual values (differences between low-flow frequency or harmonic-mean-flow statistics computed from observed streamflow and those predicted from the regression equations) from the preliminary statewide regression analyses were mapped at streamgage locations to identify spatial trends in the predictive accuracy of the regression equations. Differences in plotted residual values for the streamgages were grouped to define general low-flow regions within the study area. Streamgages were grouped into regression subsets on the basis of the low-flow regions, and OLS multiple-linear regression analyses were performed for each region. Because of the amount of variability in the residual mapping between the seven selected statistics, a cluster analysis method also was used to help define low-flow regions. A cluster analysis method called partitioning around medoids (PAM) using Spotfire S+ statistical software (TIBCO Software Inc., 2008) was used to define low-flow regions in Iowa. Cluster analysis is a statistical technique that was used to partition streamgages into groups (clusters) with similar streamflow or basin characteristics. The cluster analyses were based on the basin characteristics previously identified as significant variables in the preliminary statewide regression equations developed for each

Table 8. Significant explanatory variables and predictive accuracies of preliminary statewide regression equations.

[RMSE, root mean square error; Pseudo-R^2, pseudo coefficient of determination; SEP, average standard error of prediction; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; DRNAREA, GIS drainage area; (+), explanatory variable has positive relation to the response variable; STREAM_VAR, streamflow-variability index; (-), explanatory variable has negative relation to the response variable; SOILDSSURGO, hydrologic soil type D; NA, not applicable; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; KSATSSUR, average soil permeability; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; CLAY, percent volume of clay content of soil; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; PRC8, mean August precipitation; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; PRECIP, mean annual precipitation; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow]

Statistic	Number of streamgages used to develop preliminary equation[1]	Most significant explanatory variables identified for the preliminary equation and explanatory-variable relation signs	RMSE (percent)	Pseudo-R^2 (percent)	SEP (percent)
Preliminary generalized least-squares regression analyses results					
M1D10Y	158	DRNAREA(+), STREAM_VAR(-), SOILDSSURGO(-)	NA	79.9	157.5
M7D10Y	166	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	NA	81.1	149.8
M30D10Y	180	DRNAREA(+), STREAM_VAR(-), CLAY(-)	NA	87.3	114.6
M30D5Y	187	DRNAREA(+), STREAM_VAR(-), PRC8(+)	NA	89.2	96.8
M1D10Y1012	177	DRNAREA(+), STREAM_VAR(-), PRECIP(+)	NA	86.9	109.0
M7D10Y1012	179	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	NA	90.0	83.9
Preliminary weighted least-squares regression analysis results					
QAH	206	DRNAREA(+), STREAM_VAR(-), CLAY(-)	93.6	NA	[2]94.5

[1]Streamgages with estimates of zero flow were excluded from the regression analysis.

[2]Based on mean-square error residuals.

Table 9. Streamgages removed from regional-regression analyses.

[USGS, U.S. Geological Survey. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Streamgage name	Reason for removal of streamgage from regression analyses
29	05422470	Crow Creek at Bettendorf, Iowa	Urbanization.
69	05465500	Iowa River at Wapello, Iowa	Regulation from upstream dam.
78	05471000	South Skunk River below Squaw Creek near Ames, Iowa	Diversion by City of Ames for water supply.
87	05476000	Des Moines River at Jackson, Minn.	Regulation from Yankton, Long, Shetek and Heron Lakes.
105	05484650	Raccoon River at 63rd Street at Des Moines, Iowa	Diversion by City of Des Moines for water supply.
106	05484800	Walnut Creek at Des Moines, Iowa	Urbanization.
107	05484900	Raccoon River at Fleur Drive, Des Moines, Iowa	Diversion by City of Des Moines for water supply.
108	05485640	Fourmile Creek at Des Moines, Iowa	Diversion by City of Ankeny for water supply.
140	06482610	Split Rock Creek at Corson, S. Dak.	Large gravel-quarry operation about 1-mile upstream.
157	06608000	Tekamah Creek at Tekamah, Nebr.	Regulation from many upstream impoundment dams.
162	06799385	Pebble Creek at Scribner, Nebr.	Diversion for irrigation.
163	06799450	Logan Creek at Pender, Nebr.	Diversion for irrigation.
164	06799500	Logan Creek near Uehling, Nebr.	Diversion for irrigation.
169	06806500	Weeping Water Creek at Union, Nebr.	Regulation from flood-control and grade-stabilization structures.
176	06810500	Little Nemaha River near Syracuse, Nebr.	Diversion for irrigation.
181	06815000	Big Nemaha Falls at Falls City, Nebr.	Drainage basin extends outside 50-mile buffer used for study area.

of the seven selected statistics (table 8). Drainage area was not included in the analyses because it is not a unique characteristic for any one cluster. The PAM method of cluster analysis uses medoids instead of centroids to form groups for which average dissimilarity of basin-characteristic values in each group are minimal (*http://www.unesco.org/webworld/idams/advguide/Chapt7_1_1.htm*, accessed April 8, 2011). Cluster analyses resulted in two to three well-defined groups, which along with the residual mapping, helped to define a significant difference between the southern and northern areas of the State and between the northeastern and northwestern areas of the State.

Streamgages then were grouped into several two- and three-region data sets on the basis of Iowa's landform regions. Analysis-of-covariance regression (Helsel and Hirsch, 2002) was used to test each region for statistically significant differences by comparing the intercept for each region's regression model to that for the rest of the study area by assigning a location variable for each region. Each location-indicator variable was set at 1 if the streamgage was in a particular region, or 0 if the streamgage was not in a particular region. A two-variable OLS regression analysis that included drainage area and the location-indicator variable was performed statewide for each of the seven selected statistics for each of the low-flow regions being tested. Statistical significance for each region was determined using a 95-percent confidence level. Statistical significance for the location-indicator variable indicates a difference in the regression intercept between streamgages in that region and streamgages in the rest of the study area. Several two- and three-region combinations were determined to be significantly different from each other, and preliminary regional regression equations were developed for several of the selected low-flow frequency statistics for each of these regional combinations.

Comparisons of the preliminary regional regression analyses indicated improved overall predictive accuracies by subdividing the State into three regions rather than two regions. The goal of the regionalization analyses was to define the best overall regions for all seven selected statistics and to have an adequate number of streamgages (preferably, at least 30) in each regional data set for the regression analyses. Streamgages flagged as outliers (high leverage or high influence points) in the GLS or WLS regression analyses, using a weighted-multiple-linear regression program (WREG) (Eng and others, 2009), were reviewed for inaccurate data and for possible effects of urbanization, regulation, or diversion. In addition to the two streamgages previously removed from the low-flow frequency and harmonic-mean-flow regression data sets, 14 additional streamgages, which were flagged as outliers, also were removed from the regression data sets (table 9). These 14 streamgages were removed because streamflow at these sites were identified by field personnel in their respective

States, who were familiar with the sites, as possibly being affected by anthropogenic alterations. All other streamgages that were flagged as outliers were kept in the regression data sets because there was no justification for removing them. Thus, a total of 192 streamgages were considered to have unaltered streamflow for the regional regression analyses. All 192 of these streamgages have at least 10 years of record that can be used for the development of the two fall season low-flow frequency and the harmonic-mean-flow equations. Of the 192 streamgages, five have only 9 years of annual climatic record, thus, only a total of 187 streamgages were used for the development of the four annual low-flow frequency equations.

Three low-flow regions (northeast, northwest, and southern) were defined for Iowa after testing a number of different regional combinations. The three low-flow regions were then tested using two slightly different groupings of streamgages; first on the basis of a strict definition of landform-region boundaries, and second on the basis of residuals defining low-flow regional boundaries for streamgages located close to landform-region boundaries. Predictive accuracies were improved for regions defined on the basis of residuals compared to regions defined on the basis of strict landform-region boundaries, which appears reasonable because low-flow regional boundaries are not actually distinct lines, but the boundaries are transition zones where the hydrologic characteristics of one region transition to the hydrologic characteristics of another region. Figure 1 shows the three low-flow regions defined for Iowa for the development of final regional regression equations. Low-flow regional boundaries were defined along 12-digit WBD HUC boundaries to avoid drawing a low-flow region boundary through a HUC polygon. For a 12-digit HUC that overlies a landform region boundary, the low-flow region boundary was drawn to include the landform region that comprises the majority of the 12-digit HUC area.

The northeast low-flow region is defined by the Iowan Surface, the Paleozoic Plateau, and the East-Central Iowa Drift Plain landform regions and contains approximately 24 percent of the total land area of the State (fig. 3). The northeast low-flow region generally has shallower loess deposits, more bedrock outcropping, more springs, higher soil-permeability rates, and greater sustained base flow than the other two low-flow regions (figs. 2 and 7). The northwest low-flow region is defined by the Des Moines Lobe and the Northwest Iowa Plains landform regions and contains approximately 30 percent of the total land area of the State (fig. 3). The northwest low-flow region generally has lower relief than the other two low-flow regions. The southern low-flow region is defined by the Southern Iowa Drift Plain, the Loess Hills, the Iowa-Cedar Lowland, and the Mississippi River and Missouri River Alluvial Plains landform regions and contains approximately 46 percent of the total land area of the State (fig. 3). The southern low-flow region generally has deeper loess deposits and lower soil-permeability rates compared to the other two low-flow regions (fig. 2).

Development of Regional Regression Equations

Because a significant number of streams in Iowa have zero flow as their minimum flow during low-flow years, four types of regression analyses were performed to develop the final equations for the three low-flow regions—left-censored, logistic-, WLS-, and GLS-regression analyses. For the northeast and northwest regions, left-censored regression analyses were performed to allow the use of a censoring threshold (0.1 ft^3/s) in the development of equations to estimate the six low-flow frequency statistics (M1D10Y, M7D10Y, M30D10Y, M30D5Y, M1D10Y1012, and M7D10Y1012). A WLS multiple-linear regression analysis, weighted on the basis of streamgage record length, was used to develop an equation to estimate QAH for the northeast and northwest regions. For the southern region, logistic regression analyses were performed to develop equations to estimate the probability of zero flow for the six low-flow frequency statistics. GLS multiple-linear regression analyses, weighted on the basis of streamgage record length and the variance and cross-correlation of the annual low flows, were used to develop six equations to estimate nonzero low-flow frequency statistics. Again, WLS regression analysis was used to develop an equation to estimate QAH for the southern region.

Differences in the percentage of streamgages with estimates of zero flow, computed from observed streamflow for the six low-flow frequency statistics, between the northern and southern regions of the State required the use of different regression analyses. The percentage of streamgages with estimates of zero flow computed from observed streamflow for each selected statistic for each region are listed in the shaded columns in table 10. Estimates of zero flow computed from observed streamflow are often considered to be censored data (Kroll and Stedinger, 1996; Kroll and Vogel, 2002), and the use of multiple-linear regression is not recommended for censored data (Helsel and Hirsch, 2002). Thus, two types of censored-regression methods were used in the development of equations to estimate the six low-flow frequency statistics. The choice of censored-regression methods depends on the amount of censoring in each region for each low-flow frequency statistic (Helsel and Hirsch, 2002). If less than 20 percent of the observed low-flow frequency statistic was zero flow, then a left-censored regression method was used because a censoring threshold only applies to the low-end of the low-flow frequency statistics. If between 20 to 50 percent of the observed low-flow frequency statistic was zero flow, then a logistic regression method was used to first estimate the probability of zero flow at ungaged sites and then, if necessary, multiple-linear regression is used to estimate low-flow frequency statistics for sites that logistic-regression equations estimate are likely to have flow.

Estimates of zero flow computed from observed streamflow are less than 20 percent in the northeast and northwest regions for the six low-flow frequency statistics and are generally within the 20 to 50 percent range for the southern region (table 10). Although zero flows are not estimated for any streamgages in the northeast region for two low-flow frequency statistics (M30D10Y and M30D5Y), and multiple-linear regression is applicable, left-censored regression was used to develop all six low-flow frequency equations. Likewise, for the southern region where zero flow estimates are less than 20 percent for two low-flow frequency statistics (M30D10Y and M30D5Y), and left-censored regression is preferred, logistic regression was used to develop all six low-flow frequency equations. For both regions, the same regression method was used to develop all six low-flow frequency equations to avoid the possibility of inconsistencies in estimates, such as an estimate of M7D10Y exceeding an estimate of M30D10Y. Because there were no zero flows computed from observed streamflow for QAH, standard multiple-linear regression analyses were used to develop an equation for each region for estimating QAH.

Multiple-Linear Regression

Multiple-linear-regression analysis is the most common method used to develop equations for the estimation of streamflow statistics at ungaged sites. Multiple-linear regression models the relation between two or more basin characteristics (called explanatory or independent variables) and a streamflow statistic (called a response or dependent variable) by fitting a linear equation to the data. Every value of each basin characteristic is associated with the value of the streamflow statistic. Upon the development of regression equations, measurements of the basin characteristics at ungaged stream locations can be used to estimate the streamflow statistic.

The general form of equations developed from multiple-linear-regression analysis is:

$$Y_i = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n + e_i \quad (6)$$

where

Y_i is the response variable (estimate of the streamflow statistic computed from observed streamflow) for site *i*,

X_1 to X_n are the *n* explanatory variables (basin characteristics) for site *i*,

b_0 to b_n are the *n* + 1 regression model coefficients, and

e_i is the residual error (difference between the observed and predicted values of the response variable) for site *i*.

Assumptions for the use of regression analyses are: (1) the model adequately describes the linear relation between the response and explanatory variables, (2) the mean of e_i is zero, (3) the variance of e_i is constant and independent of the values of X_n, (4) the values of e_i are normally distributed, and (5) the values of e_i are independent of each other (Iman and Conover, 1983). Because streamflow data are naturally correlated spatially and temporally, assumption 5 is not completely satisfied with the use of OLS. As a result, WLS regression was used to develop the final equations for estimating QAH, and GLS regression was used to develop the final equations for estimating selected low-flow frequency statistics for the southern region. A general overview of the OLS, WLS, and GLS multiple-linear regression techniques used to develop the

Table 10. Percentage of streamgages with estimates of zero flow computed from observed streamflow for selected low-flow frequency statistics and harmonic mean flows in each region of Iowa.

[N, number of streamgages; QAH, harmonic mean flow; *differences in the number of streamgages between annual- and fall-frequency analyses is because some annual-climatic records only have 9 years of record, and these streamgages were not included in the development of annual-frequency equations; Q, low-flow estimate computed from observed streamflow (cubic feet per second); >, greater than; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; shaded column, the percentage of streamgages with estimates of zero flow computed from observed streamflow for each selected statistic for the region; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years]

Statistic	Northeast region (N=43 for annual-frequency analyses; N=44 for fall-frequency and QAH analyses*)			Northwest region (N=37 for annual-frequency analyses; N=38 for fall-frequency and QAH analyses*)			Southern region (N=107 for annual-frequency analyses; N=110 for fall-frequency and QAH analyses*)		
	N with Q>0	N with Q=0	Q=0 (percent)	N with Q>0	N with Q=0	Q=0 (percent)	N with Q>0	N with Q=0	Q=0 (percent)
M1D10Y	40	3	7	31	6	16	75	32	30
M7D10Y	41	2	5	32	5	14	80	27	25
M30D10Y	43	0	0	34	3	8	90	17	16
M30D5Y	43	0	0	35	2	5	96	11	10
M1D10Y1012	43	1	2	35	3	8	86	24	22
M7D10Y1012	43	1	2	35	3	8	88	22	20
QAH	44	0	0	38	0	0	110	0	0

initial and final equations is presented in the following three sections.

Ordinary-Least-Squares Regression

OLS regression analyses were used to develop initial multiple-linear regression equations, or models, for all seven selected statistics. Final equations were developed using WLS, GLS, or censored regression procedures. OLS regression analyses were used to identify the best combinations of basin characteristics to use as explanatory variables in the development of regression models and to define the low-flow regions.

Logarithmic transformations (base 10) were performed for all response variables and for selected explanatory variables used in the OLS, WLS, GLS, and censored regression analyses. Data transformations, other than logarithmic transformations, also were used for selected explanatory variables to obtain a more constant variance of the residuals about the regression line and to linearize the relation between the response variable and the explanatory variables. The response variable is assumed to be a linear function of one or more explanatory variables. A base-10 logarithmic transformation has the form of:

$$\log Y_i = b_0 + b_1 \log X_1 + b_2 \log X_2 + \ldots + b_n \log X_n + e_i \qquad (7)$$

When equation 7 is retransformed back to its original units, it is algebraically equivalent to:

$$Y_i = 10^{bo} X_1^{b1} X_2^{b2} \ldots X_n^{bn} 10^{ei} \qquad (8)$$

Several basin characteristics were deleted from the original regression data set of 54 basin characteristics because of multicollinearity. Multicollinearity is the condition wherein at least one explanatory variable is closely related to (that is, not independent of) one or more other explanatory variables. Regression models that include variables with multicollinearity may be unreliable because coefficients in the models may be unstable. Correlation coefficients greater than 0.5, or less than -0.5, and plots of the data were used as guides in identifying variables with multicollinearity. The hydrologic validity of variables with multicollinearity in the context of low flows or the harmonic mean flow was the principal criterion used in determining which basin characteristics were deleted from the data set.

OLS regression analyses were performed using Spotfire S+ statistical software (TIBCO Software Inc., 2008). Initial selections of significant explanatory variables for the OLS regression models were performed using the Efroymson stepwise-selection method (Efroymson, 1960). The Efroymson method is an automatic procedure for regression model selection when there are a large number of potential explanatory variables. The procedure is similar to forward selection, which tests basin characteristics one by one and identifies those that are statistically significant, except as each new basin characteristic is identified as being significant, partial correlations are checked to see if any previously identified variables can be deleted (Ahearn, 2010). When basin characteristics were found to be highly correlated to each other, only one basin characteristic at a time was tested in the Efroymson selection process.

The Efroymson analyses produced a subset of potential significant basin characteristics for each selected statistic. Each subset of basin characteristics was then iteratively tested using standard OLS regression analyses to identify several sets of the best equations (regression models) that contained no more than three significant explanatory variables (basin characteristics). A limit of three explanatory variables per equation was used to minimize overfitting of the regression models. Results of the OLS models were evaluated to determine their adequacy, including graphical relations and residual plots, variance inflation factor (VIF), Cook's D statistic (Cook, 1977; Helsel and Hirsch, 2002), high-leverage points, the average standard error of estimate (SEE), and the adjusted coefficient of determination (adj-R^2) (Helsel and Hirsch, 2002). The selection of explanatory variables, and the signs and magnitudes of their respective regression coefficients, were each evaluated to ensure hydrologic validity in the context of low-flow frequency and the harmonic mean flow. This criterion takes precedence over all other criteria. All explanatory variables selected by OLS regression in this study were statistically significant at the 95-percent confidence level. Explanatory variables were selected to minimize SEE and to maximize the adj-R^2. SEE is a measure of the fit of the observed data to the regression model (difference between the value of the observed streamflow statistic and the value of the predicted streamflow statistic) and of the error inherent in the regression model; SEE also is referred to as the root mean square error (RMSE). Adj-R^2 is a measure of the proportion of the variation in the response variable that is explained by the explanatory variables and adjusted for the number of streamgages and explanatory variables used in the analysis. Correlation between explanatory variables and VIF (Marquardt, 1970; Helsel and Hirsch, 2002) was used to assess multicollinearity in the regression models. Multicollinearity problems were identified with a regression-diagnostics tool implemented in the USGS library version 4.0 (Lorenz and others, 2011) for Spotfire S+ statistical software (TIBCO Software Inc., 2008) by checking each explanatory variable for VIF greater than 2.

Weighted-Least-Squares Regression

WLS multiple-linear regression was used to develop one regression equation for each of the three low-flow regions for estimating QAH because estimates of QAH at all 192 streamgages (tables 2 and 10) were greater than zero flow. Tasker (1980) reports that OLS regression assumes that the time-sampling variance in the response-variable estimates are the same for each streamgage used in the analysis (assumption of homoscedasticity); implying that all observations of the response variable are equally reliable. In hydrologic regression, this assumption is usually violated because the reliability of response-variable estimates depends primarily on the length of the observed streamflow records. WLS regression adjusts for the variation in the reliability of the response-variable estimates by using a weight for each streamgage to account for differences in the lengths of streamflow records. WLS regression analyses were performed using the WREG program (Eng and others, 2009). A customized, user-defined weighting matrix was used to weight streamgages in each low-flow region for application of WREG for the development of QAH regression equations. Each regional weighting matrix was created on the basis of record length, computed as the number of years of record at the streamgage divided by the average number of years of record of all streamgages in the regression data set. Thus, short-record streamgages received reduced weight in the regression analyses, and long-record streamgages received increased weight. The sum of the weights assigned to each streamgage in each region equaled the total number of streamgages included in the WLS regression analysis for each region. WLS models were selected for use over the OLS models for the development of the three regional QAH equations because increased weight is given to response-variable estimates with long record lengths, and thus, presumably, the WLS equations have improved accuracy. Final WLS regression models were selected primarily on the basis of minimizing values of the SEE and the average standard error of prediction (SEP). (GLS regression, described in the next section, is not applicable to the QAH statistic, because it is not a frequency-based statistic with an annual probability estimated, but it is a singular value computed directly from all the daily mean flow values for the streamgage period of record. Weights within GLS regression are derived from, in addition to the length of record, the annual flow variability and correlation of annual flows among streamgages, which affect the amount of new, independent information contributed by each streamgage included in the regression.)

Generalized-Least-Squares Regression

GLS multiple-linear regression was used to develop six regression equations for estimating selected low-flow frequency statistics for the southern region because the percentage of streamgages in this region with estimates of zero flow computed from observed streamflow was greater than 20 percent for the majority of the low-flow frequencies (table 10). GLS regression analyses were performed using the WREG program (Eng and others, 2009). GLS regression, as described by Stedinger and Tasker (1985), Tasker and Stedinger (1989), and Griffis and Stedinger (2007), is a method that weights streamgages in the regression according to differences in streamflow reliability (record lengths) and variability (record variance) and according to spatial cross correlations of concurrent streamflow among streamgages. Compared to OLS regression, GLS regression provides improved estimates of streamflow statistics and improved estimates of the predictive accuracy of the regression equations (Stedinger and Tasker, 1985). Compared to WLS regression, GLS regression may not be as appropriate for the development of equations for the estimation of low-flow frequency statistics if a set of basin characteristics cannot be identified that describes most of the variability of the low-flow frequency statistics (Ken Eng, U.S. Geological Survey, written commun., 2007). GLS regression is considered more appropriate than WLS regression if low-flow regression data are highly correlated spatially, as was the case for Iowa low-flow data (Ken Eng, U.S. Geological Survey, written commun., 2009). The correlation smoothing function used by the WREG program to compute a weighting matrix for the 81 streamgages included in the development of the GLS regression equation for estimating M7D10Y for the southern region with 30 years of concurrent flow is shown in figure 10. The smoothing function relates the correlation between annual low-flow time series at two streamgages to the geographic distance between the streamgages for every paired combination of the 81 streamgages with 30 years of concurrent flow data (annual series of minimum 7-day mean low flows for all streamgages in the southern region is shown in figure 10). Strong evidence of cross correlation is shown in figure 10, justifying the use of GLS regression over WLS regression, because of the abundance of paired points for 30 years of concurrent flow that form the long tail extending towards the bottom right side of the graph. Final GLS regression models were selected primarily on the basis of minimizing values of the standard error of model (SEM) and the SEP and maximizing values of the pseudo-R^2. The pseudo-R^2, or pseudo coefficient of determination, is a measure of the percentage of the variation explained by the basin characteristics (explanatory variables) included in the model. The pseudo-R^2 value is calculated on the basis of the degrees of freedom in the regression (Griffis and Stedinger, 2007).

Left-Censored Regression

Left-censored regression, also referred to as Tobit regression, was used to develop six equations for both the northeast and northwest regions; because the number of streamgages in these regions with estimates of zero flow for low-flow frequencies computed from observed streamflow was less than 20 percent (table 10). Censored and uncensored response data can be included together in a censored-regression analysis. Censored regression is similar to multiple-linear regression, except that the regression coefficients are fit by maximum-likelihood estimation (MLE) (Helsel and Hirsch, 2002). MLE is comparable to a curve-matching process, in which a probability distribution is best matched to the observed data. MLE assumes that residuals are normally distributed around the regression line for the estimation of the slope and intercept, and the range of predicted values has constant variance. Additional information on MLE is presented in Helsel and Hirsch (2002) and in Runkel and others (2004). Cohn (1988) has shown that censored regression estimates are slightly biased, and an adjustment for first-order bias in these estimates is made by an adjusted maximum-likelihood estimation (AMLE) computation. An AMLE procedure implemented in the USGS computer-program library version 4.0 (Lorenz and others, 2011) for Spotfire

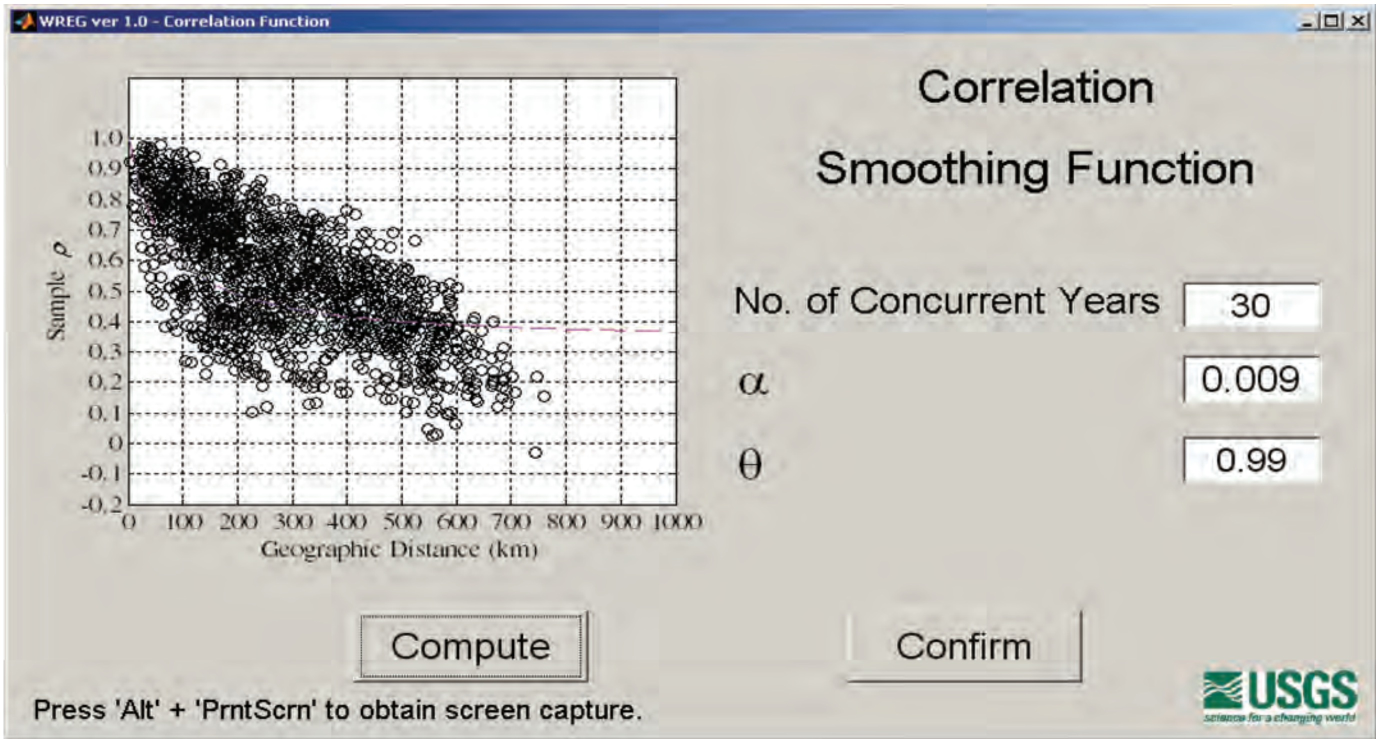

Figure 10. Screenshot of the weighted-multiple-linear regression program (WREG) smoothing function for generalized-least squares (GLS) correlation of the time series of annual minimum 7-day mean flows as a function of distance between 81 streamgages in the southern region with 30 years of concurrent flow.

S+ statistical software (TIBCO Software Inc., 2008) was used to develop the left-censored regression equations in this study. A censoring threshold of 0.1 ft^3/s was used to censor small response-variable discharges and zero flows estimated for the six low-flow frequency statistics. A censoring threshold is applied only to small values; thus the method is referred to as left-censored regression.

Daily mean discharge values are recorded for streamgages as low as 0.01 ft^3/s and low-flow frequency estimates less than 0.01 ft^3/s are computed from observed streamflow (table 2). Because of the uncertainty in measuring daily mean discharges and estimating low-flow frequencies below 0.1 ft^3/s, a censoring threshold set at 0.1 ft^3/s was used to develop the left-censored regression equations for this study. Thus, in addition to the censoring of zero flows, low-flow frequency estimates computed from observed streamflow less than or equal to 0.1 ft^3/s also were censored in the regression analyses. Final left-censored regression models were selected primarily on the basis of minimizing values of the SEE.

Logistic Regression

Logistic regression analysis was used to develop six regression equations for the southern region to estimate the probability of zero flow because the number of streamgages in this region with low-flow frequency estimates of zero flow was greater than 20 percent for the majority of the low-flow frequencies (table 10). For the logistic regression performed in this study, the response variable is binary or categorical; a response value of zero was assigned to streamgages with estimates of zero flow for low-flow frequencies computed from observed streamflow and a response value of one was assigned to streamgages with estimates greater than zero for low-flow frequencies. The probability of the response variable being in one category or the other is tested to determine if it differs as a function of continuous explanatory variables (Helsel and Hirsch, 2002). Predictions from logistic regression will fall between zero and one and are understood as the probability (p) of observing a response of one (predicts flow at ungaged site to be greater than zero). Therefore, (1-p) is the probability of observing a response of zero (predicts zero flow at ungaged site). Recent applications of logistic regression that are specific to low-flow studies can be found in Martin and Arihood (2010), Funkhouser and others (2008), Hortness (2006), and Bent and Steeves (2006). The logistic regression analyses were computed using Spotfire S+ statistical software (TIBCO Software Inc., 2008). The form of the logistic regression equation is:

$$P_{zero} = 1 - \left(\frac{e^{a_0 + c_1V_1 + \ldots + c_nV_n}}{1 + e^{a_0 + c_1V_1 + \ldots + c_nV_n}} \right) \quad (9)$$

where

P_{zero} is the probability of the low-flow frequency statistic being equal to zero,

a_0 is the regression model constant,

e is the base of the natural logarithm and is approximately equal to 2.7183,

c_1 to c_n are the regression model coefficients, and

V_1 to V_n are the explanatory variables (basin characteristics).

A separate logistic regression equation was developed for each of the six low-flow frequency statistics for the southern region. The logistic equations estimate the probability of low-flow frequency statistics being zero at an ungaged site. A probability cutpoint is used in logistic regression analyses as a threshold between the two response categories of “flow” or “zero flow.” The cutpoint probability used for this study is 0.5. Therefore, probabilities computed from the equations for ungaged sites that are greater than or equal to 0.5 are predicted to have “zero flow” and probabilities less than 0.5 are predicted to have “flow.” The predictive accuracy of the logistic regression equations was evaluated using the percentage of streamgages incorrectly estimated to have zero flow (misclassification percentage). Final logistic regression models were selected primarily on the basis of minimizing the misclassification percentage.

Final Regression Equations

Final regression equations developed for the northeast, northwest, and southern low-flow regions defined for Iowa are listed in tables 11–13, along with the number of streamgages included in each regression analysis and several performance metrics. StreamStats variable names are used for the response and explanatory variables in the final regression equations (tables 11–13); definitions of the variables and the units of measure are listed in tables 2 and 5. Ten basin characteristics are used as explanatory variables in the final regression equations (table 14 at end of report); these include three morphometric characteristics (DRNAREA, DRNFREQ, and RSD), three hydrologic characteristics (BFI, TAU_ANN, and STREAM_VAR), and four pedologic characteristics (SOILASSURGO, SOILBSSURGO, SOILCSSURGO, and KSATSSUR). GIS software is required to measure the basin characteristics included as explanatory variables in the final regression equations. All explanatory variables included in the final regression equations were statistically significant at the 95-percent confidence level and were not correlated with other explanatory variables used in the same equation. The performance metrics in tables 11–13 indicate the predictive accuracy of the final regression equations. Because four types of regression were used to develop the final equations, performance metrics are reported differently for each type of regression.

For the 12 left-censored regression equations developed for estimating selected low-flow frequencies for the northeast and northwest regions, SEE (in percent) is reported. For the six GLS regression equations developed for estimating selected low-flow frequencies for the southern region, a pseudo-R^2 (in percent), a standard error of model (SEM, in percent), and an average standard error of prediction (SEP, in percent) are reported. SEE is not appropriate for evaluating GLS regressions because of the unequal weighting given to the streamgages in GLS regression (Risley and others, 2008). The resulting unequally weighted GLS residuals produce inflated SEE values that are not comparable to SEE from the left-censored or WLS regression analyses. The pseudo-R^2, or pseudo coefficient of determination, is a measure of the percentage of the variation explained by the basin characteristics (explanatory variables) included in the model. The pseudo-R^2 value is calculated on the basis of the degrees of freedom in the regression. Griffis and Stedinger (2007) describe how the pseudo-R^2 is more appropriate than the traditional R^2 or adjusted R^2 in measuring the true variation explained by the explanatory variables in the GLS model. SEM measures the error of the model itself and does not include sampling error. SEM is the square root of the GLS model error variance (MEV) (Tasker and Stedinger, 1989). SEP represents the sum of the model error and the sampling error. SEP is the square root of the GLS average variance of prediction (Tasker and Stedinger, 1989; Eng and others, 2009). For the three WLS regression equations developed for estimating QAH for each of the three regions, a SEP (in percent) and a RMSE (in percent) are reported. The SEP reported for the WLS regression equations is based on the mean-square error (MSE) of the residuals and is computed differently than the SEP reported for the GLS regression equations. For the six logistic regression equations developed for estimating selected low-flow frequencies for the southern region, a misclassification percentage is reported. The misclassification percentage is a measure of the percentage of streamgages in the logistic regression analysis that were incorrectly estimated to have zero flow.

The logistic regression equations developed for the southern region (table 13) should be used first to determine the probability of a specific low-flow frequency statistic equaling zero flow for an ungaged site in this region before the low-flow frequency statistic is estimated using the GLS regression equation. If the resulting probability (P_{zero}) is greater or equal to 0.5, then the value for that low-flow frequency statistic is estimated to be zero flow and the appropriate GLS regression equation should not be used. If the resulting probability is less than 0.5, then the appropriate GLS regression equation should be used to estimate the value of the low-flow frequency statistic. For example, if the probability estimate (P_{zero}) for M7D10Y from the logistic regression equation is 0.55, the estimate for M7D10Y is zero flow; if the probability estimate (P_{zero}) is 0.45, an estimate for M7D10Y should be calculated from the appropriate GLS regression equation.

With the exception of SEP, the performance metrics indicate how well the equations perform on the streamgages used in the regression analyses. SEP is a measure of the accuracy that GLS and WLS regression models can predict low-flow

Table 11. Regression equations for estimating selected low-flow frequency statistics and harmonic mean flows for unregulated streams in the northeast region of Iowa.

[SEE, average standard error of estimate; RMSE, root mean square error; SEP, average standard error of prediction; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; DRNAREA, GIS drainage area; TAU_ANN, annual base-flow-recession time constant; KSATSSUR, average soil permeability; NA, not applicable; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow; STREAM_VAR, streamflow-variability index; DRNFREQ, drainage frequency]

Statistic equation	Number of streamgages used to develop equation	SEE or RMSE (percent)	SEP (percent)
Left-censored regression equations			
$M1D10Y = 10^{-8.64} DRNAREA^{1.22} TAU\_ANN^{3.69} KSATSSUR^{1.01}$	43	80.6	NA
$M7D10Y = 10^{-8.56} DRNAREA^{1.23} TAU\_ANN^{3.63} KSATSSUR^{1.04}$	43	84.6	NA
$M30D10Y = 10^{-8.26} DRNAREA^{1.23} TAU\_ANN^{3.48} KSATSSUR^{1.03}$	43	88.1	NA
$M30D5Y = 10^{-6.48} DRNAREA^{1.16} TAU\_ANN^{2.75} KSATSSUR^{0.727}$	43	64.7	NA
$M1D10Y1012 = 10^{-7.93} DRNAREA^{1.16} TAU\_ANN^{3.33} KSATSSUR^{1.08}$	44	72.3	NA
$M7D10Y1012 = 10^{-7.57} DRNAREA^{1.16} TAU\_ANN^{3.17} KSATSSUR^{1.05}$	44	66.5	NA
Weighted least-squares regression equation			
$QAH = 10^{-1.83} DRNAREA^{1.21} STREAM\_VAR^{-1.52} DRNFREQ^{0.843}$	44	63.7	66.4*

*Based on mean-square error residuals.

Table 12. Regression equations for estimating selected low-flow frequency statistics and harmonic mean flows for unregulated streams in the northwest region of Iowa.

[SEE, average standard error of estimate; RMSE, root mean square error; SEP, average standard error of prediction; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; DRNAREA, GIS drainage area; BFI, base-flow index; SOILASSURGO, hydrologic soil type A; NA, not applicable; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow; TAU_ANN, annual base-flow-recession time constant; RSD, relative stream density]

Statistic equation	Number of streamgages used to develop equation	SEE or RMSE (percent)	SEP (percent)
Left-censored regression equations			
$M1D10Y = 10^{-9.88} 10^{1.97(DRNAREA)^{0.15}} 10^{14.5(BFI)^{2}} 10^{0.135(SOILASSURGO)}$	37	104.8	NA
$M7D10Y = 10^{-9.35} 10^{1.92(DRNAREA)^{0.15}} 10^{13.5(BFI)^{2}} 10^{0.134(SOILASSURGO)}$	37	111.8	NA
$M30D10Y = 10^{-5.55} 10^{1.69(DRNAREA)^{0.15}} 10^{7.72(BFI)^{3}} 10^{0.113(SOILASSURGO)}$	37	109.7	NA
$M30D5Y = 10^{-4.87} 10^{1.55(DRNAREA)^{0.15}} 10^{4.47(BFI)^{2}} 10^{0.090(SOILASSURGO)}$	37	87.2	NA
$M1D10Y1012 = 10^{-6.07} 10^{1.61(DRNAREA)^{0.15}} 10^{6.78(BFI)^{2}} 10^{0.108(SOILASSURGO)}$	38	85.8	NA
$M7D10Y1012= 10^{-5.76} 10^{1.60(DRNAREA)^{0.15}} 10^{6.25(BFI)^{2}} 10^{0.102(SOILASSURGO)}$	38	88.4	NA
Weighted least-squares regression equation			
$QAH= 10^{-5.87} DRNAREA^{1.39} 10^{0.088(TAU\_ANN)} 10^{3.07(RSD)}$	38	71.6	75.1*

*Based on mean-square error residuals.

Table 13. Regression equations for estimating selected low-flow frequency statistics and harmonic mean flows for unregulated streams in the southern region of Iowa.

[Misclassification, percentage of streamgages incorrectly estimated to have zero flow; Pseudo-R^2, pseudo coefficient of determination; SEE, average standard error of estimate; RMSE, root mean square error; SEM, average standard error of model; SEP, average standard error of prediction; P_{zero}, probability of the low-flow frequency statistic being equal to zero; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; *e*, base of the natural logarithm, approximately equal to 2.7183; DRNAREA, GIS drainage area; BFI, base-flow index; NA, not applicable; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; STREAM_VAR, streamflow-variability index; SOILBSSURGO, hydrologic soil type B; QAH, harmonic mean flow; SOILCSSURGO, hydrologic soil type C]

Statistic equation	Number of streamgages used to develop equation	Misclassification (percent)	Pseudo-R^2 (percent)	SEE or RMSE (percent)	SEM (percent)	SEP (percent)
Logistic regression equations						
$P1D10Y = 1-[(e^{-32.7+23.7(DRNAREA)^{0.05}+8.61(BFI)})/(1+e^{-32.7+23.7(DRNAREA)^{0.05}+8.61(BFI)})]$	107	14.0	NA	NA	NA	NA
$P7D10Y = 1-[(e^{-8.84+1.52(DRNAREA)^{0.3}+9.03(BFI)})/(1+e^{-8.84+1.52(DRNAREA)^{0.3}+9.03(BFI)})]$	107	13.1	NA	NA	NA	NA
$P30D10Y = 1-[(e^{-5.76+1.65(DRNAREA)^{0.25}+5.75(BFI)})/(1+e^{-5.76+1.65(DRNAREA)^{0.25}+5.75(BFI)})]$	107	8.4	NA	NA	NA	NA
$P30D5Y = 1-[(e^{-3.99+1.73LOG10(DRNAREA)+8.21(BFI)})/(1+e^{-3.99+1.73LOG10(DRNAREA)+8.21(BFI)})]$	107	5.6	NA	NA	NA	NA
$P1D10Y1012 = 1-[(e^{-29.9+22.7(DRNAREA)^{0.05}+6.63(BFI)})/(1+e^{-29.9+22.7(DRNAREA)^{0.05}+6.63(BFI)})]$	110	10.9	NA	NA	NA	NA
$P7D10Y1012 = 1-[(e^{-6.34+1.28(DRNAREA)^{0.3}+6.47(BFI)})/(1+e^{-6.34+1.28(DRNAREA)^{0.3}+6.47(BFI)})]$	110	8.2	NA	NA	NA	NA
Generalized least-square regression equations						
$M1D10Y = 10^{-2.95}DRNAREA^{1.38}10^{-2.18(STREAM\_VAR)^2}10^{0.009(SOILBSSURGO)}$	76	NA	90.6	NA	72.3	76.8
$M7D10Y = 10^{-2.84}DRNAREA^{1.39}10^{-2.29(STREAM\_VAR)^2}10^{0.009(SOILBSSURGO)}$	81	NA	87.7	NA	91.5	96.8
$M30D10Y = 10^{-1.96}DRNAREA^{1.44}10^{-2.63(STREAM\_VAR)}10^{0.007(SOILBSSURGO)}$	91	NA	89.2	NA	93.8	98.9
$M30D5Y = 10^{-1.73}DRNAREA^{1.40}10^{-2.45(STREAM\_VAR)}10^{0.006(SOILBSSURGO)}$	97	NA	91.1	NA	83.1	87.1
$M1D10Y1012 = 10^{-2.72}DRNAREA^{1.37}10^{-2.44(STREAM\_VAR)^2}10^{0.009(SOILBSSURGO)}$	86	NA	91.1	NA	74.4	78.7
$M7D10Y1012 = 10^{-1.90}DRNAREA^{1.35}10^{-2.59(STREAM\_VAR)}10^{0.009(SOILBSSURGO)}$	88	NA	91.8	NA	67.7	71.7
Weighted least-squares regression equation						
$QAH= 10^{-1.59}10^{1.53(DRNAREA)^{0.15}}10^{-1.29(STREAM\_VAR)}10^{-0.006(SOILCSSURGO)}$	110	NA	NA	79.1	NA	80.4*

*Based on mean-square error residuals.

frequency and harmonic-mean-flow statistic values at ungaged sites. The same explanatory variables were used to develop all low-flow frequency equations for each region to minimize the possibility of predictive inconsistencies between estimates of different low-flow frequency statistics, so that estimates will decrease with decreasing n-days and increasing recurrence interval. For example, maintaining the same regression-model form (same explanatory variables) helps to maximize the probability an estimate for M1D10Y is less than an estimate for M7D10Y, an estimate for M7D10Y is less than an estimate for M30D10Y, and an estimate for M30D10Y is less than an estimate for M30D5Y.

Output from the WREG program (Eng and others, 2009) for GLS and WLS regression models identifies streamgages that are possible outliers in the data set as plotted points or tabulated values that exceed a leverage threshold value or an influence threshold value. Leverage points (Eng and others, 2009) are outliers that may unduly influence the estimation of regression constants and are a measure of how large or small explanatory variables (basin characteristics) are for a specific streamgage as compared to the centroid of values of the same explanatory variables at all other streamgages. Influence points are measured by Cook’s D statistic (Cook, 1977; Helsel and Hirsch, 2002), and these are outliers that have unduly influenced the estimation of regression constants. The WREG program also was used to develop preliminary GLS regression equations for selected low-flow frequency statistics for the northeast and northwest regions; these equations were not published because of the use of the left-censored regression analyses. Streamgages identified as outliers for the GLS or WLS regression models were noted for each low-flow frequency and harmonic-mean-flow statistic for each low-flow region. As previously noted in an earlier section Definition of Low-Flow Regions, 14 streamgages identified by the WREG program as outliers were removed from the regression data sets (table 9) because of a documented or suspected alteration in the watershed that may affect low-flow conditions.

Accuracy and Limitations of Regression Equations

The regional regression equations developed in this study apply only to stream sites in Iowa where low flows are not significantly affected by regulation, diversion, or urbanization. The applicability and accuracy of the regional equations depend on whether the basin characteristics measured for an ungaged stream site are within the range of the characteristic values used to develop the regression equations. The acceptable range of basin characteristic values used to develop each regional regression equation (tables 11–13) are tabulated as minimum and maximum values in table 14 (at end of report). The applicability of the regional equations is unknown when any characteristic value measured for an ungaged site is outside the acceptable range. In addition, basin-characteristic measurements at ungaged sites should be computed using the same GIS data sets and measurement methods used in this study; the USGS StreamStats Web-based GIS tool includes the same GIS data layers and measurement methods as used to develop the regression equations in this study.

The frequency regression equations presented in this report should be used with caution for ungaged stream sites with basin-characteristic values approaching the minimum or maximum limits (table 14) because inconsistencies in the estimates may result. Two types of inconsistencies in estimates may result for ungaged sites: (1) for the same recurrence interval, the discharge estimate for a smaller number of consecutive days may be greater than the discharge estimate for a larger number of consecutive days, for example, a M7D10Y discharge may be estimated to be greater than a M30D10Y discharge; and (2) for different recurrence intervals, the discharge estimate for a larger recurrence interval may be greater than the discharge estimate for a smaller recurrence interval, for example, a M30D10Y estimate may be greater than a M30D5Y estimate. Inconsistencies in estimates occurred for four of the streamgages listed in table 2, because some of their basin-characteristic values (table 3) are at or near the minimum or maximum limits listed in table 14. For the northwest region, the predicted discharge for M7D10Y exceeds or equals the predicted discharge for M30D10Y for streamgages 06478518 (map number 136), 06600000 (map number 143), and 06606600 (map number 153); and for the northeast region, the predicted discharge for M30D10Y exceeds the predicted discharge for M30D5Y for streamgage 05410490 (map number 13). Different regression models were tested for the northwest region to minimize the occurrence of inconsistencies in estimates. Although an attempt was made to reduce the occurrence of inconsistencies in estimates by using the same explanatory variables for each regional set of low-flow frequency equations, the possibility exists that inconsistencies in estimates may occur. Inconsistencies in estimates may occur because regional regression equations were developed separately and have variable prediction intervals depending on the size and variability of the datasets used to develop the regression equations. If inconsistencies in estimates are obtained for an ungaged stream site, a comparison of all low-flow frequency estimates for the site and a check of streamgage data or other published data may help to determine which low-flow frequency statistic is inconsistent.

Although reported SEE and SEP performance metrics are not directly comparable between the regional equations, in general, predictive accuracies tend to be the best for the northeast region, second best for the southern region, and poorest for the northwest region. For the selected low-flow frequency equations, SEE for the northeast region ranges from 64.7 to 88.1 percent, SEP for the southern region ranges from 71.7 to 98.9 percent, and SEE for the northwest region ranges from 85.8 to 111.8 percent. SEP for the regional QAH equations were 66.4 (northeast), 75.1 (northwest), and 80.4 percent (southern). The percentage of variation in the response variables explained by the explanatory variables (pseudo-R^2) for the selected low-flow frequency equations developed for the southern region ranges from 87.7 to 91.8 percent. Misclassification (the percentage of streamgages incorrectly estimated to have zero flow for the logistic equations developed for the southern region) ranges from 5.6 to 14.0 percent. Of the six low-flow frequency equations developed for each region, the M7D10Y1012, M1D10Y1012, and M30D5Y regression equations generally have the best predictive accuracy and the M30D10Y and M7D10Y equations generally have the poorest accuracy. The generally better predictive accuracies obtained for the seasonal equations (October to December), as compared to the annual equations, indicate less variation in base flows during the fall when compared to the entire climatic year.

The natural variability of streamflow may be an important factor associated with the predictive accuracy of low-flow frequency and harmonic-mean-flow regression equations. Estimation of streamflow statistics that have greater variability will have poorer predictive accuracies than estimation of statistics with less variability. Streamflow variability, as mapped for kriged STREAM_VAR values (fig. 7), generally is lower for the northeast region, compared to the other two regions, and overall predictive accuracies are best for estimating selected low-flow frequency statistics and harmonic mean flows in the northeast region.

The regression equations presented in this report also should be used with caution in areas where low flows are affected by significant gains as a result of large springs or significant losses as a result of sinkholes common to karst topography in areas underlain by limestone. The Paleozoic Plateau landform region, within the northeast low-flow region (fig. 3), contains karst areas where low flows may vary considerably spatially because of gaining or losing stream reaches. User judgment may be required to decide if an ungaged site in a karst area may be affected by significant gains or losses in low flow, and low-flow frequency and harmonic-mean-flow regression estimates should be compared against streamgage data or other published data. The regression equations also should be used with caution for streams within the Mississippi River and Missouri River Alluvial Plains landform regions (fig. 3) because streamgage data representing these landform regions were not included in the development of the regression equations. If the equations are used at ungaged sites on regulated streams, or on streams affected by water-supply and agricultural withdrawals, then the estimates will need to be adjusted by the amount of regulation or withdrawal to estimate the actual flow conditions if that is of interest.

Because of the uncertainty in measuring and estimating flows below 0.1 ft^3/s, the censoring threshold used to develop the left-censored regression equations for the northeast and northwest regions was set at 0.1 ft^3/s. Thus, selected low-flow frequency estimates calculated from left-censored regression equations that are 0.1 ft^3/s, or lower, should be reported as less than 0.1 ft^3/s. For the southern region, selected low-flow frequency estimates calculated from GLS regression equations that are lower than 0.1 ft^3/s also should be reported as less than 0.1 ft^3/s to maintain a consistent prediction-discharge-reporting limit for Iowa. Likewise, QAH estimates calculated from WLS regression equations that are lower than 0.1 ft^3/s also should be reported as less than 0.1 ft^3/s. Because the precision of response- and explanatory-variable data used to develop the equations was often limited to three significant figures, selected-statistic discharges estimated from the regression equations also should be limited to three significant figures.

Figure 11 shows the relation between observed and predicted discharges for M7D10Y for each of the three low-flow regions. The uncertainty of regression estimates can be seen graphically as a greater scatter of observed in relation to predicted points along the 1:1 line. A greater uncertainty is evident for M7D10Y discharges below the prediction-discharge-reporting limit of 0.1 ft^3/s. The point shown on figure 11 for the northeast region as map number 17 is the streamgage 05412100 Roberts Creek above Saint Olaf, Iowa (fig. 1). The Roberts Creek Basin is within a karst area of northeastern Iowa (Rowden and others, 1995) and as shown on figure 11 and listed in table 2, the predicted M7D10Y discharge for this streamgage is significantly greater than the observed M7D10Y discharge, indicating the possibility of a losing stream reach upstream from the site.

Prediction Intervals

Although regression equations presented in tables 11–13 can be used to estimate selected low-flow frequency statistics and harmonic mean flows, the true values of the selected low-flow frequency statistics and harmonic mean flows are unknown. A measure of the uncertainty associated with the regression estimate of a low-flow frequency or harmonic-mean-flow statistic is the prediction interval. The interval is the estimated value plus or minus a given margin of error. A prediction interval is the probability that the actual value of the estimated low-flow frequency or harmonic-mean-flow statistic will be within this margin of error (Helsel and Hirsch, 2002). The prediction interval determines the range of discharge values predicted for selected statistics given a confidence level and the SEP or SEE. For a 90-percent prediction interval, the true low-flow frequency or harmonic-mean-flow statistic has a 90-percent probability of being within the margin of error. The USGS StreamStats Web-based GIS tool (*http://water.usgs.gov/osw/streamstats/index.html*) uses the 90-percent prediction interval estimates as part of the computation of low-flow frequency and harmonic-mean-flow statistic estimates for ungaged stream sites. The following equation, modified from Tasker and Driver (1988), can be used to compute the 90-percent prediction interval for the true value of a low-flow frequency or harmonic-mean-flow statistic for an ungaged site:

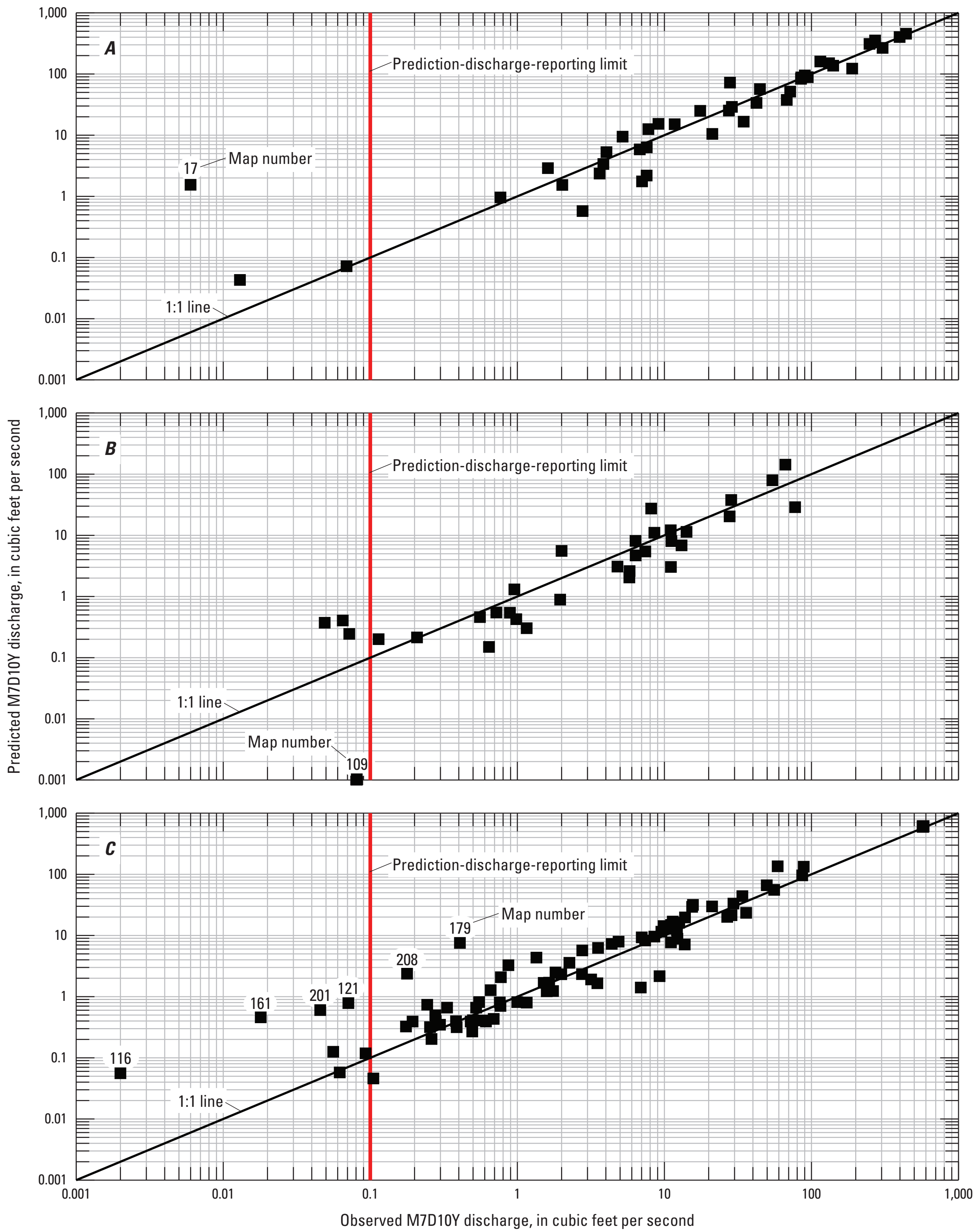

Figure 11. Relation between the annual 7-day mean low flow for a recurrence interval of 10 years (M7D10Y) discharges computed from observed streamflow and those predicted from regression equations for low-flow regions in Iowa. *A*, Northeast region. *B*, Northwest region. *C*, Southern region.

$$\frac{Q}{T} < Q < QT \quad (10)$$

where

Q is the low-flow frequency or harmonic-mean-flow discharge predicted for the ungaged site from the regression equation, and T is computed as:

$$T = 10^{\left[t_{(\alpha/2,n-p)} S_i\right]} \quad (11)$$

where

$t_{(\alpha/2,n-p)}$ is the critical value from the student's t-distribution at alpha level α (α = 0.10 for 90-percent prediction intervals, critical values may be obtained in many statistics textbooks, Iman and Conover (1983), or from the World-Wide Web;

n-p is the degrees of freedom with n streamgages included in the regression analysis and p parameters in the equation (the number of explanatory variables plus one); and

S_i is the standard error of prediction for site i, and is computed as:

$$S_i = \left[MEV + X_i U X_i'\right]^{0.5} \quad (12)$$

where

MEV is the model error variance from GLS regression or the MSE from left-censored regression or from WLS regression equations developed in this study using a user-defined weighting matrix;

X_i is the row vector for the streamgage i, starting with the number 1, followed by the logarithmic values of the basin characteristics used in the regression;

U is the covariance matrix for the annual or seasonal regression coefficients; and

X_i' is the matrix algebra transpose of X_i (Ludwig and Tasker, 1993; Ries and Friesz, 2000).

Similar to the SEP, S_i represents the sum of the model error and the sampling error for a single site i. The X_iUX_i', term in equation 12 also is referred to as the sampling error variance. The values of $t_{(\alpha/2,n-p)}$ and U needed to determine prediction intervals for estimates obtained by the regression equations in tables 11–13 are presented in table 15 (at end of report).

Application of Regression Equations

Methods for applying the regional regression equations listed in tables 11–13 are described in the following examples:

Example 1

This example is a calculation of M7D10Y (annual 7-day mean low flow for a recurrence interval of 10 years) for a stream site in the southern region. Figure 1 shows the location of the streamgage 06903700 South Fork Chariton River near Promise City, Iowa, as map number 207. This watershed is located entirely with the southern region. Estimating selected low-flow frequency statistics for the southern region is a one- or two-step process. The first step is to estimate the probability of zero flow using the logistic regression equations listed in table 13. The logistic regression equations are only used to estimate the probability of zero flow for frequency statistics for stream sites in the southern region. Using the USGS StreamStats Web-based GIS tool, DRNAREA (drainage area) is measured as 169.52 mi^2 and BFI (base-flow index) is measured as 0.192 (table 3). Because both basin-characteristic values are within the range of values listed in table 14, the logistic regression equation is applicable for estimating the probability of zero flow for M7D10Y. The M7D10Y logistic regression equation from table 13 is

$$P7D10Y = 1-[(e^{-8.84+1.52(DRNAREA)^{0.3}+9.03(BFI)})/(1+e^{-8.84+1.52(DRNAREA)^{0.3}+9.03(BFI)})]$$

$$P7D10Y = 1-[(e^{-8.84+1.52(169.52)^{0.3}+9.03(0.192)})/(1+e^{-8.84+1.52(169.52)^{0.3}+9.03(0.192)})]$$

$$P7D10Y = 1-[(e^{-0.0168})/(1+e^{-0.0168})]$$

$$P7D10Y = 0.504$$

Because the estimate for P7D10Y is greater than the cutpoint-probability threshold of 0.5 used for this study, the estimate for M7D10Y is zero flow.

Example 2

This example is a calculation of M30D10Y (annual 30-day mean low flow for a recurrence interval of 10 years) for the same stream site (map number 207, fig. 1) in the southern region as illustrated in example 1. Again, the first step is to estimate the probability of zero flow. The M30D10Y logistic regression equation from table 13 is

$$P30D10Y = 1\text{-}[(e^{-5.76+1.65(DRNAREA)^{0.25}+5.75(BFI)})/(1+e^{-5.76+1.65(DRNAREA)^{0.25}+5.75(BFI)})]$$

$$P30D10Y = 1\text{-}[(e^{-5.76+1.65(169.52)^{0.25}+5.75(0.192)})/(1+e^{-5.76+1.65(169.52)^{0.25}+5.75(0.192)})]$$

$$P30D10Y = 1\text{-}[(e^{1.2977})/(1+e^{1.2977})]$$

$$P30D10Y = 0.215$$

Because the estimate for P30D10Y is less than the cutpoint-probability threshold of 0.5 used for this study, the flow is estimated to be greater than zero for M30D10Y. Therefore, the second step is to estimate the amount of flow for M30D10Y using the GLS regression equation listed in table 13. Using StreamStats, STREAM_VAR (streamflow-variability index) is measured as 0.760 and SOILBSSURGO (hydrologic soil type B) is measured as 17.984 percent (table 3). Because all three basin characteristic values are within the range of values listed in table 14, the GLS regression equation is applicable for estimating M30D10Y. The M30D10Y GLS regression equation from table 13 is:

$$M30D10Y = 10^{-1.96}DRNAREA^{1.44}10^{-2.63(STREAM\_VAR)}10^{0.007(SOILBSSURGO)}$$

$$M30D10Y = 10^{-1.96}(169.52)^{1.44}10^{-2.63(0.760)}10^{0.007(17.984)}$$

$$M30D10Y = 0.24\ ft^3/s$$

To calculate a 90-percent prediction interval for this M30D10Y estimate using equation 10, the X_i vector is

$$X_i = \{1, \log10\ (169.52), 0.760, 17.984\},$$

the model error variance (MEV) from table 15 is 0.119068, and the covariance matrix (U) is:

	Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
Intercept	0.173419660	-0.012204313	-0.175826400	-0.000491100
DRNAREA	-.012204313	.005005351	-.002544634	.000005606
STREAM_VAR	-.175826400	-.002544634	.254156970	.000480857
SOILBSSURGO	-.000491100	.000005606	.000480857	.000002804

Using matrix algebra, the product of $X_iUX'_i$ is determined in two steps: (1) by multiplying X'_i (the transpose of X_i) by the covariance matrix, U, to obtain UX'_i, and (2) by multiplying UX'_i by X_i. In this example, the value of $X_iUX'_i$ is 0.011641.

The standard error of prediction for this site as computed from equation 12 is

$$S_i = [0.\ 119068 + 0.011641]^{0.5} = 0.361537,$$

and T from equation 11 is

$$T = 10^{(1.6626)(0.361537)} = 3.9911,$$

where the critical value ($t_{(\alpha/2,n-p)}$) from the student's t-distribution for the 90-percent prediction interval is 1.6626 (table 15).

The 90-percent prediction interval is estimated from equation 10 as

$$0.24/3.9911 < M30D10Y < (0.24)\ (3.9911),\ \text{or,}$$

$$0.06 < M30D10Y < 0.96.$$

Because the lower end of the prediction interval is below the prediction-discharge-reporting limit of 0.1 ft^3/s established for this study, the 90-percent prediction interval estimate is

$$<0.1\ ft^3/s < M30D10Y < 0.96\ ft^3/s.$$

Example 3

This example is a calculation of M1D10Y (annual 1-day mean low flow for a recurrence interval of 10 years) for a stream site in the northeast region. Figure 1 shows the location of the streamgage 05420560 Wapsipinicon River near Elma, Iowa, as map number 26. This watershed is located entirely within the northeast low-flow region. Using StreamStats, DRNAREA (drainage area) is measured as 96.44 mi^2, TAU_ANN (annual base-flow-recession time constant) is measured as 29.732 days, and KSATSSUR (average soil permeability or hydraulic conductivity of the soil) is measured as 17.800 µm/s (table 3). Because all three basin-characteristic values are within the range of values listed in table 14, the left-censored regression equation is applicable for estimating M1D10Y. The M1D10Y left-censored regression equation from table 11 is

$$M1D10Y = 10^{-8.64} DRNAREA^{1.22} TAU\_ANN^{3.69} KSATSSUR^{1.01}$$

$$M1D10Y = 10^{-8.64} (96.44)^{1.22} (29.732)^{3.69} (17.800)^{1.01}$$

$$M1D10Y = 3.02 \text{ ft}^3/\text{s}$$

To calculate a 90-percent prediction interval for this M1D10Y estimate using equation 10, the X_i vector is

$$X_i = \{1, \log10\ (96.44), \log10\ (29.732), \log10\ (17.800)\},$$

the model error variance (MEV) from table 15 is 0.094433, and the covariance matrix (U) is:

	Intercept	DRNAREA	TAU_ANN	KSATSSUR
Intercept	7.599114317	-0.017291210	-3.340946820	-2.069765708
DRNAREA	-.017291210	.076139961	.034377290	-.190210256
TAU_ANN	-3.340946818	.034377288	1.893205880	.313756238
KSATSSUR	-2.069765708	-.190210256	.313756240	1.751366356

Using matrix algebra, the product of $X_i U X'_i$ is determined in two steps: (1) by multiplying X'_i (the transpose of X_i) by the covariance matrix, U, to obtain UX'_i, and (2) by multiplying UX'_i by X_i. In this example, the value of $X_i U X'_i$ is 0.070618.

The standard error of prediction for this site as computed from equation 12 is

$$S_i = [0.\ 094433 + 0.070618]^{0.5} = 0.406265,$$

and T from equation 11 is

$$T = 10^{(1.6849)(0.406265)} = 4.8363,$$

where the critical value ($t_{(\alpha/2,n-p)}$) from the student's t-distribution for the 90-percent prediction interval is 1.6849 (table 15).

The 90-percent prediction interval is estimated from equation 10 as

$$3.02/4.8363 < M1D10Y < (3.02)\ (4.8363), \text{ or,}$$

$$0.62 \text{ ft}^3/\text{s} < M1D10Y < 14.6 \text{ ft}^3/\text{s}.$$

Region-of-Influence Method to Estimate Selected Low-Flow Frequency Statistics and Harmonic Mean Flows for Ungaged Stream Sites

The region-of-influence (RoI) method has been used to estimate flood-frequency discharges at ungaged sites by relating basin characteristics to flood-frequency discharges for a unique subset of streamgages (Burn, 1990; Eng and others, 2005, 2007). The RoI method also is applicable for the estimation of low-flow frequency statistics and harmonic mean flows. The RoI method was tested as part of this study using WREG (Eng and others, 2009) to determine whether predictive accuracies for selected low-flow frequency statistics and harmonic mean flows may be improved using RoI compared to traditional regional regression. The RoI method defines a unique subset, or region of influence, for each ungaged site determined by selecting streamgages with basin characteristics similar to those measured for the ungaged site. The RoI is defined as the N "nearest" streamgages to the ungaged site, where "nearest" is measured by similarity of basin characteristics in Euclidean space. An advantage of this method is extrapolation errors tend to be small because the predictions naturally occur near the center of the space of the basin characteristics.

To investigate the RoI method for this study, basin characteristics identified as the most significant in the statewide OLS regression analyses were selected and compiled into a RoI data set that included the same number of streamgages as used for the development of statewide regression equations (table 8). The RoI method in WREG allows three approaches for defining hydrologic similarity among streamgage basins: independent or predictor-variable space RoI (PRoI), geographic space RoI (GRoI), and a combination of predictor–variable and geographic spaces called hybrid RoI (HRoI). Preliminary RoI analyses were performed to determine the best combination of three input parameters required by the RoI program in WREG: (1) the best set of basin characteristics must be selected for use as explanatory variables, (2) the number of streamgages (N) must be selected to compose the specific region of influence for the statewide study area, and (3) the PRoI, GRoI, or HRoI RoI approach must be selected.

RMSEs were evaluated for the preliminary RoI analyses to determine the best combination of the three required input parameters for WREG. Table 16 lists the best combinations of explanatory variables with the lowest RMSEs that were identified statewide, and by low-flow regions, for each of the seven selected statistics through iterative RoI analyses using WREG. Although statewide and regional RMSE and SEP performance metrics are not directly comparable, overall, RMSEs for RoI were poorer than SEPs for statewide GLS regression equations (table 8) and were poorer than SEEs or SEPs for regional regression equations (tables 11–13). Because regional regression equations provided improved predictive accuracies, the RoI method was not developed further and RoI equations are not listed in this report but are summarized in table 16 to provide a reference for showing the improvement obtained using regional regression equations.

Weighted Drainage-Area Ratio Method to Estimate Selected Low-Flow Frequency Statistics and Harmonic Mean Flows for Ungaged Sites on Gaged Streams

Two drainage-area ratio methods were tested in this study to determine the preferred method to use for ungaged sites on gaged streams in Iowa and to determine the appropriate range of drainage-area ratios between a streamgage and an ungaged stream site. A simple drainage-area ratio (DAR) method was tested alongside a weighted drainage-area ratio (WDAR) method, hereafter these methods are referred to as DAR and WDAR. A gaged stream is a stream with a streamgage for which low-flow frequency or harmonic-mean-flow statistics have been computed.

The DAR method is based on the assumption that streamflow at an ungaged site is the same per unit area as that for a streamgage located upstream or downstream from the ungaged site. Low-flow frequency or harmonic-mean-flow statistics calculated for the streamgage are multiplied by the DAR of the ungaged site and the streamgage to estimate low-flow frequency or harmonic-mean-flow statistics at the ungaged site. The accuracy of the DAR method depends on similarities in drainage area and other basin characteristics (such as soils, geology, precipitation) between the two sites. The DAR method calculation is:

$$Q_{DARu}=[\frac{DA_u}{DA_g}]Q_{og} \qquad (13)$$

where

Q_{DARu} is the DAR low-flow frequency or harmonic-mean-flow estimate of the ungaged site,

DA_u is the drainage area of the ungaged site,

DA_g is the drainage area of the streamgage, and

Q_{og} is the low-flow frequency or harmonic-mean-flow estimate computed from the observed streamgage record.

The DAR method typically is applied when an ungaged site is on the same stream as a streamgage and the DAR of the two sites is between 0.5 and 1.5 (Hortness, 2006). Some studies have tested DARs to determine the range for which the DAR method provides estimates of low-flow statistics that are better than estimates obtained using regional regression equations (RRE). In Ohio, Koltun and Schwartz (1986)

Table 16. Significant explanatory variables and predictive accuracies of preliminary region-of-influence equations in Iowa.

[RoI, region of influence; RMSE, root mean square error; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; DRNAREA, GIS drainage area; (+), explantory variable has a positive relation with the response variable; STREAM_VAR, streamflow-variability index; (-), explanatory variable has a negative relation with the response variable; KSATSSUR, average soil permeability; PRoI, predictor-variable space RoI; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; CLAY, percent volume of clay content of soil; GRoI, geographic space RoI; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow]

Statistic	Number of streamgages used to develop preliminary RoI equation[1]	Most significant explanatory variables identified for the preliminary equation and explanatory-variable relation signs	N, number of streamgages used to form RoI	RoI method	Statewide RMSE (percent)	Northeast region RMSE (percent)	Northwest region RMSE (percent)	Southern region RMSE (percent)
Preliminary RoI analysis results								
M1D10Y	158	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	49	PRoI	170.7	96.6	417.3	117.5
M7D10Y	166	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	53	PRoI	165.2	175.5	215.5	134.3
M30D10Y	180	DRNAREA(+), STREAM_VAR(-), CLAY(-)	45	GRoI	140.6	115.1	167.4	141.0
M30D5Y	187	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	50	GRoI	115.5	79.5	167.9	110.4
M1D10Y1012	177	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	25	PRoI	112.8	99.5	171.3	94.9
M7D10Y1012	179	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	35	PRoI	94.3	86.6	115.8	88.7
QAH	206	DRNAREA(+), STREAM_VAR(-), KSATSSUR(+)	34	PRoI	84.9	73.2	103.1	78.7

[1]Streamgages with estimates of zero flow were excluded from the RoI analysis.

recommended a DAR range between 0.85 and 1.15 for estimating low-flow statistics; in Massachusetts, Ries and Friesz (2000) determined that a range of 0.3 to 1.5 was applicable for low-flow statistics.

The WDAR method applies an adjustment or weight to the RRE predicted estimate for the ungaged site on the basis of the difference between the observed and the RRE predicted estimates for the streamgage and on the basis of the difference in drainage areas between the two sites (Martin and Arihood, 2010; Eash, 2001). The WDAR method calculation is:

$$Q_{WDARu} = Q_{ru}\left[R - \left(\frac{2(|\Delta DA|)(R-1)}{DA_g}\right)\right] \quad (14)$$

where

Q_{WDARu} is the WDAR low-flow frequency or harmonic-mean-flow estimate of the ungaged site,

Q_{ru} is the RRE estimate of the ungaged site,

R is Q_{og}/Q_{rg},

Q_{og} is the low-flow frequency or harmonic-mean-flow estimate of the observed streamgage record (table 2),

Q_{rg} is the RRE predicted estimate of the streamgage (table 2),

$|\Delta DA|$ is the absolute value of the difference between the drainage areas of the streamgage and the ungaged site, and

DA_g is the drainage area of the streamgage.

As the ratio of the estimate computed from the observed streamflow (Q_{og}) to the RRE predicted estimate (Q_{rg}) approaches one for the streamgage, or as the difference in drainage area between the two sites approaches 50 percent, the value of the weighting term shown in brackets on the right side of equation 14 approaches one and it no longer has an effect on the RRE estimate for the ungaged site (Q_{ru}).

To determine which method, DAR or WDAR, is preferred for Iowa and to determine the appropriate range of DARs for applying either method, 31 pairs of streamgages were selected for testing estimates of the M7D10Y statistic (table 17 at end of report) following an experiment design described by Ries and Friesz (2000). A set totaling 48 streamgages comprise the 31 pairs of streamgages. Each pair of streamgages is located on the same stream. Fourteen streamgages were tested twice because 13 of the 14 are paired with a streamgage located upstream and a streamgage located downstream, and 1 of the 14 was paired with streamgages located on two upstream forks. The set of 48 streamgages is located on 17 different streams in Iowa, and the set is located within all the landform regions of the State with the exception of the Mississippi and Missouri River Alluvial Plains (figs. 1 and 3). The period of record used to compute the M7D10Y statistic for each streamgage ranged between 11 to 52 years, with the mean and median number of years of record equal to 38.1 and 41.0, respectively. Drainage area sizes for the 48 streamgages range from about 61 to 7,783 mi^2, with mean and median drainage area sizes of 1,760 and 1,371 mi^2, respectively (table 17). For the 31 pairs of streamgages, 9 pairs are located entirely within the northeast region with drainage area sizes ranging from 96 to 6,506 mi^2, 11 pairs are located primarily within the northwest region with drainage area sizes ranging from 227 to 3,425 mi^2, and 11 pairs are located primarily within the southern region with drainage area sizes ranging from 61 to 7,783 mi^2 (tables 2 and 17).

Thirty-one pairs of M7D10Y estimates were calculated for both the DAR and WDAR methods in which each of the paired streamgages was alternately assumed to be an ungaged site with the other paired site used as the streamgage. Absolute differences, in percent, between the estimates computed from the observed streamflow and the DAR, WDAR, and RRE estimates were determined for the M7D10Y statistic for each streamgage assumed to be an ungaged site (table 17). Figure 12 shows the absolute differences, in percent, from the estimates computed from observed streamflow and the DAR, WDAR, and RRE estimates plotted against the DAR of the assumed ungaged site and the streamgage. Smoothed curves are plotted through each data set to indicate the range of ratios in which the DAR or WDAR estimates may provide better results than the RRE estimates. The smoothed curves were obtained using a LOWESS (LOcally-WEighted Scatter plot Smoother) algorithm computed using Spotfire S+ statistical software (TIBCO Software Inc., 2008).

The LOWESS curves (fig. 12) indicate that absolute differences between the estimates computed from observed streamflow and the DAR method generally are larger than the absolute difference between estimates computed from observed streamflow and the RRE predictions. The LOWESS curves also indicate that absolute differences between the estimates computed from observed streamflow and the WDAR method generally are smaller than the absolute difference between estimates computed from observed streamflow and the RRE predictions when the ratio of the drainage area of the ungaged gage is within about 0.5 and 1.4 times the drainage area of the streamgage. This range of DARs was used to separate the data into six groups based on estimation method and whether the DAR for the hypothetical assumed ungaged location was within the noted range. The groups were (1) DAR estimates for sites with ratios less than 0.5 and greater than 1.4, (2) DAR estimates for sites with ratios between 0.5 and 1.4, (3) WDAR estimates for sites with ratios less than 0.5 and greater than 1.4, (4) WDAR estimates for sites with ratios between 0.5 and 1.4, (5) RRE estimates for sites with DARs less than 0.5 and greater than 1.4, and (6) RRE estimates for sites with DARs between 0.5 and 1.4. Medians and standard deviations of the absolute differences, in percent, are presented for each group in table 18, along with the medians and standard deviations for all DAR, WDAR, and RRE estimates.

Table 18 shows that the median absolute difference, in percent, in the estimated M7D10Y low-flow statistics for the DAR and WDAR methods are about 1 and 2 percent larger,

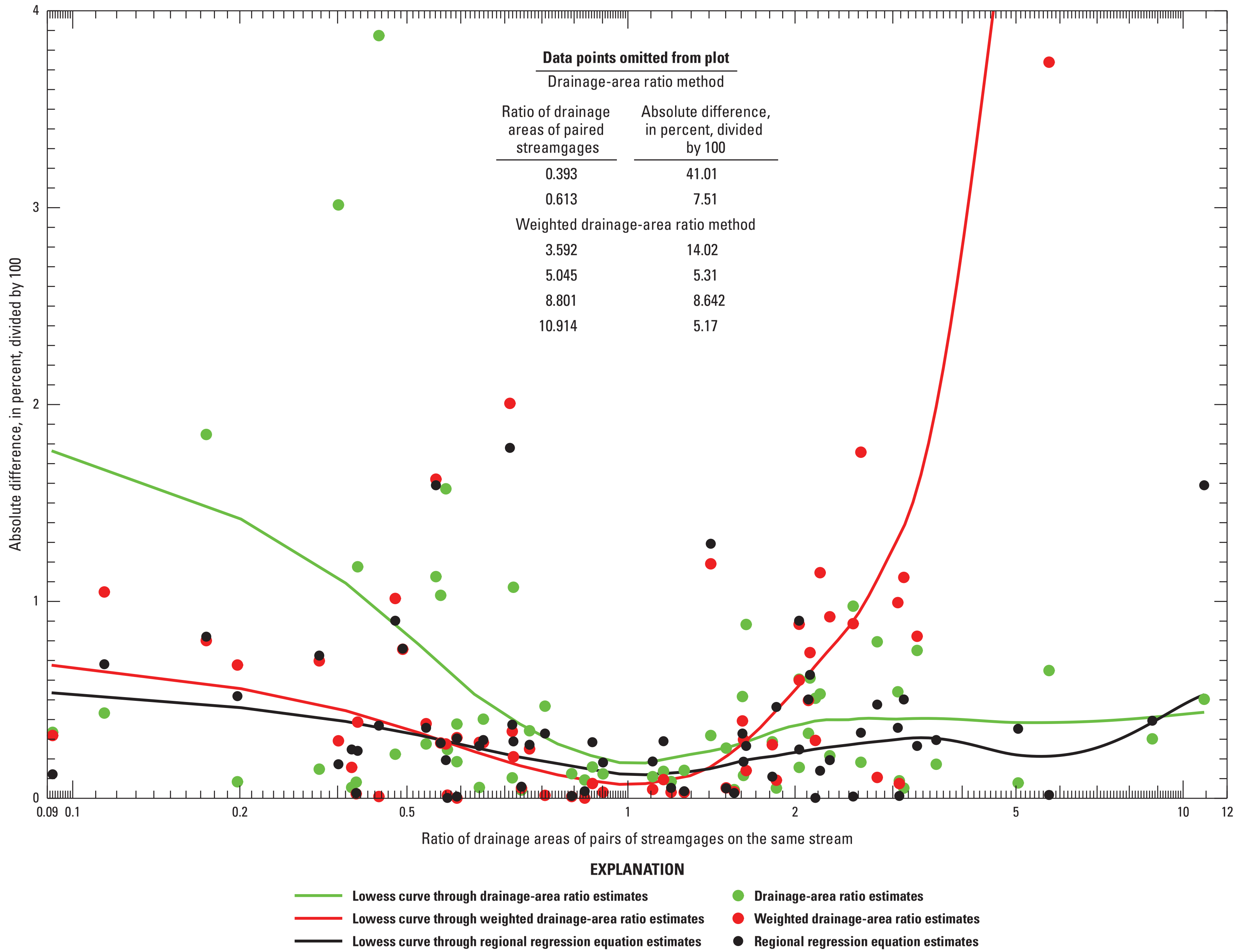

Figure 12. Relation of drainage-area ratio to absolute percent difference in annual 7-day mean low flow for a recurrence interval of 10 years (M7D10Y) statistics between estimates computed from observed streamflow and estimates derived from the drainage-area ratio method, from the weighted drainage-area ratio method, and from the regional regression equations.

respectively, than that for the RRE equations when all the data are considered, and that the standard deviations for the DAR and WDAR methods are both much larger than that for the RRE equation. When DARs for the streamgages are between 0.5 and 1.4, the median differences for the DAR and WDAR methods are about 14 and 21 percent less, respectively, and the standard deviations are about 142 and 7 percent more, respectively, than the corresponding values for the RRE equations. When drainage area ratios for the streamgages are less than 0.5 or greater than 1.4, the median differences for the DAR and WDAR methods are about 3 and 25 percent greater, respectively, and the standard deviations are much larger than the corresponding values for the RRE equations.

The Wilcoxon signed-rank test was computed using Spotfire S+ statistical software (TIBCO Software Inc., 2008) to determine the statistical difference between the medians of the groups. For the DAR method, this test showed that the median difference of the DAR estimates is not significantly less (p=0.71) than the median difference of the RRE estimates when the DAR is between 0.5 and 1.4. The test also showed that the median difference for the DAR estimates is not significantly larger (p=0.21) than the median difference for the RRE estimates when the drainage-area ratio is less than 0.5 or greater than 1.4. For the WDAR method, this test showed that the median difference of the WDAR estimates is significantly less (p=0.01) than the median difference of the RRE estimates when the drainage-area ratio is between 0.5 and 1.4. The test also showed that the median difference for the WDAR estimates is significantly larger (p=0.00) than the median difference for the RRE estimates when the DAR is less than 0.5 or greater than 1.4.

On the basis of the Wilcoxon signed-rank test, the WDAR method generally would provide estimates of M7D10Y that are better than estimates obtained using the RREs, when the DAR is between about 0.5 and 1.4. It is assumed that the WDAR method also may provide estimates that are better than estimates obtained using RREs for the five other selected low-flow frequency statistics and for harmonic mean flows presented in this report, when the drainage-area ratio is between 0.5 and 1.4 based on the results of the M7D10Y test. It should be noted that use of the WDAR method when the DAR is greater than 1.4 may produce negative values for some estimates (table 17). Users of the WDAR method should consider that potential errors of estimates (estimation accuracies) for individual ungaged sites cannot be quantified. If a standard error of the estimate or 90-percent prediction intervals are needed, then it may be better to use the RRE method. To summarize, on the basis of the drainage-area testing that is described in this section, a WDAR method is the preferred method for estimating low-flow frequency statistics and harmonic mean flows for an ungaged site on a gaged stream in Iowa when the DAR is between 0.5 and 1.4.

Table 18. Medians and standard deviations of absolute differences between annual mean 7-day low flow for a recurrence interval of 10 years (M7D10Y) statistics using observed streamflow and by using the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations.

[<, actual value is less than value shown; >, actual value is greater than value shown]

Group	Drainage-area ratio range	Number in group	Median absolute difference (percent)	Standard deviation
All estimates	ALL	186	29.1	330.2
Drainage-area ratio method	ALL	62	29.4	524.9
	< 0.5 and > 1.4	46	33.3	600.5
	0.5 to 1.4	16	13.1	183.8
Weighted drainage-area ratio method	All	62	30.3	222.2
	< 0.5 and > 1.4	46	54.9	251.4
	0.5 to 1.4	16	6.3	48.6
Regional regression equations	ALL	62	28.3	39.0
	< 0.5 and > 1.4	46	30.0	38.3
	0.5 to 1.4	16	26.9	41.4

Example 4

This example is a calculation of a WDAR (weighted drainage-area ratio) estimate for the M7D10Y (annual 7-day mean low flow for a recurrence interval of 10 years) statistic for a stream site in the northwest region. Streamgage 06605600 Little Sioux River at Gillette Grove is shown in fig. 1 as map number 151; this streamgage will be assumed to be an ungaged site for this example. Another streamgage 06605850 Little Sioux River at Linn Grove, is also shown in fig. 1 as map number 152, which is located downstream on the same stream; this site will be used as the streamgage in this example. This watershed is located entirely within the northwest region. Five steps are required to calculate an estimate for the WDAR method using equation 14:

$$Q_{WDARu} = Q_{ru}\left[R - \left(\frac{2\left(\left|\Delta DA\right|\right)\left(R-1\right)}{DA_g}\right)\right]$$

The first step is to calculate Q_{ru}, which is the RRE predicted estimate for the ungaged site (map number 151). Using the USGS StreamStats Web-based GIS tool to measure basin characteristics for the ungaged site, DRNAREA (drainage area) is measured as 1,352.59 mi^2, BFI (base-flow index) is measured as 0.569, and SOILASSURGO (hydrologic soil type A) is measured as 1.717 (table 3). Because all three basin characteristic values are within the range of values listed in table 14, the left-censored regression equation is applicable for estimating M7D10Y. The M7D10Y left-censored regression equation from table 12 is

$$\text{M7D10Y} = 10^{-9.35}10^{1.92(\text{DRNAREA})^{0.15}}10^{13.5(\text{BFI})^2}10^{0.134(\text{SOILASSURGO})}$$

$$\text{M7D10Y} = 10^{-9.35}10^{1.92(1,352.59)^{0.15}}10^{13.5(0.569)^2}10^{0.134(1.717)}$$

$$\text{M7D10Y} = 8.18\ \text{ft}^3/\text{s} = Q_{ru}$$

The second step is to calculate the DAR between the ungaged site and the streamgage to determine whether the WDAR method is applicable for the ungaged site. The drainage area of the ungaged site (1,352.59 mi^2, map number 151) divided by the drainage area of the streamgage (DA_g) in equation 14 (1,567.26 mi^2, map number 152) produces a DAR of 0.863. Because this DAR is between 0.5 and 1.4, the WDAR method is applicable for the ungaged site. The third step is to calculate |ΔDA|, which is the absolute difference between the drainage area of the ungaged site and the drainage area of the streamgage.

$$|\Delta \text{DA}| = 1,352.59—1,567.26$$

$$|\Delta \text{DA}| = 214.67\ \text{mi}^2$$

The fourth step is to calculate R, which is the ratio of Q_{og}, the M7D10Y estimate from the observed streamgage record, and Q_{rg}, the M7D10Y RRE predicted estimate for the streamgage; values for Q_{og} and Q_{rg} are obtained from table 2 (map number 152).

$$R = Q_{og}/Q_{rg}$$

$$R = 8.55/11.03$$

$$R = 0.775$$

The fifth step is to solve equation 14 by calculating Q_{WDARu}, the WDAR M7D10Y estimate for the ungaged site.

$$Q_{WDARu} = 8.18[0.775\text{-}(2(214.67)(0.775\text{-}1)/1,567.26)]$$

$$Q_{WDARu} = 6.84\ \text{ft}^3/\text{s}.$$

StreamStats

StreamStats is a USGS Web-based GIS tool (*http://water.usgs.gov/osw/streamstats/index.html*) that allows users to obtain streamflow statistics, drainage-basin characteristics, and other information for user-selected sites on streams. Users can select stream site locations of interest from an interactive map and can obtain information for these locations. If a user selects the location of a USGS streamgage, the user will get previously published information for the streamgage from a database. If a stream site location is selected where no data are available (an ungaged site), a GIS program will estimate information for the site. The GIS program determines the boundary of the drainage basin upstream from the stream site, measures the basin characteristics of the drainage basin, and solves the appropriate regression equations to estimate streamflow statistics for that site. The results are presented in a table and a map showing the basin-boundary outline. The estimates are applicable for stream sites not significantly affected by regulation, diversions or urbanization. In the past, it could take an experienced person more than a day to estimate this information at an ungaged site. StreamStats reduces the effort to only a few minutes.

StreamStats makes the process of computing streamflow statistics for ungaged sites much faster, more accurate, and more consistent than previously used manual methods. It also makes streamflow statistics for streamgages available without the need to locate, obtain, and read the publications in which they were originally provided. Examples of streamflow statistics that can be provided by StreamStats include the 1-percent flood probability, the median annual flow, and the mean 7-day, 10-year low flow. Examples of basin characteristics include the drainage area, stream slope, mean annual precipitation, percent of area underlain by hydrologic soil types, and so forth. Basin characteristics provided by StreamStats are the physical, geologic, and climatic properties that have been statistically related to movement of water through a drainage basin to a stream site.

Streamflow statistics can be needed at any location along a stream and can assist with water-resources planning, management, and permitting; design and permitting of facilities such as wastewater-treatment plants and water-supply reservoirs; and design of structures such as roads, bridges, culverts, dams, locks, and levees. In addition, planners, regulators and others often need to know the physical and climatic characteristics (basin characteristics) of the drainage basins upstream from locations of interest to help them understand the processes that control water availability and water quality at these locations.

The regression equations presented in this report will be incorporated in the USGS StreamStats Web-based GIS tool *(http://water.usgs.gov/osw/streamstats/index.html)*. StreamStats will provide users the ability to estimate six selected low-flow frequency statistics, harmonic mean flows, and 90-percent prediction intervals for ungaged stream sites in Iowa.

Summary

Reliable estimates of low-flow statistics are essential for the effective management of water resources related to water-supply planning and management, and for setting wastewater-treatment plant effluent limits and allowable pollutant loads to meet water-quality standards for irrigation, recreation, and wildlife conservation. In response to the need to update and improve the predictive accuracy of estimates of selected low-flow frequency statistics and harmonic mean flows for stream sites in Iowa, the U.S. Geological Survey, in cooperation with the Iowa Department of Natural Resources, initiated a statewide study in 2007.

Major components of the study included (1) computing seven selected statistics at 208 continuous-record streamgages within Iowa and adjacent States with at least 10 years of streamflow record using the longest, most recent period of record through September 30, 2006, without a significant trend; (2) measuring 54 basin characteristics for each streamgage that include hydrologic-characteristic measurements from five kriged grids developed for the study area; (3) developing 27 regional regression equations to estimate 7 selected statistics at ungaged stream sites based on basin characteristics; and (4) testing two drainage-area ratio methods to determine if either method provides better estimates for a selected low-flow frequency statistic for ungaged sites on gaged streams in Iowa compared to regional regression estimates and to determine the appropriate range of drainage-area ratios to use with the method.

Five Kendall's *tau* tests, one test for each annual and fall N-day record, were performed for each streamgage included in the study because trends in the N-day data could introduce a bias into the selected low-flow frequency analyses. Results of the Kendall's *tau* tests indicated statistically significant positive trends for 133 of the 208 streamgages tested when considering the entire period of record. A variable-length-record approach to determine the longest period of record without a significant trend for all five N-day records using Kendall's *tau* trend analyses was selected for use for this study because it allows for longer record lengths to be included in the selected low-flow frequency analyses for many streamgages. The number of climatic years of record used for the low-flow study for the 208 streamgages ranged from 10 to 70 years with a median of 35 years. The number of years of fall record used in the study ranged from 10 to 72 years with a median of 35 years. Drainage areas of the 208 streamgages ranged from 1.4 to 7,783 mi^2.

Methods described in this report for estimating selected low-flow frequency statistics and harmonic mean flows are applicable to streams in Iowa that are not significantly affected by regulation, diversion, or urbanization. Estimation equations were developed for six selected low-flow frequency statistics for the annual 1-, 7-, and 30-day mean low flows for a recurrence interval of 10 years (M1D10Y, M7D10Y, and M30D10Y), the annual 30-day mean low flow for a recurrence interval of 5 years (M30D5Y), the seasonal

(October 1 through December 31) 1- and 7-day mean low flows for a recurrence interval of 10 years (M1D10Y1012 and M7D10Y1012), and for the harmonic-mean-flow statistic (QAH).

Three regionalization approaches were investigated in this study for estimating selected low-flow frequency statistics and harmonic mean flows at ungaged sites in Iowa: statewide, regional, and region-of-influence regression. Regression analyses were used to relate physical and climatic characteristics of drainage basins to selected low-flow frequency statistics and harmonic mean flows. Data collected for 206 streamgages (excluded two streamgages because of regulation and drainage area being outside 50 miles of Iowa) were compiled into statewide, regional, and region-of-influence data sets for regression analyses. Root mean square errors (RMSEs), or average standard errors of estimate (SEE), and average standard errors of prediction (SEP) calculated for each equation for each selected low-flow frequency statistic and harmonic mean flow were compared for each regression to evaluate the predictive accuracy. Because the regional-regression provided the best predictive accuracy of the three approaches investigated, preliminary equations developed for the statewide and region-of-influence methods are not listed in this report.

The study area, which included all of Iowa and adjacent areas (within 50 miles of the State border) of neighboring States, was divided into three low-flow regions on the basis of hydrologic characteristics, landform regions, and soil regions. Because a significant number of streams in Iowa reach zero flow as their minimum flow during low-flow years, four different types of regression analyses were performed to develop the final equations for the three low-flow regions—left-censored, logistic-, WLS-, and GLS-regression analyses. For the northeast and northwest regions, left-censored regression analyses were performed to allow the use of a censoring threshold in the development of equations to estimate the six low-flow frequency statistics, and a weighted least-square (WLS) regression analysis was used to develop an equation to estimate QAH. For the southern region, logistic-regression analyses were performed to develop equations to estimate the probability of zero flow for the six low-flow frequency statistics, and generalized least-squares (GLS) regression analyses were used to develop six equations to estimate nonzero low-flow frequency statistics and WLS regression analysis was used to develop an equation to estimate QAH. The logistic-regression equations should be used to estimate the probability of zero flow for ungaged stream sites in the southern region, before GLS equations are used, if necessary, to estimate nonzero low-flow frequency statistics. If the resulting probability of zero flow is greater than or equal to 0.5, then the value for that low-flow frequency statistic is estimated to be zero flow, and the associated GLS-regression equation should not be used.

Preliminary multiple-linear-regression analyses, using ordinary least-squares regression (OLS), were conducted to test for significant differences among the low-flow regions and to identify the most significant basin characteristics for inclusion in the GLS, WLS, logistic, and left-censored regressions. The final regression analyses included 192 streamgages after 14 additional streamgages were removed from the regression data set. These additional 14 streamgages were removed because they were flagged as outliers in the regression analyses and were identified by field personnel as possibly being affected by alterations of flow.

All 54 basin characteristics measured for each streamgage were determined from digital databases using geographic information system (GIS) software. Ten basin characteristics are used as explanatory variables in the final regression equations; these include three morphometric characteristics: drainage area (DRNAREA), drainage frequency (DRNFREQ), and relative stream density (RSD); three hydrologic characteristics: base-flow index (BFI), annual base-flow-recession time constant (TAU_ANN), and streamflow-variability index (STREAM_VAR); and four pedologic characteristics: hydrologic soil type A (SOILASSURGO), hydrologic soil type B (SOILBSSURGO), hydrologic soil type C (SOILCSSURGO), and average soil permeability (KSATSSUR). Predictive accuracies for the selected low-flow frequency equations developed for each region are indicated by several performance metrics. SEEs for the left-censored equations for the northeast region range from 64.7 to 88.1 percent and for the northwest region range from 85.8 to 111.8 percent. Misclassification percentages for the logistic equations for the southern region range from 5.6 to 14.0 percent. SEPs for GLS equations for the southern region range from 71.1 to 98.9 percent, and the pseudo coefficients of determination (pseudo-R^2) for the GLS equations range from 87.7 to 91.8 percent. SEPs for WLS equations developed to estimate QAH for each of the three regions range from 66.4 to 80.4 percent. Although SEE and SEP performance metrics are not directly comparable between the regional equations, in general, predictive accuracies tend to be the best for the northeast region, second best for the southern region, and poorest for the northwest region. Of the six low-flow frequency equations developed for each region, the M7D10Y1012, M1D10Y1012, and M30D5Y regression equations generally have the best predictive accuracy and the M30D10Y and M7D10Y equations generally have the poorest accuracy.

Two drainage-area ratio (DAR) methods were compared with the regional regression equations using 31 pairs of streamgages to determine the most accurate method to use for ungaged sites on gaged streams in Iowa and to determine the appropriate range of DARs between a streamgage and an ungaged stream site. A simple DAR method, a weighted drainage-are ratio (WDAR) method, and the regional-regression equation (RRE) results were compared to the M7D10Y statistic computed from observed streamflow. Results of the testing indicate the WDAR method is the preferred method because it provides better estimates for the M7D10Y statistic compared to the other two methods for an ungaged site on a gaged stream in Iowa when the DAR is between 0.5 and 1.4.

The regional-regression equations developed in this study are not intended for use at ungaged stream sites in which the basin characteristics are outside the range of those used to develop the equations. Inconsistencies in estimates may result for the frequency equation estimates, if basin-characteristic values approach the minimum or maximum limits of the range. Selected low-flow frequency statistics and harmonic mean flows estimated by the equations represent flow conditions in Iowa not significantly affected by regulation, diversion, or urbanization. The regression equations should be used with caution in areas where low flows are affected by significant gains as a result of large springs or significant losses as a result of sinkholes common to karst topography. If the equations are used at ungaged sites on regulated streams, or on streams affected by water-supply and agricultural withdrawals, then the estimates will need to be adjusted if actual flow conditions are of interest.

GIS software is required to measure the basin characteristics included as explanatory variables in the regression equations. Low-flow frequency estimates calculated from censored regression equations that are 0.1 cubic feet per second (ft^3/s), or lower, should be reported as less than 0.1 ft^3/s. Selected low-flow frequency and harmonic-mean-flow estimates calculated to be lower than 0.1 ft^3/s from GLS regression equations for the southern region or from WLS regression equations for all three low-flow regions, also should be reported as less than 0.1 ft^3/s to maintain a consistent prediction-discharge-reporting limit for Iowa.

All 27 regression equations developed for this study are to be included in the USGS StreamStats Web-based GIS tool. StreamStats will provide users with a set of annual and seasonal low-flow frequency and harmonic-mean-flow estimates for ungaged stream sites within Iowa in addition to the basin characteristics for the sites. Ninety-percent prediction intervals also are automatically calculated. A 90-percent prediction interval denotes there is 90-percent certainty that the true value of a low-flow frequency or harmonic-mean-flow statistic at an ungaged stream site will be within a plus or minus interval around the predicted low-flow frequency or harmonic-mean-flow statistic.

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References Cited

Ahearn, E.A., 2010, Regional regression equations to estimate flow-duration statistics at ungaged stream sites in Connecticut: U.S. Geological Survey Scientific Investigations Report 2010–5052, 45 p. (Also available at *http://pubs.usgs.gov/sir/2010/5052/*.)

Bent, G.C., and Steeves, P.A., 2006, A revised logistic regression equation and an automated procedure for mapping the probability of a stream flowing perennially in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2006–5031, 107 p., 1 CD–ROM. (Also available at *http://pubs.usgs.gov/sir/2006/5031/*.)

Bossong, C.R., Karlinger, M.R., Troutman, B.M., and Vecchia, A.V., 1999, Overview and technical and practical aspects for use of geostatistics in hazardous-, toxic-, and radioactive-waste-site investigations: U.S. Geological Survey Water-Resources Investigations Report 98–4145, 70 p.

Boussinesq, J., 1903, Sur le de'bit, en temps de s'echeresse, d'une source allimente'e par une nappe d' eaux d' infiltration: Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, v. 136, p. 1511–1517.

Brutsaert, W., and Lopez, J.P., 1998, Basin-scale geohydrologic drought flow features of riparian aquifers in the southern Great Plains: Water Resources Research, v. 34, no. 2, p. 233–240, accessed April 7, 2011, at *http://www.agu.org/journals/wr/v034/i002/97WR03068/97WR03068.pdf*.

Brutsaert, W., and Nieber, J.L., 1977, Regionalized drought flow hydrographs from a mature glaciated plateau: Water Resources Research, v. 13, no. 3, p. 637–643, accessed April 7, 2011, at *http://www.agu.org/journals/wr/v013/i003/WR013i003p00637/WR013i003p00637.pdf*.

Burn, D.H., 1990, Evaluation of regional flood frequency analysis with region of influence approach: Water Resources Research, v. 26, no. 10, p. 2257–2265, accessed April 11, 2011, at *http://www.agu.org/journals/wr/v026/i010/WR026i010p02257/WR026i010p02257.pdf*.

Cohn, T.A., 1988, Adjusted maximum likelihood estimation of the moments of lognormal populations from type I censored samples: U.S. Geological Survey Open-File Report 88–350, 34 p.

Cook, R.D., 1977, Detection of influential observation in linear regression: Technometrics, v. 19, p. 15–18, accessed April 7, 2011, at: *http://www.ime.usp.br/~abe/lista/pdfWiH1zqnMHo.pdf*.

Eash, D.A., 2001, Techniques for estimating flood-frequency discharges for streams in Iowa: U.S. Geological Survey Water-Resources Investigations Report 00–4233, 88 p. (Also available at *http://ia.water.usgs.gov/pubs/reports/WRIR_00-4233.pdf*.)

Efroymson, M.A., 1960, Multiple regression analysis, in Ralston, A., and Wilf, H.S., eds., Mathematical methods for digital computers: New York, John Wiley and Sons, Inc., p. 191–203.

Eng, K., and Brutsaert, W., 1999, Generality of drought flow characteristics within the Arkansas River Basin: Journal Geophysical Research, v. 104, no. D16, p. 19435–19441, accessed April 7, 2011, at *http://www.agu.org/journals/jd/v104/iD16/1999JD900087/1999JD900087.pdf*.

Eng, Ken, Tasker, G.D., and Milly, P.C.D., 2005, An analysis of region-of-influence methods for flood regionalization in the Gulf-Atlantic Rolling Plains: Journal of American Water Resources Association, v. 41, no. 1, p. 135–143, accessed April 11, 2011, at *http://water.usgs.gov/nrp/proj.bib/Publications/2005/eng_tasker_etal_2005.pdf*.

Eng, K., and Milly, P.C.D., 2007, Relating low-flow characteristics to the base flow recession time constant at partial record stream gauges: Water Resources Research, v. 43, W01201, doi:10.1029/2006WR005293, accessed April 7, 2011, at *http://www.agu.org/journals/wr/wr0701/2006WR005293/2006WR005293.pdf*.

Eng, Ken, Milly, P.C.D., and Tasker, G.D., 2007, Flood regionalization: a hybrid geographic and predictor-variable region-of-influence regression method: Journal of Hydrologic Engineering, ASCE, v. 12, no. 6, p. 585–591, accessed April 11, 2011, at *http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JHYEFF000012000006000585000001&idtype=cvips&doi=10.1061/(ASCE)1084-0699(2007)12:6(585)&prog=normal*.

Eng, Ken, Chen, Yin-Yu, and Kiang, J.E., 2009, User's guide to the weighted-multiple-linear-regression program (WREG version 1.0): U.S. Geological Survey Techniques and Methods, book 4, chap. A8, 21 p. (Also available at *http://pubs.usgs.gov/tm/tm4a8/*.)

Environmental Systems Research Institute, Inc., 2001, ArcGIS geostatistical analyst, Statistical tools for data exploration, modeling, and advanced surface generation: Redlands, Calif., Environmental Systems Research Institute, Inc., 23 p., accessed April 7, 2011, at *http://www.esri.com/library/whitepapers/pdfs/geostat.pdf*.

Environmental Systems Research Institute, Inc., 2009, ArcGIS desktop help, accessed April 7, 2011, at *http://webhelp.esri.com/arcgisdesktop/9.3*.

Esralew, R.A., and Lewis, J.M., 2010, Trends in base flow, total flow, and base-flow index of selected streams in and near Oklahoma through 2008: U.S. Geological Survey Scientific Investigations Report 2010–5104, 143 p. (Also available at *http://pubs.usgs.gov/sir/2010/5104/*.)

Flynn, K.M., Hummel, P.R., Lumb, A.M., and Kittle, J.L., Jr., 1995, User's manual for ANNIE, version 2, a computer program for interactive hydrologic data management: U.S. Geological Survey Water-Resources Investigations Report 95–4085, 211 p. (Also available at *http://water.usgs.gov/software/ANNIE/*.)

Funkhouser, J.E., Eng, K., and Moix, M.W., 2008, Low-flow characteristics and regionalization of low-flow characteristics for selected streams in Arkansas: U.S. Geological Survey Scientific Investigations Report 2008–5065, 161 p. (Also available at *http://pubs.usgs.gov/sir/2008/5065/*.)

Gesch, D.B., 2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model technologies and applications: The DEM Users Manual, 2d ed.: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99–118, accessed April 7, 2011, at *http://topotools.cr.usgs.gov/pdfs/Gesch_Chp_4_Nat_Elev_Data_2007.pdf, see also http://ned.usgs.gov/*.

Griffis, V.W., and Stedinger, J.R., 2007, The use of GLS regression in regional hydrologic analyses: Journal of Hydrology, v. 344, p. 82–95, accessed April 8, 2011, at *http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V6C-4P4FVB6-5&_user=696292&_coverDate=09%2F30%2F2007&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1710990029&_rerunOrigin=google&_acct=C000038819&_version=1&_urlVersion=0&_userid=696292&md5=184db778bae1da5c1274cb01de303855&searchtype=a*.

Heinitz, A.J., 1970, Low-flow characteristics of Iowa streams through 1966: Iowa Natural Resources Council Bulletin, no. 10, 176 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p. (Also available at *http://pubs.usgs.gov/twri/twri4a3/html/pdf_new.html*.)

Homer, Collin, Huang, Chengquan, Yang, Limin, Wylie, Bruce, and Coan, Michael, 2004, *Development of a 2001 National Land-Cover Database for the United States: Photogrammetric Engineering and Remote Sensing*, v. 70, no. 7, July 2004, p. 829–840, accessed April 7, 2011, at *http://www.mrlc.gov/pdf/July_PERS.pdf*, also see *http://www.mrlc.gov/index.php*.

Horick, P.J., and Soenksen, P.J., 1989, Water resources of northeast Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Water Atlas 8, 133 p., accessed April 8, 2011, at *http://www.igsb.uiowa.edu/Mapping/abstract/wa8.htm*.

Hortness, J.E., 2006, Estimating low-flow frequency statistics for unregulated streams in Idaho: U.S. Geological Survey Scientific Investigations Report 2006–5035, 31 p. (Also available at *http://pubs.usgs.gov/sir/2006/5035/*.)

Iman, R.L., and Conover, W.J., 1983, A modern approach to statistics: New York, John Wiley and Sons, Inc., 497 p.

Institute of Hydrology, 1980a, Low flow studies: Wallingford, Oxon, United Kingdom, Report no. 1, 41 p.

Institute of Hydrology, 1980b, Low flow studies: Wallingford, Oxon, United Kingdom, Report no. 3, p. 12–19.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Reston, Va., Hydrology Subcommittee Bulletin 17B, 28 p. and appendixes, accessed April 7, 2011, at *http://water.usgs.gov/osw/bulletin17b/dl_flow.pdf*.

Iowa Department of Natural Resources and the U.S. Environmental Protection Agency, 2010, The FINAL 2010 Iowa list of Section 303(d) Impaired Waters: Technical Fact Sheet, accessed February 29, 2012, at *http://www.iowadnr.gov/Portals/idnr/uploads/watermonitoring/impairedwaters/2010/Fact%20Sheet%20for%20Final-approved%202010%20list.pdf*.

Iowa Natural Resources Council, 1958, An inventory of water resources and water problems, northeastern Iowa river basins: Des Moines, Iowa, Iowa Natural Resources Council Bulletin, no. 7, 74 p.

Koltun, G.F., and Schwartz, R.R., 1986, Multiple-regression equations for estimating low flows at ungaged stream sites in Ohio: U.S. Geological Survey Water-Resources Investigations Report 86–4354, 39 p., 6 pls. (Also available at *http://pubs.er.usgs.gov/publication/wri864354*.)

Koltun, G.F., and Whitehead, M.T., 2002, Techniques for estimating selected streamflow characteristics of rural, unregulated streams in Ohio: U.S. Geological Survey Water-Resources Investigations Report 02–4068, 50 p. (Also available at *http://oh.water.usgs.gov/reports/wrir/wrir02-4068.pdf*.)

Kroll, C.N., and Stedinger, J.R., 1996, Estimation of moments and quantiles using censored data: Water Resources Research, v. 32, no. 4, p. 1005–1012, accessed April 8, 2011, at *http://www.esf.edu/ere/kroll/estimation_of_moments_cencosred_data.pdf*.

Kroll, C.N., and Vogel, R.M., 2002, Probability distribution of low streamflow series in the United States: Journal of Hydrologic Engineering, v. 7, no. 2, p. 137–146, accessed April 8, 2011, at *http://engineering.tufts.edu/cee/people/vogel/publications/probability-low.pdf*.

Kroll, Chuck, Luz, Joana, Allen, Brad, Vogel, R.M., 2004, Developing a watershed characteristics database to improve low streamflow prediction: Journal of Hydrologic Engineering, v. 9, no. 2, p. 116–125, accessed April 11, 2011, at *http://www.esf.edu/ere/kroll/developingDatabase.pdf*.

Lane, E.W., and Lei, Kai, 1950, Stream flow variability: Proceedings of American Society of Civil Engineers, Transactions, v. 115, p. 1084–1134.

Lara, O.G., 1979, Annual and seasonal low-flow characteristics of Iowa streams: U.S. Geological Survey Open-File Report 79–555, Iowa Natural Resources Council Bulletin, no. 13, 507 p., accessed April 7, 2011, Plates 3 and 4 available at *ftp://ftp.igsb.uiowa.edu/gis_library/IA_State/Hydrologic/Surface_Waters/USGS_stream_low_flow_Plate3.html* and *ftp://ftp.igsb.uiowa.edu/gis_library/IA_State/Hydrologic/Surface_Waters/USGS_stream_low_flow_Plate4.html*.

Lins, Harry, 2005, Streamflow trends in the United States: U.S. Geological Fact Sheet 2005–3017, 4 p. (Also available at *http://pubs.usgs.gov/fs/2005/3017/*.)

Lorenz, D.L., and others, 2011, USGS library for S–PLUS for windows—Release 4.0: U.S. Geological Survey Open-File Report 2011–1130, accessed February 7, 2012, at *http://water.usgs.gov/software/S-PLUS/*.

Ludwig, A.H., and Tasker, G.D., 1993, Regionalization of low flow characteristics of Arkansas streams: U.S. Geological Survey Water-Resources Investigations Report 93–4013, 19 p. (Also available at *http://pubs.usgs.gov/wri/1993/4013/report.pdf* .)

Lumb, A.M., Kittle, J.L., Jr., and Flynn, K.M., 1990, Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89–4080, 236 p. (Also available at *http://water.usgs.gov/software/ANNIE/*.)

Marquardt, D.W., 1970, Generalized inverses, ridge regression, biased linear estimation, and nonlinear estimation: Technometrics, v. 12, no. 3, p. 591–612, accessed April 11, 2011, at *http://www.jstor.org/stable/1267205*.

Martin, G.R., and Arihood, L.D., 2010, Methods for estimating selected low-flow frequency statistics for unregulated streams in Kentucky: U.S. Geological Survey Scientific Investigations Report 2010–5217, 83 p. (Also available at *http://pubs.usgs.gov/sir/2010/5217/*.)

Martin, G.R., and Ruhl, K.J., 1993, Regionalization of harmonic-mean streamflows in Kentucky: U.S. Geological Survey Water-Resources Investigations Report 92–4173, 47 p., 1 pl. (Also available at *http://pubs.usgs.gov/wri/wri924173/index.html#pdf*.)

McCabe, G.J., and Wolock, D.M., 2002. A step increase in streamflow in the conterminous United States: Geophysical Research Letter, v. 29, p. 2185–2188. (Also available at *http://ks.water.usgs.gov/pubs/reports/dmw.grl.v29.html*.)

Miller, A.M., and Golladay, S.W., 1996, Effects of spates and drying on macroinvertebrate assemblages of an intermittent and a perennial stream: Journal of North American Benthological Society, v. 15, no. 4, p. 670–689, accessed June 7, 2011, at *http://www.jstor.org/sici?sici=0887-3593%28199612%2915%3A4%3C670%3AEOSADO%3E2.0.CO%3B2-9&*.

Multi-Resolution Land Characteristics Consortium (MRLC), 2012, National Land Cover Database (NLCD): accessed May 1, 2012, at *http://www.mrlc.gov/index.php*.

National Climatic Data Center, 2012, Climate of Iowa, accessed April 30, 2012, at *http://www.crh.noaa.gov/images/dvn/downloads/Clim_IA_01.pdf*.

National Cooperative Soil Survey and Natural Resources Conservation Service, 2012, Iowa Soil Regions Based on Parent Materials, accessed August 15, 2012, at *ftp://ftp-fc.sc.egov.usda.gov/IA/technical/IowaSoilRegionsMap.html*.

Oschwald, W.R., Riecken, F.F., Dideriksen, R.I., Scholtes, W.H., and Schaller, F.W., 1965, Principal soils of Iowa: Ames, Iowa, Iowa State University, Department of Agronomy, Special Report, no. 42, 77 p.

Pettyjohn, W.A., and Henning, Roger, 1979, Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio: Ohio State University Water Resources Center Project Completion Report Number 552, 323 p., accessed April 7, 2011, at *https://kb.osu.edu/dspace/bitstream/1811/36354/1/OH_WRC_552.pdf*.

Prior, J.C., 1991, Landforms of Iowa: Iowa City, University of Iowa Press, 154 p. , accessed April 7, 2011, at *http://www.igsb.uiowa.edu/Browse/landform.htm*.

Prior, J.C., Kohrt, C.J., and Quade, D.J., 2009, The landform regions of Iowa, vector digital data: Iowa Geological Survey, Iowa Department of Natural Resources, Iowa City, Iowa, accessed April 7, 2011, at *ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/geologic/landform/landform_regions.zip*.

PRISM Climate Group, 2008, Normal annual precipitation grid for the conterminous United States, accessed April 7, 2011, at *http://www.prism.oregonstate.edu/state_products/maps.phtml?id=US*, also see *http://www.prism.oregonstate.edu/pub/prism/docs/prisguid.pdf*.

Riggs, H.C., 1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. B1, 18 p. , accessed April 7, 2011, at *http://pubs.usgs.gov/twri/twri4b1/index.html*.

Ries, K.G., and Friesz, P.J., 2000, Methods for estimating low-flow statistics for Massachusetts streams: U.S. Geological Survey Water-Resources Investigations Report 00–4135, 81 p. (Also available at *http://pubs.usgs.gov/wri/wri004135/*.)

Risley, John, Stonewall, Adam, and Haluska, Tana, 2008, Estimating flow-duration and low-flow frequency statistics for unregulated streams in Oregon: U.S. Geological Survey Scientific Investigations Report 2008–5126, 22 p. (Also available at *http://pubs.usgs.gov/sir/2008/5126/*.)

Rossman, L.A., 1990a, Design stream flows based on harmonic means: Journal of Hydraulic Engineering, v. 116, no. 7, p. 946–950.

Rossman, L.A., 1990b, DFLOW user's manual: Cincinnati, Ohio, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, 26 p. , accessed April 7, 2011, at *http://nepis.epa.gov/Exe/ZyNET.exe/30001JEH.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1986+Thru+1990&Docs=&Query=600890051%20or%20dflow%20or%20user's%20or%20manual%20or%20rossman&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=pubnumber%5E%22600890051%22&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=pubnumber&IntQFieldOp=1&ExtQFieldOp=1&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C86thru90%5CTxt%5C00000005%5C30001JEH.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=10&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL*.

Rowden, R.D., Libra, R.D., and Hallberg, G.R., 1995, Surface water monitoring in the Big Spring Basin 1986–1992, A summary review: Iowa Department of Natural Resources Geological Survey Bureau Technical Information Series 33, 109 p., accessed April 8, 2011, at *http://www.igsb.uiowa.edu/webapps/gsbpubs/pdf/TIS-33.pdf*.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load estimator (LOADEST): A FORTRAN program for estimating constituents loads in streams and rivers: U.S. Geological Survey Techniques and Methods, book 4, chap. A5, 69 p. (Also available online at *http://pubs.usgs.gov/tm/2005/tm4A5/pdf/508final.pdf*.)

Schilling, K.E., 2005, Relation of baseflow to row crop intensity in Iowa: Agriculture, Ecosystems and Environment, v. 105, no. 1–2, p. 433–438, accessed April 7, 2011, at *http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T3Y-4CPD8FG-3&_user=696292&_coverDate=01%2F31%2F2005&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1709861362&_rerunOrigin=google&_acct=C000038819&_version=1&_urlVersion=0&_userid=696292&md5=83e59e04aff6fff8afbfdb57a097318c&searchtype=a*.

Schilling, K.E., and Libra, R.D., 2003, Increased baseflow in Iowa over the second half of the 20th century: Journal of American Water Resources Association, v. 39, no. 4, p. 851–860, accessed April 7, 2011, at *http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2003.tb04410.x/pdf*.

Schwob, H.H., 1958, Low-flow characteristics of Iowa streams: Iowa Natural Resources Council Bulletin, no. 9, 111 p.

Searcy, J.M., 1959, Flow-duration curves, manual of hydrology—Part 2, low-flow techniques: U.S. Geological Survey Water Supply Paper 1542–A, 33 p. (Also available at *http://pubs.er.usgs.gov/publication/wsp1542A*.)

Simley, J.D., and Carswell, W.J., Jr., 2009, The National Map—Hydrography: U.S. Geological Survey Fact Sheet 2009–3054, 4 p. (Also available at *http://pubs.usgs.gov/fs/2009/3054/*, also see *http://nhd.usgs.gov/*.)

Sloto, R.A., and Crouse, M.Y., 1996, HYSEP, A computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96–4010, 46 p. (Also available at *http://pubs.usgs.gov/wri/1996/4040/report.pdf*.)

Smakhtin, V.U., 2001, Low flow hydrology, a review: Journal of Hydrology, v. 240, Issues 3–4, p. 147–186, accessed April 7, 2011, at *http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V6C-420SJJR-1&_user=696292&_coverDate=01%2F10%2F2001&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1709981733&_rerunOrigin=google&_acct=C000038819&_version=1&_urlVersion=0&_userid=696292&md5=4d5b6240162e8bcbd48f6b59d936e55f&searchtype=a*.

Small, David, Islam, Shafiqul, and Vogel, R.M., 2006, Trends in precipitation and streamflow in the eastern U.S., Paradox or perception?: Geophysical Research Letters, v. 33, LO3403, 4 p., accessed April 7, 2011, at *http://engineering.tufts.edu/cee/people/vogel/publications/trends-streamflow.pdf*.

Soenksen, P.J., and Eash, D.A., 1991, Iowa floods and droughts, in National Water Summary 1988–89—Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2375. (Also available at *http://pubs.er.usgs.gov/publication/wsp2375*.)

Soil Survey Staff, 2012, Natural Resources Conservation Service, U.S. Department of Agriculture, Soil Survey Geographic (SSURGO) Database for all counties included in study area shown in figure 1, accessed April 30, 2012, at *http://soildatamart.nrcs.usda.gov/*.

Stedinger, J.R. and Tasker, G.D., 1985, Regional hydrologic analysis 1—Ordinary, weighted, and generalized least square compared: Water Resources Research, v. 21, no. 9, p. 1421–1432, accessed April 8, 2011, at *http://www.agu.org/journals/wr/v021/i009/WR021i009p01421/WR021i009p01421.pdf*.

Straub, D.E., 2001, Low-flow characteristics of streams in Ohio through water year 1997: U.S. Geological Survey Water-Resources Investigations Report 01–4140, 415 p. (Also available at *http://oh.water.usgs.gov/reports/wrir/wrir01-4140.pdf*.)

Tasker, G.D., 1980, Hydrologic regression with weighted least squares: Water Resources Research, v. 16, no. 6, p. 1107–1113, accessed April 8, 2011, at *http://www.agu.org/journals/wr/v016/i006/WR016i006p01107/WR016i006p01107.pdf*.

Tasker, G.D., and Driver, N.E., 1988, Nationwide regression models for predicting urban runoff water quality at unmonitored sites: Water Resources Bulletin, v. 24, no. 5, p. 1091–1101, accessed April 8, 2011, at *http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.1988.tb03026.x/pdf*.

Tasker, G.D., and Stedinger, J.R., 1989, An operational GLS model for hydrologic regression: Journal of Hydrology, v. 111, p. 361–375, accessed April 8, 2011, at *http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V6C-487DD3J-SK&_user=696292&_coverDate=12%2F31%2F1989&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1710988392&_rerunOrigin=google&_acct=C000038819&_version=1&_urlVersion=0&_userid=696292&md5=f5f3116e25045e16b991f7d08c4f4603&searchtype=a*.

TIBCO Software Inc., 2008, TIBCO Spotfire S+ 8.1 for Windows® User's Guide: Palo Alto, Calif., 582 p., accessed May 1, 2012, at *http://www.msi.co.jp/splus/support/download/V81/getstart.pdf*

U.S. Department of Agriculture, Natural Resources Conservation Service, 2012, Geospatial data gateway: U.S. Department of Agriculture, accessed March 30, 2012, at *http://datagateway.nrcs.usda.gov/*.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2012, Soil data mart: U.S. Department of Agriculture, accessed May 1, 2012, at *http://soildatamart.nrcs.usda.gov/SDM%20Web%20Application/default.aspx*.

U.S. Environmental Protection Agency, 2011, accessed February 29, 2012, at *http://www.iowadnr.gov/Portals/idnr/uploads/watermonitoring/impairedwaters/2010/IA%202010%20Integrated%20Report_Cat-5_30Jun2011.pdf*.

U.S. Geological Survey, 2012, National hydrography dataset: U.S. Geological Survey, accessed April 30, 2012, at *http://nhd.usgs.gov/*.

U.S. Geological Survey, 2012, National elevation dataset: U.S. Geological Survey, accessed April 30, 2012, at *http://ned.usgs.gov/*.

U.S. Geological Survey, 2012, Welcome to StreamStats: U.S. Geological Survey, accessed April 30, 2012, at *http://water.usgs.gov/osw/streamstats/index.html, also see http://water.usgs.gov/osw/streamstats/bcdefinitions1.html*.

U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2009, Federal guidelines, requirements, and procedures for the National Watershed Boundary Dataset: U.S. Geological Survey Techniques and Methods 11–A3, 55 p. (Also available at *http://pubs.usgs.gov/tm/tm11a3/*, also see *http://datagateway.nrcs.usda.gov/*).

Wahl, K.L., and Wahl, T.L., 1988, Effects of regional groundwater level declines on streamflow in the Oklahoma Panhandle, *in* Proceedings of the Symposium on Water-Use Data for Water Resources Management: American Water Resources Association, August 1988, Tucson, Ariz., p. 239–249, accessed April 7, 2011, at *http://www.usbr.gov/pmts/hydraulics_lab/twahl/bfi/bfi_beaver_river.pdf*.

Wahl, K.L., and Wahl, T.L., 1995, Determining the flow of Comal Springs at New Braunfels, Texas: Texas Water '95, American Society of Civil Engineers Symposium, August 16–17, 1995, San Antonio, Texas, p. 77–86, accessed April 7, 2011, at *http://www.usbr.gov/pmts/hydraulics_lab/pubs/PAP/PAP-0708.pdf*.

Table 1. Description of streamgages located in Iowa and in neighboring States within a 50-mile buffer of Iowa that were evaluated for use in the low-flow frequency and harmonic-mean-flow regressions for Iowa.

[USGS, U.S. Geological Survey; mi², square miles; Minn., Minnesota; Wis., Wisconsin; Ill., Illinois; NU, streamgage not used in development of regional-regression equations; Mo., Missouri, Nebr., Nebraska; S. Dak., South Dakota. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Streamgage name	Low-flow region	Published drainage area (mi²)	Entire period of record	Period of record used for low–flow study	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used in low-flow study (Apr. 1 to Mar. 31)	Number of years of fall record used in study (Oct. 1 to Dec. 31)
1	05319500	Watonwan River near Garden City, Minn.	Northwest	851	3/1/40–9/30/45, 9/1/76–9/30/06	4/1/77–9/30/06	44.0464	94.1951	29	29
2	05320500	Le Sueur River near Rapidan, Minn.	Northwest	1,110	10/1/39–9/30/45, 8/1/49–9/30/06	4/1/70–9/30/06	44.1111	94.0411	36	36
3	05376000	North Fork Whitewater River near Elba, Minn.	Northeast	101	10/1/39–9/30/41, 7/1/67–10/12/93	4/1/69–9/30/93	44.0917	92.0658	24	24
4	05378300	Straight Valley Creek near Rollingstone, Minn.	Northeast	5.16	10/1/70–9/30/85	10/1/70–9/30/85	44.0858	91.8428	14	15
5	05384000	Root River near Lanesboro, Minn.	Northeast	615	2/1/10–9/30/17, 8/1/40–9/30/90	4/1/69–9/30/90	43.7494	91.9786	19	20
6	05384500	Rush Creek near Rushford, Minn.	Northeast	132	9/1/42–9/30/79	4/1/69–9/30/79	43.8333	91.7778	10	10
7	05385000	Root River near Houston, Minn.	Northeast	1,250	10/1/09–9/30/17, 5/1/29–11/22/83, 10/1/90–9/30/00, 1/1/04–9/30/06	4/1/78–9/30/06	43.7686	91.5697	16	17
8	05385500	South Fork Root River near Houston, Minn.	Northeast	275	1/1/53–11/22/83	4/1/70–11/22/83	43.7386	91.5639	13	13
9	05387500	Upper Iowa River at Decorah, Iowa	Northeast	511	10/1/51–11/1/83, 10/1/02–9/30/06	4/1/65–11/1/83, 10/1/02–9/30/06	43.3047	91.7951	21	22
10	05388250	Upper Iowa River near Dorchester, Iowa	Northeast	770	10/1/38–9/30/39, 7/1/75–9/30/06	4/1/76–9/30/06	43.4211	91.5086	30	30
11	05388500	Paint Creek at Waterville, Iowa	Northeast	42.8	10/1/52–9/30/73	4/1/63–9/30/73	43.2103	91.3058	10	10
12	05389400	Bloody Run Creek near Marquette, Iowa	Northeast	34.13	10/1/91–9/30/06	10/1/91–9/30/06	43.0408	91.2063	14	15
13	05410490	Kickapoo River at Steuben, Wis.	Northeast	687	5/23/33–9/30/06	4/1/66–9/30/06	43.1828	90.8584	40	40
14	05411400	Sny Magill Creek near Clayton, Iowa	Northeast	27.6	10/1/91–10/8/01	10/1/91–10/8/01	42.9486	91.1861	9	10
15	05411600	Turkey River at Spillville, Iowa	Northeast	177	6/4/56–9/30/73, 10/1/77–4/14/92	4/1/62–9/30/73, 10/1/77–3/31/92	43.2069	91.9500	24	25
16	05412060	Silver Creek near Luana, Iowa	Northeast	4.39	5/13/86–9/30/98	5/13/86–9/30/98	43.0220	91.4892	11	12

Table 1. Description of streamgages located in Iowa and in neighboring States within a 50-mile buffer of Iowa that were evaluated for use in the low-flow frequency and harmonic-mean-flow regressions for Iowa.—Continued

[USGS, U.S. Geological Survey; mi², square miles; Minn., Minnesota; Wis., Wisconsin; Ill., Illinois; NU, streamgage not used in development of regional-regression equations; Mo., Missouri, Nebr., Nebraska; S. Dak., South Dakota. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Streamgage name	Low-flow region	Published drainage area (mi^2)	Entire period of record	Period of record used for low–flow study	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used in low-flow study (Apr. 1 to Mar. 31)	Number of years of fall record used in study (Oct. 1 to Dec. 31)
17	05412100	Roberts Creek above Saint Olaf, Iowa	Northeast	70.7	3/25/86–10/8/01	3/25/86–10/8/01	42.9303	91.3842	15	15
18	05412500	Turkey River at Garber, Iowa	Northeast	1,545	8/8/13–11/30/16, 5/14/19–9/30/27, 4/24/29–9/30/30, 10/1/32–9/30/06	4/1/59–9/30/06	42.7400	91.2617	47	47
19	05414500	Little Maquoketa River near Durango, Iowa	Northeast	130	10/1/34–2/9/82	4/1/58–12/31/81	42.5550	90.7461	23	24
20	05414820	Sinsinawa River near Menominee, Ill.	Northeast	39.6	10/1/67–9/30/06	10/1/67–9/30/06	42.4786	90.4867	38	39
21	05417000	Maquoketa River near Manchester, Iowa	Northeast	305	4/25/33–9/30/73	4/1/59–9/30/73	42.4561	91.4322	14	14
22	05417700	Bear Creek near Monmouth, Iowa	Northeast	61.3	10/1/57–9/30/76	10/1/57–9/30/76	42.0394	90.8825	18	19
23	05418450	North Fork Maquoketa River at Fulton, Iowa	Northeast	516	7/1/77–1/5/93	7/1/77–1/5/93	42.1467	90.6758	14	15
24	05418500	Maquoketa River near Maquoketa, Iowa	Northeast	1,553	9/1/13–9/30/06	4/1/57–9/30/06	42.0833	90.6328	49	49
25	05420000	Plum River below Carroll Creek near Savanna, Ill.	Northeast	230	10/1/40–10/5/77	4/1/64–9/30/77	42.1142	90.0928	13	13
26	05420560	Wapsipinicon River near Elma, Iowa	Northeast	95.2	10/1/58–9/30/92	10/1/58–9/30/92	43.2414	92.5328	33	34
27	05421000	Wapsipinicon River at Independence, Iowa	Northeast	1,048	7/1/33–9/30/06	4/1/57–9/30/06	42.4636	91.8950	49	49
28	05422000	Wapsipinicon River near De Witt, Iowa	Northeast	2,336	7/27/34–9/30/06	4/1/56–9/30/06	41.7669	90.5347	50	50
29	05422470	Crow Creek at Bettendorf, Iowa	NU	17.8	10/1/77–9/30/06	10/1/77–9/30/06	41.5511	90.4550	28	29
30	05422560	Duck Creek at 110th Ave at Davenport, Iowa	Southern	16.1	3/29/94–9/30/06	3/29/94–9/30/06	41.5567	90.6876	12	12
31	05422600	Duck Creek at DC Golf Course at Davenport, Iowa	Southern	57.3	11/24/93–9/30/06	11/24/93–9/30/06	41.5461	90.5239	12	12
32	05435500	Pecatonica River at Freeport, Ill.	Northeast	1,326	9/11/14–9/30/06	4/1/66–9/30/06	42.3028	89.6195	40	40
33	05444000	Elkhorn Creek near Penrose, Ill.	Northeast	146	10/1/39–9/30/06	4/1/66–9/30/06	41.9028	89.6960	40	40

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34	05448000	Mill Creek at Milan, Ill.	Southern	62.4	10/1/39–9/30/06	4/1/56–9/30/06	41.4422	90.5558	47	47
35	05449000	East Branch Iowa River near Klemme, Iowa	Northwest	133	4/148–11/5/95	4/1/64–3/31/95	43.0095	93.6278	29	30
36	05449500	Iowa River near Rowan, Iowa	Northwest	418	10/1/40–9/30/06	4/1/64–9/30/06	42.7597	93.6214	40	41
37	05451210	South Fork Iowa River NE of New Providence, Iowa	Northeast	224	10/25/95–9/30/06	10/25/95–9/30/06	42.3153	93.1520	10	11
38	05451500	Iowa River at Marshalltown, Iowa	Southern	1,532	10/1/1902–9/30/1903, 10/1/14–9/30/27, 10/1/32–9/30/06	4/1/57–9/30/06	42.0658	92.9077	49	49
39	05451700	Timber Creek near Marshalltown, Iowa	Southern	118	10/1/49–9/30/06	4/1/56–9/30/06	42.0089	92.8522	50	50
40	05451900	Richland Creek near Haven, Iowa	Southern	56.1	10/1/49–9/30/06	4/1/58–9/30/06	41.8994	92.4742	48	48
41	05452000	Salt Creek near Elberon, Iowa	Northeast	201	10/1/45–9/30/06	4/1/55–9/30/06	41.9642	92.3131	51	51
42	05452200	Walnut Creek near Hartwick, Iowa	Southern	70.9	10/1/49–9/30/06	4/1/56–9/30/06	41.8350	92.3861	50	50
43	05453000	Big Bear Creek at Ladora, Iowa	Southern	189	10/1/45–9/30/06	4/1/58–9/30/06	41.7494	92.1819	48	48
44	05453100	Iowa River at Marengo, Iowa	Southern	2,794	10/1/56–9/30/06	10/1/56–9/30/06	41.8125	92.0645	49	50
45	05454000	Rapid Creek near Iowa City, Iowa	Southern	25.3	10/1/37–9/30/06	4/1/56–9/30/06	41.7000	91.4877	50	50
46	05454220	Clear Creek near Oxford, Iowa	Southern	58.4	11/4/93–9/30/06	11/4/93–9/30/06	41.7183	91.7400	12	12
47	05454300	Clear Creek near Coralville, Iowa	Southern	98.1	10/1/52–9/30/06	4/1/57–9/30/06	41.6767	91.5986	49	49
48	05455000	Ralston Creek at Iowa City, Iowa	Southern	3.01	9/1/24–9/30/87	4/1/56–9/30/87	41.6639	91.5133	31	31
49	05455010	South Branch Ralston Creek at Iowa City, Iowa	Southern	2.94	10/1/63–3/8/98	10/1/63–3/8/98	41.6514	91.5075	31	33
50	05455100	Old Mans Creek near Iowa City, Iowa	Southern	201	10/1/50–9/30/64, 10/1/84–9/30/06	4/1/56–9/30/06	41.6064	91.6156	29	30
51	05455500	English River at Kalona, Iowa	Southern	574	9/13/39–9/30/06	4/1/53–9/30/06	41.4697	91.7144	53	53
52	05457000	Cedar River near Austin, Minn.	Northeast	399	6/1/09–9/30/14, 10/1/44–9/30/06	4/1/71–9/30/06	43.6364	92.9739	35	35
53	05457700	Cedar River at Charles City, Iowa	Northeast	1,054	10/1/64–9/30/06	10/1/64–9/30/06	43.0625	92.6731	35	38
54	05458000	Little Cedar River near Ionia, Iowa	Northeast	306	10/1/54–9/30/06	4/1/58–9/30/06	43.0331	92.5033	48	48

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55	05458500	Cedar River at Janesville, Iowa	Northeast	1,661	10/1/04–9/30/06, 10/1/14–9/30/27, 10/1/32–9/30/42, 10/1/45–9/30/06	4/1/64–9/30/06	42.6483	92.4650	42	42
56	05458900	West Fork Cedar River at Finchford, Iowa	Northeast	846	10/1/45–9/30/06	4/1/61–9/30/06	42.6294	92.5433	45	45
57	05459000	Shell Rock River near Northwood, Iowa	Northeast	300	10/1/45–9/30/86	4/1/60–9/30/86	43.4142	93.2206	26	26
58	05459500	Winnebago River at Mason City, Iowa	Northwest	526	10/1/32–9/30/06	4/1/58–9/30/06	43.1650	93.1925	48	48
59	05462000	Shell Rock River at Shell Rock, Iowa	Northeast	1,746	6/11/53–9/30/06	4/1/65–9/30/06	42.7119	92.5828	41	41
60	05463000	Beaver Creek at New Hartford, Iowa	Northeast	347	10/1/45–9/30/06	4/1/57–9/30/06	42.5728	92.6178	49	49
61	05463500	Black Hawk Creek at Hudson IA	Northeast	303	4/1/52–9/30/95, 9/7/01–9/30/06	4/1/57–9/30/06	42.4078	92.4631	42	43
62	05464000	Cedar River at Waterloo, Iowa	Northeast	5,146	10/1/40–9/30/06	4/1/59–9/30/06	42.4956	92.3342	47	47
63	05464130	Fourmile Creek near Lincoln, Iowa	Northeast	13.78	10/1/62–9/30/67, 10/1/69–9/30/80	10/1/62–9/30/67, 10/1/69–9/30/80	42.2256	92.6108	11	14
64	05464133	Half Mile Creek near Gladbrook, Iowa	Northeast	1.33	10/1/62–9/30/67, 10/1/69–9/30/80	10/1/62–9/30/67, 10/1/69–9/30/80	42.2111	92.6108	11	14
65	05464137	Fourmile Creek near Traer, Iowa	Northeast	19.51	10/1/ 62–1/13/81	10/1/ 62–1/13/81	42.2020	92.5622	15	18
66	05464500	Cedar River at Cedar Rapids, Iowa	Northeast	6,510	10/1/1902–9/30/2006	4/1/58–9/30/06	41.9719	91.6669	48	48
67	05464640	Prairie Creek at Fairfax, Iowa	Southern	178	10/1/66–9/30/82	10/1/66–9/30/82	41.9228	91.7839	15	16
68	05465000	Cedar River near Conesville, Iowa	Southern	7,787	9/16/39–9/30/06	4/1/56–9/30/06	41.4092	91.2903	50	50
69	05465500	Iowa River at Wapello, Iowa	NU	12,500	10/1/14–9/30/06	4/1/57–9/30/06	41.1781	91.1819	49	49
70	05466000	Edwards River near Orion, Ill.	Southern	155	10/1/40–9/30/06	10/1/40–9/30/06	41.2720	90.3777	65	66
71	05466500	Edwards River near New Boston, Ill.	Southern	445	10/1/34–9/30/06	4/1/41–9/30/06	41.1870	90.9672	65	65
72	05467000	Pope Creek near Keithsburg, Ill.	Southern	174	10/1/34–9/30/06	4/1/56–9/30/06	41.1289	90.9192	44	45
73	05468500	Cedar Creek at Little York, Ill.	Southern	132	10/1/40–10/5/71	4/1/60–9/30/71	41.0139	90.7458	11	11

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74	05469000	Henderson Creek near Oquawka, Ill.	Southern	432	10/1/34–9/30–06	4/1/55–9/30/06	41.0014	90.8542	49	50
75	05469500	South Henderson Creek at Biggsville, Ill.	Southern	82.9	10/1/39–9/30/71	4/1/57–9/30/71	40.8569	90.8639	14	14
76	05470000	South Skunk River near Ames, Iowa	Northwest	315	7/28/20–9/30/27, 10/1/32–10/3/95, 9/28/96–9/30/06	4/1/54–9/30/06	42.0683	93.6192	50	51
77	05470500	Squaw Creek at Ames, Iowa	Northwest	204	5/24/19–9/30/27, 5/24/65–9/30/06	4/1/66–9/30/06	42.0231	93.6303	40	40
78	05471000	South Skunk River below Squaw Creek near Ames, Iowa	NU	556	10/1/52–12/7/79, 10/1/91–9/30/06	4/1/54–12/7/79, 10/1/91–9/30/06	42.0067	93.5953	39	40
79	05471040	Squaw Creek near Colfax, Iowa	Southern	18.4	05/10/95–3/06/06	05/10/95–3/06/06	41.6592	93.2706	9	11
80	05471050	South Skunk River at Colfax, Iowa	Southern	803	10/01/85–9/30/06	10/01/85–9/30/06	41.6814	93.2464	20	21
81	05471200	Indian Creek near Mingo, Iowa	Northwest	276	5/22/58–9/30/75, 10/1/85–9/30/06	5/22/58–9/30/75, 10/1/85–9/30/06	41.8053	93.3092	36	38
82	05471500	South Skunk River near Oskaloosa, Iowa	Southern	1,635	10/1/45–9/30/06	4/1/54–9/30/06	41.3556	92.6569	52	52
83	05472500	North Skunk River near Sigourney, Iowa	Southern	730	10/1/45–9/30/06	4/1/54–9/30/06	41.3008	92.2044	52	52
84	05473400	Cedar Creek near Oakland Mills, Iowa	Southern	533	7/1/77–9/30/06	7/1/77–9/30/06	40.9253	91.6739	28	29
85	05473500	Big Creek near Mount Pleasant, Iowa	Southern	106	10/1/55–10/9/79	10/1/55–10/9/79	41.0158	91.5803	23	24
86	05474000	Skunk River at Augusta, Iowa	Southern	4,312	9/30/13–9/30/06	4/1/54–9/30/06	40.7536	91.2770	52	52
87	05476000	Des Moines River at Jackson, Minn.	NU	1,250	6/1/09–11/30/13, 9/1/30–9/30/06	4/1/59–9/30/06	43.6194	94.9861	47	47
88	05476500	Des Moines River at Estherville, Iowa	Northwest	1,372	10/1/51–1/10/97, 6/20/98, 12/1/00–12/6/00, 5/4/03–2/5/04	4/1/60–12/31/03	43.3975	94.8439	35	37
89	05476750	Des Moines River at Humboldt, Iowa	Northwest	2,256	10/1/64–9/30/06	10/1/64–9/30/06	42.7194	94.2203	41	42

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90	05478000	East Fork Des Moines River near Burt, Iowa	Northwest	462	10/1/51–9/30/74	4/1/60–9/30/74	43.2111	94.1775	14	14
91	05479000	East Fork Des Moines River at Dakota City, Iowa	Northwest	1,308	3/1/40–9/30/06	4/1/60–9/30/06	42.7236	94.1931	46	46
92	05480000	Lizard Creek near Clare, Iowa.	Northwest	257	3/6/40–1/29/82	4/1/64–12/31/81	42.5453	94.3464	17	18
93	05480500	Des Moines River at Fort Dodge, Iowa	Northwest	4,190	4/23/1905–7/19/06, 10/1/13–9/30/27, 10/1/46–9/30/06	4/1/64–9/30/06	42.5061	94.2011	42	42
94	05481000	Boone River near Webster City, Iowa	Northwest	844	3/9/40–9/30/06	4/1/58–9/30/06	42.4325	93.8056	48	48
95	05481300	Des Moines River near Stratford, Iowa	Northwest	5,452	[1]4/1/20–9/30/06	[2]4/1/61–9/30/06	42.2520	93.9967	45	45
96	05481950	Beaver Creek near Grimes, Iowa	Northwest	358	4/20/60–9/30/06	4/20/60–9/30/06	41.6883	93.7352	46	46
97	05482135	North Raccoon River near Newell, Iowa	Northwest	233	10/01/82–10/16/95	10/01/82–10/16/95	42.6044	95.0450	12	13
98	05482170	Big Cedar Creek near Varina, Iowa	Northwest	80	10/1/59–3/23/92	4/1/64–12/31/91	42.6889	94.7981	27	28
99	05482300	North Raccoon River near Sac City, Iowa	Northwest	700	06/01/1958–09/30/2006	4/1/65–9/30/06	42.3544	94.9906	41	41
100	05482500	North Raccoon River near Jefferson, Iowa	Northwest	1,619	03/01/40–12/31/06	4/1/64–12/31/06	41.9881	94.3767	42	42
101	05483000	East Fork Hardin Creek near Churdan, Iowa	Northwest	24	10/1/52–3/25/92	4/1/64–12/31/91	42.1075	94.3700	27	28
102	05483450	Middle Raccoon River near Bayard, Iowa	Southern	375	03/23/79–09/30/06	03/23/79–09/30/06	41.7786	94.4925	27	27
103	05484000	South Raccoon River at Redfield, Iowa	Southern	994	03/04/1940–09/30/2006	4/1/67–9/30/06	41.5894	94.1511	39	39
104	05484500	Raccoon River at Van Meter, Iowa	Northwest	3,441	04/15/25–09/30/06	4/1/60–9/30/06	41.5339	93.9498	46	46
105	05484650	Raccoon River at 63rd Street at Des Moines, Iowa	NU	3,529	10/01/96–9/30/06	10/01/96–9/30/06	41.5636	93.7036	9	10
106	05484800	Walnut Creek at Des Moines, Iowa	NU	78	10/01/71–09/30/06	10/01/71–09/30/06	41.5872	93.7031	34	35

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107	05484900	Raccoon River at Fleur Drive, Des Moines, Iowa	NU	3,625	10/1/96–9/30/06	10/1/96–9/30/06	41.5817	93.6428	9	10
108	05485640	Fourmile Creek at Des Moines, Iowa	NU	92.7	10/1/71–9/30/06	10/1/71–9/30/06	41.6139	93.5453	34	35
109	05486000	North River near Norwalk, Iowa	Northwest	349	02/28/40–09/30/06	4/1/54–9/30/06	41.4578	93.6547	52	52
110	05486490	Middle River near Indianola, Iowa	Southern	503	03/01/40–09/30/06	03/01/40–09/30/06	41.4242	93.5872	66	66
111	05487470	South River near Ackworth, Iowa	Southern	460	03/01/40–09/30/06	4/1/50–9/30/06	41.3372	93.4861	56	56
112	05487540	Walnut Creek near Prairie City, Iowa	Southern	6.78	5/6/95–3/6/06	5/6/95–3/6/06	41.6006	93.2739	9	11
113	05487550	Walnut Creek near Vandalia, Iowa	Southern	20.3	10/1/94–12/31/05	10/1/94–12/31/05	41.5370	93.2589	10	11
114	05487980	White Breast Creek near Dallas, Iowa	Southern	342	10/1/62–9/30/06	10/1/62–9/30/06	41.2456	93.2658	43	44
115	05488000	White Breast Creek near Knoxville, Iowa	Southern	380	7/24/45–9/30/62	4/1/50–9/30/62	41.3236	93.1497	12	12
116	05488200	English Creek near Knoxville, Iowa	Southern	90.1	7/1/85–9/30/06	7/1/85–9/30/06	41.3006	93.0453	20	21
117	05489000	Cedar Creek near Bussey, Iowa	Southern	374	10/01/47–9/30/06	10/01/47–9/30/06	41.2189	92.9083	58	59
118	05491000	Sugar Creek near Keokuk, Iowa	Southern	105	3/29/22–9/29/31, 8/29/58–10/16/73	10/1/58–9/30/73	40.4467	91.4847	14	15
119	05494300	Fox River at Bloomfield, Iowa	Southern	87.7	10/1/57–10/2/73, 5/27/97–9/30/06	4/1/66–3/31/73, 10/1/97–9/30/06	40.7694	92.4188	15	16
120	05495000	Fox River at Wayland, Mo.	Southern	400	3/1/22–9/30/06	4/1/55–9/30/06	40.3922	91.5978	51	51
121	05495500	Bear Creek near Marcelline, Ill.	Southern	349	3/1/44–9/30/06	4/1/57–9/30/06	40.1428	91.3372	49	49
122	05496000	Wyaconda River above Canton, Mo.	Southern	393	10/1/32–9/30/72, 10/1/79–9/30/06	4/1/55–9/30/06	40.1419	91.5656	43	44
123	05497000	North Fabius River at Monticello, Mo.	Southern	452	3/1/22–10/3/05	4/1/56–9/30/05	40.1081	91.7144	49	49
124	05498000	Middle Fabius River near Monticello, Mo.	Southern	393	10/1/45–10/3/05	4/1/55–9/30/05	40.0933	91.7352	50	50
125	05500000	South Fabius River near Taylor, Mo.	Southern	620	1/1/35–9/30/06	4/1/41–9/30/06	39.8964	91.5800	65	65
126	05501000	North River at Palmyra, Mo.	Southern	373	1/1/35–9/30/06	4/1/37–9/30/06	39.8178	91.5177	69	69
127	05502020	Hadley Creek near Barry, Ill.	Southern	40.9	10/1/55–9/30/66	10/1/55–9/30/66	39.7145	91.0653	10	11
128	05502040	Hadley Creek at Kinderhook, Ill.	Southern	72.7	10/1/39–9/30/86	4/1/45–9/30/86	39.6931	91.1486	41	41

Table 1. Description of streamgages located in Iowa and in neighboring States within a 50-mile buffer of Iowa that were evaluated for use in the low-flow frequency and harmonic-mean-flow regressions for Iowa.—Continued

[USGS, U.S. Geological Survey; mi², square miles; Minn., Minnesota; Wis., Wisconsin; Ill., Illinois; NU, streamgage not used in development of regional-regression equations; Mo., Missouri, Nebr., Nebraska; S. Dak., South Dakota. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Streamgage name	Low-flow region	Published drainage area (mi²)	Entire period of record	Period of record used for low–flow study	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used in low-flow study (Apr. 1 to Mar. 31)	Number of years of fall record used in study (Oct. 1 to Dec. 31)
129	05503000	Oak Dale Branch near Emden, Mo.	Southern	2.64	9/1/55–10/2/75	4/1/56–9/30/75	39.7583	91.9189	19	19
130	05557000	West Bureau Creek at Wyanet, Ill.	Southern	86.7	3/1/36–9/30/66	4/1/56–9/30/66	41.3650	89.5689	10	10
131	05568800	Indian Creek near Wyoming, Ill.	Southern	62.7	10/1/59–9/30/06	10/1/59–9/30/06	41.0189	89.8356	46	47
132	05570000	Spoon River at Seville, Ill.	Southern	1,635.8	7/24/14–9/30/06	4/1/49–9/30/06	40.4900	90.3403	57	57
133	05584400	Drowning Fork at Bushnell, Ill.	Southern	26.3	6/10/60–9/13/83	6/10/60–9/13/83	40.5625	90.5231	21	23
134	05584500	La Moine River at Colmar, Ill.	Southern	655	10/1/44–9/30/06	10/1/44–9/30/06	40.3303	90.8961	61	62
135	05585000	La Moine River at Ripley, Ill.	Southern	1,293	3/12/21–9/30/06	4/1/54–9/30/06	40.0247	90.6317	52	52
136	06478518	Bow Creek near St. James, Nebr.	Northwest	304	10/1/78–9/30/93	10/1/78–9/30/93	42.7292	97.1467	14	15
137	06480400	Spring Creek near Flandreau, S. Dak.	Northwest	63.2	10/1/82–9/30/93	10/1/82–9/30/93	44.1217	96.5887	10	11
138	06480650	Flandreau Creek above Flandreau, S. Dak.	Northwest	100	9/25/81–12/31/91	9/25/81–12/31/91	44.0625	96.4877	9	10
139	06481500	Skunk Creek at Sioux Falls, S. Dak.	Northwest	622	6/1/48–9/30/01, 10/1/03–9/30/06	4/1/77–9/30/06	43.5336	96.7906	26	27
140	06482610	Split Rock Creek at Corson, S. Dak.	NU	464	10/1/65–9/30/89, 10/1/01–9/30/06	4/1/78–9/30/06	43.6164	96.5650	15	16
141	06483500	Rock River near Rock Valley, Iowa	Northwest	1,592	6/11/48–9/30/06	4/1/69–9/30/06	43.2145	96.2940	37	37
142	06485696	Brule Creek near Elk Point, S. Dak.	Northwest	204	10/1/82–9/30/94	10/1/82–9/30/94	42.8089	96.6864	11	12
143	06600000	Perry Creek at 38th Street, Sioux City, Iowa	Northwest	65.1	10/1/45–9/30/69, 6/1/1981–9/30/05	4/1/68–3/31/69, 10/1/81–9/30/05	42.5347	96.4103	24	25
144	06600100	Floyd River at Alton, Iowa	Northwest	268	10/01/55–9/30/06	4/1/69–9/30/06	42.9820	96.0008	37	37
145	06600300	West Branch Floyd River near Struble, Iowa	Northwest	180	10/1/55–3/30/95	4/1/69–12/31/94	42.9239	96.1767	25	26
146	06600500	Floyd River at James, Iowa	Northwest	886	12/8/34–9/30/06	4/1/72–9/30/06	42.5767	96.3111	34	34
147	06601000	Omaha Creek at Homer, Nebr.	Southern	174	10/1/45–9/30/06	4/1/79–9/30/06	42.3217	96.4879	27	27
148	06602020	West Fork Ditch at Hornick, Iowa	Southern	403	4/7/39–9/30/06	4/1/77–9/30/06	42.2269	96.0778	29	29
149	06602400	Monona-Harrison Ditch near Turin, Iowa	Southern	900	5/07/42–9/30/06	4/1/78–9/30/06	41.9644	95.9917	28	28
150	06605000	Ocheyedan River near Spencer, Iowa	Northwest	426	10/1/77–9/30/06	10/1/77–9/30/06	43.1281	95.2106	28	29

Table 1. Description of streamgages located in Iowa and in neighboring States within a 50-mile buffer of Iowa that were evaluated for use in the low-flow frequency and harmonic-mean-flow regressions for Iowa.—Continued

[USGS, U.S. Geological Survey; mi², square miles; Minn., Minnesota; Wis., Wisconsin; Ill., Illinois; NU, streamgage not used in development of regional-regression equations; Mo., Missouri, Nebr., Nebraska; S. Dak., South Dakota. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Streamgage name	Low-flow region	Published drainage area (mi²)	Entire period of record	Period of record used for low–flow study	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used in low-flow study (Apr. 1 to Mar. 31)	Number of years of fall record used in study (Oct. 1 to Dec. 31)
151	06605600	Little Sioux River at Gillett Grove, Iowa	Northwest	1,334	6/13/58–10/19/73	4/1/62–9/30/73	43.0183	95.0428	11	11
152	06605850	Little Sioux River at Linn Grove, Iowa	Northwest	1,548	10/1/72–9/30/06	10/1/72–9/30/06	42.8958	95.2431	33	34
153	06606600	Little Sioux River at Correctionville, Iowa	Northwest	2,500	5/28/18–9/30/06	4/1/64–9/30/06	42.4703	95.7972	42	42
154	06607000	Odebolt Creek near Arthur, Iowa	Southern	39.3	10/1/57–9/30/75	4/1/65–9/30/75	42.3361	95.3811	10	10
155	06607200	Maple River at Mapleton, Iowa	Southern	669	10/1/41–9/30/06	4/1/67–9/30/06	42.1569	95.8098	39	39
156	06607500	Little Sioux River near Turin, Iowa	Southern	3,526	5/7/42–9/30/06	4/1/65–9/30/06	41.9644	95.9725	41	41
157	06608000	Tekamah Creek at Tekamah, Nebr.	NU	23.0	7/1/49–12/31/81	4/1/70–12/31/81	41.7761	96.2200	10	11
158	06608500	Soldier River at Pisgah, Iowa	Southern	407	3/5/40–9/30/06	4/1/69–9/30/06	41.8306	95.9311	37	37
159	06609500	Boyer River at Logan, Iowa	Southern	871	5/24/18–7/1/25, 11/4/37–9/30/06	4/1/67–9/30/06	41.6425	95.7825	39	39
160	06610500	Indian Creek at Council Bluffs, Iowa	Southern	7.99	7/1/54–9/30/76	4/1/66–9/30/76	41.2922	95.8331	10	10
161	06610520	Mosquito Creek near Earling, Iowa	Southern	32	8/9/65–9/30/79	4/1/67–9/30/79	41.7528	95.4656	12	12
162	06799385	Pebble Creek at Scribner, Nebr.	NU	204	10/1/78–9/30/93	10/1/78–9/30/93	41.6589	96.6842	14	15
163	06799450	Logan Creek at Pender, Nebr.	NU	731	10/1/65–9/30/93	4/1/80–9/30/93	42.1139	96.7017	13	13
164	06799500	Logan Creek near Uehling, Nebr.	NU	1,015	4/1/41–9/30/06	4/1/80–9/30/06	41.7128	96.5220	26	26
165	06803510	Little Salt Creek near Lincoln, Nebr.	Southern	43.6	10/1/69–9/30/06	10/1/69–9/30/06	40.8931	96.6817	36	37
166	06803530	Rock Creek near Ceresco, Nebr.	Southern	120	4/1/70–9/30/06	4/1/70–9/30/06	41.0158	96.5442	36	36
167	06804000	Wahoo Creek at Ithaca, Nebr.	Southern	273	10/1/49–9/30/06	10/1/49–9/30/06	41.1475	96.5378	56	57
168	06806000	Waubonsie Creek near Bartlett, Iowa	Southern	30.4	1/10/46–9/30/69	4/1/59–9/30/69	40.8847	95.7458	10	10
169	06806500	Weeping Water Creek at Union,NE	NU	241	3/1/50–9/30/06	4/1/55–9/30/06	40.7942	95.9114	51	51
170	06807410	West Nishnabotna River at Hancock, Iowa	Southern	609	10/2/59–9/30/06	4/1/68–9/30/06	41.3900	95.3714	38	38
171	06808500	West Nishnabotna River at Randolph, Iowa	Southern	1,326	6/1/48–9/30/06	4/1/68–9/30/06	40.8731	95.5800	38	38
172	06809000	Davids Creek near Hamlin, Iowa	Southern	26	6/20/52–10/2/73	4/1/63–10/2/73	41.6736	94.8056	10	10
173	06809210	East Nishnabotna River near Atlantic, Iowa	Southern	436	10/1/60–9/30/06	4/1/67–9/30/06	41.3461	95.0767	39	39

Table 1. Description of streamgages located in Iowa and in neighboring States within a 50-mile buffer of Iowa that were evaluated for use in the low-flow frequency and harmonic-mean-flow regressions for Iowa.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; Minn., Minnesota; Wis., Wisconsin; Ill., Illinois; NU, streamgage not used in development of regional-regression equations; Mo., Missouri, Nebr., Nebraska; S. Dak., South Dakota. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Streamgage name	Low-flow region	Published drainage area (mi^2)	Entire period of record	Period of record used for low–flow study	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used in low-flow study (Apr. 1 to Mar. 31)	Number of years of fall record used in study (Oct. 1 to Dec. 31)
174	06809500	East Nishnabotna River at Red Oak, Iowa	Southern	894	5/22/18–7/4/25, 5/29/36–9/30/06	4/1/67–9/30/06	41.0086	95.2414	39	39
175	06810000	Nishnabotna River above Hamburg, Iowa	Southern	2,806	3/1/22–9/30/23, 10/1/28–9/30/06	4/1/67–9/30/06	40.6325	95.6256	39	39
176	06810500	Little Nemaha River near Syracuse, Nebr.	NU	218	6/1/51–9/30/69	4/1/55–9/30/69	40.6325	96.1794	14	14
177	06811500	Little Nemaha River at Auburn, Nebr.	Southern	792	9/1/49–9/30/06	4/1/53–9/30/06	40.3928	95.8128	53	53
178	06811840	Tarkio River at Stanton, Iowa	Southern	49.3	10/1/57–9/30/91	4/1/67–9/30/91	40.9800	95.1147	24	24
179	06813000	Tarkio River at Fairfax, Mo.	Southern	508	4/1/22–12/31/90	4/1/54–12/31/90	40.3392	95.4058	36	37
180	06814500	North Fork Big Nemaha River at Humboldt, Nebr.	Southern	548	10/1/52–9/30/06	10/1/52–9/30/06	40.1569	95.9444	43	45
181	06815000	Big Nemaha Falls at Falls City, Nebr.	NU	1,339	4/1/44–9/30/06	4/1/44–9/30/06	40.0356	95.5958	62	62
182	06815500	Muddy Creek at Verdon, Nebr.	Southern	188	10/1/52–9/30/72	10/1/52–9/30/72	40.1456	95.7203	19	20
183	06816000	Mill Creek at Oregon, Mo.	Southern	4.90	8/1/50–9/30/76	4/1/56–9/30/76	39.9817	95.1262	20	20
184	06817000	Nodaway River at Clarinda, Iowa	Southern	762	5/17/18–7/4/25, 5/14/36–9/30/06	4/1/56–9/30/06	40.7392	95.0128	50	50
185	06817500	Nodaway River near Burlington Junction, Mo.	Southern	1,240	4/1/22–10/28/83	4/1/55–9/30/83	40.4447	95.0889	28	28
186	06817700	Nodaway River near Graham, Mo.	Southern	1,380	10/22/82–9/30/06	10/22/82–9/30/06	40.2025	95.0696	23	24
187	06818750	Platte River near Diagonal, Iowa	Southern	217	4/1/68–9/30/91	4/1/68–9/30/91	40.7692	94.4050	23	23
188	06818900	Platte River at Ravenwood, Mo.	Southern	486	9/1/58–9/30/71	9/1/58–9/30/71	40.3450	94.6861	11	12
189	06819185	East Fork 102 River at Bedford, Iowa	Southern	85.4	10/1/83–9/30/06	10/1/83–9/30/06	40.6606	94.7164	22	23
190	06819190	East Fork 102 River near Bedford, Iowa	Southern	92.1	9/10/59–9/30/83	9/10/59–9/30/83	40.6336	94.7483	23	24
191	06819500	102 River at Maryville, Mo.	Southern	500	10/1/32–12/31/90, 3/22/01–9/30/06	4/1/35–12/31/90, 3/22/01–9/30/06	40.3453	94.8319	60	61

Table 1. Description of streamgages located in Iowa and in neighboring States within a 50-mile buffer of Iowa that were evaluated for use in the low-flow frequency and harmonic-mean-flow regressions for Iowa.—Continued

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Map number	USGS streamgage number	Streamgage name	Low-flow region	Published drainage area (mi²)	Entire period of record	Period of record used for low–flow study	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used in low-flow study (Apr. 1 to Mar. 31)	Number of years of fall record used in study (Oct. 1 to Dec. 31)
192	06820000	White Cloud Creek near Maryville, Mo.	Southern	6.00	10/1/48–7/31/70	10/1/48–7/31/70	40.3892	94.9097	21	22
193	06896500	Thompson Branch near Albany, Mo.	Southern	5.58	10/1/55–9/30/72	10/1/55–9/30/72	40.2139	94.3319	16	17
194	06897000	East Fork Big Creek near Bethany, Mo.	Southern	95.0	4/1/34–9/30/72, 10/1/96–9/30/06	4/1/34–9/30/72, 10/1/96–9/30/06	40.2972	94.0261	45	47
195	06897500	Grand River near Gallatin, Mo.	Southern	2,250	10/1/20–9/30/06	4/1/38–9/30/06	39.9269	93.9425	68	68
196	06897950	Elk Creek near Decatur City, Iowa	Southern	52.5	10/1/67–9/30/94	10/1/67–9/30/94	40.7245	93.9381	26	27
197	06898000	Thompson River at Davis City, Iowa	Southern	701	5/14/18–7/2/25, 7/14/41–9/30/06	5/14/18–7/2/25, 7/14/41–9/30/06	40.6403	93.8081	70	72
198	06898100	Thompson River at Mount Moriah, Mo.	Southern	891	9/1/60–9/30/77	9/1/60–9/30/77	40.3361	93.7683	16	17
199	06898400	Weldon River near Leon, Iowa	Southern	104	10/1/58–9/30/91	10/1/58–9/30/91	40.6958	93.6353	32	33
200	06898500	Weldon River near Mercer, Mo.	Southern	246	10/1/39–9/30/59	10/1/39–9/30/59	40.5489	93.6028	19	20
201	06899000	Weldon River at Mill Grove, Mo.	Southern	494	4/3/29–9/30/72	4/1/35–9/30/72	40.3097	93.5947	37	37
202	06900000	Medicine Creek near Galt, Mo.	Southern	225	10/1/21–9/30/75, 10/1/77–12/31/90	4/1/54–12/31/90	40.1297	93.3625	33	35
203	06901500	Locust Creek near Linneus, Mo.	Southern	550	4/1/29–9/30/72, 7/14/00–9/30/06	4/1/38–9/30/06	39.8958	93.2362	39	40
204	06902500	Hamilton Branch near New Boston, Mo.	Southern	2.51	10/1/55–9/30/72	10/1/55–9/30/72	39.9522	92.9022	16	17
205	06903400	Chariton River near Chariton, Iowa	Southern	182	10/1/65–9/30/06	10/1/65–9/30/06	40.9517	93.2595	40	41
206	06903500	Honey Creek near Russell, Iowa	Southern	13.2	6/6/52–9/30/62	6/6/52–9/30/62	40.9236	93.1319	9	10
207	06903700	South Fork Chariton River near Promise City, Iowa	Southern	168	10/1/67–9/30/06	10/1/67–9/30/06	40.8006	93.1922	38	39
208	06904500	Chariton River at Novinger, Mo.	Southern	1,370	10/1/30–9/30/52, 10/1/54–3/31/69	10/1/54–3/31/69	40.2342	92.6861	14	15

[1]Includes 4/1/20-9/30/67 daily-mean-discharge record from Des Moines River near Boone (streamgage 05481500); records are considered equivalent.

[2]Includes 4/1/61-9/30/67 daily-mean-discharge record from Des Moines River near Boone (streamgage 05481500); records are considered equivalent.

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed M1D10Y (ft³/s)	Predicted M1D10Y (ft³/s)	Observed M7D10Y (ft³/s)	Predicted M7D10Y (ft³/s)	Observed M30D10Y (ft³/s)
1	05319500	Northwest	851	5.37	1.59	5.78	2.05	7.31
2	05320500	Northwest	1,110	10.5	10.6	11.0	12.1	13.2
3	05376000	Northeast	101	14.8	23.5	17.5	25.0	18.8
4	05378300	Northeast	5.16	.70	.93	.77	.96	.93
5	05384000	Northeast	615	80.9	79.4	85.3	88.0	89.4
6	05384500	Northeast	132	27.7	27.0	28.8	29.0	31.3
7	05385000	Northeast	1,250	297	241	305	267	338
8	05385500	Northeast	275	68.5	47.7	71.7	51.6	74.3
9	05387500	Northeast	511	39.7	50.4	44.7	56.8	52.0
10	05388250	Northeast	770	79.8	83.9	90.2	94.8	105
11	05388500	Northeast	42.8	1.50	2.68	1.62	2.89	1.71
12	05389400	Northeast	34.13	6.87	2.00	7.58	2.19	8.27
13	05410490	Northeast	687	238	283	248	311	270
14	05411400	Northeast	27.6	5.18	NU	5.75	NU	6.88
15	05411600	Northeast	177	8.44	13.5	9.12	15.3	10.9
16	05412060	Northeast	4.39	.01	<.1	.01	<.1	.03
17	05412100	Northeast	70.7	.00	1.41	.01	1.55	.04
18	05412500	Northeast	1,545	104	139	115	160	136
19	05414500	Northeast	130	6.42	5.70	7.59	6.32	9.82
20	05414820	Northeast	39.6	6.37	1.65	7.05	1.76	8.04
21	05417000	Northeast	305	27.0	14.5	34.6	16.6	40.1
22	05417700	Northeast	61.3	2.27	.52	2.78	.58	3.53
23	05418450	Northeast	516	62.6	33.5	68.0	37.7	85.3
24	05418500	Northeast	1,553	162	106	189	123	221
25	05420000	Northeast	230	11.0	14.0	11.8	15.1	14.4
26	05420560	Northeast	95.2	3.42	3.02	3.85	3.38	4.46
27	05421000	Northeast	1,048	26.5	62.7	27.9	72.4	34.5
28	05422000	Northeast	2,336	124	129	132	150	152
29	05422470	NU	17.8	.20	NU	.28	NU	.56
30	05422560	Southern	16.1	.08	.00	.09	.00	.18
31	05422600	Southern	57.3	.38	.56	.77	.70	1.63
32	05435500	Northeast	1,326	256	325	271	354	297
33	05444000	Northeast	146	19.5	9.71	21.2	10.5	23.7
34	05448000	Southern	62.4	.15	.59	.24	.74	.41
35	05449000	Northwest	133	.74	.44	.89	.54	.94
36	05449500	Northwest	418	10.0	2.58	11.1	3.04	13.5
37	05451210	Northeast	224	1.68	1.36	2.02	1.54	2.88

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	Predicted-M30D10Y (ft³/s)	Observed M30D5Y (ft³/s)	Predicted M30D5Y (ft³/s)	Observed M1D10Y1012 (ft³/s)	Predicted M1D10Y1012 (ft³/s)	Observed M7D10Y1012 (ft³/s)	Predicted M7D10Y1012 (ft³/s)	Observed QAH (ft³/s)	Predicted QAH (ft³/s)
1	5.72	12.3	11.4	6.99	5.59	7.94	7.17	43.4	29.0
2	15.5	20.0	25.1	13.3	15.6	14.2	19.0	71.7	65.5
3	26.6	20.6	28.7	15.7	25.4	18.5	28.3	34.8	47.3
4	1.01	1.04	1.23	.81	1.17	.92	1.29	1.72	1.25
5	97.7	106	111	82.8	86.7	88.5	101	220	240
6	31.2	34.0	33.8	33.7	29.8	34.5	33.5	49.7	54.4
7	294	373	303	342	245	357	282	725	603
8	55.8	83.8	62.3	85.1	50.6	85.8	57.6	137	117
9	64.3	62.3	74.8	45.1	60.2	53.1	71.1	153	148
10	107	122	121	91.0	97.0	104	114	304	259
11	3.22	2.11	4.53	1.56	3.45	1.64	4.03	4.69	9.87
12	2.47	9.43	3.44	8.39	2.77	8.80	3.26	16.4	8.56
13	331	294	294	263	283	277	315	448	578
14	NU	7.76	NU	6.38	3.10	7.09	3.61	15.9	7.29
15	17.6	14.5	21.2	9.85	18.4	11.1	21.9	41.9	30.9
16	<.1	.13	.11	.05	<.1	.07	<.1	.45	.36
17	1.80	.28	3.22	.14	1.91	.24	2.36	.97	11.9
18	184	174	210	120	163	136	196	473	574
19	7.24	12.4	10.5	9.11	7.44	11.9	8.96	32.0	37.8
20	1.97	9.45	3.14	6.87	2.08	7.81	2.46	16.5	10.4
21	19.5	45.3	25.9	30.1	19.8	39.1	24.1	109	70.3
22	.69	4.73	1.47	2.78	.77	2.99	.98	12.5	11.1
23	43.2	102	55.4	65.3	40.6	78.5	48.7	215	180
24	142	275	173	180	126	217	153	635	593
25	16.9	17.6	24.1	14.5	15.7	15.4	18.5	50.9	88.5
26	3.94	5.53	6.06	4.19	4.25	4.93	5.19	14.7	11.7
27	84.5	51.2	105	39.2	78.1	44.1	95.1	170	248
28	177	211	220	144	156	156	192	634	687
29	NU	.84	NU	.37	NU	.49	NU	2.86	NU
30	.12	.32	.18	.09	.00	.12	.18	.95	1.07
31	.78	2.25	1.13	.91	.79	1.23	.99	6.37	3.58
32	380	357	390	275	302	307	343	701	927
33	11.7	29.4	16.3	22.5	11.3	25.1	13.3	64.3	48.6
34	.77	1.04	1.10	.26	.81	.43	1.01	3.37	3.56
35	.91	2.22	1.78	2.02	1.05	2.59	1.29	9.47	2.71
36	4.22	19.6	7.32	12.5	4.55	14.5	5.51	54.7	19.7
37	1.90	3.89	4.18	2.37	1.97	3.01	2.59	16.1	12.8

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed M1D10Y (ft³/s)	Predicted M1D10Y (ft³/s)	Observed M7D10Y (ft³/s)	Predicted M7D10Y (ft³/s)	Observed M30D10Y (ft³/s)
38	05451500	Southern	1,532	29.9	34.6	33.9	44.0	44.6
39	05451700	Southern	118	.20	1.03	.66	1.28	1.07
40	05451900	Southern	56.1	.18	.32	.38	.40	.65
41	05452000	Northeast	201	3.14	2.11	3.63	2.36	4.78
42	05452200	Southern	70.9	.20	.40	.28	.50	.34
43	05453000	Southern	189	1.67	1.01	1.75	1.23	2.60
44	05453100	Southern	2,794	82.5	75.2	86.6	96.1	103
45	05454000	Southern	25.3	.00	.00	.00	.00	.00
46	05454220	Southern	58.4	.60	.35	.69	.43	.94
47	05454300	Southern	98.1	.88	.66	1.00	.81	1.45
48	05455000	Southern	3.01	.00	.00	.00	.00	.00
49	05455010	Southern	2.94	.00	.00	.00	.00	.00
50	05455100	Southern	201	.67	1.68	.77	2.08	1.20
51	05455500	Southern	574	2.05	4.58	2.77	5.70	4.25
52	05457000	Northeast	399	38.9	29.8	42.3	33.7	46.0
53	05457700	Northeast	1,054	82.1	77.5	94.4	88.8	110
54	05458000	Northeast	306	7.25	11.1	7.79	12.6	9.02
55	05458500	Northeast	1,661	125	119	141	137	159
56	05458900	Northeast	846	24.9	21.7	27.5	25.3	32.8
57	05459000	Northeast	300	5.00	8.32	5.20	9.47	6.60
58	05459500	Northwest	526	8.45	6.86	11.2	8.04	14.4
59	05462000	Northeast	1,746	70.4	71.5	84.9	83.5	107
60	05463000	Northeast	347	6.10	5.13	6.81	5.86	8.54
61	05463500	Northeast	303	3.33	4.64	4.04	5.28	6.53
62	05464000	Northeast	5,146	355	342	398	403	448
63	05464130	Northeast	13.78	.06	<.1	.07	<.1	.09
64	05464133	Northeast	1.33	.00	<.1	.00	<.1	.00
65	05464137	Northeast	19.51	.00	.10	.00	.11	.05
66	05464500	Northeast	6,510	329	385	440	456	504
67	05464640	Southern	178	.50	2.59	.87	3.27	1.35
68	05465000	Southern	7,787	484	459	575	606	660
69	05465500	NU	12,500	797	NU	907	NU	1,020
70	05466000	Southern	155	1.30	1.37	1.51	1.68	2.14
71	05466500	Southern	445	6.47	6.61	7.40	8.28	9.75
72	05467000	Southern	174	2.25	1.87	2.75	2.33	3.52
73	05468500	Southern	132	5.99	1.14	6.91	1.41	9.01
74	05469000	Southern	432	.00	6.77	.00	8.50	.00
75	05469500	Southern	82.9	.00	.47	.00	.57	.00

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft^3/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	Predicted-M30D10Y (ft^3/s)	Observed M30D5Y (ft^3/s)	Predicted M30D5Y (ft^3/s)	Observed M1D10Y1012 (ft^3/s)	Predicted M1D10Y1012 (ft^3/s)	Observed M7D10Y1012 (ft^3/s)	Predicted M7D10Y1012 (ft^3/s)	Observed QAH (ft^3/s)	Predicted QAH (ft^3/s)
38	54.8	68.7	71.3	47.9	44.4	52.0	53.0	239	171
39	1.39	2.66	2.00	1.07	1.35	1.37	1.71	5.94	5.82
40	.43	1.64	.65	.66	.43	.89	.55	3.58	2.43
41	2.83	7.85	5.66	4.10	2.88	4.93	3.67	26.8	33.4
42	.56	1.03	.85	.26	.54	.34	.68	2.58	2.86
43	1.52	5.71	2.27	1.72	1.27	2.14	1.66	8.19	6.63
44	125	154	160	96.7	95.9	105	113	510	446
45	.18	.04	.27	.00	.20	.00	.26	.53	1.43
46	.47	1.35	.71	.66	.47	.81	.59	6.40	2.82
47	.92	3.05	1.36	1.03	.87	1.30	1.09	9.57	4.66
48	.00	.00	<.1	.00	.00	.00	.00	.17	.29
49	.00	.03	<.1	.00	.00	.00	.00	.21	.28
50	2.42	2.29	3.50	.76	2.17	.97	2.73	6.49	9.01
51	7.56	7.50	10.9	3.14	5.78	4.04	7.27	28.6	26.5
52	38.5	52.9	47.4	46.1	37.1	47.5	44.3	120	48.7
53	103	136	124	90.4	93.2	108	112	321	150
54	14.6	14.0	21.2	10.5	14.6	12.1	17.8	46.0	49.6
55	159	198	191	140	140	163	170	509	323
56	30.5	48.2	45.3	32.3	29.4	36.0	37.0	156	109
57	11.2	11.0	17.2	9.33	11.3	11.2	14.1	6.45	14.4
58	10.1	21.9	15.2	13.2	10.4	16.1	12.2	70.4	29.0
59	99.3	153	131	102	90.2	121	112	420	217
60	7.08	13.8	12.5	9.45	7.14	11.1	9.10	49.8	47.3
61	6.36	10.5	11.1	6.80	6.45	7.99	8.18	36.5	40.9
62	474	561	555	386	395	471	486	1,520	1,080
63	<.1	.22	.22	.07	.11	.10	.14	.43	.88
64	<.1	.01	<.1	.00	<.1	.00	<.1	.10	<.1
65	.13	.23	.33	.15	.16	.23	.20	1.19	1.33
66	541	677	643	361	447	513	554	1,880	1,510
67	3.63	4.11	5.00	3.09	3.52	4.37	4.30	10.6	11.2
68	856	878	1,020	511	611	655	695	2,380	3,990
69	NU	1,350	NU	867	NU	1,040	NU	3,810	NU
70	1.85	3.35	2.64	1.56	1.76	1.85	2.25	14.7	7.44
71	9.56	13.7	13.0	7.22	8.57	8.32	10.5	56.3	28.6
72	2.59	5.03	3.65	2.68	2.47	2.97	3.07	18.8	9.11
73	1.54	10.6	2.20	5.55	1.48	6.23	1.89	29.5	6.39
74	9.79	.00	13.3	.00	8.82	.00	10.8	1.15	28.5
75	.61	.02	.90	.00	.60	.00	.79	1.48	3.39

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft^3/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi^2)	Observed M1D10Y (ft^3/s)	Predicted M1D10Y (ft^3/s)	Observed M7D10Y (ft^3/s)	Predicted M7D10Y (ft^3/s)	Observed M30D10Y (ft^3/s)
76	05470000	Northwest	315	0.07	0.15	0.11	0.20	0.21
77	05470500	Northwest	204	.00	<.1	.00	<.1	.15
78	05471000	NU	556	.00	NU	.00	NU	.00
79	05471040	Southern	18.4	.32	NU	.42	NU	.63
80	05471050	Southern	803	9.14	9.73	12.2	12.1	16.6
81	05471200	Northwest	276	.35	.11	.64	.15	1.60
82	05471500	Southern	1,635	14.1	23.6	15.4	29.4	20.9
83	05472500	Southern	730	3.76	5.90	4.39	7.28	5.99
84	05473400	Southern	533	1.12	1.02	1.59	1.22	3.30
85	05473500	Southern	106	.00	.27	.00	.33	.01
86	05474000	Southern	4,312	44.6	53.0	49.7	66.2	62.3
87	05476000	NU	1,250	.11	NU	.35	NU	1.15
88	05476500	Northwest	1,372	1.80	4.76	2.00	5.56	2.82
89	05476750	Northwest	2,256	25.1	18.3	27.8	20.4	31.3
90	05478000	Northwest	462	.85	1.08	.96	1.31	1.56
91	05479000	Northwest	1,308	11.7	5.98	13.1	6.85	15.6
92	05480000	Northwest	257	.00	.33	.07	.41	.51
93	05480500	Northwest	4,190	42.6	74.0	54.3	79.4	66.9
94	05481000	Northwest	844	5.33	2.23	5.80	2.60	7.00
95	05481300	Northwest	5,452	58.9	135	66.5	143	83.9
96	05481950	Northwest	358	.01	.30	.05	.37	.26
97	05482135	Northwest	233	.61	.46	.072	.55	1.43
98	05482170	Northwest	80	.00	<.1	.00	.10	.00
99	05482300	Northwest	700	4.65	2.72	4.80	3.08	6.15
100	05482500	Northwest	1,619	12.9	10.3	14.2	11.4	20.1
101	05483000	Northwest	24	.00	<.1	.00	<.1	.00
102	05483450	Southern	375	11.0	5.67	13.8	7.13	18.3
103	05484000	Southern	994	30.7	18.5	36.0	23.5	44.4
104	05484500	Northwest	3,441	64.7	26.0	77.5	28.9	94.7
105	05484650	NU	3,529	93.6	NU	114	NU	137
106	05484800	NU	78	.00	NU	.07	NU	.96
107	05484900	NU	3,625	56.1	NU	92.2	NU	106
108	05485640	NU	92.7	.22	NU	.52	NU	1.36
109	05486000	Northwest	349	.01	<.1	.08	<.1	.36
110	05486490	Southern	503	1.30	2.04	1.82	2.49	3.04
111	05487470	Southern	460	.57	.67	.76	.81	1.20
112	05487540	Southern	6.78	.05	NU	.08	NU	.14
113	05487550	Southern	20.3	.07	.00	.11	.00	.28

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft^3/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	Predicted-M30D10Y (ft^3/s)	Observed M30D5Y (ft^3/s)	Predicted M30D5Y (ft^3/s)	Observed M1D10Y1012 (ft^3/s)	Predicted M1D10Y1012 (ft^3/s)	Observed M7D10Y1012 (ft^3/s)	Predicted M7D10Y1012 (ft^3/s)	Observed QAH (ft^3/s)	Predicted QAH (ft^3/s)
76	0.67	1.18	1.71	0.35	0.74	0.42	0.99	3.51	4.33
77	.37	.66	1.00	.00	.42	.00	.56	2.36	2.14
78	NU	.05	NU	.00	NU	.00	NU	3.00	NU
79	NU	.78	NU	.36	.00	.47	<.1	2.43	.74
80	15.1	26.3	20.8	16.3	12.1	18.2	15.3	88.4	53.1
81	.51	2.93	1.35	2.05	.58	2.61	.77	10.7	5.03
82	38.7	38.4	52.1	17.7	28.9	20.0	36.6	135	148
83	9.76	14.3	13.9	4.92	7.25	5.45	9.42	23.5	37.0
84	2.11	4.72	3.46	1.40	1.19	1.71	1.75	19.3	12.5
85	.44	.04	.71	.00	.34	.00	.46	1.00	2.60
86	102	105	139	53.6	63.2	61.9	80.9	397	594
87	NU	3.65	NU	1.29	NU	3.24	NU	10.2	NU
88	9.13	6.06	17.4	3.54	9.27	4.78	11.8	18.9	51.1
89	25.5	48.2	43.2	34.4	24.9	41.0	31.3	182	79.9
90	2.37	2.35	4.78	1.29	2.58	1.84	3.26	13.4	12.0
91	9.80	23.1	17.9	13.5	10.0	15.9	12.7	86.4	50.6
92	.77	.93	1.73	.34	.89	.55	1.14	2.43	3.64
93	84.3	101	130	54.8	78.0	71.0	97.3	355	222
94	4.08	13.7	8.14	7.23	4.36	8.53	5.57	14.6	18.1
95	144	132	212	76.0	129	90.2	161	492	289
96	.91	.81	2.19	.31	1.03	.57	1.35	2.49	6.47
97	.86	3.50	1.81	1.24	1.00	1.45	1.26	11.4	7.75
98	.20	.00	.49	.00	.25	.00	.32	.96	2.16
99	3.92	12.3	7.38	7.83	4.27	9.33	5.35	42.0	56.5
100	13.5	35.6	23.7	18.3	13.8	21.1	17.3	127	141
101	<.1	.00	.12	.00	<.1	.00	<.1	.20	.54
102	8.24	23.9	11.2	14.5	7.44	17.7	9.07	69.3	24.2
103	29.2	56.7	38.9	40.7	24.0	46.8	28.7	164	82.9
104	38.9	126	67.6	82.8	36.9	96.8	47.2	429	481
105	NU	167	NU	109	NU	123	NU	488	NU
106	NU	1.68	NU	.19	NU	.51	NU	3.06	NU
107	NU	129	NU	84.9	NU	104	NU	159	NU
108	NU	2.47	NU	.48	NU	.84	NU	5.90	NU
109	<.1	.96	.28	.10	<.1	.23	<.1	4.28	5.56
110	3.62	4.99	5.54	2.05	2.48	2.48	3.33	20.8	15.9
111	1.44	2.30	2.42	.85	.78	1.16	1.19	8.44	8.52
112	NU	.19	NU	.02	.00	.04	.00	.51	.33
113	<.1	.38	<.1	.10	.00	.13	<.1	.90	.70

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed M1D10Y (ft³/s)	Predicted M1D10Y (ft³/s)	Observed M7D10Y (ft³/s)	Predicted M7D10Y (ft³/s)	Observed M30D10Y (ft³/s)
114	05487980	Southern	342	0.24	0.27	0.39	0.32	0.93
115	05488000	Southern	380	.31	.33	.48	.39	.68
116	05488200	Southern	90.1	.00	.00	.00	.00	.08
117	05489000	Southern	374	.19	.34	.28	.40	.63
118	05491000	Southern	105	.00	.00	.00	.00	.00
119	05494300	Southern	87.7	.04	.00	.06	.00	.29
120	05495000	Southern	400	.16	.33	.19	.39	.66
121	05495500	Southern	349	.00	.66	.07	.78	.38
122	05496000	Southern	393	.10	.27	.18	.33	.71
123	05497000	Southern	452	.29	.34	.58	.41	.89
124	05498000	Southern	393	.21	.27	.26	.32	.43
125	05500000	Southern	620	.28	.55	.33	.66	.66
126	05501000	Southern	373	.19	.29	.30	.35	.57
127	05502020	Southern	40.9	.00	.00	.00	.00	.00
128	05502040	Southern	72.7	.00	.00	.00	.00	.03
129	05503000	Southern	2.64	.00	.00	.00	.00	.00
130	05557000	Southern	86.7	.00	.71	.00	.88	.00
131	05568800	Southern	62.7	.35	.34	.50	.41	.95
132	05570000	Southern	1,635.8	19.0	23.9	21.1	29.9	31.9
133	05584400	Southern	26.3	.00	.00	.00	.00	.01
134	05584500	Southern	655	1.10	3.59	1.35	4.35	2.89
135	05585000	Southern	1,293	6.98	7.87	8.55	9.60	13.0
136	06478518	Northwest	304	6.85	26.2	8.14	27.4	10.6
137	06480400	Northwest	63.2	.00	<.1	.00	<.1	.03
138	06480650	Northwest	100	.00	NU	.00	NU	.00
139	06481500	Northwest	622	.11	.16	.21	.21	.24
140	06482610	NU	464	3.30	NU	4.31	NU	4.87
141	06483500	Northwest	1,592	5.63	3.93	6.38	4.69	8.00
142	06485696	Northwest	204	.69	.36	.98	.43	1.75
143	06600000	Northwest	65.1	.74	.27	1.16	.30	1.86
144	06600100	Northwest	268	.46	.39	.56	.46	.87
145	06600300	Northwest	180	.07	.20	.07	.24	.09
146	06600500	Northwest	886	6.77	4.98	7.42	5.45	9.28
147	06601000	Southern	174	2.45	4.80	3.54	6.26	4.80
148	06602020	Southern	403	9.12	10.0	10.5	12.9	13.4
149	06602400	Southern	900	26.1	25.4	29.5	33.2	37.1
150	06605000	Northwest	426	1.53	.74	1.96	.89	2.21
151	06605600	Northwest	1,334	5.85	7.12	6.37	8.18	8.85

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft^3/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	Predicted-M30D10Y (ft^3/s)	Observed M30D5Y (ft^3/s)	Predicted M30D5Y (ft^3/s)	Observed M1D10Y1012 (ft^3/s)	Predicted M1D10Y1012 (ft^3/s)	Observed M7D10Y1012 (ft^3/s)	Predicted M7D10Y1012 (ft^3/s)	Observed QAH (ft^3/s)	Predicted QAH (ft^3/s)
114	0.63	1.56	1.12	0.39	0.31	0.61	0.49	6.07	4.23
115	.77	1.06	1.36	.38	.38	.53	.60	3.92	5.02
116	.10	.17	.19	.03	<.1	.04	<.1	.74	.96
117	.78	1.29	1.37	.45	.39	.58	.61	4.50	5.31
118	.12	.00	.23	.00	<.1	.00	.10	1.23	1.49
119	.10	.38	.19	.13	.00	.20	.00	1.44	1.25
120	.78	1.41	1.39	.24	.38	.32	.59	4.80	6.66
121	1.28	.88	2.08	.14	.76	.22	1.20	3.08	8.26
122	.68	1.54	1.23	.25	.31	.43	.50	5.46	6.45
123	.84	3.67	1.51	1.26	.39	1.72	.62	10.8	7.18
124	.66	1.29	1.19	.33	.31	.50	.49	5.98	6.04
125	1.38	1.71	2.45	.57	.64	.58	.96	8.20	13.5
126	.69	1.47	1.25	.37	.34	.64	.51	5.97	8.36
127	.00	.01	.11	.00	.00	.00	.00	.79	.76
128	.16	.19	.27	.00	.00	.00	.00	1.88	1.47
129	.00	.00	.00	.00	.00	.00	.00	.06	.15
130	.94	.00	1.36	.00	.94	.00	1.19	1.41	4.36
131	.45	1.55	.67	.54	.44	.74	.57	6.11	2.60
132	39.3	46.6	52.8	23.6	29.4	27.2	37.1	192	147
133	.13	.02	.20	.00	.00	.00	.00	.52	1.22
134	6.16	5.51	9.05	1.29	4.25	1.66	5.98	19.1	27.6
135	14.5	20.1	21.1	9.46	9.21	10.6	12.9	75.0	70.8
136	15.2	14.5	16.9	11.6	15.8	13.8	17.2	37.3	33.7
137	<.1	.13	.14	.00	<.1	.03	<.1	1.04	.52
138	NU	.02	NU	.15	.10	.20	.14	.69	.78
139	1.06	.87	2.83	.43	1.07	.62	1.47	3.02	13.7
140	NU	8.56	NU	5.84	NU	7.17	NU	21.6	NU
141	9.18	15.0	18.3	7.28	9.15	10.3	11.9	22.8	41.7
142	.67	2.88	1.46	.90	.80	1.27	1.01	9.48	8.22
143	.30	3.19	.58	1.12	.37	1.71	.46	5.52	4.15
144	.76	1.92	1.70	1.39	.90	1.76	1.15	8.41	4.84
145	.44	.58	1.04	.55	.53	.69	.69	3.00	6.72
146	5.64	19.5	10.0	11.7	6.08	15.0	7.57	61.8	61.6
147	8.17	8.80	10.6	3.15	7.05	4.40	9.59	18.7	16.1
148	15.2	21.3	19.8	11.2	13.8	13.5	16.8	57.2	34.0
149	46.7	52.8	60.7	29.8	35.6	36.7	43.5	129	120
150	1.58	5.54	3.38	3.18	1.77	4.10	2.26	15.2	12.4
151	11.2	12.9	20.0	11.3	11.4	12.8	14.3	60.1	72.6

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed M1D10Y (ft³/s)	Predicted M1D10Y (ft³/s)	Observed M7D10Y (ft³/s)	Predicted M7D10Y (ft³/s)	Observed M30D10Y (ft³/s)
152	06605850	Northwest	1,548	7.17	9.77	8.55	11.0	11.5
153	06606600	Northwest	2,500	25.4	35.2	28.5	37.9	33.8
154	06607000	Southern	39.3	.41	.22	.49	.27	.64
155	06607200	Southern	669	12.4	15.4	13.8	19.7	16.6
156	06607500	Southern	3,526	53.3	106	59.0	135	71.3
157	06608000	NU	23.0	.01	NU	.02	NU	.08
158	06608500	Southern	407	9.58	11.5	11.1	14.9	14.1
159	06609500	Southern	871	13.6	24.6	15.6	31.6	20.3
160	06610500	Southern	7.99	.00	.00	.00	.00	.00
161	06610520	Southern	32	.00	.36	.02	.46	.09
162	06799385	NU	204	1.26	NU	1.91	NU	3.79
163	06799450	NU	731	14.8	NU	17.2	NU	23.4
164	06799500	NU	1,015	30.9	NU	35.6	NU	44.4
165	06803510	Southern	43.6	.40	.00	.53	.00	1.03
166	06803530	Southern	120	1.49	2.74	2.26	3.58	3.39
167	06804000	Southern	273	8.15	8.75	9.54	11.5	11.9
168	06806000	Southern	30.4	.35	.00	.61	.00	1.32
169	06806500	NU	241	1.47	NU	1.87	NU	2.74
170	06807410	Southern	609	11.1	12.7	12.6	16.2	16.2
171	06808500	Southern	1,326	50.4	42.9	55.8	55.7	71.0
172	06809000	Southern	26	.00	.00	.00	.16	.04
173	06809210	Southern	436	7.95	6.08	11.1	7.71	13.6
174	06809500	Southern	894	23.1	15.8	26.8	20.1	34.1
175	06810000	Southern	2,806	78.8	102	88.7	133	113
176	06810500	NU	218	.09	NU	.38	NU	.88
177	06811500	Southern	792	7.82	10.8	9.89	14.3	16.3
178	06811840	Southern	49.3	.00	.00	.00	.00	.04
179	06813000	Southern	508	.08	5.95	.41	7.56	3.17
180	06814500	Southern	548	3.35	6.02	4.88	7.93	8.79
181	06815000	NU	1,339	9.28	NU	13.5	NU	25.0
182	06815500	Southern	188	2.27	1.28	3.50	1.66	6.09
183	06816000	Southern	4.90	.00	.00	.00	.00	.00
184	06817000	Southern	762	9.96	7.04	12.3	8.85	16.3
185	06817500	Southern	1,240	7.65	13.4	11.4	16.9	17.8
186	06817700	Southern	1,380	24.0	16.9	28.6	21.5	35.8
187	06818750	Southern	217	.34	.67	.55	.82	1.01
188	06818900	Southern	486	2.72	1.57	3.18	1.91	4.99
189	06819185	Southern	85.4	.00	.00	.00	.00	.15

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	Predicted-M30D10Y (ft³/s)	Observed M30D5Y (ft³/s)	Predicted M30D5Y (ft³/s)	Observed M1D10Y1012 (ft³/s)	Predicted M1D10Y1012 (ft³/s)	Observed M7D10Y1012 (ft³/s)	Predicted M7D10Y1012 (ft³/s)	Observed QAH (ft³/s)	Predicted QAH (ft³/s)
152	14.4	23.4	25.2	14.0	14.5	17.3	18.2	87.1	89.6
153	37.6	55.9	58.9	33.7	36.7	41.4	45.3	213	167
154	.28	.88	.42	.71	.29	.86	.38	3.56	1.87
155	23.5	29.4	30.8	18.8	20.7	24.2	24.6	96.0	57.7
156	178	117	225	74.5	134	89.6	158	410	693
157	NU	.17	NU	.09	NU	.12	NU	.44	NU
158	17.9	23.1	23.2	13.6	16.1	16.1	19.8	57.2	37.1
159	38.5	36.4	49.5	23.3	33.2	27.5	39.4	106	89.4
160	<.1	.05	<.1	.00	.00	.00	.00	.30	.71
161	.49	.18	.69	.06	.52	.10	.68	.88	2.44
162	NU	5.39	NU	2.70	NU	3.84	NU	13.9	NU
163	NU	31.0	NU	21.1	NU	27.2	NU	80.7	NU
164	NU	64.8	NU	41.9	NU	49.4	NU	144	NU
165	.95	1.41	1.35	.50	.77	.75	1.14	4.01	3.98
166	5.10	4.13	6.76	3.22	4.10	3.94	5.93	10.4	11.2
167	17.0	15.2	21.8	9.20	13.0	10.9	18.5	31.3	28.9
168	.42	1.60	.60	1.17	.45	1.51	.58	3.96	2.27
169	NU	5.62	NU	2.58	NU	3.21	NU	14.6	NU
170	19.6	28.5	26.0	17.5	17.0	20.4	20.3	85.5	48.1
171	71.0	97.4	90.1	62.3	58.1	72.7	68.5	265	164
172	.16	.11	.25	.00	.17	.00	.22	.83	1.32
173	9.58	20.1	13.2	11.8	8.12	14.1	9.77	59.8	26.4
174	26.0	47.7	35.0	31.2	20.9	37.7	24.8	140	69.8
175	178	167	223	88.6	136	108	158	490	512
176	NU	1.93	NU	.34	NU	.56	NU	4.91	NU
177	26.1	23.3	36.8	18.0	15.5	21.2	20.3	66.3	106
178	.35	.13	.54	.00	.34	.04	.43	.59	2.29
179	9.71	6.48	13.6	1.99	7.94	3.31	9.54	18.8	27.1
180	14.7	13.4	21.2	7.63	8.73	9.59	11.5	25.0	64.4
181	NU	33.5	NU	16.2	NU	22.0	NU	96.0	NU
182	2.66	7.94	4.03	3.48	1.84	4.79	2.36	18.8	14.7
183	.00	.05	<.1	.00	.00	.00	.00	.46	.52
184	12.1	21.3	17.3	11.9	9.02	14.8	11.0	70.3	40.2
185	24.2	24.8	34.2	10.3	17.0	15.0	20.6	89.1	84.2
186	31.1	45.6	43.7	32.7	21.6	36.0	25.9	159	107
187	1.13	1.58	1.78	.78	.83	1.32	1.13	7.49	6.22
188	2.93	6.36	4.60	3.04	1.90	3.66	2.57	22.1	14.2
189	.21	.26	.36	.00	.15	.04	.22	.91	1.65

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed M1D10Y (ft³/s)	Predicted M1D10Y (ft³/s)	Observed M7D10Y (ft³/s)	Predicted M7D10Y (ft³/s)	Observed M30D10Y (ft³/s)
190	06819190	Southern	92.1	0.00	0.00	0.00	0.00	0.04
191	06819500	Southern	500	.00	1.93	.18	2.37	.24
192	06820000	Southern	6.00	.00	.00	.00	.00	.00
193	06896500	Southern	5.58	.00	.00	.00	.00	.00
194	06897000	Southern	95.0	.00	.00	.00	.00	.00
195	06897500	Southern	2,250	5.76	7.47	7.02	9.32	10.2
196	06897950	Southern	52.5	.00	.00	.00	.00	.00
197	06898000	Southern	701	1.15	1.40	1.65	1.69	2.86
198	06898100	Southern	891	9.10	1.78	9.27	2.16	12.2
199	06898400	Southern	104	.00	.00	.00	.00	.08
200	06898500	Southern	246	.00	.20	.00	.23	.00
201	06899000	Southern	494	.00	.51	.05	.60	.25
202	06900000	Southern	225	.07	.17	.26	.20	1.12
203	06901500	Southern	550	1.04	.66	1.16	.80	1.68
204	06902500	Southern	2.51	.00	.00	.00	.00	.00
205	06903400	Southern	182	.00	.00	.00	.12	.03
206	06903500	Southern	13.2	.00	NU	.00	NU	.00
207	06903700	Southern	168	.04	.00	.06	.00	.26
208	06904500	Southern	1,370	1.58	1.93	1.99	2.32	2.82

Table 2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow and predicted from regional regression equations for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; ft^3/s, cubic feet per second; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure 1; NU, streamgage not used in development of regional-regression equations; <, less than]

Map number	Predicted-M30D10Y (ft^3/s)	Observed M30D5Y (ft^3/s)	Predicted M30D5Y (ft^3/s)	Observed M1D10Y1012 (ft^3/s)	Predicted M1D10Y1012 (ft^3/s)	Observed M7D10Y1012 (ft^3/s)	Predicted M7D10Y1012 (ft^3/s)	Observed QAH (ft^3/s)	Predicted QAH (ft^3/s)
190	0.23	0.11	0.39	0.02	0.16	0.07	0.24	0.66	1.78
191	3.55	1.28	5.51	.26	2.39	.60	3.10	4.85	14.9
192	.00	.00	.00	.00	.00	.00	.00	.18	.19
193	.00	.00	.00	.00	.00	.00	.00	.19	.11
194	.12	.00	.22	.00	.00	.00	.00	.54	1.04
195	17.6	17.7	27.9	7.26	9.06	8.46	11.5	62.6	92.3
196	.00	.00	<.1	.00	.00	.00	.00	.25	.57
197	3.00	4.94	4.89	2.01	1.64	2.74	2.37	18.4	16.2
198	3.91	16.8	6.36	9.55	2.09	11.1	2.99	66.2	21.1
199	.12	.20	.22	.02	.00	.13	.10	.99	1.23
200	.45	.00	.79	.00	.23	.00	.37	.58	3.42
201	1.17	1.02	2.03	.24	.58	.29	.91	3.76	7.74
202	.39	2.05	.70	.36	.20	.62	.31	5.70	2.87
203	1.54	2.76	2.67	1.59	.78	1.81	1.13	12.0	8.94
204	.00	.00	.00	.00	.00	.00	.00	.13	<.1
205	.24	.14	.44	.02	.12	.06	.19	.68	2.18
206	NU	.00	NU	.00	.00	.00	.00	.32	.15
207	.24	.44	.43	.09	.12	.15	.20	1.67	2.42
208	4.88	5.46	8.22	1.81	2.20	2.08	3.29	20.4	36.6

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed BFI (mean ratio of base flow to annual streamflow)	Observed HYSEP (median percentage of base flow to annual streamflow)	Observed TAU_ANN (days)	Observed STREAM_VAR	GIS drainage area, DRNAREA (mi²)
1	05319500	Northwest	851	0.548	56.84	25.434	0.641	872.99
2	05320500	Northwest	1,110	.509	52.69	33.629	.645	1,128.00
3	05376000	Northeast	101	.734	72.94	66.702	.198	102.80
4	05378300	Northeast	5.16	.792	79.35	64.307	.147	5.41
5	05384000	Northeast	615	.648	66.19	69.716	.297	615.38
6	05384500	Northeast	132	.854	85.27	108.559	.107	132.03
7	05385000	Northeast	1,250	.780	76.95	56.766	.218	1,248.89
8	05385500	Northeast	275	.822	82.25	110.862	.152	274.48
9	05387500	Northeast	511	.570	58.46	33.045	.368	510.82
10	05388250	Northeast	770	.686	67.94	38.376	.327	767.69
11	05388500	Northeast	42.8	.456	47.45	50.484	.361	41.61
12	05389400	Northeast	34.13	.851	86.71	47.945	.180	34.30
13	05410490	Northeast	687	.852	84.95	110.402	.137	699.75
14	05411400	Northeast	27.6	.830	84.58	43.300	.183	27.61
15	05411600	Northeast	177	.586	60.99	37.982	.410	176.49
16	05412060	Northeast	4.39	.632	68.93	35.542	.505	4.37
17	05412100	Northeast	70.7	.563	55.97	23.685	.693	70.53
18	05412500	Northeast	1,545	.607	60.47	32.589	.357	1,553.30
19	05414500	Northeast	130	.506	52.72	29.291	.357	130.05
20	05414820	Northeast	39.6	.676	67.41	66.290	.207	39.97
21	05417000	Northeast	305	.505	52.48	31.297	.344	307.42
22	05417700	Northeast	61.3	.508	51.80	26.928	.420	60.41
23	05418450	Northeast	516	.659	67.58	51.512	.241	514.11
24	05418500	Northeast	1,553	.648	64.28	33.427	.285	1,550.93
25	05420000	Northeast	230	.575	58.72	32.398	.421	230.43
26	05420560	Northeast	95.2	.477	46.65	36.064	.455	96.44
27	05421000	Northeast	1,048	.536	50.06	17.914	.493	1,052.54
28	05422000	Northeast	2,336	.655	65.38	28.724	.410	2,335.58
29	05422470	NU	17.8	.535	59.06	23.054	.493	18.11
30	05422560	Southern	16.1	.556	55.72	21.745	.584	15.52
31	05422600	Southern	57.3	.439	41.74	17.630	.526	57.32
32	05435500	Northeast	1,326	.765	76.08	59.951	.234	1,336.74
33	05444000	Northeast	146	.695	69.60	57.395	.267	146.91
34	05448000	Southern	62.4	.491	51.38	22.239	.604	62.85

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	Interpolated BFI from kriged grid (ratio of mean annual streamflow that is base flow)	Interpolated TAU_ANN from kriged grid (days)	Interpolated STREAM_VAR from kriged grid	SOILA-SSURGO (percent area)	SOILB-SSURGO (percent area)	SOILC-SSURGO (percent area)	KSATSSUR (µm/s)	DRNFREQ (number of first-order streams/mi²)	RSD
1	0.528	25.497	0.676	4.482	90.649	2.845	14.825	0.473	0.327
2	.568	27.813	.573	4.197	58.756	25.671	8.754	.392	.326
3	.700	56.518	.285	.997	96.195	1.703	12.021	2.023	.377
4	.767	61.194	.218	.000	97.615	1.843	12.878	1.293	.346
5	.650	41.948	.350	1.364	89.434	7.271	13.744	1.438	.315
6	.761	52.450	.278	2.634	93.949	1.793	13.394	1.598	.319
7	.663	45.084	.327	2.230	89.157	6.637	13.467	1.410	.328
8	.649	50.188	.293	.959	95.506	2.679	11.420	1.497	.320
9	.617	35.983	.377	1.767	86.561	6.650	19.201	1.180	.282
10	.609	36.522	.373	1.955	89.294	5.042	18.422	1.269	.282
11	.613	41.451	.329	3.159	89.473	5.576	12.990	1.370	.275
12	.613	37.068	.343	.001	99.367	.393	18.444	1.633	.265
13	.772	54.134	.206	.855	90.974	7.376	16.296	1.776	.329
14	.613	37.068	.343	.275	98.700	.474	25.819	1.847	.299
15	.576	31.951	.396	3.828	81.255	7.548	28.982	.907	.285
16	.613	30.938	.403	.088	98.001	1.839	9.118	.916	.361
17	.599	31.251	.400	.224	96.745	2.783	10.206	1.106	.285
18	.573	32.097	.395	2.015	87.796	4.788	20.819	1.329	.291
19	.603	33.645	.381	.382	93.563	5.415	14.819	1.699	.271
20	.624	40.716	.336	.000	94.411	2.464	8.968	1.601	.250
21	.570	28.339	.444	8.131	86.489	3.682	24.738	1.376	.314
22	.571	24.960	.467	1.104	95.346	2.976	10.383	1.755	.289
23	.584	33.484	.386	4.270	91.110	1.565	16.531	1.558	.280
24	.577	30.516	.416	6.318	89.583	1.941	19.224	1.527	.290
25	.659	41.669	.395	.000	89.225	7.778	8.260	2.226	.373
26	.601	29.732	.434	1.156	90.905	7.049	17.800	.798	.243
27	.577	29.042	.441	3.601	92.502	2.604	21.769	1.043	.314
28	.559	27.220	.461	7.138	89.391	2.038	21.466	1.240	.328
29	.533	24.213	.499	.106	88.506	3.148	9.936	1.380	.363
30	.534	24.213	.499	.000	92.037	7.755	8.858	3.609	.425
31	.533	24.213	.499	.000	90.469	3.350	8.972	2.198	.447
32	.708	53.256	.272	.148	83.242	6.151	9.091	1.669	.279
33	.659	41.988	.457	.351	98.424	.086	9.644	2.784	.400
34	.541	24.679	.548	.000	99.404	.000	8.991	1.846	.381

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed BFI (mean ratio of base flow to annual streamflow)	Observed HYSEP (median percentage of base flow to annual streamflow)	Observed TAU_ANN (days)	Observed STREAM_VAR	GIS drainage area, DRNAREA (mi²)
35	05449000	Northwest	133	.589	58.46	21.541	.594	133.87
36	05449500	Northwest	418	0.577	57.13	24.954	0.514	427.13
37	05451210	Northeast	224	.573	57.94	15.326	.627	223.69
38	05451500	Southern	1,532	.585	57.72	24.613	.484	1,534.17
39	05451700	Southern	118	.578	57.39	25.385	.570	119.74
40	05451900	Southern	56.1	.518	49.71	26.111	.541	56.07
41	05452000	Northeast	201	.552	53.34	27.898	.484	199.28
42	05452200	Southern	70.9	.497	50.28	23.748	.612	70.54
43	05453000	Southern	189	.551	54.17	26.803	.541	186.75
44	05453100	Southern	2,794	.598	62.50	34.446	.463	2,792.77
45	05454000	Southern	25.3	.448	47.69	18.389	.932	25.28
46	05454220	Southern	58.4	.593	61.52	21.703	.509	60.80
47	05454300	Southern	98.1	.470	51.00	23.620	.539	98.18
48	05455000	Southern	3.01	.419	42.20	18.438	.564	3.11
49	05455010	Southern	2.94	.320	36.01	14.746	.695	2.94
50	05455100	Southern	201	.497	50.76	19.649	.663	201.42
51	05455500	Southern	574	.398	40.18	19.329	.636	574.10
52	05457000	Northeast	399	.574	57.25	31.342	.372	397.66
53	05457700	Northeast	1,054	.599	58.02	32.936	.353	1,074.95
54	05458000	Northeast	306	.522	50.60	28.745	.452	294.96
55	05458500	Northeast	1,661	.602	60.84	27.576	.366	1,670.93
56	05458900	Northeast	846	.636	62.59	30.472	.462	850.51
57	05459000	Northeast	300	.620	61.33	23.637	.497	301.80
58	05459500	Northwest	526	.618	61.51	23.158	.504	516.76
59	05462000	Northeast	1,746	.651	64.89	27.659	.405	1,730.93
60	05463000	Northeast	347	.563	54.56	30.092	.471	351.39
61	05463500	Northeast	303	.556	54.51	27.121	.485	298.32
62	05464000	Northeast	5,146	.633	63.00	27.240	.377	5,149.46
63	05464130	Northeast	13.78	.448	47.98	21.223	.641	13.83
64	05464133	Northeast	1.33	.506	47.81	25.870	.565	1.40
65	05464137	Northeast	19.51	.485	51.42	24.850	.572	19.51
66	05464500	Northeast	6,510	.644	64.25	31.398	.376	6,505.95
67	05464640	Southern	178	.521	52.69	26.733	.496	178.40
68	05465000	Southern	7,787	.655	66.81	36.817	.365	7,782.62
69	05465500	NU	12,500	.672	67.85	33.790	.372	12,493.94

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	Interpolated BFI from kriged grid (ratio of mean annual stream-flow that is base flow)	Interpolated TAU_ANN from kriged grid (days)	Interpolated STREAM_VAR from kriged grid	SOILA-SSURGO (percent area)	SOILB-SSURGO (percent area)	SOILC-SSURGO (percent area)	KSATSSUR (µm/s)	DRNFREQ (number of first-order streams/mi²)	RSD
35	.576	23.571	.540	4.535	91.166	3.709	16.867	.291	.418
36	0.574	22.924	0.564	4.611	90.046	4.121	16.403	0.389	0.488
37	.547	21.152	.610	1.040	97.822	.498	10.133	.590	.462
38	.553	22.425	.590	2.055	94.501	2.361	13.865	.690	.437
39	.542	24.208	.595	.014	96.434	2.321	8.475	1.662	.340
40	.531	24.554	.582	.283	87.009	12.074	8.533	2.176	.371
41	.543	25.352	.547	.335	96.420	2.943	9.304	1.706	.321
42	.531	24.396	.582	.264	82.401	16.696	8.142	1.786	.380
43	.531	22.638	.641	.332	79.425	19.100	8.107	1.772	.359
44	.544	23.261	.589	1.609	91.770	5.372	11.846	1.111	.394
45	.507	24.022	.569	.000	98.974	.681	8.951	1.662	.302
46	.491	24.097	.587	5.955	87.240	5.885	14.050	1.628	.404
47	.491	24.111	.586	8.444	85.429	4.871	15.222	1.508	.379
48	.507	24.133	.586	.000	99.834	.118	8.977	1.927	.313
49	.507	24.133	.586	.000	99.835	.082	8.985	1.699	.336
50	.493	23.631	.603	.217	87.391	11.465	7.529	1.872	.359
51	.465	22.970	.626	.587	73.070	24.413	7.182	1.688	.340
52	.588	33.527	.438	3.871	84.691	6.928	19.993	.581	.315
53	.582	31.360	.444	1.790	88.344	6.177	19.777	.549	.336
54	.591	29.591	.443	.836	86.685	11.622	17.036	.949	.319
55	.583	30.459	.446	1.933	88.640	6.512	19.699	.744	.340
56	.578	23.708	.534	1.866	96.096	.893	20.705	.804	.376
57	.576	26.881	.527	8.621	79.024	7.182	17.681	.295	.373
58	.571	24.779	.535	7.089	85.462	3.871	19.348	.432	.452
59	.574	25.698	.513	4.566	87.069	4.903	21.266	.594	.390
60	.576	23.680	.558	.520	97.528	1.158	14.492	1.192	.337
61	.545	24.419	.542	.274	97.997	1.151	14.302	1.177	.346
62	.576	27.467	.486	3.203	90.147	4.105	21.061	.752	.355
63	.545	24.229	.578	.000	98.861	1.116	8.905	1.157	.386
64	.545	24.336	.592	.000	97.140	2.854	8.822	1.433	.609
65	.545	24.260	.582	.000	97.674	2.278	8.857	1.179	.377
66	.565	26.148	.505	4.317	89.594	3.400	21.380	.880	.357
67	.507	25.098	.534	1.268	97.469	.510	10.850	1.328	.341
68	.559	25.757	.509	4.769	89.583	3.105	20.475	.982	.359
69	.544	24.751	.542	4.186	88.819	5.657	11.791	1.090	.364

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed BFI (mean ratio of base flow to annual streamflow)	Observed HYSEP (median percentage of base flow to annual streamflow)	Observed TAU_ANN (days)	Observed STREAM_VAR	GIS drainage area, DRNAREA (mi²)
70	05466000	Southern	155	.519	49.90	27.962	.560	155.61
71	05466500	Southern	445	.517	51.14	28.070	.525	442.08
72	05467000	Southern	174	0.544	52.98	25.194	0.552	172.39
73	05468500	Southern	132	.604	61.30	25.420	.416	132.43
74	05469000	Southern	432	.491	47.72	24.373	.343	435.78
75	05469500	Southern	82.9	.521	50.56	22.421	.794	79.02
76	05470000	Northwest	315	.460	47.83	17.350	.760	316.78
77	05470500	Northwest	204	.520	52.70	17.898	.852	209.65
78	05471000	NU	556	.495	49.06	19.207	1.080	558.37
79	05471040	Southern	18.4	.679	65.35	34.171	.524	18.40
80	05471050	Southern	803	.621	64.94	30.224	.544	806.29
81	05471200	Northwest	276	.473	49.56	18.978	.679	277.28
82	05471500	Southern	1,635	.546	54.19	26.253	.561	1,640.23
83	05472500	Southern	730	.466	48.40	22.365	.592	733.88
84	05473400	Southern	533	.268	27.06	16.434	.709	533.17
85	05473500	Southern	106	.328	32.22	12.010	.908	104.81
86	05474000	Southern	4,312	.461	46.25	21.438	.562	4,310.35
87	05476000	NU	1250	.570	58.76	24.838	.761	1,240.18
88	05476500	Northwest	1,372	.561	59.12	26.392	.738	1,390.29
89	05476750	Northwest	2,256	.654	66.88	23.378	.565	2,269.87
90	05478000	Northwest	462	.489	52.89	20.903	.699	464.56
91	05479000	Northwest	1,308	.558	55.23	21.520	.632	1,306.44
92	05480000	Northwest	257	.463	46.49	19.187	.744	251.99
93	05480500	Northwest	4,190	.614	61.12	22.673	.569	4,202.17
94	05481000	Northwest	844	.494	49.27	18.582	.633	846.15
95	05481300	Northwest	5,452	.582	60.18	26.043	.560	5,463.88
96	05481950	Northwest	358	.505	52.83	18.724	.841	370.27
97	05482135	Northwest	233	.639	61.30	23.127	.607	227.44
98	05482170	Northwest	80	.496	49.53	17.200	.966	81.53
99	05482300	Northwest	700	.551	55.09	19.522	.608	696.70
100	05482500	Northwest	1,619	.558	56.56	24.491	.569	1,609.35
101	05483000	Northwest	24	.617	56.19	17.104	.972	23.41
102	05483450	Southern	375	.644	58.51	32.151	.435	381.79
103	05484000	Southern	994	.562	55.52	33.388	.433	986.86
104	05484500	Northwest	3,441	.520	52.16	28.478	.433	3,424.70

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	Interpolated BFI from kriged grid (ratio of mean annual stream-flow that is base flow)	Interpolated TAU_ANN from kriged grid (days)	Interpolated STREAM_VAR from kriged grid	SOILA-SSURGO (percent area)	SOILB-SSURGO (percent area)	SOILC-SSURGO (percent area)	KSATSSUR (µm/s)	DRNFREQ (number of first-order streams/mi²)	RSD
70	.531	21.367	.616	.055	98.691	.953	8.902	1.889	.409
71	.536	23.175	.591	.428	97.844	1.162	9.374	1.948	.389
72	0.539	24.201	0.576	0.358	95.541	3.316	8.841	2.187	0.440
73	.488	23.045	.607	.000	98.092	.948	8.368	1.216	.384
74	.507	24.059	.583	.000	97.820	1.481	8.398	1.526	.326
75	.486	21.513	.641	.000	99.734	.030	8.896	1.316	.375
76	.537	21.500	.627	1.528	88.029	9.376	10.436	.474	.372
77	.535	22.174	.629	1.487	93.732	4.358	11.726	.534	.335
78	.536	21.810	.629	1.589	90.140	7.139	10.941	.500	.355
79	.543	20.823	.689	1.868	94.297	3.068	9.611	1.522	.359
80	.540	21.767	.639	2.110	90.878	5.852	11.974	.639	.320
81	.538	22.398	.641	1.145	97.485	.380	11.571	.750	.394
82	.513	21.872	.649	1.677	89.252	7.648	10.969	.980	.344
83	.448	21.927	.656	1.077	78.133	18.772	7.786	1.744	.319
84	.285	17.308	.722	.611	36.758	51.030	5.431	1.562	.339
85	.370	20.143	.652	.020	58.301	37.894	6.263	1.088	.404
86	.431	20.403	.670	1.323	70.721	23.461	8.469	1.372	.336
87	.525	26.758	.688	1.083	84.398	10.795	12.394	.500	.324
88	.560	24.894	.682	1.349	85.047	10.076	12.307	.567	.352
89	.568	23.093	.664	1.361	89.269	6.391	14.050	.468	.376
90	.564	23.358	.661	2.596	94.841	.165	11.628	.224	.388
91	.568	22.799	.644	1.513	97.005	.266	11.184	.263	.403
92	.572	22.370	.649	1.017	97.832	.279	15.288	.242	.368
93	.568	22.695	.653	1.349	92.914	3.587	13.410	.382	.391
94	.570	21.213	.642	.747	93.672	4.718	11.601	.313	.388
95	.567	22.204	.650	1.363	92.038	4.632	12.920	.374	.388
96	.555	23.205	.628	.805	96.576	1.971	14.299	.494	.350
97	.583	24.512	.615	1.198	96.468	2.082	14.367	.189	.435
98	.583	22.653	.642	.467	98.473	.399	11.357	.135	.511
99	.584	25.401	.612	.866	96.508	1.376	13.383	.254	.469
100	.578	25.400	.617	.675	97.041	.889	12.997	.381	.433
101	.558	27.669	.595	.912	88.728	8.324	8.537	.085	.419
102	.568	29.510	.574	.567	95.435	3.048	11.466	.995	.406
103	.558	29.125	.576	.309	89.712	8.752	9.884	1.186	.362
104	.560	26.361	.607	.469	93.205	5.061	11.546	.658	.429

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed BFI (mean ratio of base flow to annual streamflow)	Observed HYSEP (median percentage of base flow to annual streamflow)	Observed TAU_ANN (days)	Observed STREAM_VAR	GIS drainage area, DRNAREA (mi²)
105	05484650	NU	3,529	.558	53.86	23.513	.487	3,505.11
106	05484800	NU	78	.506	49.88	21.035	.627	76.76
107	05484900	NU	3,625	.548	52.59	22.624	.518	3,602.79
108	05485640	NU	92.7	0.524	50.32	18.296	0.611	91.35
109	05486000	Northwest	349	.373	39.07	19.443	.786	349.31
110	05486490	Southern	503	.373	37.71	24.623	.637	489.37
111	05487470	Southern	460	.230	24.19	18.188	.772	457.59
112	05487540	Southern	6.78	.715	67.35	24.188	.594	6.77
113	05487550	Southern	20.3	.619	58.86	25.493	.605	20.25
114	05487980	Southern	342	.218	22.77	17.405	.763	339.86
115	05488000	Southern	380	.216	20.76	14.469	.892	376.74
116	05488200	Southern	90.1	.252	26.66	14.710	.853	90.66
117	05489000	Southern	374	.225	23.31	19.575	.775	371.90
118	05491000	Southern	105	.214	21.17	13.111	.813	106.25
119	05494300	Southern	87.7	.201	22.90	17.032	.759	87.31
120	05495000	Southern	400	.198	20.52	14.114	.798	395.71
121	05495500	Southern	349	.144	15.25	16.011	.861	349.00
122	05496000	Southern	393	.165	17.85	13.965	.810	398.00
123	05497000	Southern	452	.214	22.53	15.865	.712	443.61
124	05498000	Southern	393	.185	19.74	13.536	.806	386.68
125	05500000	Southern	620	.180	18.70	12.892	.815	620.86
126	05501000	Southern	373	.182	18.39	14.246	.752	366.62
127	05502020	Southern	40.9	.136	14.42	14.650	.760	41.88
128	05502040	Southern	72.7	.243	23.59	16.265	.767	73.06
129	05503000	Southern	2.64	.049	6.23	10.146	.706	2.66
130	05557000	Southern	86.7	.472	45.88	19.859	.844	85.97
131	05568800	Southern	62.7	.579	56.24	24.549	.562	63.20
132	05570000	Southern	1,635.8	.465	48.12	23.138	.547	1,637.87
133	05584400	Southern	26.3	.513	53.84	19.877	.803	26.75
134	05584500	Southern	655	.330	33.99	17.038	.702	663.48
135	05585000	Southern	1293	.300	30.93	19.241	.657	1,312.34
136	06478518	Northwest	304	.636	63.76	33.437	.295	315.20
137	06480400	Northwest	63.2	.454	47.02	37.629	.518	61.58
138	06480650	Northwest	100	.431	43.53	24.357	.807	100.18
139	06481500	Northwest	622	.547	57.16	19.916	.815	620.96

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	Interpolated BFI from kriged grid (ratio of mean annual streamflow that is base flow)	Interpolated TAU_ANN from kriged grid (days)	Interpolated STREAM_VAR from kriged grid	SOILA-SSURGO (percent area)	SOILB-SSURGO (percent area)	SOILC-SSURGO (percent area)	KSATSSUR (µm/s)	DRNFREQ (number of first-order streams/mi^2)	RSD
105	.556	26.320	.608	.460	92.915	5.217	11.469	.671	.425
106	.551	24.581	.651	.000	90.300	.000	10.392	.951	.366
107	.555	26.273	.609	.448	92.764	5.082	11.434	.677	.424
108	0.551	21.203	0.678	0.317	96.453	0.000	9.488	0.712	0.436
109	.358	24.509	.652	.086	67.974	26.924	7.403	1.294	.302
110	.373	23.364	.673	.149	59.308	35.717	6.566	1.759	.294
111	.284	19.126	.737	.034	32.343	60.668	4.708	2.017	.328
112	.543	20.823	.689	.000	92.020	7.582	7.985	1.182	.403
113	.527	20.823	.689	.000	86.138	13.088	7.552	1.185	.346
114	.232	17.790	.751	.022	12.724	80.411	3.691	2.204	.323
115	.237	17.754	.752	.033	16.290	77.322	3.843	2.182	.320
116	.283	17.395	.755	.000	19.186	76.902	3.701	1.886	.342
117	.228	16.811	.748	.058	16.717	72.827	4.226	2.256	.308
118	.255	15.291	.743	1.361	12.081	59.974	4.320	1.534	.282
119	.222	14.894	.735	.000	15.622	59.180	3.668	1.695	.352
120	.213	14.905	.748	.090	11.521	62.291	3.952	4.579	.843
121	.227	15.533	.752	.000	55.098	34.107	5.647	1.845	.302
122	.197	14.295	.757	.000	5.718	63.130	3.412	1.334	.282
123	.193	14.079	.752	.000	7.255	66.940	3.672	1.776	.284
124	.188	13.365	.753	.000	4.711	66.293	3.525	1.797	.282
125	.187	12.895	.738	.000	2.792	57.104	3.650	1.419	.283
126	.186	12.740	.733	.000	5.205	41.973	3.738	1.432	.299
127	.224	14.954	.755	.188	60.571	38.679	7.982	2.364	.282
128	.210	14.922	.757	.108	69.003	29.994	9.093	2.382	.283
129	.185	12.865	.742	.000	.000	9.931	2.294	1.501	.235
130	.560	31.914	.580	2.630	96.162	1.157	16.034	1.012	.237
131	.531	21.134	.620	.021	92.291	7.495	7.894	2.927	.406
132	.513	22.260	.647	.040	89.465	8.774	8.172	1.834	.358
133	.437	21.513	.641	.000	99.817	.012	7.127	1.196	.452
134	.327	18.150	.703	.000	76.463	19.606	6.980	1.491	.330
135	.315	17.936	.709	.000	70.962	22.893	6.591	1.651	.320
136	.620	35.821	.409	7.867	88.477	2.304	17.163	1.240	.257
137	.496	27.396	.674	.313	93.284	4.967	24.155	1.039	.228
138	.496	27.396	.674	1.733	95.314	.761	18.963	1.118	.189
139	.509	25.044	.604	1.064	71.476	15.193	10.344	.636	.301

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi^2)	Observed BFI (mean ratio of base flow to annual streamflow)	Observed HYSEP (median percentage of base flow to annual streamflow)	Observed TAU_ANN (days)	Observed STREAM_VAR	GIS drainage area, DRNAREA (mi^2)
140	06482610	NU	464	.531	53.20	22.952	.512	482.77
141	06483500	Northwest	1,592	.565	55.35	25.446	.610	1,583.94
142	06485696	Northwest	204	.567	55.56	23.445	.535	205.55
143	06600000	Northwest	65.1	.595	59.01	39.074	.372	64.97
144	06600100	Northwest	268	0.565	57.81	24.380	0.611	267.17
145	06600300	Northwest	180	.537	54.82	29.465	.662	180.57
146	06600500	Northwest	886	.658	65.22	34.453	.461	886.46
147	06601000	Southern	174	.660	66.11	42.933	.357	173.97
148	06602020	Southern	403	.635	62.93	43.569	.366	402.20
149	06602400	Southern	900	.649	63.13	38.164	.339	928.97
150	06605000	Northwest	426	.642	64.43	26.124	.588	440.37
151	06605600	Northwest	1,334	.516	54.01	24.685	.565	1,352.59
152	06605850	Northwest	1,548	.628	62.71	23.849	.576	1,567.26
153	06606600	Northwest	2,500	.653	63.62	29.013	.526	2,519.63
154	06607000	Southern	39.3	.615	60.48	38.402	.480	39.67
155	06607200	Southern	669	.661	67.02	38.063	.411	670.05
156	06607500	Southern	3,526	.642	64.60	32.327	.467	3,552.93
157	06608000	NU	23.0	.392	39.11	35.931	.546	22.93
158	06608500	Southern	407	.654	64.08	44.432	.370	408.56
159	06609500	Southern	871	.613	63.38	36.039	.432	870.20
160	06610500	Southern	7.99	.594	61.99	31.160	.485	6.95
161	06610520	Southern	32	.396	41.30	36.670	.624	33.00
162	06799385	NU	204	.383	33.37	36.147	.411	206.46
163	06799450	NU	731	.592	59.69	37.074	.347	748.17
164	06799500	NU	1,015	.666	67.12	42.947	.318	1,035.35
165	06803510	Southern	43.6	.458	46.68	31.276	.326	43.13
166	06803530	Southern	120	.445	39.55	36.620	.317	119.80
167	06804000	Southern	273	.539	49.00	56.655	.290	272.27
168	06806000	Southern	30.4	.542	51.04	37.927	.304	30.30
169	06806500	NU	241	.525	53.53	34.533	.427	241.39
170	06807410	Southern	609	.644	64.62	40.636	.441	610.58
171	06808500	Southern	1,326	.664	66.08	51.883	.388	1,328.69
172	06809000	Southern	26	.503	53.86	28.214	.644	26.31
173	06809210	Southern	436	.573	57.34	32.577	.477	439.67
174	06809500	Southern	894	.600	59.68	32.882	.449	894.50

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	Interpolated BFI from kriged grid (ratio of mean annual stream-flow that is base flow)	Interpolated TAU_ANN from kriged grid (days)	Interpolated STREAM_VAR from kriged grid	SOILA-SSURGO (percent area)	SOILB-SSURGO (percent area)	SOILC-SSURGO (percent area)	KSATSSUR (µm/s)	DRNFREQ (number of first-order streams/mi^2)	RSD
140	.511	26.034	.660	.316	92.899	5.404	13.360	.990	.245
141	.549	25.539	.637	1.190	96.671	1.244	15.314	1.138	.258
142	.585	30.888	.477	.647	93.432	3.910	9.534	1.027	.282
143	.623	34.545	.459	.000	99.657	.000	9.044	1.709	.310
144	0.582	25.617	0.605	0.050	97.284	2.100	9.550	1.100	0.304
145	.581	28.584	.536	.014	96.759	2.817	8.892	1.656	.345
146	.594	29.299	.538	.031	97.916	1.519	9.243	1.375	.323
147	.581	38.432	.394	.000	97.549	1.893	7.382	1.805	.304
148	.617	32.686	.494	.010	98.708	.313	9.034	1.579	.314
149	.617	35.345	.455	.062	78.957	1.250	7.528	1.477	.333
150	.570	24.702	.645	.913	94.052	3.539	22.500	.738	.365
151	.569	24.573	.659	1.717	86.771	7.275	21.562	.562	.397
152	.570	24.533	.654	1.607	88.007	6.650	20.237	.588	.398
153	.579	26.054	.619	1.357	90.804	4.941	16.755	.840	.349
154	.600	28.164	.587	.401	93.111	6.361	9.566	1.361	.317
155	.606	31.185	.538	.193	96.638	2.607	9.107	1.470	.292
156	.588	28.024	.589	1.005	92.160	4.164	14.674	1.020	.332
157	.549	39.493	.399	.136	97.974	.000	5.802	1.832	.300
158	.596	36.504	.472	.001	99.390	.165	9.034	1.623	.298
159	.584	33.430	.519	.156	96.909	1.955	9.310	1.407	.299
160	.566	36.538	.468	.000	98.537	.000	9.053	1.440	.331
161	.568	36.584	.470	.000	99.720	.270	8.935	1.000	.430
162	.512	40.401	.359	.005	95.321	4.349	6.245	1.443	.279
163	.576	38.570	.376	1.212	91.737	5.366	8.349	1.329	.307
164	.565	39.046	.375	.876	90.164	7.018	7.498	1.298	.302
165	.394	34.671	.362	.000	76.445	5.660	3.528	1.855	.217
166	.453	35.889	.362	.000	89.335	4.995	5.404	1.895	.225
167	.470	36.882	.361	.000	90.662	5.159	6.585	1.451	.248
168	.464	33.889	.470	.000	97.950	.000	9.040	1.155	.306
169	.464	30.054	.398	.000	78.298	.460	3.622	1.719	.246
170	.561	33.185	.534	.027	92.219	7.247	8.417	1.608	.339
171	.553	34.148	.508	.016	92.756	6.650	8.501	1.617	.344
172	.553	29.040	.570	.354	89.944	8.632	31.225	1.102	.364
173	.543	31.778	.547	.229	82.181	15.827	7.789	1.517	.309
174	.533	31.516	.550	.153	81.534	16.172	7.803	1.596	.313

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi², square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	Low-flow region	Published drainage area (mi²)	Observed BFI (mean ratio of base flow to annual streamflow)	Observed HYSEP (median percentage of base flow to annual streamflow)	Observed TAU_ANN (days)	Observed STREAM_VAR	GIS drainage area, DRNAREA (mi²)
175	06810000	Southern	2,806	.616	62.73	39.348	.419	2,809.05
176	06810500	NU	218	.316	30.75	20.473	.534	209.13
177	06811500	Southern	792	.398	39.78	29.345	.398	793.13
178	06811840	Southern	49.3	.417	43.52	26.814	.798	50.12
179	06813000	Southern	508	.460	46.14	29.581	.574	479.35
180	06814500	Southern	548	0.300	30.98	25.518	0.422	548.99
181	06815000	NU	1,339	.306	31.46	23.846	.488	ND
182	06815500	Southern	188	.407	41.30	31.576	.331	186.57
183	06816000	Southern	4.90	.475	46.92	31.879	.432	4.96
184	06817000	Southern	762	.445	43.17	28.221	.525	761.32
185	06817500	Southern	1,240	.326	33.62	27.010	.575	1,293.70
186	06817700	Southern	1,380	.454	45.09	26.190	.537	1,516.23
187	06818750	Southern	217	.296	31.70	26.444	.669	215.75
188	06818900	Southern	486	.215	22.86	15.810	.618	485.80
189	06819185	Southern	85.4	.239	22.65	21.377	.821	85.78
190	06819190	Southern	92.1	.178	18.39	17.623	.840	92.04
191	06819500	Southern	500	.204	22.35	16.698	.791	491.03
192	06820000	Southern	6.00	.155	17.65	12.163	.465	6.06
193	06896500	Southern	5.58	.147	15.48	12.893	.433	5.45
194	06897000	Southern	95.0	.166	17.18	10.910	.968	90.80
195	06897500	Southern	2,250	.248	23.79	20.843	.695	2,245.71
196	06897950	Southern	52.5	.168	16.56	13.600	1.024	52.26
197	06898000	Southern	701	.285	29.20	18.442	.688	695.38
198	06898100	Southern	891	.354	33.08	25.582	.583	856.10
199	06898400	Southern	104	.147	15.77	19.759	.828	101.79
200	06898500	Southern	246	.119	4.81	10.531	.227	250.58
201	06899000	Southern	494	.142	14.91	17.258	.794	479.87
202	06900000	Southern	225	.235	22.24	16.489	.699	231.89
203	06901500	Southern	550	.193	20.20	17.735	.736	554.36
204	06902500	Southern	2.51	.099	12.75	9.420	.458	2.54
205	06903400	Southern	182	.182	18.98	12.043	.958	185.68
206	06903500	Southern	13.2	.235	19.73	20.883	.509	13.30
207	06903700	Southern	168	.184	20.02	13.825	.829	169.52
208	06904500	Southern	1,370	.238	24.70	12.487	.810	1,364.30

Table 3. Hydrologic characteristics computed from observed streamflow and basin characteristics measured for streamgages evaluated in study.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; BFI, base-flow index; HYSEP, hydrograph separation and analysis of base flow; TAU_ANN, annual base-flow-recession time constant; STREAM_VAR, streamflow-variability index; GIS, geographic information system; SOILASSURGO, hydrologic soil type A; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; KSATSSUR, average soil permeability; µm/s, micrometer per second; DRNFREQ, drainage frequency; RSD, relative stream density; NU, streamgage not used in development of regional-regression equations. Streamgage locations are shown in figure 1]

Map number	Interpolated BFI from kriged grid (ratio of mean annual streamflow that is base flow)	Interpolated TAU_ANN from kriged grid (days)	Interpolated STREAM_VAR from kriged grid	SOILA-SSURGO (percent area)	SOILB-SSURGO (percent area)	SOILC-SSURGO (percent area)	KSATSSUR (µm/s)	DRNFREQ (number of first-order streams/mi^2)	RSD
175	.531	32.503	.523	.072	88.529	10.216	8.290	1.593	.330
176	.435	29.901	.390	.003	29.497	2.712	2.569	1.817	.236
177	.401	29.251	.402	.012	37.169	4.823	2.889	1.693	.234
178	.433	30.070	.563	.000	77.288	12.941	7.311	1.676	.375
179	.392	26.963	.549	.001	75.816	21.684	6.663	1.957	.322
180	0.336	27.258	0.397	0.006	32.560	4.941	3.245	1.874	0.235
181	ND	ND	ND	ND	ND	ND	ND	ND	ND
182	.352	27.478	.437	.000	37.817	5.326	2.858	1.844	.251
183	.366	27.054	.493	.000	99.732	.000	8.864	1.411	.383
184	.460	27.598	.601	.302	67.507	28.350	6.573	1.982	.313
185	.414	26.760	.601	.221	63.240	31.941	6.072	2.099	.312
186	.398	26.482	.593	.188	61.743	33.966	5.804	2.104	.308
187	.266	22.701	.676	.241	61.455	28.365	5.728	1.826	.346
188	.271	21.117	.678	.122	48.996	42.133	5.063	2.120	.329
189	.304	19.874	.701	.000	49.237	45.000	5.336	1.994	.336
190	.308	19.874	.701	.000	48.849	45.000	5.321	1.988	.335
191	.329	21.954	.648	.000	48.539	46.000	5.074	2.464	.335
192	.293	24.507	.537	.000	27.176	73.000	2.364	3.466	.422
193	.223	19.786	.624	.000	7.837	91.856	2.203	4.951	.347
194	.210	17.587	.697	.000	7.401	83.539	3.178	3.921	.398
195	.249	19.680	.658	.011	15.683	77.525	3.189	3.510	.348
196	.224	18.023	.751	.006	19.312	75.250	3.814	2.794	.314
197	.278	20.668	.717	.108	32.729	59.838	4.702	2.379	.307
198	.265	20.094	.714	.112	29.347	63.136	4.501	2.546	.309
199	.191	16.536	.757	.003	18.816	67.443	3.846	1.768	.265
200	.193	16.068	.758	.003	21.345	66.881	3.957	1.848	.267
201	.197	16.461	.748	.133	19.492	69.727	3.780	2.930	.325
202	.206	15.715	.739	.000	12.368	76.911	3.327	2.493	.323
203	.210	15.469	.716	.000	11.229	80.446	3.417	2.493	.311
204	.212	14.001	.683	.000	3.224	87.231	2.453	.789	.253
205	.191	16.000	.759	.043	8.858	73.825	3.186	1.707	.329
206	.192	15.789	.755	.000	1.850	86.501	3.191	2.030	.391
207	.192	15.734	.760	.003	17.984	58.410	3.440	1.935	.323
208	.197	14.840	.739	.122	10.896	68.601	3.402	1.905	.304

Table 5. Basin characteristics tested for significance in developing regression equations.

[USGS, U.S. Geological Survey; DEM, digital elevation model; WBD, watershed boundary dataset; m, meters; 24K, 1:24,000 scale; BFI, base-flow index; HYSEP, hydrograph separation and analysis; TAU_ANN, annual base-flow-recession time constant; NHD, national hydrography dataset; NRSC, Natural Resource Conservation Service; SSURGO, Soil Survey Geographic database; IDNR, Iowa Department of Natural Resources; PRISM, parameter-elevation regressions on independent slopes model]

Morphometric characteristics	Source
DRNAREA—Drainage area (square miles)	USGS DEM (10 m), WBD (24k)
BASINPERIM—Basin perimeter (miles)	USGS DEM (10 m), WBD (24k)
BASLEN—Basin length (miles)	USGS DEM (150 m), WBD (24k)
BSLDEM10M—Average basin slope computed from 10 m DEM (percent)	USGS DEM (10 m)
RELIEF—Basin relief computed as maximum elevation minus minimum elevation (feet)	USGS DEM (10 m)
RELRELF—Relative relief computed as RELIEF divided by BASINPERIM (feet per mile)	USGS DEM (10 m), WBD (24k)
SHAPE—Shape factor measure of basin shape computed as BASLEN squared divided by DRNAREA (dimensionless)	USGS DEM (10 m), WBD (24k)
ELONGRATIO—Elongation ratio measure of basin shape (dimensionless) (Eash, 2001)	USGS DEM (10 m), WBD (24k)
ROTUND—Rotundity of basin measure of basin shape (dimensionless) (Eash, 2001)	USGS DEM (10 m), WBD (24k)
COMPRAT—Compactness ratio measure of basin shape (dimensionless) (Eash, 2001)	USGS DEM (10 m), WBD (24k)
LENGTH—Main-channel length as measured from basin outlet to basin divide (miles)	USGS DEM NHD (24k)
MCSR—Main-channel sinuosity ratio computed as LENGTH divided by BASLEN (dimensionless)	USGS DEM (10 m), WBD, NHD (24k)
STRMTOT—Total length of mapped streams in basin (miles)	USGS DEM NHD (24k)
STRDEN—Stream density computed as STRMTOT divided by DRNAREA (miles per square mile)	USGS DEM (10 m), WBD, NHD (24k)
SLENRAT—Slenderness ratio computed as LENGTH squared divided by DRNAREA (dimensionless)	USGS DEM (10 m), WBD, NHD (24k)
CCM—Constant of channel maintenance computed as DRNAREA divided by STRMTOT (square miles per mile)	USGS DEM (10 m), WBD, NHD (24k)
CSL1085LFP—Stream slope computed as the change in elevation between points 10 and 85 percent of length along the longest flow path determined by a GIS divided by length between the points (feet per mile)	USGS DEM (10 m), NHD (24k)
CSL100—Stream slope computed as entire LENGTH (feet per mile)	USGS DEM (10 m), NHD (24k)
MCSP—Main-channel slope proportion computed as LENGTH divided by the square root of CSL1085LFP (dimensionless)	USGS DEM (10 m), NHD (24k)
RUGGED—Ruggedness number computed as STRMTOT multiplied by RELIEF and divided by DRNAREA (feet per mile)	USGS DEM (10 m), WBD, NHD (24k)
SLOPERAT—Slope ratio computed as CSL1085LFP divided by BSLDEM10M (dimensionless)	USGS DEM (10 m), NHD (24k)
FOSTREAM—Number of first-order streams within basin using the Strahler stream ordering method (dimensionless)	USGS DEM NHD (24k)
DRNFREQ—Drainage frequency computed as FOSTREAM divided by DRNAREA (number of first-order streams per square mile)	USGS DEM (10 m), WBD, NHD (24k)
RSD—Relative stream density computed as FOSTREAM multiplied by DRNAREA and divided by STRMTOT squared (dimensionless)	USGS DEM (10 m), WBD, NHD (24k)
SLOP30—Percent area with slopes greater than 30 percent	USGS DEM (10 m)
NFSL30 – Percent area with slopes greater than 30 percent facing north	USGS DEM (10 m)

Table 5. Basin characteristics tested for significance in developing regression equations.—Continued

[USGS, U.S. Geological Survey; DEM, digital elevation model; WBD, watershed boundary dataset; m, meters; 24K, 1:24,000 scale; BFI, base-flow index; HYSEP, hydrograph separation and analysis; TAU_ANN, annual base-flow-recession time constant; NHD, national hydrography dataset; NRSC, Natural Resource Conservation Service; SSURGO, Soil Survey Geographic database; IDNR, Iowa Department of Natural Resources; PRISM, parameter-elevation regressions on independent slopes model]

Hydrologic characteristics	Source
BFI—Base-flow index is the mean ratio of base flow to annual streamflow (dimensionless) (Wahl and Wahl, 1988)	USGS kriged BFI grid
HYSEP—Hydrograph separation and analysis is the median percentage of baseflow to annual streamflow (percent) (Sloto and Crouse, 1996)	USGS kriged HYSEP grid
TAU_ANN—Annual base-flow-recession time constant computes the rate of baseflow recession between storm events (days) (Eng and Milly, 2007)	USGS kriged TAU_ANN grid
TAU_1012—Seasonal base-flow-recession time constant computed for October to December (days)	USGS kriged TAU_1012 grid
STREAM_VAR—Streamflow-variability index is a measure of the steepness of the slope of a duration curve (dimensionless) (Koltun and Whitehead, 2002)	USGS kriged STREAM_VAR grid
Pedologic/geologic/land-use characteristics	**Source**
SOILASSURGO—Percent area underlain by hydrologic soil type A (percent area)	NRCS SSURGO Web Soil Survey
SOILBSSURGO—Percent area underlain by hydrologic soil type B (percent area)	NRCS SSURGO Web Soil Survey
SOILCSSURGO—Percent area underlain by hydrologic soil type C (percent area)	NRCS SSURGO Web Soil Survey
SOILDSSURGO—Percent area underlain by hydrologic soil type D (percent area)	NRCS SSURGO Web Soil Survey
SAND—Percent volume of sand content of soil (percent volume)	NRCS SSURGO Web Soil Survey
CLAY—Percent volume of clay content of soil (percent volume)	NRCS SSURGO Web Soil Survey
KSATSSUR—Average soil permeability or saturated hydraulic conductivity of soil (micrometers per second)	NRCS SSURGO Web Soil Survey
DESMOIN—Percent area of basin within Des Moines Lobe landform region (percent area)	Iowa Geological & Water Survey, IDNR grid
ROWCROP—Percent area of cultivated crops (percent area), see <*http://www.mrlc.gov/index.php*> and Homer and others (2004)	2001 National Landcover Database grid
Climatic characteristics	**Source**
PRECIP—Mean annual precipitation 1971–2000, see <*http://www.prism.oregonstate.edu/*> (inches)	PRISM Climate Group
PRC1—Mean January precipitation 1971–2000 (inches)	PRISM Climate Group
FEBAVPRE—Mean February precipitation 1971–2000 (inches)	PRISM Climate Group
MARAVPRE—Mean March precipitation 1971–2000 (inches)	PRISM Climate Group
PRC4—Mean April precipitation 1971–2000 (inches)	PRISM Climate Group
MAYAVEPRE– Mean May precipitation 1971–2000 (inches)	PRISM Climate Group
JUNEAVPRE—Mean June precipitation 1971–2000 (inches)	PRISM Climate Group
JULYAVPRE—Mean July precipitation 1971–2000 (inches)	PRISM Climate Group
PRC8—Mean August precipitation 1971–2000 (inches)	PRISM Climate Group
SEPAVPRE—Mean September precipitation 1971–2000 (inches)	PRISM Climate Group
OCTAVPRE—Mean October precipitation 1971–2000 (inches)	PRISM Climate Group
NOVAVPRE—Mean November precipitation 1971–2000 (inches)	PRISM Climate Group
DECAVPRE—Mean December precipitation 1971–2000 (inches)	PRISM Climate Group
PRC10_12—Mean October to December precipitation 1971–2000 (inches)	PRISM Climate Group

Table 14. Range of basin-characteristic values used to develop selected low-flow frequency and harmonic-mean-flow regression equations for unregulated streams in Iowa.

[DRNAREA, GIS drainage area; TAU_ANN, annual base-flow-recession time constant; KSATSSUR, average soil permeability; STREAM_VAR, streamflow-variability index; DRNFREQ, drainage frequency; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; NA, not applicable; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow; BFI, base-flow index; SOILASSURGO, hydrologic soil type A; RSD, relative stream density; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C; GLS, generalized least-squares regression]

Northeast Region

Statistic equation	DRNAREA		TAU_ANN		KSATSSUR		STREAM_VAR		DRNFREQ	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
M1D10Y	1.40	6,505.95	21.2	61.2	8.260	29.0	NA	NA	NA	NA
M7D10Y	1.40	6,505.95	21.2	61.2	8.260	29.0	NA	NA	NA	NA
M30D10Y	1.40	6,505.95	21.2	61.2	8.260	29.0	NA	NA	NA	NA
M30D5Y	1.40	6,505.95	21.2	61.2	8.260	29.0	NA	NA	NA	NA
M1D10Y1012	1.40	6,505.95	21.2	61.2	8.260	29.0	NA	NA	NA	NA
M7D10Y1012	1.40	6,505.95	21.2	61.2	8.260	29.0	NA	NA	NA	NA
QAH	1.40	6,505.95	NA	NA	NA	NA	0.206	0.610	0.295	2.78

Northwest Region

	DRNAREA		BFI		SOILASSURGO		TAU_ANN		RSD	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
M1D10Y	23.41	5,463.88	0.358	0.623	0.000	7.87	NA	NA	NA	NA
M7D10Y	23.41	5,463.88	.358	.623	.000	7.87	NA	NA	NA	NA
M30D10Y	23.41	5,463.88	.358	.623	.000	7.87	NA	NA	NA	NA
M30D5Y	23.41	5,463.88	.358	.623	.000	7.87	NA	NA	NA	NA
M1D10Y1012	23.41	5,463.88	.358	.623	.000	7.87	NA	NA	NA	NA
M7D10Y1012	23.41	5,463.88	.358	.623	.000	7.87	NA	NA	NA	NA
QAH	23.41	5,463.88	NA	NA	NA	NA	21.2	35.8	0.189	0.511

Southern Region

	DRNAREA		STREAM_VAR		SOILBSSURGO		BFI		SOILCSSURGO	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Logistic M1D10Y	2.54	7,782.62	NA	NA	NA	NA	0.185	0.617	NA	NA
GLS M1D10Y	15.52	7,782.62	0.361	0.760	2.79	99.4	NA	NA	NA	NA
Logistic M7D10Y	2.54	7,782.62	NA	NA	NA	NA	.185	.617	NA	NA
GLS M7D10Y	15.52	7,782.62	.361	.760	2.79	99.7	NA	NA	NA	NA
Logistic M30D10Y	2.54	7,782.62	NA	NA	NA	NA	.185	.617	NA	NA
GLS M30D10Y	2.94	7,782.62	.361	.760	2.79	99.8	NA	NA	NA	NA
Logistic M30D5Y	2.54	7,782.62	NA	NA	NA	NA	.185	.617	NA	NA
GLS M30D5Y	2.94	7,782.62	.361	.760	2.79	99.8	NA	NA	NA	NA
Logistic M1D10Y1012	2.54	7,782.62	NA	NA	NA	NA	.185	.617	NA	NA
GLS M1D10Y1012	6.77	7,782.62	.361	.760	2.79	99.7	NA	NA	NA	NA
Logistic M7D10Y1012	2.54	7,782.62	NA	NA	NA	NA	.185	.617	NA	NA
GLS M7D10Y1012	6.77	7,782.62	.361	.760	2.79	99.7	NA	NA	NA	NA
QAH	2.54	7,782.62	.361	.760	NA	NA	NA	NA	0.000	91.9

Table 15. Values needed to determine the 90-percent prediction intervals for estimates obtained from regional regression equations using covariance matrices in Iowa.

[*t*, the critical value from Students t-distribution for the 90-percent probability used in equation 11; MEV, regression model error variance used in equation 12; U, covariance matrix as used in equation 12; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; Intercept, y-axis intercept of regression equation; DRNAREA, GIS drainage area; TAU_ANN, annual base-flow-recession time constant; KSATSSUR, average soil permeability; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow; STREAM_VAR, streamflow-variability index; DRNFREQ, drainage frequency; BFI, base-flow index; SOILASSURGO, hydrologic soil type A; RSD, relative stream density; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C]

Response variable	*t*	MEV	U				
			Northeast Region				
M1D10Y	1.6849	0.094433		Intercept	DRNAREA	TAU_ANN	KSATSSUR
			Intercept	7.599114317	-0.017291210	-3.340946820	-2.069765708
			DRNAREA	-.017291210	.076139961	.034377290	-.190210256
			TAU_ANN	-3.340946818	.034377288	1.893205880	.313756238
			KSATSSUR	-2.069765708	-.190210256	.313756240	1.751366356
M7D10Y	1.6849	.101761		Intercept	DRNAREA	TAU_ANN	KSATSSUR
			Intercept	.762503417	-.000897220	-.335973808	-.208716499
			DRNAREA	-.000897220	.007662226	.003190338	-.019486129
			TAU_ANN	-.335973808	.003190338	.191164619	.031199431
			KSATSSUR	-.208716499	-.019486129	.031199431	.177863382
M30D10Y	1.6849	.108373		Intercept	DRNAREA	TAU_ANN	KSATSSUR
			Intercept	.793968482	.000478687	-.351083267	-.219075139
			DRNAREA	.000478687	.008013299	.002886411	-.020961169
			TAU_ANN	-.351083267	.002886411	.201070289	.032009097
			KSATSSUR	-.219075139	-.020961169	.032009097	.188787122
M30D5Y	1.6849	.065895		Intercept	DRNAREA	TAU_ANN	KSATSSUR
			Intercept	.457715110	.002539564	-.204308271	-.129156000
			DRNAREA	.002539564	.004599962	.000978897	-.013011620
			TAU_ANN	-.204308271	.000978897	.118864628	.017930270
			KSATSSUR	-.129156021	-.013011623	.017930274	.113984800
M1D10Y1012	1.6839	.079242		Intercept	DRNAREA	TAU_ANN	KSATSSUR
			Intercept	.544668465	-.003052465	-.247067666	-.134596361
			DRNAREA	-.003052465	.004878885	.002683491	-.010940184
			TAU_ANN	-.247067666	.002683491	.144197798	.017617988
			KSATSSUR	-.134596361	-.010940184	.017617988	.113849923
M7D10Y1012	1.6839	.069064		Intercept	DRNAREA	TAU_ANN	KSATSSUR
			Intercept	.467067779	-.002043783	-.212581552	-.115859593
			DRNAREA	-.002043783	.004193583	.002127599	-.009646189
			TAU_ANN	-.212581552	.002127599	.124687389	.014807554
			KSATSSUR	-.115859593	-.009646189	.014807554	.098972394
QAH	1.6839	.063096		Intercept	DRNAREA	STREAM_VAR	DRNFREQ
			Intercept	.035791870	-.005151654	.060272042	.008821268
			DRNAREA	-.005151654	.002804042	.002412907	.002994435
			STREAM_VAR	.060272042	.002412907	.176496080	.056149500
			DRNFREQ	.008821268	.002994435	.056149500	.078638516

Table 15. Values needed to determine the 90-percent prediction intervals for estimates obtained from regional regression equations using covariance matrices in Iowa.—Continued

[*t*, the critical value from Students t-distribution for the 90-percent probability used in equation 11; MEV, regression model error variance used in equation 12; U, covariance matrix as used in equation 12; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; Intercept, y-axis intercept of regression equation; DRNAREA, GIS drainage area; TAU_ANN, annual base-flow-recession time constant; KSATSSUR, average soil permeability; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow; STREAM_VAR, streamflow-variability index; DRNFREQ, drainage frequency; BFI, base-flow index; SOILASSURGO, hydrologic soil type A; RSD, relative stream density; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C]

Response variable	*t*	MEV	U				
			Northwest Region				
M1D10Y	1.6924	0.139876		Intercept	DRNAREA	BFI	SOILASSURGO
			Intercept	1.116986117	-0.096944921	-2.625551520	-0.001103476
			DRNAREA	-.096944921	.024009167	.099802193	.000288171
			BFI	-2.625551520	.099802193	7.300792106	-.005641572
			SOILASSURGO	-.001103476	.000288171	-.005641572	.001185742
M7D10Y	1.6924	.152881		Intercept	DRNAREA	BFI	SOILASSURGO
			Intercept	1.171136876	-.101006775	-2.763205635	-.000976308
			DRNAREA	-.101006775	.025551256	.100325011	.000271142
			BFI	-2.763205635	.100325011	7.734058520	-.006451345
			SOILASSURGO	-.000976308	.000271142	-.006451345	.001291650
M30D10Y	1.6924	.149073		Intercept	DRNAREA	BFI	SOILASSURGO
			Intercept	.336147131	-.059461701	-.967775525	.000016853
			DRNAREA	-.059461701	.021094851	.021513273	.000042693
			BFI	-.967775525	.021513273	5.145668378	-.012732158
			SOILASSURGO	.000016853	.000042693	-.012732158	.001246902
M30D5Y	1.6924	.106733		Intercept	DRNAREA	BFI	SOILASSURGO
			Intercept	.257940977	-.033739537	-.533918426	.001023266
			DRNAREA	-.033739537	.013442856	-.003647511	-.000049056
			BFI	-.533918426	-.003647511	1.757619808	-.007587411
			SOILASSURGO	.001023267	-.000049056	-.007587411	.000886260
M1D10Y1012	1.6909	.104006		Intercept	DRNAREA	BFI	SOILASSURGO
			Intercept	.353810019	-.036910912	-.797470706	.000205088
			DRNAREA	-.036910912	.013913613	.001272260	.000062751
			BFI	-.797470706	.001272260	2.518883535	-.005931879
			SOILASSURGO	.000205088	.000062751	-.005931879	.000866894
M7D10Y1012	1.6909	.108966		Intercept	DRNAREA	BFI	SOILASSURGO
			Intercept	.286643214	-.034206609	-.616597909	.000495948
			DRNAREA	-.034206609	.013934567	-.006658254	.000030661
			BFI	-.616597909	-.006658254	2.036173814	-.006763448
			SOILASSURGO	.000495948	.000030661	-.006763448	.000905649
QAH	1.6909	.078149		Intercept	DRNAREA	TAU_ANN	RSD
			Intercept	.345129160	-.021457849	-.007853233	-.242009270
			DRNAREA	-.021457849	.007355831	.000235725	-.010169980
			TAU_ANN	-.007853233	.000235725	.000215234	.004742037
			RSD	-.242009270	-.010169980	.004742037	.417416010

Table 15. Values needed to determine the 90-percent prediction intervals for estimates obtained from regional regression equations using covariance matrices in Iowa.—Continued

[*t*, the critical value from Students t-distribution for the 90-percent probability used in equation 11; MEV, regression model error variance used in equation 12; U, covariance matrix as used in equation 12; M1D10Y, annual 1-day mean low flow for a recurrence interval of 10 years; Intercept, y-axis intercept of regression equation; DRNAREA, GIS drainage area; TAU_ANN, annual base-flow-recession time constant; KSATSSUR, average soil permeability; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow for a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow for a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow for a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow for a recurrence interval of 10 years; QAH, harmonic mean flow; STREAM_VAR, streamflow-variability index; DRNFREQ, drainage frequency; BFI, base-flow index; SOILASSURGO, hydrologic soil type A; RSD, relative stream density; SOILBSSURGO, hydrologic soil type B; SOILCSSURGO, hydrologic soil type C]

Response variable	*t*	MEV	U				
Southern region							
M1D10Y	1.6663	0.079258		Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
			Intercept	0.095067686	-0.011671308	-0.095541657	-0.000358963
			DRNAREA	-.011671308	.004691041	-.002870995	.000001022
			STREAM_VAR	-.095541657	-.002870995	.194641660	.000457369
			SOILBSSURGO	-.000358963	.000001022	.000457369	.000002678
M7D10Y	1.6649	.114630		Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
			Intercept	.117828480	-.015261218	-.113299210	-.000455246
			DRNAREA	-.015261218	.006142951	-.004152428	.000004283
			STREAM_VAR	-.113299210	-.004152428	.236293490	.000560245
			SOILBSSURGO	-.000455246	.000004283	.000560245	.000003392
M30D10Y	1.6626	.119068		Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
			Intercept	.173419660	-.012204313	-.175826400	-.000491100
			DRNAREA	-.012204313	.005005351	-.002544634	.000005606
			STREAM_VAR	-.175826400	-.002544634	.254156970	.000480857
			SOILBSSURGO	-.000491100	.000005606	.000480857	.000002804
M30D5Y	1.6614	.098940		Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
			Intercept	.132793520	-.008105183	-.138738960	-.000397572
			DRNAREA	-.008105183	.003230364	-.001694329	.000009210
			STREAM_VAR	-.138738960	-.001694329	.199461740	.000384879
			SOILBSSURGO	-.000397572	.000009210	.000384879	.000002158
M1D10Y1012	1.6636	.083018		Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
			Intercept	.083591716	-.010600974	-.082242062	-.000326449
			DRNAREA	-.010600974	.004049098	-.001421091	.000005334
			STREAM_VAR	-.082242062	-.001421091	.164914150	.000390301
			SOILBSSURGO	-.000326449	.000005334	.000390301	.000002429
M7D10Y1012	1.6632	.071144		Intercept	DRNAREA	STREAM_VAR	SOILBSSURGO
			Intercept	.115965200	-.008228895	-.116654910	-.000325263
			DRNAREA	-.008228895	.003490721	-.002221434	.000002318
			STREAM_VAR	-.116654910	-.002221434	.173249900	.000310996
			SOILBSSURGO	-.000325263	.000002318	.000310996	.000001909
QAH	1.6594	.091578		Intercept	DRNAREA	STREAM_VAR	SOILCSSURGO
			Intercept	.062762333	-.006177235	-.087224045	.000190519
			DRNAREA	-.006177235	.003024484	-.000023460	-.000003348
			STREAM_VAR	-.087224045	-.000023460	.157021380	-.000379627
			SOILCSSURGO	.000190519	-.000003348	-.000379627	-.000001922

Table 17. Estimates of annual mean 7-day low flow for a recurrence interval of 10 years (M7D10Y) statistics computed from observed streamflow, the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations; and absolute differences between the estimates computed from observed streamflow and estimates from the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations for pairs of streamgages used to analyze the applicability of the drainage-area ratio and weighted drainage-area ratio methods for estimating M7D10Y statistics for ungaged sites on gaged Iowa streams.

[USGS, U.S. Geological Survey; GIS, geographic information system; mi², square miles; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	GIS drainage area, DRNAREA (mi²)	Drainage-area ratio	Observed M7D10Y (ft³/s)	Drainage-area ratio method		Weighted drainage-area ratio method			Regional regression equations	
					Estimate (ft³/s)	Absolute difference (percent)	Ratio of observed to predicted M7D10Y statistics (R)	Estimate (ft³/s)	Absolute difference (percent)	Estimate (ft³/s)	Absolute difference (percent)
9	05387500	510.82	0.665	44.67	59.99	34.3	0.951	55.89	25.1	56.81	27.2
10	05388250	767.69	1.503	90.16	67.13	25.5	.786	94.91	5.3	94.79	5.1
15	05411600	176.49	.114	9.12	13.06	43.3	.717	18.67	104.8	15.32	68.1
18	05412500	1,553.30	8.801	114.96	80.23	30.2	.595	1108.45	864.2	160.29	39.4
21	05417000	307.42	.198	34.62	37.53	8.4	1.544	11.17	67.7	16.64	51.9
24	05418500	1,550.93	5.045	189.35	174.64	7.8	2.080	-816.37	531.2	122.60	35.3
26	05420560	96.44	.092	3.85	2.56	33.5	.386	5.07	31.9	3.38	12.2
27	05421000	1,052.54	10.914	27.94	42.00	50.3	1.139	-116.61	517.3	72.36	159.0
27	05421000	1,052.54	.451	27.94	59.41	112.6	.877	73.24	162.1	72.36	159.0
28	05422000	2,335.58	2.219	131.82	62.00	53.0	.386	282.88	114.6	150.25	14.0
36	05449500	427.13	.278	11.08	9.44	14.8	.772	3.35	69.8	3.04	72.5
38	05451500	1,534.17	3.592	33.92	39.80	17.3	3.641	-441.81	1402.5	43.96	29.6
38	05451500	1,534.17	.549	33.92	47.56	40.2	.901	43.53	28.3	43.96	29.6
44	05453100	2,792.77	1.820	86.58	61.75	28.7	.772	110.17	27.2	96.11	11.0
46	05454220	60.80	.619	.69	.62	10.4	1.229	.46	34.0	.43	37.4
47	05454300	98.18	1.615	1.00	1.12	11.6	1.597	.70	29.8	.81	18.6
53	05457700	1,074.95	.643	94.40	90.46	4.2	1.027	89.50	5.2	88.81	5.9
55	05458500	1,670.93	1.554	140.62	146.74	4.4	1.063	135.95	3.3	136.89	2.7
55	05458500	1,670.93	.324	140.62	129.08	8.2	.988	137.45	2.3	136.89	2.7
62	05464000	5,149.46	3.082	397.80	433.36	8.9	1.027	367.80	7.5	402.53	1.2
57	05459000	301.80	.174	5.20	14.81	184.8	1.017	9.37	80.1	9.47	82.1
59	05462000	1,730.93	5.735	84.93	29.82	64.9	.549	402.54	373.9	83.52	1.7
62	05464000	5,149.46	.792	397.80	348.25	12.5	.965	394.34	.9	402.53	1.2
66	05464500	6,505.95	1.263	439.98	502.58	14.2	.988	453.35	3.0	455.89	3.6
66	05464500	6,505.95	.836	439.98	480.82	9.3	.949	440.39	.1	455.89	3.6
68	05465000	7,782.62	1.196	575.17	526.32	8.5	0.965	592.99	3.1	605.83	5.3

Table 17. Estimates of annual mean 7-day low flow for a recurrence interval of 10 years (M7D10Y) statistics computed from observed streamflow, the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations; and absolute differences between the estimates computed from observed streamflow and estimates from the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations for pairs of streamgages used to analyze the applicability of the drainage-area ratio and weighted drainage-area ratio methods for estimating M7D10Y statistics for ungaged sites on gaged Iowa streams.—Continued

[USGS, U.S. Geological Survey; GIS, geographic information system; mi^2, square miles; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; ft^3/s, cubic feet per second. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	GIS drainage area, DRNAREA (mi^2)	Drainage-area ratio	Observed M7D10Y (ft^3/s)	Drainage-area ratio method		Weighted drainage-area ratio method			Regional regression equations	
					Estimate (ft^3/s)	Absolute difference (percent)	Ratio of observed to predicted M7D10Y statistics (R)	Estimate (ft^3/s)	Absolute difference (percent)	Estimate (ft^3/s)	Absolute difference (percent)
76	05470000	316.78	.393	.11	4.79	4,100.5	1.009	.20	75.7	.20	76.0
80	05471050	806.29	2.545	12.19	.29	97.6	.568	23.00	88.7	12.08	.9
80	05471050	806.29	.492	12.19	7.59	37.7	.526	12.18	.1	12.08	.9
82	05471500	1,640.23	2.034	15.45	24.79	60.5	1.009	29.10	88.4	29.37	90.2
82	05471500	1,640.23	.381	15.45	18.91	22.4	.750	31.12	101.5	29.37	90.2
86	05474000	4,310.35	2.628	49.68	40.59	18.3	.526	137.01	175.8	66.20	33.3
88	05476500	1,390.29	.613	2.00	17.02	751.1	1.362	6.01	200.6	5.56	178.0
89	05476750	2,269.87	1.633	27.79	3.27	88.3	.360	23.87	14.1	20.41	26.6
89	05476750	2,269.87	.540	27.79	29.31	5.5	.683	19.89	28.4	20.41	26.6
93	05480500	4,202.17	1.851	54.26	51.45	5.2	1.362	59.25	9.2	79.45	46.4
90	05478000	464.56	.356	.96	4.65	387.4	1.910	.96	.9	1.31	36.9
91	05479000	1,306.44	2.812	13.09	2.69	79.5	.730	11.70	10.6	6.85	47.6
97	05482135	227.44	.326	.72	1.57	117.6	1.557	.44	38.7	.55	24.1
99	05482300	696.70	3.063	4.80	2.21	54.1	1.317	.03	99.4	3.08	35.8
99	05482300	696.70	.433	4.80	6.13	27.6	1.241	2.98	37.9	3.08	35.8
100	05482500	1,609.35	2.310	14.15	11.09	21.6	1.557	1.11	92.2	11.40	19.4
100	05482500	1,609.35	.470	14.15	36.40	157.2	2.684	10.24	27.6	11.40	19.4
104	05484500	3,424.70	2.128	77.45	30.11	61.1	1.241	20.11	74.0	28.86	62.7
114	05487980	339.86	.902	.39	.43	12.4	1.230	.38	3.1	.32	18.2
115	05488000	376.74	1.108	.48	.43	11.0	1.223	.46	4.5	.39	18.7
144	06600100	267.17	.301	.56	2.24	301.4	1.362	.39	29.2	.46	17.3
146	06600500	886.46	3.318	7.42	1.85	75.1	1.209	1.31	82.3	5.45	26.6
151	06605600	1,352.59	.863	6.37	7.38	15.9	.775	6.84	7.5	8.18	28.5
152	06605850	1,567.26	1.159	8.55	7.38	13.7	.778	9.36	9.5	11.03	29.0

Table 17. Estimates of annual mean 7-day low flow for a recurrence interval of 10 years (M7D10Y) statistics computed from observed streamflow, the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations; and absolute differences between the estimates computed from observed streamflow and estimates from the drainage-area ratio method, the weighted drainage-area ratio method, and regional regression equations for pairs of streamgages used to analyze the applicability of the drainage-area ratio and weighted drainage-area ratio methods for estimating M7D10Y statistics for ungaged sites on gaged Iowa streams.—Continued

[USGS, U.S. Geological Survey; GIS, geographic information system; mi², square miles; M7D10Y, annual 7-day mean low flow for a recurrence interval of 10 years; ft³/s, cubic feet per second. Streamgage locations are shown in figure 1]

Map number	USGS streamgage number	GIS drainage area, DRNAREA (mi²)	Drainage-area ratio	Observed M7D10Y (ft³/s)	Drainage-area ratio method		Weighted drainage-area ratio method			Regional regression equations	
					Estimate (ft³/s)	Absolute difference (percent)	Ratio of observed to predicted M7D10Y statistics (R)	Estimate (ft³/s)	Absolute difference (percent)	Estimate (ft³/s)	Absolute difference (percent)
152	06605850	1,567.26	.622	8.55	17.72	107.2	.753	10.36	21.1	11.03	28.9
153	06606600	2,519.63	1.608	28.49	13.75	51.7	.776	39.68	39.3	37.85	32.9
153	06606600	2,519.63	.709	28.49	41.81	46.8	.436	28.92	1.5	37.85	32.9
156	06607500	3,552.93	1.410	58.96	40.17	31.9	.753	129.19	119.1	135.21	129.3
170	06807410	610.58	.460	12.63	25.64	103.1	1.002	16.18	28.1	16.18	28.1
171	06808500	1,328.69	2.176	55.79	27.48	50.8	.780	72.19	29.4	55.65	.2
171	06808500	1,328.69	.473	55.79	41.94	24.8	.666	56.66	1.6	55.65	.2
175	06810000	2,809.05	2.114	88.66	117.95	33.0	1.002	132.76	49.7	133.17	50.2
173	06809210	439.67	.492	11.09	13.15	18.6	1.330	7.67	30.8	7.71	30.4
174	06809500	894.50	2.035	26.76	22.56	15.7	1.438	10.71	60.0	20.13	24.8
174	06809500	894.50	.318	26.76	28.23	5.5	.666	22.57	15.7	20.13	24.8
175	06810000	2,809.05	3.140	88.66	84.03	5.2	1.330	-10.79	112.2	133.17	50.2

Appendix 1

Appendix 1. Excluded Streamgages

Streamflow data from 22 streamgages operated by the Iowa Water Science Center were excluded from consideration in the development of low-flow frequency and harmonic-mean-flow regression equations for Iowa (table A–1, figure A–1). Twenty-one of the streamgages are located on regulated streams, and one streamgage, 06485500 Big Sioux River at Akron (map number 223), has a drainage area that extends outside of the 50-mile buffer used for the study area. Table A–2 lists the same six selected low-flow frequency statistics and the harmonic-mean-flow statistic for these 22 streamgages as computed for all other streamgages included in this study.

The low-flow statistics listed in table A–2 were computed from observed regulated streamflow records using data through September 30, 2006, with the exception of the Akron streamgage for which the streamflow record is unregulated. Because significant positive trends in annual low flows were found when considering the entire period of regulated streamflow record for some of the streamgages listed in table A–1, low-flow frequency statistics and harmonic mean flows were computed for each streamgage in table A–2 using the longest, most-recent period of regulated record without a significant trend in low flow.

Table A–1. Description of streamgages operated by the Iowa Water Science Center that were excluded from use in the development of low-flow frequency and harmonic-mean-flow regressions for Iowa.

[no., number; USGS, U.S. Geological Survey; mi², square miles; Nebr., Nebraska. Streamgage locations are shown in figure A–1]

Map no.	USGS streamgage number	Streamgage name	Published drainage area (mi²)	Entire period of record	Period of regulated record used for computing low-flow statistics	Latitude (decimal degrees)	Longitude (decimal degrees)	Number of climatic years of record used for computing low-flow statistics (Apr. 1 to Mar. 31)	Number of years of fall record used for computing low-flow statistics (Oct. 1 to Dec. 31)
209	05389500	Mississippi River at McGregor, Iowa	67,500	8/15/36–12/31/05	4/1/63–12/31/05	43.027	91.173	42	43
210	05420500	Mississippi River at Clinton, Iowa	85,600	6/2/1873–7/28/1873, 10/1/1873–9/30/2006	4/1/62–9/30/06	41.781	90.252	44	44
211	05453520	Iowa River below Coralville Dam near Coralville, Iowa	3,115	10/1/92–9/30/06	10/1/92–9/30/06	41.715	91.530	13	14
212	05454500	Iowa River at Iowa City, Iowa	3,271	6/1/1903–9/30/2006	9/17/58–9/30/06	41.657	91.541	47	48
213	05455700	Iowa River near Lone Tree, Iowa	4,293	10/1/56–9/30/06	9/17/58–9/30/06	41.423	91.475	47	48
214	05474500	Mississippi River at Keokuk, Iowa	119,000	1/1/1878–9/30/2006	4/1/62–9/30/06	40.394	91.374	44	44
215	05481650	Des Moines River near Saylorville, Iowa	5,841	10/1/61–9/30/06	4/12/77–9/30/06	41.681	93.668	29	29
216	05483600	Middle Raccoon River at Panora, Iowa	440	6/24/58–9/30/06	10/1/70–9/30/06	41.687	94.371	35	36
217	05485500	Des Moines River below Raccoon River at Des Moines, Iowa	9,879	4/1/40–9/30/06	4/12/77–9/30/06	41.578	93.605	29	29
218	05487500	Des Moines River near Runnells, Iowa	11,655	10/1/85–9/30/06	10/1/85–9/30/06	41.489	93.338	20	21
219	05488110	Des Moines River near Pella, Iowa	12,330	10/1/92–9/30/06	10/1/92–9/30/06	41.361	92.973	13	14
220	05488500	Des Moines River near Tracy, Iowa	12,479	3/1/20–9/30/06	3/12/69–9/30/06	41.281	92.862	37	37
221	05489500	Des Moines River at Ottumwa, Iowa	13,374	3/28/17–9/30/06	3/12/69–9/30/06	41.011	92.411	37	37
222	05490500	Des Moines River at Keosauqua, Iowa	14,038	5/29/1903–7/31/1906, 4/1/1910–12/31/1910, 8/1/1911–9/30/2006	3/12/69–9/30/06	40.728	91.960	37	37
223	06485500*	Big Sioux River at Akron, Iowa	7,879	10/1/28–9/30/06	4/1/76–9/30/06	42.833	96.550	30	30
224	06486000	Missouri River at Sioux City, Iowa	314,600	10/1/28–9/30/31, 10/1/38–9/30/06	4/1/62–9/30/06	42.486	96.414	44	44
225	06601200	Missouri River at Decatur, Nebr.	316,200	10/1/87–9/30/06	10/1/87–9/30/06	42.007	96.242	18	19
226	06610000	Missouri River at Omaha, Nebr.	322,800	9/1/28–9/30/06	4/1/68–9/30/06	41.259	95.923	38	38
227	06807000	Missouri River at Nebraska City, Nebr.	410,000	8/11/29–9/30/06	4/1/68–9/30/06	40.682	95.847	38	38
228	06813500	Missouri River at Rulo, Nebr.	414,900	10/1/49–9/30/06	4/1/69–9/30/06	40.054	95.422	37	37
229	06903900	Chariton River near Rathbun, Iowa	549	10/1/69–9/30/06	4/1/71–9/30/06	40.822	92.891	35	35
230	06904010	Chariton River near Moulton, Iowa	740	8/2/79–9/30/06	8/2/79–9/30/06	40.693	92.772	26	27

*Streamgage is not regulated. Drainage basin extends outside 50–mile buffer used for study area.

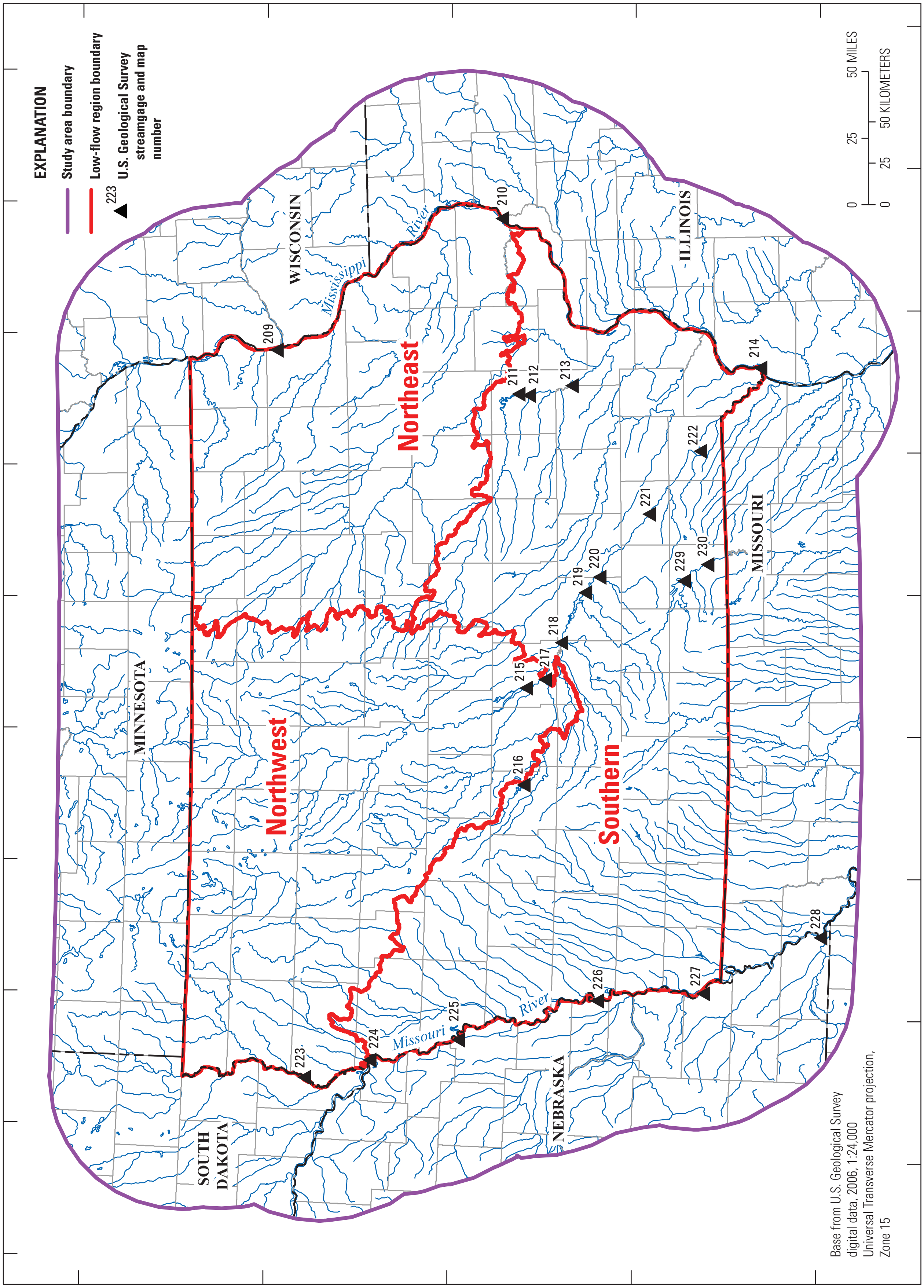

Figure A–1. Streamgages operated by the Iowa Water Science Center that were excluded from regionalizing selected low-flow frequency statistics and harmonic mean flows in Iowa.

Table A–2. Selected low-flow frequency statistics and harmonic mean flows computed from observed streamflow for streamgages in the study area operated by the Iowa Water Science Center that were excluded from the development of regression equations.

[no., number; USGS, U.S. Geological Survey; mi², square miles; M1D10Y, annual 1-day mean low flow with a recurrence interval of 10 years; ft³/s, cubic feet per second; M7D10Y, annual 7-day mean low flow with a recurrence interval of 10 years; M30D10Y, annual 30-day mean low flow with a recurrence interval of 10 years; M30D5Y, annual 30-day mean low flow with a recurrence interval of 5 years; M1D10Y1012, seasonal (October through December) 1-day mean low flow with a recurrence interval of 10 years; M7D10Y1012, seasonal (October through December) 7-day mean low flow with a recurrence interval of 10 years; QAH, harmonic mean flow. Streamgage locations are shown in figure A–1]

Map no.	USGS streamgage number	Published drainage area (mi²)	Observed M1D10Y (ft³/s)	Observed M7D10Y (ft³/s)	Observed M30D10Y (ft³/s)	Observed M30D5Y (ft³/s)	Observed M1D10Y1012 (ft³/s)	Observed M7D10Y1012 (ft³/s)	Observed QAH (ft³/s)
209	05389500	67,500	8,540	9,860	11,600	13,400	9,250	10,600	27,600
210	05420500	85,600	12,500	13,600	15,600	18,300	13,800	15,100	37,500
211	05453520	3,115	127	130	162	199	118	125	726
212	05454500	3,271	99.1	106	128	173	140	151	634
213	05455700	4,293	128	141	182	240	179	197	875
214	05474500	119,000	14,600	17,100	20,800	24,700	16,200	19,600	51,700
215	05481650	5,841	128	139	150	202	164	190	747
216	05483600	440	14.4	13.6	17.1	25.3	15.5	17.9	63.2
217	05485500	9,879	190	229	274	392	285	382	1,440
218	05487500	11,655	334	365	410	540	366	406	1,860
219	05488110	12,330	241	255	293	403	244	275	1,740
220	05488500	12,479	231	255	299	411	274	329	1,670
221	05489500	13,374	97.7	266	326	462	142	330	1,780
222	05490500	14,038	212	310	374	526	251	377	1,990
223	06485500	7,879	39.8	42.4	51.7	106	71.6	84.3	302
224	06486000	314,600	6,390	8,620	9,720	11,800	7,950	9,750	25,000
225	06601200	316,200	8,470	10,100	10,700	12,100	9,390	10,400	24,700
226	06610000	322,800	7,650	11,100	13,400	14,900	9,850	12,100	30,100
227	06807000	410,000	8,930	12,300	16,000	17,800	11,100	13,900	35,700
228	06813500	414,900	10,500	13,100	16,900	18,900	13,700	15,400	38,100
229	06903900	549	5.99	10.5	11.1	12.3	10.6	12.0	37.4
230	06904010	740	15.9	19.3	19.6	21.3	15.2	15.5	68.4

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