Prepared in cooperation with the Iowa Department of Natural Resources

Simulation of Daily Streamflow for Nine River Basins in Eastern Iowa Using the Precipitation-Runoff Modeling System

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U.S. Geological Survey

Cover. Turkey River at Elkader, Iowa, 2014 (front cover); Maquoketa River near Green Island, Iowa, 2015 (upper, back cover); and Wapsipinicon River at Oxford Mills, Iowa, 2014 (lower, back cover). Photographs by U.S. Geological Survey, Iowa Water Science Center.

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	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).

The water year (WY) begins October 1 and ends September 30 of the following year. The WY is designated by the calendar year in which it ends; for example, WY 2014 begins on October 1, 2013, and ends on September 30, 2014.

Simulation of Daily Streamflow for Nine River Basins in Eastern Iowa Using the Precipitation-Runoff Modeling System

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Abstract

The U.S. Geological Survey, in cooperation with the Iowa Department of Natural Resources, constructed Precipitation-Runoff Modeling System models to estimate daily streamflow for nine river basins in eastern Iowa that drain into the Mississippi River. The models are part of a suite of methods for estimating daily streamflow at ungaged sites. The Precipitation-Runoff Modeling System is a deterministic, distributed-parameter, physical-process-based modeling system developed to evaluate the response of streamflow and general drainage basin hydrology to various combinations of climate and land use. Calibration and validation periods used in each basin mostly were October 1, 2002, through September 30, 2012, but differed depending on the period of record available for daily mean streamflow measurements at U.S. Geological Survey streamflow-gaging stations.

A geographic information system tool was used to delineate each basin and estimate values for model parameters based on basin physical and geographical features. A U.S. Geological Survey auto-calibration tool that uses a shuffled complex evolution algorithm was used for initial calibration, and then manual modifications were made to parameter values to complete the calibration of each basin model. The main objective of the calibration was to match daily discharge values of simulated streamflow to measured daily discharge values.

The accuracy of Precipitation-Runoff Modeling System model streamflow estimates of nine river basins in eastern Iowa as compared to measured values at U.S. Geological Survey streamflow-gaging stations varied. The Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa were satisfactory at estimating daily streamflow at 57 of the 79 calibration sites and 13 of the 14 validation sites based on statistical results. Unsatisfactory performance can be contributed to several factors: (1) low flow, no flow, and flashy flow conditions in headwater subbasins having a small drainage area; (2) poor representation of the groundwater and storage components of flow within a basin; (3) lack of accounting for basin withdrawals and water use; and (4) the availability and accuracy of meteorological input data. The Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa will provide water-resource managers with a consistent and documented method for estimating streamflow at ungaged sites and aid in environmental studies, hydraulic design, water management, and water-quality projects.

Introduction

The U.S. Geological Survey (USGS), in cooperation with State, county, municipal, and other Federal agencies, collects a large amount of data pertaining to the water resources of Iowa each year. These data constitute a valuable database for developing an improved understanding of State water resources. Surface-water data for Iowa include records of stage, discharge, and water quality of streams and records of stage of lakes and reservoirs. Iowa has 71,000 miles (mi) of rivers and streams (Iowa Department of Natural Resources, 2000), and measurements collected from USGS streamflow-gaging stations on those streams (gaged sites) only account for a very narrow representation of the surface-water flow in the State. There is a strong need by water-resource managers of the Iowa Department of Natural Resources (IDNR) for a consistent and documented method for providing streamflow estimates in Iowa at locations where no USGS streamflow-gaging station is present (ungaged sites). Streamflow estimates at ungaged sites would aid water-resource managers in environmental studies, hydraulic design, water management, and water-quality projects.

The USGS maintains about 149 real-time streamflow-gaging stations in Iowa where daily mean streamflow information is available (U.S. Geological Survey, 2014). This streamflow information provides the basis for understanding the hydrologic characteristics of drainage basins (basins), and, in combination with water-quality information collected at a monthly time step at 75 locations across the State by State and Federal agencies, aids in the understanding of risks imposed on human and ecosystem health. Because the information collected at gaged sites is site specific, the ability to confidently use these data to infer information at ungaged sites within a basin for adaptive management and decisions can be limited.

Hydrological models are one tool that can be used to overcome the lack of hydrologic information at ungaged sites in eastern Iowa (Christiansen, 2012). Precipitation-Runoff Modeling System (PRMS) models (Leavesley and others, 1983; Markstrom and others, 2008; Markstrom and others, 2015) were constructed, in cooperation with the IDNR, for nine river basins in eastern Iowa as part of an ongoing research project to examine methods of estimating daily streamflow at gaged and ungaged sites. Hydrological models can be combined with other predictive methods and techniques, such as the Flow Duration Curve Transfer and the Flow Anywhere methods (Linhart and others, 2013), to provide a comprehensive approach in developing near real-time streamflow estimates.

Purpose and Scope

This report describes the use of the USGS PRMS (Leavesley and others, 1983; Markstrom and others, 2008; Markstrom and others, 2015) for simulating daily streamflow in nine eastern Iowa River basins draining into the Mississippi River. The construction, calibration, and evaluation of PRMS models of nine river basins in eastern Iowa to simulate daily streamflow at gaged and ungaged sites are described. Model performance is assessed to determine the ability of PRMS to estimate streamflow and, thus, the suitability for the model to serve as part of a suite of methods for estimating daily streamflow at ungaged sites. Model limitations are investigated and described.

Description of Study Areas

The PRMS models were constructed for a total of nine river basins in eastern Iowa that are tributaries to the Mississippi River: Upper Iowa River Basin, Yellow River Basin, Turkey River Basin, Maquoketa River Basin, Wapsipinicon River Basin, Iowa River Basin, Skunk River Basin, Des Moines River Basin, and Fox River Basin (figs. 1 and 2). Although the percentage varies, all basins are dominated by agriculture in the form of corn and soybeans (U.S. Department of Agriculture, 2014). There are livestock operations (including beef and dairy cattle, hogs, sheep, and poultry) in varying amounts in each of the nine river basins in eastern Iowa. In addition, tile drainage is extensive throughout each basin to enhance crop production by removing excess water from the soil. The eastern part of the State spans seven of Iowa's landform regions, and each has a characteristic topography and glacial history (Prior and others, 2009; Prior, 1991) (fig. 1).

The first of these nine basins in eastern Iowa, the Upper Iowa River Basin, is in northeast Iowa, drains about 1,005 square miles (mi^2), and extends from its headwaters in Mower County, Minnesota, to the Mississippi River in northeast Allamakee County, Iowa (figs. 1 and 2). The Upper Iowa River Basin is in an area of the State characterized by rugged hills, steep topography, a complex network of springs, and diverse land use. Most of the Upper Iowa River Basin is within the Paleozoic Plateau landform region; the western part of the Upper Iowa River Basin is within the Iowan Surface landform region (fig. 1). Three USGS streamflow-gaging stations in the Upper Iowa River Basin were used in this study (table 1; fig. 2).

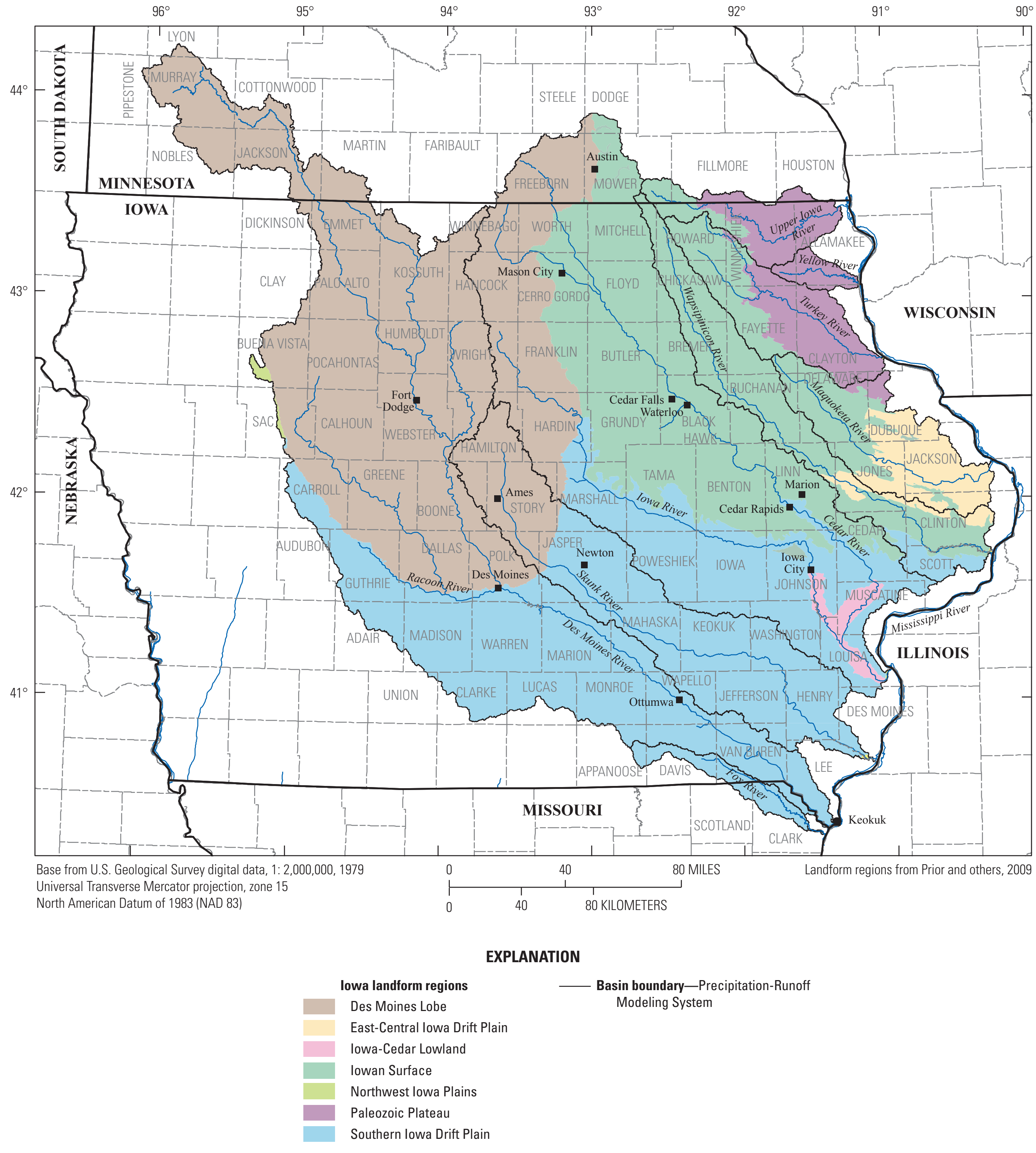
The Yellow River Basin originates in southwestern Winneshiek County, northeast Iowa, and drains about 240 mi^2 before its confluence with the Mississippi River in Allamakee County, Iowa (fig. 1). The Yellow River Basin is within the Paleozoic Plateau (figs. 1 and 2). The Yellow River Basin is mainly forest or agricultural land with little urban development (Iowa Department of Natural Resources, 2009). One USGS streamflow-gaging station in the Yellow River Basin was used in this study (table 1; fig. 2).

The Turkey River Basin originates in Howard County, northeast Iowa, and drains about 1,685 mi^2 into the Mississippi River in Clayton County, Iowa (figs. 1 and 2). The upper part of the Turkey River Basin is within the Iowan Surface, and the lower part lies within the Paleozoic Plateau (fig. 1). Six USGS streamflow-gaging stations in the Turkey River Basin were used in this study (table 1; fig. 2).

The Maquoketa River Basin drains about 1,880 mi^2 in northeast Iowa, originates in Fayette County, Iowa, and flows southeast to the Mississippi River in Jackson County, Iowa (figs. 1 and 2). The Maquoketa River Basin consists of the Iowan Surface and East-Central Iowa Drift Plain landform regions, and a small part in the northeast extends into the Paleozoic Plateau (fig. 1). Three USGS streamflow-gaging stations in the Maquoketa River Basin were used in this study (table 1; fig. 2).

The Wapsipinicon River Basin drains 2,540 mi^2, originates in Mower County, southeastern Minnesota, and extends about 225 mi southeast to its confluence with the Mississippi River (figs. 1 and 2). Most of the Wapsipinicon River Basin lies within the Iowan Surface, but small parts cross into the East-Central Iowa Drift Plain and Southern Iowa Drift Plain landform region in the eastern part of the Wapsipinicon River Basin near the outlet (fig. 1). Seven USGS streamflow-gaging stations in the Wapsipinicon River Basin were used in this study (table 1; fig. 2).

The Iowa River Basin drains about 12,640 mi^2 and extends from its headwaters in southern Minnesota to its outlet in Louisa County, southern Iowa (fig. 1). The Cedar River is the largest tributary to the Iowa River and drains about 7,815 mi^2 before its confluence. The Iowa River Basin is the second largest basin in Iowa that extends into the Des Moines Lobe landform region in the northwest part, the Iowan Surface in the central and eastern parts, and the Southern Iowa Drift Plain and the Iowa-Cedar Lowland in the southern part of the basin (fig. 1). Cedar Rapids, Waterloo, and Iowa City, Iowa, are the primary urban centers within the Iowa River Basin. A total of 33 USGS streamflow-gaging stations in the Iowa River Basin were used in this study (table 1; fig. 2).



Base from U.S. Geological Survey digital data, 1: 2,000,000, 1979
Universal Transverse Mercator projection, zone 15
North American Datum of 1983 (NAD 83)

Landform regions from Prior and others, 2009

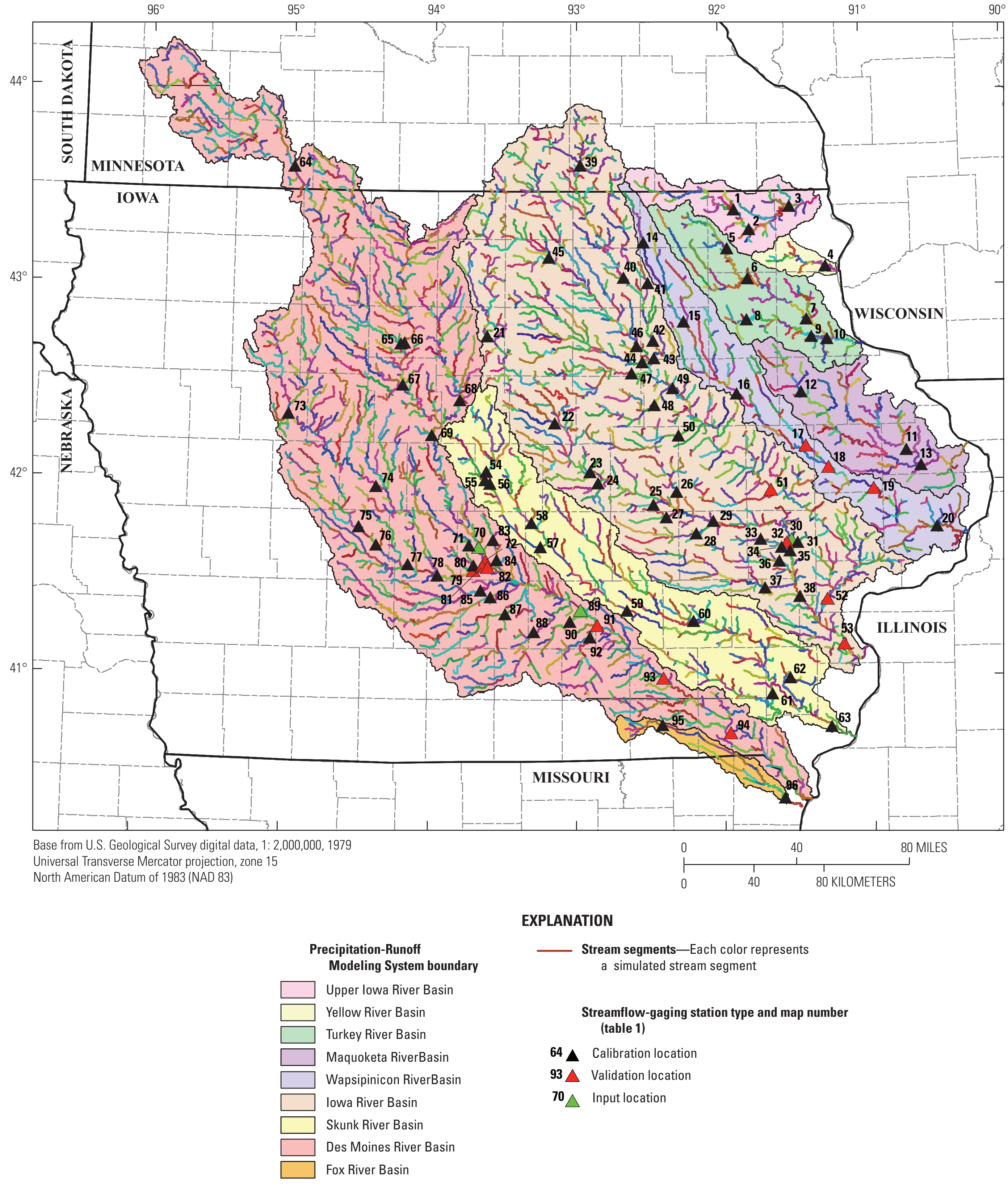
EXPLANATION

Iowa landform regions

- ▨ Des Moines Lobe
- ▨ East-Central Iowa Drift Plain
- ▨ Iowa-Cedar Lowland
- ▨ Iowan Surface
- ▨ Northwest Iowa Plains
- ▨ Paleozoic Plateau
- ▨ Southern Iowa Drift Plain

—— **Basin boundary**—Precipitation-Runoff Modeling System

Figure 1. Landform regions for Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.



Base from U.S. Geological Survey digital data, 1: 2,000,000, 1979
Universal Transverse Mercator projection, zone 15
North American Datum of 1983 (NAD 83)

Figure 2. Simulated stream segments and U.S. Geological Survey streamflow-gaging stations providing measured data for Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.

Table 1. U.S. Geological Survey streamflow-gaging stations used for input, calibrating, and validating the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.

[USGS, U.S. Geological Survey; latitude and longitude in decimal degrees; mi^2, square miles; IA, Iowa; Cr, creek; NE, Northeast; nr, near; MN, Minnesota; DS, downstream; MO, Missouri]

Map number (fig. 2)	USGS station number	USGS station name	Latitude (north)	Longitude (west)	Drainage area measured at gage (mi^2)	Period of record used
Upper Iowa River Basin						
1	05387440	Upper Iowa River at Bluffton, IA	43.4069	91.8990	367	10/01/2002–09/30/2012
2	05387500	Upper Iowa River at Decorah, IA	43.3049	91.7955	511	10/01/2002–09/30/2012
3	05388250	Upper Iowa River near Dorchester, IA	43.4211	91.5088	770	10/01/2002–09/30/2012
Yellow River Basin						
4	05389000	Yellow River near Ion, IA	43.1119	91.2651	221	10/01/2004–09/30/2012
Turkey River Basin						
5	05411600	Turkey River at Spillville, IA	43.2073	91.9503	177	05/01/2010–09/30/2012
6	05411850	Turkey River near Eldorado, IA	43.0542	91.8091	641	10/01/2002–09/30/2012
7	05412020	Turkey River above French Hollow Cr at Elkader, IA	42.8435	91.4013	903	10/01/2002–09/30/2012
8	05412340	Volga River at Fayette, IA	42.8441	91.8182	130	05/01/2010–09/30/2012
9	05412400	Volga River at Littleport, IA	42.7539	91.3690	348	10/01/2002–09/30/2012
10	05412500	Turkey River at Garber, IA	42.7400	91.2618	1,545	10/01/2002–09/30/2012
Maquoketa River Basin						
11	05416900	Maquoketa River at Manchester, IA	42.1643	90.7293	275	06/23/2003–09/30/2012
12	05418400	North Fork Maquoketa River near Fulton, IA	42.4700	91.4487	505	10/01/2002–09/30/2012
13	05418500	Maquoketa River near Maquoketa, IA	42.0834	90.6329	1,553	10/01/2002–09/30/2012
Wapsipinicon River Basin						
14	05420560	Wapsipinicon River near Elma, IA	43.2416	92.5331	95.2	10/01/1981–09/30/1992
15	05420680	Wapsipinicon River near Tripoli, IA	42.8361	92.2574	346	10/01/2006–09/30/2012
16	05421000	Wapsipinicon River at Independence, IA	42.4636	91.8952	1,048	10/01/2002–09/30/2012
17	05421682	Buffalo Creek South of Prairieburg, IA	42.1958	91.4228	189	04/09/2002–09/30/2012
18	05421740	Wapsipinicon River near Anamosa, IA	42.0833	91.2674	1,575	10/01/2002–09/30/2012
19	05421760	Wapsipinicon River at Oxford Mills, IA	41.9719	90.9600	1,792	04/13/2002–09/30/2012
20	05422000	Wapsipinicon River near De Witt, IA	41.7670	90.5349	2,336	10/01/2002–09/30/2012
Iowa River Basin						
21	05449500	Iowa River near Rowan, IA	42.7599	93.6218	429	10/01/2002–09/30/2012
22	05451210	South Fork Iowa River NE of New Providence, IA	42.3151	93.1521	224	10/01/2002–09/30/2012
23	05451500	Iowa River at Marshalltown, IA	42.0658	92.9077	1,532	10/01/2002–09/30/2012
24	05451700	Timber Creek near Marshalltown, IA	42.0089	92.8524	118	10/01/2002–09/30/2012
25	05451900	Richland Creek near Haven, IA	41.8994	92.4744	56.1	10/01/2002–09/30/2012
26	05452000	Salt Creek near Elberon, IA	41.9642	92.3132	201	10/01/2002–09/30/2012
27	05452200	Walnut Creek near Hartwick, IA	41.8350	92.3863	70.9	10/01/2002–09/30/2012
28	05453000	Big Bear Creek at Ladora, IA	41.7494	92.1821	189	10/01/2002–09/30/2012
29	05453100	Iowa River at Marengo, IA	41.8127	92.0648	2,794	10/01/2002–09/30/2012
30	05453520	Iowa River below Coralville Dam nr Coralville, IA[1]	41.7153	91.5302	3,115	10/01/2002–09/30/2012
31	05454000	Rapid Creek near Iowa City, IA	41.7000	91.4877	25.3	10/01/2002–09/30/2012
32	05454090	Muddy Creek at Coralville, IA	41.7000	91.5628	8.7	10/01/2002–09/30/2012

Table 1. U.S. Geological Survey streamflow-gaging stations used for input, calibrating, and validating the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[USGS, U.S. Geological Survey; latitude and longitude in decimal degrees; mi^2, square miles; IA, Iowa; Cr, creek; NE, Northeast; nr, near; MN, Minnesota; DS, downstream; MO, Missouri]

Map number (fig. 2)	USGS station number	USGS station name	Latitude (north)	Longitude (west)	Drainage area measured at gage (mi^2)	Period of record used
		Iowa River Basin—Continued				
33	05454220	Clear Creek near Oxford, IA	41.7183	91.7402	58.4	10/01/2002–09/30/2012
34	05454300	Clear Creek near Coralville, IA	41.6767	91.5988	98.1	10/01/2002–09/30/2012
35	05454500	Iowa River at Iowa City, IA	41.6567	91.5410	3,271	10/01/2002–09/30/2012
36	05455100	Old Mans Creek near Iowa City, IA	41.6064	91.6157	201	10/01/2002–09/30/2012
37	05455500	English River at Kalona, IA	41.4697	91.7146	574	10/01/2002–09/30/2012
38	05455700	Iowa River near Lone Tree, IA	41.4238	91.4785	4,293	10/01/2002–09/30/2012
39	05457000	Cedar River near Austin, MN	43.6372	92.9746	399	10/01/2002–09/30/2012
40	05457700	Cedar River at Charles City, IA	43.0622	92.6739	1,054	10/01/2002–09/30/2012
41	05458000	Little Cedar River near Ionia, IA	43.0333	92.5035	306	10/01/2002–09/30/2012
42	05458300	Cedar River at Waverly, IA	42.7372	92.4701	1,547	10/01/2002–09/30/2012
43	05458500	Cedar River at Janesville, IA	42.6483	92.4652	1,661	10/01/2002–09/30/2012
44	05458900	West Fork Cedar River at Finchford, IA	42.6294	92.5435	846	10/01/2002–09/30/2012
45	05459500	Winnebago River at Mason City, IA	43.1650	93.1927	526	10/01/2002–09/30/2012
46	05462000	Shell Rock River at Shell Rock, IA	42.7119	92.5830	1,746	10/01/2002–09/30/2012
47	05463000	Beaver Creek at New Hartford, IA	42.5720	92.6183	347	10/01/2002–09/30/2012
48	05463500	Black Hawk Creek at Hudson, IA	42.4078	92.4632	303	10/01/2002–09/30/2012
49	05464000	Cedar River at Waterloo, IA	42.4955	92.3344	5,146	10/01/2002–09/30/2012
50	05464220	Wolf Creek near Dysart, IA	42.2515	92.2989	299	10/01/2002–09/30/2012
51	05464500	Cedar River at Cedar Rapids, IA	41.9719	91.6671	6,510	10/01/2002–09/30/2012
52	05465000	Cedar River near Conesville, IA	41.4092	91.2904	7,787	10/01/2002–09/30/2012
53	05465500	Iowa River at Wapello, IA	41.1781	91.1821	12,500	10/01/2002–09/30/2012
		Skunk River Basin				
54	05470000	South Skunk River near Ames, IA	42.0665	93.6201	315	10/01/2002–09/30/2012
55	05470500	Squaw Creek at Ames, IA	42.0230	93.6305	204	10/01/2002–09/30/2012
56	05471000	South Skunk River below Squaw Creek near Ames, IA	42.0067	93.5955	556	10/01/2002–09/30/2012
57	05471050	South Skunk River at Colfax, IA	41.6814	93.2466	803	10/01/2002–09/30/2012
58	05471200	Indian Creek near Mingo, IA	41.8053	93.3094	276	10/01/2002–09/30/2012
59	05471500	South Skunk River near Oskaloosa, IA	41.3557	92.6574	1,635	10/01/2002–09/30/2012
60	05472500	North Skunk River near Sigourney, IA	41.3008	92.2046	730	10/01/2002–09/30/2012
61	05473400	Cedar Creek near Oakland Mills, IA	40.9253	91.6742	530	10/01/2002–09/30/2012
62	05473450	Big Creek North of Mount Pleasant, IA	41.0070	91.5516	58	10/01/2002–09/30/2012
63	05474000	Skunk River at Augusta, IA	40.7537	91.2771	4,312	10/01/2002–09/30/2012
		Des Moines River Basin				
64	05476000	Des Moines River at Jackson, MN	43.6183	94.9850	1,250	10/01/2002–09/30/2012
65	05476750	Des Moines River at Humboldt, IA	42.7194	94.2205	2,256	10/01/2002–09/30/2012
66	05479000	East Fork Des Moines River at Dakota City, IA	42.7236	94.1935	1,308	10/01/2002–09/30/2012
67	05480500	Des Moines River at Fort Dodge, IA	42.5083	94.2036	4,190	10/01/2002–09/30/2012

Table 1. U.S. Geological Survey streamflow-gaging stations used for input, calibrating, and validating the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[USGS, U.S. Geological Survey; latitude and longitude in decimal degrees; mi^2, square miles; IA, Iowa; Cr, creek; NE, Northeast; nr, near; MN, Minnesota; DS, downstream; MO, Missouri]

Map number (fig. 2)	USGS station number	USGS station name	Latitude (north)	Longitude (west)	Drainage area measured at gage (mi^2)	Period of record used
		Des Moines River Basin—Continued				
68	05481000	Boone River near Webster City, IA	42.4325	93.8058	844	10/01/2002–09/30/2012
69	05481300	Des Moines River near Stratford, IA	42.2519	93.9969	5,452	10/01/2002–09/30/2012
70	05481650	Des Moines River near Saylorville, IA[1]	41.6805	93.6683	5,841	10/01/2002–09/30/2012
71	05481950	Beaver Creek near Grimes, IA	41.6883	93.7355	358	10/01/2002–09/30/2012
72	05482000	Des Moines River at 2nd Avenue at Des Moines, IA	41.6125	93.6210	6,245	10/01/2002–09/30/2012
73	05482300	North Raccoon River near Sac City, IA	42.3548	94.9903	700	10/01/2002–09/30/2012
74	05482500	North Raccoon River near Jefferson, IA	41.9880	94.3769	1,619	10/01/2002–09/30/2012
75	05483450	Middle Raccoon River near Bayard, IA	41.7791	94.4929	375	10/01/2002–09/30/2012
76	05483600	Middle Raccoon River at Panora, IA	41.6872	94.3711	440	10/01/2002–09/30/2012
77	05484000	South Raccoon River at Redfield, IA	41.5894	94.1513	994	10/01/2002–09/30/2012
78	05484500	Raccoon River at Van Meter, IA	41.5339	93.9500	3,441	10/01/2002–09/30/2012
79	05484650	Raccoon River at 63rd Street at Des Moines, IA	41.5617	93.7036	3,529	10/01/2002–09/30/2012
80	05484800	Walnut Creek at Des Moines, IA	41.5872	93.7033	78.4	10/01/2002–09/30/2012
81	05484900	Raccoon River at Fleur Drive at Des Moines, IA	41.5817	93.6430	3,625	10/01/2002–09/30/2012
82	05485500	Des Moines River below Raccoon River at Des Moines, IA	41.5778	93.6055	9,879	10/01/2002–09/30/2012
83	05485605	Fourmile Creek near Ankeny, IA DS1	41.7174	93.5701	62.0	10/01/2003–09/30/2012
84	05485640	Fourmile Creek at Des Moines, IA	41.6139	93.5455	92.7	10/01/2002–09/30/2012
85	05486000	North River near Norwalk, IA	41.4579	93.6550	349	10/01/2002–09/30/2012
86	05486490	Middle River near Indianola, IA	41.4242	93.5874	489.4	10/01/2002–09/30/2012
87	05487470	South River near Ackworth, IA	41.3372	93.4863	460	10/01/2002–09/30/2012
88	05487980	White Breast Creek near Dallas, IA	41.2466	93.2902	333	10/01/2002–09/30/2012
89	05488110	Des Moines River near Pella, IA[1]	41.3606	92.9733	12,330	10/01/2002–09/30/2012
90	05488200	English Creek near Knoxville, IA	41.3006	93.0455	90.1	10/01/2002–09/30/2012
91	05488500	Des Moines River near Tracy, IA	41.2814	92.8615	12,479	10/01/2002–09/30/2012
92	05489000	Cedar Creek near Bussey, IA	41.2190	92.9085	374	10/01/2002–09/30/2012
93	05489500	Des Moines River at Ottumwa, IA	41.0108	92.4113	13,374	10/01/2002–09/30/2012
94	05490500	Des Moines River at Keosauqua, IA	40.7278	91.9596	14,038	10/01/2002–09/30/2012
		Fox River Basin				
95	05494300	Fox River at Bloomfield, IA	40.7695	92.4188	87.7	10/01/2002–09/30/2012
96	05495000	Fox River at Wayland, MO	40.3924	91.5979	400	10/01/2002–09/30/2012

[1] Sites used for historical streamflows.

The Skunk River Basin drains about 4,355 mi^2 southeast into the Mississippi River and extends from Hamilton County, central Iowa, to Des Moines and Lee Counties, southeast Iowa (figs. 1 and 2). Most of the Skunk River Basin is in the Southern Iowa Drift Plain, but the most northern part is within the Des Moines Lobe (fig. 1). The largest metropolitan areas in the Skunk River Basin are Ames and Newton, Iowa. A total of 10 USGS streamflow-gaging stations in the Skunk River Basin were used in this study (table 1; fig. 2).

The Des Moines River Basin drains about 14,470 mi^2 and extends from its headwaters in southwest Minnesota to its outlet near Keokuk, southeast Iowa (fig. 1). The Raccoon River drains about 3,625 mi^2 and is the largest tributary to the Des Moines River. The Des Moines River Basin lies within the Des Moines Lobe in the northern part, and the Southern Iowa Drift Plain in the remainder of the basin (fig. 1). The Des Moines metropolitan area, Fort Dodge, and Ottumwa, Iowa, are the largest urban centers within the Des Moines River Basin. A total of 31 USGS streamflow-gaging stations in the Des Moines River Basin were used in this study (table 1; fig. 2).

The Fox River Basin drains about 405 mi^2 of southeast Iowa and northeast Missouri to the Mississippi River. The Fox River Basin lies within the Southern Iowa Drift Plain (fig. 1). The Fox River Basin is mainly agricultural land with little urban development. Two USGS streamflow-gaging stations in the Fox River Basin were used in this study (table 1; fig. 2).

Model Development

The PRMS is a deterministic, distributed-parameter, physical-process-based modeling system developed to evaluate the response of streamflow and general basin hydrology to various combinations of climate and land use (Markstrom and others, 2015). The PRMS simulates the hydrologic system with known physical laws and empirical relations derived from basin characteristics (Markstrom and others, 2008). The PRMS is designed to account for spatially distributed parameters and basin characteristics. A schematic diagram of how basin and climate inputs are simulated in a typical PRMS model is shown in figure 3.

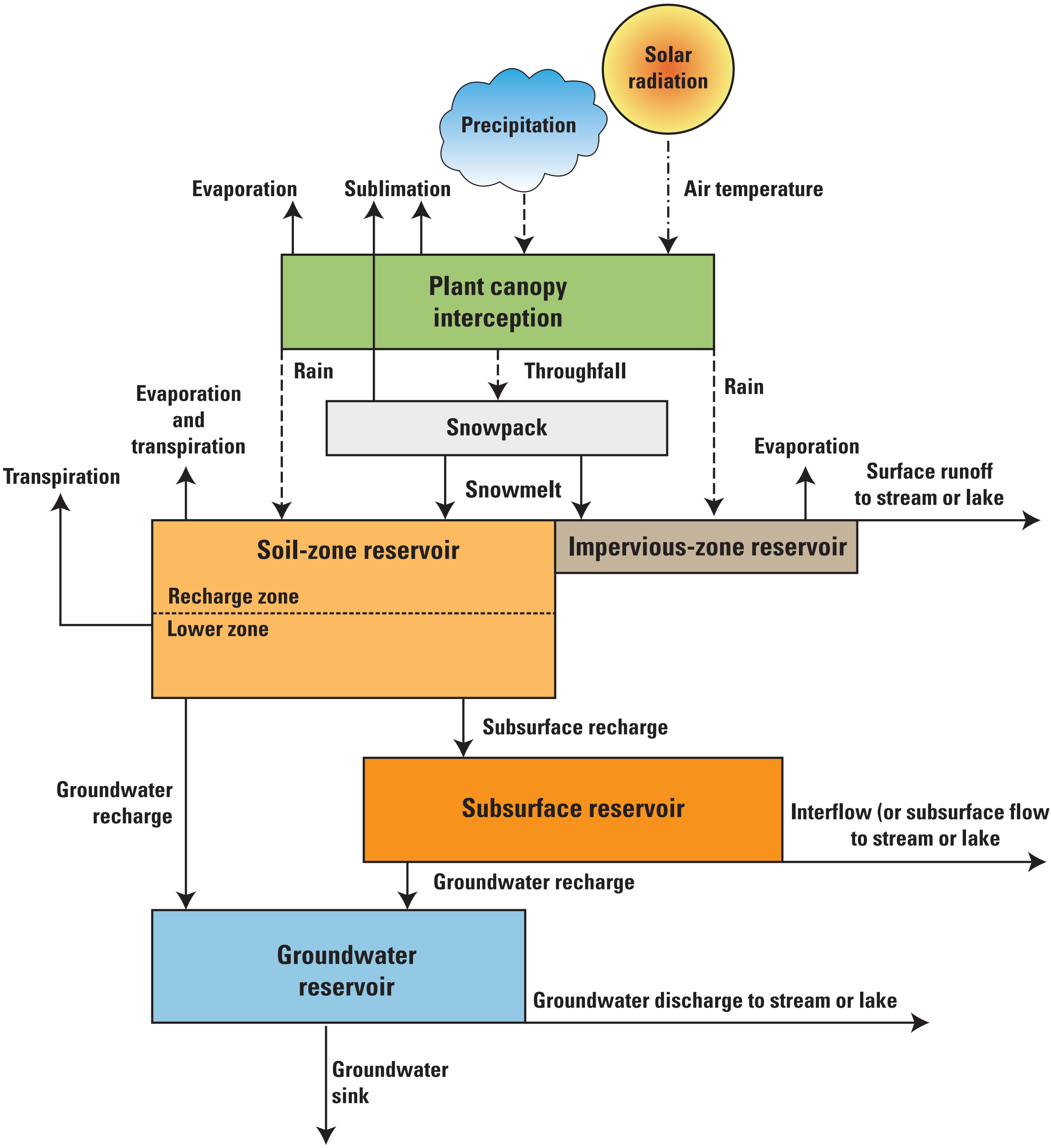
In PRMS, a basin is divided into a series of contiguous spatial units called hydrologic response units (HRUs) based on hydrologic and physical characteristics such as land surface altitude, slope, aspect, plant type and cover, land use, soil morphology, geology, drainage boundaries, distribution of precipitation, temperature, solar radiation, and flow direction (Markstrom and others, 2008). The HRUs receive and produce streamflow to and from each other, and to the drainage network consisting of stream segments (Goode and others, 2010). Individual HRUs are considered homogenous with respect to hydrologic and physical characteristics, and storage components are instantaneously and fully mixed. Energy and water balance are computed by PRMS daily for each HRU (Markstrom and others, 2008).

The PRMS models of nine river basins in eastern Iowa were constructed in several steps, which included the compilation of necessary datasets, the delineation of HRU boundaries to accommodate the stream network and provide streamflows at specific locations for calibration and validation, and the parameterization of model HRUs and stream segments. This section describes the procedures used to prepare input datasets, basin discretization, and parameterization for the PRMS models of nine river basins in eastern Iowa.

Delineation and Parameterization of Spatial Features

For this study, a geospatial database was created for use within a geographic information system (GIS) to support model discretization, characterize the physical features of the basins, and estimate PRMS model parameters. The geospatial database consisted of the National Land Cover Database, Percent Impervious, U.S. Forest types, U.S. Forest Density, State Soil Geographic Database (STATSGO) general soil maps, and a digital elevation model (DEM) derived from the USGS National Elevation Dataset (NED) (U.S. Geological Survey, 2007; Homer and others, 2007; U.S. Department of Agriculture, 1994).

The GIS Weasel (Viger and Leavesley, 2007) was used to delineate, characterize the physical features of, and estimate initial parameter values for input into PRMS models of nine river basins in eastern Iowa. The DEMs were processed by the GIS Weasel, which created raster datasets of flow direction and flow accumulation. A drainage network was extracted from this surface by finding all points at which the flow accumulation is equal to or greater than a user-specified threshold (Viger and Leavesley, 2007). Each drainage network was segmented at stream tributaries from headwater to the confluence with the Mississippi River. An interactive process in the GIS Weasel was used to discretize the HRUs based on the drainage network dataset and location of USGS streamflow-gaging stations (Viger and Leavesley, 2007). Two-plane HRUs are developed to separate contributing areas from left and right banks of each stream segment. The Upper Iowa River Basin model discretization consists of 66 stream segments and 132 HRUs; the Yellow River Basin model discretization consists of 17 stream segments and 34 HRUs; the Turkey River Basin model discretization consists of 91 stream segments and 186 HRUs; the Maquoketa River Basin model discretization consists of 98 stream segments and 195 HRUs; the Wapsipinicon River Basin model discretization consists of 133 stream segments and 265 HRUs; the Iowa River Basin model discretization consists of 1,174 stream segments and 2,340 HRUs; the Skunk River Basin model discretization consists of 275 stream segments and 550 HRUs; the Des Moines River Basin model discretization consists of 1,308 stream segments and



Modified from Markstrom and others, 2008

Figure 3. Schematic diagram of a basin and its meteorological inputs (precipitation, air temperature, and solar radiation) simulated by the Precipitation-Runoff Modeling System.

2,627 HRUs; and the Fox River Basin model discretization consists of 20 stream segments and 40 HRUs (figs. 2 and 4).

Model Input and Measured Data

The PRMS can use many meteorological inputs. Precipitation, minimum temperature, and maximum temperature were used in the PRMS models of nine river basins in eastern Iowa as the main climatic drivers. In addition to meteorological inputs, PRMS also can use streamflow-gaging station data in place of simulated streamflow. This is especilly useful where flows are heavily affected by upstream regulation. The Iowa River and Des Moines River Basin models used streamflow-gaging station data as input at USGS streamflow-gaging stations 05453520, 05481650, and 05488110 to accurately account for outflows from upstream reservoirs during simulations (table 1; fig. 2).

The USGS streamflow-gaging station data and meteorological datasets for precipitation and temperature were prepared using the USGS Downsizer program (Ward-Garrison and others, 2009). The Downsizer program is a computer application that selects, downloads, verifies, and formats station-based time-series data for PRMS and other environmental modeling programs. The quality-control dialog in Downsizer was used to select National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations that had data from January 1, 1980, through September 30, 2012 (National Oceanic and Atmospheric Administration, 2014). Meteorological stations that had large amounts of missing or bad data values were removed from the PRMS input data list, and stations with period of record from October 1, 2002, through September 30, 2012 were retained. The Downsizer software program also was used to retrieve USGS streamflow-gaging station daily mean streamflow observations at gaged sites in the model areas from October 1, 1980, through September 30, 2012. Gaged sites were selected based on being in current operation, having a minimum period of record of 5 years, and having a period of record from October 1, 2002, through September 30, 2012, with a few exceptions (table 1). The 96 USGS streamflow-gaging stations and 155 meteorological stations included in the PRMS model data files of nine river basins in eastern Iowa are listed in tables 1–2 and shown in figures 2 and 4.

Model Calibration, Validation, and Evaluation

Calibration and validation periods used in each basin mostly were October 1, 2002, through September 30, 2012. The calibration or validation period differed depending on the period of record available for daily mean streamflow measurements at U.S. Geological Survey streamflow-gaging stations (table 1).

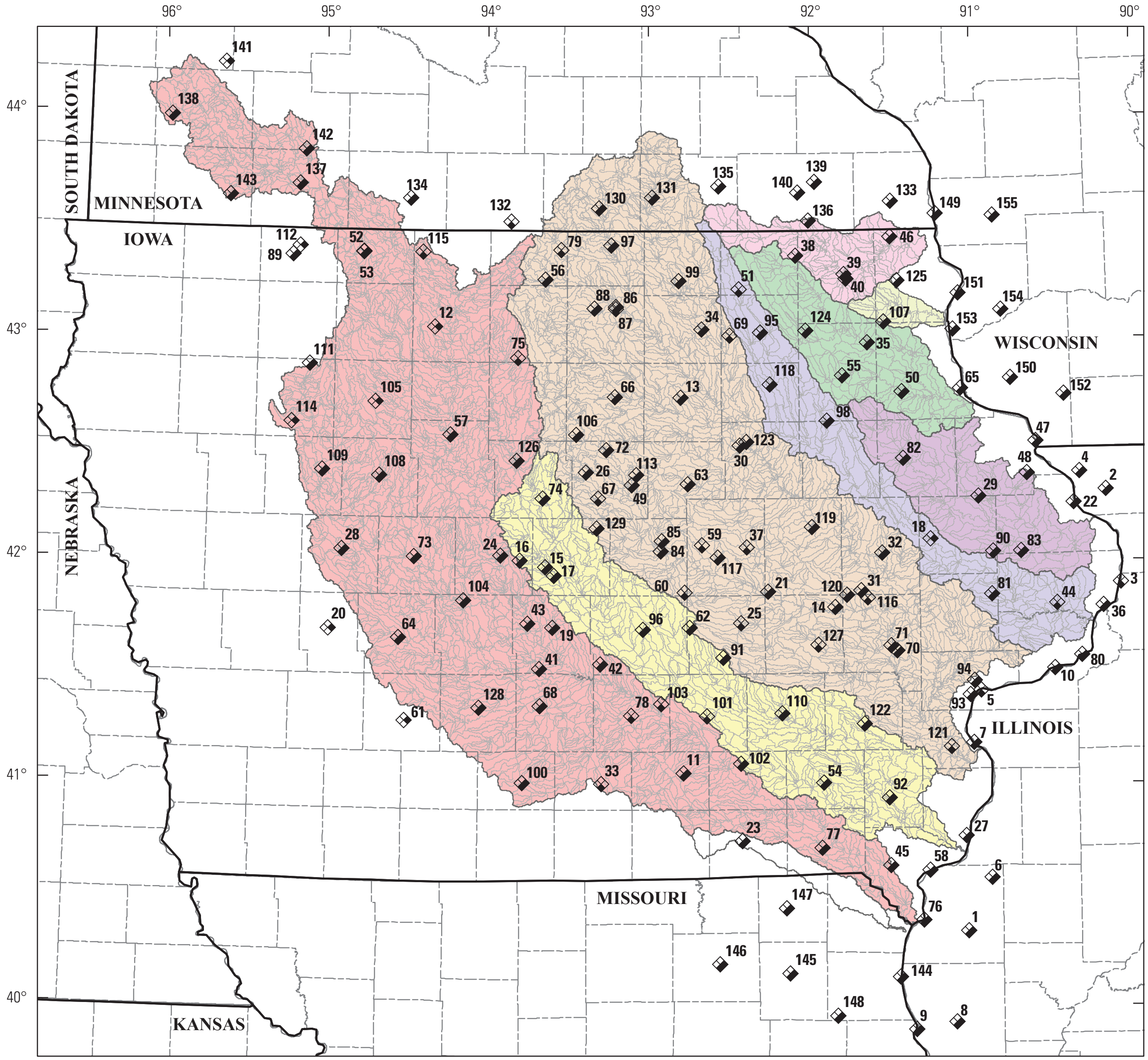
The PRMS model was calibrated using the Luca computer program (Hay and Umemoto, 2006). Luca is a graphical user interface that provides a simple, systematic way of implementing a multiple-objective, stepwise calibration of the PRMS model parameters. Luca uses the Shuffled Complex Evolution (SCE) (Duan and others, 1993) global search algorithm to calibrate model parameters. Luca has been used by researchers to calibrate many PRMS models (Hay and Umemoto 2006; Dudley, 2008; Goode and others, 2010; Christiansen, 2012; LaFontaine and others, 2013; Haj and others, 2014).

In this study, Luca was used to complete a multiple-objective, stepwise calibration of the PRMS models of nine river basins in eastern Iowa. A total of 79 USGS streamflow-gaging stations throughout the nine river basins in eastern Iowa were used for calibration with emphasis on matching model simulated daily streamflow with measured daily streamflow (fig. 2; table 3). The Luca calibration includes three objective functions—low, high, and mean flows—in an effort to accurately represent all flow regimes. A basin-wide, six-step calibration of climate and streamflow related parameters (table 4) was initially completed, and additional calibration of subbasin streamflow parameters (table 4) was completed at selected gaged sites (table 3) to increase the parameter resolution and accuracy. Of the remaining 17 gaged sites (tables 1 and 3), data from 3 were used for input to account for outflows from reservoirs (as discussed in "Model Input and Measured Data"), and data from 14 were used for model validation to demonstrate potential accuracy of model estimated daily streamflows at ungaged sites.

Statistical tests were used to evaluate how well each PRMS model of the nine river basins in eastern Iowa estimated daily streamflow. The Nash Sutcliffe efficiency (NSE), coefficient of determination (R^2), percent bias (PBIAS), and root mean square error-observation standard deviation ratio (RSR) statistics (Moriasi and others, 2007; Singh and others, 2004; Nash and Sutcliffe, 1970) were used to evaluate model performance. The NSE is a normalized statistic that provides a measure of how well simulated values match measured datasets. The NSE values range from $-\infty$ to 1. Values of 0 or less indicate that the mean measured streamflow is a better predictor than simulated streamflows. A value of 0.0 indicates the simulated streamflow is as good as using the average value of all the measured data, and a value of 1 indicates a perfect fit between measured and simulated values. Moriasi and others (2007) suggest that a monthly NSE of greater than 0.50 is satisfactory in basin models such as PRMS. Although daily values may be lower than 0.50 and still hold a satisfactory rating, an NSE value of greater than 0.50 is considered satisfactory.

The R^2 evaluates how accurately the model tracks the variability in the measured data that is explained by the simulated data. The R^2 can reveal the strength of the linear relationship between the predicted and the measured values. It can range from 0 and 1, and the closer the value is to 1 the better the linear correlation between simulated and measured values (Kalin and Hantush, 2006). Values above 0.5 are considered to be satisfactory (Gassman and others, 2007).

The PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed



Base from U.S. Geological Survey digital data, 1: 2,000,000, 1979
Universal Transverse Mercator projection, zone 15
North American Datum of 1983 (NAD 83)

0 40 80 MILES
0 40 80 KILOMETERS

EXPLANATION

Hydrologic response units used in the Precipitation-Runoff Modeling System

- 🟪 Upper Iowa River Basin
- 🟨 Yellow River Basin
- 🟩 Turkey River Basin
- 🟪 Maquoketa River Basin
- 🟪 Wapsipinicon River Basin
- 🟫 Iowa River Basin
- 🟨 Skunk River Basin
- 🟥 Des Moines River Basin
- 🟧 Fox River Basin

Meteorological stations and map number (table 3)

- 21 ◇ Precipitation
- 14 ◇ Temperature
- 2 ◆ Precipitation and temperature

Figure 4. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations and hydrologic response units used in the Precipitation-Runoff Modeling System models or nine river basins in eastern Iowa.

Table 2. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.

[Latitude and longitude in decimal degrees; IL, Illinois; NNE, north, northeast; IA, Iowa; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; Wsfo, weather service forecast office; N, north; ft, fort; Mt, Mount; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; MN, Minnesota; MO, Missouri; WI, Wisconsin]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation	Period of record used
1	110598	Bentley, IL	40.3444	91.1125	650.00	10/01/2001–09/30/2012
2	112745	Elizabeth, IL	42.3161	90.2269	675.00	10/01/2001–09/30/2012
3	113290	Fulton Dam, IL	41.8978	90.1544	592.00	10/01/2001–09/30/2012
4	113312	Galena, IL	42.3994	90.3861	753.00	10/01/2001–09/30/2012
5	114355	Illinois City Dam 16, IL	41.4256	91.0094	550.00	10/01/2001–09/30/2012
6	114823	La Harpe, IL	40.5839	90.9686	690.00	10/01/2001–09/30/2012
7	116080	New Boston Dam 17, IL	41.1925	91.0578	548.00	10/01/2001–09/30/2012
8	117072	Quincy Regional Airport, IL	39.9369	91.1919	769.00	10/01/2001–09/30/2012
9	117077	Quincy Dam 21, IL	39.9058	91.4281	483.00	10/01/2001–09/30/2012
10	117388	Rock Island Lock and Dam 15, IL	41.5181	90.5647	568.00	10/01/2001–09/30/2012
11	130112	Albia 3 NNE, IA	41.0656	92.7867	880.00	10/01/2001–09/30/2012
12	130133	Algona 3 W, IA	43.0683	94.3053	1,239.00	10/01/2001–09/30/2012
13	130157	Allison, IA	42.7536	92.8022	1,048.00	10/01/2001–09/30/2012
14	130193	Amana, IA	41.8083	91.8750	730.00	10/01/2001–09/30/2012
15	130197	Ames Municipal Airport, IA	41.9906	93.6189	955.00	10/01/2001–09/30/2012
16	130200	Ames 8 WSW, IA	42.0208	93.7742	1,099.00	10/01/2001–09/30/2012
17	130203	Ames 5 SE, IA	41.9519	93.5656	870.00	10/01/2001–09/30/2012
18	130213	Anamosa 1 WNW, IA	42.1117	91.2933	805.00	10/01/2001–09/30/2012
19	130241	Ankeny, IA	41.7183	93.5742	940.00	10/01/2001–09/30/2012
20	130385	Audubon, IA	41.7069	94.9222	1,280.00	10/01/2001–09/30/2012
21	130600	Belle Plaine, IA	41.8814	92.2764	810.00	10/01/2001–09/30/2012
22	130608	Bellevue Lock and Dam 12, IA	42.2611	90.4231	603.00	10/01/2001–09/30/2012
23	130753	Bloomfield 1 WNW, IA	40.7597	92.4394	812.00	10/01/2001–09/30/2012
24	130807	Boone, IA	42.0417	93.8906	1,051.00	10/01/2001–09/30/2012
25	130933	Brooklyn, IA	41.7394	92.4400	910.00	10/01/2001–09/30/2012
26	130999	Buckeye, IA	42.4172	93.3775	1,150.00	10/01/2001–09/30/2012
27	131060	Burlington 2 S, IA	40.7747	91.1164	690.00	10/01/2001–09/30/2012
28	131233	Carroll, IA	42.0650	94.8500	1,240.00	10/01/2001–09/30/2012
29	131257	Cascade, IA	42.2989	90.9983	870.00	10/01/2001–09/30/2012
30	131300	Cedar Falls, IA	42.5378	92.4431	763.00	10/01/2001–09/30/2012
31	131314	Cedar Rapids Municipal Airport, IA	41.8833	91.7167	868.00	10/01/2001–09/30/2012
32	131319	Cedar Rapids 1, IA	42.0500	91.5881	810.00	10/01/2001–09/30/2012
33	131394	Chariton 1 E, IA	41.0164	93.2792	940.00	10/01/2001–09/30/2012
34	131402	Charles City, IA	43.0603	92.6717	993.00	10/01/2001–09/30/2012
35	131610	Clermont, IA	42.9975	91.6583	840.00	10/01/2001–09/30/2012
36	131635	Clinton 1, IA	41.7947	90.2639	585.00	10/01/2001–09/30/2012
37	131704	Clutier, IA	42.0800	92.4050	900.00	10/01/2001–09/30/2012
38	131954	Cresco 1 NE, IA	43.3894	92.0939	1,255.00	10/01/2001–09/30/2012
39	132110	Decorah, IA	43.3042	91.7953	860.00	10/01/2001–09/30/2012

Table 2. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[Latitude and longitude in decimal degrees; IL, Illinois; NNE, north, northeast; IA, Iowa; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; Wsfo, weather service forecast office; N, north; ft, fort; Mt, Mount; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; MN, Minnesota; MO, Missouri; WI, Wisconsin]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation	Period of record used
40	132112	Decorah 2 S, IA	43.2833	91.7833	879.00	10/01/2001–09/30/2012
41	132203	Des Moines International Airport, IA	41.5339	93.6531	957.00	10/01/2001–09/30/2012
42	132205	Des Moines 17 E, IA	41.5561	93.2856	921.00	10/01/2001–09/30/2012
43	132209	Des Moines Wsfo Johnston, IA	41.7367	93.7236	959.00	10/01/2001–09/30/2012
44	132235	De Witt, IA	41.8108	90.5406	685.00	10/01/2001–09/30/2012
45	132299	Donnellson, IA	40.6458	91.5639	705.00	10/01/2001–09/30/2012
46	132311	Dorchester, IA	43.4706	91.5108	758.00	10/01/2001–09/30/2012
47	132364	Dubuque Lock and Dam 11, IA	42.5400	90.6461	620.00	10/01/2001–09/30/2012
48	132367	Dubuque Regional Airport, IA	42.3978	90.7036	1,056.00	10/01/2001–09/30/2012
49	132573	Eldora, IA	42.3619	93.0989	1,144.00	10/01/2001–09/30/2012
50	132603	Elkader, IA	42.7753	91.4536	788.00	10/01/2001–09/30/2012
51	132638	Elma, IA	43.2419	92.4433	1,172.00	10/01/2001–09/30/2012
52	132724	Estherville 2 N, IA	43.4036	94.7472	1,320.00	10/01/2001–09/30/2012
53	132725	Estherville Municipal Airport, IA	43.4011	94.7472	1,317.00	10/01/2001–09/30/2012
54	132789	Fairfield, IA	41.0211	91.9553	740.00	10/01/2001–09/30/2012
55	132864	Fayette, IA	42.8503	91.8158	1,130.00	10/01/2001–09/30/2012
56	132977	Forest City 2 NNE, IA	43.2844	93.6306	1,300.00	10/01/2001–09/30/2012
57	132999	Ft Dodge 5 NNW, IA	42.5836	94.2006	1,140.00	10/01/2001–09/30/2012
58	133007	Ft Madison, IA	40.6222	91.3339	530.00	10/01/2001–09/30/2012
59	133120	Garwin, IA	42.0900	92.6756	912.00	10/01/2001–09/30/2012
60	133239	Gilman, IA	41.8781	92.7786	1,040.00	10/01/2001–09/30/2012
61	133438	Greenfield, IA	41.2981	94.4561	1,340.00	10/01/2001–09/30/2012
62	133473	Grinnell 3 SW, IA	41.7203	92.7489	905.00	10/01/2001–09/30/2012
63	133487	Grundy Center, IA	42.3647	92.7594	1,045.00	10/01/2001–09/30/2012
64	133509	Guthrie Center, IA	41.6686	94.4972	1,075.00	10/01/2001–09/30/2012
65	133517	Guttenberg Lock and Dam 10, IA	42.7858	91.0958	618.00	10/01/2001–09/30/2012
66	133584	Hampton, IA	42.7561	93.2011	1,230.00	10/01/2001–09/30/2012
67	133960	Hubbard, IA	42.3008	93.3008	1,089.00	10/01/2001–09/30/2012
68	134063	Indianola, IA	41.3656	93.6481	942.00	10/01/2001–09/30/2012
69	134094	Ionia 2 W, IA	43.0336	92.5017	1,019.00	10/01/2001–09/30/2012
70	134101	Iowa City, IA	41.6092	91.5050	640.00	10/01/2001–09/30/2012
71	134106	Iowa City Municipal Airport, IA	41.6328	91.5431	650.00	10/01/2001–09/30/2012
72	134142	Iowa Falls, IA	42.5189	93.2536	1,130.00	10/01/2001–09/30/2012
73	134228	Jefferson, IA	42.0347	94.4114	1,055.00	10/01/2001–09/30/2012
74	134244	Jewell, IA	42.3008	93.6389	1,060.00	10/01/2001–09/30/2012
75	134308	Kanawha, IA	42.9311	93.7933	1,185.00	10/01/2001–09/30/2012
76	134381	Keokuk Lock and Dam 19, IA	40.3967	91.3750	527.00	10/01/2001–09/30/2012
77	134389	Keosauqua, IA	40.7275	91.9683	592.00	10/01/2001–09/30/2012
78	134502	Knoxville, IA	41.3247	93.1008	915.00	10/01/2001–09/30/2012

Table 2. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[Latitude and longitude in decimal degrees; IL, Illinois; NNE, north, northeast; IA, Iowa; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; Wsfo, weather service forecast office; N, north; ft, fort; Mt, Mount; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; MN, Minnesota; MO, Missouri; WI, Wisconsin]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation	Period of record used
79	134557	Lake Mills, IA	43.4178	93.5347	1,260.00	10/01/2001–09/30/2012
80	134705	Le Claire Lock and Dam 14, IA	41.5747	90.4006	577.00	10/01/2001–09/30/2012
81	134963	Lowden, IA	41.8564	90.9300	715.00	10/01/2001–09/30/2012
82	135086	Manchester 2, IA	42.4733	91.4517	990.00	10/01/2001–09/30/2012
83	135131	Maquoketa, IA	42.0494	90.7489	762.00	10/01/2001–09/30/2012
84	135198	Marshalltown, IA	42.0647	92.9244	870.00	10/01/2001–09/30/2012
85	135199	Marshalltown Municipal Airport, IA	42.1106	92.9161	974.00	10/01/2001–09/30/2012
86	135230	Mason City, IA	43.1631	93.1953	1,105.00	10/01/2001–09/30/2012
87	135232	Mason City 1, IA	43.1533	93.1981	1,097.00	10/01/2001–09/30/2012
88	135235	Mason City Municipal Airport, IA	43.1544	93.3269	1,225.00	10/01/2001–09/30/2012
89	135493	Milford 4 NW, IA	43.3828	95.1842	1,402.00	10/01/2001–09/30/2012
90	135622	Monmouth 4 SW, IA	42.0500	90.9167	869.00	10/01/2001–09/30/2012
91	135650	Montezuma 1 W, IA	41.5836	92.5497	965.00	10/01/2001–09/30/2012
92	135796	Mt Pleasant 1 SSW, IA	40.9486	91.5647	730.00	10/01/2001–09/30/2012
93	135837	Muscatine, IA	41.4075	91.0728	549.00	10/01/2001–09/30/2012
94	135844	Muscatine 2 N, IA	41.4714	91.0464	680.00	10/01/2001–09/30/2012
95	135952	New Hampton, IA	43.0453	92.3122	1,148.00	10/01/2001–09/30/2012
96	135992	Newton, IA	41.7117	93.0297	960.00	10/01/2001–09/30/2012
97	136103	Northwood, IA	43.4386	93.2253	1,190.00	10/01/2001–09/30/2012
98	136200	Oelwein 2 S, IA	42.6467	91.9131	1,010.00	10/01/2001–09/30/2012
99	136305	Osage, IA	43.2794	92.8106	1,170.00	10/01/2001–09/30/2012
100	136316	Osceola, IA	41.0194	93.7503	1,028.00	10/01/2001–09/30/2012
101	136327	Oskaloosa, IA	41.3214	92.6467	830.00	10/01/2001–09/30/2012
102	136389	Ottumwa Industrial Airport, IA	41.1078	92.4467	842.00	10/01/2001–09/30/2012
103	136527	Pella 1 S, IA	41.3761	92.9203	780.00	10/01/2001–09/30/2012
104	136566	Perry, IA	41.8394	94.1106	965.00	10/01/2001–09/30/2012
105	136719	Pocahontas, IA	42.7292	94.6614	1,212.00	10/01/2001–09/30/2012
106	136755	Popejoy 1S, IA	42.5864	93.4364	1,175.00	10/01/2001–09/30/2012
107	136766	Postville, IA	43.0900	91.5581	1,165.00	10/01/2001–09/30/2012
108	137161	Rockwell City, IA	42.3969	94.6292	1,195.00	10/01/2001–09/30/2012
109	137312	Sac City, IA	42.4194	94.9761	1,210.00	10/01/2001–09/30/2012
110	137678	Sigourney, IA	41.3328	92.1975	800.00	10/01/2001–09/30/2012
111	137726	Sioux Rapids 4 E, IA	42.8931	95.0653	1,420.00	10/01/2001–09/30/2012
112	137859	Spirit Lake, IA	43.4231	95.1394	1,420.00	10/01/2001–09/30/2012
113	137932	Steamboat Rock, IA	42.4069	93.0697	980.00	10/01/2001–09/30/2012
114	137979	Storm Lake 2 E, IA	42.6347	95.1694	1,425.00	10/01/2001–09/30/2012
115	138026	Swea City, IA	43.4022	94.3831	1,239.00	10/01/2001–09/30/2012
116	138062	Swisher, IA	41.8497	91.6764	790.00	10/01/2001–09/30/2012
117	138296	Toledo 3 N, IA	42.0356	92.5806	949.00	10/01/2001–09/30/2012

Table 2. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[Latitude and longitude in decimal degrees; IL, Illinois; NNE, north, northeast; IA, Iowa; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; Wsfo, weather service forecast office; N, north; ft, fort; Mt, Mount; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; MN, Minnesota; MO, Missouri; WI, Wisconsin]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation	Period of record used
118	138339	Tripoli, IA	42.8125	92.2575	960.00	10/01/2001–09/30/2012
119	138568	Vinton, IA	42.1703	92.0078	850.00	10/01/2001–09/30/2012
120	138632	Walford 2 SE, IA	41.8625	91.8025	790.00	10/01/2001–09/30/2012
121	138668	Wapello, IA	41.1761	91.1922	590.00	10/01/2001–09/30/2012
122	138688	Washington, IA	41.2825	91.7078	687.00	10/01/2001–09/30/2012
123	138706	Waterloo Municipal Airport, IA	42.5544	92.4011	868.00	10/01/2001–09/30/2012
124	138742	Waucoma 3 SE, IA	43.0533	92.0372	1,045.00	10/01/2001–09/30/2012
125	138755	Waukon, IA	43.2742	91.4711	1,275.00	10/01/2001–09/30/2012
126	138806	Webster City, IA	42.4686	93.7972	1,170.00	10/01/2001–09/30/2012
127	139067	Williamsburg, IA	41.6403	91.9783	810.00	10/01/2001–09/30/2012
128	139132	Winterset 2 NNW, IA	41.3561	94.0128	1,040.00	10/01/2001–09/30/2012
129	139750	Zearing, IA	42.1669	93.3097	1,116.00	10/01/2001–09/30/2012
130	210075	Albert Lea 3 SE, MN	43.6064	93.3019	1,230.00	10/01/2001–09/30/2012
131	210355	Austin Waste Water Treatment Facility, MN	43.6542	92.9739	1,199.00	10/01/2001–09/30/2012
132	210981	Bricelyn, MN	43.5439	93.8422	1,170.00	10/01/2001–09/30/2012
133	211198	Caledonia, MN	43.6308	91.5028	1,166.00	10/01/2001–09/30/2012
134	212698	Fairmont, MN	43.6447	94.4656	1,187.00	10/01/2001–09/30/2012
135	213290	Grand Meadow, MN	43.7047	92.5644	1,350.00	10/01/2001–09/30/2012
136	213520	Harmony, MN	43.5458	92.0122	1,350.00	10/01/2001–09/30/2012
137	214453	Lakefield, MN	43.7022	95.1519	1,530.00	10/01/2001–09/30/2012
138	214534	Lake Wilson, MN	43.9981	95.9572	1,650.00	10/01/2001–09/30/2012
139	214563	Lanesboro, MN	43.7203	91.9717	955.00	10/01/2001–09/30/2012
140	216654	Preston, MN	43.6725	92.0747	930.00	10/01/2001–09/30/2012
141	218323	Tracy, MN	44.2394	95.6308	1,403.00	10/01/2001–09/30/2012
142	219033	Windom, MN	43.8575	95.1167	1,375.00	10/01/2001–09/30/2012
143	219170	Worthington 2 NNE, MN	43.6450	95.5803	1,570.00	10/01/2001–09/30/2012
144	231275	Canton Lock and Dam 20, MO	40.1433	91.5158	490.00	10/01/2001–09/30/2012
145	232482	Edina, MO	40.1636	92.1658	808.00	10/01/2001–09/30/2012
146	234544	Kirksville, MO	40.2058	92.5747	970.00	10/01/2001–09/30/2012
147	235492	Memphis, MO	40.4575	92.1822	770.00	10/01/2001–09/30/2012
148	238051	Steffenville, MO	39.9714	91.8872	690.00	10/01/2001–09/30/2012
149	473038	Genoa Dam 8, WI	43.5706	91.2294	639.00	10/01/2001–09/30/2012
150	474546	Lancaster 4 WSW, WI	42.8278	90.7889	1,040.00	10/01/2001–09/30/2012
151	474937	Lynxville Dam 9, WI	43.2117	91.0986	633.00	10/01/2001–09/30/2012
152	476646	Platteville, WI	42.7489	90.4656	990.00	10/01/2001–09/30/2012
153	476827	Prairie Du Chien, WI	43.0514	91.1350	658.00	10/01/2001–09/30/2012
154	478164	Steuben 4 SE, WI	43.1342	90.8372	1,015.00	10/01/2001–09/30/2012
155	478827	Viroqua, WI	43.5594	90.8761	1,255.00	10/01/2001–09/30/2012

Table 3. Nash-Sutcliffe efficiency, coefficient of determination, percent bias, and root mean square error-observation standard deviation ratio statistic values at U.S. Geological Survey streamflow-gaging stations used for calibration or validation periods in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.

[Red indicates that statistic value below satisfactory rating level. USGS, U.S. Geological Survey; NSE, Nash-Sutcliffe efficiency; R^2, coefficient of determination; PBIAS, percent bias; RSR, root mean square error-observation standard deviation ratio; IA, Iowa; C, calibration location; Cr, Creek; V, validation location; NE, Northeast; MN, Minnesota; DS, downstream; MO, Missouri]

Map number (fig. 2)	USGS station number	USGS station name	Type	NSE	R^2	PBIAS	RSR
		Upper Iowa River Basin					
1	05387440	Upper Iowa River at Bluffton, IA	C	0.79	0.79	1.25	0.46
2	05387500	Upper Iowa River at Decorah, IA	C	0.84	0.85	5.23	0.40
3	05388250	Upper Iowa River near Dorchester, IA	C	0.88	0.88	-2.68	0.35
		Yellow River Basin					
4	05389000	Yellow River near Ion, IA	C	0.68	0.71	-7.74	0.56
		Turkey River Basin					
5	05411600	Turkey River at Spillville, IA	C	0.49	0.52	-5.88	0.71
6	05411850	Turkey River near Eldorado, IA	C	0.51	0.51	-9.04	0.70
7	05412020	Turkey River above French Hollow Cr at Elkader, IA	C	0.61	0.61	-4.06	0.62
8	05412340	Volga River at Fayette, IA	C	0.41	0.46	2.64	0.77
9	05412400	Volga River at Littleport, IA	C	0.67	0.68	-14.67	0.57
10	05412500	Turkey River at Garber, IA	C	0.66	0.66	-8.42	0.59
		Maquoketa River Basin					
11	05416900	Maquoketa River at Manchester, IA	C	0.50	0.51	23.89	0.71
12	05418400	North Fork Maquoketa River near Fulton, IA	C	0.55	0.58	11.15	0.67
13	05418500	Maquoketa River near Maquoketa, IA	C	0.65	0.68	16.76	0.59
		Wapsipinicon River Basin					
14	05420560	Wapsipinicon River near Elma, IA	C	0.43	0.44	-17.54	0.75
15	05420680	Wapsipinicon River near Tripoli, IA	C	0.66	0.70	-24.15	0.58
16	05421000	Wapsipinicon River at Independence, IA	V	0.70	0.72	-12.93	0.55
17	05421682	Buffalo Creek South of Prairieburg, IA	C	0.53	0.53	-2.30	0.68
18	05421740	Wapsipinicon River near Anamosa, IA	V	0.67	0.71	-4.68	0.58
19	05421760	Wapsipinicon River at Oxford Mills, IA	V	0.76	0.78	14.79	0.49
20	05422000	Wapsipinicon River near De Witt, IA	C	0.70	0.72	1.47	0.55
		Iowa River Basin					
21	05449500	Iowa River near Rowan, IA	C	0.52	0.58	16.15	0.69
22	05451210	South Fork Iowa River NE of New Providence, IA	C	0.62	0.65	30.26	0.61
23	05451500	Iowa River at Marshalltown, IA	C	0.65	0.68	23.52	0.59
24	05451700	Timber Creek near Marshalltown, IA	C	0.45	0.46	14.66	0.74
25	05451900	Richland Creek near Haven, IA	C	0.50	0.52	20.46	0.70
26	05452000	Salt Creek near Elberon, IA	C	0.65	0.66	16.53	0.59
27	05452200	Walnut Creek near Hartwick, IA	C	0.29	0.47	1.29	0.84
28	05453000	Big Bear Creek at Ladora, IA	C	0.54	0.55	17.65	0.68
29	05453100	Iowa River at Marengo, IA	C	0.73	0.76	20.90	0.52
31	05454000	Rapid Creek near Iowa City, IA	C	0.42	0.48	21.18	0.76
32	05454090	Muddy Creek at Coralville, IA	V	0.50	0.43	9.51	0.71
33	05454220	Clear Creek near Oxford, IA	C	0.54	0.56	20.03	0.68

Table 3. Nash-Sutcliffe efficiency, coefficient of determination, percent bias, and root mean square error-observation standard deviation ratio statistic values at U.S. Geological Survey streamflow-gaging stations used for calibration or validation periods in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[Red indicates that statistic value below satisfactory rating level. USGS, U.S. Geological Survey; NSE, Nash-Sutcliffe efficiency; R^2, coefficient of determination; PBIAS, percent bias; RSR, root mean square error-observation standard deviation ratio; IA, Iowa; C, calibration location; Cr, Creek; V, validation location; NE, Northeast; MN, Minnesota; DS, downstream; MO, Missouri]

Map number (fig. 2)	USGS station number	USGS station name	Type	NSE	R^2	PBIAS	RSR
Iowa River Basin—Continued							
34	05454300	Clear Creek near Coralville, IA	C	0.60	0.62	21.99	0.63
35	05454500	Iowa River at Iowa City, IA	C	0.99	1.00	1.56	0.08
36	05455100	Old Mans Creek near Iowa City, IA	C	0.56	0.58	17.97	0.66
37	05455500	English River at Kalona, IA	C	0.52	0.54	22.77	0.69
38	05455700	Iowa River near Lone Tree, IA	C	0.92	0.92	5.10	0.28
39	05457000	Cedar River near Austin, MN	C	0.39	0.42	14.97	0.78
40	05457700	Cedar River at Charles City, IA	C	0.63	0.66	14.52	0.61
41	05458000	Little Cedar River near Ionia, IA	C	0.70	0.70	-3.57	0.55
42	05458300	Cedar River at Waverly, IA	C	0.73	0.74	11.24	0.52
43	05458500	Cedar River at Janesville, IA	C	0.77	0.78	17.50	0.48
44	05458900	West Fork Cedar River at Finchford, IA	C	0.64	0.66	18.59	0.60
45	05459500	Winnebago River at Mason City, IA	C	0.53	0.60	17.06	0.69
46	05462000	Shell Rock River at Shell Rock, IA	C	0.65	0.68	16.34	0.59
47	05463000	Beaver Creek at New Hartford, IA	C	0.69	0.73	26.88	0.55
48	05463500	Black Hawk Creek at Hudson, IA	C	0.59	0.62	31.82	0.64
49	05464000	Cedar River at Waterloo, IA	C	0.79	0.82	21.84	0.46
50	05464220	Wolf Creek near Dysart, IA	C	0.56	0.59	30.32	0.66
51	05464500	Cedar River at Cedar Rapids, IA	V	0.77	0.79	17.26	0.48
52	05465000	Cedar River near Conesville, IA	V	0.67	0.70	17.56	0.58
53	05465500	Iowa River at Wapello, IA	V	0.74	0.77	11.53	0.51
Skunk River Basin							
54	05470000	South Skunk River near Ames, IA	C	0.69	0.69	-6.26	0.56
55	05470500	Squaw Creek at Ames, IA	C	0.65	0.66	-6.92	0.59
56	05471000	South Skunk River below Squaw Creek near Ames, IA	C	0.72	0.74	-10.67	0.52
57	05471050	South Skunk River at Colfax, IA	C	0.57	0.66	-4.22	0.66
58	05471200	Indian Creek near Mingo, IA	C	0.69	0.72	-6.51	0.55
59	05471500	South Skunk River near Oskaloosa, IA	C	0.50	0.63	0.89	0.70
60	05472500	North Skunk River near Sigourney, IA	C	0.68	0.70	-2.61	0.57
61	05473400	Cedar Creek near Oakland Mills, IA	C	0.68	0.71	1.03	0.57
62	05473450	Big Creek North of Mount Pleasant, IA	C	0.57	0.60	19.07	0.66
63	05474000	Skunk River at Augusta, IA	C	0.82	0.82	-3.39	0.42
Des Moines River Basin							
64	05476000	Des Moines River at Jackson, MN	C	0.50	0.58	-4.81	0.71
65	05476750	Des Moines River at Humboldt, IA	C	0.64	0.65	12.93	0.60
66	05479000	East Fork Des Moines River at Dakota City, IA	C	0.49	0.63	1.35	0.72
67	05480500	Des Moines River at Fort Dodge, IA	C	0.69	0.71	7.93	0.55
68	05481000	Boone River near Webster City, IA	C	0.61	0.65	24.13	0.62

Table 3. Nash-Sutcliffe efficiency, coefficient of determination, percent bias, and root mean square error-observation standard deviation ratio statistic values at U.S. Geological Survey streamflow-gaging stations used for calibration or validation periods in the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

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Map number (fig. 2)	USGS station number	USGS station name	Type	NSE	R^2	PBIAS	RSR
		Des Moines River Basin—Continued					
69	05481300	Des Moines River near Stratford, IA	C	0.73	0.74	10.46	0.52
71	05481950	Beaver Creek near Grimes, IA	C	0.64	0.70	9.18	0.60
72	05482000	Des Moines River at 2nd Avenue at Des Moines, IA	V	0.99	0.99	3.04	0.11
73	05482300	North Raccoon River near Sac City, IA	C	0.44	0.48	32.56	0.75
74	05482500	North Raccoon River near Jefferson, IA	C	0.65	0.65	9.37	0.59
75	05483450	Middle Raccoon River near Bayard, IA	C	0.44	0.45	11.20	0.75
76	05483600	Middle Raccoon River at Panora, IA	C	0.48	0.48	6.97	0.72
77	05484000	South Raccoon River at Redfield, IA	C	0.57	0.57	4.72	0.66
78	05484500	Raccoon River at Van Meter, IA	C	0.69	0.71	3.59	0.56
79	05484650	Raccoon River at 63rd Street at Des Moines, IA	V	0.72	0.73	9.64	0.52
80	05484800	Walnut Creek at Des Moines, IA	C	0.55	0.56	5.70	0.67
81	05484900	Raccoon River at Fleur Drive at Des Moines, IA	V	0.74	0.74	10.04	0.51
82	05485500	Des Moines River below Raccoon River at Des Moines, IA	V	0.93	0.93	2.56	0.27
83	05485605	Fourmile Creek near Ankeny, IA DS1	C	0.56	0.56	8.91	0.67
84	05485640	Fourmile Creek at Des Moines, IA	C	0.59	0.61	14.97	0.64
85	05486000	North River near Norwalk, IA	C	0.60	0.60	-2.25	0.63
86	05486490	Middle River near Indianola, IA	C	0.47	0.47	-1.36	0.73
87	05487470	South River near Ackworth, IA	C	0.46	0.47	9.80	0.74
88	05487980	White Breast Creek near Dallas, IA	C	0.45	0.47	-2.09	0.74
90	05488200	English Creek near Knoxville, IA	C	0.54	0.55	-8.39	0.68
91	05488500	Des Moines River near Tracy, IA	V	1.00	1.00	1.65	0.06
92	05489000	Cedar Creek near Bussey, IA	C	0.49	0.50	12.64	0.71
93	05489500	Des Moines River at Ottumwa, IA	V	0.98	0.98	1.64	0.14
94	05490500	Des Moines River at Keosauqua, IA	V	0.96	0.97	4.63	0.19
		Fox River Basin					
95	05494300	Fox River at Bloomfield, IA	C	0.25	0.27	-12.09	0.87
96	05495000	Fox River at Wayland, MO	C	0.61	0.61	-13.99	0.63

Table 4. Calibrated parameters and Let Us Calibrate (Luca) calibration steps for the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.

[PRMS, Precipitation-Runoff Modeling System; ET, evapotranspiration; nmonth, 12 months; one, one basin-wide value; NRMSE; normalized root mean square error; nhru, number of hydrologic response units; nssr, number of subsurface reservoirs equal to nhru; HRU, hydrologic response unit; ngw, number of groundwater reservoirs equal to nhru; nseg, number of model segments]

Calibration dataset	Objective function	PRMS parameter	Dimensions	Range	Parameter description
Calibration step 1					
Solar radiation and potential ET	Absolute difference	dday_intcp	nmonth	-60–10	Monthly (January to December) intercept in degree-day equation.
	1. Mean monthly	dday_slope	nmonth	0.2–0.9	Monthly (January to December) slope in degree-day equation.
		jh_coef	nmonth	0.005–0.09	Monthly (January to December) air temperature coefficient used in Jensen-Haise potential ET calculations.
Calibration step 2					
Water balance	NRMSE:	adjust_rain	nmonth	0–2.0	Precipitation adjustment factor for rain days.
	1. Annual 2. Monthly mean 3. Mean monthly	adjust_snow	nmonth	0–2.0	Precipitation adjustment factor for snow days.
Calibration step 3					
Daily flow	NRMSE:	adjmix_rain	nmonth	0.6–1.4	Factor to adjust proportion in mixed rain/snow event.
	1. Daily 2. Monthly mean	cecn_coef	nmonth	0.6–1.4	Convection condensation energy coefficient.
		freeh2o_cap	one	0.01–0.2	Free-water holding capacity of the snowpack.
		potet_sublim	one	0.1-0.75	Fraction of potential ET that is sublimated from snow surface.
		slowcoef_lin[1]	nhru	0.0001–0.05	Linerar subsurface reservoir routing coefficient.
		soil_moist_max[1]	nssr	2–10	Maximum available water holding capacity of soil profile.
		soil_rech_max[1]	nssr	1.5–5	Maximum available water holding capacity of recharge zone.
		emis_noppt	one	0.757–1	Emissivity of air on days without precipitation.
		tmax_allrain	nmonth	30–40	If HRU maximum temperature exceeds this value, precipitation is assumed rain.
		tmax_allsnow	one	30–40	If HRU maximum temperature is below this value, precipitation is assumed snow.
Calibration step 4					
Daily flow	NRMSE:	fastcoef_lin[1]	nhru	0.0001–0.8	Linear preferential-flow routing coeficient.
	1. Daily high 2. Monthly high	pref_flow_den[1]	nhru	0–.1	Preferential-flow pore density.
		sat_threshold[1]	nhru	1–15	Soil saturation threshold, above field-capacity threshold.
		smidx_coef[1]	nhru	0.0001–0.8	Coefficient in nonlinear surface runoff contributing area algorithm.
Calibration step 5					
Daily flow	NRMSE:	gwflow_coef[1]	ngw	0.001–0.89	Groundwater routing coefficient.
	1. Daily low 2. Monthly low	soil2gw_max[1]	nhru	0–0.5	Maximum value for lower zone excess to groundwater reservoir.
		ssr2gw_rate[1]	nssr	0.05–0.8	Coefficient to route water from subsurface reservoir to groundwater reservoir.

Table 4. Calibrated parameters and Let Us Calibrate (Luca) calibration steps for the Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa.—Continued

[PRMS, Precipitation-Runoff Modeling System; ET, evapotranspiration; nmonth, 12 months; one, one basin-wide value; NRMSE; normalized root mean square error; nhru, number of hydrologic response units; nssr, number of subsurface reservoirs equal to nhru; HRU, hydrologic response unit; ngw, number of groundwater reservoirs equal to nhru; nseg, number of model segments]

Calibration dataset	Objective function	PRMS parameter	Dimensions	Range	Parameter description
		Calibration step 6			
Daily flow	NRMSE:	K_coef[1]	nseg	1–24	Muskingum storage coefficient.
	1. Daily	slowcoef_sq[1]	nhru	0–1	Nonlinerar subsurface reservoir routing coefficient.
		fastcoef_sq[1]	nhru	0–1	Nonlinear preferential-flow routing coeficient.

[1] Parameter calibrated in both basin-wide and subbasin calibration.

counterparts (Gupta and others, 1999). A PBIAS value of 0.0 indicates ideal performance, whereas positive values indicate underestimation bias and negative values indicate overestimation bias (Moriasi and others, 2007). Model performance for streamflow is considered “very good” if the PBIAS is between 0 and plus or minus (+/-) 10 percent, “good” if the PBIAS is between +/- 10 and +/- 15 percent, “satisfactory” if the PBIAS is between +/-15 and +/- 25 percent, and “unsatisfactory” if the PBIAS is +/- 25 percent and greater (Moraisi and others, 2007).

The RSR was developed to use the standard deviation of observations to qualify what is considered a low root mean square error for model performance (Singh and others, 2004). The RSR incorporates the benefits of error index statistics and includes a normalization/scaling factor. The RSR ranges from 0 (optimal value) to a large positive value (poor fit) (Singh and others, 2004). The lower the RSR value, the better the model simulation performance. If RSR is between 0 and 0.5 then performance is “very good,” if RSR is between 0.5 and 0.6 then performance is “good,” RSR between 0.6 and 0.7 is “satisfactory,” and RSR greater than 0.7 is “unsatisfactory” (Moraisi and others, 2007).

The statistics NSE, R^2, PBIAS, and RSR are defined as:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n} \left(Q_{obs,i} - \bar{Q}_{obs,i}\right)^2} \right], \tag{1}$$

$$R^2 = \frac{\left[\sum_{i=0}^{n} \left(Q_{obs,i} - \bar{Q}_{obs,i}\right)\left(Q_{sim,i} - \bar{Q}_{sim,i}\right)\right]^2}{\left[\sum_{i=0}^{n} \left(Q_{obs,i} - \bar{Q}_{obs,i}\right)^2\right]\left[\sum_{i=0}^{n} \left(Q_{sim,i} - \bar{Q}_{sim,i}\right)^2\right]} \tag{2}$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Q_{obs,i} - Q_{sim,i}\right)}{\sum_{i=1}^{n} \left(Q_{obs,i}\right)} \right] * 100 \tag{3}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=0}^{n} \left(Q_{obs,i} - Q_{sim,i}\right)^2}\right]}{\left[\sqrt{\sum_{i=0}^{n} \left(Q_{obs,i} - \bar{Q}_{obs,i}\right)^2}\right]} \tag{4}$$

where

$Q_{obs,i}$ is the *i*th measurement for basin streamflow,

$Q_{sim,i}$ is the *i*th simulated basin streamflow,

$\bar{Q}_{obs,i}$ is the mean of the measured basin streamflow,

$\bar{Q}_{sim,i}$ is the mean of the simulated basin streamflow,

RMSE is the root mean square error,

$STDEV_{obs}$ is the standard deviation of the observations, and

n is the total number of measurements.

The PRMS models of nine river basins in eastern Iowa were evaluated at 79 calibration and 14 validation gaged sites (fig. 2; table 3). The NSE, R^2, PBIAS, and RSR daily values for the period used for calibration are listed for each of these sites (table 3). Based on statistical results, the nine eastern Iowa river basin PRMS models are a good fit for daily streamflow estimation at most sites because PBIAS and RSR ratings range from very good to good, and NSE and R^2 ratings are satisfactory (table 3). Some headwater sites show unsatisfactory ratings. Explanation of the statistical results by river basin is provided in “Simulation of Daily Streamflow for Nine River Basins in Eastern Iowa Using the Precipitation-Runoff Modeling System.”

Simulation of Daily Streamflow for Nine River Basins in Eastern Iowa Using the Precipitation-Runoff Modeling System

The estimates of PRMS models of nine river basins in eastern Iowa for daily streamflow at USGS streamflow-gaging stations varied in accuracy when compared to measured daily streamflow data. Models were satisfactory at estimating daily streamflow at USGS streamflow-gaging stations based on statistical results; however, at some gaged sites, the models were below a satisfactory level. Results from the nine eastern Iowa River Basin models are presented below.

The Upper Iowa River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at all streamflow-gaging stations (table 3). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 05388250, shows that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates peak timing and volumes well, but either overestimates or underestimates some peak flow volumes (fig. 5).

The Yellow River Basin PRMS model also meets the criteria for satisfactory fit or better for streamflow estimation at all streamflow-gaging stations (table 3). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 0589000, shows that for the calibration period (October 1, 2004, through September, 30, 2012) model output estimates peak timing and volumes well (fig. 5). Peak flow events that happen during the winter months (January, February, and March) are underestimated possibly because of the effects of frozen ground, which are not captured in the version of the model used for this study, the underestimation of rainfall in a rain-snow event, or underestimation of snow-melt runoff. The model also underestimates the record peak flows during 2007 and 2008. These two exceptions and minor base flow discrepancies could be improved upon with more extensive and informed calibration.

The Turkey River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation in all streamflow-gaging stations except at stations 05411600 and 05412340 (table 3). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 05412500, shows that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates peak timing and volumes well; however, peak flow volumes tend to be underestimated (fig. 5). As with the Yellow River Basin model, the Turkey River Basin model also underestimates peak flow events that happen during the winter months (January, February, and March).

The Maquoketa River Basin PRMS model exceeds the minimum criteria for satisfactory fit or for streamflow estimation in all streamflow-gaging stations except at station 05416900. A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 05418500, shows that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates peak timing and volumes well; however, peak flow volumes during lower flows tend to be overestimated, whereas peak flow volumes during higher flows tend to be underestimated. (table 3; fig. 5).

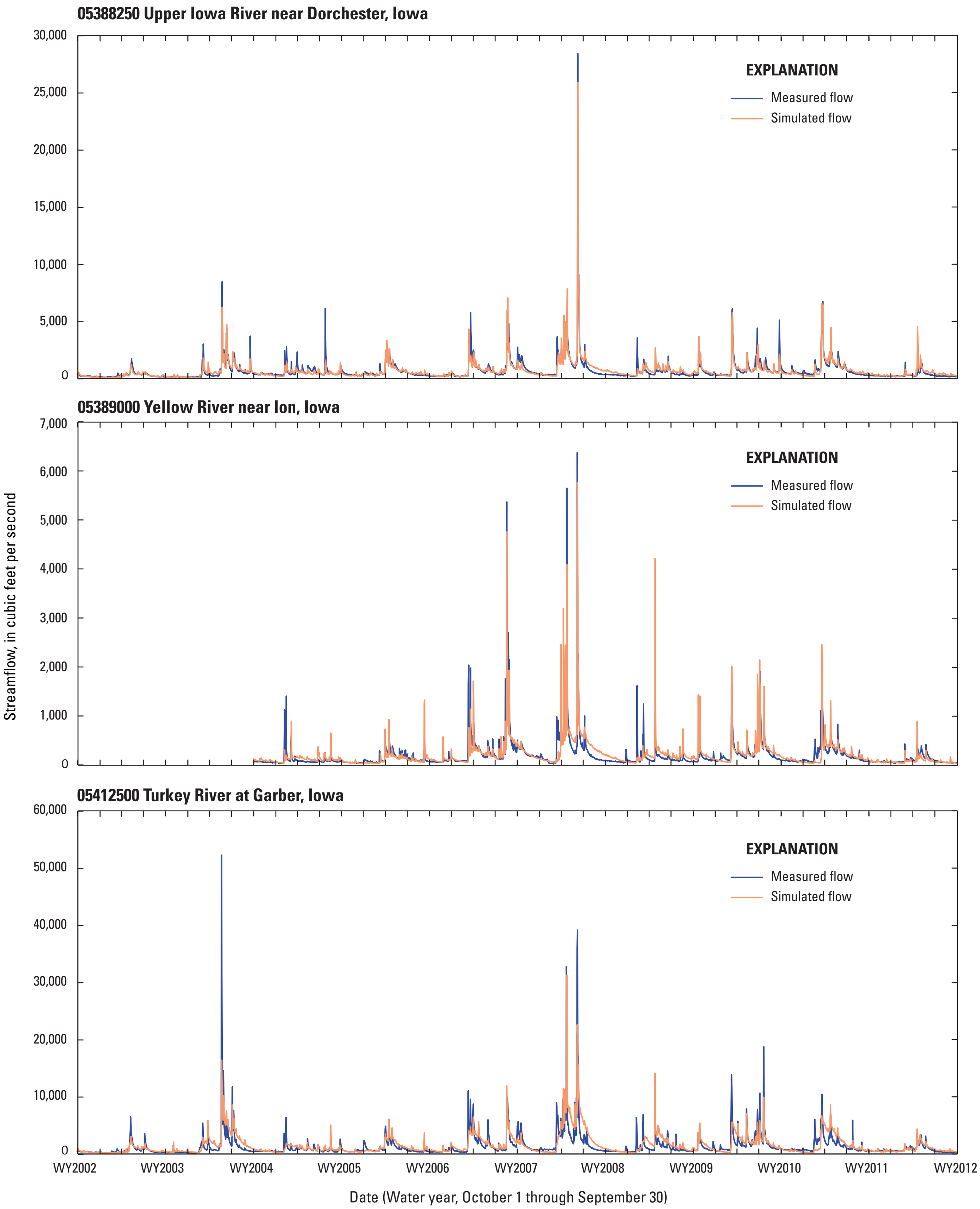
The Wapsipinicon River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation in all streamflow-gaging stations except at station 05420560. A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 05422000, indicates that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates timing of peak flows well; however, peak flow volumes during lower flows tend to be overestimated, whereas peak flow volumes during higher flows tend to be underestimated (table 3; fig. 5).

The Iowa River Basin PRMS model also exceeds the minimum criteria for satisfactory fit or for streamflow estimation in all but 9 of the 32 streamflow-gaging stations (table 3). A comparison of simulated and measured streamflow at the streamflow-gaging stations 05453100 and 05465000 indicates that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates peak flow timing well (table 3; fig. 5). Peak flow volumes are generally underestimated.

The Skunk River Basin PRMS model also meets the criteria for satisfactory fit or better for streamflow estimation in all streamflow-gaging stations (table 3). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 05474000, indicates that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates peak timing and volumes well; however, peak flow volumes during lower flows tend to be overestimated, whereas peak flow volumes during higher flows tend to be underestimated (table 3; fig. 5).

The Des Moines River Basin PRMS model exceeds the minimum criteria for satisfactory fit or for streamflow estimation in all but 9 of the 29 streamflow-gaging stations (table 3). A comparison of simulated and measured streamflow at station 05484500 on the Raccoon River indicates that for the calibration period (October 1, 2002 through September, 30, 2012) model output estimates peak flow timing and volumes well, however peak flow volumes are generally overestimated. A comparison of simulated and measured streamflow at station 05481300 on the Des Moines River shows that for the calibration period (October 1, 2002, through September, 30, 2012) model output estimates peak flow timing and volumes well; however, peak flow volumes during lower flows tend to be overestimated, whereas peak flow volumes during higher flows tend to be underestimated (table 3; fig. 5).

The Fox River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at one of the two streamflow-gaging stations, the streamflow-gaging station nearest to the outlet, station 05495000. For the calibration


05388250 Upper Iowa River near Dorchester, Iowa

05389000 Yellow River near Ion, Iowa

05412500 Turkey River at Garber, Iowa

Figure 5. A comparison of measured and simulated flow (October 1, 2002, through September 30, 2012) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa, water years (WYs) 2002–12.

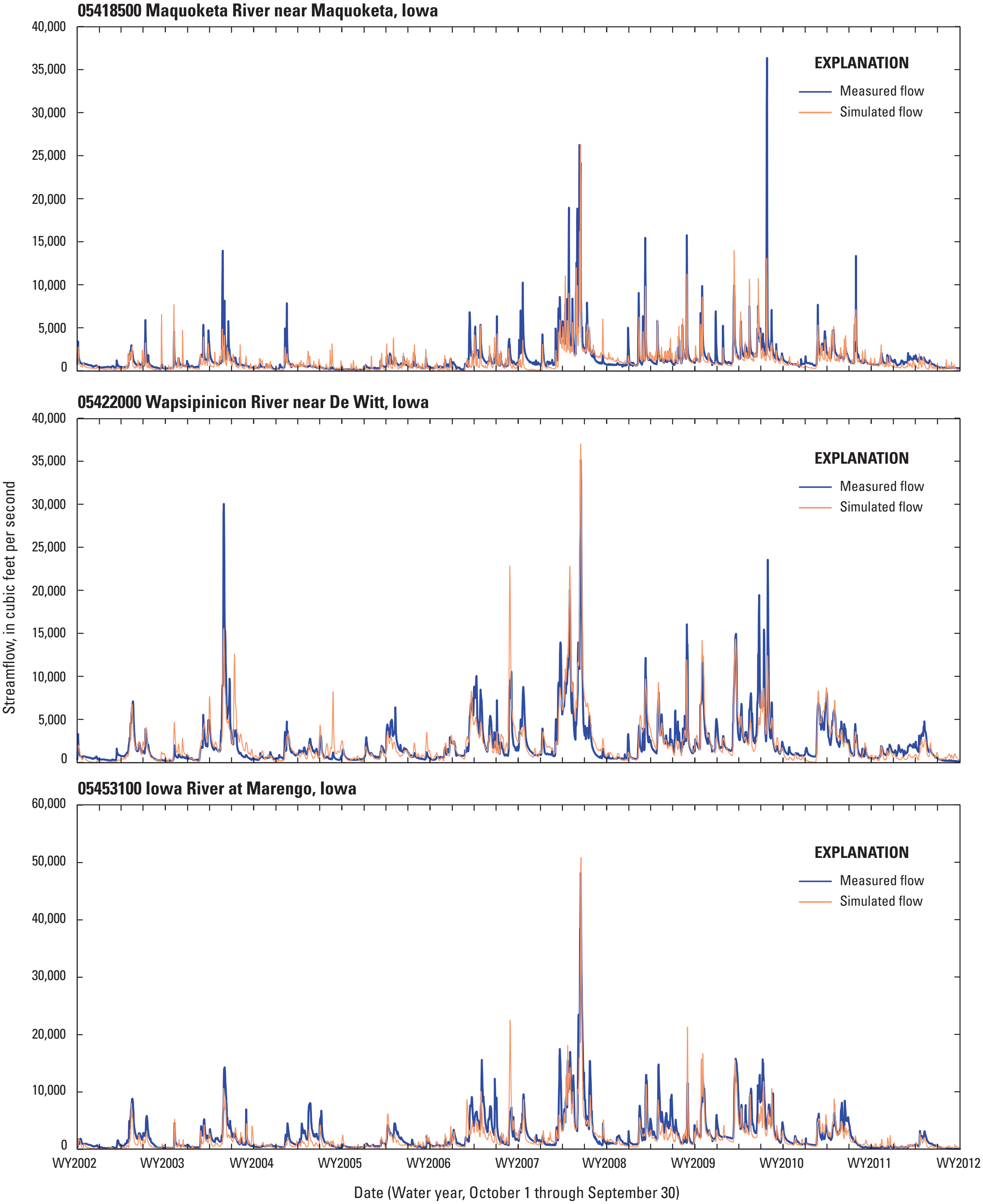
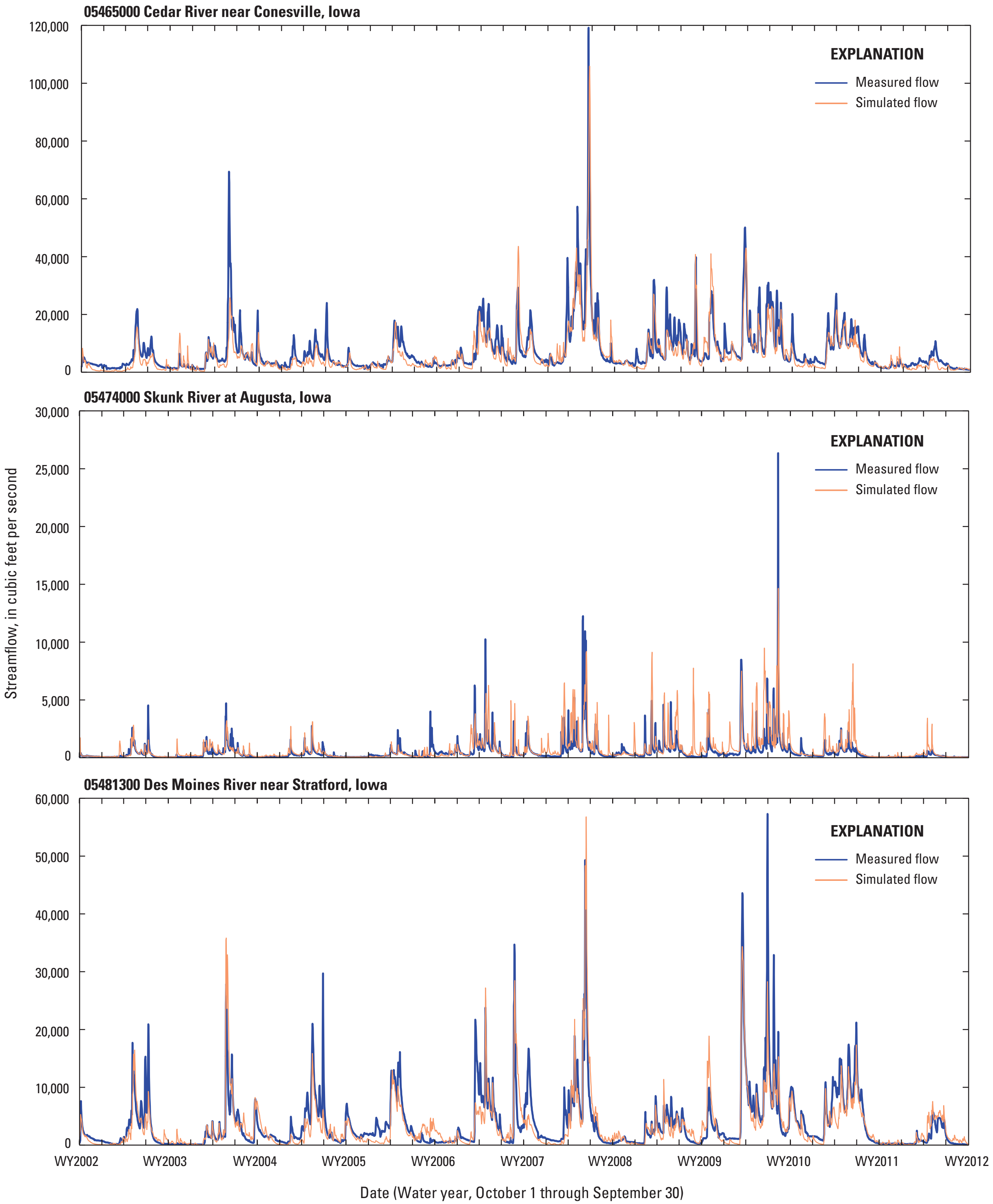


Figure 5. A comparison of measured and simulated flow (October 1, 2002, through September 30, 2012) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa, water years (WYs) 2002–12.—Continued



05465000 Cedar River near Conesville, Iowa

05474000 Skunk River at Augusta, Iowa

05481300 Des Moines River near Stratford, Iowa

Figure 5. A comparison of measured and simulated flow (October 1, 2002, through September 30, 2012) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa, water years (WYs) 2002–12.—Continued

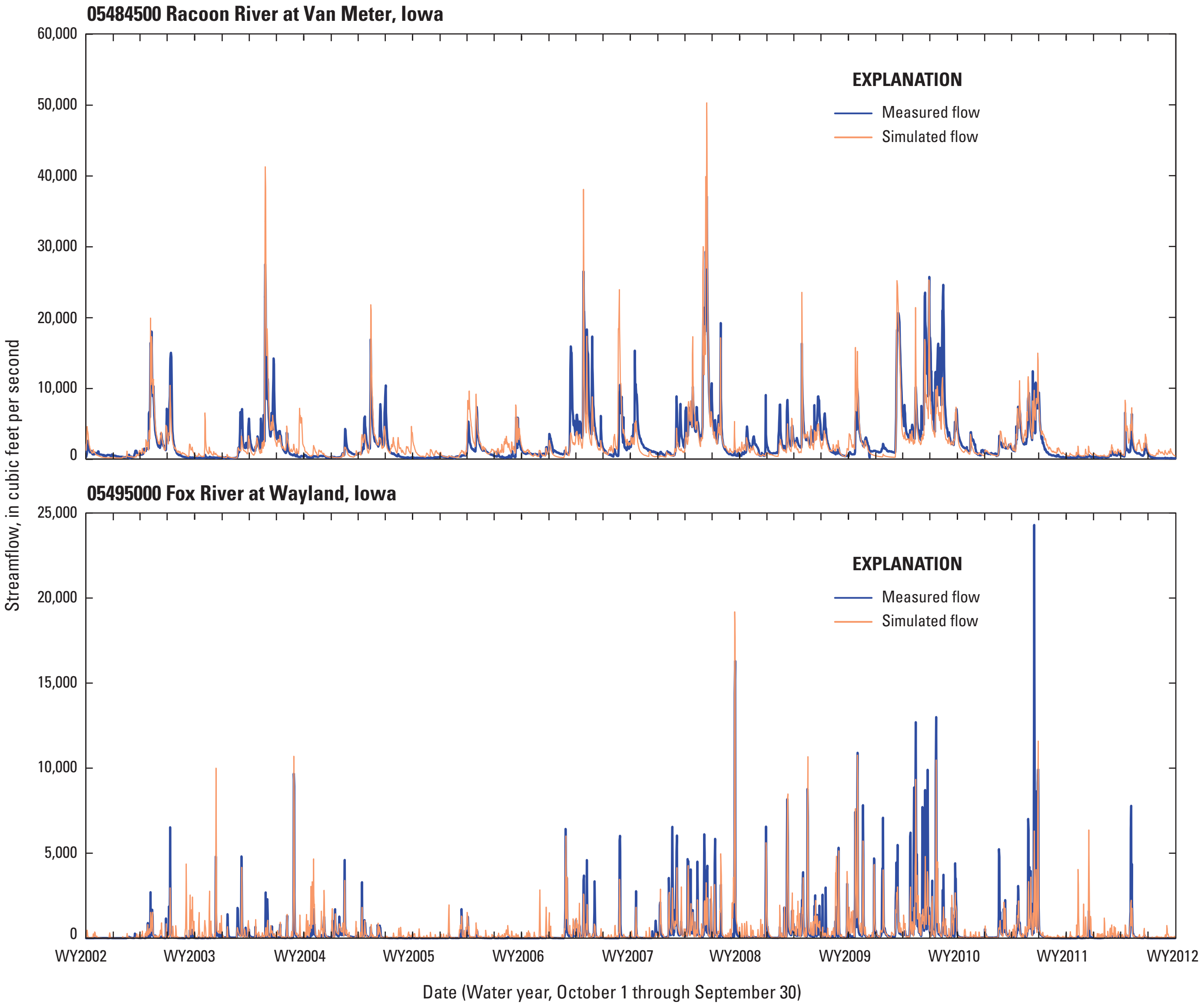


Figure 5. A comparison of measured and simulated flow (October 1, 2002, through September 30, 2012) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of nine river basins in eastern Iowa, water years (WYs) 2002–12.—Continued

period (October 1, 2002, through September, 30, 2012), the model output estimates peak flow timing well, but tends to underestimate peak flow volumes, and overestimate and poorly characterize base flow volumes (table 3; fig. 5).

Overall, the PRMS models of nine river basins in eastern Iowa constructed for this investigation satisfactorily estimate daily streamflow at 57 of the 79 calibration and 13 of the 14 validation gaged sites as indicated by the NSE, R^2, PBIAS, and RSR values presented in table 3. In general, gaged sites in headwater subbasins with small drainage areas and streamflows tended to have less accuracy than the main-stem gaged sites with larger drainage areas and streamflows. The graphs of measured and simulated values at selected USGS streamflow-gaging stations within the basins show that the models indicate that unsatisfactory performance may be attributed to several factors: (1) low flow, no flow, and flashy flow conditions in headwater subbasins having a small drainage area; (2) poor representation of the groundwater and storage components of flow within a basin; (3) lack of accounting for basin withdrawals and water use; and (4) the availability and accuracy of meteorological input data. In addition, streamflow is simulated at a daily time step, so shorter-duration, flashy streamflow events are not well represented. A more robust subdaily modeling routine may be necessary at the smaller headwater subbasins to accurately reflect flashy, subdaily climatic events. Further refinement and calibration with more detailed information on groundwater and subsurface storage, water use, and local precipitation and temperature would better guide the proper modeling of low and peak flows and improve model performance.

As indicated in the statistical results at validation gaged sites (which evaluate the accuracy of the model at potential ungaged sites), calibrated models can provide satisfactory streamflow estimates throughout the nine river basins in eastern Iowa, at a model HRU and stream segment scale (table 3). The PRMS models provide a consistent and documented method for streamflow estimation at locations within the basin that may not have available USGS streamflow-gaging station information.

Model Limitations

The PRMS model uses parameters generated by the GIS Weasel that are dependent upon soil and land cover input datasets (see “Delineation and Parameterization of Spatial Features”). These datasets are dated, have variable degrees of resolution, and may not reflect current land cover or land use conditions in parts of the study area. These inaccuracies may contribute to the overestimation or underestimation of streamflow by the PRMS model.

The PRMS model depends on the use of meteorological datasets to drive the model computations to simulate streamflow. In this study, a network of meteorological stations was used to derive precipitation and temperature model inputs. The spatial distribution of the meteorological stations used to interpolate the spatial distribution of temperature and precipitation within the nine river basins in eastern Iowa is shown in figure 4. Temperature and precipitation can vary over small distances; this variability may not be captured by meteorological stations; for example, summer thunderstorm activity can produce rapid changes in temperature and a large amount of precipitation in a small area. Summer thunderstorm activity can be missed if there is no meteorological station in the area; thus, the lack of accurate meteorological data over each basin could have contributed to the underestimation or overestimation of daily streamflow. The use of a more robust spatial distribution of climatic data such as Next Generation Radar (NEXRAD), a product of the National Weather Service (NWS), may aid in improving climatic calculations that are the driving forces of the PRMS model (Kalin and Hantush, 2006).

There are several notable limitations in the PRMS models. First, the PRMS models have a daily time step that has all flows and storages expressed as daily mean values. Because of this, error may result because of the daily averaging of near land-surface flows, or when streamflow changes during subdaily time increments (Markstrom and others, 2012). Second, flows and storages are assumed to be homogeneous within each HRU, and some hydrologic complexity and parameter variability within an HRU may be lost. Third, the method of simulating solar radiation values for each HRU does not account for variations in solar activity or changes in atmospheric events. This limitation, however, typically results in only small changes in solar radiation, which have a minimal effect on hydrologic variables and projected basin runoff (Markstrom and others, 2012). Fourth, there are complications in simulations when rain falls on the snowpack in excess of its available pore space. Either the water will runoff the snowpack, in which case it is erroneously considered as snowmelt, or the water will freeze to the snowpack causing the model to later report more snowmelt than snowfall (Markstrom and others, 2012). Both of these cases may complicate interpretation of the model with regard to rain on snowpack events. This study used the Jensen-Haise method (Jensen and others 1970; and Markstrom and others, 2008) to estimate stationary monthly mean values for potential evapotranspiration (PET) at each calibration point for subbasin calibration, which may be a source of uncertainty in the model. Studies (Kingston and others, 2009; and Donohue and others, 2010) show that this uncertainty is reduced because PRMS uses simulated PET, vegetation type, land-use characteristics, soil type, simulated atmospheric conditions, and soil moisture availability to compute actual evapotranspiration (AET), and it is AET that PRMS used in the water balance simulation (Markstrom and others, 2008; and Markstrom and others, 2012). A more detailed discussion of PET uncertainty in the PRMS model is presented in Markstrom and others (2012).

Summary

The U.S. Geological Survey (USGS) maintains about 149 real-time streamflow-gaging stations in Iowa where daily mean streamflow information is available. This streamflow information provides the basis for understanding the hydrologic characteristics of basins and, in combination with water-quality information collected at a monthly time step at 75 locations across the State by State and Federal agencies, aids in understanding risks imposed on human and ecosystem health. Because the information collected at these streamflow-gaging stations is site specific, the ability to confidently use these data to infer streamflow information at ungaged sites within a basin for adaptive management and decisions can be limited. Hydrological models are one tool that can be used to overcome this limitation in eastern Iowa. Precipitation-Runoff Modeling System (PRMS) models were constructed in cooperation with the Iowa Department of Natural Resources for nine river basins in eastern Iowa as part of an ongoing research project to examine methods of estimating daily streamflow at gaged and ungaged sites.

The PRMS models were constructed for a total of nine river basins in eastern Iowa that are each a tributary to the Mississippi River: Upper Iowa River Basin, Yellow River Basin, Turkey River Basin, Maquoketa River Basin, Wapsipinicon River Basin, Iowa River Basin, Skunk River Basin, Des Moines River Basin, and Fox River Basin. The construction, calibration, and evaluation of PRMS basin models to simulate daily streamflows and hydrologic components for river basins in eastern Iowa were described. Model performance was assessed to determine the ability of PRMS to estimate streamflow and the suitability for models to serve as part of a suite of methods for estimating daily streamflow at ungaged sites. Model limitations were investigated and described.

The PRMS is a modular, distributed-parameter, physical-process basin model developed to evaluate the effects of various combinations of precipitation, climate, and land use on surface-water runoff. The PRMS simulates the hydrologic system with known physical laws and empirical relations derived from basin characteristics. The nine river basins in eastern Iowa were delineated with the GIS Weasel. The GIS Weasel was used to characterize the physical features of each river basin in eastern Iowa into the requisite sets of parameters for input into PRMS.

Precipitation, minimum temperature, and maximum temperature were used in the PRMS models of nine river basins in eastern Iowa as the main climatic drivers. In addition to meteorological inputs, PRMS can also use streamflow-gaging station data in place of simulated streamflow. The USGS streamflow-gaging station data and meteorological datasets for precipitation and temperature were collected using the USGS Downsizer program. The PRMS model was calibrated using the Luca program, which is a multiple-objective, stepwise procedure. Calibration and validation periods used in each basin mostly were October 1, 2002, through September 30, 2012, but differed depending on the period of record available for daily mean streamflow measurements at U.S. Geological Survey streamflow-gaging stations.

Overall, PRMS models of nine river basins in eastern Iowa constructed for this investigation satisfactorily estimate daily streamflow at 57 of the 79 calibration and 13 of the 14 validation gaged sites as indicated by the NSE, R^2, PBIAS, and RSR values. Unsatisfactory performance may be attributed to several factors: (1) low flow, no flow, and flashy flow conditions in headwater subbasins having a small drainage area; (2) poor representation of the groundwater and storage components of flow within a basin; (3) lack of accounting for basin withdrawals and water use; and (4) the availability and accuracy of meteorological input data. In addition, the version of PRMS used for this study will average a short-duration, flashy streamflow event during a daily time step, whereas a more robust subdaily modeling routine may be necessary at the smaller headwater subbasins to accurately reflect flashy, subdaily climatic events. Further refinement and calibration with more detailed information would better guide the proper modeling of these flow components and improve model performance.

The PRMS models of nine river basins in eastern Iowa can provide satisfactory streamflow estimates at model HRU and stream segment scale. The PRMS models will provide a consistent and documented method for estimating streamflow at locations within the basin that may not have available USGS streamflow-gaging station information.

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