Prepared in cooperation with the Iowa Department of Natural Resources

Comparison Between Two Statistically Based Methods, and Two Physically Based Models Developed to Compute Daily Mean Streamflow at Ungaged Locations in the Cedar River Basin, Iowa

Scientific Investigations Report 2013–5111

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

Cover Photograph: Cedar River at Waterloo, Iowa (photograph taken by Don Becker, U.S. Geological Survey).

Comparison Between Two Statistically Based Methods, and Two Physically Based Models Developed to Compute Daily Mean Streamflow at Ungaged Locations in the Cedar River Basin, Iowa

By S. Mike Linhart, Jon F. Nania, Daniel E. Christiansen, Kasey J. Hutchinson, Curtis L. Sanders, Jr., and Stacey A. Archfield

Prepared in cooperation with the Iowa Department of Natural Resources

Scientific Investigations Report 2013–5111

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Linhart, S.M., Nania, J.F., Christiansen, D.E., Hutchinson, K.J., Sanders, C.L., Jr., and Archfield, S.A., 2013, Comparison between two statistically based methods, and two physically based models developed to compute daily mean streamflow at ungaged locations in the Cedar River Basin, Iowa: U.S. Geological Survey Scientific Investigations Report 2013–5111, 7 p., *http://pubs usgs.gov/sir/2013/5111*.

Contents

Figures

Tables

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)

Acknowledgments

The authors express their gratitude to the personnel of the Iowa Department of Natural Resources, Water Monitoring Division, for their assistance in project planning.

The authors also thank the following USGS personnel: David Eash, for technical assistance with regression analysis; Ken Eng, for assistance with initial project development; Julie Kiang, for technical assistance with regression analysis. The authors also express their appreciation to the many other USGS personnel who assisted with the collection and analysis of streamflow data used in this study.

Comparison Between Two Statistically Based Methods, and Two Physically Based Models Developed to Compute Daily Mean Streamflow at Ungaged Locations in the Cedar River Basin, Iowa

By S. Mike Linhart, Jon F. Nania, Daniel E. Christiansen, Kasey J. Hutchinson, Curtis L. Sanders, Jr., and Stacey A. Archfield

Abstract

A variety of individuals from water resource managers to recreational users need streamflow information for planning and decisionmaking at locations where there are no streamgages. To address this problem, two statistically based methods, the Flow Duration Curve Transfer method and the Flow Anywhere method, were developed for statewide application and the two physically based models, the Precipitation Runoff Modeling-System and the Soil and Water Assessment Tool, were only developed for application for the Cedar River Basin. Observed and estimated streamflows for the two methods and models were compared for goodness of fit at 13 streamgages modeled in the Cedar River Basin by using the Nash-Sutcliffe and the percent-bias efficiency values.

Based on median and mean Nash-Sutcliffe values for the 13 streamgages the Precipitation Runoff Modeling-System and Soil and Water Assessment Tool models appear to have performed similarly and better than Flow Duration Curve Transfer and Flow Anywhere methods. Based on median and mean percent bias values, the Soil and Water Assessment Tool model appears to have generally overestimated daily mean streamflows, whereas the Precipitation Runoff Modeling-System model and statistical methods appear to have underestimated daily mean streamflows. The Flow Duration Curve Transfer method produced the lowest median and mean percent bias values and appears to perform better than the other models.

Introduction

The U.S. Geological Survey (USGS) maintains approximately 148 real-time streamgages in Iowa where daily mean streamflow information is available. A variety of individuals from water resource managers to recreational users rely on streamflow information in their planning and decisionmaking. Often there is a need for daily mean streamflow information at locations where there are no streamgages. To address this problem, the USGS in cooperation with the Iowa Department of Natural Resources evaluated two statistically based methods and two physically based watershed models for estimating daily mean streamflow at ungaged locations within the Cedar River Basin, Iowa. The two statistically based methods are the Flow Duration Curve Transfer method and the Flow Anywhere method, and the two physically based models are the Precipitation Runoff Modeling-System (PRMS) and the Soil and Water Assessment Tool (SWAT). This report compares the results of these methods and models developed to estimate daily mean streamflow at ungaged locations within the Cedar River Basin, Iowa. The two statistically based methods are presented in one report (Linhart and others, 2012), and the two physically based models are presented in two reports (Christiansen, 2012; Hutchinson and Christiansen, 2013). Although the two statistically based methods were developed for estimating daily mean streamflow at ungaged locations for the entire state of Iowa, the two physically based models were specifically developed for only the Cedar River Basin.

Study Area

The Cedar River Basin extends from its headwaters in southern Minnesota to its confluence with the Iowa River in southeastern Iowa .The Cedar River is the largest tributary to the Iowa River with a drainage area of approximately 7,815 square miles (fig. 1) (Iowa Department of Natural Resources, 2006; Squillace and others, 1996). Four of the 10 distinct landform regions in Iowa are present in the Cedar River Basin (Prior and others, 2009) (fig. 2). Corn and soybean row-crop agriculture is the dominate land use in the basin. The basin has extensive, artificial drainage which includes open ditches and subsurface drainage tile; both of which are designed to remove excess water from the land and soil subsurface (Iowa Department of Natural Resources, 2006). Confined and unconfined livestock operations that

Figure 1. U.S. Geological Survey streamgages in the Cedar River Basin.

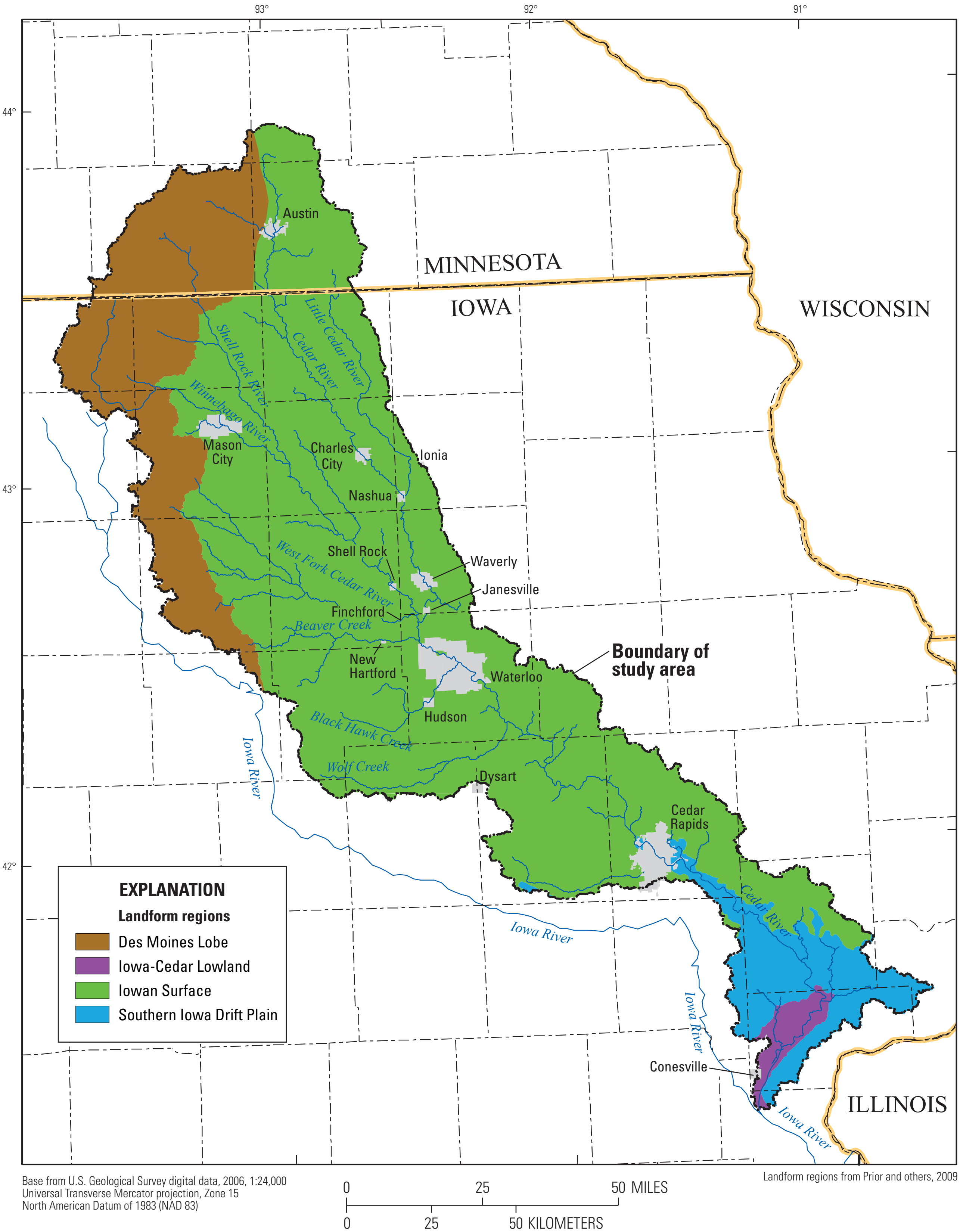

Figure 2. Cedar River Basin landform regions.

Table 1. U.S. Geological Survey streamgages used in the Cedar River Basin included in the comparison of the Flow Duration Curve Transfer method, the Flow Anywhere method, the Precipitation Runoff Modeling-System model, and the Soil and Water Assessment Tool model.

[USGS, U.S. Geological Survey; latitude and longitude in degrees, minutes, and seconds; mi^2, square miles]

Map number (fig. 1)	USGS streamgage number	USGS streamgage name	Latitude (north)	Longitude (west)	Drainage area measured at streamgage (mi^2)
1	05457000	Cedar River near Austin, Minnesota	43°38’14”	92°58’28”	399
2	05457700	Cedar River at Charles City, Iowa	43°03’44”	92°40’25”	1,054
3	05458000	Little Cedar River near Ionia, Iowa	43°01’60”	92°30’12”	306
4	[1]05458300	Cedar River at Waverly, Iowa	42°44’14”	92°28’12”	1,547
5	05458500	Cedar River at Janesville, Iowa	42°38’54”	92°27’54”	1,661
6	05458900	West Fork Cedar River at Finchford, Iowa	42°37’46”	92°32’36”	846
7	05459500	Winnebago River at Mason City, Iowa	43°09’54”	93°11’33”	526
8	05462000	Shell Rock River at Shell Rock, Iowa	42°42’43”	92°34’58”	1,746
9	05463000	Beaver Creek at New Hartford, Iowa	42°34’22”	92°37’04”	347
10	05463500	Black Hawk Creek at Hudson, Iowa	42°24’28”	92°27’47”	303
11	05464000	Cedar River at Waterloo, Iowa	42°29’44”	92°20’03”	5,146
12	05464220	Wolf Creek near Dysart, Iowa	42°15’06”	92°17’55”	299
13	05464500	Cedar River at Cedar Rapids, Iowa	41°58’19”	91°40’01”	6,510
14	05465000	Cedar River near Conesville, Iowa	41°24’33”	91°17’25”	7,787

[1]Used only as a validation site for the Precipitation-Runoff Modeling System model. The site was not used for any of the other models.

include beef and dairy cattle, hogs, sheep, and poultry are located throughout the basin (Iowa Department of Natural Resources, 2006). Designated uses for the Cedar River include primary contact recreation and drinking water supply (Iowa Department of Natural Resources, 2006). There are 14 USGS streamgages in the Cedar River Basin (fig. 1, table 1), 13 of which were used in this comparison.

Comparison of Methods and Models

Observed and estimated streamflows for the two methods and two models were compared for goodness of fit at each of the streamgages (table 2) by using the Nash-Sutcliffe (NS) (Nash and Sutcliffe, 1970) and the percent bias (PBIAS) efficiency values (Gupta and others, 1999). The NS value is a measure of how well the method and model estimates match the observed values. NS values range from $-\infty$ to 1. Values of 0.0 or less indicate unacceptable model performance; a value of 1 indicates a perfect fit between observed and estimated values (Moriasi and others, 2007). The PBIAS value is a measure of the average tendency of the method or model estimates to be larger or smaller than the observed values, with an optimal value of 0.0. Positive values indicate method or model underestimation bias and negative values indicate method or model overestimation bias. Method and model estimates can be considered satisfactory if NS is greater than 0.50 and the absolute value of PBIAS is less than 25 percent (Moriasi and others, 2007). For the Flow Duration Curve Transfer method, NS values ranged from 0.09 to 0.79 with median and mean values of 0.55 and 0.54, respectively; PBIAS values ranged from -13.2 to 20.0 with median and mean values of 4.6 and 3.3, respectively. For the Flow Anywhere method, NS values ranged from 0.15 to 0.77 with median and mean values of 0.37 and 0.43, respectively; PBIAS values ranged from 5.4 to 46.2 with median and mean values of 14.8 and 18.7, respectively. For the PRMS model, NS values ranged from 0.04 to 0.87 with median and mean values of 0.66 and 0.61, respectively; PBIAS values ranged from -27.5 to 19.8 with median and mean values of 6.6 and 4.6, respectively. For the SWAT model, NS values ranged from 0.44 to 0.78 with median and mean values of 0.63 and 0.62, respectively; PBIAS values ranged from -26.1 to 11.2 with median and mean values of -9.1 and -8.1, respectively.

Method and Model Results

Observed and estimated hydrographs of the daily mean streamflow for the two methods and two models for the streamgage 05464000, Cedar River at Waterloo, Iowa (see location at fig. 1, map number 11) for the period October 1, 2001, to September 30, 2009 are shown in figure 3. A visual comparison of the Flow Duration Curve Transfer hydrographs (fig. 3*A*) show the observed as compared to the estimated daily mean streamflows appear to be a combination of underes-

Table 2. Comparison results between the two statistically based methods and the two physically based models of the observed and estimated daily mean streamflows, October 1, 2001, to September 30, 2009.

[PRMS, Precipitation Ruoff Modeling System; SWAT, Soil and Water Assessment Tool; NS, Nash-Sutcliffe Efficiency Value; PBIAS, percent bias.]

USGS streamgage number	USGS streamgage name	[1]Flow Duration Curve Transfer		Flow Anywhere method		PRMS		SWAT	
		NS	PBIAS	NS	PBIAS	NS	PBIAS	NS	PBIAS
05457000	Cedar River near Austin, Minnesota	0.27	20.0	0.15	14.2	0.29	-11.4	0.44	-10.1
05457700	Cedar River at Charles City, Iowa	0.71	4.9	0.37	9.4	0.04	-27.5	0.49	-10.9
05458000	Little Cedar River near Ionia, Iowa	0.73	-5.2	0.30	15.3	0.50	-0.5	0.6	-17.3
05458500	Cedar River at Janesville, Iowa	0.47	4.6	0.55	8.7	0.63	-8.1	0.67	-7.8
05458900	West Fork Cedar River at Finchford, Iowa	0.79	12.3	[2]NA	[2]NA	0.71	13.9	0.6	-12.8
05459500	Winnebago River at Mason City, Iowa	0.64	6.7	0.37	46.2	0.68	13.1	0.69	-2.4
05462000	Shell Rock River at Shell Rock, Iowa	0.72	-3.1	0.66	5.4	0.66	4.5	0.56	-23.1
05463000	Beaver Creek at New Hartford, Iowa	0.73	15.4	0.41	30.5	0.63	16.8	0.68	-0.6
05463500	Black Hawk Creek at Hudson, Iowa	0.53	14.4	0.35	27.8	0.63	19.8	0.66	11.2
05464000	Cedar River at Waterloo, Iowa	0.43	-13.2	0.77	7.5	0.87	7.4	0.48	-26.1
05464220	Wolf Creek near Dysart, Iowa	0.55	-5.4	0.34	22.4	0.66	19.2	0.63	7.7
05464500	Cedar River at Cedar Rapids, Iowa	0.35	-2.7	[3]NA	[3]NA	0.86	6.6	0.78	-9.1
05465000	Cedar River near Conesville, Iowa	0.09	-5.8	[3]NA	[3]NA	0.82	6.1	0.74	-4.6
	Maximum	0.79	20.0	0.77	46.2	0.87	19.8	0.78	11.2
	Minimum	0.09	-13.2	0.15	5.4	0.04	-27.5	0.44	-26.1
	Median	0.55	4.6	0.37	14.8	0.66	6.6	0.63	-9.1
	Mean	0.54	3.3	0.43	18.7	0.61	4.6	0.62	-8.1

[1]Model estimates of streamflow are missing for some days because observed streamflow values were outside the applicable computational range of the Flow Duration Curve Tranfer method.

[2]Reference streamgage for the Flow Anywhere method.

[3]Drainage areas are too large for the Flow Anywhere method.

timated and overestimated streamflows computed from the method, but overall, the estimated daily mean streamflows from the method are underestimated. A visual comparison of observed and estimated daily mean streamflows using the Flow Anywhere method (fig. 3*B*) indicates that, for the most, part daily mean streamflows are underestimated. For the PRMS model (fig. 3*C*), daily mean streamflows are underestimated, especially at low flows. For the SWAT model (fig. 3*D*), daily mean streamflows appear to be underestimated at very low streamflows and overestimated at higher streamflows; in general, the PBIAS results indicate daily mean streamflows are overestimated. On the basis of the NS values for the Cedar River at Waterloo, Iowa, streamgage 05464000, the PRMS model appears to provide the best estimates with the highest NS value of 0.87, whereas the Flow Duration Curve Transfer method appears to provide the poorest estimate with the lowest NS value of 0.43. On the basis of the PBIAS values for the same streamgage, the PRMS model appears to provide the best estimates with the lowest absolute PBIAS value of 7.4 and the SWAT model appears to provide the poorest estimates with the highest absolute PBIAS value of -26.1. On the basis of both the NS and PBIAS values, the PRMS model appears to provide the best prediction of streamflow for the Cedar River at Waterloo, Iowa, streamgage 05464000.

Conclusion and Discussion of Methods and Models

Based on median and mean Nash-Sutcliffe values for the 13 streamgages modeled in the Cedar River Basin; the Precipitation Runoff Modeling-System and the Soil and Water Assessment Tool models appear to have performed similarly and better than the Flow Duration Curve Transfer and Flow Anywhere methods. Based on median and mean percent bias values, the Soil and Water Assessment Tool model appears to have generally overestimated daily mean streamflows, whereas the statistical methods and Precipitation Runoff Modeling-System model appear to have underestimated daily mean streamflows. The Flow Duration Curve Transfer method produced the lowest median and mean percent bias values and appears to perform better than the Flow Anywhere method and the Precipitation Runoff Modeling-System and the Soil and

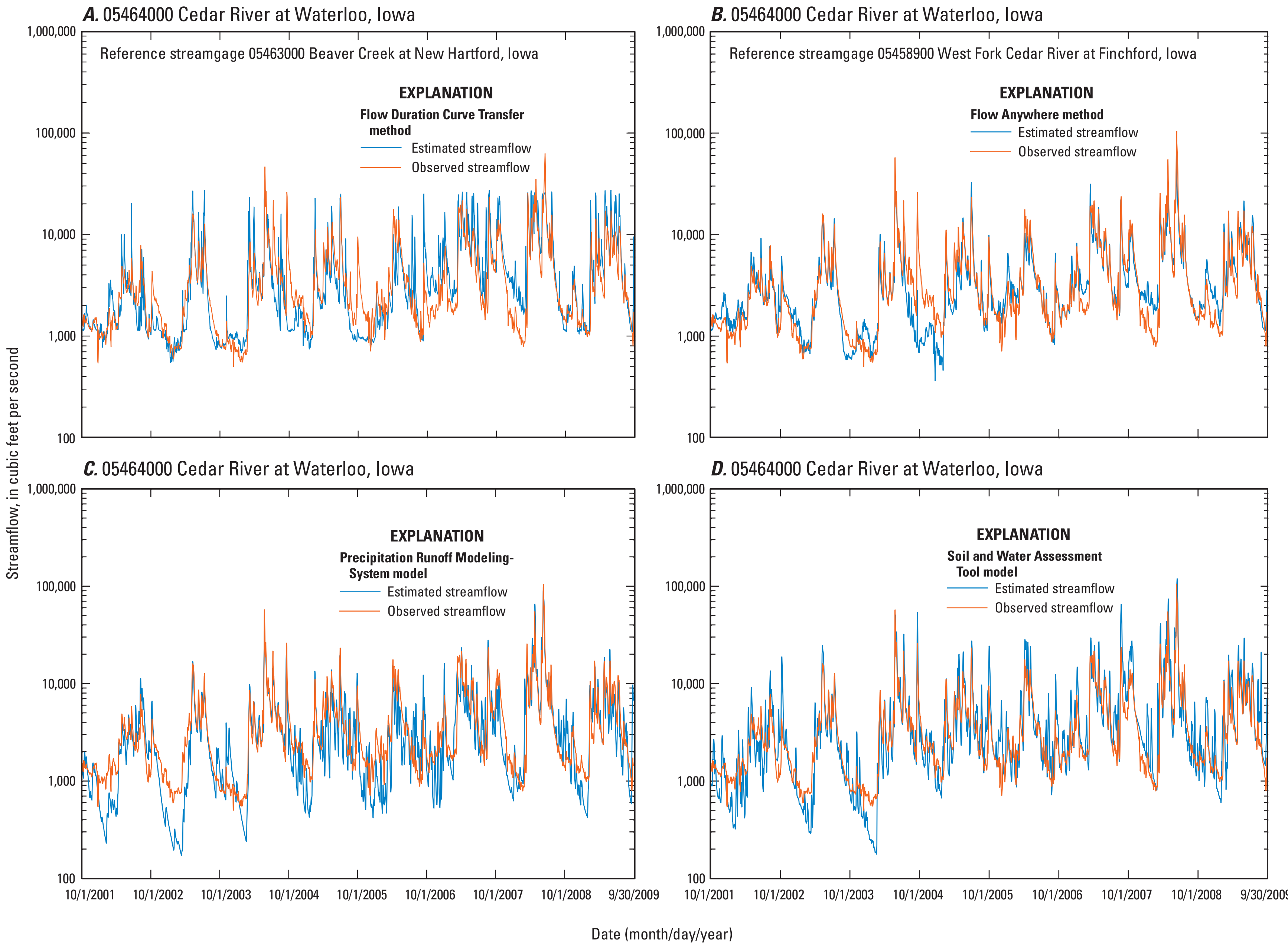

Figure 3. Observed and estimated hydrographs of daily mean streamflow for U.S. Geological Survey streamgage 05464000, Cedar River at Waterloo, Iowa, using; *A*, the Flow Duration Curve Transfer method; *B*, the Flow Anywhere method; *C*, the Precipitation Runoff Modeling-System model; and *D*, the Soil and Water Assessment Tool model for the period October 1, 2001, to September 30, 2009.

Water Assessment Tool models. It is likely that no one method or model out-performs other methods or models for all magnitudes of streamflow (high, low, or mid-range streamflows). A more detailed study is needed to determine which methods or models will perform best at specific magnitudes of streamflows. For estimating very large streamflows with exceedance probabilities of less than 1 percent, the Flow Duration Curve Transfer method is not applicable because these streamflows are outside the computational range of the current model. The Flow Anywhere method is limited to estimating streamflow for basins less than 5,500 square miles (Linhart and others, 2012). The Precipitation Runoff Modeling-System and the Soil and Water Assessment Tool models are limited to estimating streamflow for only the Cedar River Basin.

References Cited

Christiansen, D.E., 2012, Simulation of daily streamflows at gaged and ungaged locations within the Cedar River Basin, Iowa, using a Precipitation-Runoff Modeling System model: U.S. Geological Survey Scientific Investigations Report 2012–5213, 20 p.

Gupta, H.V., Sorooshian, S., and Yapo, P.O., 1999, Status of automatic calibration for hydrologic models—Comparison with multilevel expert calibration: Journal of Hydrologic Engineering, v. 4, no. 2, p. 135–143.

Hutchinson, K.J., and Christiansen, D.E., 2013, Use of the soil and water assessment tool (SWAT) for simulating hydrology and water quality in the Cedar River Basin, Iowa, 2000–2010: U.S. Geological Survey Scientific Investigations Report 2013–5002, 36 p.

Iowa Department of Natural Resources, 2006, Total maximum daily load for nitrate, Cedar River, Linn County, Iowa, 2006: Iowa Department of Natural Resources, Des Moines, Iowa, 62 p. (Also available at *http://www.epa.gov/waters/tmdldocs/32009_IACedarRiverTMDL.pdf*).

Linhart, S.M., Nania, J.F., Sanders, C.L., Jr., and Archfield, S.A., 2012, Computing daily mean streamflow at ungaged locations in Iowa by using the Flow Anywhere and Flow Duration Curve Transfer statistical methods: U.S. Geological Survey Scientific Investigations Report 2012–5232, 50 p.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Binger, R.L., Harmel, R.D., and Veith, T.L., 2007, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations: American Society of Agricultural and Biological Engineers, p. 885–900

Nash, J.E., and Sutcliffe, J.V., 1970, River flow forecasting through conceptual models part I—A discussion of principles: Journal of Hydrology, v. 10, no. 3, p. 282–290.

Prior, J.C., Kohrt, C.J., and Quade, D.J., 2009, The landform regions of Iowa: Iowa City, Iowa, Iowa Geological Survey, Iowa Department of Natural Resources, vector digital data, accessed December 15, 2011, at *http://www.igsb.uiowa.edu/webapps/nrgislibx/.*

Squillace, P.J., Caldwell, J.P., Schulmeyer, P.M., and Harvey, C.A., 1996, Movement of agricultural chemicals between surface water and ground water, lower Cedar River Basin, Iowa: U.S. Geological Survey Water–Supply Paper 2448, 59 p.

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Iowa Water Science Center
P.O. Box 1230
Iowa City, IA 52244
(319) 337–4191

Or visit the Iowa Water Science Center Web site at:
http://ia.water.usgs.gov

USGS

Linhart and others—**Comparison Between Two Statistically Based Methods, and Two Physically Based Models**—Scientific Investigations Report 2013–5111