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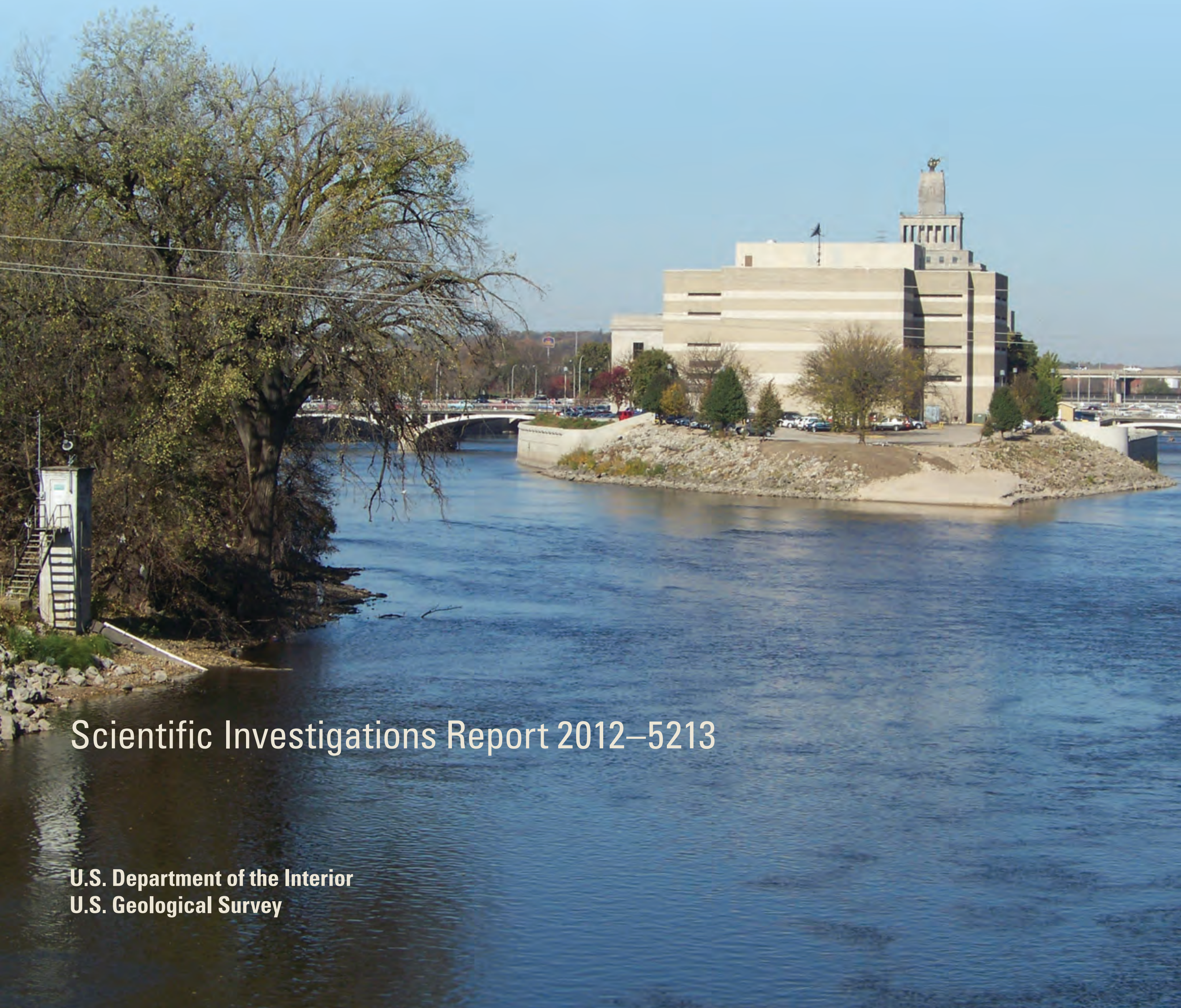
# Simulation of Daily Streamflows at Gaged and Ungaged Locations within the Cedar River Basin, Iowa, Using a Precipitation-Runoff Modeling System Model



Scientific Investigations Report 2012–5213

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

**Cover.** Cedar River at Cedar Rapids, Iowa looking upstream from the 8th Ave bridge, and U.S. Geological Survey streamflow-gaging station 05464500 Cedar River at Cedar Rapids, Iowa. Photograph by Kaylene F. Carney, U.S. Geological Survey.

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

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U.S. Geological Survey, Reston, Virginia: 2012

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# Acknowledgments

The author would like to express gratitude to the Iowa Department of Natural Resources, Iowa Geological and Water Survey for their assistance in project planning. The author would also like to express appreciation to other USGS personnel who assisted with the collection and analysis of streamflow and GIS-related information used in this study.

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# Tables



# Conversion Factors

Inch/Pound to SI

| 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 ($m^3/s$) |

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NAVD 29).

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

Altitude, as used in this report, refers to distance above the vertical datum.

# Simulation of Daily Streamflows at Gaged and Ungaged Locations within the Cedar River Basin, Iowa, Using a Precipitation-Runoff Modeling System Model

By Daniel E. Christiansen

## Abstract

The U.S. Geological Survey, in cooperation with the Iowa Department of Natural Resources, conducted a study to examine techniques for estimation of daily streamflows using hydrological models and statistical methods. This report focuses on the use of a hydrologic model, the U.S. Geological Survey's Precipitation-Runoff Modeling System, to estimate daily streamflows at gaged and ungaged locations. The Precipitation-Runoff Modeling System is a modular, physically based, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on surface-water runoff and general basin hydrology. The Cedar River Basin was selected to construct a Precipitation-Runoff Modeling System model that simulates the period from January 1, 2000, to December 31, 2010. The calibration period was from January 1, 2000, to December 31, 2004, and the validation periods were from January 1, 2005, to December 31, 2010 and January 1, 2000 to December 31, 2010.

A Geographic Information System tool was used to delineate the Cedar River Basin and subbasins for the Precipitation-Runoff Modeling System model and to derive parameters based on the physical geographical features. Calibration of the Precipitation-Runoff Modeling System model was completed using a U.S. Geological Survey calibration software tool. The main objective of the calibration was to match the daily streamflow simulated by the Precipitation-Runoff Modeling System model with streamflow measured at U.S. Geological Survey streamflow gages. The Cedar River Basin daily streamflow model performed with a Nash-Sutcliffe efficiency ranged from 0.82 to 0.33 during the calibration period, and a Nash-Sutcliffe efficiency ranged from 0.77 to -0.04 during the validation period. The Cedar River Basin model is meeting the criteria of greater than 0.50 Nash-Sutcliffe and is a good fit for streamflow conditions for the calibration period at all but one location, Austin, Minnesota. The Precipitation-Runoff Modeling System model accurately simulated streamflow at four of six uncalibrated sites within the basin. Overall, there was good agreement between simulated and measured seasonal and annual volumes throughout the basin for calibration and validation sites. The calibration period ranged from 0.2 to 20.8 percent difference, and the validation period ranged from 0.0 to 19.5 percent difference across all seasons and total annual runoff. The Precipitation-Runoff Modeling System model tended to underestimate lower streamflows compared to the observed streamflow values. This is an indication that the Precipitation-Runoff Modeling model needs more detailed groundwater and storage information to properly model the low-flow conditions in the Cedar River Basin.

## 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, accumulated during many years, constitute a valuable data base for developing an improved understanding of the water resources of the State. Surface-water data for Iowa include records of stage, discharge, and water quality of streams as well as stage of lakes and reservoirs. The USGS maintains approximately 170 real-time streamflow gages in Iowa where daily mean streamflow information is available (U.S. Geological Survey, 2011). Iowa has 71,000 miles of rivers and streams (Iowa Department of Natural Resources, 2000), and the gaged sites on those streams only account for a very limited picture 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 at ungaged sites in Iowa. The streamflow estimates would aid the water-resource managers in environmental studies, hydraulic design, water management, and water-quality projects across the State. A Cedar River Basin Precipitation-Runoff Modeling System (PRMS) model (Leavesley and others, 1983; Markstrom and others, 2008) was constructed in cooperation with the IDNR as part of an ongoing research project to examine methods of estimating daily streamflow at gaged and ungaged locations.

# Purpose and Scope

This report documents a distributed-parameter, physically based, PRMS model (Leavesley and others, 1983; Markstrom and others, 2008) constructed for the Cedar River Basin. The report discusses the construction, calibration, and validation of the Cedar River Basin PRMS model and evaluates the suitability of the model as a predictive tool to estimate daily streamflows at gaged and ungaged locations. The constructed PRMS model simulates daily streamflows for the Cedar River Basin from January 1, 2000, to December 31, 2010.

# Description of Study Area

The Cedar River Basin drains from northwest to southeast across eastern Iowa. The Cedar River Basin at its confluence with the Iowa River has a drainage area of 7,819 square miles ($mi^2$), of which 1,024 $mi^2$ are in Minnesota (Schwob, 1963). The Cedar River Basin includes four landform regions in Iowa (fig. 1)—the Des Moines Lobe, the Iowan Surface, the Southern Iowa Drift Plain, and the Iowa-Cedar Lowland (Prior, 1991; Prior and others, 2009). A detailed description of landform regions can be found in Prior (1991) and Prior and others (2009) as well as in Linhart and Eash (2010).

The headwaters of the Cedar River originate in south-central Minnesota and flow in a southeasterly direction to its confluence with the Iowa River in southeastern Iowa (fig. 1). Cedar River Basin land use is predominately agricultural with two large urban areas—the City of Waterloo in Black Hawk County and the City of Cedar Rapids in Linn County. Table 1 and figure 2 show the 14 USGS streamflow-gaging stations that are included in this study. A detailed description of the Cedar River Basin can be found in Linhart and Eash (2010).

# Modeling Methods and Techniques

The cooperative project developed a PRMS (Leavesley and others, 1983; Markstrom and others, 2008) model for the Cedar River Basin. The calibration of the PRMS model was completed using the Luca (**L**et **u**s **ca**librate) software, a multiple-objective, stepwise, automated procedure for hydrologic model calibration (Hay and Umemoto, 2006). The following sections of this report describe the PRMS model and the methods used to develop the Cedar River Basin PRMS model. In addition, a description of Luca and the techniques used within Luca to calibrate the PRMS model are discussed in subsequent sections.

## Model Development

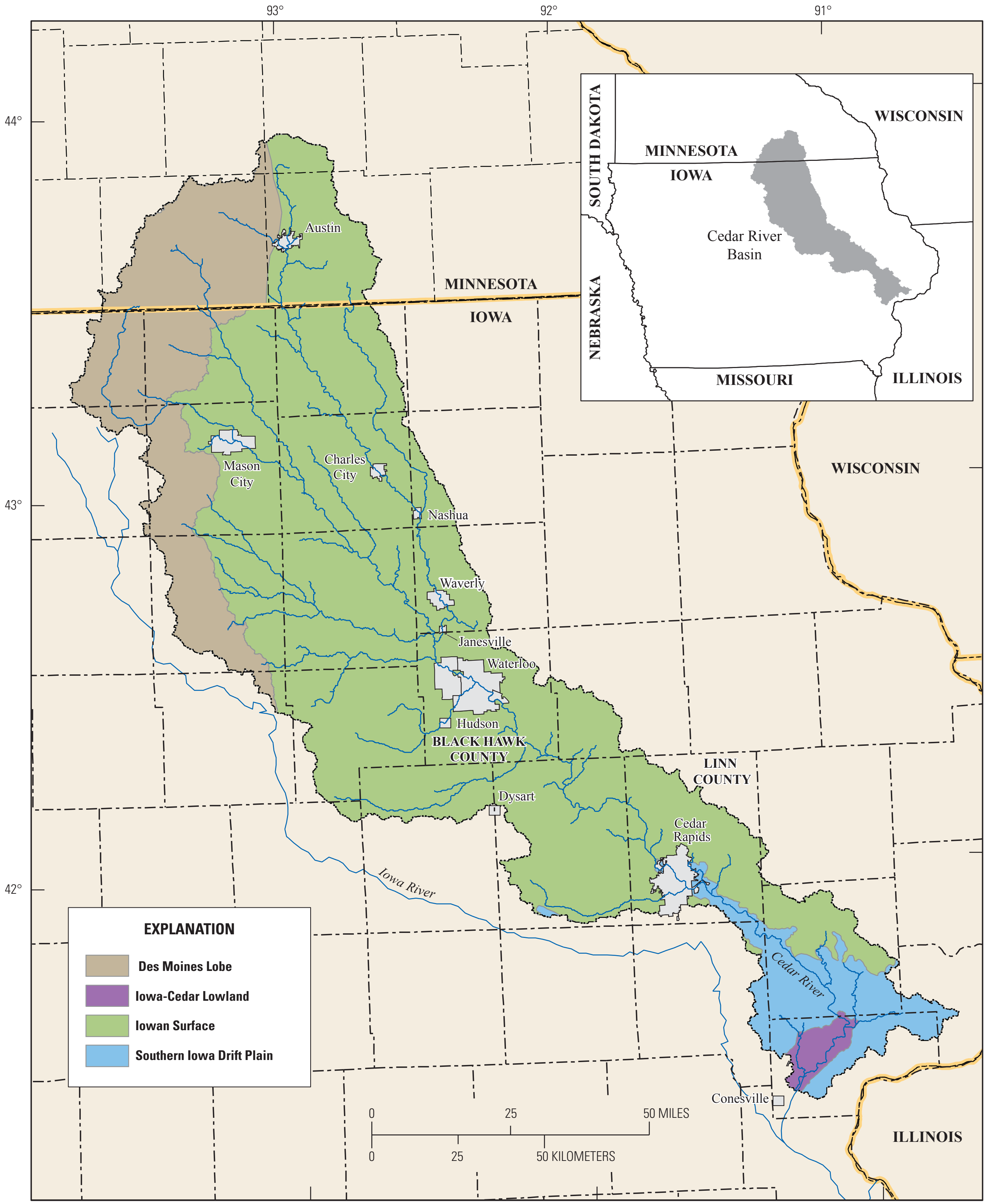
The PRMS modeling software was selected as the tool for hydrologic watershed simulation for the Cedar River Basin. PRMS is a modular, distributed parameter, physical process watershed model developed to evaluate the effects of various combinations of precipitation, climate, and land use on surface-water runoff (Leavesley and others, 1983; Leavesley and others, 1996). PRMS simulates the hydrologic system with known physical laws and empirical relations derived from watershed characteristics (Markstrom and others, 2008). PRMS is designed to account for spatially distributed parameters and watershed characteristics. Figure 3 shows a schematic diagram of how watershed and meteorological inputs are simulated in the PRMS model. The watershed 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). HRUs receive and produce streamflow to and from each other, to the atmosphere, 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 are instantaneously and fully mixed. Energy and a water balance are computed by PRMS daily for each HRU (Markstrom and others, 2008).

The development of the Cedar River Basin PRMS model involved several organizational steps to compile the necessary data sets to construct the model. In the development of the PRMS model, HRU boundaries were delineated to accommodate the stream network and provide streamflows at specific locations for calibration and validation. This section describes the procedures used to prepare input data sets, watershed discretization, and parameterization for the Cedar River Basin PRMS model.

### Precipitation-Runoff Modeling System (PRMS) Input and Measured Data

The PRMS model minimally requires precipitation and minimum and maximum air temperature as the main climate drivers. PRMS can handle many meteorological inputs; precipitation, minimum and maximum temperature, solar radiation, and potential evapotranspiration were used as the climatic inputs for the Cedar River Basin model.

The streamflow-gaging station data and meteorological data sets for precipitation and temperature were collected using the USGS Downsizer program (Ward-Garrison and




Base from U.S. Geological Survey digital data, 2006, 1:24,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983 (NAD 83)

Landform regions from Prior, Kohrt, and Quade,
Iowa Geological Survey, 2006 (edited 2009)

**Figure 1.** Cedar River Basin landform regions.

others, 2009). The Downsizer computer application selects, downloads, verifies, and formats station-based time-series data for PRMS and other environmental modeling programs. The Downsizer report (Ward-Garrison and others, 2009) details the processes used within the application for downloading the data file. The quality-control dialog in Downsizer was used to select meteorological stations that had data from January 1, 2000, through September 30, 2009. The Downsizer database at the time of this modeling effort was populated until September 30, 2009, the solar radiation, potential evapotranspiration, and additional climatic data from October 1, 2009, to December 31, 2010, for meteorological stations were collected from the Iowa Environmental Mesonet located at the Web site *http://mesonet.agron.iastate.edu/agclimate/index.phtml*. Meteorological stations that had large amounts of missing or bad data values were removed from the PRMS input data list. The 23 meteorological stations, including the solar radiation and potential evapotranspiration station at Nashua, Ia. (map letter W), that were included in the PRMS model data file are shown in table 2 and figure 2. The Downsizer software program also was used to retrieve streamflow-gaging station daily observations at 14 sites from January 1, 2000, to September 30, 2009. Data from October 1, 2009, to December 31, 2010, were obtained from the USGS National Water Information System (U.S. Geological Survey, 2011). Four streamflow record locations for the calendar year 2000 were incomplete: Wolf Creek at Dysart, Iowa; Black Hawk Creek, at Hudson, Iowa; Cedar River at Waverly, Iowa; and Cedar River at Charles City, Iowa. For these sites, measured streamflow data sets covered the period from October 1, 2001, to December 31, 2010. The 14 streamflow sites were selected based upon having a minimum period of record of 5 years. Table 1 lists the streamflow-gaging stations that were included in the model and figure 2 shows the locations of the streamflow-gaging stations and meteorological stations spatially distributed across the entire basin.

## Watershed Discretization and Parameterization

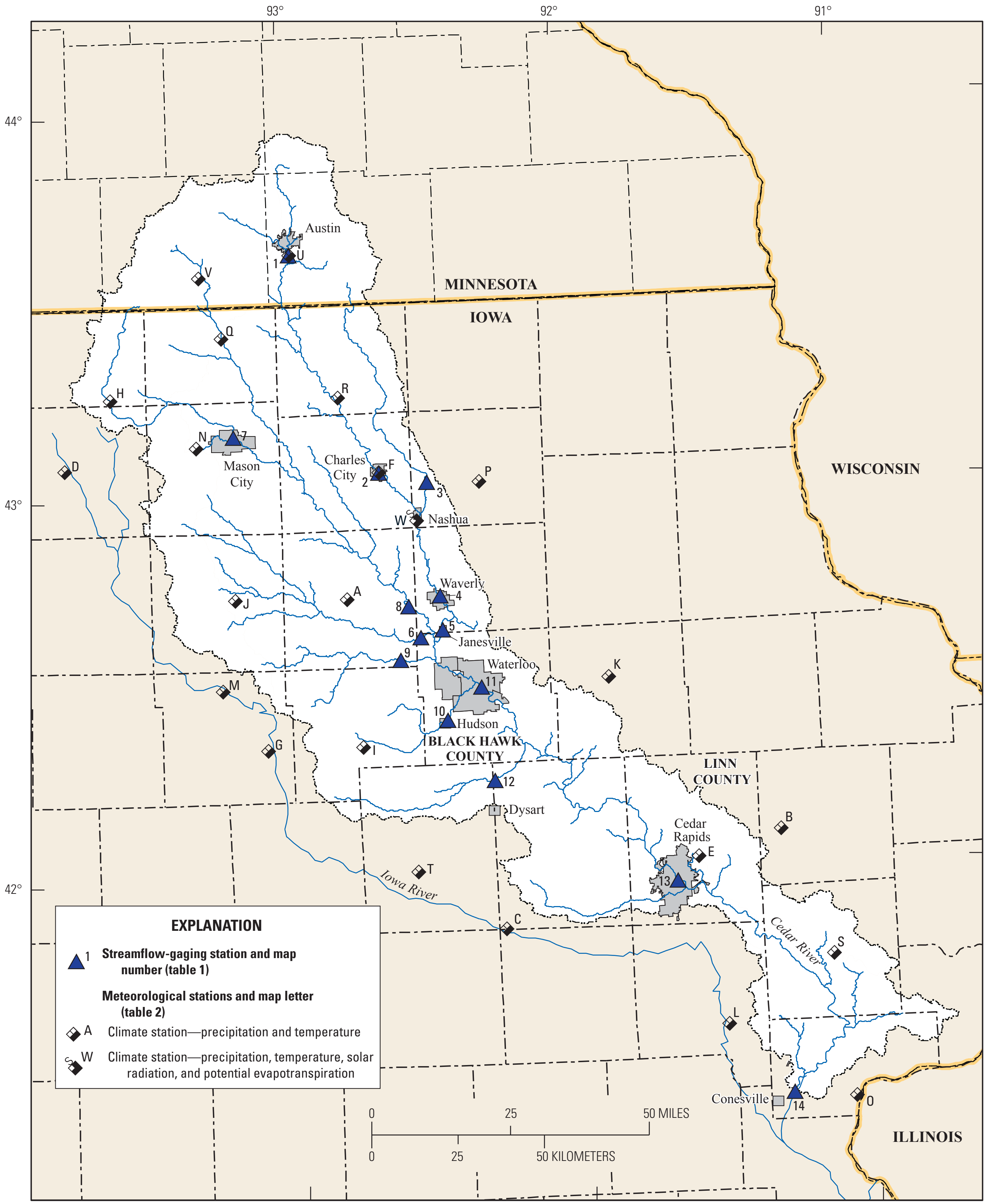
For this study, a geospatial database was created for use within a Geographic Information System (GIS) to support model discretization, to characterize the physical features of the watershed, and to estimate PRMS model parameters. The geospatial database consisted of National Land Cover Data Base, Percent 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 USGS National Elevation Dataset (NED) (U.S. Geological Survey, 2007; Homer and others, 2007; U.S. Department of Agriculture, 1994).

**Table 1.** U.S. Geological Survey streamflow-gaging stations used in the Cedar River Basin Precipitation-Runoff Modeling System model.

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

| 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 |
|---|---|---|---|---|---|---|
| 1 | [1]05457000 | Cedar River near Austin, Minnesota | 43°38′14″ | 92°58′28″ | 399 | 01/01/2000 – 12/31/2010 |
| 2 | 05457700 | Cedar River at Charles City, Iowa | 43°03′44″ | 92°40′25″ | 1,054 | 10/01/2001 – 12/31/2010 |
| 3 | [1]05458000 | Little Cedar River near Ionia, Iowa | 43°01′60″ | 92°30′12″ | 306 | 01/01/2000 – 12/31/2010 |
| 4 | 05458300 | Cedar River at Waverly, Iowa | 42°44′14″ | 92°28′12″ | 1,547 | 10/01/2001 – 12/31/2010 |
| 5 | 05458500 | Cedar River at Janesville, Iowa | 42°38′54″ | 92°27′54″ | 1,661 | 01/01/2000 – 12/31/2010 |
| 6 | [1]05458900 | West Fork Cedar River at Finchford, Iowa | 42°37′46″ | 92°32′36″ | 846 | 01/01/2000 – 12/31/2010 |
| 7 | [1]05459500 | Winnebago River at Mason City, Iowa | 43°09′54″ | 93°11′33″ | 526 | 01/01/2000 – 12/31/2010 |
| 8 | 05462000 | Shell Rock River at Shell Rock, Iowa | 42°42′43″ | 92°34′58″ | 1,746 | 01/01/2000 – 12/31/2010 |
| 9 | [1]05463000 | Beaver Creek at New Hartford, Iowa | 42°34′22″ | 92°37′04″ | 347 | 01/01/2000 – 12/31/2010 |
| 10 | [1]05463500 | Black Hawk Creek at Hudson, Iowa | 42°24′28″ | 92°27′47″ | 303 | 10/01/2001 – 12/31/2010 |
| 11 | 05464000 | Cedar River at Waterloo, Iowa | 42°29′44″ | 92°20′03″ | 5,146 | 01/01/2000 – 12/31/2010 |
| 12 | [1]05464220 | Wolf Creek near Dysart, Iowa | 42°15′06″ | 92°17′55″ | 299 | 10/01/2001 – 12/31/2010 |
| 13 | 05464500 | Cedar River at Cedar Rapids, Iowa | 41°58′19″ | 91°40′01″ | 6,510 | 01/01/2000 – 12/31/2010 |
| 14 | [1]05465000 | Cedar River near Conesville, Iowa | 41°24′33″ | 91°17′25″ | 7,787 | 01/01/2000 – 12/31/2010 |

[1]Sites used in calibration of the Precipitation-Runoff Modeling System model.




Base from U.S. Geological Survey digital data, 2006, 1:24,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983 (NAD 83)

**Figure 2.** Cedar River Basin streamflow-gaging and meteorological stations.

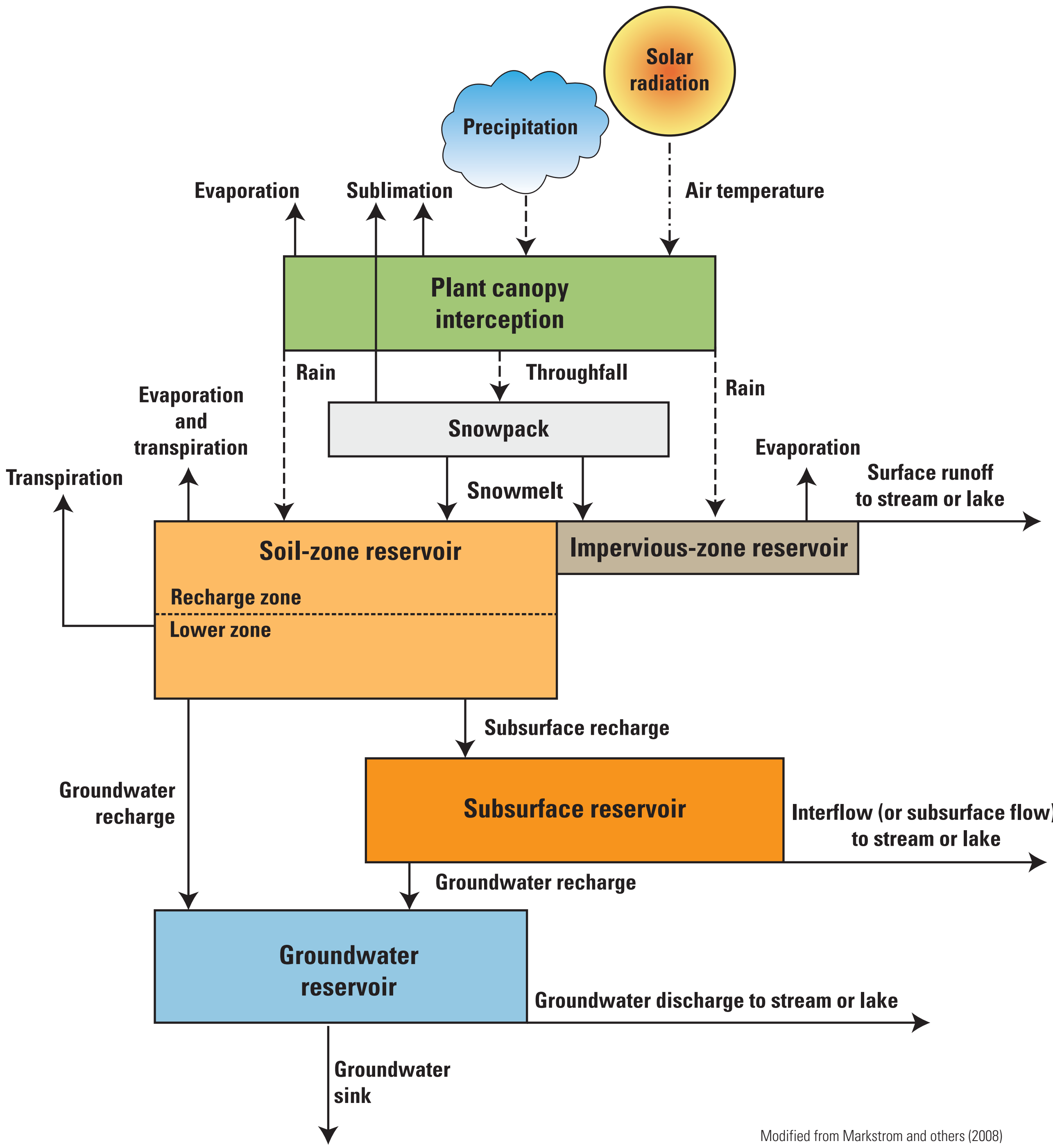



**Figure 3.** Schematic diagram of a watershed and its meteorological inputs (precipitation, air temperature, and solar radiation) simulated by Precipitation-Runoff Modeling System. Figure modified from Leavesley and others (1983).

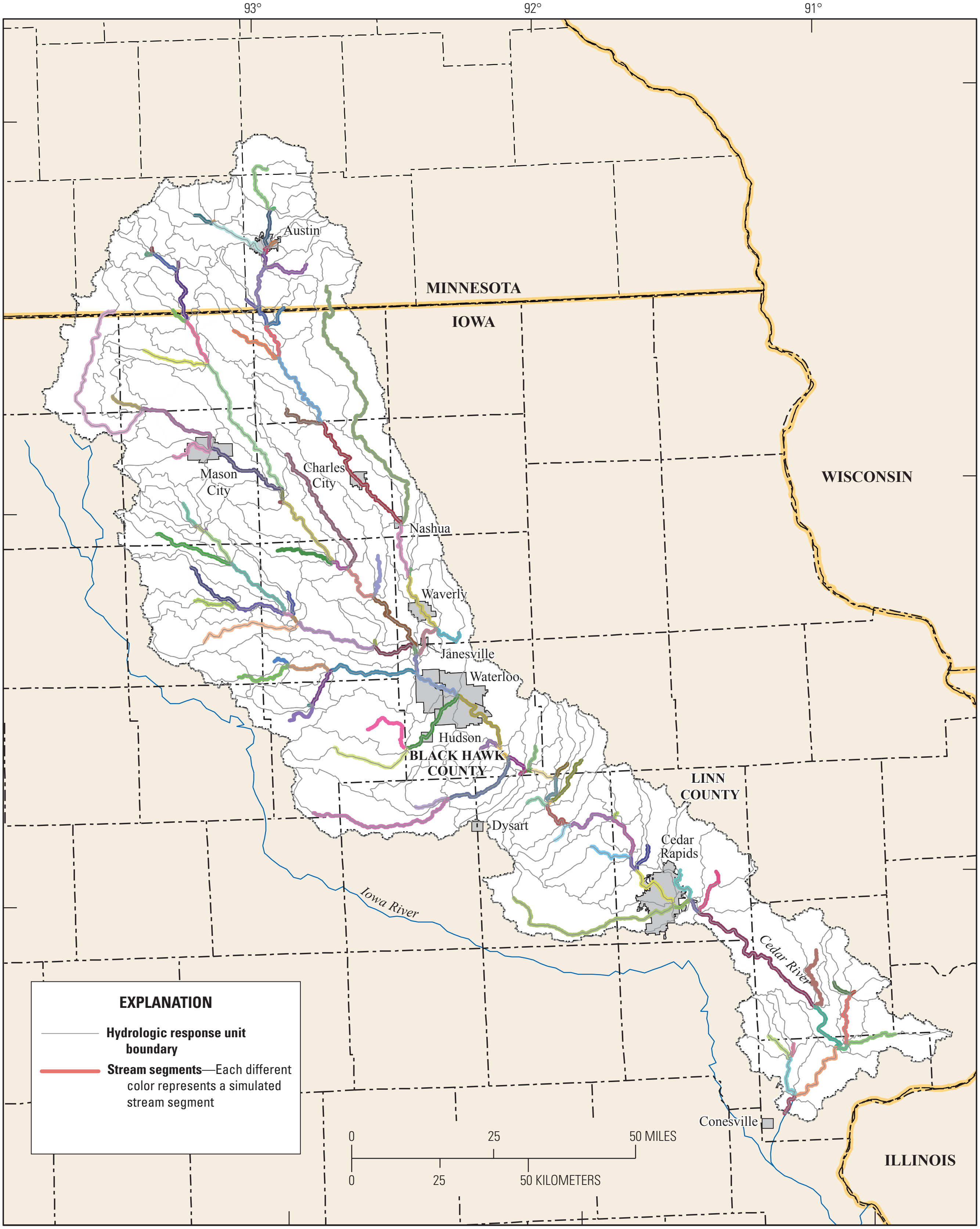
**Table 2.** National Oceanic and Atmospheric Administration's National Weather Service Cooperative Observer Program meteorological stations used in the Cedar River Basin Precipitation-Runoff Modeling System model.

[Latitude and longitude in degrees, minutes, and seconds; WNW, west, northwest; NNE, north, northeast; N, north]

| Map letter (fig. 2) | Number | Meteorological station name | Latitude (north) | Longitude (west) | Altitude (feet) | Period of record used |
|---|---|---|---|---|---|---|
| A | 130157 | Allison, Iowa | 42°45′14″ | 92°48′07″ | 1,048 | 01/01/2000 – 12/31/2010 |
| B | 130213 | Anamosa, Iowa; 1 WNW | 42°06′43″ | 92°16′34″ | 805 | 01/01/2000 – 12/31/2010 |
| C | 130600 | Belle Plaine, Iowa | 41°52′52″ | 91°17′35″ | 810 | 01/01/2000 – 12/31/2010 |
| D | 130923 | Britt, Iowa | 43°06′07″ | 93°48′04″ | 1,240 | 01/01/2000 – 12/31/2010 |
| E | 131319 | Cedar Rapids, Iowa; 1 | 42°03′00″ | 91°35′17″ | 810 | 01/01/2000 – 12/31/2010 |
| F | 131402 | Charles City, Iowa | 43°04′37″ | 92°40′16″ | 1,014 | 01/01/2000 – 12/31/2010 |
| G | 132573 | Eldora, Iowa | 42°21′43″ | 93°05′56″ | 1,144 | 01/01/2000 – 12/31/2010 |
| H | 132977 | Forest City, Iowa; 2 NNE | 43°17′02″ | 93°37′52″ | 1,300 | 01/01/2000 – 12/31/2010 |
| I | 133487 | Grundy Center, Iowa | 42°21′54″ | 92°45′32″ | 1,045 | 01/01/2000 – 12/31/2010 |
| J | 133584 | Hampton, Iowa | 42°45′22″ | 93°12′04″ | 1,230 | 01/01/2000 – 12/31/2010 |
| K | 134049 | Independence, Iowa; 1 | 42°31′37″ | 91°52′41″ | 1,010 | 01/01/2000 – 12/31/2010 |
| L | 134101 | Iowa City, Iowa | 41°36′32″ | 91°30′18″ | 640 | 01/01/2000 – 12/31/2010 |
| M | 134142 | Iowa Falls, Iowa | 41°31′08″ | 93°15′14″ | 1,130 | 01/01/2000 – 12/31/2010 |
| N | 135235 | Mason City, Iowa; Municipal Airport | 43°09′14″ | 93°19′37″ | 1,225 | 01/01/2000 – 12/31/2010 |
| O | 135837 | Muscatine, Iowa | 41°24′29″ | 91°04′19″ | 549 | 01/01/2000 – 12/31/2010 |
| P | 135952 | New Hampton, Iowa | 43°26′42″ | 93°18′43″ | 1,148 | 01/01/2000 – 12/31/2010 |
| Q | 136103 | Northwood, Iowa | 43°26′20″ | 93°13′30″ | 1,190 | 01/01/2000 – 12/31/2010 |
| R | 136305 | Osage, Iowa | 43°16′44″ | 92°48′40″ | 1,170 | 01/01/2000 – 12/31/2010 |
| S | 138266 | Tipton, Iowa | 41°46′48″ | 91°07′37″ | 820 | 01/01/2000 – 12/31/2010 |
| T | 138296 | Toledo, Iowa; 3 N | 42°02′10″ | 92°34′52″ | 949 | 01/01/2000 – 12/31/2010 |
| U | 210355 | Austin, Minnesota | 43°39′00″ | 92°58′12″ | 1,199 | 01/01/2000 – 12/31/2010 |
| V | 210075 | Albert Lea, Minnesota | 43°36′00″ | 93°18′00″ | 868 | 01/01/2000 – 12/31/2010 |
| W | 135879 | Nashua, Iowa[1] | 42°56′13″ | 92°34′12″ | 1,138 | 01/01/2000 – 12/31/2010 |

[1]Climate station included additional data for solar radiation and potential evapotranspiration.

The Cedar River Basin and subbasins were delineated with the GIS Weasel (Viger and Leavesley, 2007). The GIS Weasel was used to characterize the physical features of the Cedar River Basin into the requisite sets of parameters for input into PRMS. The DEM was processed by the GIS Weasel, which created raster data sets of flow direction and flow accumulation. A drainage network is 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). The drainage network is segmented at stream tributaries from the headwaters to the main stem of the Cedar River. An interactive process in the GIS Weasel was used to discretize the HRUs based upon the drainage network data set and location of USGS streamflow gages (Viger and Leavesley, 2007). Two-plane HRUs are developed to separate contributing areas from left and right banks of each stream segment. The Cedar River Model discretization consists of 243 HRUs and 121 stream segments (fig. 4).




Base from U.S. Geological Survey digital data, 2006, 1:24,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983 (NAD 83)

**Figure 4.** Hydrologic response units (HRUs), stream segments, and subbasins for the Precipitation-Runoff Modeling System representation of the hydrologic system.

## Surface-Water Model Calibration and Validation

The PRMS model was calibrated using a multiple-objective, stepwise procedure, using Luca (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 many researchers to calibrate many PRMS models (Hay and Umento 2006; Dudley, 2008; Goode and others, 2010).

In this study, Luca was used to complete a multiple-objective, stepwise calibration of the Cedar River Basin PRMS model. Calibration was performed at eight USGS streamflow-gaging stations throughout the basin with emphasis on matching model simulated daily streamflows with measured daily streamflows from USGS streamflow-gaging stations. The Luca calibration includes three objective functions—low, high, and mean flows—in an effort to accurately represent all flow regimes. A basin wide, two-step calibration of climate and streamflow related parameters (table 3) was completed using the USGS streamflow-gaging station 05465000 near Conesville, Iowa (table 1, fig. 2, map number 14), as the measured data set to match to simulated daily streamflows. An additional calibration of a selected set of headwater basin streamflow parameters (table 3) was completed at seven headwater streamflow sites (map numbers 1, 3, 6, 7, 9, 10, 12; table 1) to increase the parameter resolution and accuracy of the smaller-sized basins within the model extent. The remaining six streamflow sites (table 1) were not calibrated and were used for the purpose of validation of PRMS simulated daily streamflows at unknown sites.

The Nash Sutcliffe efficiency (NSE) statistic (Moriasi and others, 2007; Nash and Sutcliffe, 1970) was used to determine model performance. The NSE is a normalized statistic that provides a measure of how well simulated values match measured data sets. The NSE is defined as:

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

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, and

$n$ is the total number of measurements.

NSE values range from -∞ 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 NSE of greater than 0.50 is satisfactory in watershed models such as PRMS. Table 4 lists all of the NSE values by streamflow-gaging station within the model. Based on the results in table 4, the Cedar River Basin PRMS model is meeting the criteria of greater than 0.50 and is a good fit for streamflow estimation in all but one location, Austin, Minn., for the calibration period (January 1, 2000 to December 31, 2004). During the validation periods (January 1, 2005 to December 31, 2010 and January 1, 2000 to December 31, 2010), four streamflow-gaging stations are below the 0.50 threshold for accuracy: Cedar River near Austin, Minn. (05457000), Cedar River at Charles City, Iowa (05457700), Shell Rock River at Shell Rock, Iowa (05462000), and Wolf Creek near Dysart, Iowa (05464220) (table 4, fig. 2).

A main objective of this research was to determine how well the model would perform at ungaged streamflow locations. To further research this objective, six streamflow sites were not used in the calibration of the PRMS model but were included in the observation data set. The six validation sites and NSE values in table 4 show that the PRMS model accurately simulated streamflow at four of six uncalibrated locations within the basin based upon the use of the eight calibration sites. There is a slight bias at the lower flows where the model tends to under predict low-flow conditions (figs. 5 and 6). Overall, the graphs in figures 5 and 6 show the model fit is good.

Simulated annual and seasonal runoff volumes were compared with measured volumes from USGS streamflow-gaging stations (figs. 7 and 8). The seasonal runoff volumes were defined as total runoff for the months associated with the four seasons: winter—December, January, February; spring—March, April, May; summer—June, July, August; autumn—September, October, and November. Overall, there was good agreement between simulated and measured seasonal and annual volumes throughout the basin. The calibration period ranged from 0.2 to 20.8 percent difference, and the validation period ranged from 0.0 to 19.5 percent difference across all seasons and annual runoff (fig. 7). The seasonal and annual runoff volumes were computed for the validation only sites (fig. 8), and the range was from 0.2 to 18.6 percent difference between measured and simulated values. At the validation only sites winter volumes were underestimated with a range of -4.3 to -9.3 percent difference, while summer and total runoff volumes were overestimated with a range of 0.24 to 18.6 percent difference. Overall the largest percentage differences tended to occur in the winter season across all streamflow-gaging stations, which is related to the low-flow underestimation by the PRMS model (figs. 5 and 6).

The Cedar River PRMS model tended to underestimate at the lower flows (figs. 5–8). This is an indication that the PRMS model is not accurately representing the groundwater and storage components of flow within the basin. Further refinement with more detailed groundwater and storage information would guide the proper modeling of the flow components related to both groundwater and storage.

## Cedar River Model Results

The PRMS model depends on the use of meteorological data sets to drive the model computations to simulate streamflow. In this study, a sparse network of meteorological stations was used to derive precipitation and temperature model inputs. The spatial distribution of the meteorological stations used to interpolate a spatial distribution within the Cedar River Basin are shown in figure 2. Temperature and precipitation can vary over small distances; thus, the climatic data sets used in this study contributed to inexact comparisons of simulated daily streamflow and measured daily streamflow on an event–by-event basis. The use of a more robust spatial distribution of climatic data such as Next Generation Radar (NEXRAD), a product of National Weather Service (NWS), may aid in improving the future climatic calculations that are the driving forces of the PRMS model (Kalin and Hantush, 2006).

The Cedar River model HRUs discretization was based upon the 14 streamflow-gaging stations (fig. 2) that limited the minimum size of HRUs within the model extent and the distribution of climatic data to larger HRU areas. Hence, a model with smaller discretization of HRUs may improve simulation results, especially in the headwater basins where daily simulated streamflows seem to be the least accurate.

**Table 3.** Calibrated parameters and Let us calibrate (Luca) procedural steps.

[--, not used in calibration procedure; X, used in calibration; HRU, hydrologic response unit]

| Parameter | Description | Calibration | | |
|---|---|---|---|---|
| | | Step 1 | Step 2 | Headwater |
| adjmix_rain | Monthly adjustment factor for the proportion of rain in a mixed rain/snow event (decimal fraction) | -- | X | -- |
| adjust_rain | Downscaling adjustment for rain (decimal fraction) | X | -- | -- |
| adjust_snow | Downscaling adjustment for snow (decimal fraction) | X | -- | -- |
| fastcoef_lin | Linear coefficient in downslope routing equation for preferential-flow storage (day$^{-1}$) | -- | X | X |
| gwflow_coef | Groundwater routing coefficient to obtain the groundwater-flow contribution to streamflow (day$^{-1}$) | -- | X | X |
| K_coef | Travel time through stream segment (hours) | -- | X | X |
| slowcoef_lin | Linear gravity-flow reservoir routing coefficient (day$^{-1}$) | -- | X | X |
| smidx_coef | Coefficient in the nonlinear contributing are algorithm computing surface runoff (decimal fraction) | -- | X | X |
| smidx_exp | Exponent in nonlinear contributing are algorithm computing surface runoff (inch$^{-1}$) | -- | X | X |
| soil_moist_max | Maximum available water--holding capacity of soil profile (inches) | -- | X | X |
| soil_rechr_max | Maximum value for available water in soil recharge zone (inches) | -- | X | X |
| soil2gw_max | Amount of soil water excess for an HRU that is routed directly to the associated groundwater reservoir each day (inches) | -- | X | X |
| ss2gw_rate | Coefficient to route water from subsurface reservoirs to groundwater reservoirs (day$^{-1}$) | -- | X | X |

Overall, the PRMS basin model constructed for this investigation has proven to be an accurate predictor of streamflow throughout the Cedar River Basin. Figures 5 and 6 show the graphs of measured values compared to simulated values at the streamflow-gaging stations within the basin that were used in both calibration and validation of model output. The graphs show that measured values compared to simulated daily streamflow values closely follow the one to one line, which represents a perfect model fit. Seasonal and total runoff values between simulated and measured values for all streamflow gages within the basin for both the calibration and validation periods are shown in figures 7 and 8. Overall, the PRMS model estimated the seasonal and total runoff simulated values satisfactorily (figs. 7 and 8). The PRMS model daily streamflow simulations performed satisfactorily at 7 of the 8 calibration sites and 10 of the 14 validation sites as indicated by the NSE values presented in table 4. In general, the smaller drainage area headwater basin streamflow-gaging stations tended to be less accurate than the Cedar River Basin main-stem streamflow-gaging stations. This inaccuracy could be related to meteorological inputs and actual storm event timing and the flashy streamflow hydrograph of the smaller headwater subbasins. In addition, the limitation of a daily streamflow time step will average a short duration, flashy streamflow event over a daily time step, where a more robust sub daily modeling routine may be necessary at the smaller headwater subbasins to accurately reflect flashy, sub daily climatic events.

Streamflow estimates are crucial to water-resource managers in understanding hydrologic characteristics of the basin and for use in calculating nutrient loads, contaminant transport, and other possible uses (table 5). The calibrated model provides streamflow information throughout the Cedar River Basin by HRU and stream segment. The PRMS model will aid water-resource managers with a consistent and documented method for providing streamflow estimates at locations within the basin that may not have streamflow-gaging station information.

**Table 4.** Cedar River Basin Precipitation-Runoff Modeling System model streamflow-gaging stations used for calibration and validation purposes using Nash-Sutcliff efficiency (NSE) values.

[USGS, U.S. Geological Survey; --, no data]

| Map number (fig. 2) | USGS station number | USGS station name | Calibration data set | Calibration NSE (1/1/2000–12/31/2004) | Validation NSE 1/1/2005–12/31/2010) | Validation NSE (1/1/2000–12/31/2010) |
|---|---|---|---|---|---|---|
| 1 | 05457000 | Cedar River near Austin, Minnesota | YES | 0.33 | -0.04 | -- |
| 2 | [1]05457700 | Cedar River at Charles City, Iowa | NO | -- | -- | 0.44 |
| 3 | 05458000 | Little Cedar River near Ionia, Iowa | YES | 0.64 | 0.60 | -- |
| 4 | [2]05458300 | Cedar River at Waverly, Iowa | NO | -- | -- | 0.55 |
| 5 | 05458500 | Cedar River at Janesville, Iowa | NO | -- | -- | 0.64 |
| 6 | 05458900 | West Fork Cedar River at Finchford, Iowa | YES | 0.72 | 0.62 | -- |
| 7 | 05459500 | Winnebago River at Mason City, Iowa | YES | 0.78 | 0.56 | -- |
| 8 | 05462000 | Shell Rock River at Shell Rock, Iowa | NO | -- | -- | 0.45 |
| 9 | 05463000 | Beaver Creek at New Hartford, Iowa | YES | 0.58 | 0.63 | -- |
| 10 | [3]05463500 | Black Hawk Creek at Hudson, Iowa | YES | 0.71 | 0.50 | -- |
| 11 | 05464000 | Cedar River at Waterloo, Iowa | NO | -- | -- | 0.75 |
| 12 | [4]05464220 | Wolf Creek near Dysart, Iowa | YES | 0.71 | 0.37 | -- |
| 13 | 05464500 | Cedar River at Cedar Rapids, Iowa | NO | -- | -- | 0.77 |
| 14 | 05465000 | Cedar River near Conesville, Iowa | YES | 0.82 | 0.65 | -- |

[1]Cedar River at Charles City, Iowa, validation period October 1, 2001, to December 31, 2010.

[2]Cedar River at Waverly, Iowa, validation period October 1, 2001, to December 31, 2010.

[3]Black Hawk Creek at Hudson, Iowa, calibration period October 1, 2001, to December 31, 2004.

[4]Wolf Creek near Dysart, Iowa, calibration period October 1, 2001, to December 31, 2004.

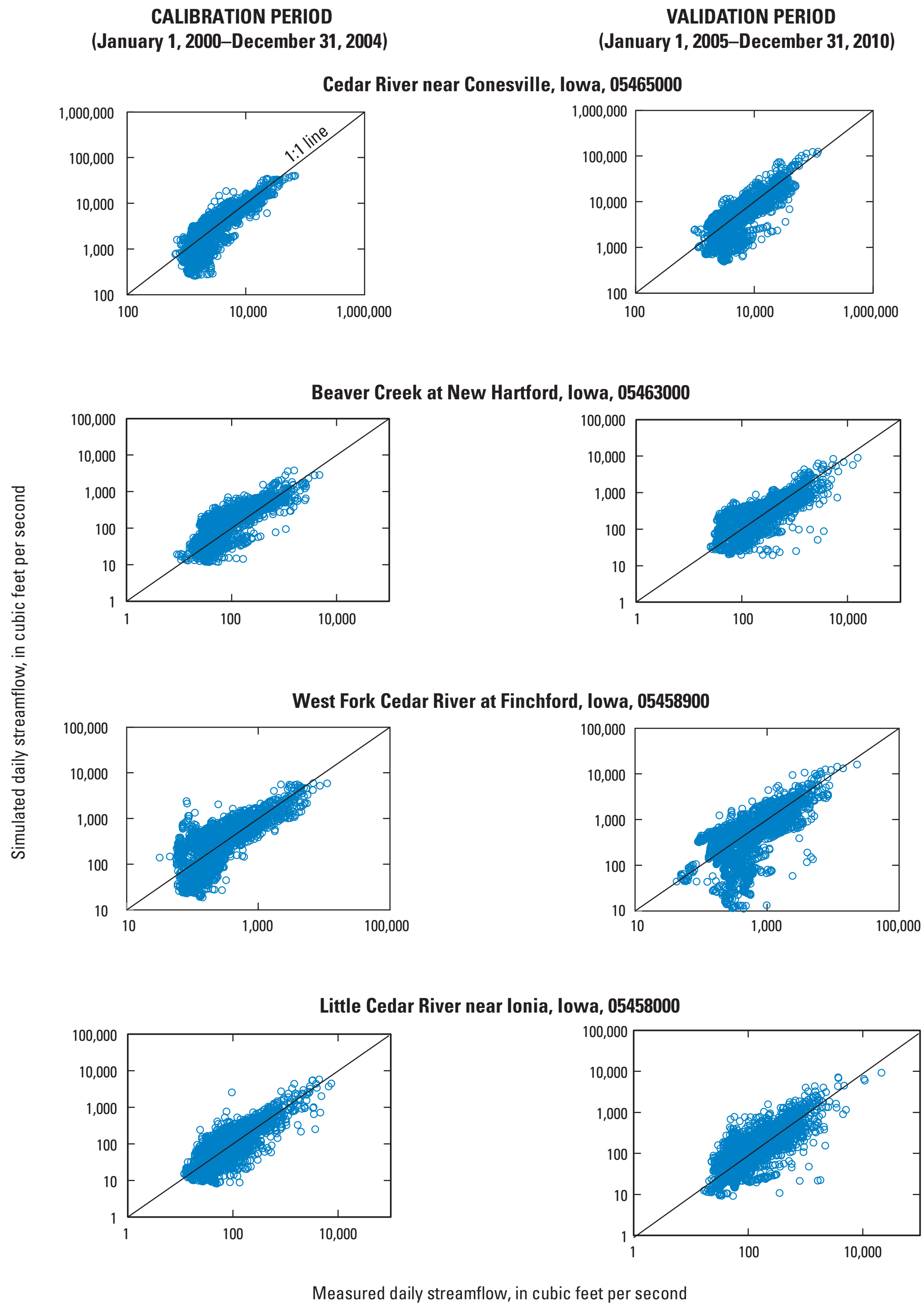



**Figure 5.** Calibration and validation sites for the Cedar River Basin model output for daily streamflow.

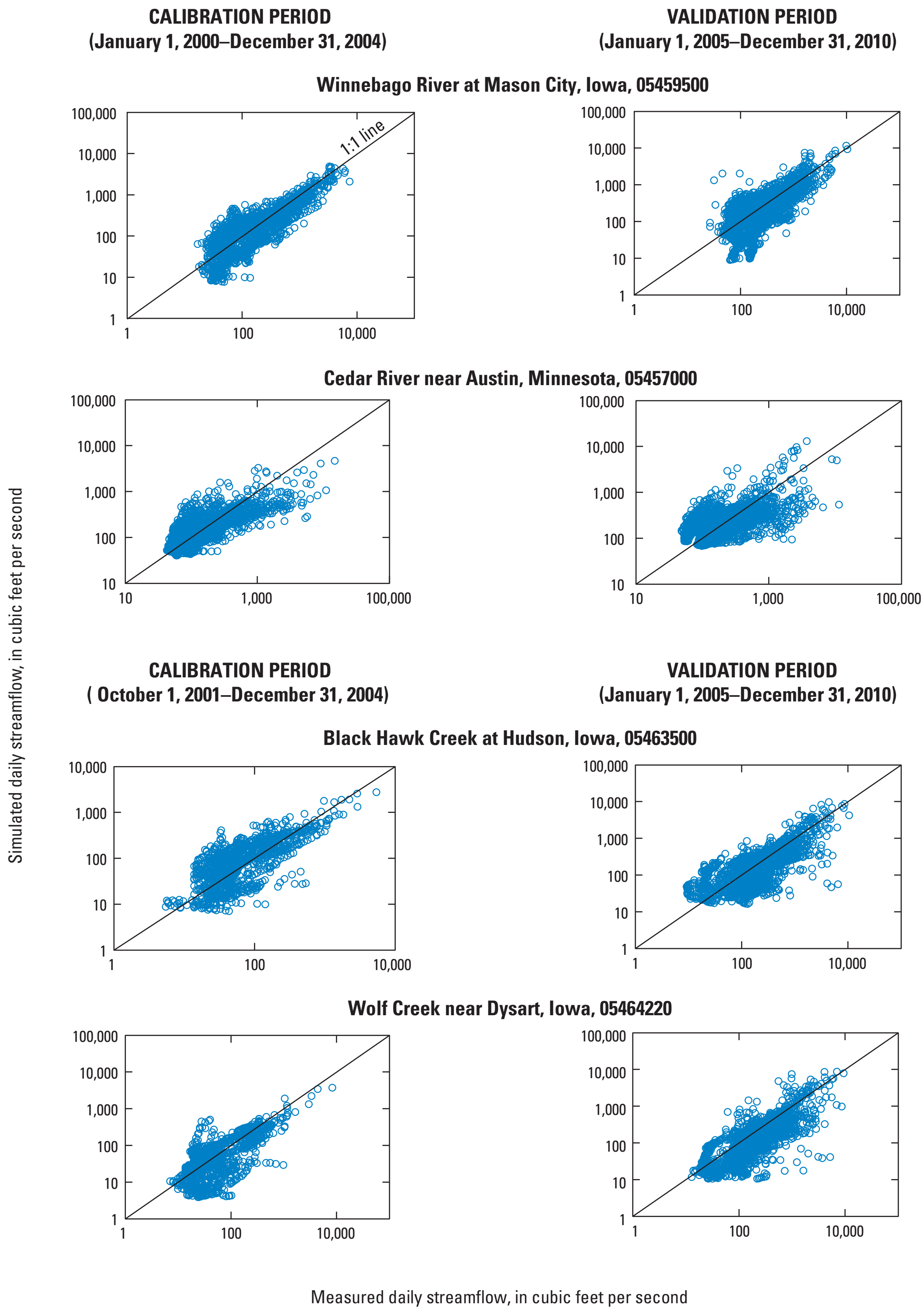



**Figure 5.** Calibration and validation sites for the Cedar River Basin model output for daily streamflow.—Continued

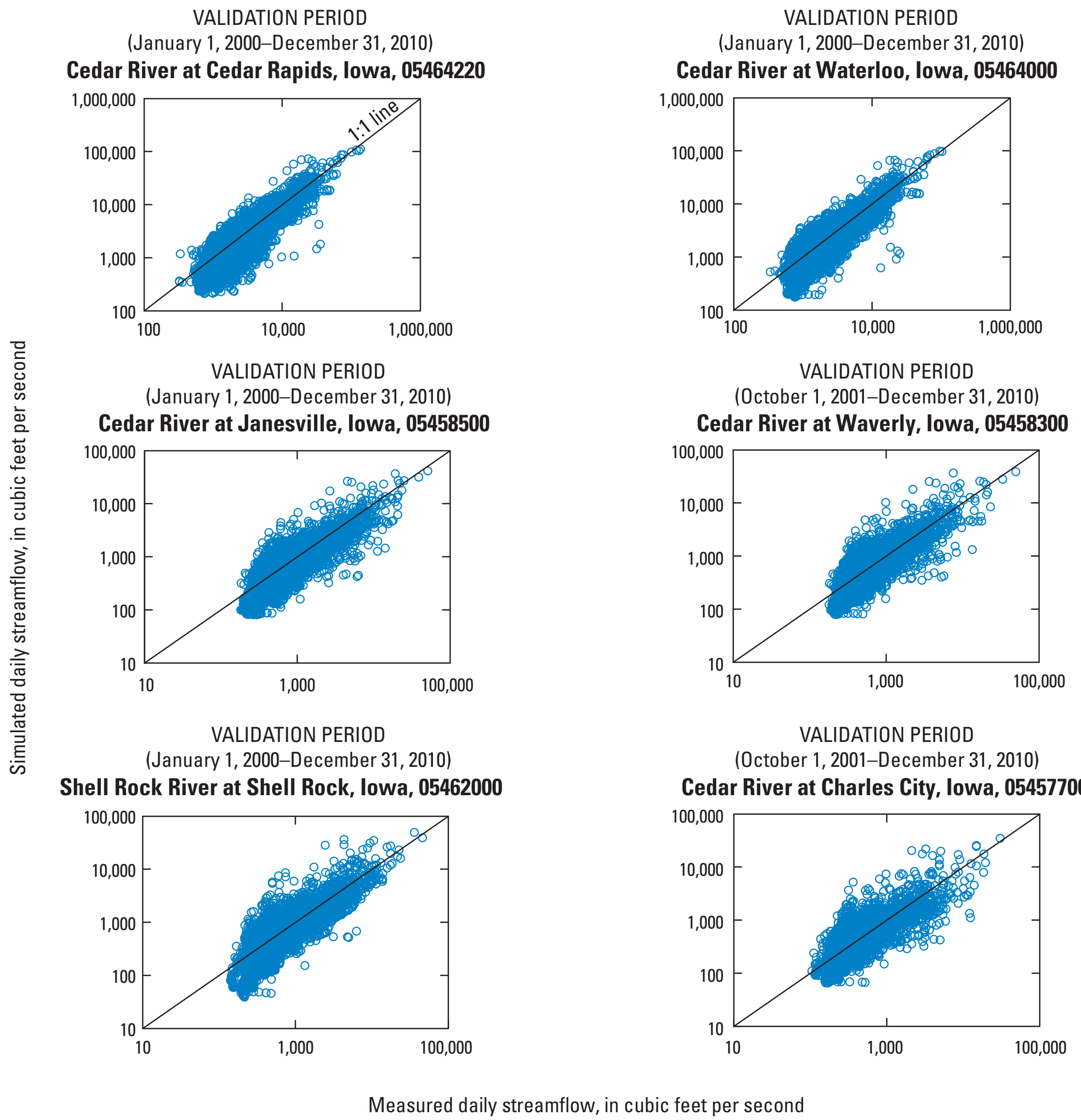



**Figure 6.** Validation only sites within the Cedar River Basin model output for daily streamflow.

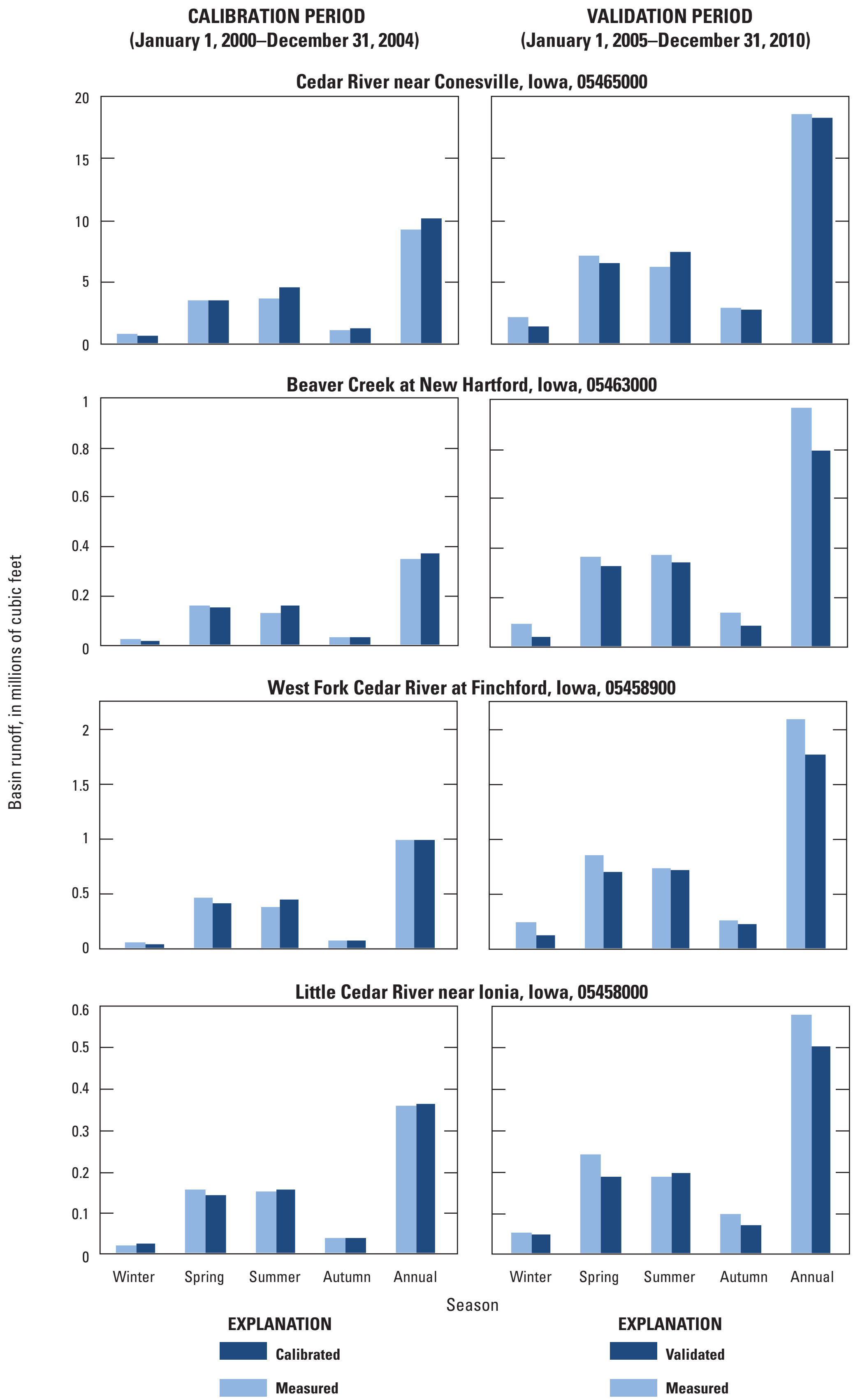



**Figure 7.** Calibration and validation sites within the Cedar River Basin model for mean seasonal and annual outflow volumes.

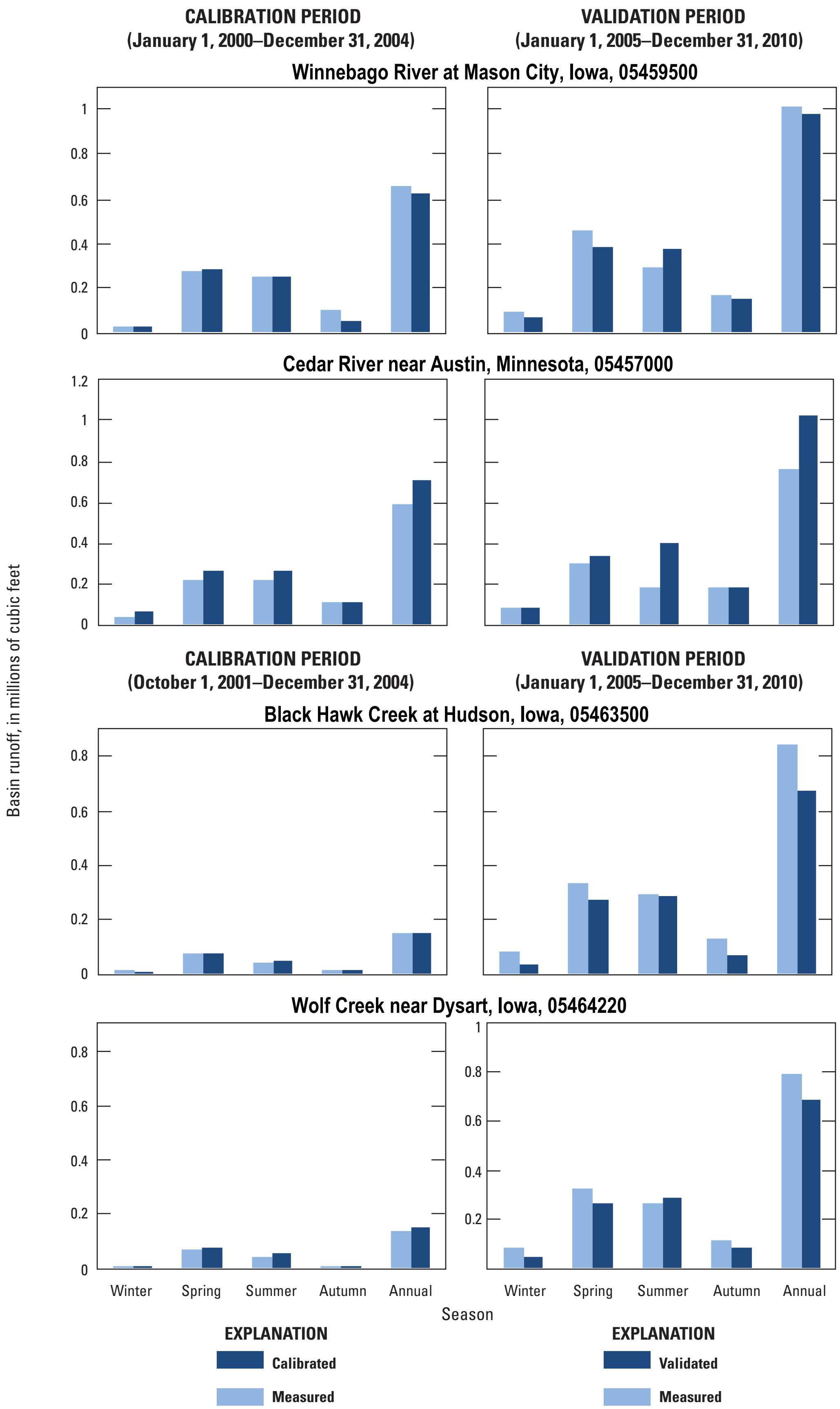



**Figure 7.** Calibration and validation sites within the Cedar River Basin model for mean seasonal and annual outflow volumes.—Continued

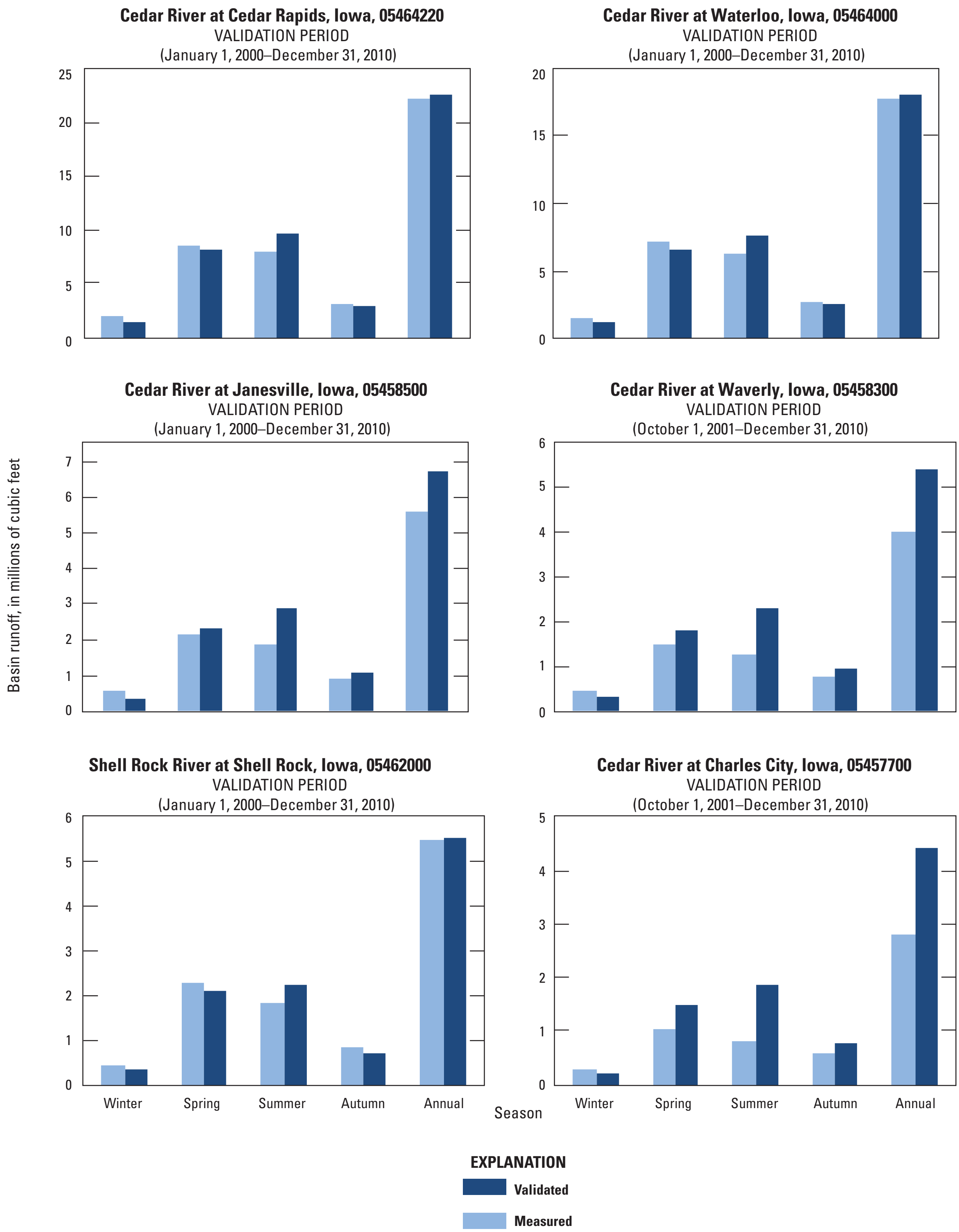



**Figure 8.** Validation only sites within the Cedar River Basin model for mean seasonal and annual outflow volumes.

**Table 5.** Examples of potential uses of estimated surface-water flow data.

| Environmental studies |
|---|
| • Nonpoint source pollution |
| • Channel morphology evolution |
| • Sediment studies |
| • Wetlands ecology |
| • Vegetation studies |
| • Wildlife studies |
| • Fish studies |
| • Benthic studies |
| • Instream flow analysis |
| • Aquatic habitat studies |
| • Wild and scenic determination |

| Hydraulic design |
|---|
| • Roadways |
| • Bridges and culverts |
| • Dams, spillways, and reservoirs |
| • Channel modifications |
| • Flood-plain development |
| • Hydraulic modeling |
| • Urban beautification |
| • Navigable rivers for travel |

| Reservoir management |
|---|
| • Routine operations |
| • Flood suppression |
| • Droughts |
| • Hydropower operation |
| • Scheduling bridge and dam inspections/ repairs |

| Statistical analysis |
|---|
| • Flood frequency |
| • Low-flow frequency |
| • Flow duration |
| • Storage requirements |
| • Areal studies |
| • Safe yield analysis |

| Water management |
|---|
| • Water supply, public and private |
| • Waste-disposal allocation |
| • Water use |
| • Irrigation |
| • Emergency flood alert |
| • Water diversion permits |
| • Compliance with instream flow requirements |

| Urban studies |
|---|
| • Storm runoff |
| • Flood inundation |
| • Zoning and design regulations |
| • Pollution studies |
| • Scenic and wildlife suitability assessments |

| Water quality |
|---|
| • Assimilative capacity |
| • Cumulative impacts assessment |
| • Baseline conditions |
| • Long-term trends |
| • Point-source and nonpoint source impacts |
| • Interstate contaminant transport |
| • Surface water—groundwater relations |
| • Salinity studies |
| • Dissolved oxygen studies |
| • Vegetation studies |
| • Nutrient loading studies |
| • Recreation suitability |
| • Regulatory monitoring |

| Recreation |
|---|
| • Canoeing activities |
| • Scenic river tour operations |
| • Sport fishing |
| • Competition rowing, swimming, waterskiing |
| • Pleasure |

## Summary

The U.S. Geological Survey (USGS), in cooperation with the Iowa Department of Natural Resources (IDNR), conducted a study to estimate daily streamflows at gaged and ungaged locations using hydrological models and statistical methods. This report focuses on the use of a hydrologic model, the USGS Precipitation-Runoff Modeling System (PRMS) model, to estimate daily streamflows at gaged and ungaged locations. PRMS is a modular, physically based, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on surface-water runoff and general basin hydrology. The Cedar River Basin was selected to construct a PRMS model that simulates the period from January 1, 2000, to December 31, 2010. The calibration period is from January 1, 2000, to December 31, 2004, and the validation periods are from January 1, 2005, to December 31, 2010, and from January 1, 2000, to December 31, 2010.

Calibration of the PRMS model was completed using a multiple-objective, stepwise calibration at eight USGS streamflow-gaging stations throughout the basin with the objective to minimize the difference between daily streamflow measured at USGS streamflow-gaging stations and the daily streamflow simulated by the PRMS model. Calibration procedures were completed using the USGS software application Let us calibrate (Luca), which provides the user with an organized way to construct user-defined calibration procedures for any PRMS model. Luca uses the Shuffled Complex Evolution (SCE) global search algorithm to optimize PRMS model parameters.

The Cedar River Basin was calibrated on 5 years of streamflow data collected from January 1, 2000, to December 31, 2004, at all but two streamflow-gaging station locations; the Wolf Creek at Dysart, Iowa, and Black Hawk Creek at Hudson, Iowa, sites were calibrated for the period October 1, 2001, to December 31, 2004, because streamflow records for the calendar year 2000 were not complete at these two sites. The validation period for all USGS streamflow-gaging stations was January 1, 2004, to December 31, 2010. In addition to the eight calibration/validation USGS streamflow-gaging stations, six additional USGS streamflow-gaging stations were included for model validation, and all but two were evaluated for the entire January 1, 2000, to December 31, 2010, period. The USGS streamflow- gaging stations Cedar River at Waverly, Iowa, and Cedar River at Charles City, Iowa, were evaluated for the period October 1, 2001, to December 31, 2010, because of incomplete streamflow records for the 2000 calendar year.

The calibrated Cedar River model will provide daily streamflow data for any of the HRUs and stream segments for the time series from January 1, 2000, to December 31, 2010. Updating the PRMS model with current climatic data will provide water-resource managers with an estimate of daily streamflow in near real time. Water-resource managers will be able to use the quantity and timing of streamflow data at locations within the basin that would not have streamflow information from a USGS streamflow-gaging station. The ability to estimate daily streamflow is critical in understanding the hydrologic characteristics of the basin. The Cedar River PRMS model will fill a need by water-resource managers for a consistent and documented method for providing streamflow estimates at unmonitored sites in the basin.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