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Computing Daily Mean Streamflow at Ungaged Locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer Statistical Methods

Scientific Investigations Report 2012–5232

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

Cover. Turkey River near Eldorado, Iowa. Photograph by Jon Nania, U.S. Geological Survey.

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By S. Mike Linhart, Jon F. Nania, Curtis L. Sanders, Jr., and Stacey A. Archfield

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

A water year is the 12-month period October 1 through September 30 designated by the year in which it ends.

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Computing Daily Mean Streamflow at Ungaged Locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer Statistical Methods

By S. Mike Linhart, Jon F. Nania, Curtis L. Sanders, Jr., and Stacey A. Archfield

Abstract

The U.S. Geological Survey (USGS) maintains approximately 148 real-time streamgages in Iowa for which daily mean streamflow information is available, but daily mean streamflow data commonly are needed at locations where no streamgages are present. Therefore, the USGS conducted a study as part of a larger project in cooperation with the Iowa Department of Natural Resources to develop methods to estimate daily mean streamflow at locations in ungaged watersheds in Iowa by using two regression-based statistical methods. The regression equations for the statistical methods were developed from historical daily mean streamflow and basin characteristics from streamgages within the study area, which includes the entire State of Iowa and adjacent areas within a 50-mile buffer of Iowa in neighboring states. Results of this study can be used with other techniques to determine the best method for application in Iowa and can be used to produce a Web-based geographic information system tool to compute streamflow estimates automatically.

The Flow Anywhere statistical method is a variation of the drainage-area-ratio method, which transfers same-day streamflow information from a reference streamgage to another location by using the daily mean streamflow at the reference streamgage and the drainage-area ratio of the two locations. The Flow Anywhere method modifies the drainage-area-ratio method in order to regionalize the equations for Iowa and determine the best reference streamgage from which to transfer same-day streamflow information to an ungaged location. Data used for the Flow Anywhere method were retrieved for 123 continuous-record streamgages located in Iowa and within a 50-mile buffer of Iowa. The final regression equations were computed by using either left-censored regression techniques with a low limit threshold set at 0.1 cubic feet per second (ft^3/s) and the daily mean streamflow for the 15th day of every other month, or by using an ordinary-least-squares multiple linear regression method and the daily mean streamflow for the 15th day of every other month.

The Flow Duration Curve Transfer method was used to estimate unregulated daily mean streamflow from the physical and climatic characteristics of gaged basins. For the Flow Duration Curve Transfer method, daily mean streamflow quantiles at the ungaged site were estimated with the parameter-based regression model, which results in a continuous daily flow-duration curve (the relation between exceedance probability and streamflow for each day of observed streamflow) at the ungaged site. By the use of a reference streamgage, the Flow Duration Curve Transfer is converted to a time series. Data used in the Flow Duration Curve Transfer method were retrieved for 113 continuous-record streamgages in Iowa and within a 50-mile buffer of Iowa. The final statewide regression equations for Iowa were computed by using a weighted-least-squares multiple linear regression method and were computed for the 0.01-, 0.05-, 0.10-, 0.15-, 0.20-, 0.30-, 0.40-, 0.50-, 0.60-, 0.70-, 0.80-, 0.85-, 0.90-, and 0.95-exceedance probability statistics determined from the daily mean streamflow with a reporting limit set at 0.1 ft^3/s. The final statewide regression equation for Iowa computed by using left-censored regression techniques was computed for the 0.99-exceedance probability statistic determined from the daily mean streamflow with a low limit threshold and a reporting limit set at 0.1 ft^3/s.

For the Flow Anywhere method, results of the validation study conducted by using six streamgages show that differences between the root-mean-square error and the mean absolute error ranged from 1,016 to 138 ft^3/s, with the larger value signifying a greater occurrence of outliers between observed and estimated streamflows. Root-mean-square-error values ranged from 1,690 to 237 ft^3/s. Values of the percent root-mean-square error ranged from 115 percent to 26.2 percent. The logarithm (base 10) streamflow percent root-mean-square error ranged from 13.0 to 5.3 percent. Root-mean-square-error observations standard-deviation-ratio values ranged from 0.80 to 0.40. Percent-bias values ranged from 25.4 to 4.0 percent. Untransformed streamflow Nash-Sutcliffe efficiency values ranged from 0.84 to 0.35. The logarithm (base 10) streamflow Nash-Sutcliffe efficiency values ranged from 0.86 to 0.56. For the streamgage with the best agreement between observed and estimated streamflow, higher streamflows appear to be underestimated. For the streamgage with the worst agreement between observed and estimated streamflow, low flows appear to be overestimated whereas higher flows seem to be

underestimated. Estimated cumulative streamflows for the period October 1, 2004, to September 30, 2009, are underestimated by -25.8 and -7.4 percent for the closest and poorest comparisons, respectively.

For the Flow Duration Curve Transfer method, results of the validation study conducted by using the same six streamgages show that differences between the root-mean-square error and the mean absolute error ranged from 437 to 93.9 ft^3/s, with the larger value signifying a greater occurrence of outliers between observed and estimated streamflows. Root-mean-square-error values ranged from 906 to 169 ft^3/s. Values of the percent root-mean-square-error ranged from 67.0 to 25.6 percent. The logarithm (base 10) streamflow percent root-mean-square error ranged from 12.5 to 4.4 percent. Root-mean-square-error observations standard-deviation-ratio values ranged from 0.79 to 0.40. Percent-bias values ranged from 22.7 to 0.94 percent. Untransformed streamflow Nash-Sutcliffe efficiency values ranged from 0.84 to 0.38. The logarithm (base 10) streamflow Nash-Sutcliffe efficiency values ranged from 0.89 to 0.48. For the streamgage with the closest agreement between observed and estimated streamflow, there is relatively good agreement between observed and estimated streamflows. For the streamgage with the poorest agreement between observed and estimated streamflow, streamflows appear to be substantially underestimated for much of the time period. Estimated cumulative streamflow for the period October 1, 2004, to September 30, 2009, are underestimated by -9.3 and -22.7 percent for the closest and poorest comparisons, respectively.

Introduction

Streamflow data are used by a variety of individuals including water resource managers and recreationists. The U.S. Geological Survey (USGS) provides daily mean streamflow information at many streamgage locations in Iowa and surrounding states (fig. 1). Commonly, however, daily mean streamflow data are needed at locations where no streamgages are present. Therefore, the USGS conducted a study as part of a larger project in cooperation with the Iowa Department of Natural Resources to develop methods to estimate daily mean streamflow at locations in ungaged watersheds in Iowa by using two regression-based statistical methods. Two statistical methods were used to estimate streamflow: a variation of the drainage-area-ratio method (Flow Anywhere method) and a quantile-based regression model referred to here as the Flow Duration Curve Transfer method.

The drainage-area-ratio method is a commonly used technique for computing flow in ungaged watersheds. In this method, same-day streamflow information is transferred from a reference streamgage to another location on the basis of the ratio of the drainage areas of the two locations (Asquith and others, 2006). The drainage-area-ratio equation (Emerson and others, 2006) is

$$Q_u = \frac{A_u}{A_r} Q_r \quad , \qquad (1)$$

where

- Q_u is the streamflow at the ungaged location,
- A_u is the drainage area at the ungaged location,
- A_r is the drainage area at the reference streamgage, and
- Q_r is the streamflow at the reference streamgage.

In the Flow Anywhere method, the drainage-area-ratio method is modified in order to regionalize the equation for Iowa and determine the most appropriate reference streamgage to use for the transfer of same-day streamflow information from that reference streamgage to an ungaged location. First, the correlation of historical streamflow data between streamgages in the study area is examined to determine local region boundaries. A local region is an area in which the streamflows measured at all the streamgages are highly correlated. Within each local region, an appropriate reference streamgage is selected that most closely represents historical streamflow in the local region. Local regions are sized so that any storm system that passes through the region is likely to affect the entire area equally, as confirmed by the high correlation exhibited between streamflows measured at streamgages in a local area. In addition, the local regions are defined so that the basins within the regions are physiographically similar. After establishment of local regions, regression techniques are used to identify local regions that exhibit similar hydrologic properties and, therefore, can be aggregated for analysis. Historical streamflow data from each aggregated region are then used to develop regression equations that modify the drainage-area ratio equation as follows:

$$Q_u = C\left(\frac{A_u}{A_r}\right)^{\beta} Q_r^{\gamma} \quad , \qquad (2)$$

where

- C is the intercept (which is a constant),
- β is the drainage-area-ratio exponent, and
- γ is the reference streamgage exponent.

The regression intercept and exponents in equation 2 were used to calibrate equation 1 for Iowa. The drainage-area-ratio exponent has the effect of adjusting the predicted streamflow hydrograph higher or lower by means of the drainage-area ratio. The exponent for streamflow at the reference streamgage has the effect of increasing or decreasing the variability of streamflows at the reference streamgage for the predicted streamflow hydrograph.

The Flow Duration Curve Transfer method, a quantile- and parameter-based regression model, was used to estimate unregulated daily mean streamflow statistics from the physical and climatic characteristics of gaged basins. This method was initially introduced by Fennessey (1994) and also was published by Hughes and Smakhtin (1996), Smakhtin (1999), Smakhtin and Masse (2000), Mahamoud (2008), and Archfield and others (2009). With use of the regression model together with streamflows at a reference streamgage, estimates of unregulated, daily mean streamflow time series at ungaged sites can be made. For the Flow Duration Curve Transfer method, daily mean streamflow quantiles at the ungaged site are estimated by using the parameter-based regression model, resulting in a continuous daily flow-duration curve (the relation between exceedance probability and streamflow for each day of observed streamflow) at the ungaged site. By the use of a reference streamgage, the flow-duration curve is converted to a time series. As explained in Waldron and Archfield (2006), the observed time series of streamflow at the reference gage (Q) (fig. 2*A*) is used to develop a flow-duration curve (fig. 2*B*), which represents the probability of exceedance (P) for each streamflow value in the record. The assumption is then made that the probability of exceeding a flow at the reference streamgage is equivalent to the probability of exceeding a flow at the ungaged site (P) (fig. 2*C*). Then, by equating the exceedance probabilities at the ungaged site and the reference streamgage, the dates of streamflow associated with each exceedance probability at the reference streamgage are transferred to the ungaged site to construct a time series of streamflow at the ungaged site (Q) (fig. 2*D*).

The methods developed in this study can be compared with other methods for estimating streamflows at ungaged locations to determine the best method for use in Iowa. In addition, the results of this study can be used to produce a Web-based Geographic Information System (GIS) tool, similar to the USGS Streamstats interface (Ries and others, 2009), to compute streamflow at ungaged locations in Iowa automatically.

Purpose and Scope

Regression equations developed for estimating daily mean streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods are described. The period of record from which the regression equations were developed is based on a trend analysis that is discussed in the report. Methods for selecting the streamgages to be used in developing the regression equations are presented. The types of regression analysis used, along with the accuracies and limitations of both methods, also are included.

Description of Study Area

The regression equations for estimating mean daily streamflow in ungaged watersheds with the Flow Anywhere and Flow Duration Curve Transfer methods were developed for use only in Iowa. The equations were developed from recorded daily mean streamflow and basin characteristics for streamgages within the study area (fig. 1), which includes the entire State of Iowa and adjacent areas within a 50-mile (mi) buffer of Iowa in the neighboring States of Illinois, Minnesota, Missouri, Nebraska, and Wisconsin. No streamgages within the buffer area in South Dakota were used because of either upstream diversions or regulation. There are 10 landform regions in Iowa with distinct characteristics (Prior, 1991; Prior and others, 2009) and are used to help develop regions for the Flow Anywhere method.

Previous Studies

Studies have been completed to compute streamflow at ungaged locations outside Iowa by using variations of the drainage-area-ratio method. Asquith and others (2006) evaluate the effects of computing the drainage-area-ratio exponent for selected streams in Texas and describe similar, previously published studies. Sanders (2002) uses similar reference-streamgage selection techniques to compare hydrographs of observed streamflows. Archfield and others (2009) evaluate the Flow Duration Curve Transfer method for use in an interactive decision-support tool referred to as the Massachusetts Sustainable-Yield Estimator (MA SYE). Esralew and Smith (2010) use the Flow Duration method for estimating flow-duration and annual mean-flow statistics for ungaged streams in Oklahoma. Risley and others (2008) estimate flow-duration and low-flow-frequency statistics for unregulated stream in Oregon to provide decision makers with surface-water information needed for activities such as water-quality regulation, water-rights adjudication, biological habitat assessment, infrastructure design, water-supply planning, and management.

Trend Analysis

Stationarity is assumed in both the Flow Anywhere and Flow Duration Curve Transfer methods; therefore, a trend analysis was conducted to determine whether this assumption was met. Trend analyses were performed for the 90-percent, 50-percent, and 10-percent exceedance probabilities by using annual mean streamflow (mean of daily mean streamflows for each water year; a water year is the 12-month period October 1 through September 30 designated by the year in which it ends). Prior to the final selection of the streamgages used in the Flow Anywhere and Flow Duration Curve Transfer methods, 102 streamgages in Iowa with periods of record greater than 10 years were tested by using Kendall's *tau* hypothesis test. Positive trends were found in the annual mean streamflow quantiles at the 90-percent exceedance probability statistic for 61 of those streamgages. Trends in these data could introduce a bias into the Flow Duration Curve Transfer analyses, violating the assumption that flow-duration statistics are independent and stationary over time. Positive trends were found for the annual 90-percent streamflow quantiles at 3 of those 61 streamgages (fig. 3): 05412500, Turkey River at Garber, Iowa, (fig. 1, map no. 13, and table 1); 05452200, Walnut Creek near Hartwick, Iowa (fig. 1, map no. 32, and table 1);

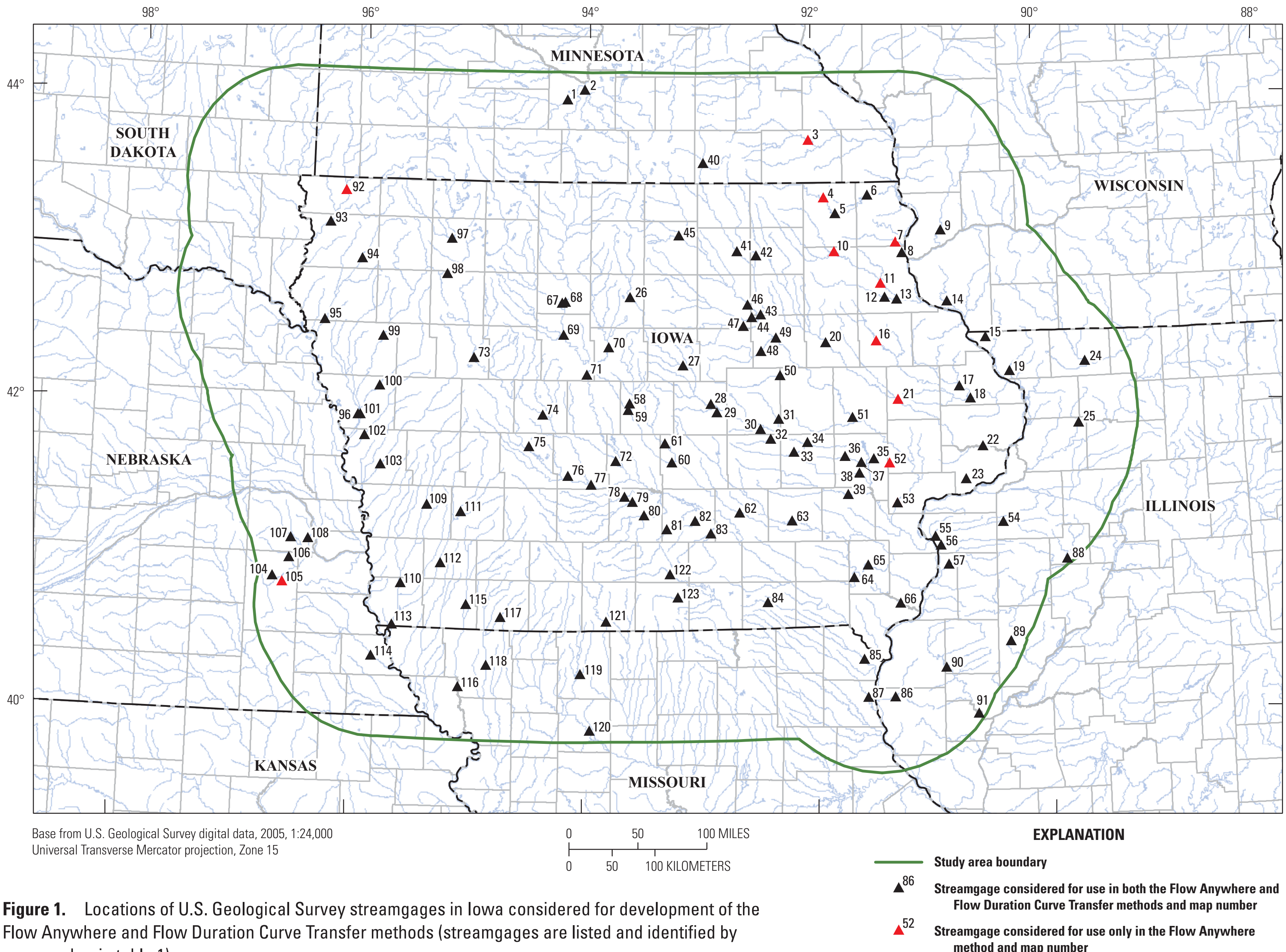


Figure 1. Locations of U.S. Geological Survey streamgages in Iowa considered for development of the Flow Anywhere and Flow Duration Curve Transfer methods (streamgages are listed and identified by map number in table 1).

Table 1. Description of streamgages used to estimate streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods.

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi², square miles; NAD 83, North American Datum of 1983; MN, Minnesota; IA, Iowa; WI, Wisconsin; IL, Illinois; MO, Missouri; NE, Nebraska; shaded rows, streamgages used in the Flow Anywhere method but not used in the Flow Duration Curve Transfer method]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi²)	Published drainage area[1] (mi²)	Entire period of record	Number of years of record used	Latitude, NAD 83 (decimal degrees)	Longitude, NAD 83 (decimal degrees)
1	05319500	Watonwan River near Garden City, MN	873	851	03/01/1940–09/30/1945, 09/01/1976–09/30/2009	32	44.0464	-94.1955
2	05320500	Le Sueur River near Rapidan, MN	1,128	1,110	10/01/1939–09/30/1945, 08/01/1949–09/30/2009	32	44.1111	-94.0413
3	05383950	Root River near Pilot Mound, MN[2]	565	565	08/09/2002–09/30/2009	7	43.7847	-92.0302
4	05387440	Upper Iowa River at Bluffton, IA[2]	367	367	10/01/2002–09/30/2009	7	43.4069	-91.8990
5	05387500	Upper Iowa River at Decorah, IA	511	511	10/01/1951–11/01/1983, 10/01/2002–09/30/2009	13	43.3049	-91.7955
6	05388250	Upper Iowa River near Dorchester, IA	768	770	10/01/1938–09/30/1939, 07/01/1975–09/30/2009	32	43.4211	-91.5088
7	05389000	Yellow River at Ion, IA[2]	219	221	10/01/1934–09/30/1951, 09/21/2004–09/30/2009	5	43.1119	-91.2651
8	05389400	Bloody Run Creek near Marquette, IA	34.3	34.1	10/01/1991–09/30/2009	18	43.0408	-91.2065
9	05410490	Kickapoo River at Steuben, WI	700	687	05/23/1933–09/30/2009	32	43.1828	-90.8585
10	05411850	Turkey River near Eldorado, IA[2]	642	641	09/28/2000–09/30/2009	9	43.0542	-91.8091
11	05412020	Turkey River above French Hollow Creek at Elkader, IA[2]	905	903	09/06/2001–09/30/2009	8	42.8435	-91.4013
12	05412400	Volga River at Littleport, IA	350	348	09/16/1999–09/30/2009	10	42.7539	-91.3690
13	05412500	Turkey River at Garber, IA	1,553	1,545	08/08/1913–11/30/1916, 05/14/1919–09/30/1927, 04/24/1929–09/30/1930, 10/01/1932–09/30/2009	32	42.7400	-91.2618
14	05413500	Grant River at Burton, WI	269	269	10/01/1934–09/30/2009	32	42.7203	-90.8193
15	05414820	Sinsinawa River near Menominee, IL	40.0	39.6	10/01/1967–09/30/2009	32	42.4786	-90.4867
16	05416900	Maquoketa River at Manchester, IA[2]	279	275	04/26/2000–12/16/2002, 06/23/2003–09/30/2009	7	42.4700	-91.4487
17	05418400	North Fork Maquoketa River near Fulton, IA	503	505	10/01/1998–09/30/2009	11	42.1644	-90.7282
18	05418500	Maquoketa River near Maquoketa, IA	1,551	1,553	09/01/1913–09/30/2009	32	42.0834	-90.6329
19	05419000	Apple River near Hanover, IL	247	247	10/01/1934–09/30/2009	32	42.2528	-90.2860
20	05421000	Wapsipinicon River at Independence, IA	1,053	1,048	07/01/1933–09/30/2009	32	42.4636	-91.8952

Table 1. Description of streamgages used to estimate streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi^2, square miles; NAD 83, North American Datum of 1983; MN, Minnesota; IA, Iowa; WI, Wisconsin; IL, Illinois; MO, Missouri; NE, Nebraska; shaded rows, streamgages used in the Flow Anywhere method but not used in the Flow Duration Curve Transfer method]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi^2)	Published drainage area[1] (mi^2)	Entire period of record	Number of years of record used	Latitude, NAD 83 (decimal degrees)	Longitude, NAD 83 (decimal degrees)
21	05421740	Wapsipinicon River near Anamosa, IA[2]	1,581	1,575	07/10/2002–09/30/2009	7	42.0833	-91.2674
22	05422000	Wapsipinicon River near De Witt, IA	2,336	2,336	07/27/1934–09/30/2009	32	41.7670	-90.5349
23	05422560	Duck Creek at 110th Ave at Davenport, IA	15.5	16.1	03/29/1994–09/30/2009	15	41.5567	-90.6876
24	05435500	Pecatonica River at Freeport, IL	1,337	1,326	09/11/1914–09/30/2009	32	42.3028	-89.6196
25	05444000	Elkhorn Creek near Penrose, IL	147	146	10/01/1939–9/30/2009	32	41.9028	-89.6962
26	05449500	Iowa River near Rowan, IA	427	418	10/01/1940–09/30/2009	32	42.7599	-93.6218
27	05451210	South Fork Iowa River northeast of New Providence, IA	224	224	10/25/1995–09/30/2009	13	42.3150	-93.1524
28	05451500	Iowa River at Marshalltown, IA	1,534	1,532	10/01/1902–09/30/1903, 10/01/1914–09/30/1927, 10/01/1932–09/30/2009	32	42.0658	-92.9077
29	05451700	Timber Creek near Marshalltown, IA	120	118	10/01/1949–09/30/2009	32	42.0089	-92.8524
30	05451900	Richland Creek near Haven, IA	56.1	56.1	10/01/1949–09/30/2009	32	41.8994	-92.4744
31	05452000	Salt Creek near Elberon, IA	199	201	10/01/1945–9/30/2009	32	41.9642	-92.3132
32	05452200	Walnut Creek near Hartwick, IA	70.5	70.9	10/01/1949–09/30/2009	32	41.8350	-92.3863
33	05453000	Big Bear Creek at Ladora, IA	187	189	10/01/1945–09/30/2009	32	41.7494	-92.1821
34	05453100	Iowa River at Marengo, IA	2,793	2,794	10/01/1956–09/30/2009	32	41.8127	-92.0648
35	05454000	Rapid Creek near Iowa City, IA	25.3	25.3	10/01/1937–09/30/2009	32	41.7000	-91.4877
36	05454220	Clear Creek near Oxford, IA	60.8	58.4	11/04/1993–09/30/2009	15	41.7183	-91.7402
37	05454300	Clear Creek near Coralville, IA	98.1	98.1	10/01/1952–09/30/2009	32	41.6767	-91.5988
38	05455100	Old Mans Creek near Iowa City, IA	201	201	10/01/1950–09/30/1964, 10/01/1984–09/30/2009	25	41.6064	-91.6157
39	05455500	English River at Kalona, IA	574	574	09/13/1939–09/30/2009	32	41.4697	-91.7146
40	05457000	Cedar River near Austin, MN	398	399	06/01/1909–09/30/1914, 10/01/1944–09/30/2009	32	43.6372	-92.9746
41	05457700	Cedar River at Charles City, IA	1,075	1,054	10/01/1964–09/30/1995, 10/01/2000–09/30/2009	27	43.0625	-92.6732
42	05458000	Little Cedar River near Ionia, IA	295	306	10/01/1954–09/30/2009	32	43.0333	-92.5035

Table 1. Description of streamgages used to estimate streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi², square miles; NAD 83, North American Datum of 1983; MN, Minnesota; IA, Iowa; WI, Wisconsin; IL, Illinois; MO, Missouri; NE, Nebraska; shaded rows, streamgages used in the Flow Anywhere method but not used in the Flow Duration Curve Transfer method]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi²)	Published drainage area[1] (mi²)	Entire period of record	Number of years of record used	Latitude, NAD 83 (decimal degrees)	Longitude, NAD 83 (decimal degrees)
43	05458500	Cedar River at Janesville, IA	1,671	1,661	10/01/1904–09/30/1906, 10/01/1914–09/30/1927, 10/01/1932–09/30/1942, 10/01/1945–09/30/2009	32	42.6483	-92.4652
44	05458900	West Fork Cedar River at Finchford, IA	851	846	10/01/1945–09/30/2009	32	42.6294	-92.5435
45	05459500	Winnebago River at Mason City, IA	517	526	10/01/1932–09/30/2009	32	43.1650	-93.1927
46	05462000	Shell Rock River at Shell Rock, IA	1,731	1,746	06/11/1953–09/30/2009	32	42.7119	-92.5830
47	05463000	Beaver Creek at New Hartford, IA	351	347	10/01/1945–09/30/2009	32	42.5728	-92.6180
48	05463500	Black Hawk Creek at Hudson IA	298	303	04/01/1952–09/30/1995, 09/07/2001–09/30/2009	26	42.4078	-92.4632
49	05464000	Cedar River at Waterloo, IA	5,149	5,146	10/1/1940–9/30/2009	32	42.4955	-92.3344
50	05464220	Wolf Creek near Dysart, IA	298	299	10/24/1995–09/30/1998, 05/16/2001–09/30/2009	10	42.2517	-92.2988
51	05464500	Cedar River at Cedar Rapids, IA	6,506	6,510	10/1/1902–9/30/2009	32	41.9719	-91.6671
52	05464942	Hoover Creek at Hoover Nat Hist Site, West Branch, IA[2]	2.60	2.58	04/27/2000–09/30/2009	9	41.6696	-91.3506
53	05465000	Cedar River near Conesville, IA	7,783	7,787	09/16/1939–09/30/2009	32	41.4092	-91.2904
54	05466000	Edwards River near Orion, IL	156	155	10/01/1940–09/30/2009	32	41.2720	-90.3776
55	05466500	Edwards River near New Boston, IL	442	445	10/01/1934–09/30/2009	32	41.1870	-90.9674
56	05467000	Pope Creek near Keithsburg, IL	172	174	10/01/1934–09/30/1986, 03/01/1987–09/30/1987, 03/01/1988–09/30/1988, 03/01/1989–09/30/1989, 03/01/1990–09/30/1996, 10/01/1997–09/30/2009	27	41.1289	-90.9193
57	05469000	Henderson Creek near Oquawka, IL	436	432	10/01/1934–09/30/1996, 10/01/1997–09/30/2009	31	41.0014	-90.8543
58	05470000	South Skunk River near Ames, IA	317	315	07/28/1920–09/30/1927, 10/01/1932–10/03/1995, 09/28/1996–09/30/2009	30	42.0665	-93.6201
59	05470500	Squaw Creek at Ames, IA	210	204	05/24/1919–09/30/1927, 05/24/1965–09/30/2009	32	42.0230	-93.6305

Table 1. Description of streamgages used to estimate streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi², square miles; NAD 83, North American Datum of 1983; MN, Minnesota; IA, Iowa; WI, Wisconsin; IL, Illinois; MO, Missouri; NE, Nebraska; shaded rows, streamgages used in the Flow Anywhere method but not used in the Flow Duration Curve Transfer method]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi²)	Published drainage area[1] (mi²)	Entire period of record	Number of years of record used	Latitude, NAD 83 (decimal degrees)	Longitude, NAD 83 (decimal degrees)
60	05471050	South Skunk River at Colfax, IA	806	803	10/01/1985–09/30/2009	24	41.6814	-93.2466
61	05471200	Indian Creek near Mingo, IA	277	276	05/22/1958–09/30/1975, 10/01/1985–09/30/2009	24	41.8053	-93.3094
62	05471500	South Skunk River near Oskaloosa, IA	1,640	1,635	10/01/1945–09/30/2009	32	41.3557	-92.6574
63	05472500	North Skunk River near Sigourney, IA	734	730	10/01/1945–09/30/2009	32	41.3008	-92.2046
64	05473400	Cedar Creek near Oakland Mills, IA	533	533	07/01/1977–09/30/2009	32	40.9253	-91.6742
65	05473450	Big Creek north of Mount Pleasant, IA	60.9	58.0	10/01/1997–09/30/2009	12	41.0070	-91.5515
66	05474000	Skunk River at Augusta, IA	4,310	4,312	09/30/1913–11/15/1913, 10/01/1914–09/30/2009	32	40.7537	-91.2771
67	05476750	Des Moines River at Humboldt, IA	2,270	2,256	10/01/1964–09/30/2009	32	42.7194	-94.2205
68	05479000	East Fork Des Moines River at Dakota City, IA	1,306	1,308	03/01/1940–09/30/2009	32	42.7236	-94.1935
69	05480500	Des Moines River at Fort Dodge, IA	4,202	4,190	04/23/1905–07/19/1906, 10/01/1913–09/30/1927, 10/01/1946–09/30/2009	32	42.5083	-94.2036
70	05481000	Boone River near Webster City, IA	846	844	03/09/1940–09/30/2009	32	42.4325	-93.8058
71	05481300	Des Moines River near Stratford, IA	5,464	5,452	10/01/1967–09/30/2009	32	42.2519	-93.9969
72	05481950	Beaver Creek near Grimes, IA	370	358	04/20/1960–09/30/2009	32	41.6883	-93.7355
73	05482300	North Raccoon River near Sac City, IA	697	700	06/01/1958–09/30/2009	32	42.3544	-94.9908
74	05482500	North Raccoon River near Jefferson, IA	1,609	1,619	03/01/1940–09/30/2009	32	41.9880	-94.3769
75	05483450	Middle Raccoon River near Bayard, IA	382	375	03/23/1979–09/30/2009	30	41.7786	-94.4927
76	05484000	South Raccoon River at Redfield, IA	987	994	03/04/1940–09/30/2009	32	41.5894	-94.1513
77	05484500	Raccoon River at Van Meter, IA	3,425	3,441	04/25/1915–09/30/2009	32	41.5339	-93.9500
78	05486000	North River near Norwalk, IA	349	349	02/28/1940–09/30/2009	32	41.4579	-93.6550
79	05486490	Middle River near Indianola, IA	489	503	03/01/1940–09/30/2009	32	41.4242	-93.5874
80	05487470	South River near Ackworth, IA	458	460	03/01/1940–09/30/2009	32	41.3372	-93.4863
81	05487980	White Breast Creek near Dallas, IA	340	342	10/01/1962–09/30/2009	32	41.2466	-93.2902
82	05488200	English Creek near Knoxville, IA	90.7	90.1	07/01/1985–09/30/2009	24	41.3006	-93.0455
83	05489000	Cedar Creek near Bussey, IA	372	374	10/01/1947–09/30/2009	32	41.2190	-92.9085

Table 1. Description of streamgages used to estimate streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi², square miles; NAD 83, North American Datum of 1983; MN, Minnesota; IA, Iowa; WI, Wisconsin; IL, Illinois; MO, Missouri; NE, Nebraska; shaded rows, streamgages used in the Flow Anywhere method but not used in the Flow Duration Curve Transfer method]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi²)	Published drainage area[1] (mi²)	Entire period of record	Number of years of record used	Latitude, NAD 83 (decimal degrees)	Longitude, NAD 83 (decimal degrees)
84	05494300	Fox River at Bloomfield, IA	87.3	87.7	10/01/1957–10/02/1973, 05/27/1997–09/30/2009	12	40.7695	-92.4188
85	05495000	Fox River at Wayland, MO	396	400	03/01/1922–09/30/2009	32	40.3924	-91.5979
86	05495500	Bear Creek near Marcelline, IL	349	349	03/01/1944–09/30/2009	32	40.1428	-91.3374
87	05496000	Wyaconda River above Canton, MO	398	393	10/01/1932–09/30/1972,10/01/1979–09/30/2009	30	40.1421	-91.5657
88	05568800	Indian Creek near Wyoming, IL	63.2	62.7	10/01/1959–09/30/2009	32	41.0189	-89.8356
89	05570000	Spoon River at Seville, IL	1,638	1,636	07/24/1914–09/30/2009	32	40.4900	-90.3404
90	05584500	La Moine River at Colmar, IL	663	655	10/01/1944–09/30/2009	32	40.3303	-90.8962
91	05585000	La Moine River at Ripley, IL	1,312	1,293	03/12/1921–09/30/2009	32	40.0248	-90.6318
92	06483290	Rock River below Tom Creek at Rock Rapids, IA[2]	851	853	05/01/2001–09/30/2009	8	43.4230	-96.1649
93	06483500	Rock River near Rock Valley, IA	1,584	1,592	06/11/1948–09/30/2009	32	43.2144	-96.2945
94	06600100	Floyd River at Alton, IA	267	268	10/01/1955–09/30/2009	32	42.9819	-96.0011
95	06600500	Floyd River at James, IA	886	886	12/08/1934–09/30/2009	32	42.5767	-96.3114
96	06602400	Monona-Harrison Ditch near Turin, IA	929	900	05/07/1942–09/30/2009	32	41.9644	-95.9920
97	06605000	Ocheyedan River near Spencer, IA	440	426	10/01/1977–09/30/2009	32	43.1280	-95.2108
98	06605850	Little Sioux River at Linn Grove, IA	1,567	1,548	10/01/1972–09/30/2009	32	42.8958	-95.2433
99	06606600	Little Sioux River at Correctionville, IA	2,520	2,500	05/28/1918–09/30/2009	32	42.4823	-95.7929
100	06607200	Maple River at Mapleton, IA	670	669	10/01/1941–09/30/2009	32	42.1569	-95.8100
101	06607500	Little Sioux River near Turin, IA	3,553	3,526	10/01/1977–09/30/2009	32	41.9644	-95.9725
102	06608500	Soldier River at Pisgah, IA	409	407	03/05/1940–09/30/2009	32	41.8305	-95.9314
103	06609500	Boyer River at Logan, IA	870	871	05/24/1918–11/30/1924, 02/01/1925–07/01/1925, 11/04/1937–09/30/2009	32	41.6425	-95.7828
104	06803510	Little Salt Creek near Lincoln, NE	43.1	43.6	10/01/1969–09/30/2009	32	40.8931	-96.6817
105	06803520	Stevens Creek near Lincoln, NE[2]	50.0	47.8	10/01/1968–09/30/2009	32	40.8569	-96.5953
106	06803530	Rock Creek near Ceresco, NE	120	120	04/01/1970–09/30/2009	32	41.0158	-96.5442
107	06804000	Wahoo Creek at Ithaca, NE	272	273	10/01/1949–09/30/2009	32	41.1475	-96.5378

Table 1. Description of streamgages used to estimate streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer methods.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi^2, square miles; NAD 83, North American Datum of 1983; MN, Minnesota; IA, Iowa; WI, Wisconsin; IL, Illinois; MO, Missouri; NE, Nebraska; shaded rows, streamgages used in the Flow Anywhere method but not used in the Flow Duration Curve Transfer method]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi^2)	Published drainage area[1] (mi^2)	Entire period of record	Number of years of record used	Latitude, NAD 83 (decimal degrees)	Longitude, NAD 83 (decimal degrees)
108	06804900	Johnson Creek near Memphis, NE	23.4	21.5	08/28/1990–09/30/2009	19	41.1464	-96.3869
109	06807410	West Nishnabotna River at Hancock, IA	611	609	10/02/1959–09/30/2009	32	41.3900	-95.3717
110	06808500	West Nishnabotna River at Randolph, IA	1,329	1,326	06/01/1948–09/30/2009	32	40.8731	-95.5803
111	06809210	East Nishnabotna River near Atlantic, IA	440	436	10/01/1960–09/30/2009	32	41.3461	-95.0769
112	06809500	East Nishnabotna River at Red Oak, IA	895	894	05/22/1918–11/30/1924, 02/08/1925–07/04/1925, 05/29/1936–09/30/2009	32	41.0086	-95.2417
113	06810000	Nishnabotna River above Hamburg, IA	2,809	2,806	03/01/1922–09/30/1923, 10/01/1928–09/30/2009	32	40.6017	-95.6450
114	06811500	Little Nemaha River at Auburn, NE	793	792	09/01/1949–09/30/2009	32	40.3928	-95.8128
115	06817000	Nodaway River at Clarinda, IA	761	762	05/17/1918–07/04/1925, 05/14/1936–09/30/2009	32	40.7433	-95.0142
116	06817700	Nodaway River near Graham, MO	1,516	1,380	10/22/1982–09/30/2009	27	40.2025	-95.0696
117	06819185	East Fork 102 River at Bedford, IA	85.8	85.4	10/01/1983–09/30/2009	27	40.6605	-94.7166
118	06819500	102 River at Maryville, MO	491	500	10/01/1932–12/31/1990, 03/22/2001–09/30/2009	21	40.3455	-94.8322
119	06897000	East Fork Big Creek near Bethany, MO	90.8	95.0	04/01/1934–09/30/1972, 10/01/1996–09/30/1999, 10/01/2000–9/30/2009	12	40.2972	-94.0262
120	06897500	Grand River near Gallatin, MO	2,246	2,250	10/01/1920–09/30/2009	32	39.9270	-93.9427
121	06898000	Thompson River at Davis City, IA	695	701	05/14/1918–07/02/1925, 07/14/1941–09/30/2009	32	40.6403	-93.8083
122	06903400	Chariton River near Chariton, IA	186	182	10/01/1965–09/30/2009	32	40.9519	-93.2598
123	06903700	South Fork Chariton River near Promise City, IA	170	168	10/01/1967–09/30/2009	32	40.8006	-93.1924

[1]Published in National Water Information System (NWIS).

[2]Data from this streamgage were used in the Flow Anywhere method but not in the Flow Duration Curve Transfer method.

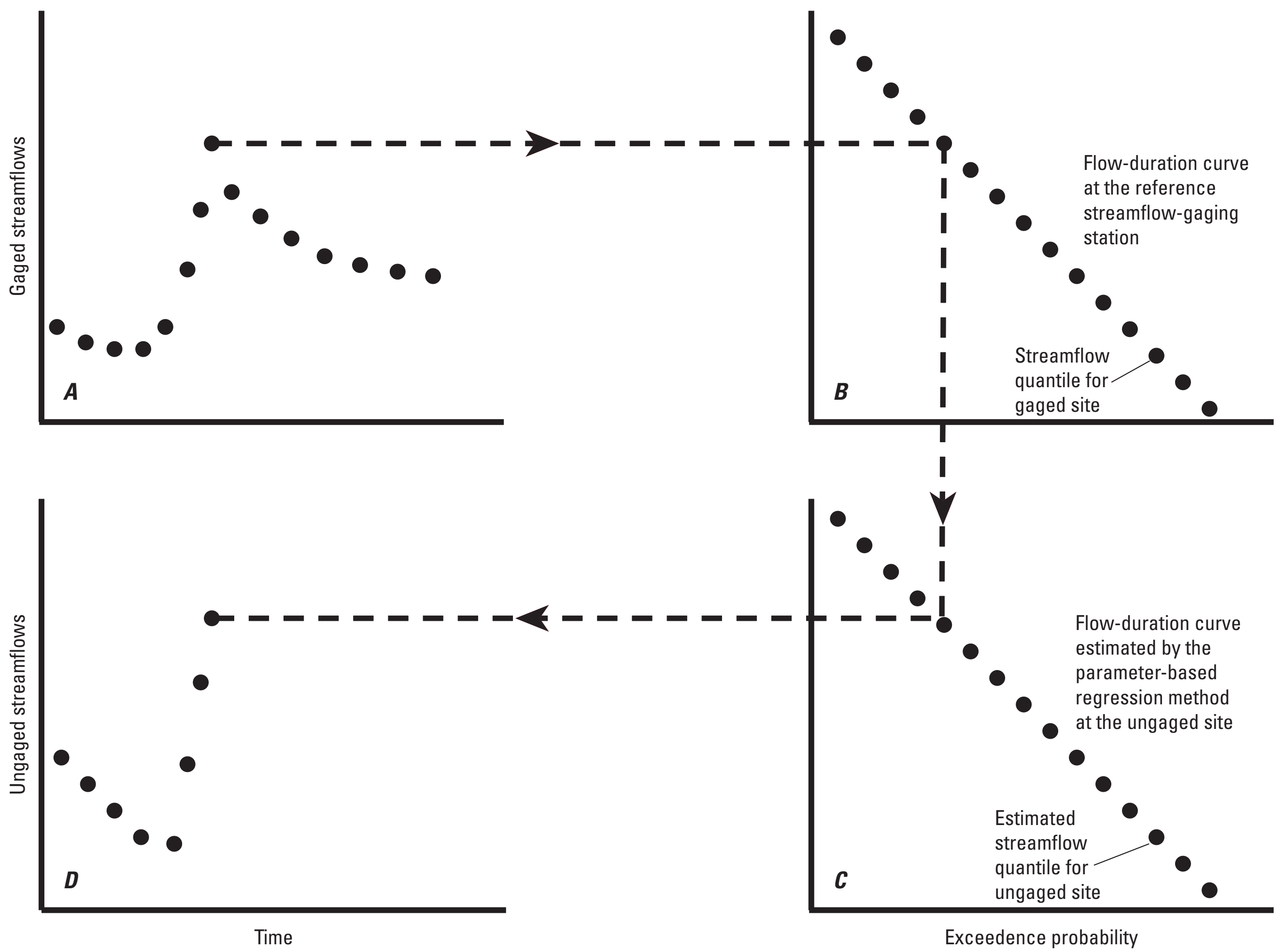


Figure 2. Translation of a flow-duration curve to a time series of estimated streamflow by using the Flow Duration Curve Transfer method showing (*A*) the observed time series, (*B*) flow-duration curve, (*C*) exceedance probability, and (*D*) estimated time series at the ungaged site (from Archfield, 2009).

and 06483500, Rock River near Rock Valley, Iowa (fig. 1, map no. 93, and table 1). Positive trends also were seen in the data from 2 of the 34 out-of-state streamgages tested. Tests for trends also were completed for the 50-percent and 10-percent exceedance probabilities; however, the number of streamgages that showed trends in streamflow decreased with decreasing percent exceedances (higher streamflows). At the 90-percent exceedance probability, one streamgage in Iowa had a negative trend in streamflow and no out-of-state streamgages had negative trends in streamflow. Testing for Kendall's *tau* hypothesis test was done with the SWSTAT statistical program (Lumb and others, 1990). A P-value threshold of 5 percent (α=0.05) was used for this method and values less than or equal to 5 percent were flagged as having statistically significant trends (positive or negative).

Possible reasons for the trends in low-flow statistics have been examined in several previous studies. Positive trends in low-flow statistics were found at 133 of the 208 Iowa and out-of-state streamgages tested for a low-flow study (Eash and Barnes, 2012). For some areas of the state and for some periods of record, trends in precipitation were found to be statistically significant but the precipitation data did not appear to fully explain low-flow trends (Eash and Barnes, 2012). Changes in agricultural practices are thought to be the main cause of positive low-flow trends in Iowa (Shilling and Libra, 2003: Shilling, 2005). For the mean annual streamflow 90-percent exceedance probability statistic, 1978 was found to be the latest date beyond which no data exhibit a trend as determined by using the trend analysis test.

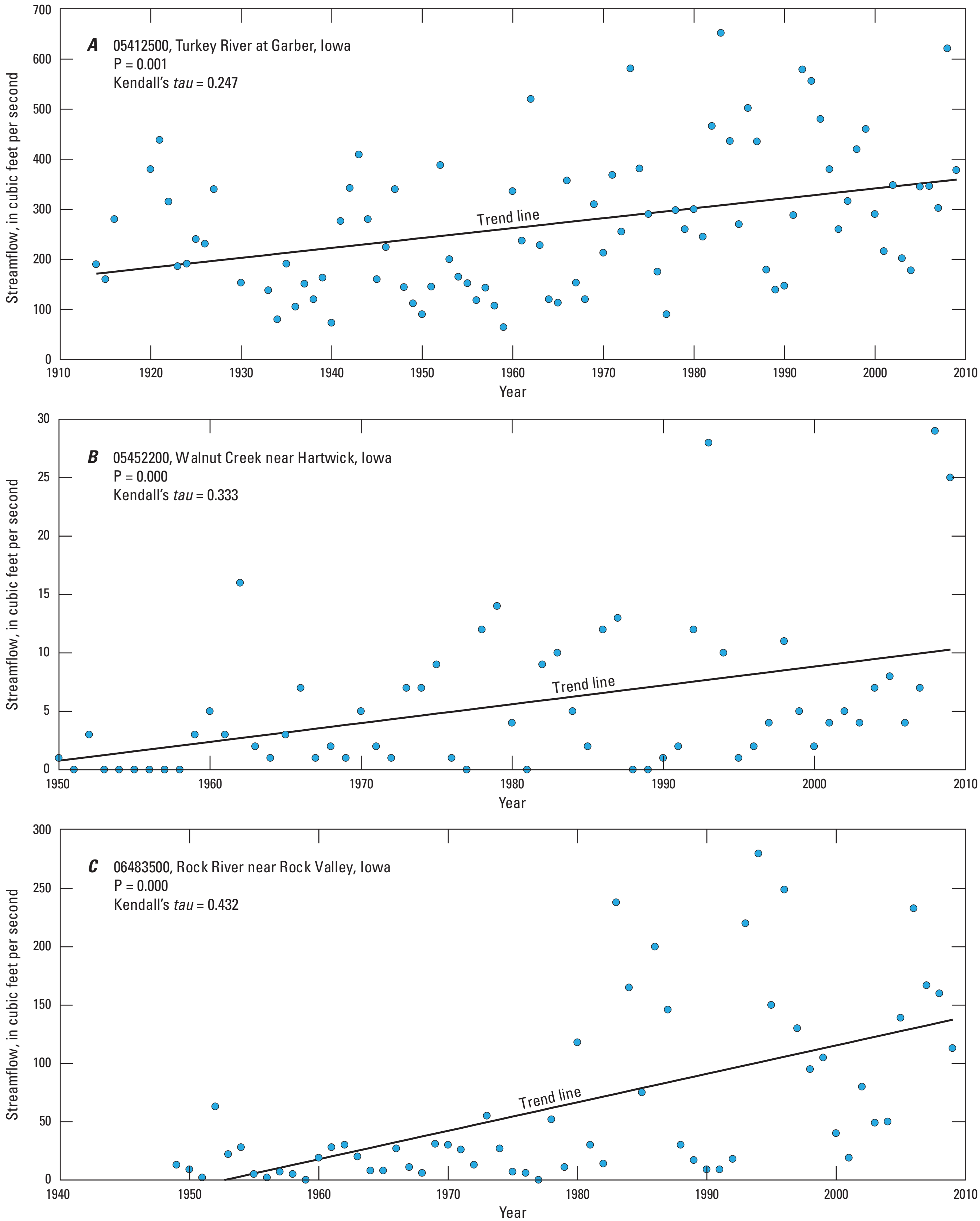


Figure 3. The 90-percent exceedance probability of daily mean streamflow by water year for U.S. Geological Survey streamgages (*A*) 05412500, Turkey River at Garber, Iowa; (*B*) 05452200, Walnut Creek near Hartwick, Iowa; and (*C*) 06483500, Rock River near Rock Valley, Iowa.

Flow Anywhere Method Analytical Procedures

Data used in the Flow Anywhere method were retrieved for 123 continuous-record streamgages located in Iowa and within a 50-mi buffer of Iowa in the neighboring States of Illinois, Minnesota, Missouri, Nebraska, and Wisconsin (fig. 1, table 1). A continuous-record streamgage is a gage at which stage is recorded continuously; streamflow is then computed from the stage data (Nalley and others, 2002). Streamgages with at least 5 complete years of daily mean streamflow through the 2009 water year (October 1, 2004, to September 30, 2009) and that are minimally affected by regulation or diversion were initially selected for evaluation in the study; these included 92 streamgages in Iowa and 31 streamgages in adjacent states. A period of record encompassing 5 complete years of data was used so that the number of streamgages in the local regions was adequate to perform the analysis. Because 10 complete years of daily mean streamflow data were used in the Flow Duration Curve Transfer method, the set of streamgages used was slightly different than the set used in the Flow Anywhere method. In another flow-duration study (Risley and others, 2008), a period of 10 complete years of record also was used because estimates of the extremes of the daily mean flows are more accurate the longer the period of record used. Streamgages in adjacent states were included in the study to improve the representation of streamflow characteristics near the Iowa border and improve the results of the regression analysis for locations near the state border. Daily mean streamflow values prior to the beginning of the 1978 water year (October 1, 1977) were not used in the final analyses because trends were found in the entire record for some streamgages. As noted in the Trend Analysis section, this is the latest date beyond which no data exhibit a trend as determined by using the trend-analysis test. Daily mean streamflow data for the 123 streamgages were retrieved from the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2011). The drainage areas of the 123 streamgages were measured by using a GIS. The drainage areas were measured by following procedures used by Eash and Barnes (2012). Drainage-area values from the GIS were compared to the published values in the NWIS database (table 1). The GIS drainage-area value is used in this study to develop the regression equations in order to remain consistent with the measurement techniques that would be used in a Web-based tool.

Identification of Local Regions

Areas of highly correlated streamflows are determined as part of the Flow Anywhere method. The Pearson's *r* correlation value of 0.866 was used to represent high correlation, as this value results in a concentrated area of correlation for most areas of the study area. The areas, referred to as local regions, contain streamgages at which streamflows historically are highly correlated to streamflows at other streamgages in the local region. Local regions are used to limit the selection area for reference streamgages to areas of similar streamflow characteristics. The correlation of streamflows between streamgages was quantified by using the Pearson's *r* correlation coefficient (Helsel and Hirsch, 2002), and is determined as

$$r = \frac{1}{(n-1)} \sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{s_x} \right) \left(\frac{y_i - \bar{y}}{s_y} \right), \qquad (3)$$

where

r is the Pearson's *r* correlation coefficient,

n is the number of pairs of observations,

x_i is the *i*th value of the x parameter,

$\bar{x}$ is the mean value of the x parameter,

$\bar{y}$ is the mean value of the y parameter,

y_i is the *i*th value of the y parameter,

s_x is the standard deviation of the x parameter, and

s_y is the standard deviation of the y parameter.

The computation for the Pearson's *r* correlation coefficient requires that the number of observations between the two datasets being compared be the same. Because record lengths vary between streamgages, the number of observations used when comparing two streamgages was limited by the shorter record length of the two streamgages being compared. For example, when the Pearson's *r* correlation coefficient between streamgages 05388250, Upper Iowa River near Dorchester, Iowa (fig. 1, map no. 6, and table 1), and 05411850, Turkey River near Eldorado, Iowa (fig. 1, map no. 10, table 1), was computed, 9 years of observations were used because station 05411850, Turkey River near Eldorado, Iowa, has the shorter of the two record lengths at 9 years.

An absolute value of the Pearson's *r* correlation coefficient equal to 1.0 represents a perfect correlation between two streamgages and 0.0 represents no correlation. The Pearson's *r* correlation coefficient was computed for the relation between the logarithm (base 10) of the streamflow at each streamgage and every other streamgage in the study area. The use of the logarithm (base 10) streamflow value creates a more constant variance among the data (Helsel and Hirsch, 2002). The results were examined geographically by developing a map for each streamgage showing its Pearson's *r* correlation value with every other streamgage in the study area (figs. 4*A*, 4*B*, and 4*C* show results for three selected gages). Streamgages with high correlation—Pearson's *r* correlation values greater than or equal to 0.800—are shown as green, blue, or red symbols. A polygon that follows the basin boundaries of the most highly correlated streamgages—those with a Pearson's *r* correlation value greater than 0.866—was drawn on each correlation map for the study area. These polygons showed common areas of high correlation throughout the study area. These common areas were determined to be local regions of high correlation where streamflow data historically are generally closely related to those at other locations. In some instances, a streamgage did not have a Pearson's *r* correlation coefficient of 0.87 or higher with respect to any other streamgage in the study area. In such instances, the streamgage was placed in the same local region as nearby streamgages. Final local region boundaries were determined by using Iowa landform regions (Prior, 1991; Prior and others, 2009) and the 12-digit hydrologic-unit-code boundaries as a guide (figs. 5 and 6). Streamflow data from some streamgages in the neighboring states were found to be poorly correlated to those from any streamgages in Iowa. These streamgages were removed from the study with the assumption that they likely lie in a local region not characteristic of Iowa, and therefore are not relevant to this study (table 2). This process left 107 streamgages for the development of the Flow Anywhere method. Each remaining streamgage used in the study was classified for inclusion in a specific local region (table 3).

Regression Methods

Regression techniques are used in the Flow Anywhere method to determine the reference streamgage in each local region and also to group together local regions that have similar hydrologic properties. Regression methods also are used to develop final regional regression equations to compute streamflows at ungaged locations. Logarithmic (base 10) transformations of streamflows and drainage areas were performed. The transformations were used to achieve homoscedacity of the residuals about the regression line between variables and to linearize the relations (Eash, 2001). The statistical software package R was used for computations and to develop regression equations (R Development Core Team, 2010). Ordinary-least-squares and left-censored regression techniques were used. Weighting methods, such as a weighted-least-squares (WLS) analysis, were not applied in this study. Even though the streamgages in the study area have records of varying lengths, the quality of individual daily mean streamflow values does not depend on the length of record at a streamgage.

Determination of Reference Streamgages

The Flow Anywhere method relies on the selection of an appropriate continuous-record streamgage from which to transfer streamflow characteristics to the ungaged location. Within each local region, a reference streamgage is selected that is determined to best represent streamflows for that area. The reference streamgage for each local region was selected by comparing hydrographs and results of ordinary-least-squares regressions. An ordinary-least-squares regression analysis was completed for each streamgage in a local region by using it as a potential reference streamgage, a process similar to that described by equation 2. The independent variables, also known as the explanatory variables, were the daily mean streamflows at the candidate reference streamgage and the drainage-area ratio between the nonreference streamgage and the candidate reference streamgage. The dependent variable, also known as the response variable, was the same-day streamflow at the nonreference streamgage in the local region. This process was repeated for each streamgage in the local region by using it as a candidate reference streamgage. The candidate reference streamgage that resulted in the regression equation having the highest coefficient of determination (R^2) was selected as the reference streamgage for that local region. R^2 is a measure of the percent of the variation in the response (y) variable that is accounted for by the variation in the explanatory variables (Helsel and Hirsch, 2002). Additional visual analysis of observed and estimated hydrographs for goodness of fit was used to verify the selection of the appropriate reference streamgage. This analysis was completed for all of the local regions to determine a unique reference streamgage for each region (table 3). The selected reference streamgage in each local region was used to relate known streamflow measurements made at a streamgage to an ungaged location within the same local region.

Determination of Aggregated Regions

The previously determined local regions contain an insufficient number of streamgages from which to compute reliable regional regression equations. The number of streamgages in each local region ranges from 3 to 13 (table 3). In order to achieve an adequate number of streamgages for regression analyses, local regions of similar hydrologic properties were grouped together. To develop these groupings, an ordinary-least-squares regression initially was computed by using all the streamgages in the study area except those that had been removed as a result of low correlation to other streamgages in Iowa, as noted in the section Identification of Local Regions. The independent variables of the regression were the streamflow at the reference streamgage and the ratio of the drainage area of the nonreference streamgage to that of the associated reference streamgage. The dependent variable was the same-day streamflow at the nonreference streamgage, as noted in equations 1 and 2. Residual values at each streamgage from the preliminary regression analysis were examined geographically to identify spatial trends in the results. Residual values indicate the differences between observed streamflows and estimated streamflows from the regression equations. Three general groupings of residual values from local regions were observed: consistently positive, consistently negative, and evenly distributed about zero. These groupings were used to define three areas of aggregated local regions. An ordinary-least-squares regression was computed again, as noted above, on each aggregated local region to determine whether an individual local region demonstrated a consistent residual value rather than being distributed about zero. Local regions found to have consistent residual values in the positive or negative direction were moved to a different aggregated region

A

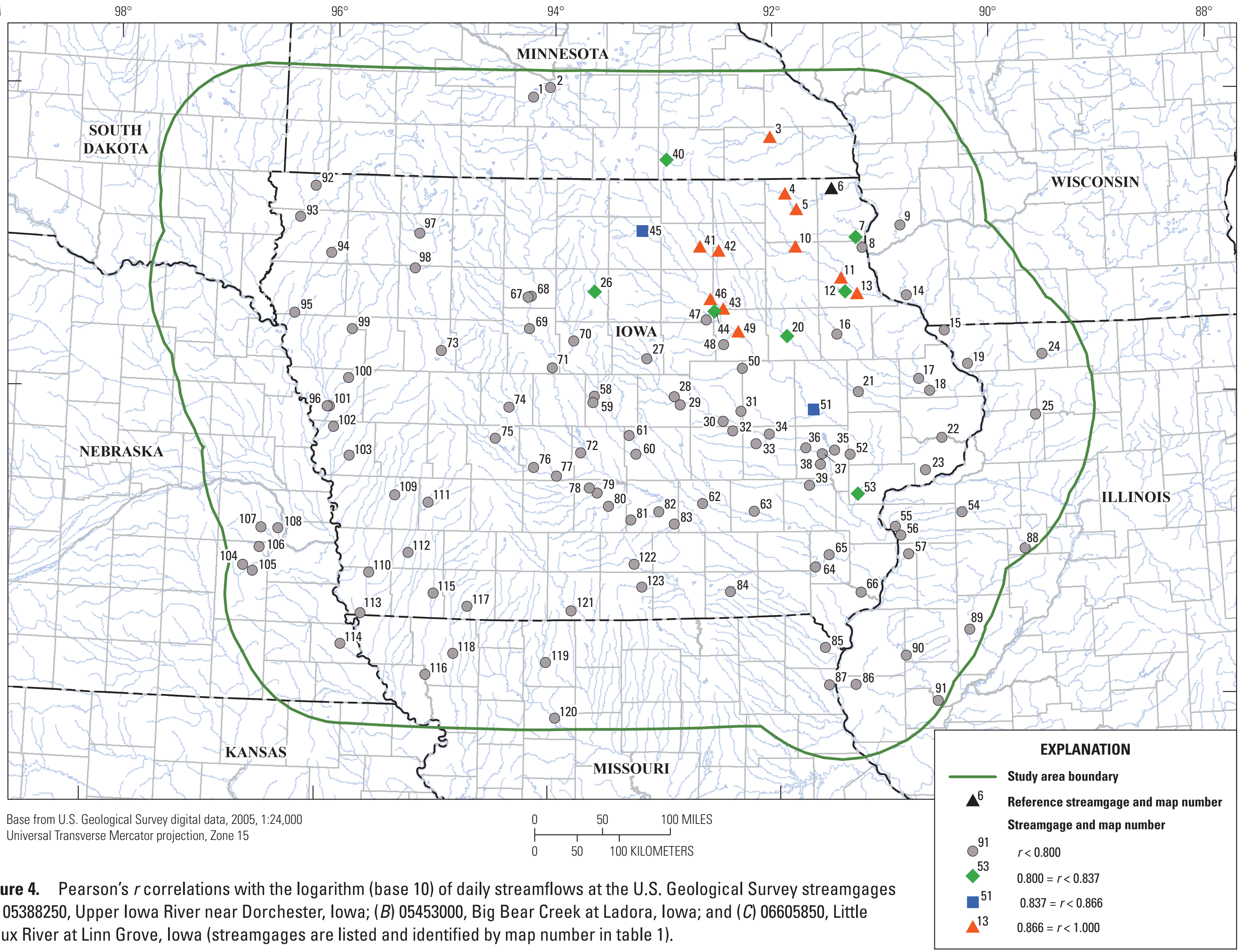
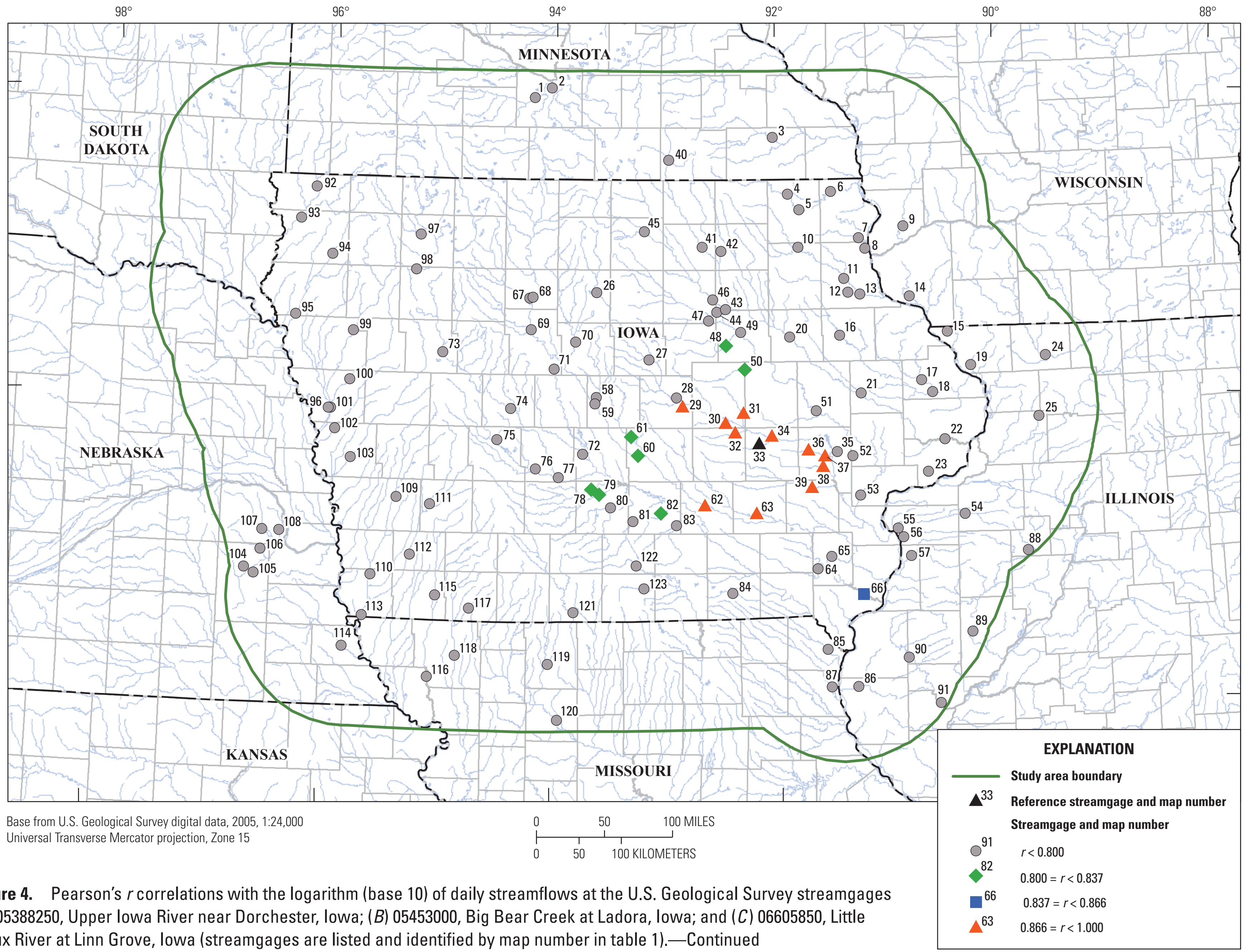


Figure 4. Pearson's *r* correlations with the logarithm (base 10) of daily streamflows at the U.S. Geological Survey streamgages (*A*) 05388250, Upper Iowa River near Dorchester, Iowa; (*B*) 05453000, Big Bear Creek at Ladora, Iowa; and (*C*) 06605850, Little Sioux River at Linn Grove, Iowa (streamgages are listed and identified by map number in table 1).

B



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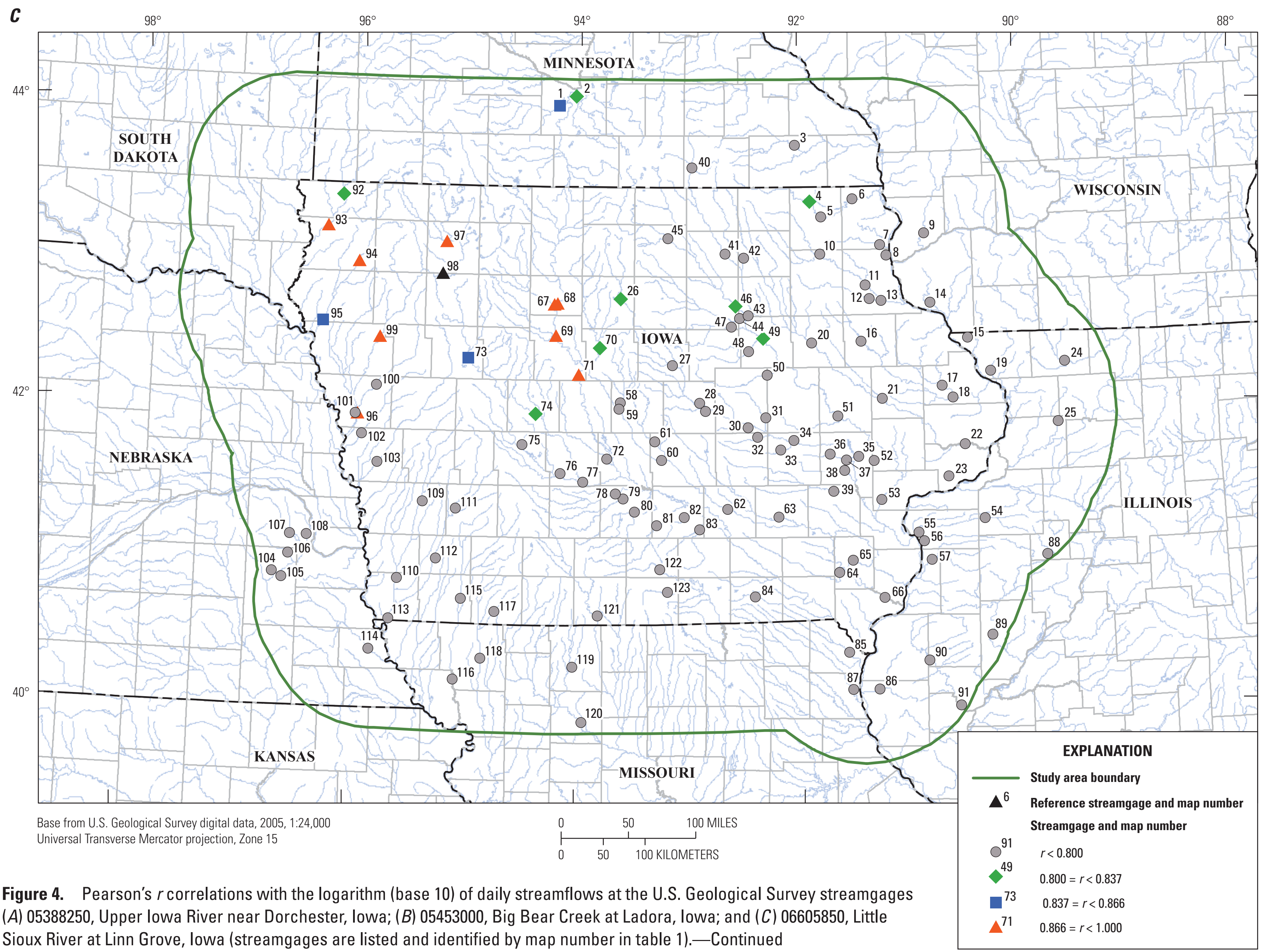

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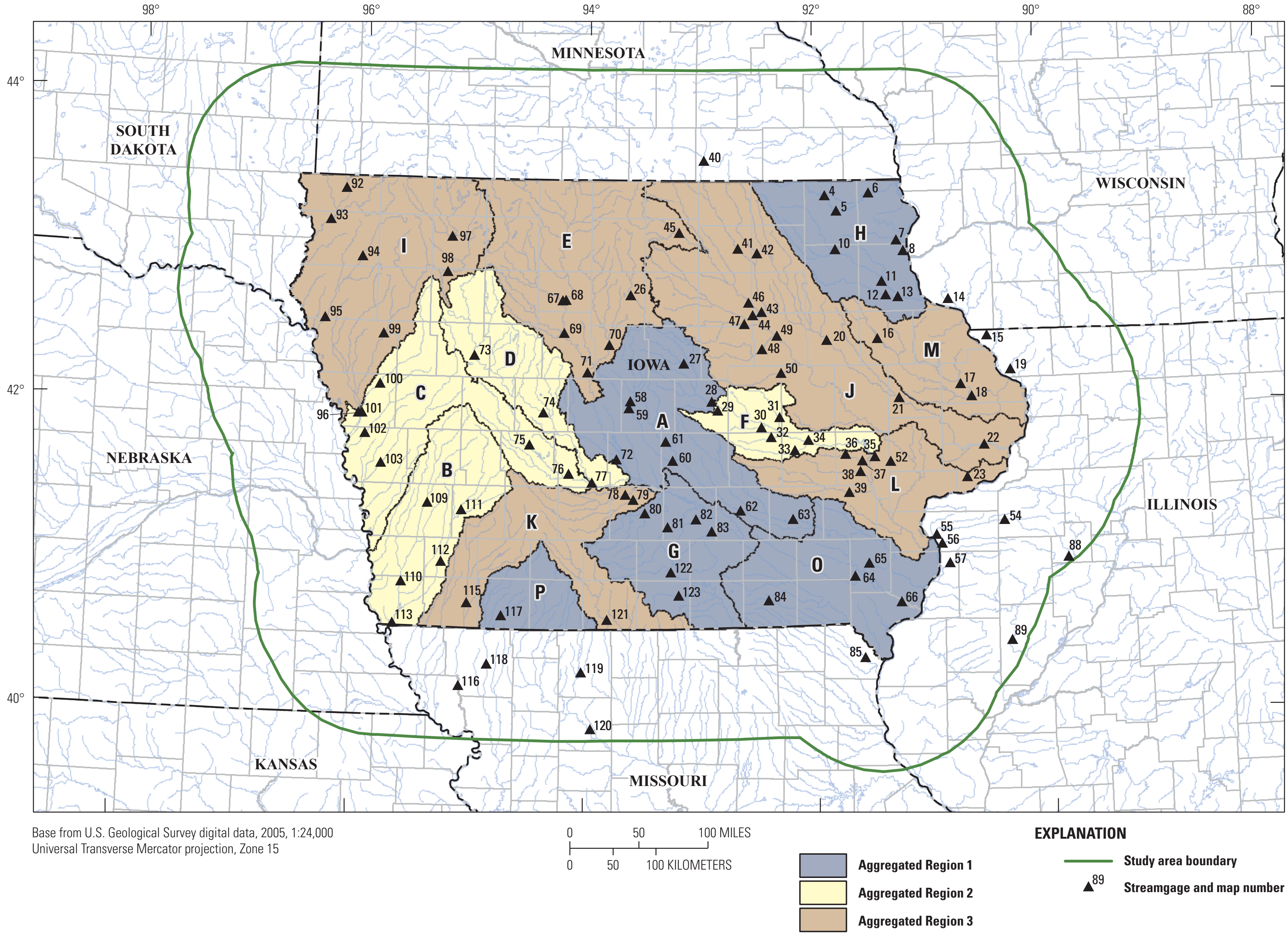


Figure 5. Local and aggregated region boundaries in Iowa for the Flow Anywhere method.

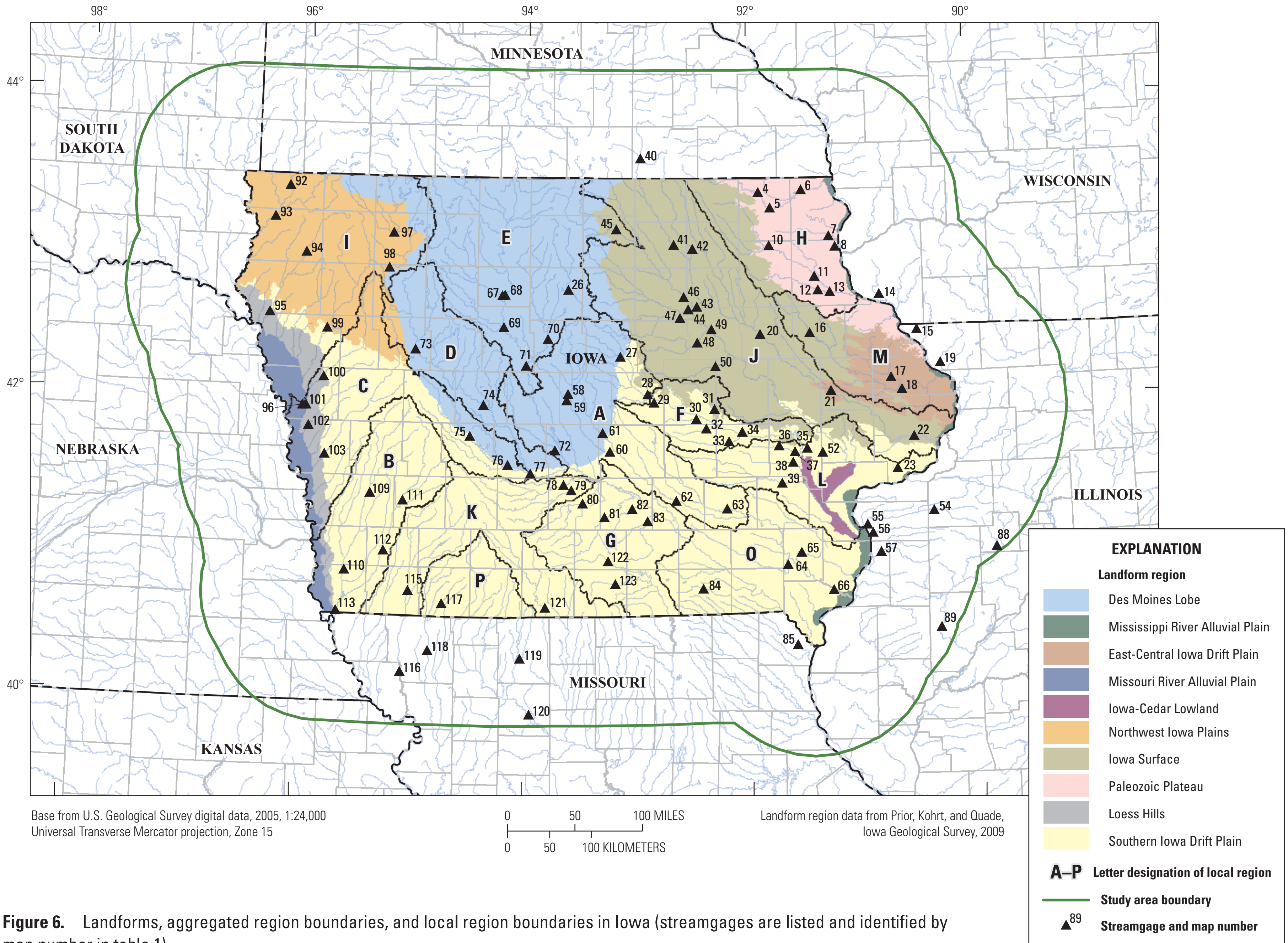


Figure 6. Landforms, aggregated region boundaries, and local region boundaries in Iowa (streamgages are listed and identified by map number in table 1).

Table 2. Streamgages removed from the Flow Anywhere regression analyses.

[no., number; USGS, U.S. Geological Survey; MN, Minnesota; WI, Wisconsin; IL, Illinois; IA, Iowa; GIS, Geographic Information System; mi^2, square miles MO, Missouri, NE, Nebraska]

Map no.	USGS streamgage number	Streamgage name	Reason for removal of streamgage from regression analyses
1	05319500	Watonwan River near Garden City, MN	Located in local region completely outside Iowa border.
2	05320500	Le Sueur River near Rapidan, MN	Located in local region completely outside Iowa border.
3	05383950	Root River near Pilot Mound, MN	Located in local region completely outside Iowa border.
9	05410490	Kickapoo River at Steuben, WI	Located in local region completely outside Iowa border.
24	05435500	Pecatonica River at Freeport, IL	Located in local region completely outside Iowa border.
25	05444000	Elkhorn Creek near Penrose, IL	Located in local region completely outside Iowa border.
51	05464500	Cedar River at Cedar Rapids, IA	GIS drainage area larger than 5,500 mi^2.
53	05465000	Cedar River at Conesville, IA	GIS drainage area larger than 5,500 mi^2.
86	05495500	Bear Creek near Marcelline, IL	Located in local region completely outside Iowa border.
87	05496000	Wyaconda River above Canton, MO	Located in local region completely outside Iowa border.
90	05584500	La Moine River at Colmar, IL	Located in local region completely outside Iowa border.
91	05585000	La Moine River at Ripley, IL	Located in local region completely outside Iowa border.
104	06803510	Little Salt Creek near Lincoln, NE	Located in local region completely outside Iowa border.
105	06803520	Stevens Creek near Lincoln, NE	Located in local region completely outside Iowa border.
106	06803530	Rock Creek near Ceresco, NE	Located in local region completely outside Iowa border.
107	06804000	Wahoo Creek at Ithaca, NE	Located in local region completely outside Iowa border.
108	06804900	Johnson Creek near Memphis, NE	Located in local region completely outside Iowa border.
114	06811500	Little Nemaha River at Auburn, NE	Located in local region completely outside Iowa border.

and the ordinary-least-squares regression was recomputed. This process was repeated until local regions did not indicate an obvious positive or negative residual value and were evenly distributed about zero.

Streamgages with large drainage areas, greater than 5,500 square miles (mi^2), greatly influenced the results for the local region to which they were assigned. The drainage basins of two streamgages in the study area are larger than 5,500 mi^2 (table 2). These streamgages were removed from the study and the ordinary-least-squares regression was recomputed. Removing the two largest basins restricts the application slightly because it is not appropriate to use the method outside the range of values of the explanatory variables. The application therefore is restricted to basins smaller than 5,500 mi^2. The results of the final ordinary-least-squares regression determined the association of each local region to one of three aggregated regions for the study area (table 3; fig. 5).

Development of Regional Regression Equations

After the aggregated regions were finalized, regional regression equations were solved to compute streamflow for ungaged locations. As in the preliminary ordinary-least-squares regression analyses to determine the reference streamgages and aggregated regions, the independent variables were the ratio of the drainage area of the nonreference streamgages to those of the associated reference streamgages, and the streamflow at the reference streamgages. The dependent variable was the same-day streamflow at the nonreference streamgage as in equation 2. Because the records of a number of streamgages in the study area include observed zero streamflows, two types of regression analyses were performed to develop the final equations for the three aggregated regions. Left-censored regression analyses were performed in aggregated regions where zero streamflows were observed. Ordinary-least-squares regression analyses were used in aggregated regions where zero flows were not observed.

Table 3. Streamgages used to develop regression equations for the Flow Anywhere method, Iowa.

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi², square miles; IA, Iowa; MO, Missouri; IL, Illinois; MN, Minnesota; WI, Wisconsin. Locations of aggregated and local regions for the Flow Anywhere method are shown in fig. 5]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi²)	Aggregated region	Local region	Reference streamgage
60	05471050	South Skunk River at Colfax, IA	806	1	A	Yes.
27	05451210	South Fork Iowa River northeast of New Providence, IA	224	1	A	No.
28	05451500	Iowa River at Marshalltown, IA	1,534	1	A	No.
58	05470000	South Skunk River near Ames, IA	317	1	A	No.
59	05470500	Squaw Creek at Ames, IA	210	1	A	No.
61	05471200	Indian Creek near Mingo, IA	277	1	A	No.
62	05471500	South Skunk River near Oskaloosa, IA	1,640	1	A	No.
63	05472500	North Skunk River near Sigourney, IA	734	1	A	No.
72	05481950	Beaver Creek near Grimes, IA	370	1	A	No.
83	05489000	Cedar Creek near Bussey, IA	372	1	G	Yes.
80	05487470	South River near Ackworth, IA	458	1	G	No.
81	05487980	White Breast Creek near Dallas, IA	340	1	G	No.
82	05488200	English Creek near Knoxville, IA	90.7	1	G	No.
122	06903400	Chariton River near Chariton, IA	186	1	G	No.
123	06903700	South Fork Chariton River near Promise City, IA	170	1	G	No.
6	05388250	Upper Iowa River near Dorchester, IA	768	1	H	Yes.
4	05387440	Upper Iowa River at Bluffton, IA	367	1	H	No.
5	05387500	Upper Iowa River at Decorah, IA	511	1	H	No.
7	05389000	Yellow River at Ion, IA	219	1	H	No.
8	05389400	Bloody Run Creek near Marquette, IA	34.3	1	H	No.
10	05411850	Turkey River near Eldorado, IA	642	1	H	No.
11	05412020	Turkey River above French Hollow Creek at Elkader, IA	905	1	H	No.
12	05412400	Volga River at Littleport, IA	350	1	H	No.
13	05412500	Turkey River at Garber, IA	1,553	1	H	No.
85	05495000	Fox River at Wayland, MO	396	1	O	Yes.
64	05473400	Cedar Creek near Oakland Mills, IA	533	1	O	No.
65	05473450	Big Creek north of Mount Pleasant, IA	60.9	1	O	No.
66	05474000	Skunk River at Augusta, IA	4,310	1	O	No.
84	05494300	Fox River at Bloomfield, IA	87.3	1	O	No.
120	06897500	Grand River near Gallatin, MO	2,246	1	P	Yes.
117	06819185	East Fork 102 River at Bedford, IA	85.8	1	P	No.
118	06819500	102 River at Maryville, MO	491	1	P	No.
119	06897000	East Fork Big Creek near Bethany, MO	90.8	1	P	No.
112	06809500	East Nishnabotna River at Red Oak, IA	895	2	B	Yes.
109	06807410	West Nishnabotna River at Hancock, IA	611	2	B	No.
110	06808500	West Nishnabotna River at Randolph, IA	1,329	2	B	No.
111	06809210	East Nishnabotna River near Atlantic, IA	440	2	B	No.
113	06810000	Nishnabotna River above Hamburg, IA	2,809	2	B	No.
103	06609500	Boyer River at Logan, IA	870	2	C	Yes.
75	05483450	Middle Raccoon River near Bayard, IA	382	2	C	No.
76	05484000	South Raccoon River at Redfield, IA	987	2	C	No.

Table 3. Streamgages used to develop regression equations for the Flow Anywhere method, Iowa.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi², square miles; IA, Iowa; MO, Missouri; IL, Illinois; MN, Minnesota; WI, Wisconsin. Locations of aggregated and local regions for the Flow Anywhere method are shown in fig. 5]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi²)	Aggregated region	Local region	Reference streamgage
96	06602400	Monona-Harrison Ditch near Turin, IA	929	2	C	No.
100	06607200	Maple River at Mapleton, IA	670	2	C	No.
101	06607500	Little Sioux River near Turin, IA	3,553	2	C	No.
102	06608500	Soldier River at Pisgah, IA	409	2	C	No.
74	05482500	North Raccoon River near Jefferson, IA	1,609	2	D	Yes.
73	05482300	North Raccoon River near Sac City, IA	697	2	D	No.
77	05484500	Raccoon River at Van Meter, IA	3,425	2	D	No.
33	05453000	Big Bear Creek at Ladora, IA	187	2	F	Yes.
29	05451700	Timber Creek near Marshalltown, IA	120	2	F	No.
30	05451900	Richland Creek near Haven, IA	56.1	2	F	No.
31	05452000	Salt Creek near Elberon, IA	199	2	F	No.
32	05452200	Walnut Creek near Hartwick, IA	70.5	2	F	No.
34	05453100	Iowa River at Marengo, IA	2,793	2	F	No.
57	05469000	Henderson Creek near Oquawka, IL	436	2	N	Yes.
54	05466000	Edwards River near Orion, IL	156	2	N	No.
55	05466500	Edwards River near New Boston, IL	442	2	N	No.
56	05467000	Pope Creek near Keithsburg, IL	172	2	N	No.
88	05568800	Indian Creek near Wyoming, IL	63.2	2	N	No.
89	05570000	Spoon River at Seville, IL	1,638	2	N	No.
68	05479000	East Fork Des Moines River at Dakota City, IA	1,306	3	E	Yes.
26	05449500	Iowa River near Rowan, IA	427	3	E	No.
45	05459500	Winnebago River at Mason City, IA	517	3	E	No.
67	05476750	Des Moines River at Humboldt, IA	2,270	3	E	No.
69	05480500	Des Moines River at Fort Dodge, IA	4,202	3	E	No.
70	05481000	Boone River near Webster City, IA	846	3	E	No.
71	05481300	Des Moines River near Stratford, IA	5,464	3	E	No.
98	06605850	Little Sioux River at Linn Grove, IA	1,567	3	I	Yes.
92	06483290	Rock River below Tom Creek at Rock Rapids, IA	851	3	I	No.
93	06483500	Rock River near Rock Valley, IA	1,584	3	I	No.
94	06600100	Floyd River at Alton, IA	267	3	I	No.
95	06600500	Floyd River at James, IA	886	3	I	No.
97	06605000	Ocheyedan River near Spencer, IA	440	3	I	No.
99	06606600	Little Sioux River at Correctionville, IA	2,520	3	I	No.
44	05458900	West Fork Cedar River at Finchford, IA	851	3	J	Yes.
20	05421000	Wapsipinicon River at Independence, IA	1,053	3	J	No.
21	05421740	Wapsipinicon River near Anamosa, IA	1,581	3	J	No.
22	05422000	Wapsipinicon River near De Witt, IA	2,336	3	J	No.
40	05457000	Cedar River near Austin, MN	398	3	J	No.
41	05457700	Cedar River at Charles City, IA	1,075	3	J	No.
42	05458000	Little Cedar River near Ionia, IA	295	3	J	No.
43	05458500	Cedar River at Janesville, IA	1,671	3	J	No.

Table 3. Streamgages used to develop regression equations for the Flow Anywhere method, Iowa.—Continued

[no., number; USGS, U.S. Geological Survey; GIS, Geographic Information System; mi^2, square miles; IA, Iowa; MO, Missouri; IL, Illinois; MN, Minnesota; WI, Wisconsin. Locations of aggregated and local regions for the Flow Anywhere method are shown in fig. 5]

Map no.	USGS streamgage number	Streamgage name	GIS drainage area (mi^2)	Aggregated region	Local region	Reference streamgage
46	05462000	Shell Rock River at Shell Rock, IA	1,731	3	J	No.
47	05463000	Beaver Creek at New Hartford, IA	351	3	J	No.
48	05463500	Black Hawk Creek at Hudson IA	298	3	J	No.
49	05464000	Cedar River at Waterloo, IA	5,149	3	J	No.
50	05464220	Wolf Creek near Dysart, IA	298	3	J	No.
121	06898000	Thompson River at Davis City, IA	695	3	K	Yes.
78	05486000	North River near Norwalk, IA	349	3	K	No.
79	05486490	Middle River near Indianola, IA	489	3	K	No.
115	06817000	Nodaway River at Clarinda, IA	761	3	K	No.
116	06817700	Nodaway River near Graham, MO	1,516	3	K	No.
38	05455100	Old Mans Creek near Iowa City, IA	201	3	L	Yes.
23	05422560	Duck Creek at 110th Ave at Davenport, IA	15.5	3	L	No.
35	05454000	Rapid Creek near Iowa City, IA	25.3	3	L	No.
36	05454220	Clear Creek near Oxford, IA	60.8	3	L	No.
37	05454300	Clear Creek near Coralville, IA	98.2	3	L	No.
39	05455500	English River at Kalona, IA	574	3	L	No.
52	05464942	Hoover Creek at Hoover Nat Hist Site, West Branch, IA	2.6	3	L	No.
19	05419000	Apple River near Hanover, IL	247	3	M	Yes.
14	05413500	Grant River at Burton, WI	269	3	M	No.
15	05414820	Sinsinawa River near Menominee, IL	40.0	3	M	No.
16	05416900	Maquoketa River at Manchester, IA	279	3	M	No.
17	05418400	North Fork Maquoketa River near Fulton, IA	503	3	M	No.
18	05418500	Maquoketa River near Maquoketa, IA	1,551	3	M	No.

Left-Censored Regression

Left-censored regression, also referred to as "Tobit regression," is used when less than 20 percent of the dataset is censored (Helsel and Hirsch, 2002). The datasets for aggregated regions 1 and 2 contain a small number of zero streamflow values (less than 20 percent); therefore, a left-censored regression was used for these areas. Left-censored regression analyses allow the use of a censoring threshold in the development of the equations to estimate flow at ungaged locations within those regions. A censoring threshold of 0.10 ft^3/s was used to censor small dependent-variable streamflows and zero flows because of the uncertainty inherent in measuring daily mean streamflow values below 0.1 ft^3/s. Daily mean streamflow values as low as 0.01 ft^3/s are recorded at streamgages; therefore, in addition to the zero flows, streamflows less than or equal to 0.1 ft^3/s were censored in the regression analyses. Censored regression is similar to multiple linear regression except that the regression coefficients are fit by maximum-likelihood estimation (MLE) (Helsel and Hirsch, 2002). 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.

In regression analysis, an assumption is made that residual values are not correlated to one another or do not exhibit a trend (Helsel and Hirsch, 2002). To test for correlation or trends in the residual values, graphical representations of the residual values for each aggregated region were examined with respect to their relation to the estimated streamflow, time, and lagged residuals (fig. 7). Residual values as a function of the estimated value were examined for curvature and heteroscedasticity, with none being noted (fig. 7*A*). The "slice" feature at the low flows is attributed to censoring the data below 0.1 ft^3/s. Residual values as a function of time also were examined for trends or patterns through time, with none being noted (fig. 7*C*). Residual values as a function of the 1-day lagged residuals also were examined, and a linear trend was noted by visual observation (fig. 7*E*). To remedy this issue, samples from the dataset were discarded from the left-censored regression in a regular pattern until the residuals were found not to be serially correlated. Using the daily mean streamflow from the 15th day of every other month resulted in the removal of visual serial correlation from the residuals (figs. 7*B*, 7*D*, and 7*F*). It is believed that this process does not affect the results or accuracy of the regression because the correlation that existed indicated the presence of a considerable amount of redundant information in the dataset (Helsel and Hirsch, 2002). Using any day of every other month would achieve the same results as there is nothing significant about the 15th day of every other month—for example, the 1st day of every other month or the 28th day of every other month is assumed to work just as well. The final regression equations for aggregated regions 1 and 2 were computed by using left-censored regression techniques with a low limit threshold set at 0.1 ft^3/s and the daily mean streamflow from the 15th day of every other month (table 4).

Ordinary-Least-Squares Regression

The dataset for aggregated region 3 did not contain any zero streamflow values; therefore, a censored regression was not needed. An ordinary-least-squares regression was used for aggregated region 3. As in the left-censored regression analysis of aggregated regions 1 and 2, the initial ordinary-least-squares regression results were examined for correlation between residual values. Results of the analysis of residuals and their relation to the estimated streamflow, time, and lagged residuals for the ordinary-least-squares regression were similar to those found for the left-centered regression. The correlation between residuals and lagged residuals again was observed by using the entire dataset. The dataset for aggregated region 3 also was sampled until no correlation was observed. This process also resulted in a dataset of daily mean streamflows from the 15th day of every other month. The final regression equation for aggregated region 3 was computed by using an ordinary-least-squares multiple linear regression method and the daily mean streamflow from the 15th day of every other month (table 4).

Accuracy and Limitations of Regression Estimates

The accuracies of the final regression equations for aggregated regions 1, 2, and 3 were analyzed and quantified. The final equations are presented in table 4, along with the associated standard errors of the model. The average standard error of estimate (SEE) measures how well the regression model fits the data that were used to develop it. The values of standard error were determined by using equations presented in Riggs (1968). The standard error values in logarithm (base 10) format represent the errors of equations developed by using the logarithm (base 10) transformed data. The range of percent error represents the errors for the final untransformed equations (Hortness, 2006). The standard error of prediction (SEP) also was computed for the ordinary-least-squares regression (table 4). The SEP is a measure of the accuracy with which the regression model can estimate daily mean streamflows at ungaged sites. The SEP accounts for model error, SEE, and the sampling error (error that results from estimating model parameters from limited data) in estimating the accuracy of the equations. Compared to the SEE, the SEP provides a better overall measure of the predictive ability of a model (Eash, 2001). The SEP is not applicable to a left-censored regression analysis.

Comparison of Observed and Estimated Streamflows

The time series of unregulated, daily mean streamflow at ungaged locations is created by the following steps: (1) determine which local region contains the ungaged location, (2) select the appropriate reference streamgage within the same local region, (3) determine the drainage areas at the ungaged location and the reference streamgage, (4) determine which aggregated region contains the local region, (5) obtain the daily mean streamflow at the reference streamgage for the desired dates of computation, and (6) compute the estimated streamflow at the ungaged location from the appropriate aggregated-region equation. The performance of the Flow Anywhere method in each aggregated region was examined by comparing the observed and estimated streamflows throughout the aggregated region (fig. 8). The comparisons did not demonstrate an obvious range of streamflows that were consistently over- or underestimated, with the exception of the extreme low streamflows, as shown in figure 8. These streamflows generally appear to be slightly overestimated. Tests were completed by removing or adding local regions within the study area from or to different aggregated regions. These changes did not improve the estimation for the lower streamflows; therefore, the results presented in table 4 are believed to produce the best possible agreement with the dataset. Hydrographs of observed and estimated streamflows for non-reference streamgages in the dataset also were analyzed. Any consistencies of over- or underestimation of streamflows that were observed in a local region were removed by moving local regions to a different aggregated region to determine whether regression errors could be improved. As noted above for the comparison of observed and estimated streamflows, tests were completed by removing or adding local regions from or to different aggregated regions to determine whether regression errors could be improved.

To evaluate the Flow Anywhere method for estimating streamflow at ungaged locations, a validation procedure was completed for six streamgages in the dataset (table 5). These six streamgages were selected because they were not

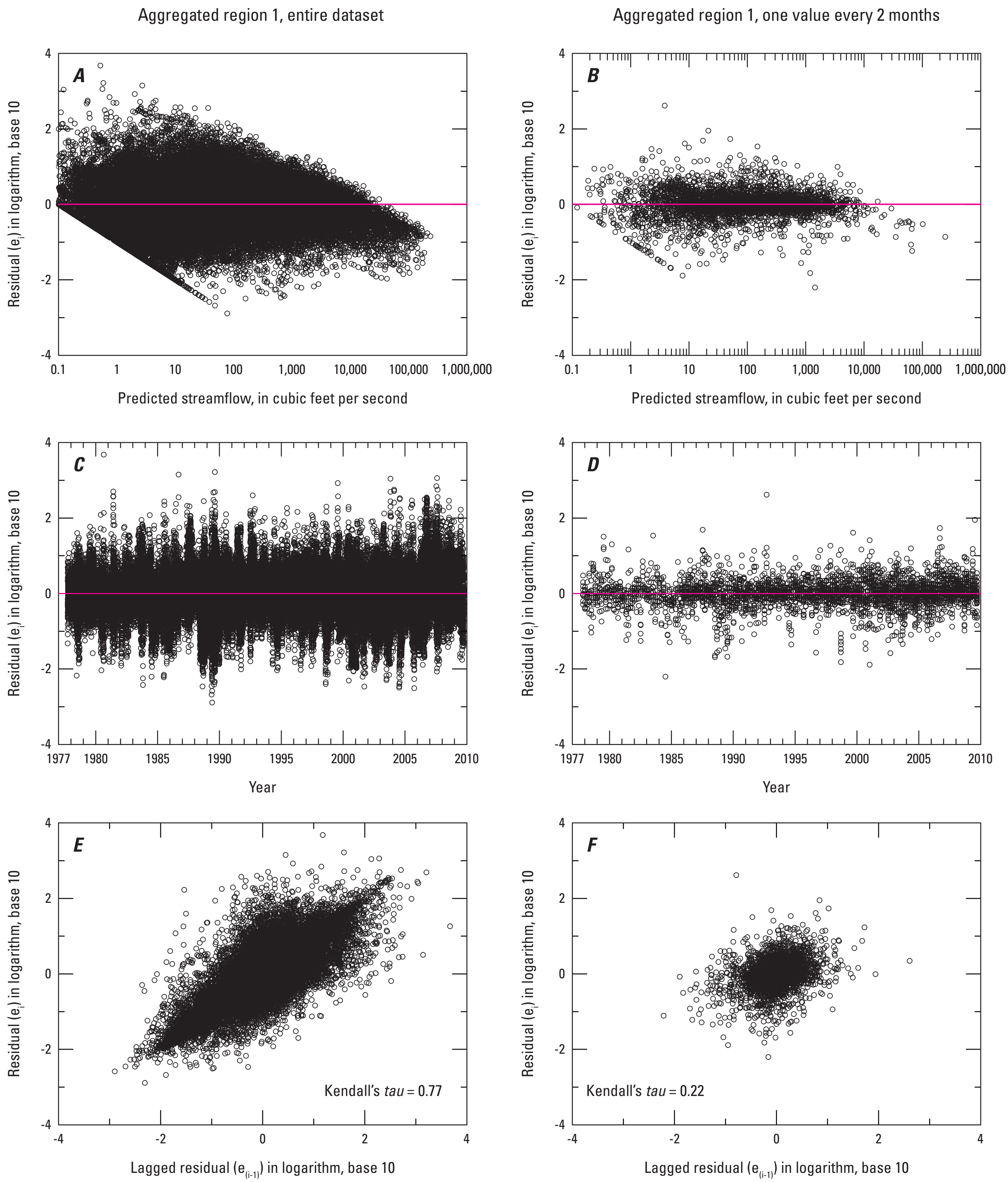


Figure 7. Correlation between residual (e_i) and (*A, B*) predicted streamflow, (*C, D*) time, and (*E, F*) lagged residual ($e_{(i-1)}$) for aggregated region 1 in the Flow Anywhere method determined by using the entire dataset (left column) and by using one value every 2 months (right column).

Table 4. Regression equations for estimating streamflow at ungaged locations in Iowa by using the Flow Anywhere method.

[SEE, average standard error of estimate; SEP, average standard error of prediction; DA_u, Geographic Information System (GIS) drainage area at ungaged location in the ungaged watershed; DA_r, GIS drainage area at the reference streamgage; Q_u, streamflow at the ungaged location; Q_r, streamflow at the reference streamgage; NA, not applicable. Aggregated regions are shown in fig. 5]

Aggregated region	Equation	Number of streamgages used to develop equation	Number of left-censored values	Standard error of model		SEE (percent)	SEP (percent)
				Log_{10}	Percent		
1	$Q_u = 1.06(DA_u/DA_r)^{1.20}Q_r^{0.979}$	33	30	0.377	+138 to -58.0	98.2	NA
2	$Q_u = 1.52(DA_u/DA_r)^{1.05}Q_r^{0.922}$	27	21	0.229	+69.4 to -41.0	55.2	NA
3	$Q_u = 3.30(DA_u/DA_r)^{1.07}Q_r^{0.800}$	45	NA	0.256	+80.1 to -44.8	62.3	64.3

used for the Flow Duration Curve Transfer method. A validation study for the Flow Duration Curve Transfer method in which one streamgage at a time would be removed would be a more robust validation, but is beyond the scope of this report, as manually regenerating regression equations for the Flow Duration Curve Transfer method after a streamgage has been removed is a lengthy process. For each of the six streamgages used to evaluate the Flow Anywhere method, the regional regression equations were redeveloped without that particular streamgage in the dataset. Using this method to evaluate the estimates of daily mean streamflow at a streamgage that was not used in the development of the Flow Anywhere method resembles the scenario of computing daily mean streamflow at an ungaged location. Observed and estimated flows at the six streamgages were compared for goodness of fit. To quantify the goodness of fit, the mean absolute error (MAE), root-mean-square error (RMSE), percent root-mean-square error (PRMSE), RMSE-observations standard deviation ratio (RSR), percent bias (PBIAS), and Nash-Sutcliffe (NS) efficiency value (Nash and Sutcliffe, 1970) were computed for each of the six streamgages. The percent RMSE is an indication of how well the estimated values match the observed values. A percent RMSE value of 0.0 indicates a perfect fit between observed and estimated flows; the larger the value, the poorer the fit between observed and estimated flows. In general, the RMSE exceeds the MAE, and the degree to which this occurs is an indicator of the extent to which outliers (or variance in the differences between modeled and observed values) exist in the data (Legates and McCabe, 1999). The RSR is an indicator of model-simulation performance and is the RMSE divided by the standard deviation of the observed data. A value of 0.0 would indicate zero RMSE or residual variation and, therefore, perfect model simulation (Moriasi and others, 2007). The PBIAS measures the average tendency of the estimated data to be larger or smaller than their observed counterparts, with an optimal value of 0.0. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta and others, 1999). The NS value is a measure of how well the estimated values match the observed values. NS values range from $-\infty$ to 1. Values of 0.0 or less indicate that the mean measured streamflow is a better predictor than simulated streamflows; a value of 1 indicates a perfect fit between observed and estimated values (Moriasi and others, 2007). The NS and percent PRMSE were computed for both the logarithm (base 10) and untransformed streamflows. The logarithmic transformation helps to overcome the sensitivity that extreme values can have as a result of squaring of differences. Streamflow-model simulations can be considered satisfactory if NS is greater than 0.50, RSR is less than 0.70, and PBIAS is plus or minus 25 percent (Moriasi and others, 2007). Results of the validation studies for the Flow Anywhere and Flow Duration Curve Transfer methods are compiled in table 5. For the Flow Anywhere method, differences between the RMSE and the MAE (differences not shown in table 5) ranged from 1,016 ft^3/s at 05421740, Wapsipinicon River near Anamosa, Iowa, to 138 ft^3/s at 05387440, Upper Iowa River at Bluffton, Iowa, signifying a greater occurrence of outliers between observed and estimated streamflows at 05421740, Wapsipinicon River near Anamosa, Iowa. RMSE values ranged from 1,690 ft^3/s at 05421740, Wapsipinicon River near Anamosa, Iowa, to 237 ft^3/s at 05387440, Upper Iowa River at Bluffton, Iowa. PRMSE values ranged from 115 percent at 06483290, Rock River below Tom Creek at Rock Rapids, Iowa, to 26.2 percent at 05387440, Upper Iowa River at Bluffton, Iowa. The logarithm (base 10) streamflow PRMSE ranged from 13.0 percent at 06483290, Rock River below Tom Creek at Rock Rapids, Iowa, to 5.3 percent at 05387440, Upper Iowa River at Bluffton, Iowa. RSR values ranged from 0.80 at 05416900, Maquoketa River at Manchester, Iowa, to 0.40 at 05387440, Upper Iowa River at Bluffton, Iowa. PBIAS values ranged from 25.4 percent at 05387440, Upper Iowa River at Bluffton, Iowa, to 4.0 percent at both 05412020, Turkey River above French Hollow Creek at Elkader, Iowa, and 06483290, Rock River below Tom Creek at Rock Rapids, Iowa. Untransformed streamflow NS values ranged from 0.84 at 05387440, Upper Iowa River at Bluffton, Iowa, to 0.35 at 05416900, Maquoketa River at Manchester, Iowa. The logarithm (base 10) streamflow NS values ranged

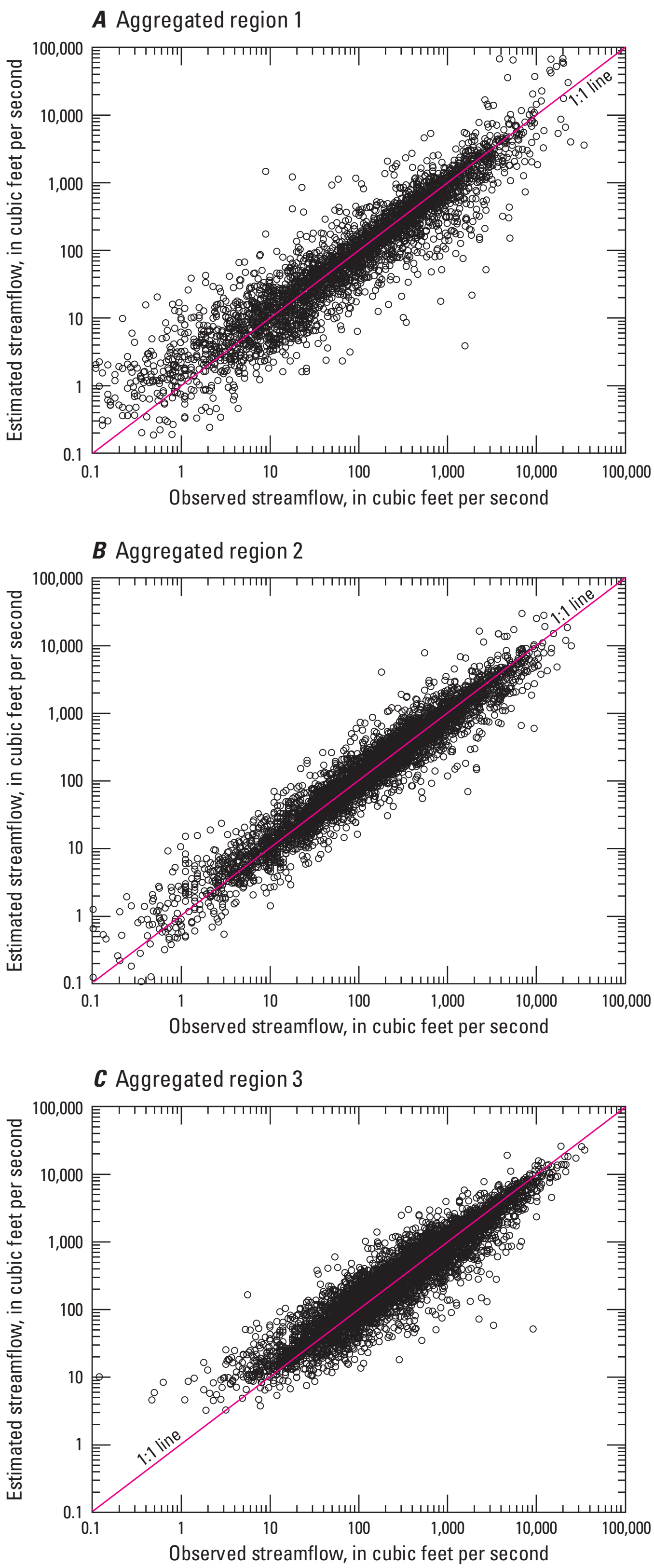


Figure 8. Observed and estimated daily mean streamflows relative to the 1:1 line for (*A*) aggregated region 1, (*B*) aggregated region 2, and (*C*) aggregated region 3, Iowa.

from 0.86 to 0.56 for the same two sites, respectively. On the basis of all the ranges of statistics reported above, including the difference between the RMSE and MAE, the observed and estimated daily mean streamflows for the streamgages with the closest (05387440, Upper Iowa River at Bluffton, Iowa, map no. 4) and poorest (05416900, Maquoketa River at Manchester, Iowa, map no. 16) agreements were analyzed further (fig. 9). A comparison of observed and estimated hydrographs for the same streamgages also was completed (fig. 10). For 05387440, Upper Iowa River at Bluffton, Iowa, the higher flows appear to be underestimated. For 05416900, Maquoketa River at Manchester, Iowa, low flows appear to be overestimated whereas higher flows seem to be underestimated. Estimated cumulative streamflows for the period October 1, 2004, to September 30, 2009, are underestimated for 05387440, Upper Iowa River at Bluffton, Iowa, and 05416900, Maquoketa River at Manchester, Iowa, by -25.8 and -7.4 percent, respectively (fig. 11). Cumulative daily mean streamflows for the observed, Flow Anywhere, and Flow Duration Curve Transfer methods shown in figure 11 are limited to those days when estimated streamflows could be computed for streamflows greater than the 0.99-percent exceedance probability (or less than the 0.01-percent exceedance probability) with the Flow Duration Curve Transfer method. As discussed in the Flow Duration Curve Transfer Analytical Procedures section (farther on in this report), one of the limitations of the Flow Duration Curve Transfer method is that streamflows outside the bounds of the 0.99- to 0.01- percent exceedance probability range used for this study cannot be estimated. On those days when streamflows could not be estimated by using the Flow Duration Curve Transfer method, those daily mean streamflows for the same days for the observed and estimated Flow Anywhere streamflows also were removed to compute and compare the cumulative daily mean streamflows.

Uncertainty of Estimated Streamflows

The total uncertainty associated with estimated time series of unregulated, daily mean flow at an ungaged location determined by using the Flow Anywhere method is impossible to quantify. The regional regression equations have quantified standard errors (table 4). Differences between actual and estimated daily mean streamflows are attributed to the possible unequal effect of localized storm events at the reference streamgage and ungaged location. It is impossible to quantify the uncertainty associated with differences in rainfall patterns because the intensity and location of all storm events are not known. Although local regions were sized so that basin characteristics were similar in each region, some differences can be attributed to the unique physiographic characteristics of the basins, such as storage along channels, channel shape, stream slope, and infiltration properties.

Table 5. Results of validation study for the Flow Anywhere and Flow Duration Curve Transfer methods.

[USGS, U.S. Geological Survey; FA, Flow Anywhere; FDCT, Flow Duration Curve Transfer; Min, minimum; ft^3/s, cubic foot per second; Max, maximum; SD, standard deviation; MAE, mean absolute error; NA, not applicable; RMSE, root mean square error; PRMSE, percent root mean square error; RSR, RMSE observations standard deviation ratio; PBIAS, percent bias; NS, Nash-Sutcliffe efficiency value]

Statistic	USGS streamgage 05387440				USGS streamgage 05411850				USGS streamgage 05412020			
	Observed FA	FA	Observed FDCT	FDCT	Observed FA	FA	Observed FDCT	FDCT	Observed FA	FA	Observed FDCT	FDCT
Min (ft^3/s)	53.0	52.7	53.0	45.0	68.0	103	68.0	76.0	152	155	152	155
Max (ft^3/s)	13,800	10,000	3,780	2,260	35,600	19,600	5,390	4,010	32,100	29,600	6,300	5,560
Median (ft^3/s)	203	159	201	196	277	310	274	298	425	469	421	370
Mean (ft^3/s)	363	271	326	296	579	529	505	500	832	799	716	709
SD (ft^3/s)	594	429	347	316	1,220	840	639	586	1,450	1,270	758	910
MAE (ft^3/s)	NA	99.5	NA	75.1	NA	196	NA	160	NA	230	NA	149
RMSE (ft^3/s)	NA	237	NA	169	NA	593	NA	334	NA	641	NA	302
PRMSE	NA	26.2	NA	25.6	NA	65.9	NA	55.3	NA	63.4	NA	26.5
PRMSE (log)	NA	5.3	NA	4.4	NA	8.0	NA	6.9	NA	5.5	NA	4.5
RSR	NA	0.40	NA	0.49	NA	0.48	NA	0.52	NA	0.44	NA	0.40
PBIAS	NA	25.4	NA	9.3	NA	8.6	NA	0.94	NA	4.0	NA	0.94
NS	NA	0.84	NA	0.76	NA	0.77	NA	0.73	NA	0.81	NA	0.84
NS (log)	NA	0.86	NA	0.89	NA	0.78	NA	0.81	NA	0.83	NA	0.87

Statistic	USGS streamgage 05416900				USGS streamgage 05421740				USGS streamgage 06483290			
	Observed FA	FA	Observed FDCT	FDCT	Observed FA	FA	Observed FDCT	FDCT	Observed FA	FA	Observed FDCT	FDCT
Min (ft^3/s)	29.0	49.3	29.0	28.2	144	97.9	144	173	27.0	46.1	27.0	38.0
Max (ft^3/s)	14,200	6,000	14,200	1,810	31,000	21,300	19,900	9,740	10,100	2,800	7,920	2,360
Median (ft^3/s)	137	167	135	109	786	832	769	784	203	244	201	171
Mean (ft^3/s)	320	270	271	210	1,590	1,340	1,380	1,420	379	364	356	280
SD (ft^3/s)	768	335	533	293	2,520	1,420	1,730	1,630	610	350	486	330
MAE (ft^3/s)	NA	177	NA	114	NA	674	NA	469	NA	182	NA	153
RMSE (ft^3/s)	NA	617	NA	419	NA	1,690	NA	906	NA	465	NA	332
PRMSE	NA	113	NA	57.5	NA	64.7	NA	52.9	NA	115	NA	67.0
PRMSE (log)	NA	11.7	NA	12.5	NA	7.5	NA	6.5	NA	13.0	NA	11.4
RSR	NA	0.80	NA	0.79	NA	0.67	NA	0.52	NA	0.76	NA	0.68
PBIAS	NA	15.7	NA	22.7	NA	16.1	NA	-2.8	NA	4.0	NA	21.6
NS	NA	0.35	NA	0.38	NA	0.55	NA	0.73	NA	0.42	NA	0.53
NS (log)	NA	0.56	NA	0.48	NA	0.73	NA	0.79	NA	0.58	NA	0.62

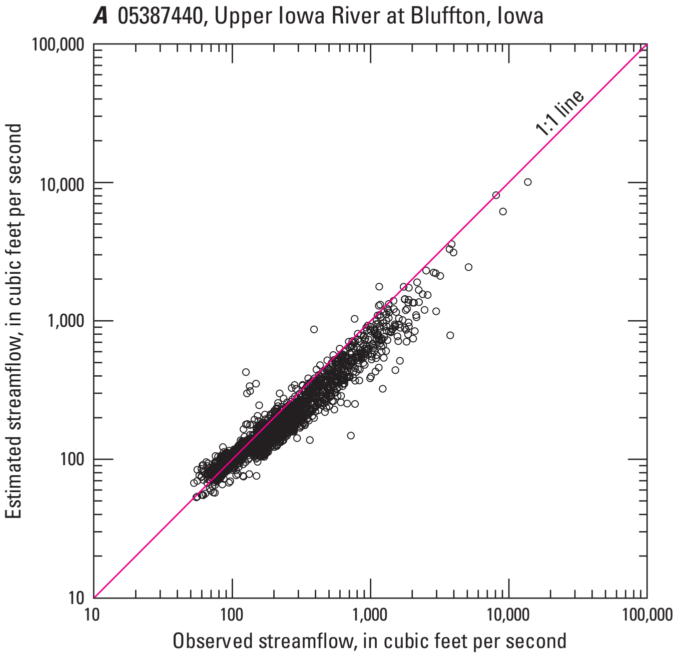


Figure 9. Observed and estimated daily mean streamflow relative to the 1:1 line for U.S. Geological Survey streamgages (*A*) 05387440, Upper Iowa River at Bluffton, Iowa; and (*B*) 05416900, Maquoketa River at Manchester, Iowa, showing the (*A*) closest and (*B*) poorest agreement between unregulated observed and estimated mean daily streamflow, October 1, 2004, to September 30, 2009, determined by using the Flow Anywhere method.

Limitations of Methods

The regional regression equations developed in this study apply only to stream locations in Iowa where flows are not significantly affected by regulation, diversion, or urbanization. The applicability and accuracy of the regional equations depend on whether the measured drainage area for an ungaged stream location is within the range of drainage areas used to develop the equations. The acceptable range of drainage areas used to develop the regional regression equations (table 4) is tabulated as maximum and minimum values in table 6. The applicability of the regional equations when the drainage area at the ungaged location is smaller than the minimum drainage area or larger than the maximum drainage area used to develop the regression equation for that particular region is unknown. In addition, drainage areas at ungaged locations should be measured by using the same techniques used in this study.

Estimates of daily mean streamflow at ungaged locations computed from the regression equations that are less than 0.1 ft^3/s should be reported as less than 0.1 ft^3/s. For aggregated region 3, estimates of daily mean streamflow at ungaged locations computed from the ordinary-least-squares regression equation that are less than 0.1 ft^3/s also should be reported as less than 0.1 ft^3/s to maintain a consistent reporting limit for Iowa.

The reliability or use of the method for other streamflow durations (monthly or annual mean streamflow) or classifications (annual peak streamflow) is uncertain or inappropriate (Asquith and others, 2006).

Computations made on a stream segment on which a streamgage is located should be made with caution. The resulting estimated streamflow at the ungaged location should be verified to be hydrologically reasonable with respect to the streamflows at the streamgage. A general "rule of thumb" in other regression analyses is to use the traditional drainage-area ratio (equation 1) to estimate streamflow when the ratio of the drainage area of the ungaged location to that of the streamgage is between 0.5 and 1.5 (Hortness, 2006). Although the drainage-area ratio attempts to ensure continuity in streamflow as the distance between gages decreases, Archfield and Vogel (2010) noted that this rule of thumb generally appears to result in poorer agreement between observed and estimated streamflows. Users need to consider the limitations of both approaches when applying these methods in practice.

The estimation of daily mean streamflows at ungaged locations with the Flow Anywhere method is appropriate for any date after September 30, 1977, provided that valid daily mean streamflow data are available for the associated reference streamgage for the days of interest. Estimation of daily mean streamflows on or prior to this date would not be appropriate as a result of trends in streamflow, as described in

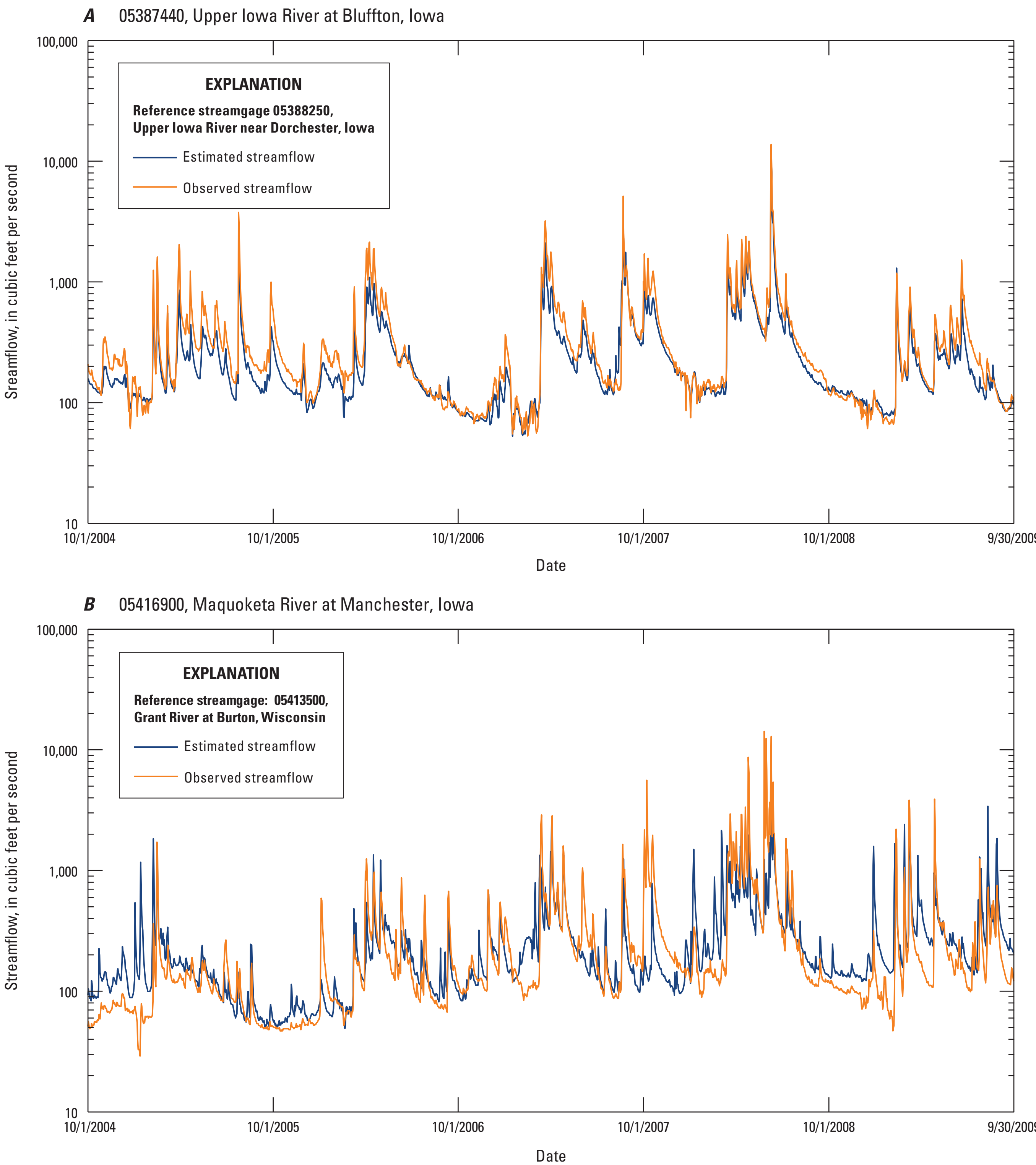


Figure 10. Observed and estimated hydrographs for U.S. Geological Survey streamgages (*A*) 05387440, Upper Iowa River at Bluffton, Iowa; and (*B*) 05416900, Maquoketa River at Manchester, Iowa, showing the (*A*) closest and (*B*) poorest agreement between unregulated observed and estimated, daily mean streamflows, October 1, 2004, to September 30, 2009, determined by using the Flow Anywhere method.

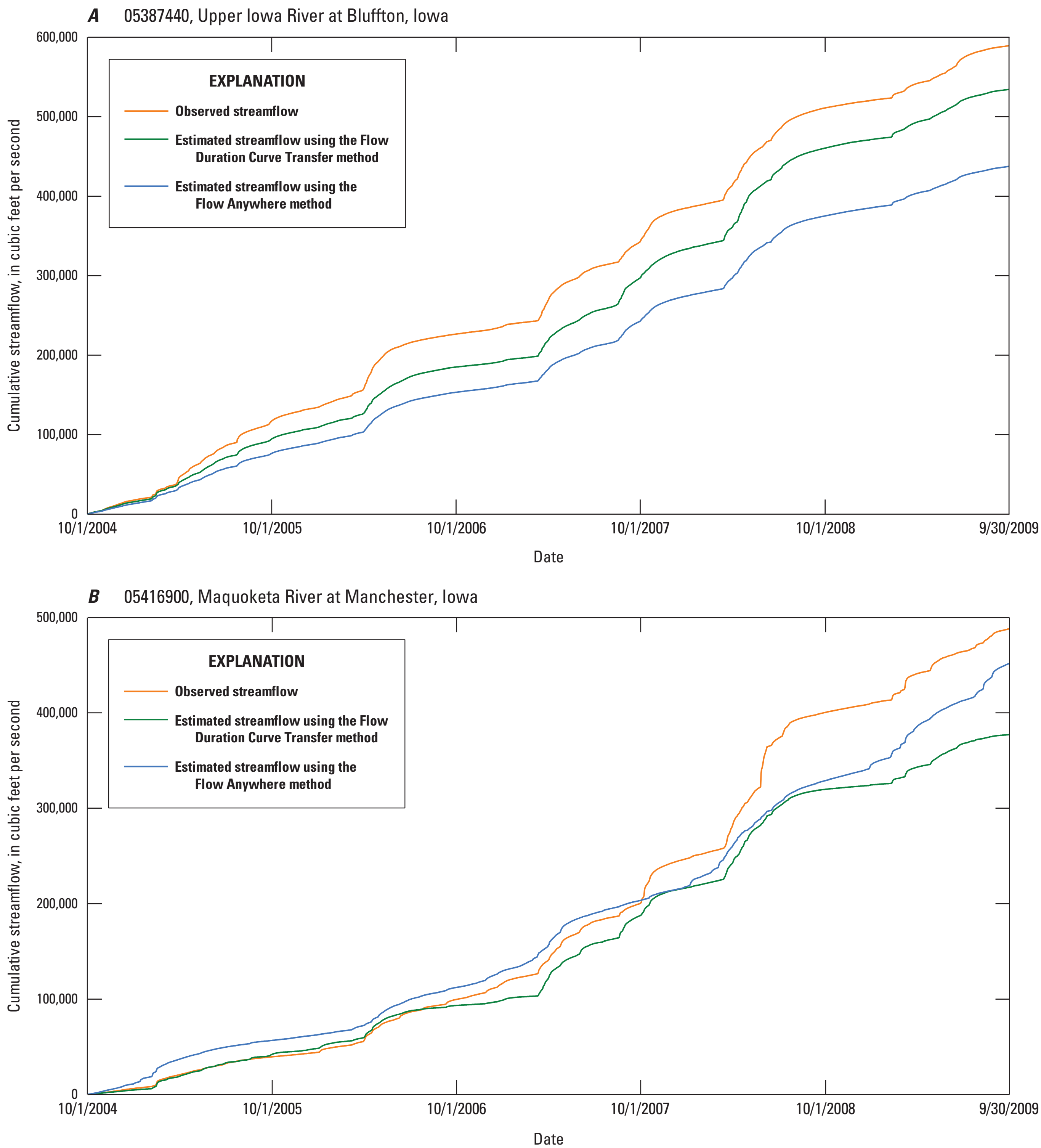


Figure 11. Observed and estimated cumulative daily mean streamflows for U.S. Geological Survey streamgages (*A*) 05387440, Upper Iowa River at Bluffton, Iowa; and (*B*) 05416900, Maquoketa River at Manchester, Iowa, October 1, 2004, to September 30, 2009.

Table 6. Statistical summary of drainage areas used to develop regional regression equations in Iowa.

[GIS, Geographical information system. Locations of aggregated regions are shown in fig. 5]

Statistic	GIS drainage area (mi^2)
Aggregated region 1	
Maximum	4,310
Minimum	34.3
Mean	648
Median	370
Aggregated region 2	
Maximum	3,425
Minimum	56.1
Mean	861
Median	526
Aggregated region 3	
Maximum	5,464
Minimum	2.60
Mean	1,065
Median	574

the Trend Analysis section above. Computations of estimated daily mean streamflow at ungaged locations after September 30, 2009, are to be made with the assumption that no trends occur in the streamflow records and that no significant changes have been made to basins that would alter the relation between streamflows used in the development of the method. By using documented regression techniques, the error values of equation 2 can be computed for results produced from the regression equations. The final equations then can be used to estimate a daily mean streamflow at ungaged locations in Iowa with an associated percent error.

Flow Duration Curve Transfer Analytical Procedures

Data used for the Flow Duration Curve Transfer method were retrieved for 113 continuous-record streamgages located in Iowa and within a 50-mi buffer of Iowa in the neighboring States of Illinois, Minnesota, Missouri, Nebraska, and Wisconsin (table 1). Streamgages with at least 10 complete years of daily mean streamflow data through September 30, 2009, at locations where streamflow is unaffected by regulation or diversion were selected for evaluation in the study, which included 84 streamgages in Iowa and 29 streamgages in adjacent states. Streamgages in neighboring states were included to improve representation of basin characteristics near the Iowa border and to improve regressions near the state border. Streamgages in South Dakota within the 50-mi buffer of Iowa were not used because of upstream regulation or diversion. Daily mean streamflow values for dates earlier than October 1, 1977, were not retrieved as a result of trends found in the record, as described in the Trend Analysis section above. Daily mean streamflow data for the 113 streamgages were retrieved from the USGS NWIS database. The drainage areas of the 113 streamgages were measured by using a GIS. The drainage areas were measured by following procedures in Eash and Barnes (2012). The drainage-area values from the GIS are compared with the values published in NWIS in table 1. The GIS drainage-area value was used to develop the regression equations in this study in order to remain consistent with the measurement techniques used in a Web-based tool similar to the USGS Streamstats interface (Ries and others, 2009).

Regression Methods

To develop the quantile-based regression equations, the dependent variable, the streamflow quantiles, and the independent variables, which are the physical and climate basin characteristics, were quantified for each of the 113 streamgages. The physical and climatic basin characteristics are shown in table 7 for three streamgages: 05412500, Turkey River at Garber, Iowa (fig. 1, map no. 13, and table 1); 05452200, Walnut Creek near Hartwick, Iowa (fig. 1, map no. 32, and table 1); and 06483500, Rock River near Rock Valley, Iowa (fig. 1, map no. 93, and table 1). To compute the streamflow quantiles, the observed daily streamflows were ranked and an exceedance probability was computed. Streamflow quantiles were estimated at the following exceedance probabilities: 0.01, 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.85, 0.90, 0.95, and 0.99. Streamflow quantiles at each of the 15 exceedance probabilities were estimated from the observed streamflow records by using the nonparametric quantile estimators presented in Vogel and Fennessey (1994, eq. 2a and 2b). A total of 57 physical and climate basin characteristics were tested for use as explanatory (independent) variables (table 7). A detailed description of the basin characteristics, as well as details about their source, methodology, and resolution, can be found in Eash and Barnes (2012).

Regression equations were developed for the 0.01-, 0.05-, 0.10-, 0.15-, 0.20-, 0.30-, 0.40-, 0.50-, 0.60-, 0.70-, 0.80-, 0.85-, 0.90-, and 0.95-exceedance probability streamflow values by using WLS regression. The regression equation for the 0.99-percent exceedance probability streamflow value was developed by using a left-censored regression equation (table 8). When WLS regression was used, regression weights were applied to the dependent variable and were computed as a function of the number of years of observed streamflow on which the estimated streamflow statistic was based. For the left-censored regression equation for the 0.99-percent exceedance probability streamflow values, there were 9 values less than or equal to the censor threshold of 0.1 ft^3/s and 5 zero flows. Two sets of regression equations initially were

Table 7. Basin, climate, and land-use characteristics at three U.S. Geological streamgages, tested for use in the estimation of streamflow at ungaged sites.

[USGS, U.S. Geological Survey. Elevation characteristics are determined from the U.S. Geological Survey (USGS) 30-meter National Elevation Dataset]

Basin, climate, or land-use characteristic	USGS streamgage number and name		
	05412500, Turkey River at Garber, Iowa	0545220, Walnut Creek near Hartwick, Iowa	06483500, Rock River near Rock Valley, Iowa
Drainage area (in square miles)	1,553	70.5	1,584
Average basin slope (in percent)	6.6	5.7	2.4
Main channel slope (between points 10 and 85 percent of length, in feet per mile)	4.5	8.1	3.8
Slope of entire length main channel (in feet per mile)	5.0	10.2	5.6
Percent basin area within Des Moines Lobe landform region (in percent area)	0.0	0.0	13.7
Base-flow index (mean ratio of base flow to annual streamflow)	0.6	0.5	0.5
Hydrograph separation and analysis (median percentage of baseflow to annual streamflow, in percent)	57.7	53.2	55.6
Annual base-flow recession time constant (rate of base-flow recession between storm events, in days)	32.1	24.4	25.5
2-year runoff coefficient	0.2	0.2	0.1
5-year runoff coefficient	0.3	0.3	0.2
10-year runoff coefficient	0.3	0.3	0.2
25-year runoff coefficient	0.4	0.4	0.3
50-year runoff coefficient	0.5	0.4	0.4
100-year runoff coefficient	0.6	0.4	0.5
24-hour, 2-year precipitation (in inches)	3.0	3.0	2.7
24-hour, 5-year precipitation (in inches)	3.8	3.8	3.3
24-hour, 10-year precipitation (in inches)	4.3	4.5	3.9
24-hour, 25-year precipitation (in inches)	5.4	5.0	4.8
24-hour, 50-year precipitation (in inches)	6.0	6.0	5.6
24-hour, 100-year precipitation (in inches)	6.2	6.5	6.6
Row crop production 2001 (in percent basin area)	58.1	69.9	82.8
Streamflow-variability index (a measure of the steepness of the slope of a duration curve)	0.4	0.6	0.6
Mean annual precipitation 1971–2000 (in inches)	34.8	35.6	27.7
Mean January precipitation 1971–2000 (in inches)	1.0	1.1	0.6
Mean February precipitation 1971–2000 (in inches)	1.0	1.1	0.6
Mean March precipitation 1971–2000 (in inches)	2.1	2.2	1.9
Mean April precipitation 1971–2000 (in inches)	3.6	3.5	2.8
Mean May precipitation 1971–2000 (in inches)	4.0	4.3	3.4
Mean June precipitation 1971–2000 (in inches)	4.6	4.7	4.3
Mean July precipitation 1971–2000 (in inches)	4.3	4.2	3.5
Mean August precipitation 1971–2000 (in inches)	4.9	4.5	3.6
Mean September precipitation 1971–2000 (in inches)	3.3	3.6	2.6
Mean October precipitation 1971–2000 (in inches)	2.4	2.7	2.0

Table 7. Basin, climate, and land-use characteristics at three U.S. Geological streamgages, tested for use in the estimation of streamflow at ungaged sites.—Continued

[USGS, U.S. Geological Survey. Elevation characteristics are determined from the U.S. Geological Survey (USGS) 30-meter National Elevation Dataset]

Basin, climate, or land-use characteristic	USGS streamgage number and name		
	05412500, Turkey River at Garber, Iowa	0545220, Walnut Creek near Hartwick, Iowa	06483500, Rock River near Rock Valley, Iowa
Mean November precipitation 1971–2000 (in inches)	2.3	2.4	1.6
Mean December precipitation 1971–2000 (in inces)	1.3	1.3	0.7
Percent of area with slopes greater than 30 percent	1.4	0.0	0.0
Percent of area with slopes greater than 30 percent facing north	0.5	0.0	0.0
Percent of area underlain by hydrologic soil type A (in percent area)	2.0	0.3	1.2
Percent of area underlain by hydrologic soil type B (in percent area)	87.8	82.4	96.7
Percent of area underlain by hydrologic soil type C (in percent area)	4.8	16.7	1.2
Percent of area underlain by hydrologic soil type D (in percent area)	2.7	0.2	0.1
Clay content of soil as a percent (by percent volume)	23.4	30.0	27.3
Sand content of soil as a percent (by percent volume)	28.7	11.9	22.6
Average saturated hydraulic conductivity of soil (in micrometers per second)	20.8	8.1	15.3
Relative relief (basin relief/basin perimeter)	2.4	3.7	2.4
Shape factor (measure of basin shape)	4.3	5.0	3.0
Elongation ratio (measure of basin shape)	0.5	0.5	0.7
Rotundity of basin (measure of basin shape)	3.3	3.9	2.3
Compactness ratio (measure of basin shape)	2.3	2.1	2.2
Main channel sinuosity ratio	1.8	1.1	1.9
Stream density (in miles per square mile)	2.1	2.2	2.1
Slenderness ratio	14.5	6.2	10.5
Constant of channel maintenance (in square miles per mile)	0.5	0.5	0.5
Ruggedness number (in feet per mile)	1,614	506	1,557
Ratio of main channel slope to average basin slope	0.7	1.4	1.6
Drainage frequency (number of first-order streams per square mile)	1.3	1.8	1.1
Relative stream density	0.3	0.4	0.3

developed; one set of equations resulted from the use of the ordinary-least-squares (OLS) method and the other set of equations resulted from the use of the WLS method or the left-censored method, as was mentioned previously. The OLS method was used for preliminary model selection and to decrease the candidate pool of potential explanatory variables. With the exception of the equation (left-censored) for the 0.99-percent exceedance probability, all final equations for the exceedance probabilities were developed by using the WLS method (table 8). Percent exceedance streamflow values used as the dependent variables in the regression equations were estimated by using at least 10 years of daily observations. The dependent variables and the independent variables, drainage area, were transformed to base-10 logarithms to obtain linear regression equations. The form of the equation developed by using the original units (anti-logarithm) is

$$Y_i = 10^{bo} X_1^{b1} X_2^{b2} \ldots X_n^{bn} 10^{ei} , \quad (4)$$

Table 8. Regression equations for estimating flow-duration statistics for unregulated streams in Iowa.

[SEE, average standard error of estimate; SEP, average standard error of prediction; D01–D99, daily mean streamflow at 0.01-, 0.05-, 0.10-, 0.15-, 0.20-, 0.30-, 0.40-, 0.50-, 0.60-, 0.70-, 0.80-, 0.85-, 0.90-, 0.95-, and 0.99-exceedance probability; DRNAREA, drainage area; PRECIP, mean annual precipitation 1971–2000; SOILCSSURGO, percent area underlain by hydrologic soil type C; NA, not applicable; RSD, relative stream density; HYSEP, hydrograph separation and analysis is the median percentage of baseflow to annual streamflow; STREAM_VAR, streamflow-variability index, a measure of the steepness of the slope of a duration curve; SOILBSSURGO, percent area underlain by hydrologic soil type B; SOILDSSURGO, percent area underlain by hydrologic soil type D]

Weighted-least-squares regression equations	Flow Duration Curve Transfer statistic		
	Number of streamgages used to develop equation	SEP (percent)	SEE (percent)
$D01=10^{-0.717}DRNAREA^{0.974}10^{0.045(PRECIP)}10^{0.003(SOILCSSURGO)}$	113	23.5	NA
$D05=10^{-2.039}DRNAREA^{1.110}10^{0.051(PRECIP)}10^{1.142(RSD)}$	113	23.6	NA
$D10=10^{-1.977}DRNAREA^{1.133}10^{0.038(PRECIP)}10^{1.362(RSD)}$	113	24.2	NA
$D15=10^{-2.603}DRNAREA^{1.113}10^{0.009(HYSEP)}10^{0.055(PRECIP)}$	113	24.6	NA
$D20=10^{-2.726}DRNAREA^{1.102}10^{0.011(HYESP)}10^{0.053(PRECIP)}$	113	22.1	NA
$D30=10^{-2.931}DRNAREA^{1.085}10^{0.014(HYESP)}10^{0.051(PRECIP)}$	113	17.1	NA
$D40=10^{-3.187}DRNAREA^{1.075}10^{0.017(HYESP)}10^{0.050(PRECIP)}$	113	14.9	NA
$D50=10^{-3.449}DRNAREA^{1.065}10^{0.020(HYESP)}10^{0.050(PRECIP)}$	113	16.4	NA
$D60=10^{-3.770}DRNAREA^{1.066}10^{0.024(HYESP)}10^{0.049(PRECIP)}$	113	22.1	NA
$D70=10^{-4.083}DRNAREA^{1.079}10^{0.027(HYESP)}10^{0.047(PRECIP)}$	113	32.4	NA
$D80=10^{-0.883}DRNAREA^{1.179}10^{-2.050(STREAM\_VAR)}10^{0.006(SOILBSSURGO)}$	113	40.1	NA
$D85=10^{-0.888}DRNAREA^{1.207}10^{-2.365(STREAM\_VAR)}10^{0.006(SOILBSSURGO)}$	113	42.5	NA
$D90=10^{-0.970}DRNAREA^{1.241}10^{-2.716(STREAM\_VAR)}10^{0.007(SOILBSSURGO)}$	113	51.0	NA
$D95=10^{-1.225}DRNAREA^{1.317}10^{-3.170(STREAM\_VAR)}10^{0.008(SOILBSSURGO)}$	113	74.9	NA
Left-censored regression equation			
$D99=10^{-0.18302282}DRNAREA^{1.37420784}10^{-4.60344452(STREAM\_VAR)}10^{-0.01341188(SOILDSSURGO)}$	108	NA	97.7

where

Y_i is the dependent variable (the exceedance-probability streamflows),

X_n is the independent variables (basin characteristics),

b_n is the regression-estimated coefficient for the explanatory variable X_n,

b_o is the regression-estimated constant term, and

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

Initial OLS regression analyses were performed using Spotfire S+® statistical software (TIBCO Software Inc., 2008). Prior to OLS, initial selections of significant independent variables were performed by using the Efroymson stepwise selection method (Efroymson, 1960), which is an automatic procedure for regression-model selection when the number of potential independent variables is large. The Efroymson analyses produced a subset of potential significant basin characteristics for each exceedance-probability streamflow statistic. Each subset of basin characteristics then was iteratively tested by using OLS regression analyses to identify the best sets of equations, as determined by the model diagnostic statistics listed below, and in which no more than three significant independent variables (basin characteristics) were used. A limit of three independent variables per equation was used to minimize overfitting of the regression models. Results of the OLS models were evaluated to determine their adequacy by using graphical relations and residual plots, variance inflation factor (VIF), 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 the independent variables, and the signs and magnitudes of their respective regression coefficients, were evaluated to ensure that they are hydrologically valid in the context of the different exceedance-probability statistics. All independent variables selected through use of OLS regression in this study were statistically significant at the 95-percent confidence level. Independent variables were selected to minimize SEE and to maximize adj-R^2. Adj-R^2 is a measure of the proportion of the variation in the dependent variable that is explained by the independent variables, and is adjusted for the number of streamgages and independent variables used in the analysis. Correlation between the independent variables and VIF (Marquardt, 1970; Helsel and Hirsch, 2002) was used to evaluate multicollinearity in the regression models. By using 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), multicollinearity problems were identified by checking each independent variable for VIF greater than 2.

WLS multiple linear regression was used to develop 14 of the final regression equations for Iowa streamflow because all exceedance-probability streamflows were greater than zero and because the lengths of record varied. WLS regression adjusts for the variation in the reliability of the dependent-variable estimates by using a weight for each streamgage to account for differences in length of streamflow records. WLS regression analyses were performed by using the WREG program (version 1.01) (Eng and others, 2009). A user-defined weighting matrix was used to weight streamgages in Iowa and the 50-mi buffer extending into Illinois, Minnesota, Missouri, and Nebraska for application of WREG for the development of exceedance-probability streamflow equations. The weighting matrix was developed on the basis of record length and was 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 dataset. Thus, streamgages with shorter periods of record received less weight in the regression analyses and those with longer periods of record received greater weight. WLS models were selected for use over the OLS models for the development of the statewide regression equations because the WLS models give greater weight to the dependent-variable estimates with longer record lengths; therefore, the WLS equations are assumed to be more accurate. Final WLS regression models (table 8) were selected primarily on the basis of minimizing values of the average standard error of prediction (SEP).

Left-censored regression was used to develop one equation for Iowa because the number of streamgages in Iowa with estimates of zero flow for exceedance-probability streamflows was less than 5 percent. A censoring threshold of 0.1 ft^3/s was used to censor small dependent-variable discharges and zero flows estimated for the 0.99-percent exceedance probability statistic (table 8). Censored and uncensored dependent-variable data can be included together in a censored regression analysis (Eash and Barnes, 2012). To develop the left-censored regression equation for this study, an AMLE procedure implemented in the USGS library version 4.0 (Lorenz and others, 2011) for Spotfire S+® statistical software (TIBCO Software Inc., 2008) was used. The final left-censored regression model was selected primarily on the basis of minimizing values of the SEE.

Determination of Reference Streamgages

In order to determine how well the Flow Duration Curve Transfer method might estimate streamflow at ungaged sites, gaged sites were iteratively treated as ungaged, or nonreference, sites. Comparisons then could be made by examining the observed and estimated streamflows for the gaged sites. In this section, sites that are referred to as ungaged (nonreference) sites are actually gaged sites that were treated as ungaged sites for comparison purposes. In the Flow Duration Curve Transfer method, a single reference streamgage was selected from the 113 reference streamgages in this study (fig. 1; table 1). In this study, 10 years of record (October 1, 1999, through September 30, 2009) were used for the reference streamgages because 10 years was the minimum period of record used to generate the flow-duration curves and regression equations. Values of streamflow at the reference streamgage were not used in the Flow Duration Curve Transfer method; only the date and exceedance probabilities at the reference streamgage were used.

In the Flow Duration Curve Transfer method, it is implied that the date on which a specific streamflow is exceeded at the nonreference site is the same as that at the reference streamgage (that is, if the streamflow on October 1, 1999, is exceeded 95 percent of the time at the reference streamgage, the streamflow exceeded 95 percent of the time at the nonreference site also occurred on October 1, 1999). The same is true for the other exceedance probabilities; in the Flow Duration Curve Transfer method, it is assumed that the high-flow, midrange-flow, and low-flow events occur on the same day at both the reference streamgage and the nonreference site. As a result, the most appropriate reference streamgage would be the one for which the largest number of streamflows correlate with those at the nonreference site. The Flow Duration Curve Transfer method quantifies the correlation between the timing of the streamflows at 112 reference streamgages and those at the nonreference site by using Pearson's *r* correlation coefficient (equation 3) (Helsel and Hirsch, 2002). The likelihood of equivalent exceedance probabilities occurring on the same day is greater for two sites that have a value of Pearson's *r* correlation coefficient near 1, which indicates that the high-flow, midrange-flow, and low-flow events occur on the same day at both the reference streamgage and the nonreference site, than for two sites that have a lower Pearson's *r* correlation coefficient value.

The Pearson's *r* correlation coefficient can be calculated for two gaged sites but cannot be measured directly for streamflows at a gaged and an ungaged site. As a result, the Flow Duration Curve Transfer method is used to estimate the correlation between the logarithm (base 10) of the streamflows at the nonreference site and each possible reference streamgage and then selects the reference streamgage for which logarithms (base 10) of the daily streamflow are estimated to have the highest correlation with the logarithms (base 10) of the daily streamflows at the nonreference site.

The correlation between the streamflows at a nonreference site and those at a potential reference gage is estimated by examining the spatial patterns of streamflow correlation across all gages in the study area. Time-series correlations at gaged sites were spatially interpolated to ungaged areas by using kriging (Isaaks and Srivastava, 1989), a geostatistical method. For a particular reference streamgage, the Pearson's *r* correlation coefficient value was computed from the logarithms of observed, concurrent daily streamflows at the given reference streamgage and each of the other reference streamgages used in the Flow Duration Curve Transfer method. A spherical variogram model (Isaaks and Srivastava, 1989) then was developed for each reference streamgage to quantify the relation between the distances between each pair of reference streamgages and the differences in the Pearson's *r* correlation coefficient values between each pair of reference streamgages. Each variogram model quantifies the Pearson's *r* correlation coefficient value for the relation between streamflow at any ungaged site and that at a reference streamgage. The reference streamgage with the highest Pearson's *r* correlation coefficient value between streamflow at the reference site and that at the ungaged site is then selected for use with the Flow Duration Curve Transfer method. The Flow Duration Curve Transfer method requires only the Universal Transverse Mercator (UTM) coordinates of the ungaged site in order to select the reference streamgage. The variogram models can be used to create prediction maps of the Pearson's *r* correlation coefficient value for each reference streamgage; these maps show the correlation between streamflow at a reference streamgage and that at any ungaged site in Iowa. For this report, prediction maps were generated for three streamgages (fig. 12). For the 05412500, Turkey River at Garber, Iowa, streamgage (fig. 12*A*), the areas with the higher estimated correlations form a triangle but the correlations tend to be slightly greater along the major axis from northwest to southeast than elsewhere. For the 05452200, Walnut Creek near Hartwick, Iowa, streamgage (fig. 12*B*), the areas with the higher estimated correlations form an ellipsoid with the major axis trending northwest-southeast. For the 06483500, Rock River near Rock Valley, Iowa, streamgage (fig. 12*C*), the areas with the higher estimated correlations form an ellipsoid with the major axis trending southwest-northeast. If the Flow Duration Curve Transfer method ultimately is implemented as the most accurate model for estimating streamflow at ungaged sites, variograms would be generated for all the streamgages in the study area.

Comparison of Observed and Estimated Streamflows

In the Flow Duration Curve Transfer method, a time series of unregulated, daily mean streamflow at an ungaged site is constructed in the following order: (1) solve the regression equations, (2) interpolate between the regression-estimated streamflow quantiles to obtain a daily flow-duration curve for the ungaged site, (3) select the reference streamgage from the kriged maps of Pearson's *r* correlations, and (4) apply the Flow Duration Curve Transfer method to compute the estimated streamflow at the ungaged site for the desired time period. To evaluate the Flow Duration Curve Transfer method for use in estimating daily, unregulated streamflows at an ungaged site, a validation procedure was used at six streamgages that were not used either to develop the regression equations or to conduct the kriging procedure because they did not have at least 10 years of record. These same six sites were used in developing the regression for the Flow Anywhere method and in the Flow Anywhere validation procedure by removing one of the six streamgages at a time. Five years of record were used for the validation procedure for these six streamgages. In effect, the validation procedure evaluates the estimates of streamflow at a streamgage that was not used in the development of the Flow Duration Curve Transfer method. The six streamgages used were 05387440, Upper Iowa River at Bluffton, Iowa (fig. 1, table 1, map no. 4); 054118850, Turkey River near Eldorado, Iowa (fig. 1, table 1, map no. 10); 05412020, Turkey River above French Hollow Creek at Elkader, Iowa (fig. 1, table 1, map no. 11); 05416900, Maquoketa River at Manchester, Iowa (fig. 1, table 1, map no. 16); 05421740, Wapsipinicon River near Anamosa, Iowa (fig. 1, table 1, map no. 21); and 06483290, Rock River below Tom Creek at Rock Rapids, Iowa (fig. 1, table 1, map no. 92).

As for the Flow Anywhere method, observed and estimated streamflows were compared for goodness of fit at each of the streamgages (table 5) by using the mean-absolute-error (MAE), root-mean-square-error (RMSE), percent-root-mean-square-error (PRMSE), RMSE-observations standard-deviation ratio (RSR), percent-bias (PBIAS), and Nash-Sutcliffe (NS) efficiency values (Nash and Sutcliffe, 1970). The PRMSE and NS values also were computed for each of the six streamgages by using the base-10 logarithmic values of the observed and estimated daily streamflows (table 5). For the Flow Duration Curve Transfer method, differences between the RMSE and the MAE (differences not shown in table 5) ranged from 437 ft^3/s at 05421740, Wapsipinicon River near Anamosa, Iowa, to 93.9 ft^3/s at 05387440, Upper Iowa River at Bluffton, Iowa, signifying a greater occurrence of outliers with respect to the relation between observed and estimated streamflows at 05421740, Wapsipinicon River near Anamosa, Iowa, than at the other five streamgages. RMSE values ranged from 906 ft^3/s at 05421740, Wapsipinicon River near

A

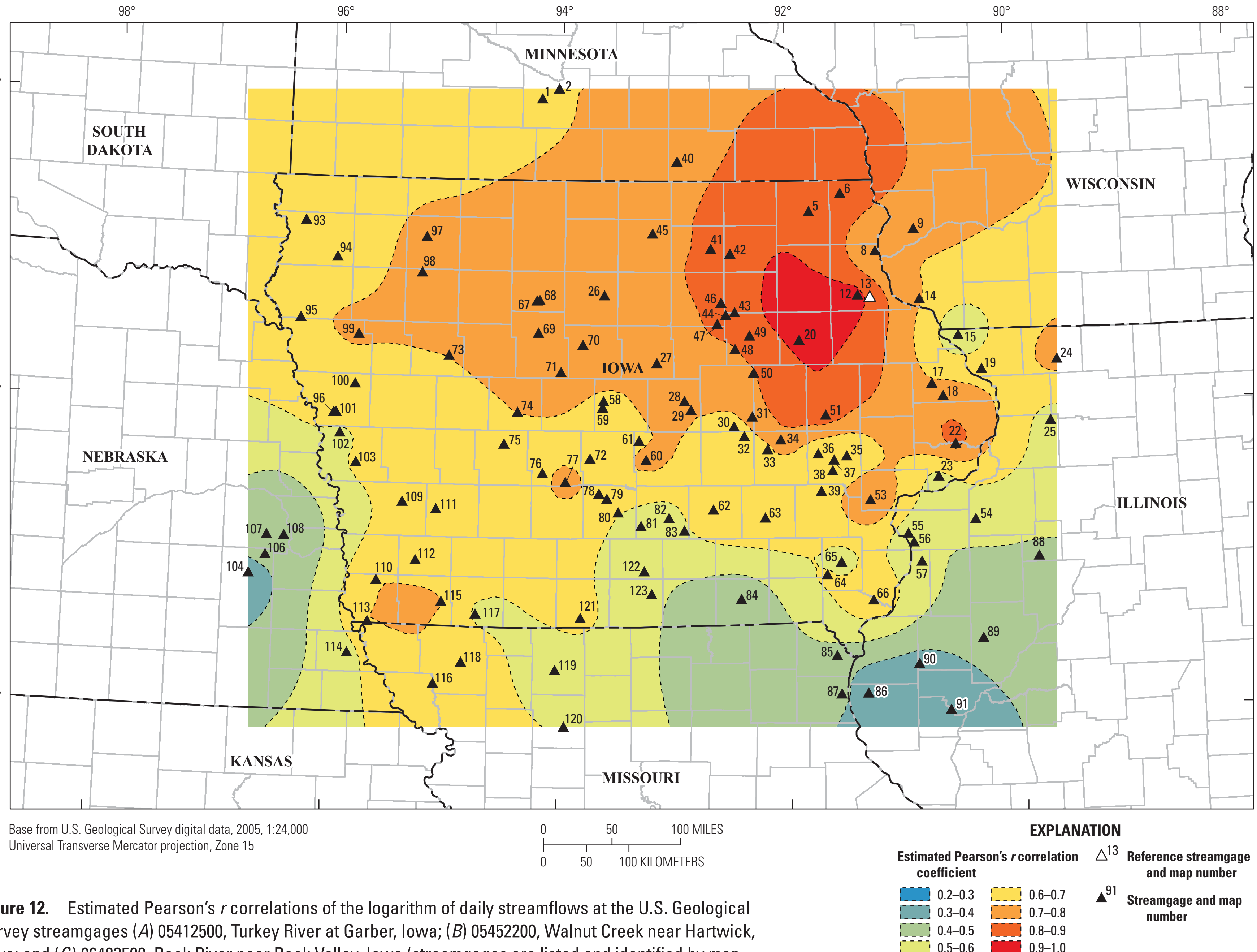


Figure 12. Estimated Pearson's *r* correlations of the logarithm of daily streamflows at the U.S. Geological Survey streamgages (*A*) 05412500, Turkey River at Garber, Iowa; (*B*) 05452200, Walnut Creek near Hartwick, Iowa; and (*C*) 06483500, Rock River near Rock Valley, Iowa (streamgages are listed and identified by map number in table 1).

B

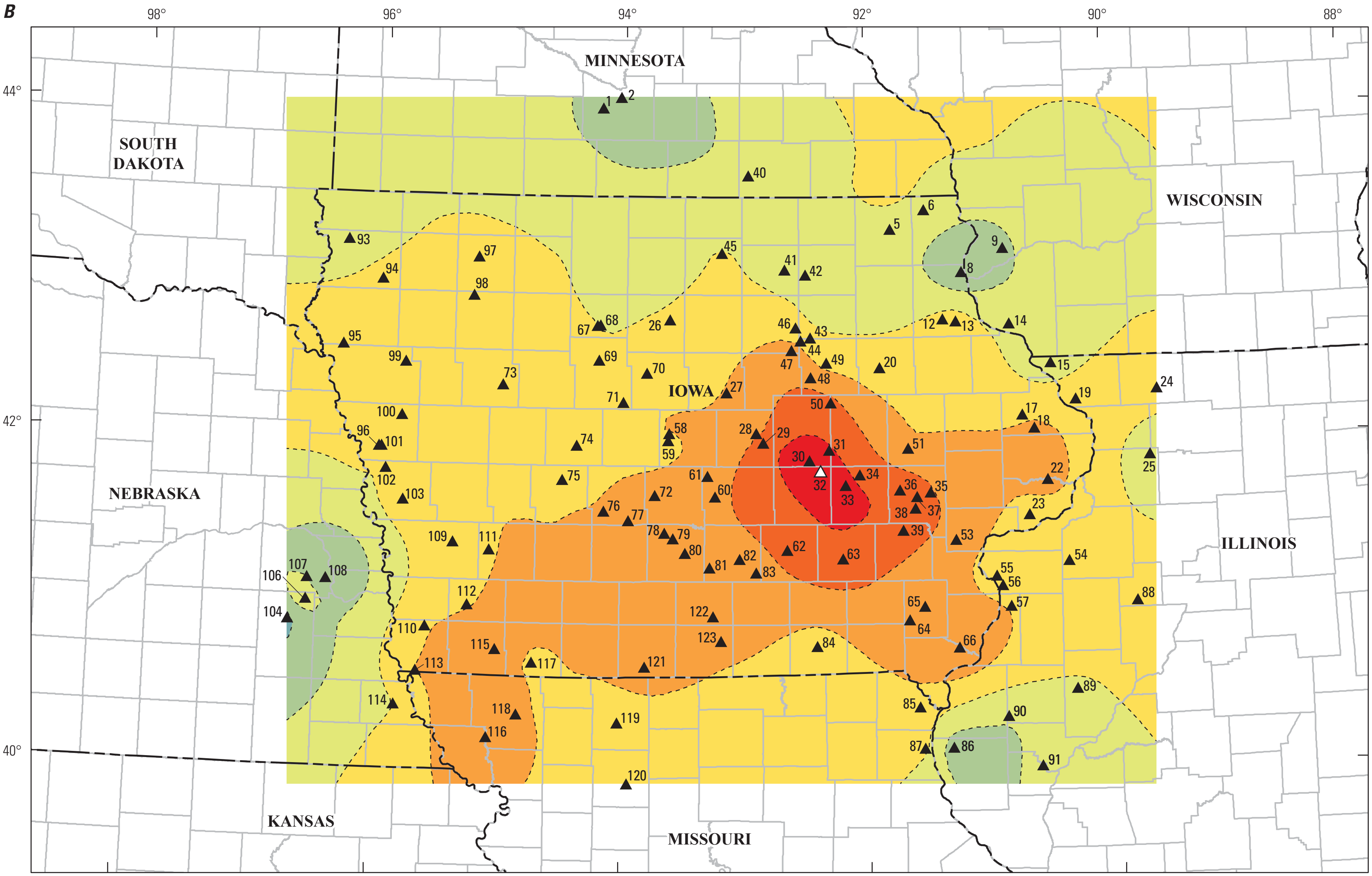
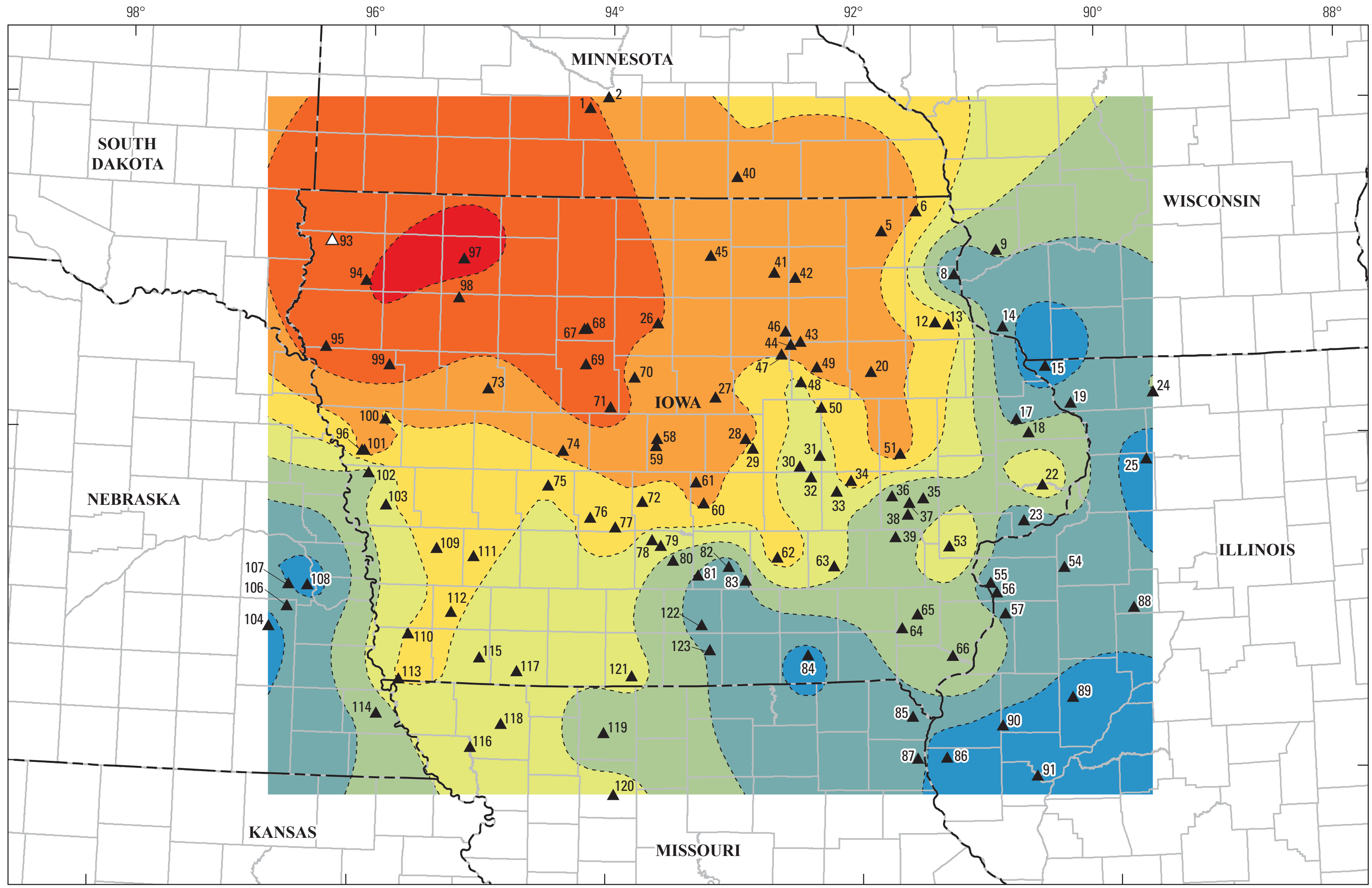


Figure 12. Estimated Pearson's *r* correlations of the logarithm of daily streamflows at the U.S. Geological Survey streamgages (*A*) 05412500, Turkey River at Garber, Iowa; (*B*) 05452200, Walnut Creek near Hartwick, Iowa; and (*C*) 06483500, Rock River near Rock Valley, Iowa (streamgages are listed and identified by map number in table 1).—Continued

C



Base from U.S. Geological Survey digital data, 2005, 1:24,000
Universal Transverse Mercator projection, Zone 15

0 50 100 MILES
0 50 100 KILOMETERS

EXPLANATION

Estimated Pearson's *r* correlation coefficient

- 0.2–0.3
- 0.3–0.4
- 0.4–0.5
- 0.5–0.6
- 0.6–0.7
- 0.7–0.8
- 0.8–0.9
- 0.9–1.0

△93 **Reference streamgage and map number**

▲91 **Streamgage and map number**

Figure 12. Estimated Pearson's *r* correlations of the logarithm of daily streamflows at the U.S. Geological Survey streamgages (*A*) 05412500, Turkey River at Garber, Iowa; (*B*) 05452200, Walnut Creek near Hartwick, Iowa; and (*C*) 06483500, Rock River near Rock Valley, Iowa (streamgages are listed and identified by map number in table 1).—Continued

Anamosa, Iowa, to 169 ft^3/s at 05387440, Upper Iowa River at Bluffton, Iowa. PRMSE values ranged from 67 percent at 06483290, Rock River below Tom Creek at Rock Rapids, Iowa, to 25.6 percent at 05387440, Upper Iowa River at Bluffton, Iowa. The logarithm (base 10) streamflow PRMSE ranged from 12.5 percent at 05416900, Maquoketa River at Manchester, Iowa, to 4.4 percent at 05387440, Upper Iowa River at Bluffton, Iowa. RSR values ranged from 0.79 at 05416900, Maquoketa River at Manchester, Iowa, to 0.40 at 05412020, Turkey River above French Hollow Creek at Elkader, Iowa. PBIAS values ranged from 22.7 percent at 05416900, Maquoketa River at Manchester, Iowa, to 0.94 percent at 05411850, Turkey River near Eldorado, Iowa, and 05412020, Turkey River above French Hollow Creek at Elkader, Iowa. For the Flow Duration Curve Transfer method, NS values ranged from 0.84 at 05412020, Turkey River above French Hollow Creek at Elkader, Iowa, to 0.38 at 05416900, Maquoketa River at Manchester, Iowa, by using the untransformed observed and estimated daily streamflows, and from 0.89 at 05387440, Upper Iowa River at Bluffton, Iowa, to 0.48 at 05416900, Maquoketa River at Manchester, Iowa, by using the base-10 logarithmic values of the observed and estimated daily streamflows. On the basis of all the ranges of statistics reported above, including the difference between the RMSE and MAE, the observed and estimated daily mean streamflows for streamgages with the closest and poorest agreement over the 5-year period, 05387440, Upper Iowa River at Bluffton, Iowa (fig. 1, table 1, map no. 4), and 05416900, Maquoketa River at Manchester, Iowa (fig. 1, table 1, map no. 16), respectively, are shown in figure 13. For the closest agreement between the observed and estimated daily mean streamflows (fig. 13*A*), the relation at the higher flows appears to show a “hook-like” feature, which may indicate that the assumption of a log-linear relation between streamflow quantiles at the highest flows (and possibly the lowest flows) may not be appropriate (Archfield and others, 2009). The lowest flows in figure 13*B* appear to be underestimated.

Observed and estimated hydrographs (in logarithmic space) for streamgages with the closest (05387440, Upper Iowa River at Bluffton, Iowa), and poorest (05416900, Maquoketa River at Manchester, Iowa) agreements over the period October 1, 2004, through September 30, 2009, are shown in figures 14*A* and 14*B*, respectively. A visual comparison of the hydrographs in figure 14*A* shows relatively good agreement between observed and estimated streamflows, whereas those in figure 14*B* appear to indicate that streamflows are substantially underestimated for much of the time period. Estimated cumulative streamflow (fig. 11) for the period October 1, 2004, to September 30, 2009, is underestimated for 05387440, Upper Iowa River at Bluffton, Iowa, and 05416900, Maquoketa River at Manchester, Iowa, by -9.3 and -22.7 percent, respectively, and verifies the degree to which streamflows are underestimated for the closest (figs. 13*A* and 14*A*) and poorest (figs. 13*B* and 14*B*) agreements for the six validation sites.

For both the closest and poorest agreements between observed and estimated daily mean streamflows, a set of data points that plot horizontally can be seen at about 500 and 360 ft^3/s in figures 13*A* and 13*B*, respectively. These results for 05387440, Upper Iowa River at Bluffton, Iowa, and 05416900, Maquoketa River at Manchester, Iowa (flow-duration curves not shown), correspond to those portions of the transferred (estimated flows) flow-duration curve, as is evident in the flow-duration curve for the streamgage 05412500, Turkey River at Garber, Iowa (fig. 15*A*), where

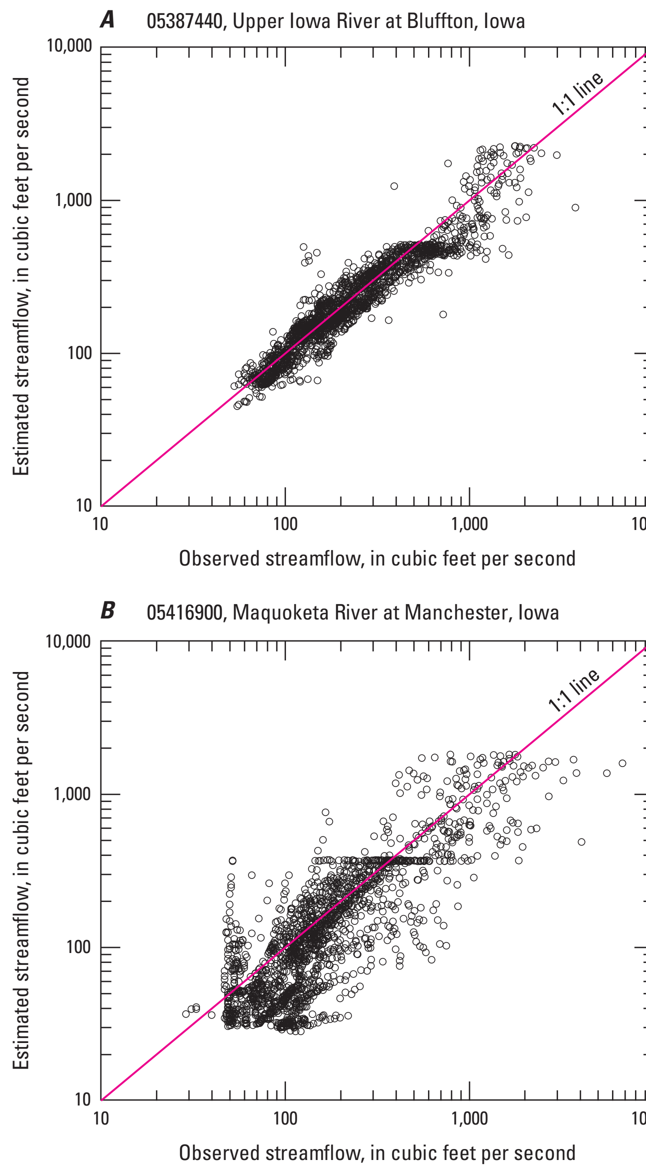


Figure 13. Observed and estimated daily mean streamflows for U.S. Geological Survey streamgages (*A*) 05387440, Upper Iowa River at Bluffton, Iowa; and (*B*) 05416900, Maquoketa River at Manchester, Iowa, showing the (*A*) closest and (*B*) poorest agreement between unregulated observed and estimated daily mean streamflow, October 1, 2004, to September 30, 2009, determined by using the Flow Duration Curve Transfer method.

along the curve at the higher flows, one estimated streamflow value becomes greater than the previous streamflow as the exceedance probabilities increase (lower flows). Also in figure 15*A*, along the lower flows, one estimated streamflow value becomes less than the previous value as the exceedance probabilities decrease (greater flows). This is a limitation of the Flow Duration Curve Transfer method (Archfield and others, 2009) and is discussed in the Limitations of Methods section for this method. This "jagging" occurs at the exceedance probabilities (10 to 15 percent and 80 to 70 percent) at which the basin characteristics used in the regression equations change appreciably (table 8). Of the streamgages used for the Flow Duration Curve Transfer method, this "jagging" occurs at 12 streamgages in Iowa, 5 streamgages in Nebraska, 5 streamgages in Wisconsin, and 1 streamgage in Missouri; these streamgages are primarily in either the western or northeastern portion of the study area. Of these 23 streamgages, this "jagging" occurs only for 11 streamgages, all in the northeastern part of the study area, and only at the high flows. It occurs only at the low flows for nine streamgages, all in the western portion of the study area, and at both high and low flows for three streamgages, all in the northeastern portion of the study area.

Uncertainty of Estimated Streamflows

The overall uncertainty inherent in estimating a time series of unregulated, daily mean flow at an ungaged site by using the Flow Duration Curve Transfer method is difficult to quantify. The key components are (1) estimation of the flow-duration curve at the ungaged site, (2) choosing a reference streamgage on the basis of maps of cross-correlations among flow records from existing gaged sites, and (3) transfer of daily streamflows from the reference streamgage to the ungaged site by using the Flow Duration Curve Transfer method and its inherent assumptions. Each component of the Flow Duration Curve Transfer method adds unique uncertainty to the estimated streamflows at the ungaged site, in addition to the measurement error associated with the observed streamflows used to develop the regression equations and the selection and use of the reference gage. As previously mentioned in the discussion of the Flow Anywhere Method, localized storm events could introduce additional uncertainty into the observed streamflows, and as a result introduce error into the estimated streamflows.

If the Flow Duration Curve Transfer method were based on a single modeling approach or a physically based model, standard methods of uncertainty analysis could be used; however, because the estimated streamflows used in the Flow Duration Curve Transfer method are derived through a variety of complex modeling steps, the standard methods of uncertainty analysis do not provide meaningful prediction intervals (Archfield and others, 2009). In this report, to address the issue of uncertainty for the Flow Duration Curve Transfer method, the conditions under which one might be expected to obtain the type of goodness-of-fit values reported are documented in table 5. Because the goodness-of-fit values are based on cross-validation tests, they may indicate a range of uncertainty that could be expected in future uses of the Flow Duration Curve Transfer method for estimating streamflows at ungaged sites, although it would have been preferable to use more than six sites for the validation tests. Only six sites were used, however, as a result of the limited availability of streamgages that were not used in the Flow Duration Curve Transfer method.

Limitations of Methods

One of the limitations of the Flow Duration Curve Transfer method for estimating time series of unregulated, daily mean streamflow is that the use of the regression equations is limited to the range of basin characteristics (table 9) used to develop those equations. The appropriateness of the statewide equations is unknown when basin characteristics outside the range of measured basin characteristics are used to develop the regression equations. As previously mentioned, for the three components of the Flow Duration Curve Transfer method, (1) regression equations, (2) reference-streamgage selection criteria, and (3) the assumption of equivalent exceedance probabilities on the same day, all contribute to the uncertainty associated with estimates of unregulated, daily mean streamflows. There is no current theoretical framework from which prediction or confidence intervals for the Flow Duration Curve Transfer method-estimated daily streamflows can be derived (Archfield and others, 2009).

The regression equations developed for the Flow Duration Curve Transfer method were intended for use as a statewide model similar to that described by Archfield and others (2009), and no attempt was made to develop smaller regional equations because of potential complications involving the kriging for selection of the reference streamgages around smaller regional boundary areas. It is possible that the SEE for some areas in Iowa could improve, whereas the SEE for other parts of the state, especially around the boundary areas, could increase.

As indicated in the Limitations of Methods section for the Flow Anywhere method, because of the uncertainties associated with measuring and estimating streamflows less than 0.1 ft^3/s, the censoring threshold used to develop the left-censored regression equation for the 99-percent exceedance probability was set to 0.1 ft^3/s. As a result and to provide consistency, daily mean streamflow estimates computed from the regression equations at ungaged locations for any exceedance probabilities where estimates are less than 0.1 ft^3/s are reported as less than 0.1 ft^3/s.

Also, as previously mentioned in the Limitations of Methods section for the Flow Anywhere method, estimates of daily mean streamflows by using the Flow Duration Curve Transfer method at unregulated, ungaged locations in Iowa are limited to days after September 30, 1977 (32 years of record).

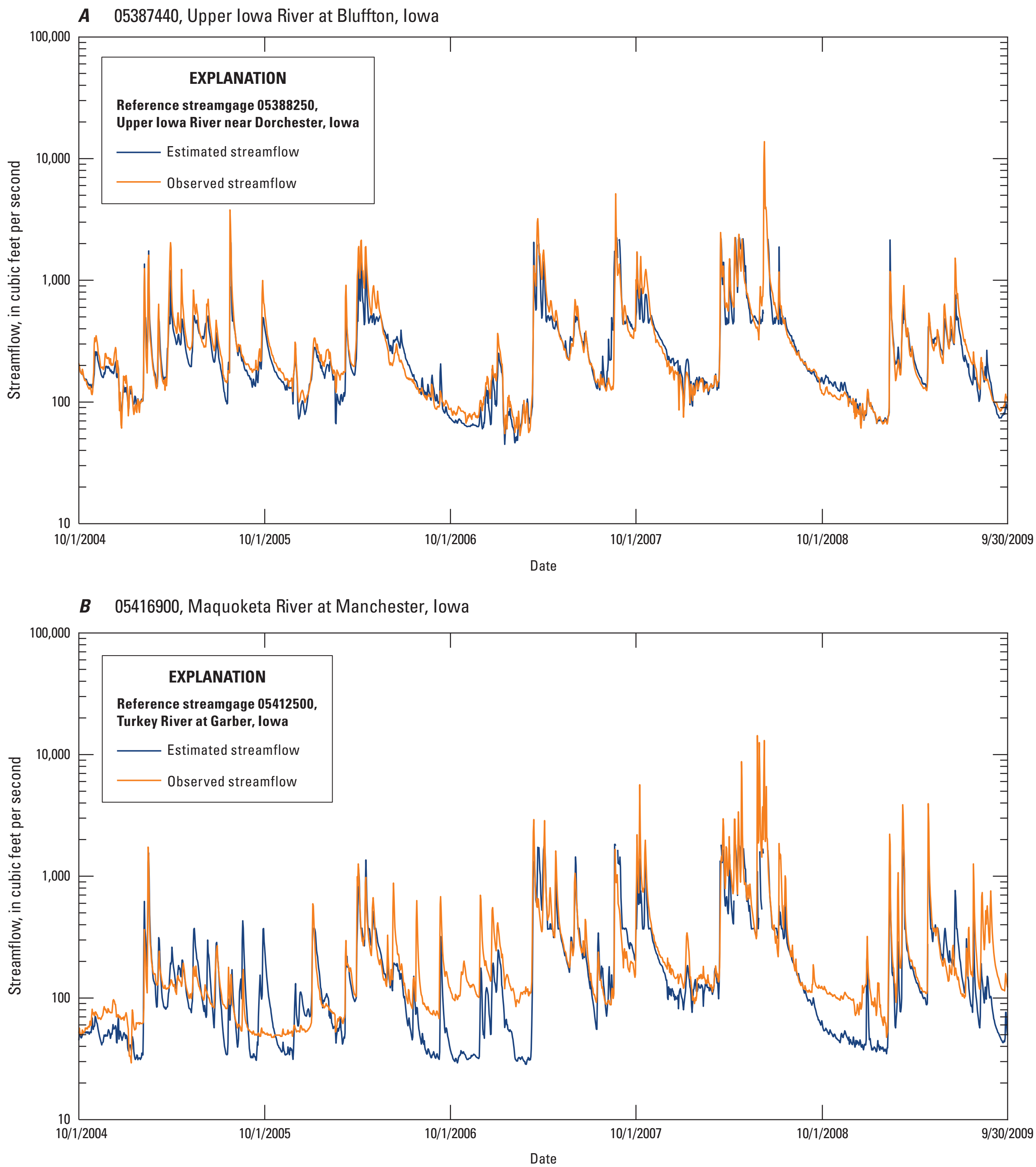


Figure 14. Observed and estimated hydrographs for U.S. Geological Survey streamgages (*A*) 05387440, Upper Iowa River at Bluffton, Iowa; and (*B*) 05416900, Maquoketa River at Manchester, Iowa, showing the (*A*) closest and (*B*) poorest agreement between unregulated observed and estimated, daily mean streamflow, October 1, 2004, to September 30, 2009, determined by using the Flow Duration Curve Transfer method.

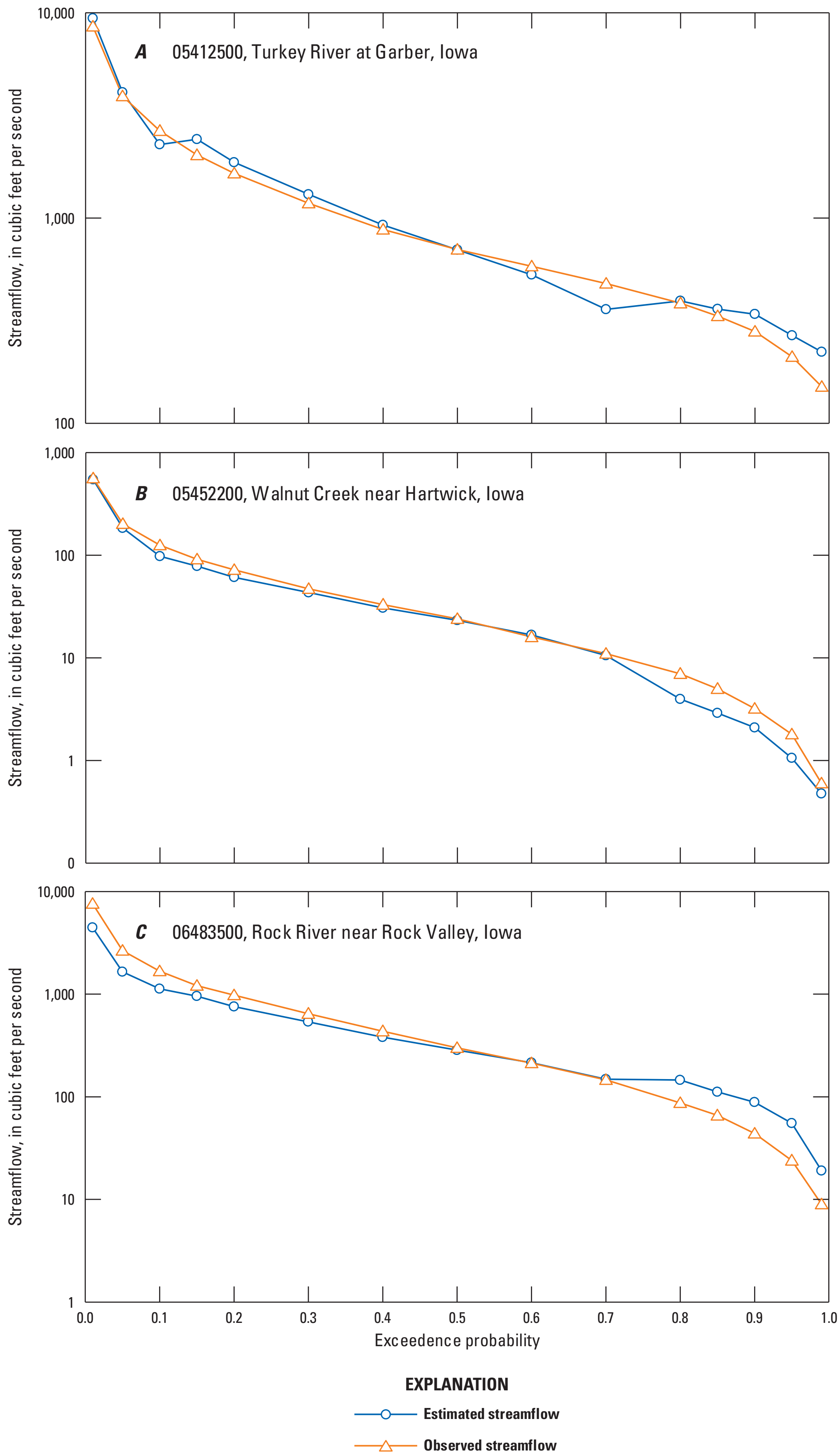


Figure 15. Observed and estimated flow duration exceedance probabilities for selected streamgages in Iowa.

Two streamgages have only 10 years of record (the minimum for the Flow Duration Curve Transfer method); therefore, if those streamgages were selected as reference gages, estimated daily mean streamflows could be computed only for days after September 30, 1999 (table 1). Most streamgages used for the Flow Duration Curve Transfer method have 32 years of record (October 1, 1977, to September 30, 2009).

Another limitation of the Flow Duration Curve Transfer method is the "jagging" that occurs along the Flow Duration Curve Transfers for some streamgages where along the curve at the higher flows, an estimated streamflow value becomes greater than the previous streamflow value as the exceedance probabilities increase (smaller flows), and where along the curve at lower flows, an estimated streamflow value becomes smaller than the previous value as the exceedance probabilities decrease (greater flows). As a result, the inherent structure of the Flow Duration Curve Transfer data at some of the potential reference streamgages is a physical impossibility. This issue has been addressed in a previous study by recursively regressing against other estimated streamflow quantiles (Archfield and others, 2009). As previously mentioned, this condition occurs at 23 streamgages in the study area for the Flow Duration Curve Transfer method, but no effort was made to address this issue in this study.

Table 9. Range of basin characteristics used for final regression equations for estimating flow-duration statistics for unregulated streams in Iowa.

[DA, drainge area; PRECIP, mean annual precipitation 1971–2000; SOILCSSURGO, percent area underlain by hydrologic soil type C; RSD, relative stream density; HYSEP, hydrograph separation and analysis is the median percentage of baseflow to annual streamflow; STREAM_VAR, streamflow-variability index, a measure of the steepness of the slope of a duration curve; SOILBSSURGO, percent area underlain by hydrologic soil type B; SOILDSSURGO, percent area underlain by hydrologic soil type D]

Basin characteristic	Minimum	Maximum	Median	Mean
DA	15.5	7,782	491	999
PRECIP	27.7	38.0	34.6	34.1
SOILCSSURGO	0.09	83.5	5.4	15.3
RSD	0.22	0.49	0.34	0.34
HYSEP	20.3	78.0	54.5	50.3
STREAM_VAR	0.21	0.76	0.59	0.57
SOILBSSURGO	5.7	99.4	89.3	78.9
SOILDSSURGO	0	57.0	0.63	3.6

Summary

This study is part of a larger project conducted by the U.S. Geological Survey (USGS) in cooperation with the Iowa Department of Natural Resources (IDNR) to develop a variety of methods for estimating daily mean streamflow at ungaged locations in Iowa. In this study, two methods for estimating streamflow at ungaged locations were investigated: a variation of the drainage-area-ratio method (Flow Anywhere method) and a quantile-based regression model (Flow Duration Curve Transfer method). The regression equations for both methods were developed for use only in Iowa from recorded daily mean streamflows and basin characteristics for streamgages within the study area, which includes the entire State of Iowa and adjacent areas within a 50-mile buffer of Iowa in the neighboring states of Illinois, Minnesota, Missouri, Nebraska, and Wisconsin. No streamgages in the South Dakota buffer area were used as a result of upstream regulation or diversion.

The Flow Anywhere method is a variation of the drainage-area-ratio method in which same-day streamflow information is transferred from a reference streamgage to an ungaged location by using the daily mean streamflow at the reference streamgage and the drainage-area ratio of the two locations. The drainage-area-ratio method was modified to regionalize the equations for Iowa and select the most appropriate reference streamgage. In the development of the Flow Anywhere method, streamgages with at least 5 complete years of daily mean streamflow record through September 30, 2009, and minimally affected by regulation or diversion were selected for evaluation. This process resulted in 92 streamgages in Iowa and 31 streamgages in adjacent states. Historic streamflow records prior to October 1, 1977, were not included in this analysis because trends were found in the data.

In the Flow Anywhere method, the correlation of historical streamflows between streamgages in the study area is first examined to determine local region boundaries. The local regions are defined so that the basins within the regions are physiographically similar. Some streamgages in the neighboring states were found to have low correlation to any streamgages within Iowa. These streamgages were removed from the study with the likelihood that they lie in a local region completely outside Iowa, and therefore are not relevant to this study. The remaining 107 streamgages were used in the development of the Flow Anywhere method. Reference streamgages were selected for each local region by examining results of an ordinary-least-squares regression. Streamgages in local regions that exhibit similar hydrologic properties were grouped together into three aggregated regions. Regression computations were completed to develop regional regression equations to compute streamflow for ungaged locations. Left-censored regression analyses were performed in aggregated regions 1 and 2 where there were observed zero streamflows. An ordinary-least-squares regression analysis was used in aggregated region 3, where zero flows were not observed. Two additional streamgages were removed from the regression analyses because streamgages with drainage areas larger than 5,500 square miles greatly influenced the results for the local region to which they belong, bringing the total number of streamgages used in the Flow Anywhere method to 105. The accuracy of the final regression equations for aggregated regions 1, 2, and 3 was quantified. The final equations are presented in this report along with the associated standard errors of the model.

The performance of the Flow Anywhere method in each aggregated region was examined by comparing the observed and estimated streamflows throughout the aggregated region. No obvious range of streamflows that were consistently over- or underestimated were found, with the exception of the extreme low streamflows, which generally appear to be slightly overestimated. Removing or adding local regions within the study area from or to different aggregated regions did not improve the estimates for the lower streamflows; therefore, the final equations presented in the report are believed to produce the best possible results that can be achieved with the dataset.

To evaluate the use of the Flow Anywhere method for estimating streamflow at ungaged locations, a validation procedure was completed for six streamgages in the study area. For each of the six streamgages, the regional regression equations were redeveloped without that particular streamgage in the dataset, thus simulating the scenario of computing daily mean streamflow at an ungaged location. To quantify the goodness of fit between observed and estimated flows at each of the six streamgages, the mean absolute error (MAE), root-mean-square error (RMSE), percent root-mean-square error (PRMSE), RMSE-observations standard-deviation ratio (RSR), percent bias (PBIAS), and Nash-Sutcliffe (NS) efficiency value were computed. Differences between the RMSE and the MAE ranged from 1,016 ft^3/s at USGS streamgage 05421740, Wapsipinicon River near Anamosa, Iowa (all streamgages named below are in Iowa), to 138 ft^3/s at 05387440, Upper Iowa River at Bluffton, signifying a greater occurrence of outliers between observed and estimated streamflows at 05421740, Wapsipinicon River near Anamosa. RMSE values ranged from 1,690 ft^3/s at 05421740, Wapsipinicon River near Anamosa, to 237 ft^3/s at 05387440, Upper Iowa River at Bluffton. PRMSE values ranged from 115 percent at 06483290, Rock River below Tom Creek at Rock Rapids, to 26.2 percent at 05387440, Upper Iowa River at Bluffton. The logarithm (base 10) of the streamflow PRMSE ranged from 13.0 percent at 06483290, Rock River below Tom Creek at Rock Rapids, to 5.3 percent at 05387440, Upper Iowa River at Bluffton. RSR values ranged from 0.80 at 05416900, Maquoketa River at Manchester, to 0.40 at 05387440, Upper Iowa River at Bluffton. PBIAS values ranged from 25.4 percent at 05387440, Upper Iowa River at Bluffton, to 4.0 percent at both 05412020, Turkey River above French Hollow Creek at Elkader, and 06483290, Rock River below Tom Creek at Rock Rapids. Untransformed streamflow NS values ranged from 0.84 at 05387440, Upper Iowa River at Bluffton, to 0.35 at 05416900, Maquoketa River at Manchester. The logarithm (base 10) of the streamflow NS values ranged from 0.86 to 0.56 for the same two sites, respectively. These statistics indicate that the closest match was for 05387440, Upper Iowa River at Bluffton, and the poorest was for 05416900, Maquoketa River at Manchester. Also, a visual comparison of observed and estimated hydrographs for the same streamgages shows relatively close agreement between observed and estimated streamflows for 05387440, Upper Iowa River at Bluffton, Iowa, whereas the estimated streamflows for 05416900, Maquoketa River at Manchester, Iowa, appear to be substantially either under- or overestimated for much of the time period.

Because of the uncertainty inherent in measuring and estimating flows less than 0.1 ft^3/s, the censoring threshold used to develop the left-censored regression equations for aggregated regions 1 and 2 was set to 0.1 ft^3/s. Therefore, daily mean streamflow estimates computed from the regression equations for ungaged locations that are less than 0.1 ft^3/s are to be reported as less than 0.1 ft^3/s for all ungaged locations to maintain a consistent reporting limit. Estimates of streamflows made on the same stream segment as a streamgage are to be made with caution because the resulting estimated streamflow at the ungaged location needs to be verified as hydrologically reasonable with respect to the streamflows at the streamgage. Also, a general "rule of thumb" used in other regression analyses is to use the traditional drainage-area ratio to estimate streamflow when the ratio of the drainage area of the ungaged location to that of the streamgage is between 0.5 and 1.5. The data used in the development of the Flow Anywhere method consisted of daily mean streamflows from October 1, 1977, to September 30, 2009. Computations of estimated daily mean streamflows at ungaged locations can be made for any date after September 30, 1977, provided that daily mean streamflow values for the associated reference streamgage are available for the days of interest. The Flow Anywhere method should not be applied to dates prior to October 1, 1977, as a result of trends found in annual mean streamflows. Computations of estimated daily mean streamflow at ungaged locations for dates after September 30, 2009, should be made with the assumptions that trends do not exist in the streamflow records and that no changes to basins have been made that would alter the relation between streamflows used in the development of the method.

Daily mean streamflow data used in the Flow Duration Curve Transfer method were retrieved for 113 continuous-record streamgages located in and within a 50-mile buffer of Iowa in the neighboring states. No streamgages in South Dakota were used as a result of regulation or diversion. Streamgages with at least 10 complete years of daily mean streamflow record through September 30, 2009, and minimally affected by regulation or diversion, which included 84 streamgages in Iowa and 29 streamgages in adjacent states, were selected for evaluation. Daily mean streamflow values prior to October 1, 1977, were not retrieved because trends were found in the record. Prior to the final selection of the streamgages used in this method, 102 streamgages in Iowa with periods of record greater than 10 years were tested by using Kendall's *tau* hypothesis test; positive trends were found in the annual mean streamflow quantiles at the 90-percent exceedance probability statistic for 61 of those streamgages. Trends in these data could introduce a bias into the Flow Duration Curve Transfer analyses, violating the assumption that flow-duration statistics are independent and stationary over time. Tests for trends in streamflow also were completed for the 50-percent and 10-percent exceedance probabilities; however, the number of streamgages showing trends in streamflow decreased with decreasing percent exceedances (higher streamflows). For the annual mean streamflow 90-percent exceedance probability statistic, 1978 was found to be the latest date beyond which the streamflow data do not exhibit a trend as determined by using the trend analysis test.

To develop the quantile-based regression equations, the dependent variable, the streamflow quantiles, and the independent variables, which are the physical and climate basin characteristics, were quantified for each of the 113 streamgages. To compute the streamflow quantiles, the observed daily streamflows were ranked and an exceedance probability was computed. Streamflow quantiles were estimated at the following exceedance probabilities: 0.01, 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.85, 0.90, 0.95, and 0.99. Regression equations then were developed for the above quantiles. A total of 57 physical and climate basin characteristics were tested for use as explanatory (independent) variables. Two sets of regression equations initially were developed; one set of equations was generated using ordinary-least-squares regression and one set of equations resulted from the use of the weighted-least-squares method or the left-censored method. With the exception of the equation (left-censored) for the 0.99-percent exceedance probability, all final equations were developed by using the weighted-least-squares method. For the left-censored regression equation for the 0.99-percent exceedance probability streamflow values, nine values were less than or equal to the censor threshold of 0.1 ft^3/s. Five values were zero flows. The dependent variables and the independent variable, drainage area, were transformed to base-10 logarithms to obtain linear-regression equations.

In the Flow Duration Curve Transfer method, a single reference streamgage was selected from the 113 reference streamgages in Iowa, Illinois, Minnesota, Missouri, Nebraska, and Wisconsin. Each streamgage in turn was treated as an ungaged (nonreference) site. The Flow Duration Curve Transfer method requires that daily streamflow records are available for both the reference streamgage and the nonreference site for the time period of interest. For this study, a 10-year period of record (October 1, 1999, through September 30, 2009) was used for the reference streamgages, because 10 years was the minimum period of record used to generate the flow-duration curves and regression equations. It is implied that the date of a specific streamflow being exceeded at the nonreference site is the same as that at the reference streamgage (that is, if the streamflow on October 1, 1999, is exceeded 95 percent of the time at the reference streamgage, the streamflow exceeded 95 percent of the time at the nonreference site also occurred on October 1, 1999). The same is true for the other exceedance probabilities. As a result, the most appropriate reference streamgage would be the one for which the most streamflows are correlated to those at the nonreference site. The Flow Duration Curve Transfer method quantifies the correlation between the timing of the streamflows at 112 reference streamgages and those at the nonreference site by using Pearson's *r* correlation coefficient.

Time-series correlations between the nonreference site and each reference streamgage were achieved through kriging. A spherical variogram model then was then developed for each reference streamgage to quantify the relation between the distances between each pair of reference streamgages and the differences in the Pearson's *r* correlation coefficient values between each pair of reference streamgages. Each variogram model quantifies the Pearson's *r* correlation coefficient value for any ungaged site in relation to a reference streamgage. The reference streamgage with the highest Pearson's *r* correlation coefficient value in relation to the ungaged site is then selected for use with the Flow Duration Curve Transfer method. The variogram models can be used to create prediction maps of the Pearson's *r* correlation coefficient value for each reference streamgage, which show the correlation between streamflow at a reference streamgage and at any ungaged site in Iowa.

To evaluate the Flow Duration Curve Transfer method for use in estimating daily, unregulated streamflows at an ungaged site, a validation procedure was used at six streamgages that were not used to develop the regression equations and were not used in the kriging procedure. Five years of record were used for the validation procedure for these six streamgages. Observed and estimated streamflows for each of the streamgages were compared for goodness of fit by using the mean absolute error (MAE), root-mean-square error (RMSE), percent root-mean-square error (PRMSE), RMSE-observations standard-deviation ratio (RSR), percent bias (PBIAS), and Nash-Sutcliffe (NS) efficiency values. For the Flow Duration Curve Transfer method, differences between the RMSE and the MAE ranged from 437 ft^3/s at 05421740, Wapsipinicon River near Anamosa, Iowa (all streamgages named below are in Iowa), to 93.9 ft^3/s at 05387440, Upper Iowa River at Bluffton, signifying a greater occurrence of outliers between observed and estimated streamflows at 05421740, Wapsipinicon River near Anamosa. RMSE values ranged from 906 ft^3/s at 05421740, Wapsipinicon River near Anamosa, to 169 ft^3/s at 05387440, Upper Iowa River at Bluffton. PRMSE values ranged from 67 percent at 06483290, Rock River below Tom Creek at Rock Rapids, to 25.6 percent at 05387440, Upper Iowa River at Bluffton. The logarithm (base 10) of the streamflow PRMSE ranged from 12.5 percent at 05416900, Maquoketa River at Manchester, to 4.4 percent at 05387440, Upper Iowa River at Bluffton. RSR values ranged from 0.79 at 05416900, Maquoketa River at Manchester, to 0.40 at 05412020, Turkey River above French Hollow Creek at Elkader. PBIAS values ranged from 22.7 percent at 05416900, Maquoketa River at Manchester, to 0.94 percent at 05411850, Turkey River near Eldorado, and 05412020, Turkey

River above French Hollow Creek at Elkader. For the Flow Duration Curve Transfer method, NS values ranged from 0.84 at 05412020, Turkey River above French Hollow Creek at Elkader, to 0.38 at 05416900, Maquoketa River at Manchester, as determined by using the untransformed observed and estimated daily streamflows, and from 0.89 at 05387440, Upper Iowa River at Bluffton, to 0.48 at 05416900, Maquoketa River at Manchester, as determined by using the base-10 logarithms of the observed and estimated daily streamflows. Of the six validation sites, the closest and poorest agreements between the observed and estimated daily mean streamflows for streamgages over the 5-year period were found for 05387440, Upper Iowa River at Bluffton, and 05416900, Maquoketa River at Manchester, respectively. A visual comparison of observed and estimated hydrographs for the same streamgages shows relatively close agreement between observed and estimated streamflows for 05387440, Upper Iowa River at Bluffton, whereas the estimated streamflows for 05416900, Maquoketa River at Manchester, appear to be substantially underestimated for much of the time period. Estimated cumulative streamflow for the period October 1, 2004, to September 30, 2009, are underestimated for 05387440, Upper Iowa River at Bluffton, and 05416900, Maquoketa River at Manchester, by -9.3 and -22.7 percent, respectively.

The overall uncertainty of estimating a time series of unregulated, daily mean streamflow at an ungaged site with the Flow Duration Curve Transfer method is difficult to quantify. To address this issue, the goodness-of-fit values (NS and percent RMSE) are documented. For the three components of the Flow Duration Curve Transfer method, (1) regression equations, (2) reference-streamgage selection criteria, and (3) the assumption of equivalent exceedance probabilities on the same day, all contribute to the uncertainty associated with estimates of unregulated, daily mean streamflows determined by using the Flow Duration Curve Transfer method. No theoretical framework currently exists from which prediction or confidence intervals for the daily streamflows estimated with the Flow Duration Curve Transfer method can be derived.

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