Prepared in cooperation with the Iowa Department of Natural Resources

Simulation of Daily Streamflow for 12 River Basins in Western Iowa Using the Precipitation-Runoff Modeling System

Scientific Investigations Report 2017–5091

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

Front cover photograph. The Nodaway River at Clarinda, looking downstream. Photograph by U.S. Geological Survey, Iowa Water Science Center.

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Conversion Factors

U.S. customary units 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)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to mean sea level or the North American Vertical Datum of 1988 (NAVD 88).

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

Supplemental Information

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

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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 12 river basins in western Iowa that drain into the Missouri River. 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 periods for each basin varied 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 initial values for model parameters based on basin physical and geographical features. A U.S. Geological Survey automatic 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 Precipitation-Runoff Modeling System model was calibrated at 42 sites located in the 12 river basins in western Iowa.

The accuracy of the simulated daily streamflow values at the 42 calibration sites varied by river and by site. The models were satisfactory at 36 of the sites based on statistical results. Unsatisfactory performance at the six other sites can 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) limited availability and accuracy of meteorological input data. The Precipitation-Runoff Modeling System models of 12 river basins in western 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, 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 located on some of those rivers and streams (gaged sites) only account for a limited representation of total surface-water flow in the State. Water-resource managers of the Iowa Department of Natural Resources (IDNR) have a strong need 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 148 real-time streamflow-gaging stations in Iowa where daily mean streamflow information is available (U.S. Geological Survey, 2016). This streamflow information provides the basis for understanding the hydrologic characteristics of drainage 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 western 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

12 river basins in western Iowa as part of an ongoing research project to develop methods of estimating daily streamflow at gaged and ungaged sites. This report is a complementary report to "Simulation of Daily Streamflow for Nine River Basins in Eastern Iowa Using the Precipitation-Runoff Modeling System" (Haj and others, 2015). 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 models for simulating hydrologic processes in 12 western Iowa River basins draining into the Missouri River. The construction, calibration, and evaluation of these PRMS models to simulate daily streamflow are described. Model performance is assessed by evaluating the ability of PRMS models to estimate daily streamflow at ungaged sites. Model limitations are investigated and described.

Description of Study Areas

The PRMS models were constructed for 12 river basins in western Iowa that are tributaries to the Missouri River: Big Sioux River, Floyd River, Monona-Harrison Ditch, Little Sioux River, Soldier River, Boyer River, Keg Creek, Nishnabotna River, Nodaway River, One Hundred and Two River, Thompson River, and Chariton River basins (fig. 1). Although the percentage varies, all basins are dominated by agriculture in the form of corn and soybeans (U.S. Department of Agriculture, 2014). Livestock operations (including beef and dairy cattle, hogs, sheep, and poultry) are present in varying amounts in each of the 12 basins. In addition, tile drainage is extensive throughout each basin to enhance crop production by removing excess water from the soil. The western part of the State spans five of Iowa's landform regions, and each has a characteristic topography and glacial history (Prior and others, 2009; Prior, 1991) (fig. 1).

The Big Sioux River Basin originates in Roberts and Grant Counties, northeast South Dakota, and drains about 9,570 square miles (mi^2) into the Missouri River in Union County, South Dakota (fig. 1). The upper and western most parts of the Big Sioux River Basin are within South Dakota, which does not define landform regions (fig. 1). The lower and eastern part of the basin mainly lies within the Northwest Iowa Plains landform region, and small portions are located within the Des Moines Lobe, Southern Iowa Drift Plain, and the Loess Hills landform regions (fig. 1) (Prior, 1991). Eleven USGS streamflow-gaging stations in the Big Sioux River Basin were used in this study (table 1; fig. 2).

The Floyd River Basin drains 916 mi^2. It originates in Osceola and O'Brien Counties in western Iowa and extends about 69 mi southwest to its confluence with the Missouri River. Most of the Floyd River Basin lies within the Northwestern Iowa Plains landform region, but small parts extend into the Southern Iowa Drift Plain and Loess Hills landform regions in the southern part of the Floyd River Basin near the outlet (fig. 1) (Prior, 1991). Two USGS streamflow-gaging stations in the Floyd River Basin were used in this study (table 1; fig. 2).

The Monona-Harrison Ditch Basin drains about 967 mi^2 and extends from its headwaters in Cherokee County, Iowa, to its outlet in Harrison County, Iowa (fig. 1). The Monona-Harrison Ditch Basin lies within the Northwest Iowa Plains, Southern Iowa Drift Plain, Loess Hills, and Missouri River Alluvial Plain landform regions (fig. 1) (Prior, 1991). Two USGS streamflow-gaging stations in the Monona-Harrison Ditch Basin were used in this study (table 1; fig. 2).

The Little Sioux River Basin drains about 3,572 mi^2 south into the Missouri River and extends from Nobles and Jackson Counties in southwestern Minnesota to Harrison County, Iowa (fig. 1). The Little Sioux River Basin lies within the Des Moines Lobe, Northwest Iowa Plains, Southern Iowa Drift Plain, Loess Hills, and Missouri River Alluvial Plain landform regions (fig. 1) (Prior, 1991). A total of six USGS streamflow-gaging stations in the Little Sioux River Basin were used in this study (table 1; fig. 2).

The Soldier River Basin originates in Ida and Sac Counties in west-central Iowa and drains about 449 mi^2 before its confluence with the Missouri River in Harrison County, Iowa (fig. 1). The Solider River Basin is within three landform regions in Iowa, originating in the Southern Iowa Drift Plain and crossing both the Loess Hills and Missouri River Alluvial Plain (fig. 1) (Prior, 1991). The Soldier River Basin is predominately agricultural land with little urban development. One USGS streamflow-gaging station in the Soldier River Basin was used in this study (table 1; fig. 2).

The Boyer River Basin originates in southern Buena Vista County in west-central Iowa and drains about 1,190 mi^2 before its confluence with the Missouri River in Pottawattamie County, Iowa (fig. 1). The Boyer River Basin is within four landform regions in Iowa. Its headwaters are in the Northwest Iowa Plains. It crosses both the Southern Iowa Drift Plain and Loess Hills before reaching its outlet in the Missouri River Alluvial Plain (fig. 1) (Prior, 1991). The Boyer River Basin is predominately agricultural land with little urban development. One USGS streamflow-gaging station in the Boyer River Basin was used in this study (table 1; fig. 2).

The Keg Creek Basin drains about 209 mi^2 and extends from its headwaters in Shelby County, Iowa, to its outlet in Mills County in western Iowa (fig. 1). The basin lies primarily within the Southern Iowa Drift Plains, but small parts of the basin near the outlet extend into the Loess Hills and Missouri River Alluvial Plain landform regions (fig. 1) (Prior, 1991). One USGS streamflow-gaging station in the Keg Creek Basin was used in this study (table 1; fig. 2).

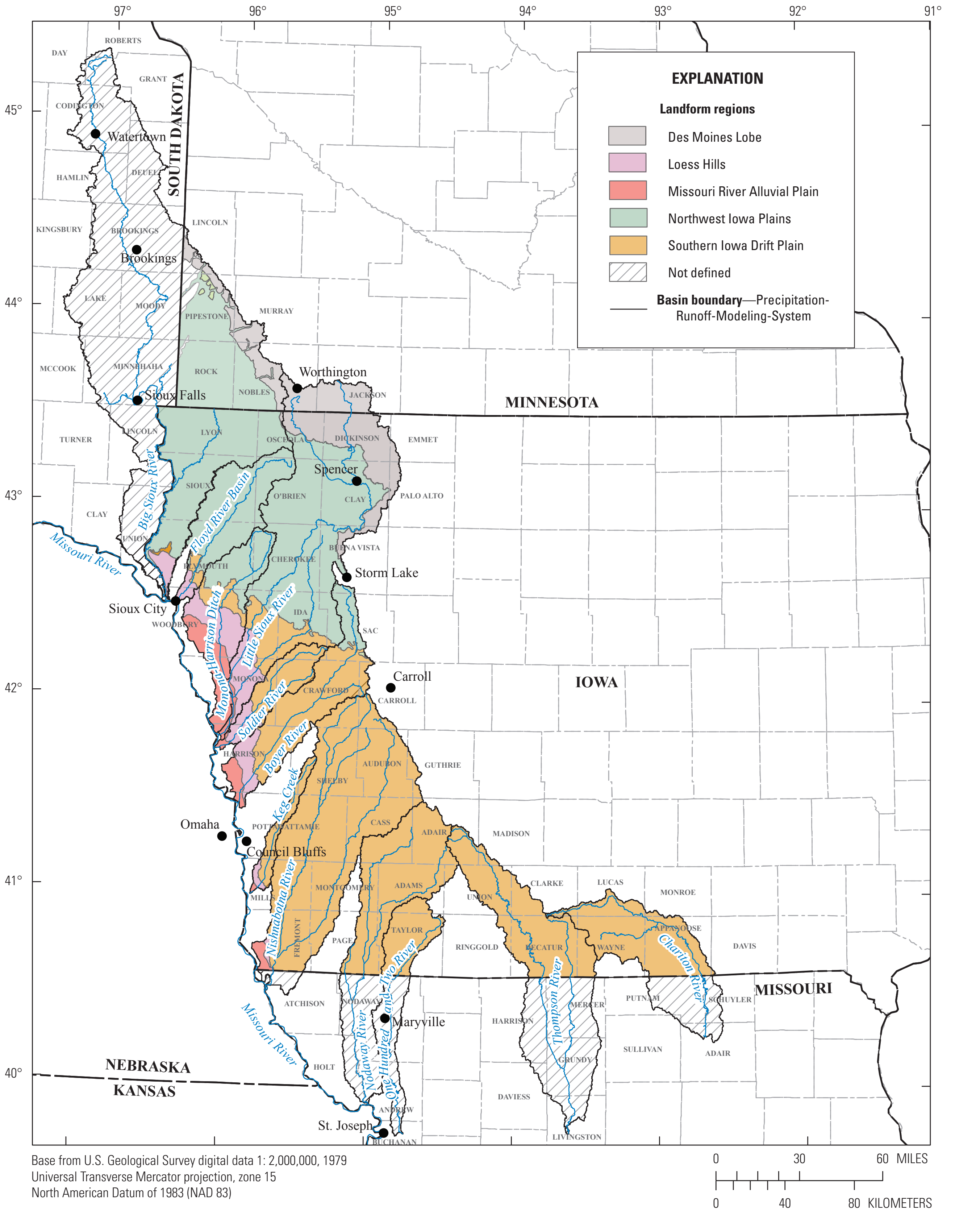

Figure 1. Iowa landform regions of the 12 river basins in western Iowa for which Precipitation-Runoff Modeling System models were developed.

Table 1. U.S. Geological Survey streamflow-gaging stations used for input and calibrating the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.

[USGS, U.S. Geological Survey; latitude amd longitude in decimal degrees; mi², square miles; Mo., Missouri; S. Dak., South Dakota]

Map number (fig. 2)	USGS station number	USGS station name	Latitude (north)	Longitude (west)	Drainage area measured at gage (mi²)	Period of record used
		Big Sioux River Basin				
1	06480000	Big Sioux River near Brookings, S. Dak.	44.1802	96.7495	3,338	10/1/2005–9/30/2015
2	06480650	Flandreau Creek above Flandreau, S. Dak.	44.0627	96.4856	101	10/1/1981–9/30/1991
3	06481000	Big Sioux River near Dell Rapids, S. Dak.	43.7904	96.7457	3,927	10/1/2005–9/30/2015
4	06481480	Skunk Creek near Chester, S. Dak.	43.8482	96.8368	262	10/1/2005–9/30/2015
5	06481500	Skunk Creek at Sioux Falls, S. Dak.	43.5336	96.7909	620	10/1/2005–9/30/2015
6	06482000	Big Sioux River at Sioux Falls, S. Dak.	43.5011	96.7484	4,642	10/1/2005–9/30/2015
7	06482020	Big Sioux River at North Cliff Avenue at Sioux Falls, S. Dak.	43.5670	96.7113	4,662	10/1/2005–9/30/2015
8	06482610	Split Rock Creek at Corson, S. Dak.	43.6164	96.5653	482	10/1/2005–9/30/2015
9	06483290	Rock River below Tom Creek at Rock Rapids, Iowa	43.4230	96.1649	853	10/1/2005–9/30/2015
10	06483500	Rock River near Rock Valley, Iowa	43.2144	96.2945	1,592	10/1/2005–9/30/2015
11	06485500	Big Sioux River at Akron, Iowa	42.8375	96.5619	7,879	10/1/2005–9/30/2015
		Floyd River Basin				
12	06600100	Floyd River at Alton, Iowa	42.9819	96.0011	268	10/1/2005–9/30/2015
13	06600500	Floyd River at James, Iowa	42.5767	96.3114	886	10/1/2005–9/30/2015
		Monona-Harrison Ditch Basin				
14	06602020	West Fork Ditch at Hornick, Iowa	42.2269	–96.0781	403	10/1/2007–9/30/2015
15	06602400	Monona-Harrison Ditch near Turin, Iowa	41.9644	–95.9920	900	10/1/2005–9/30/2015
		Little Sioux River Basin				
16	06604440	Little Sioux River at 300th St near Spencer, Iowa	43.2128	95.2392	523	10/1/2008–9/30/2015
17	06605000	Ocheyedan River near Spencer, Iowa	43.1280	95.2108	426	10/1/2005–9/30/2015
18	06605850	Little Sioux River at Linn Grove, Iowa	42.8958	95.2433	1,548	10/1/2005–9/30/2015
19	06606600	Little Sioux River at Correctionville, Iowa	42.4822	95.7926	2,500	10/1/2005–9/30/2015
20	06607200	Maple River at Mapleton, Iowa	42.1569	95.8100	669	10/1/2005–9/30/2015
21	06607500	Little Sioux River near Turin, Iowa	41.9644	95.9728	3,526	10/1/2005–9/30/2015
		Soldier River Basin				
22	06608500	Soldier River at Pisgah, Iowa	41.8305	95.9314	407	10/1/2005–9/30/2015
		Boyer River Basin				
23	06609500	Boyer River at Logan, Iowa	41.6416	95.7822	871	10/1/2005–9/30/2015
		Keg Creek Basin				
24	06805850	Keg Creek at Epperson Ave near Glenwood, Iowa	41.1021	95.7184	154	4/1/2012–9/30/2015
		Nishnabotna River Basin				
25	06807410	West Nishnabotna River at Hancock, Iowa	41.3900	95.3717	609	10/1/2005–9/30/2015
26	06808500	West Nishnabotna River at Randolph, Iowa	40.8731	95.5803	1,326	10/1/2005–9/30/2015
27	06808820	West Nishnabotna River near Riverton, Iowa	40.6871	95.6005	1,647	10/1/2008–9/30/2015
28	06809210	East Nishnabotna River near Atlantic, Iowa	41.3461	95.0769	436	10/1/2005–9/30/2015
29	06809500	East Nishnabotna River at Red Oak, Iowa	41.0086	95.2417	894	10/1/2005–9/30/2015
30	06809900	East Nishnabotna River at Riverton, Iowa	40.6946	95.5626	1,105	10/1/2008–9/30/2015
31	06810000	Nishnabotna River above Hamburg, Iowa	40.6017	95.6450	2,806	10/1/2005–9/30/2015

Table 1. U.S. Geological Survey streamflow-gaging stations used for input and calibrating the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.—Continued

[USGS, U.S. Geological Survey; latitude amd longitude in decimal degrees; mi^2, square miles; Mo., Missouri; S. Dak., South Dakota]

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
		Nodaway River Basin				
32	06817000	Nodaway River at Clarinda, Iowa	40.7433	95.0142	762	10/1/2005–9/30/2015
33	06817700	Nodaway River near Graham, Mo.	40.2025	95.0696	1,520	10/1/2005–9/30/2015
		One Hundred and Two River Basin				
34	06819185	East Fork One Hundred and Two River at Bedford, Iowa	40.6605	94.7166	85	10/1/2005–9/30/2015
35	06819500	One Hundred and Two River at Maryville, Mo.	40.3455	94.8322	515	10/1/2005–9/30/2015
36	06820410	One Hundred and Two River near Bolckow, Mo.	40.1136	94.8383	647	3/1/2008–9/30/2015
		Thompson River Basin				
37	06898000	Thompson River at Davis City, Iowa	40.6403	93.8083	701	10/1/2005–9/30/2015
38	06899500	Thompson River at Trenton, Mo.	40.0693	93.6380	1,720	10/1/2005–9/30/2015
		Chariton River Basin				
39	06903400	Chariton River near Chariton, Iowa	40.9519	93.2598	182	10/1/2005–9/30/2015
40	06903700	South Fork Chariton River near Promise City, Iowa	40.8006	93.1924	168	10/1/2005–9/30/2015
41	06903900	Chariton River near Rathbun, Iowa[1]	40.8219	92.8913	549	10/1/2005–9/30/2015
42	06904010	Chariton River near Moulton, Iowa	40.6925	92.7724	740	10/1/2005–9/30/2015
43	06904050	Chariton River at Livonia, Mo.	40.4840	92.6859	864	10/1/2005–9/30/2015

[1]Site was used as input to account for outflows from upstream reservoirs during simulations.

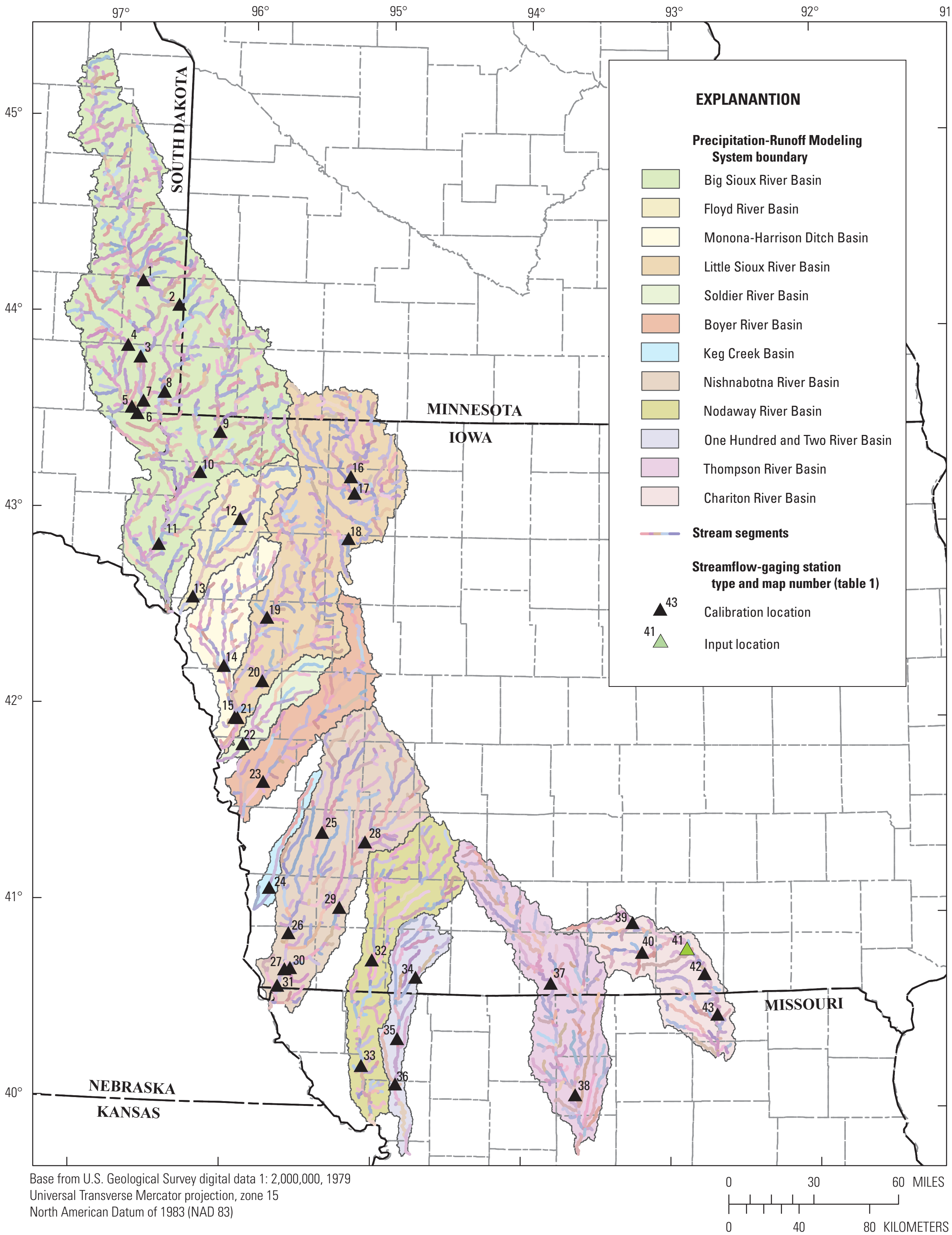

Figure 2. Simulated stream segments and U.S. Geological Survey streamflow-gaging stations providing measured data for Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.

The Nishnabotna River Basin drains about 2,975 mi^2 of southwest Iowa to the Missouri River. The Nishnabotna River Basin lies within mainly the Southern Iowa Drift Plain landform region, and very small portions of the basin are located in the Loess Hills and Missouri River Alluvial Plains landform regions (fig. 1) (Prior, 1991). The Nishnabotna River Basin is mainly agricultural land with little urban development. Seven USGS streamflow-gaging stations in the Nishnabotna River Basin were used in this study (table 1; fig. 2).

The Nodaway River Basin, in southwest Iowa, drains about 1,794 mi^2, and extends from its headwaters in Adair County, Iowa, to the Missouri River in Holt County, Missouri (fig. 1). The Nodaway River Basin is in an area of the State characterized by diverse land use across steeply rolling hills and valleys. Approximately half of the Nodaway River Basin is within the Southern Iowa Drift Plain landform region while the remaining half extends into Missouri, which does not define the landform regions (fig. 1) (Prior, 1991). Two USGS streamflow-gaging stations in the Nodaway River Basin were used in this study (table 1; fig. 2).

The One Hundred and Two River Basin, in southwest Iowa, drains about 776 mi^2 and extends from its headwaters in Adams County, Iowa, to the Missouri River in Buchanan County, Missouri (fig. 1). The One Hundred and Two River Basin is in an area of the State characterized by diverse land use across steeply rolling hills and valleys. Approximately one third of the One Hundred and Two River Basin is within the Southern Iowa Drift Plain landform region; the remaining two-thirds extend into Missouri, which does not define landform regions (fig. 1). Three USGS streamflow-gaging stations in the One Hundred and Two River Basin were used in this study (table 1; fig. 2).

The modeled portion of the Thompson River Basin drains about 2,199 mi^2 in south-central Iowa, originates in Adair County, Iowa, and flows southeast into Livingston County in Missouri (fig. 1). The Thompson River Basin lies within the Southern Iowa Drift Plain landform region, and a portion extends into Missouri, which does not define landform regions (fig. 1) (Prior, 1991). Two USGS streamflow-gaging stations in the Thompson River Basin were used in this study (table 1; fig. 2).

The modeled portion of the Chariton River Basin drains about 1,351 mi^2 in south-central Iowa, originates in Clarke and Decatur Counties, Iowa, and extends to Adair County in northern Missouri (fig. 1). The modeled area of the Chariton River Basin lies within the Southern Iowa Drift Plain landform region, and a portion is in Missouri, a State which does not define its landform regions (fig. 1). Five USGS streamflow-gaging stations in the Chariton 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 by using known physical laws and empirical relations derived from basin characteristics (Markstrom and others, 2008). The PRMS uses spatially distributed parameters to account for varying basin characteristics. A schematic diagram of how basin hydrologic processes using climate inputs are simulated in a typical PRMS model is shown in figure 3.

In the PRMS, a basin is divided into a series of spatial units called hydrologic response units (HRUs) based on hydrologic and physical characteristics such as land surface altitude, slope, aspect, vegetation type and cover, land use, soil morphology, geology, drainage boundaries, distribution of precipitation, temperature, solar radiation, and flow direction (Markstrom and others, 2008). 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. The energy and water balances are computed by the PRMS daily for each HRU (Markstrom and others, 2008).

The PRMS models of 12 river basins in western Iowa were constructed in several steps. These included the delineation of HRU boundaries to accommodate the stream network and provide streamflows at specific locations for calibration, parameterization of model HRUs and stream segments, and compilation of necessary datasets. This section describes the procedures used for delineation and parameterization of spatial features, model input of data, and model calibration and evaluation.

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).

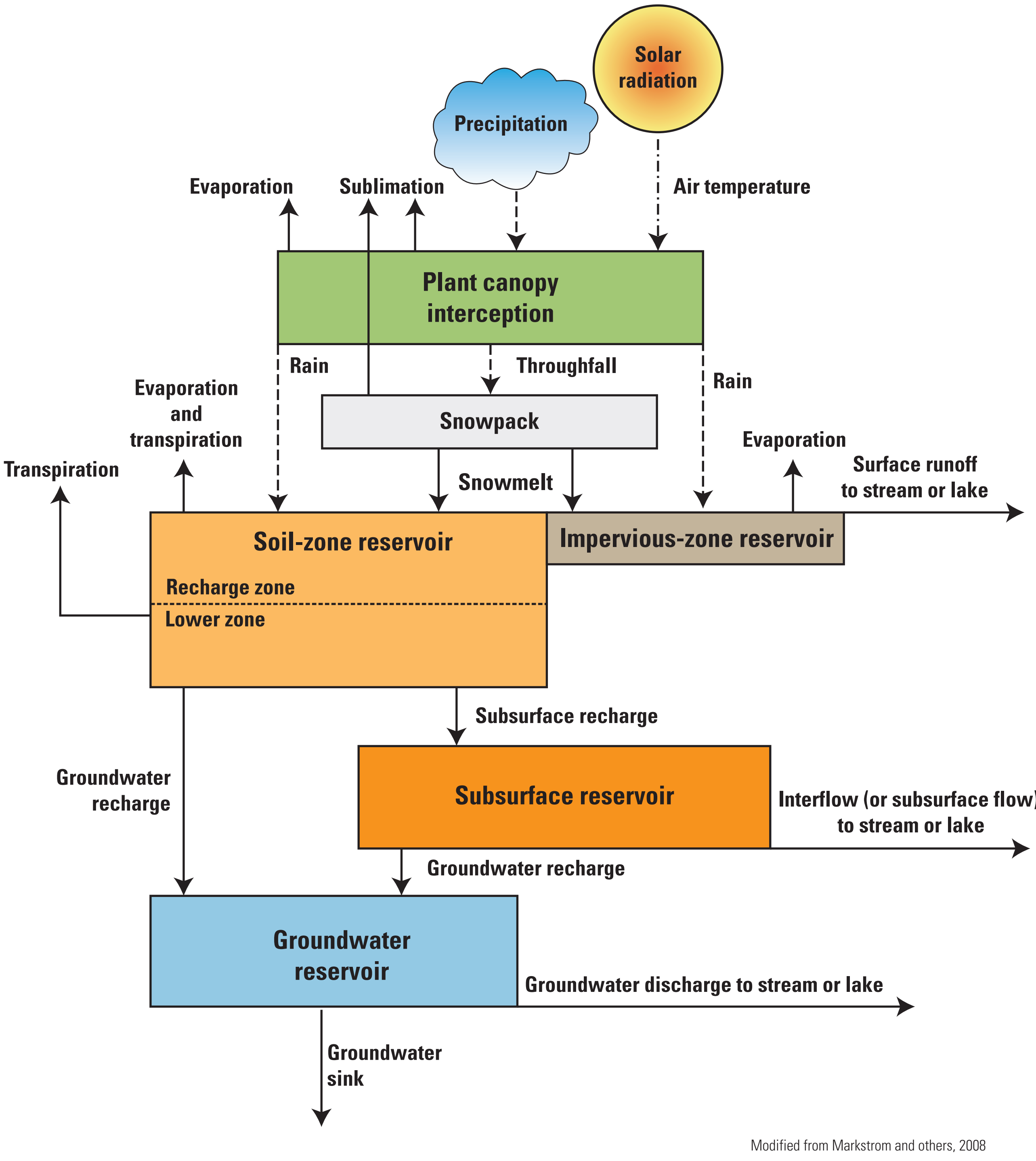

Figure 3. Schematic diagram of a basin and its meteorological inputs (precipitation, air temperature, and solar radiation) simulated by the Precipitation-Runoff Modeling System.

The GIS Weasel software (Viger and Leavesley, 2007) was used to delineate, characterize the physical features of, and estimate initial parameter values for the PRMS models of 12 river basins in western 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 Missouri River or to a downstream point within Missouri. 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 were developed to separate contributing areas from the left and right banks of each stream segment (fig. 2, fig. 4, and table 2). The HRUs and number of stream segments for the 12 basins are shown in table 2.

Model Input and Measured Data

The PRMS can use many meteorological inputs. Daily precipitation, minimum temperature, and maximum temperature were used in the PRMS models of 12 river basins in western Iowa as the main climatic drivers. In addition to meteorological inputs, PRMS models can also use streamflow-gaging station data in place of simulated streamflow. This is especially useful where flows are heavily affected by upstream regulation. For the Chariton River Basin model, data from USGS streamflow-gaging station 06903900 was used as input to 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 compiled 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 the PRMS and other environmental modeling programs. The quality-control dialog in the Downsizer program was used to select meteorological stations from the National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program that had data from January 1, 1980, to September 30, 2015 and to select stations with shorter periods of record to enhance spatial coverage within and near the basins (National Oceanic and Atmospheric Administration, 2014) (table 3). The Downsizer software program also was used to retrieve daily mean streamflow observations from USGS streamflow-gaging stations at gaged sites in the model areas from October 1, 1980, to September 30, 2015. Streamflow-gaging stations 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, 2005, to September 30, 2015, with a few exceptions (table 1). The exceptions included one station that was selected to enhance temporal calibration of streamflow with a period of record beginning in October 1981 and several stations with periods of record that began after October 2005 that were selected to enhance spatial coverage of calibration points within the basins. The 43 USGS streamflow-gaging stations and 117 meteorological stations included in the PRMS model data files of 12 river basins in western Iowa are listed in tables 1 and 3 and are shown in figures 2 and 4.

Model Calibration and Evaluation

The PRMS model was calibrated using the Let Us Calibrate (Luca) optimization 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 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. A total of 42 USGS streamflow-gaging stations throughout the 12 river basins were used for calibration with emphasis on matching the modeled simulated daily streamflow with measured daily streamflow (fig. 2; table 4). For this study, a six-step Luca calibration strategy focused on low, high, and mean flows to accurately represent all flow regimes. A basin-wide, six-step calibration of climate- and streamflow-related parameters (table 5) was initially completed, and additional calibration of subbasin streamflow parameters (table 5) was completed at selected gaged sites (table 4) to increase the parameter resolution and accuracy. One gage on the Chariton River was used for input to account for outflows from reservoirs (as discussed in "Model Input and Measured Data").

Table 2. Number of hydrologic response units and stream segments in each of the 12 PRMS models in western Iowa.

Basin name	Hydrologic response units	Stream segments
One Hundred and Two River	104	52
Big Sioux River	1 ,431	716
Boyer River	131	65
Chariton River	249	125
Floyd River	93	46
Keg Creek	14	7
Little Sioux River	664	334
Monona-Harrison Ditch	100	51
Nishnabotna River	432	216
Nodaway River	306	153
Soldier River	37	22
Thompson River	361	179

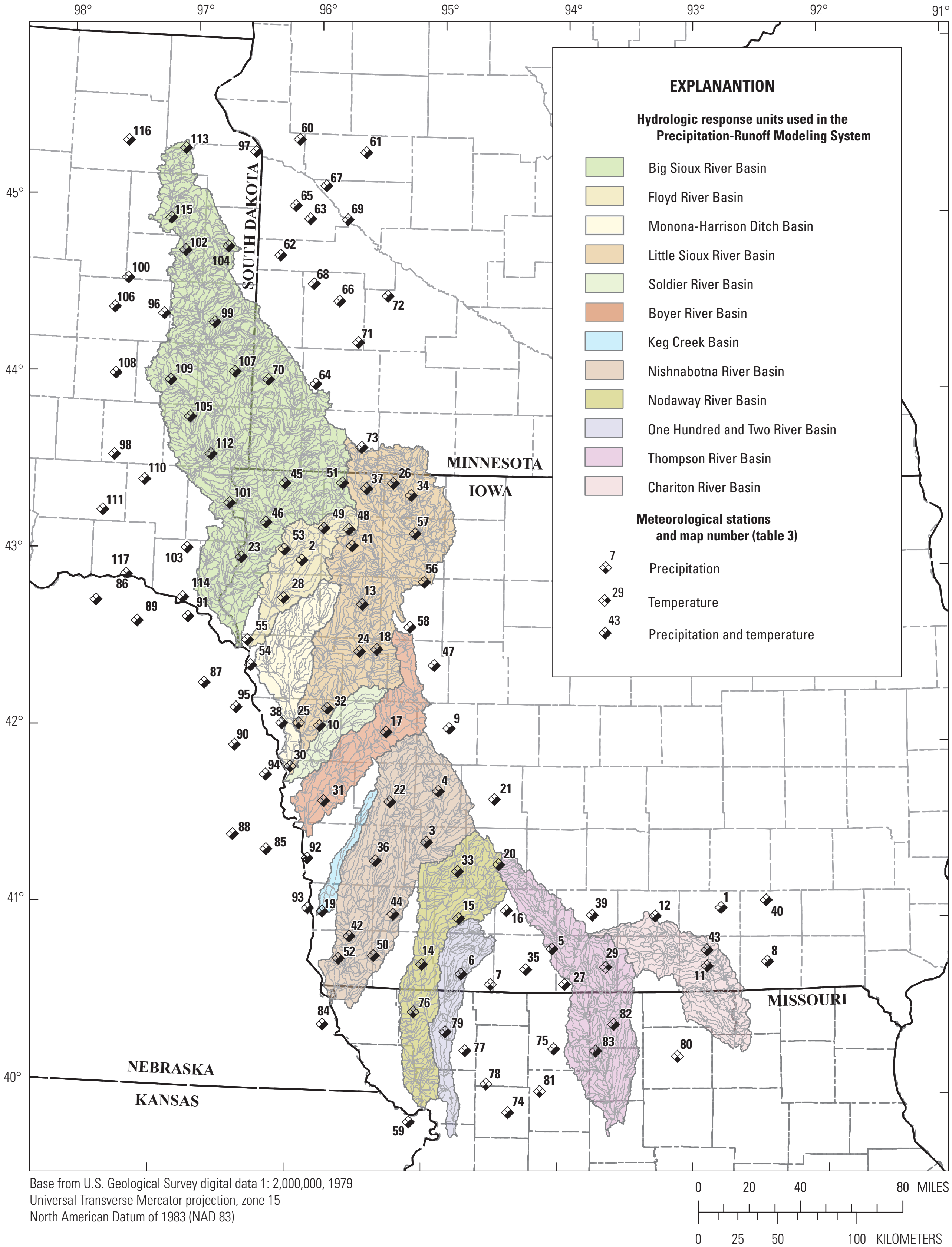

Figure 4. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations and hydrologic response units used in the 12 Precipitation-Runoff Modeling System river basin models in western Iowa.

Table 3. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.

[latitude and longitude in decimal degrees; NNE, north, northeast; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; SE, southeast; N, north; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; Kans., Kansas; Minn., Minnesota; Mo., Missouri; Nebr., Nebraska; S. Dak., South Dakota; AP, airport; WWTP, waste water treatment plant]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation (feet above sea level)	Period of record used
1	130112	Albia 3 NNE, Iowa	41.066	92.787	880	10/01/2004–09/30/2015
2	130181	Alton, Iowa	42.998	96.018	1,355	1/1/1980–09/30/2015
3	130364	Atlantic 1 NE, Iowa	41.418	95.004	1,160	10/01/2004–09/30/2015
4	130385	Audubon, Iowa	41.707	94.922	1,280	10/01/2004–09/30/2015
5	130536	Beaconsfield, Iowa	40.824	94.048	1,200	10/01/2004–09/30/2015
6	130576	Bedford, Iowa	40.674	94.724	1,190	10/01/2003–09/30/2015
7	130745	Blockton 1 W, Iowa	40.619	94.505	1,120	10/01/2003–09/30/2015
8	130753	Bloomfield 1 WNW, Iowa	40.760	92.439	812	10/01/2004–09/30/2015
9	131233	Carroll, Iowa	42.065	94.850	1,240	10/01/2004–09/30/2015
10	131277	Castana Exp Farm, Iowa	42.063	95.836	1,450	10/01/2004–09/30/2015
11	131354	Centerville, Iowa	40.733	92.890	915	10/01/2004–09/30/2015
12	131394	Chariton 1 E, Iowa	41.016	93.279	940	10/01/2004–09/30/2015
13	131442	Cherokee, Iowa	42.757	95.538	1,180	1/1/1980–09/30/2015
14	131533	Clarinda, Iowa	40.724	95.019	980	10/01/2003–09/30/2015
15	131833	Corning, Iowa	40.989	94.749	1,215	10/01/2003–09/30/2015
16	131962	Creston 2 SW, Iowa	41.037	94.394	1,320	10/01/2004–09/30/2015
17	132171	Denison, Iowa	42.036	95.329	1,401	10/01/2004–09/30/2015
18	133108	Galva, Iowa	42.503	95.418	1,400	1/1/1980–09/30/2015
19	133290	Glenwood 3 SW, Iowa	41.010	95.774	980	10/01/2004–09/30/2015
20	133438	Greenfield, Iowa	41.298	94.456	1,340	10/01/2004–09/30/2015
21	133509	Guithrie Center, Iowa	41.669	94.497	1,075	10/01/2004–09/30/2015
22	133632	Harlan, Iowa	41.640	95.288	1,360	10/01/2004–09/30/2015
23	133718	Hawarden, Iowa	43.003	96.485	1,190	1/1/1980–09/30/2015
24	133909	Holstein, Iowa	42.490	95.549	1,370	1/1/1980–09/30/2015
25	134342	Kennebec, Iowa	42.073	95.996	1,090	10/01/2004–09/30/2015
26	134561	Lake Park, Iowa	43.448	95.325	1,465	10/01/2004–09/30/2015
27	134585	Lamoni, Iowa	40.623	93.951	1,128	10/01/2004–09/30/2015
28	134735	Le Mars, Iowa	42.782	96.146	1,195	1/1/1980–09/30/2015
29	134758	Leon 6 ESE, Iowa	40.724	93.645	1,000	10/01/2004–09/30/2015
30	134874	Little Sioux 2 NW, Iowa	41.826	96.051	1,025	10/01/2004–09/30/2015
31	134894	Logan, Iowa	41.638	95.788	990	10/01/2004–09/30/2015
32	135123	Mapleton No.2, Iowa	42.162	95.784	1,200	10/01/2004–09/30/2015
33	135250	Massena, Iowa	41.255	94.765	1,325	10/01/2004–09/30/2015
34	135493	Milford 4 NW, Iowa	43.383	95.184	1,402	10/01/2004–09/30/2015
35	135769	Mount Ayer, Iowa	40.705	94.243	1,180	10/01/2004–09/30/2015
36	136151	Oakland, Iowa	41.304	95.384	1,260	10/01/2004–09/30/2015
37	136190	Ocheyedan, Iowa	43.414	95.531	1,250	1/1/1980–09/30/2015
38	136243	Onawa 3 NW, Iowa	42.070	96.126	1,060	10/01/2004–09/30/2015
39	136316	Osceola, Iowa	41.019	93.750	1,028	10/01/2004–09/30/2015

Table 3. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa. —Continued

[latitude and longitude in decimal degrees; NNE, north, northeast; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; SE, southeast; N, north; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; Kans., Kansas; Minn., Minnesota; Mo., Missouri; Nebr., Nebraska; S. Dak., South Dakota; AP, airport; WWTP, waste water treatment plant]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation (feet above sea level)	Period of record used
40	136389	Ottumwa Industrial AP, Iowa	41.108	92.447	842	10/01/2004–09/30/2015
41	136800	Primghar, Iowa	43.086	95.629	1,520	1/1/1980–09/30/2015
42	136891	Randolph, Iowa	40.874	95.567	980	10/01/2004–09/30/2015
43	136910	Rathbun Dam, Iowa	40.825	92.893	965	10/01/2004–09/30/2015
44	136940	Red Oak, Iowa	41.004	95.242	1,040	10/01/2004–09/30/2015
45	137147	Rock Rapids, Iowa	43.430	96.169	1,350	1/1/1980–09/30/2015
46	137152	Rock Valley, Iowa	43.204	96.306	1,246	1/1/1980–09/30/2015
47	137312	Sac City, Iowa	42.419	94.976	1,210	10/01/2004–09/30/2015
48	137386	Sanborn, Iowa	43.179	95.660	1,551	1/1/1980–09/30/2015
49	137594	Sheldon, Iowa	43.181	95.853	1,420	1/1/1980–09/30/2015
50	137613	Shenandoah, Iowa	40.767	95.380	975	10/01/2004–09/30/2015
51	137664	Sibley, Iowa	43.440	95.723	1,598	1/1/1980–09/30/2015
52	137669	Sidney 1 NNW, Iowa	40.745	95.642	1,120	10/01/2004–09/30/2015
53	137700	Sioux Center 2 SE, Iowa	43.056	96.153	1,360	1/1/1980–09/30/2015
54	137708	Sioux City AP, Iowa	42.391	96.379	1,095	10/01/2004–09/30/2015
55	137713	Sioux City Perry Creek, Iowa	42.536	96.411	1,200	1/1/1980–09/30/2015
56	137726	Sioux Rapids 4 E, Iowa	42.893	95.065	1,420	10/01/2004–09/30/2015
57	137844	Spencer 1 N, Iowa	43.165	95.147	1,326	10/01/2004–09/30/2015
58	137979	Storm Lake, Iowa	42.635	95.169	1,425	10/01/2004–09/30/2015
59	148250	Troy 3 N, Kans.	39.828	95.088	1,040	10/01/2004–09/30/2015
60	210287	Artichoke Lake, Minn.	45.378	96.154	1,093	1/1/1980–09/30/2015
61	210667	Benson, Minn.	45.317	95.617	1,040	1/1/1980–09/30/2015
62	211263	Canby, Minn.	44.718	96.270	1,243	1/1/1980–09/30/2015
63	212038	Dawson, Minn.	44.932	96.045	1,055	1/1/1980–09/30/2015
64	214534	Lake Wilson, Minn.	43.998	95.957	1,650	1/1/1980–09/30/2015
65	214994	Madison WWTP, Minn.	45.003	96.166	1,080	1/1/1980–09/30/2015
66	215204	Marshall, Minn.	44.471	95.791	1,152	1/1/1980–09/30/2015
67	215400	Milan 1 NW, Minn.	45.122	95.927	1,020	1/1/1980–09/30/2015
68	215482	Minneota, Minn.	44.563	95.997	1,211	1/1/1980–09/30/2015
69	215563	Montevideo 1 SW, Minn.	44.934	95.746	990	1/1/1980–09/30/2015
70	216565	Pipestone, Minn.	44.014	96.326	1,705	1/1/1980–09/30/2015
71	218323	Tracy, Minn.	44.239	95.631	1,403	1/1/1980–09/30/2015
72	218520	Vesta, Minn.	44.508	95.411	1,062	1/1/1980–09/30/2015
73	219170	Worthington 2 NNE, Minn.	43.645	95.580	1,570	1/1/1980–09/30/2015
74	230143	Amity 4 NE, Mo.	39.891	94.360	974	10/01/2004–09/30/2015
75	230608	Bethany, Mo.	40.258	94.027	949	10/01/2004–09/30/2015
76	231141	Burlington Junction 1 NW, Mo.	40.453	95.073	922	10/01/2003–09/30/2015
77	231822	Conception, Mo.	40.239	94.683	1,108	10/01/2003–09/30/2015
78	234505	King City, Mo.	40.051	94.525	1,102	10/01/2003–09/30/2015

Table 3. National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa. —Continued

[latitude and longitude in decimal degrees; NNE, north, northeast; W, west; WSW, west, southwest; SE, southeast; WNW, west, northwest; S, south; E, east; NE, northeast; SE, southeast; N, north; NNW, north, northwest; SW, southwest; NW, northwest; SSW, south, southwest; Kans., Kansas; Minn., Minnesota; Mo., Missouri; Nebr., Nebraska; S. Dak., South Dakota; AP, airport; WWTP, waste water treatment plant]

Map number (fig. 4)	Station number	Meteorological station name	Latitude (north)	Longitude (west)	Elevation (feet above sea level)	Period of record used
79	235340	Maryville 2 E, Mo.	40.346	94.834	985	10/01/2003–09/30/2015
80	235578	Milan, Mo.	40.221	93.110	840	10/01/2004–09/30/2015
81	236563	Pattonsburg 2 S, Mo.	40.015	94.129	825	10/01/2004–09/30/2015
82	236866	Princeton, Mo.	40.399	93.584	980	10/01/2004–09/30/2015
83	237963	Spickard 7 W, Mo.	40.247	93.716	875	10/01/2004–09/30/2015
84	250435	Auburn 5 ESE, Nebr.	40.371	95.747	930	10/01/2004–09/30/2015
85	250781	Bennington 3 WSW, Nebr.	41.354	96.209	1,245	10/01/2004–09/30/2015
86	252037	Crofton, Nebr.	42.736	97.497	1,400	1/1/1980–09/30/2015
87	252715	Emerson, Nebr.	42.282	96.726	1,445	10/01/2004–09/30/2015
88	253050	Fremont, Nebr.	41.430	96.467	1,180	10/01/2004–09/30/2015
89	253630	Hartington, Nebr.	42.617	97.261	1,370	1/1/1980–09/30/2015
90	255050	Lyons, Nebr.	41.938	96.479	1,280	10/01/2004–09/30/2015
91	255895	Newcastle, Nebr.	42.653	96.873	1,350	1/1/1980–09/30/2015
92	256255	Omaha Eppley Airfield, Nebr.	41.310	95.899	982	10/01/2004–09/30/2015
93	256795	Plattsmouth 1 E, Nebr.	41.027	95.883	1,005	10/01/2004–09/30/2015
94	258480	Tekamah, Nebr.	41.777	96.233	1,140	10/01/2004–09/30/2015
95	258935	Walthill 1 E, Nebr.	42.151	96.476	1,280	10/01/2004–09/30/2015
96	390281	Arlington 1 W, S. Dak.	44.363	97.170	1,824	1/1/1980–09/30/2015
97	390662	Big Stone City 2 NW, S. Dak.	45.299	96.500	1,117	1/1/1980–09/30/2015
98	391032	Bridgewater, S. Dak.	43.553	97.502	1,446	1/1/1980–09/30/2015
99	391076	Brookings 2 NE, S. Dak.	44.325	96.769	1,632	1/1/1980–09/30/2015
100	391102	Bryant, S. Dak.	44.555	97.469	1,830	1/1/1980–09/30/2015
101	391392	Canton, S. Dak.	43.306	96.592	1,345	1/1/1980–09/30/2015
102	391519	Castlewood, S. Dak.	44.727	97.026	1,685	1/1/1980–09/30/2015
103	391579	Centerville 6 SE, S. Dak.	43.043	96.903	1,260	1/1/1980–09/30/2015
104	391777	Clear Lake, S. Dak.	44.759	96.687	1,815	1/1/1980–09/30/2015
105	391851	Colton, S. Dak.	43.785	96.928	1,620	1/1/1980–09/30/2015
106	392302	De Smet, S. Dak.	44.387	97.561	1,761	1/1/1980–09/30/2015
107	392984	Flandreau, S. Dak.	44.052	96.593	1,600	1/1/1980–09/30/2015
108	394037	Howard, S. Dak.	44.012	97.524	1,558	1/1/1980–09/30/2015
109	395090	Madison 2 SE, S. Dak.	43.991	97.093	1,660	1/1/1980–09/30/2015
110	395228	Marion, S. Dak.	43.421	97.257	1,450	1/1/1980–09/30/2015
111	395481	Menno, S. Dak.	43.236	97.571	1,324	1/1/1980–09/30/2015
112	397667	Sioux Falls AP, S. Dak.	43.578	96.754	1,428	1/1/1980–09/30/2015
113	398116	Summit 1 W, S. Dak.	45.304	97.063	1,955	1/1/1980–09/30/2015
114	398622	Vermillion 2 SE, S. Dak.	42.763	96.919	1,190	1/1/1980–09/30/2015
115	398932	Watertown Regional AP, S. Dak.	44.905	97.149	1,748	1/1/1980–09/30/2015
116	399004	Webster, S. Dak.	45.333	97.523	1,855	1/1/1980–09/30/2015
117	399502	Yankton 2 E, S. Dak.	42.878	97.363	1,180	1/1/1980–09/30/2015

Table 4. Nash Sutcliffe efficiency, coefficient of determination, percent bias, and root mean square error-observation standard deviation ratio statistic values at all U.S. Geological Survey streamflow-gaging station locations used for calibration periods in the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.

[Red indicates that statistic value below satisfactory rating level; USGS, U.S. Geological Survey; Mo., Missouri; S. Dak., South Dakota; NSE, Nash Sutcliffe efficiency; R^2, coefficient of determination; PBIAS, percent bias; RSR, root mean square error–observation standard deviation ratio ; na, not applicable]

Map number (fig. 2)	USGS station number	USGS station name	NSE	R^2	PBIAS	RSR
		Big Sioux River Basin				
1	06480000	Big Sioux River near Brookings, S. Dak.	0.72	0.73	–4.5	0.53
2	06480650	Flandreau Creek above Flandreau, S. Dak.	0.52	0.52	3.9	0.69
3	06481000	Big Sioux River near Dell Rapids, S. Dak.	0.78	0.79	–3.2	0.47
4	06481480	Skunk Creek near Chester, S. Dak.	0.59	0.6	–19	0.64
5	06481500	Skunk Creek at Sioux Falls, S. Dak.	0.67	0.67	–11	0.58
6	06482000	Big Sioux River at Sioux Falls, S. Dak.	0.65	0.66	4.6	0.59
7	06482020	Big Sioux River at North Cliff Avenue at Sioux Falls, S. Dak.	0.79	0.8	–8.9	0.46
8	06482610	Split Rock Creek at Corson, S. Dak.	0.68	0.68	–5.9	0.56
9	06483290	Rock River below Tom Creek at Rock Rapids, Iowa	0.64	0.64	–1.6	0.6
10	06483500	Rock River near Rock Valley, Iowa	0.67	0.68	–3.7	0.57
11	06485500	Big Sioux River at Akron, Iowa	0.76	0.76	–3.7	0.49
		Floyd River Basin				
12	06600100	Floyd River at Alton, Iowa	0.35	0.36	–3.9	0.81
13	06600500	Floyd River at James, Iowa	0.77	0.77	–0.3	0.48
		Monona-Harrison Ditch Basin				
14	06602020	West Fork Ditch at Hornick, Iowa	0.69	0.69	2.4	0.56
15	06602400	Monona-Harrison Ditch near Turin, Iowa	0.69	0.69	–2.1	0.56
		Little Sioux River Basin				
16	06604440	Little Sioux River at 300th St near Spencer, Iowa	0.56	0.56	–7.1	0.67
17	06605000	Ocheyedan River near Spencer, Iowa	0.63	0.63	3.5	0.61
18	06605850	Little Sioux River at Linn Grove, Iowa	0.63	0.63	–11.2	0.61
19	06606600	Little Sioux River at Correctionville, Iowa	0.65	0.66	–7.4	0.59
20	06607200	Maple River at Mapleton, Iowa	0.65	0.65	–1.9	0.59
21	06607500	Little Sioux River near Turin, Iowa	0.69	0.7	–5.6	0.56
		Soldier River Basin				
22	06608500	Soldier River at Pisgah, Iowa	0.58	0.58	1.9	0.65
		Boyer River Basin				
23	06609500	Boyer River at Logan, Iowa	0.73	0.74	–3.4	0.52
		Keg Creek Basin				
24	06805850	Keg Creek at Epperson Ave near Glenwood, Iowa	0.43	0.43	–3.8	0.76
		Nishnabotna River Basin				
25	06807410	West Nishnabotna River at Hancock, Iowa	0.67	0.68	–1.8	0.57
26	06808500	West Nishnabotna River at Randolph, Iowa	0.73	0.73	1.5	0.52
27	06808820	West Nishnabotna River near Riverton, Iowa	0.61	0.63	8.1	0.62
28	06809210	East Nishnabotna River near Atlantic, Iowa	0.61	0.61	–3.6	0.62
29	06809500	East Nishnabotna River at Red Oak, Iowa	0.7	0.7	–0.8	0.55
30	06809900	East Nishnabotna River at Riverton, Iowa	0.55	0.6	5.9	0.67
31	06810000	Nishnabotna River above Hamburg, Iowa	0.68	0.71	–0.8	0.56

Table 4. Nash Sutcliffe efficiency, coefficient of determination, percent bias, and root mean square error-observation standard deviation ratio statistic values at all U.S. Geological Survey streamflow-gaging station locations used for calibration periods in the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.—Continued

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Map number (fig. 2)	USGS station number	USGS station name	NSE	R^2	PBIAS	RSR
		Nodaway River Basin				
32	06817000	Nodaway River at Clarinda, Iowa	0.56	0.56	–3.2	0.66
33	06817700	Nodaway River near Graham, Mo.	0.61	0.61	–4.9	0.63
		One Hundred and Two River Basin				
34	06819185	East Fork One Hundred and Two River at Bedford, Iowa	0.37	0.38	1.1	0.79
35	06819500	One Hundred and Two River at Maryville, Mo.	0.48	0.5	–5.8	0.72
36	06820410	One Hundred and Two River near Bolckow, Mo.	0.56	0.56	–6.2	0.66
		Thompson River Basin				
37	06898000	Thompson River at Davis City, Iowa	0.56	0.57	–14.3	0.66
38	06899500	Thompson River at Trenton, Mo.	0.67	0.67	–10.6	0.58
		Chariton River Basin				
39	06903400	Chariton River near Chariton, Iowa	0.46	0.55	–3.3	0.74
40	06903700	South Fork Chariton River near Promise City, Iowa	0.39	0.42	–5.5	0.78
41	06903900	Chariton River near Rathbun, Iowa[1]	na	na	na	na
42	06904010	Chariton River near Moulton, Iowa	0.78	0.78	–1.9	0.47
43	06904050	Chariton River at Livonia, Mo.	0.71	0.71	–0.9	0.54

[1]Site used for histroical streamflows.

Table 5. Calibrated parameters and Let Us Calibrate (Luca) calibration steps for the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.

[PRMS, Precipitation-Runoff Modeling System; nmonth, 12 months; one, one basin-wide value; ET, evapotranspiration; nhru, number of Hydrologic Response Units; nssr, number of subsurface reservoirs, equal to nhru; ngw, number of groundwater reservoirs, equal to nhru; nseg, number of model segments; NRMSE, Normalized Root Mean Square Error]

Calibration data set	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	Linear gravity-flow 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 exceed 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	0–0.1	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.

Table 5. Calibrated parameters and Let Us Calibrate (Luca) calibration steps for the Precipitation-Runoff Modeling System models of 12 river basins in western Iowa.—Continued

[PRMS, Precipitation-Runoff Modeling System; nmonth, 12 months; one, one basin-wide value; ET, evapotranspiration; nhru, number of Hydrologic Response Units; nssr, number of subsurface reservoirs, equal to nhru; ngw, number of groundwater reservoirs, equal to nhru; nseg, number of model segments; NRMSE, Normalized Root Mean Square Error]

Calibration data set	Objective function	PRMS parameter	Dimensions	Range	Parameter description
		Calibration step 5			
Daily flow	NRMSE:	gwflow_coef[1]	ngw	0.001–0.89	Groundwater routing coefficient.
	1.Daily high 2.Monthly high	soil2gw_max[1]	nhru	0–0.5	Maximum value for capillary reservoir excess to groundwater reservoir.
		ssr2gw_rate[1]	nssr	0.05–0.8	Coefficient to route water from gravity reservoir to groundwater reservoir.
		Calibration step 6			
Daily flow	NRMSE:	K_coef[1]	nseg	1–24	Muskingum storage coefficient.
	1.Daily	slowcoef_sq[1]	nhru	0–1	Nonlinear gravity-flow reservoir routing coefficient.
		fastcoef_sq[1]	nhru	0–1	Nonlinear preferential-flow routing coeficient.

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

Four statistical tests were used to evaluate model performance for how well each PRMS model of the 12 river basins simulated 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). The NSE is a normalized statistic that provides a measure of how well simulated values match measured data. NSE values range from $-\infty$ to 1. Values less than 0 indicate that the mean measured streamflow is a better predictor than simulated streamflow. A value of 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 the PRMS. However, daily values may be lower than 0.50 and still be 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 to 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 0.50 are considered satisfactory (Gassman and others, 2007).

The PBIAS measures the average tendency of the simulated data to be larger or smaller than its observed 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). If the RSR is between 0 and 0.50, then performance is very good. If the RSR is between 0.50 and 0.60, then performance is good. An RSR between 0.60 and 0.70 is satisfactory, and an RSR greater than 0.70 is unsatisfactory (Moraisi and others, 2007).

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

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

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

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

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

where

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

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

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

$\underline{Q}_{sim,i}$ 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 12 river basins in western Iowa were evaluated using NSE, R^2, PBIAS, and RSR at 42 calibration locations (fig. 2; table 4). The NSE, R^2, PBIAS, and RSR daily values for the period used for calibration are listed for each of these locations (table 4).

Simulation of Daily Streamflow for 12 River Basins in Western Iowa Using the Precipitation-Runoff Modeling System

The estimates of PRMS models of 12 river basins in western Iowa for daily streamflow at most USGS streamflow-gaging stations varied in accuracy when compared to measured daily streamflow data. Based on statistical results, the 12 western Iowa River basin PRMS models are a good fit for daily streamflow estimation at most locations because PBIAS and RSR ratings range from very good to good, and NSE and R^2 ratings are satisfactory (table 4). Some headwater locations show unsatisfactory ratings. Results from the 12 western Iowa River Basin models are presented below.

The Big Sioux River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at all streamflow-gaging stations (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06485500, shows that for the period (October 1, 2005, to September 30, 2015), model output estimates peak timing and volumes well but underestimates some peak flow volumes and overestimates the lower flow volumes (fig. 5).

Graph showing a comparison of measured and simulated flow (October 1, 2005, through September 30, 2015) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of 12 river basins in western Iowa, water years 2006–15.

The Floyd River Basin PRMS model also meets the criteria for satisfactory fit or better for streamflow estimation at 1 of its 2 streamflow-gaging stations (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06600500, shows that for the period (October 1, 2005, to September 30, 2015), model output estimates peak timing and volumes (fig. 5). Peak flow events that happen during the winter months (January, February, and March) are a mix of over- and underestimated, possibly because of the effects of frozen ground (which are not captured in the version of the model used for this study), an underestimation of rainfall in a rain-snow event, or an underestimation of snowmelt runoff. The model also underestimates the record peak flows during 2013 and 2014. These two exceptions and minor base flow discrepancies could be improved upon with more extensive and informed calibration.

The Monona-Harrison Ditch Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at all streamflow-gaging stations (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06602400, shows that for the period (October 1, 2005, to September 30, 2015), model output estimates peak timing and volumes; however, peak flow volumes tend to be underestimated, which could be related to frozen ground or rain on snow events (fig. 5).

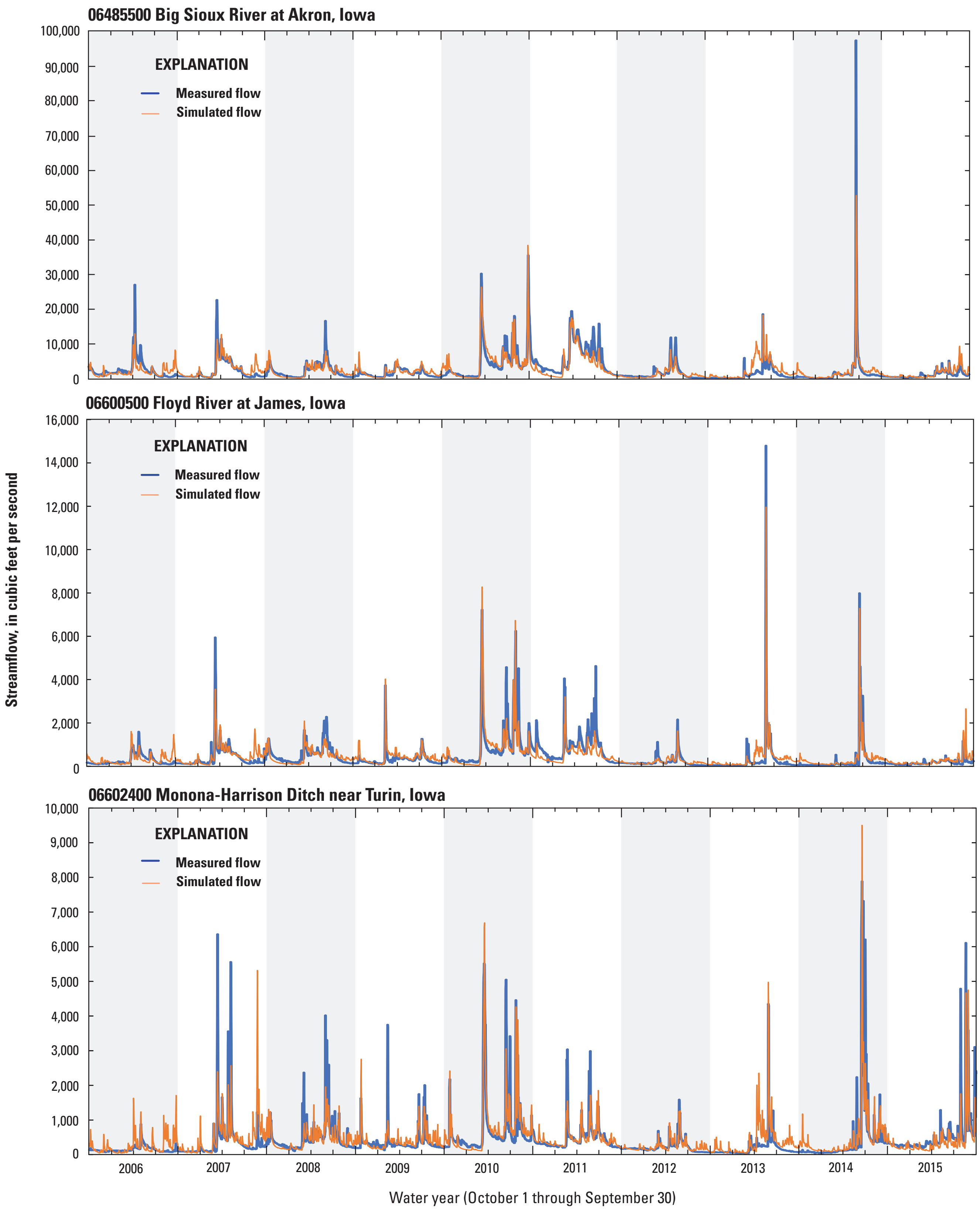

Figure 5. A comparison of measured and simulated flow (October 1, 2005, through September 30, 2015) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of 12 river basins in western Iowa, water years 2006–15.

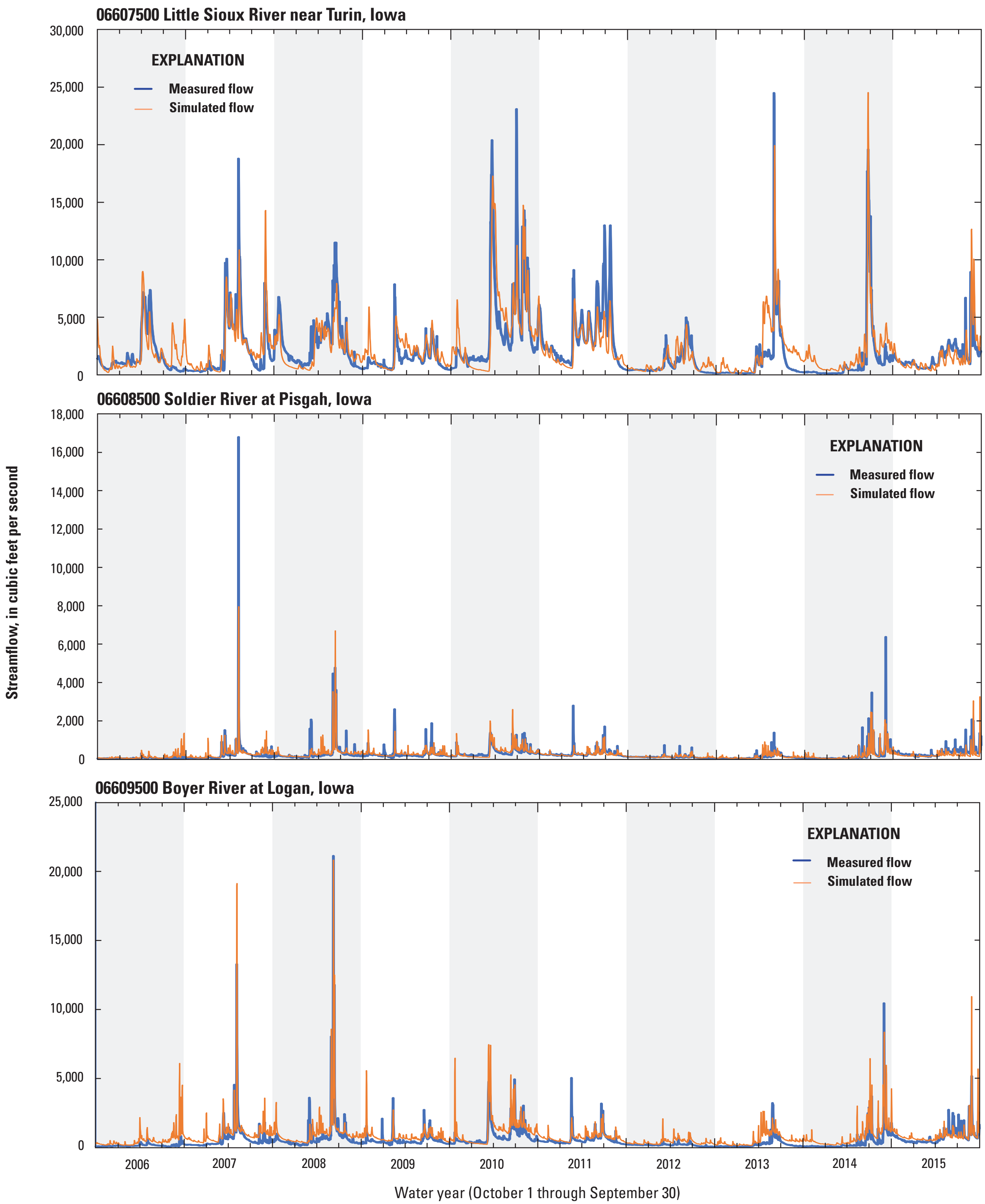

Figure 5. A comparison of measured and simulated flow (October 1, 2005, through September 30, 2015) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of 12 river basins in western Iowa, water years 2006–15.—Continued

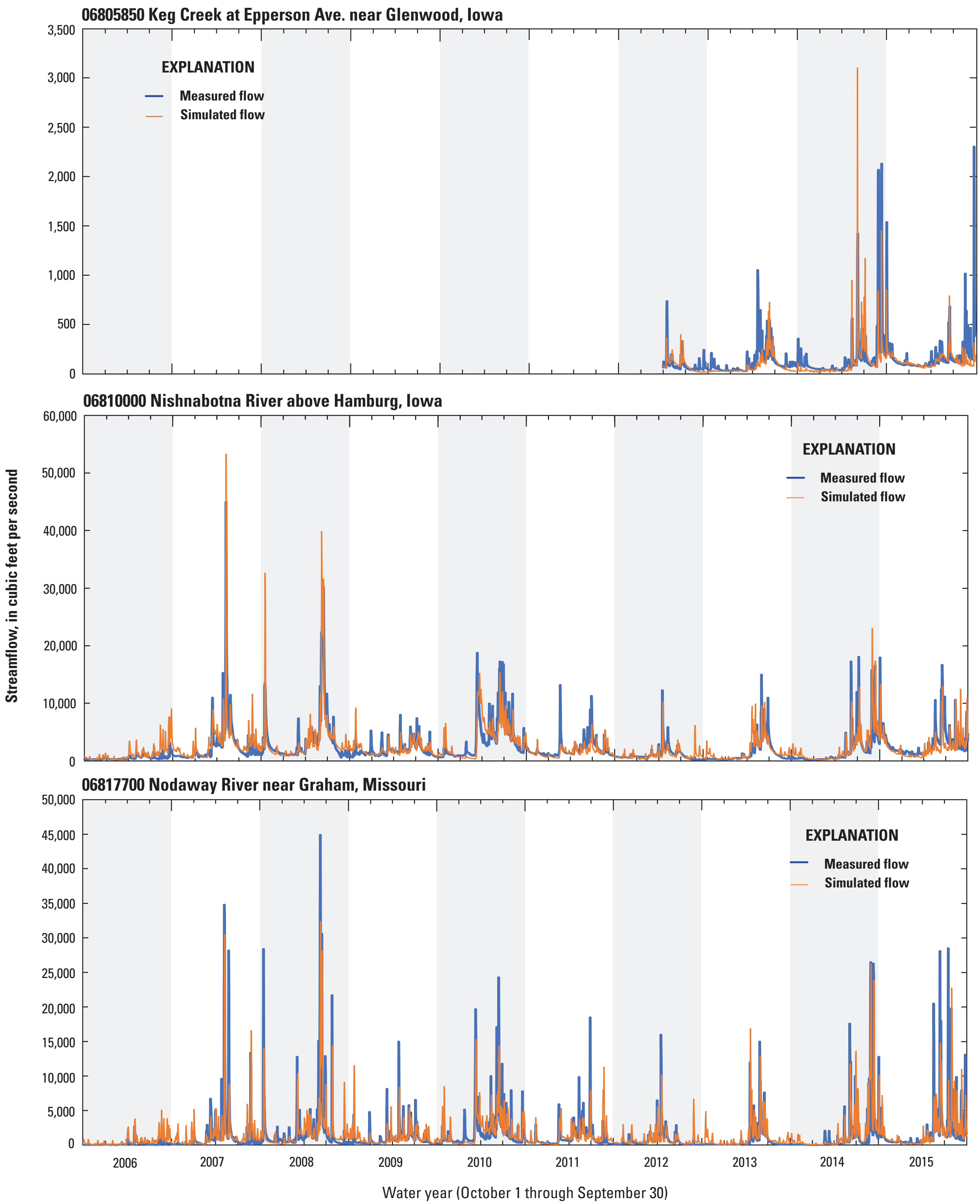

Figure 5. A comparison of measured and simulated flow (October 1, 2005, through September 30, 2015) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of 12 river basins in western Iowa, water years 2006–15.—Continued

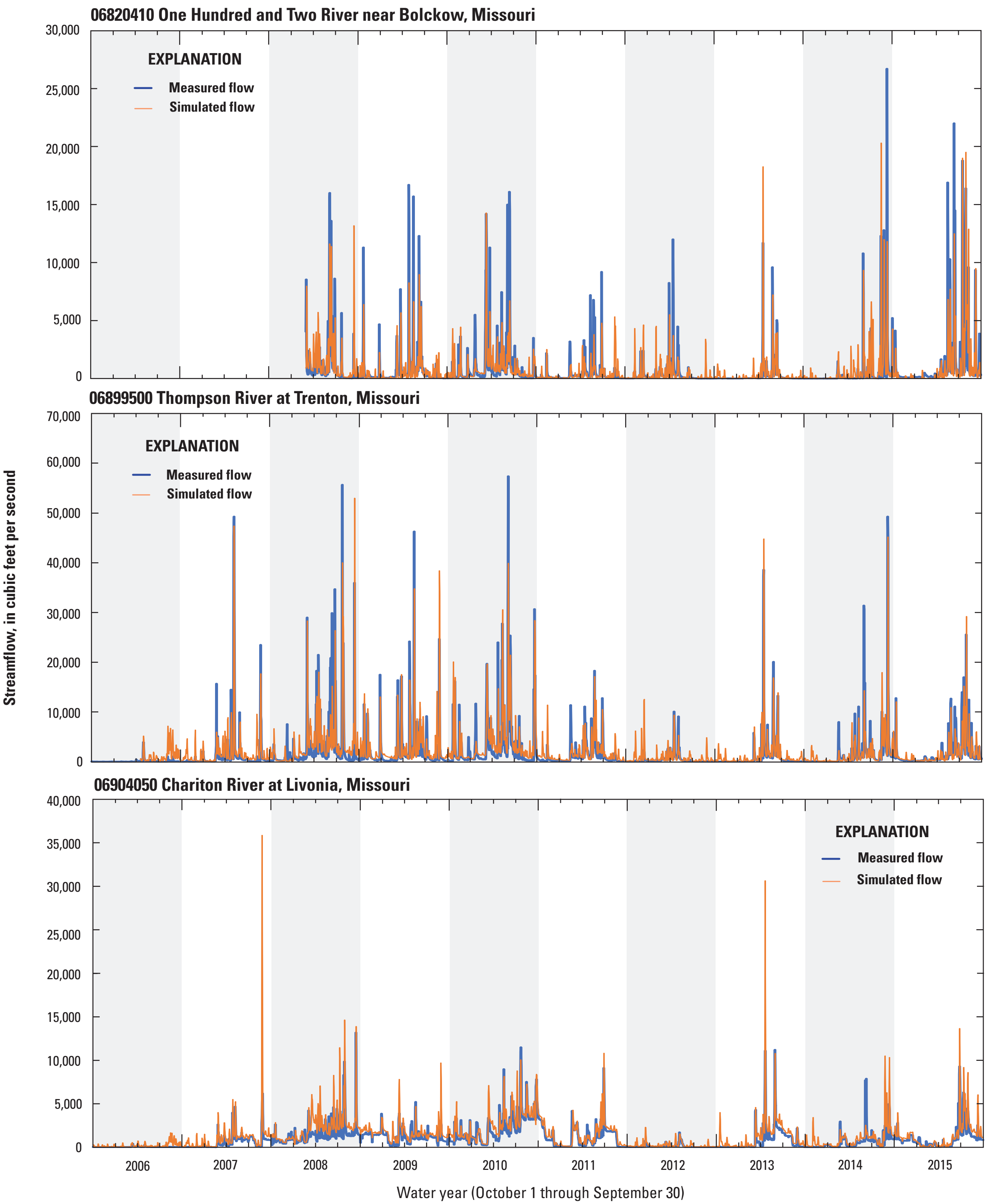

Figure 5. A comparison of measured and simulated flow (October 1, 2005, through September 30, 2015) at selected U.S. Geological Survey streamflow-gaging stations used in calibrating Precipitation-Runoff Modeling System models of 12 river basins in western Iowa, water years 2006–15.—Continued

The Little Sioux River Basin PRMS model exceeds the minimum criteria for satisfactory fit or better for streamflow estimation at all six streamflow-gaging stations. A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 006607500, shows that for the period (October 1, 2005, to September, 30, 2015), model output estimates peak timing and volumes; however, peak flow volumes during higher flows tend to be underestimated (table 4; fig. 5).

The Soldier River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at the single streamflow-gaging station in the basin. A comparison of simulated and measured streamflow at streamflow-gaging station 06608500, which is near the outlet, indicates that for the period (October 1, 2005, to September 30, 2015), model output estimates timing of peak flows; however, peak flow volumes tend to be underestimated (table 4; fig. 5).

The Boyer River Basin PRMS model also exceeds the minimum criteria for satisfactory fit or better for streamflow estimation at the one streamflow-gaging station (table 3). A comparison of simulated and measured streamflow at streamflow-gaging station 06609500, which is near the outlet, indicates that for the period (October 1, 2005, to September 30, 2015), model output estimates peak flow timing; however, lower flows tend to be overestimated (table 4; fig. 5).

The Keg Creek Basin PRMS model did not meet the criteria for satisfactory fit or better for streamflow estimation at the one streamflow-gaging station (table 4). In general, model results were less than satisfactory for basins draining less than 270 mi^2 (table 4.). A comparison of simulated and measured streamflow at streamflow-gaging station 06805850, which is near the outlet, indicates that for the period (April, 1, 2012 to September 30, 2015), model output estimates peak timing; however, peak flow volumes tend to be underestimated (table 4; fig. 5).

The Nishnabotna River Basin PRMS model exceeds the minimum criteria for satisfactory fit or better for streamflow estimation at all seven streamflow-gaging stations (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06810000, shows that for the period (October 1, 2005, to September 30, 2015), model output estimates peak flow timing and volumes; however, peak flow volumes during lower flows tend to be underestimated, whereas peak flow volumes during higher flows tend to be overestimated (table 4; fig. 5).

The Nodaway River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at both streamflow-gaging stations in the basin (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06817700, shows that for the period (October 1, 2005, to September 30, 2015), the model output estimates peak flow timing, but tends to underestimate peak flow volumes (table 4; fig. 5).

The One Hundred and Two River Basin PRMS model meets the criteria for satisfactory fit or better for 1 of 3 streamflow-gaging stations (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06820410, shows that for the period (March 1, 2008, to September 30, 2015), model output estimates peak flow timing and volumes; however, peak flow volumes during lower flows tend to be overestimated, whereas peak flow volumes during higher flows tend to be underestimated (table 4; fig. 5).

The Thompson River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at both streamflow-gaging stations in the basin (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06899500, shows that for the period (October 1, 2005, to September 30, 2015), model output estimates peak flow timing and volumes; however, peak flow volumes during lower flows tend to be overestimated, whereas peak flow volumes during higher flows tend to be underestimated (table 4; fig. 5).

The Chariton River Basin PRMS model meets the criteria for satisfactory fit or better for streamflow estimation at 2 of 4 streamflow-gaging stations (table 4). A comparison of simulated and measured streamflow at the streamflow-gaging station nearest to the outlet, station 06904050, shows that for the period (October 1, 2005, to September 30, 2015), model output estimates peak flow timing; however, peak flow volumes during lower flows tend to be overestimated (table 4; fig. 5).

Overall, the PRMS models of 12 river basins in western Iowa constructed for this investigation satisfactorily estimate daily streamflow at 36 of the 42 calibration gaged sites as indicated by the NSE, R^2, PBIAS, and RSR values presented in table 4. In general, gaged sites in headwater subbasins having small drainage areas and streamflows tended to have less accuracy than the main-stem gaged sites with larger drainage areas and streamflows. The graphs in figure 5 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; (4) the availability and accuracy of meteorological input data; and (5) the sizes of the drainages areas of all but one basin where results were unsatisfactory were less than 270 mi^2. In addition, streamflow is simulated at a daily time step, and thus shorter-duration, flashy streamflow events are not well-represented. A more robust subdaily modeling routine may be necessary for the smaller headwater subbasins to accurately reflect flashy, sub-daily 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, the calibrated models can provide satisfactory streamflow estimates throughout 11 of 12 river basins in western Iowa at a model HRU and stream segment scale (table 4). 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

Some of the limitations to the 12 PRMS river basin models in western Iowa include use by the PRMS of model parameters generated by the GIS Weasel that are dependent upon soil, vegetation, land cover, and urbanization input datasets (see “Delineation and Parameterization of Spatial Features”). These datasets are not current, 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 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 temperature and precipitation for all HRUs within the 12 river basins in western Iowa is shown in figure 4. Temperature and precipitation can vary over small distances, and this variability may not be captured by meteorological stations. As an 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. The lack of accurate meteorological data over each basin can contribute 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 computations that are driving the PRMS model (Kalin and Hantush, 2006).

Several notable limitations are specific to PRMS in this and other studies. First, the PRMS models have a daily time step, and all flows and storages are expressed as daily mean values. As noted previously, error may result because of the daily averaging of flashy flows near land surface 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 due to the parameter’s monthly time step. This third 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, simulations are complicated when rain falls on the snowpack in excess of its available pore space. Under that condition, either the water will run off the snowpack, and it is erroneously considered to be snowmelt, or the water will freeze to the snowpack, thus 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.

An additional source of uncertainty in the PRMS model used for this study may be the use of 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. Studies by Kingston and others (2009) and Donohue and others (2010) show that this uncertainty is reduced because the PRMS uses simulated PET, vegetation type, land-use characteristics, soil type, simulated atmospheric conditions, and soil moisture availability to compute actual evapotranspiration, and it is actual evapotranspiration that the PRMS models 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 148 realtime 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 throughout Iowa 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. Precipitation-Runoff Modeling System (PRMS) models were constructed in cooperation with the Iowa Department of Natural Resources for 12 river basins in western 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 12 river basins in western Iowa that are tributaries to the Missouri River; Big Sioux River, Floyd River, Monona-Harrison Ditch, Little Sioux River, Soldier River, Boyer River, Keg

Creek, Nishnabotna River, Nodaway River, One Hundred and Two River, Thompson River, and Chariton River basins. The construction, calibration, and evaluation of PRMS basin models to simulate daily streamflows and hydrologic components for river basins in western Iowa are discussed. Model performance is assessed to determine the ability of PRMS models to estimate streamflow and the suitability for the 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 using known physical laws and empirical relations derived from basin characteristics. The 12 river basins in western Iowa were delineated with the GIS Weasel software. The GIS Weasel was used to characterize the physical features of each river basin in western Iowa into the requisite sets of parameters for input into the PRMS.

Daily precipitation, minimum temperature, and maximum temperature were used in the PRMS models of 12 river basins in western Iowa as the main climatic drivers. In addition to meteorological inputs, the 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 optimization program, which is a multiple-objective, stepwise procedure.

Overall, PRMS models of 12 river basins in western Iowa constructed for this investigation satisfactorily estimate daily streamflow at 36 of the 42 calibration gaged sites as indicated by the Nash Sutcliffe efficiency, coefficient of determination, percent bias, and root mean square error-observation standard deviation ratio statistics 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; (4) the availability and accuracy of meteorological input data; and (5) all but one basin where results were unsatisfactory were less than 270 mi^2. In addition, the version of the PRMS used for this study averaged 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 12 river basins in western Iowa can provide satisfactory streamflow estimates at model hydrologic response units and stream segment scale. The PRMS models will provide a consistent and documented method for estimating streamflow at locations within the basins that may not have available USGS streamflow-gaging station information.

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Back cover photograph, top. The East Nishnabotna River near Atlantic, looking upstream. Photograph by U.S. Geological Survey, Iowa Water Science Center.

Back cover photograph, bottom. The East Nishnabotna River at Riverton, looking downstream. Photograph by U.S. Geological Survey, Iowa Water Science Center.

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