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Hydrologic Model Development for the Illinois River Basin Using BASINS 3.0

by
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Prepared for the
U.S. Army Corps of Engineers,
Rock Island District
and the Illinois Department of Natural Resources,
Springfield, Illinois

May 2007

Illinois State Water Survey
Center for Watershed Science
Champaign, Illinois

A Division of the Illinois Department of Natural Resources
and an affiliated agency of the University of Illinois

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Executive Summary

The Illinois State Water Survey has completed the initial phase of a study to develop a continuous hydrologic simulation model of the entire Illinois River basin for analyses in support of the Restoration Needs Assessment for the Illinois River Ecosystem Restoration Project. This model will be used in assessing flow characteristics throughout the basin, potential effects of changes in land use and climate, changes due to project alternatives, and restoration alternatives. The BASINS 3.0 modeling system, developed by the U.S. Environmental Protection Agency, was selected for this study, and the Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate daily streamflows in the basin. The HSPF comprehensive and dynamic watershed-scale model simulates hydrology and water quality in stream reaches. It has been widely used for hydrologic simulations and for assessing the effects of land-use changes on watershed-scale hydrology and water quality.

The initial task of the study involved preparation of data used for developing the model. The meteorological data for the 17 climate stations included in the BASINS database was augmented with daily precipitation data from roughly 80 additional stations located throughout the Illinois River basin. Daily precipitation data were disaggregated to produce estimates of hourly precipitation at each station, which were used as input into the HSPF model. In the second task of the study, the hydrologic component of the HSPF model was calibrated and validated separately for the upper Kankakee, Iroquois, and Spoon River watersheds. Data from a 9-year period (1987-1995) were used to calibrate the HSPF model, and the calibrated model was validated separately for a 16-year period (1971-1986). Agreement between simulated and observed streamflow data was evaluated using performance measures such as Nash-Sutcliffe efficiency (NSE), the coefficient of determination (R^2), and the percentage of the prediction error. Based on these performance measurements, the comparison of simulated to observed streamflows is, in general, judged to be satisfactory (fair to good) as described in the model calibration and validation sections pertaining to these tributary watersheds.

In the final task of the study, an HSPF model of the entire Illinois River basin was developed and hydrologic simulations were performed. The HSPF model for the entire basin was developed using two different approaches: a) developing a single HSPF project for the entire basin, in which the basin was delineated into 60 sub-watershed units; and b) creating separate HSPF modules for each of nine major tributary watersheds and the mainstem watershed, delineating the entire basin into 250 sub-watershed units. Both approaches have useful applications, but the modular approach for modeling the entire Illinois River basin is preferred for this study for two reasons.

- Use of the modular approach provides a broader framework for future modeling work, leading to more detailed applications in the major tributaries and sub-watersheds.
- There are computation limits to the total number of land segments and sub-watersheds that can be used in a single HSPF project, restricting both model detail and the number of precipitation gages that can be used to simulate the entire basin.

In this initial phase of the model development, model calibration was not performed for the entire Illinois River basin for either of the two approaches; detailed routing characteristics for the Illinois River also were not included. Significant improvements in the model can be made in future phases of model development through the calibration of additional major tributary watersheds and adjustments to the hydraulic function tables used for simulation of flows in the Illinois River.

In addition to providing a useful tool for analyzing broad-scale restoration issues for the entire Illinois River basin, it is envisioned that the Illinois River BASINS-HSPF model will provide a framework for additional development and refinement of the model for more detailed modeling within each sub-watershed. The current model at this stage is considered preliminary and is not ready for widespread applications throughout the watershed. The following steps should be conducted to further prepare the model for application to various Illinois River basin management issues:

- Calibration should be performed for more major tributaries, and efforts should be taken to match simulated and observed flows at a greater number of gages, including smaller tributaries.
- The hydraulic function tables in the model, particularly those for the Illinois River, should be modified using more detailed stream geometry and storage information for each river reach. However, best results for simulating the dynamic characteristics of flows in the Illinois River should be obtained by linking the HSPF model output for the nine major watersheds with a hydraulic model such as UNET.
- The current model should be refined further by more rigorously classifying the landscape based on significant differences in soil type and land use and, in particular, using the calibration process to develop regional parameter values for different soil type and land-use segments. This process can be facilitated by updating the available Geographic Information Systems data layers used as input into the BASINS model, including available improvements in the accuracy and resolution of data on watershed characteristics such as land use, soil type, land elevation, and the stream network.
- Once the hydrologic calibration is fully completed, then attention should be given to developing the sediment and water quality components of the model.

Acknowledgments

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Center for Watershed Science
Illinois State Water Survey

Introduction

The BASINS Modeling System

The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) model is a multipurpose environmental analysis system developed by the U.S. Environmental Protection Agency (USEPA). BASINS was designed to facilitate examination of environmental information, support analysis of environmental systems, and provide an integrated watershed and modeling framework for examining management alternatives. It combines a geographic information system (GIS), national watershed data, and state-of-the-art environmental assessment and modeling tools into one convenient package composed of six interrelated components:

- Nationally derived databases with data extraction tools and project builders.
- Assessment and data mining tools that address large- and small-scale characterization needs.
- Utilities to facilitate organizing and evaluating data, including watershed delineation, import, land-use reclassification, Digital Elevation Model (DEM) reclassification, and lookup tables.
- Watershed characterization reports that facilitate compilation and output of information on selected watersheds.
- An in-stream water quality model (Enhanced Stream Water Quality model or QUAL2E).
- Two watershed loading and transport models (Hydrological Simulation Program-FORTRAN or HSPF and Soil and Water Assessment Tool or SWAT).

With these tools, BASINS can explore a variety of management alternatives. The model can delineate sub-watersheds and generate models for hydrology, sediment, and pollutant transport for watersheds of different scales. It can analyze a variety of pollutants and support development of total maximum daily loads (TMDLs), which requires a watershed-based approach integrating both point and nonpoint sources. The model also is capable of simulating changes in the floodplain, watersheds, channels, land uses, and hydrological conditions under varying management conditions.

The USEPA has compiled spatially distributed data, environmental monitoring data, point source data, and meteorological data for the BASINS model. These data files are available on CD-ROM from the USEPA or can be downloaded from their Web site (www.epa.gov/waterscience/basins/b3webdwn.htm). Users can incorporate their own datasets as well. The BASINS database allows addition of grid datasets including U.S. Geological Survey (USGS) DEM grids (1:250,000 scale) and user-defined data layers such as elevation, land use, soils, streams, and point source.

Approach to Modeling the Illinois River Basin

The objective of this study was to initiate the development of a continuous-simulation hydrologic model of the entire Illinois River basin. The BASINS (version 3.0) system was selected to develop this model for several reasons.

- It was designed for multiple purposes in environmental and hydrological practices.
- It is based on state-of-the-art ArcView technology for easy data processing.
- It incorporates HSPF and SWAT models to simulate transport of nutrients, pesticides, and sediments in the watershed, along channels, and through reservoirs.
- It has a user-friendly interface to generate hydrologic parameters for HSPF or SWAT models.
- It includes a comprehensive and versatile stream water quality model (QUAL2E) that can simulate up to 15 water quality constituents in any combination desired by users.
- It has a complete dataset for the Illinois River basin.

This system offered the best-integrated modeling framework for examining management alternatives within the Illinois River basin.

The model developed for the Illinois River basin at the Illinois State Water Survey (ISWS) delineates the basin into sub-watersheds at different scales. The major tributary watersheds form one layer of sub-watersheds, and each tributary watershed is further divided into smaller sub-watersheds. In its final form, the model simulates more than 200 individual sub-watersheds.

The study plan to develop a calibrated and validated HSPF watershed model for the entire Illinois River basin involves tasks performed in different phases. The initial phase involved preparation of data for use in model development. The second phase involved selecting two tributary watersheds and calibrating the model for these watersheds. The two watersheds selected were the Kankakee and the Spoon River watersheds (shown in Figure 1). The third phase was to use lessons learned for the calibration of the two watersheds to make the necessary adjustments in parameters and run the model for the entire Illinois River basin. This report discusses the work performed in all three phases. These three initial phases of model development were designed to provide a basic framework in which future modeling studies can add greater detail for specific applications and watersheds. Additional model calibration is needed for specific applications in watersheds not yet calibrated, including applications on tributary streams and smaller watersheds.

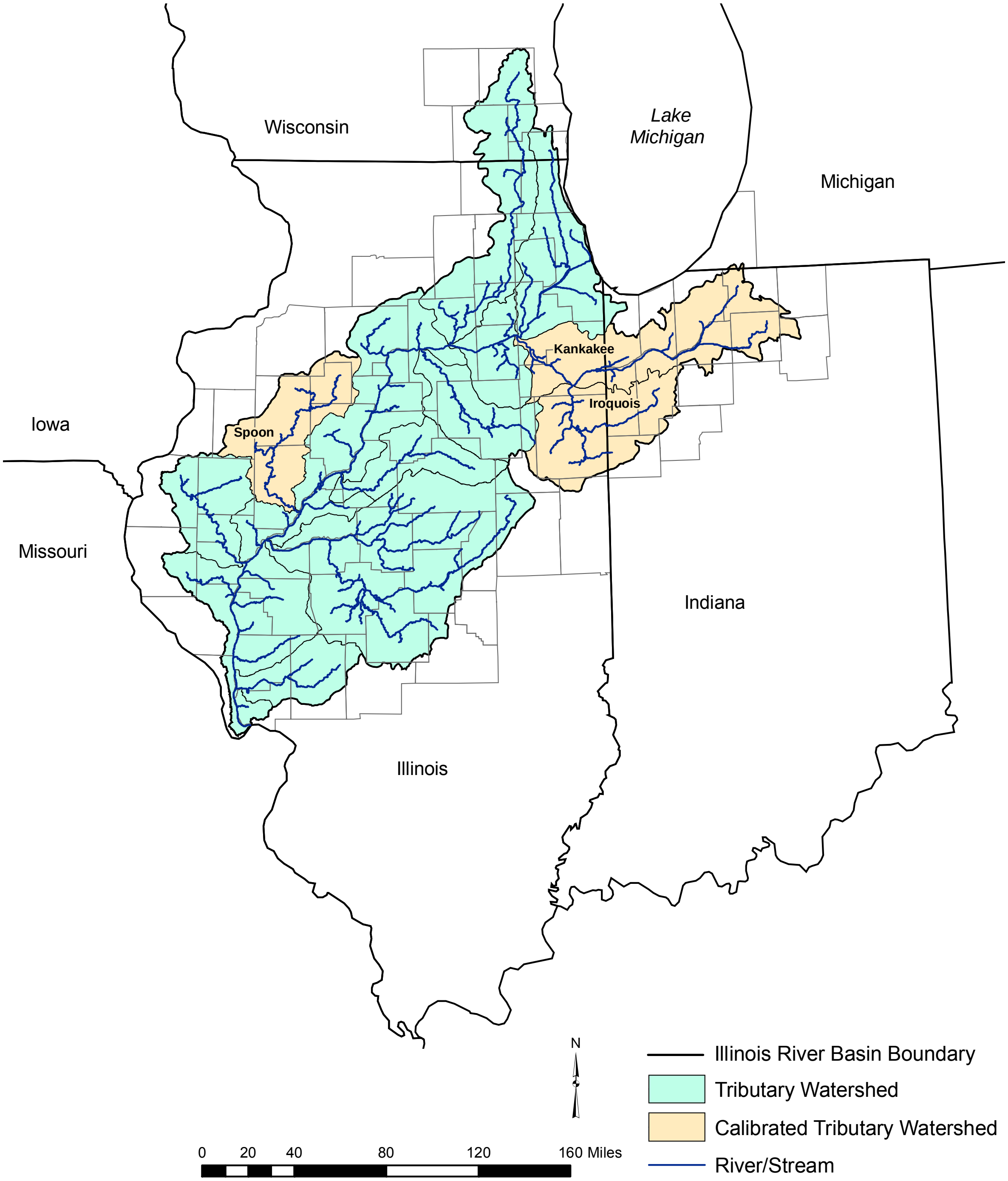


Figure 1. Illinois River basin and its tributary watersheds: Kankakee, Iroquois, and Spoon River watersheds (shaded areas).

Uncertainties in Continuous-Simulation Watershed Modeling

There are two general categories of watershed models: continuous-simulation and event models. Continuous-simulation models, such as the HSPF model used in this study, typically are calibrated to simulate the hydrologic processes in a watershed over a series of years that contain numerous rainfall-runoff events and intervening dry periods. The continuous-simulation model, once calibrated, is ideally able to simulate the observed flows of other time periods with the same or nearly the same accuracy as that of the calibration period. Climate records can be used as input into the model to simulate long periods of varying high and low flow conditions, retaining the overall characteristic of the watershed's hydrology (assuming that no substantive changes in land use or other basic hydrologic processes have occurred over that modeling period). Event models, in contrast, are applied to individual rainfall-runoff events and are used typically to examine runoff events in greater detail, but are not designed to simulate hydrologic processes between runoff events or over an extended time period.

Continuous simulation models will overestimate the flows of some runoff events and underestimate the flows of other events, but "on average" are expected to produce flow hydrographs that are characteristic of the stream response to given rainfall amounts, and produce a series of simulated flow values that are statistically similar to the series of observed flows. There is usually no predefined level of accuracy specified for various types of modeling applications. Watershed models typically are calibrated to the extent possible given the data available, limitations and assumptions of the model, and the objective and budget of the modeling project. Model studies should present information regarding the accuracy of the completed model and related assumptions and uncertainties, which then should be evaluated by decision makers in determining the appropriate use of model results.

Typically, the goodness of fit for continuous-simulation models is evaluated using statistics such as the Nash-Sutcliffe Efficiency (NSE) coefficient, the coefficient of determination (R^2), and the percentage of prediction error, all described later in this report. A subjective classification of whether the model results are "good," "very good," "fair," etc., are based in this study on published guidelines (Duncker and Melching, 1998; Donigian et al., 1984; Donigian, 2002), described later in the report, that have been derived through comparisons of a variety of model applications. For example, for a given monthly flow simulation this report provides the NSE, R^2, and percent error values, all of which will have a subjective classification associated with them. No single statistic should be used to evaluate model performance, and Donigian (2002) suggests establishing model credibility through a "weight of evidence" approach using multiple statistics and evaluation tools. Although herein we have defined subjective classifications using published guidelines, not all model studies have used such guidelines. Therefore, it is always best to examine the NSE and other measures of goodness of fit when evaluating model performance. To our knowledge, no similar types of classification exist for water quality simulations.

Even for continuous-simulation modeling applications that can be classified as "good" or "very good," the standard error of estimate for any given day of record can be considerable — ranging from around 30 percent for Illinois rivers with less variable flow conditions to well over 50 percent for highly variable rivers and streams. The standard percentage error of estimate is frequently much greater for low flows than for medium and high flows, as 1) there is often little or no geophysical data to describe the subsurface processes that control the movement of baseflow from groundwater to streams during periods of low flow, and 2) the storage and movement of shallow groundwater usually is characterized in most watershed models with very simple equations.

The HSPF Model

The Hydrologic Simulation Program – FORTRAN (HSPF, version 12) was used to simulate daily watershed streamflows. It was accessed through a graphical user interface (WINHSPF) that interacts with BASINS 3.0 utilities and datasets to aid in the development of an HSPF project. The BASINS program collates DEM, land-use, and stream network coverages to partition a large watershed and its reaches into smaller land segments and reaches, and helps to parameterize the HSPF input file. The comprehensive long-term continuous watershed scale HSPF model simulates nonpoint source hydrology and water quality, combines these with point source contributions, and performs flow and water quality routing in watershed reaches. It has been widely used for hydrologic simulations at a watershed scale and to assess the effects of land-use changes on hydrology and water quality at a watershed scale (Laroche, 1996; Schwar, 1998; Srinivasan et al., 1998; Jones and Winterstein, 2000; Brun and Band, 2000; Lohani et al., 2002). Donigian (1999) compiled an exhaustive bibliography of various research studies using the HSPF model.

The HSPF model can be used for watershed modeling using available hydrologic, topographic, soils, land-use, and meteorological data, and drainage and other system characteristics data for the study area. The model can be run for a single watershed and reach system, or for a set of hydrologically connected sub-watersheds (delineated using BASINS 3.0 watershed delineation tool) and representative reaches. Each watershed/sub-watershed is subdivided into pervious or impervious land segments (e.g., agriculture, forest, urban, etc.). A reach normally represents a stream, a channel, or a completely mixed lake/reservoir.

The model has three main modules PERLND, IMPLND, and RCHRES that help simulate pervious land segments, impervious land segments, and free-flow reaches/mixed reservoirs, respectively. For hydrologic simulations, the model treats each land segment as a lumped catchment. This means that all land-use types defined within a sub-watershed are grouped together, and the associated runoff of both flow and water quality are loaded into the top of the reach within that sub-watershed. The HSPF model uses storage routing to route water from one reach to the next. For each reach, a fixed relationship is assumed between water level and surface area, storage, and discharge. This relationship is defined in automatically generated tables (FTABLEs) using topographic, and stream geometry and network information contained in the reach file. The user can modify these tables. The BASINS-HSPF model calculates the hydraulic variables assuming that the cross section of the reach is constant throughout the entire reach in a sub-watershed.

For pervious areas, precipitation is distributed among six vertically arranged storages (interception, surface depression, lower and upper zones, groundwater, and deep groundwater) that produce three streamflow components: surface runoff, interflow, and baseflow. For impervious areas, only two storages (interception and surface depression) produce surface runoff that contributes to the streamflow. Evapotranspiration (ET), a major component of the overall water balance, can take place from most of these moisture storages, but it is possible that potential ET demand may not be satisfied during dry conditions when insufficient soil moisture is available. Actual ET from the watershed is always less than or equal to the potential ET in the input time-series data.

Input Data and Model Preparation

The HSPF model requires spatial information about watershed topography, river/stream reaches, land use, and meteorology to simulate streamflow accurately. For this study, most data were extracted from the GIS database provided by USEPA with the BASINS software. Table 1 gives details on data type used and their sources. As shown in this table, additional precipitation data were taken from the National Oceanic and Atmospheric Administration–National Climatic Data Center (NOAA-NCDC) and Midwestern Regional Climate Center (MRCC) databases. The major input files needed to run the HSPF model for a watershed are the Watershed Data Management (WDM) file and the User Control Input (UCI) data file. The WDM file is a binary, direct-access file that stores time-series data, such as observed meteorological data, observed daily streamflow data, and model-simulated time-series data. Hourly meteorological time-series data and USGS daily streamflow gage data in different watersheds/sub-watersheds studied were obtained in an ASCII format from respective sources (see Table 1). Data were imported into the WDM file(s) using the utility's module (WDMUtil) of the BASINS system. The UCI files for these models also were generated when the HSPF model is invoked after watershed sub-delineation in BASINS. A UCI file is the core input file for running the HSPF model and contains all model parameters, initial conditions, input/output WDM file specifications, and starting and finishing times of simulation runs. Information in the UCI file also controls HSPF model functions, links between different land segments and stream reaches, specifications for different meteorological datasets for different sub-watersheds, and the format of simulation results.

For HSPF modeling, any large watershed is subdivided into smaller sub-watersheds, each comprised of different types of land segments based on land use in that sub-watershed. This was done using the automatic delineation tool (as explained in the "Sub-Watershed and Land-Use Delineation" section) of BASINS. The connectivity of these watersheds then was mapped in the

Table 1. HSPF Model Input Data Type and Sources for Hydrologic Modeling of the Illinois River Basin

Data type	*Source*
Topography (1:250,000 scale)	USGS
Land use/Land cover (1:250,000 scale)	USGS GIRAS spatial data
Reach File version 1 (RF1) (1:500,000 scale)	USEPA
National Hydrography Dataset (1:100,000 scale)	USEPA – USGS*
Daily Streamflow	USGS**
Meteorology	
Hourly weather data	USEPA WDM weather stations NOAA-NCDC weather stations
Daily precipitation data	NCDC - MRCC

Notes:
Unless otherwise noted, data were derived from the BASINS 3.0 database.
***Source:** http://nhd.usgs.gov/, accessed May 2002.
****Source:** http://Water.usgs.gov/, accessed May 2002.

HSPF model once the WinHSPF interface was invoked. A representative meteorological station then was assigned to each sub-watershed using the WinHSPF interface. Although the HSPF model uses only hourly precipitation and potential ET time-series data to perform hydrologic simulations (when snow is not a consideration), the user also must input other hourly time-series weather data (evaporation, cloud cover, air temperature, dewpoint temperature, solar radiation, and wind speed) in the WDM file due to hardwiring in the WinHSPF code. Temperature, wind speed, and solar radiation time-series data were used during hydrologic simulations that included snow.

In the BASINS database, the WDM files created for each state by the USEPA contain approximately 10 stations per state per file. These stations have eight sets of hourly time-series data needed to run the HSPF model and eight sets of daily time-series data. Only 17 USEPA-WDM stations, located in five states, were available to represent the 29,000 square-mile Illinois River basin (Figure 2 and Table 2). Hourly precipitation data for 16 more stations (Figure 2 and Table 3) within the basin were extracted from the NOAA-NCDC database. However, none of these stations had a complete dataset for the 1970-1995 time period (the maximum HSPF model run period used in this study), so these stations were used only as reference stations for disaggregating daily precipitation from the USEPA-WDM stations into hourly precipitation.

Because it is a primary model input, precipitation should be represented temporally and spatially as accurately as possible. Several scientists have reported the significance of spatial rainfall variability on runoff modeling (Beven and Hornberger, 1982; Schilling and Fuchs, 1986; and Faures et al., 1995). Daily data from 86 additional precipitation gages (Figure 3 and Table 4) were available for the 1970-1995 time period, and were used to more accurately reflect the spatial variability of rainfall over the large area of the modeled basin. Daily data were extracted from the MRCC database and disaggregated to estimate hourly precipitation. The combined MRCC daily and WDM hourly stations provide a gage density of roughly one gage per 300 square miles.

Rainfall Data Disaggregation

Daily precipitation time-series data for each local precipitation station were disaggregated into hourly data using the methodology available in the BASINS WDMUtil module. Hourly precipitation time-series data available at the WDM stations and NOAA-NCDC hourly stations (Tables 2 and 3) were used as reference data for this purpose. This procedure distributes the daily precipitation values based on the hourly time-series data from up to five nearby reference stations. For any given day, the total amount of precipitation is disaggregated according to the nearby reference station at which the daily total is closest to the daily value at the daily time-series station. In order to better capture the spatial variability of the precipitation, only those WDM/NOAA-NCDC stations that were closer to each local station were used in the disaggregation. The last column of Table 4 shows the serial numbers of the WDM/NOAA-NCDC hourly stations from Tables 2 and 3 that were used to disaggregate the daily precipitation data for the respective MRCC daily precipitation station.

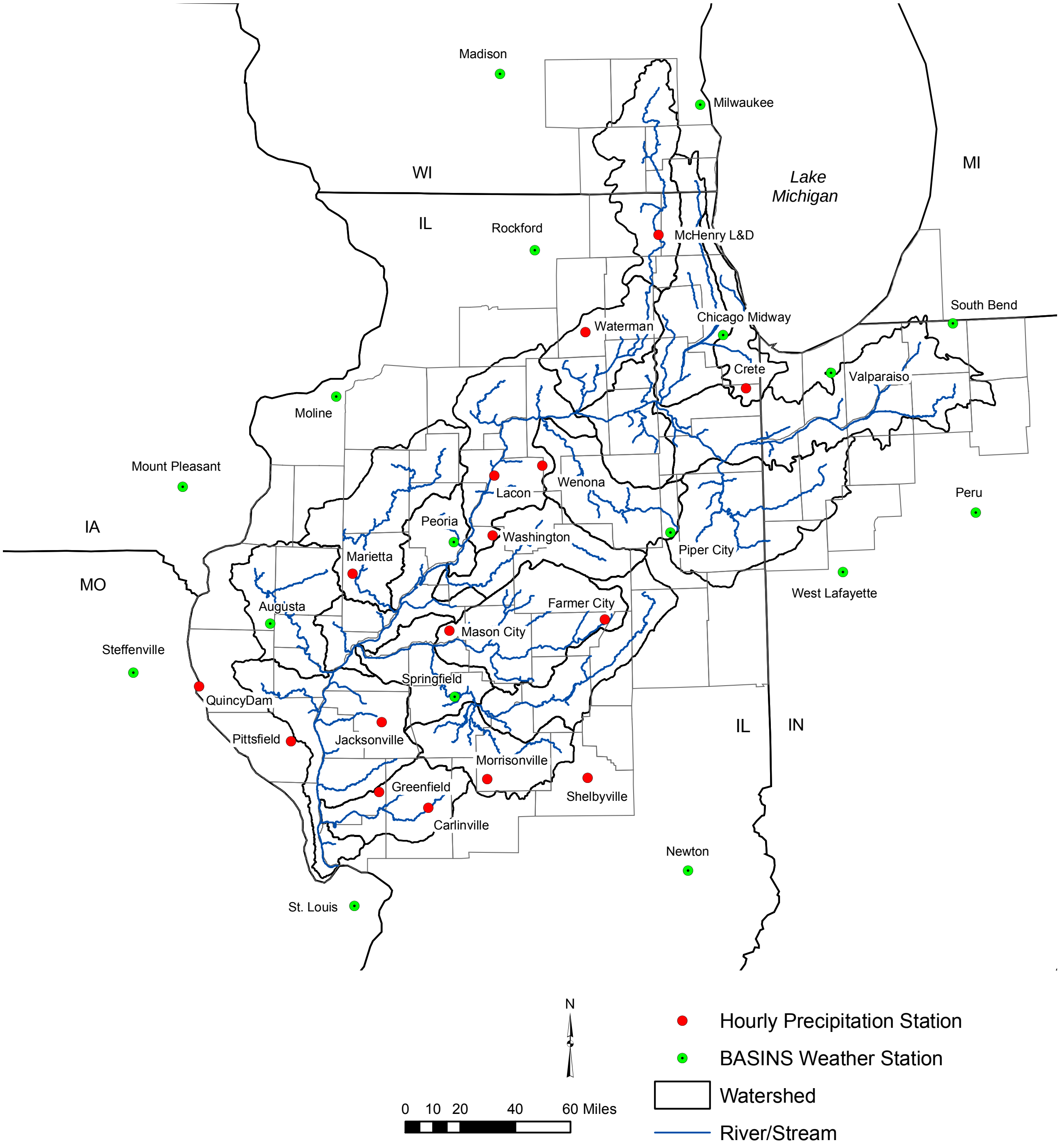


Figure 2. The USEPA-WDM weather data stations and NOAA-NCDC hourly precipitation gages used for disaggregation of daily precipitation data available at local stations.

Table 2. USEPA-WDM Weather Stations Available in the BASINS 3.0 Database for the Illinois River Basin

Sr.No.	*Coop ID*	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**
W1	5796	Mount Pleasant 1 SSW	IA	40.95000	-91.56670
W2	0330	Augusta	IL	40.23330	-90.95000
W3	1577	Chicago Midway AP 3	IL	41.73330	-87.78330
W4	5751	Moline WSO AP	IL	41.43330	-90.50000
W5	6159	Newton 6 SSE	IL	38.91670	-88.11670
W6	6711	Peoria WSO AP	IL	40.66670	-89.68330
W7	6819	Piper City	IL	40.70000	-88.18330
W8	7382	Rockford WSO AP	IL	42.20000	-89.10000
W9	8179	Springfield WSO AP	IL	39.85000	-89.68330
W10	6864	Peru Waste Water Plant	IN	40.75000	-86.06670
W11	8187	South Bend WSO AP	IN	41.75000	-86.16670
W12	8999	Valparaiso Waterworks	IN	41.51670	-87.03330
W13	9430	West Lafayette 6 NW	IN	40.46670	-87.00000
W14	7455	St Louis WSCMO AP	MO	38.75000	-90.36670
W15	8051	Steffenville	MO	39.96670	-91.88330
W16	4961	Madison WSO AP	WI	43.13330	-89.33330
W17	5479	Milwaukee WSO AP	WI	42.95000	-87.90000

Note:
*DD – Decimal degrees.

Table 3. Additional Hourly Precipitation Data Stations from NOAA-NCDC Database Used as Reference Stations during Disaggregation of Daily Precipitation Data into Hourly Data

Sr.No.	*Coop ID*	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**
H1	111280	Carlinville	IL	39.26667	-89.86670
H2	112011	Crete	IL	41.45000	-87.63333
H3	112993	Farmer City	IL	40.25000	-88.65000
H4	113666	Greenfield	IL	39.35000	-90.20000
H5	114442	Jacksonville	IL	39.71667	-90.18330
H6	114805	Lacon	IL	41.01667	-89.50000
H7	115334	Marietta	IL	40.50000	-90.38333
H8	115413	Mason City	IL	40.20000	-89.71670
H9	115493	McHenry L&D	IL	42.27000	-88.22000
H10	115841	Morrisonville	IL	39.41667	-89.46667
H11	116837	Pittsfield	IL	39.61667	-90.80000
H12	117077	Quincy Dam	IL	39.90000	-91.43333
H13	117876	Shelbyville	IL	39.41667	-88.78333
H14	118990	Washington	IL	40.70000	-89.41667
H15	119010	Waterman	IL	41.76670	-88.75000
H16	119090	Wenona	IL	41.06667	-89.06667

Notes:
All of the stations are missing some data between 01/01/1970 and 12/31/1995.
*DD – Decimal degrees.

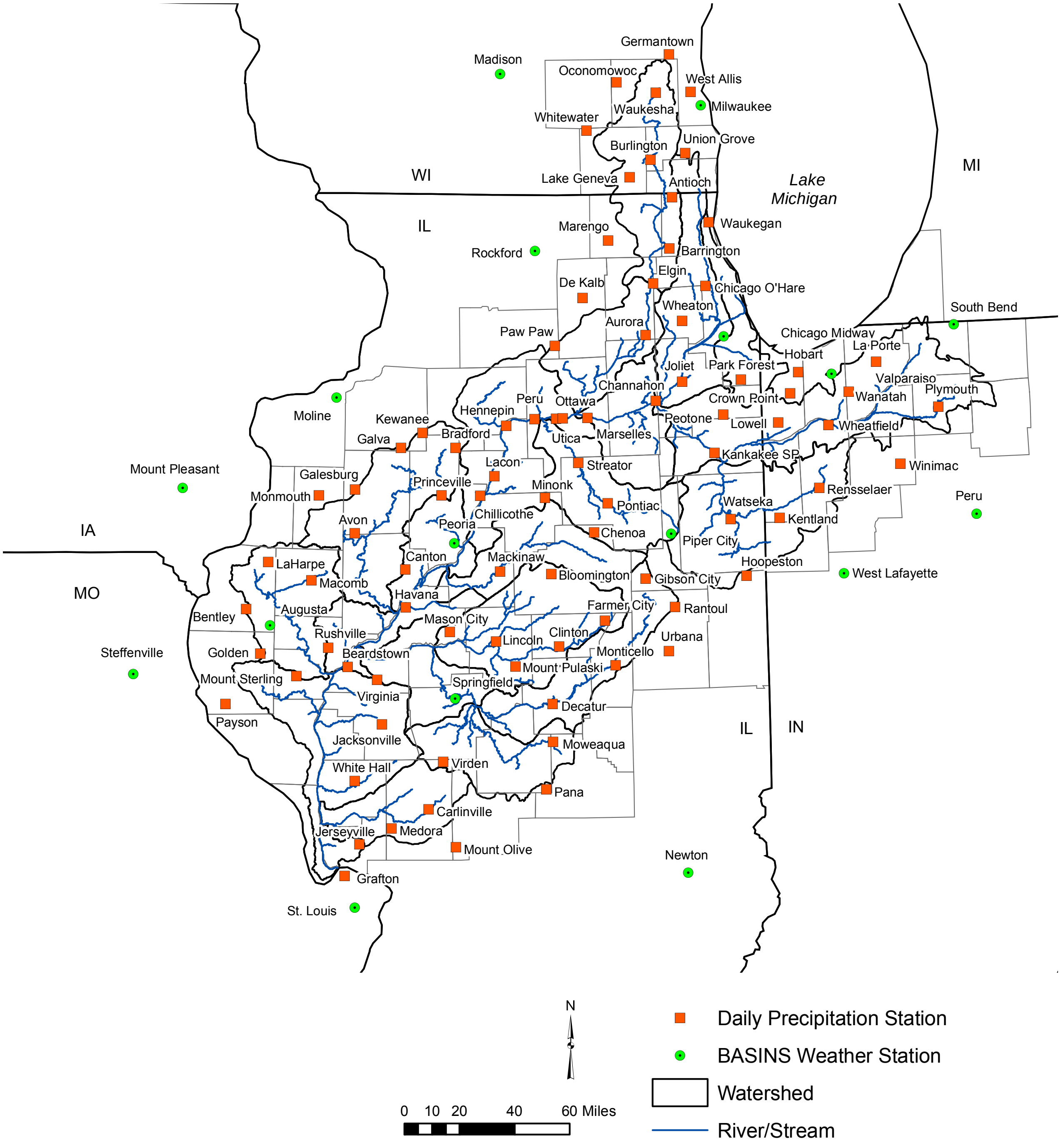


Figure 3. Local daily precipitation gages (from the Midwestern Regional Climate Center).

Table 4. Daily Precipitation Data and USEPA-WDM and NOAA-NCDC Reference Hourly Data Used for Disaggregation

Station	*Coop ID*	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**	*WDM & NOAA Hourly** stations used for disaggregation*
D1	110203	Antioch	IL	42.47000	-88.12000	W3,W8,W17,H9,H15
D2	110338	Aurora College	IL	41.75000	-88.33000	W3,W8,H2,H9,H15
D3	110356	Avon	IL	40.72000	-90.37000	W2,W4,W6
D4	110442	Barrington	IL	42.20000	-88.15000	W3,W8,W17,H9,H15
D5	110492	Beardstown	IL	40.01667	-90.41670	W2
D6	110598	Bentley	IL	40.31667	-91.11670	W2,W9,H5,H8
D7	110761	Bloomington	IL	40.50000	-89.01670	W6,W7,H3,H8,H14
D8	110868	Bradford	IL	41.17000	-89.67000	W2,W4
D9	111250	Canton	IL	40.53000	-90.02000	W6
D10	111280	Carlinville	IL	39.26667	-89.86670	W9,W14,H1,H4,H10
D11	111420	Channahon	IL	41.40000	-88.27000	W3,W7
D12	111475	Chenoa	IL	40.71667	-88.71670	W6,W7,H6,H14,H16
D13	111549	Chicago O'Hare	IL	42.00000	-87.90000	W3,W8,H2,H9,H15
D14	111627	Chillicothe	IL	40.91667	-89.50000	W6,W7,H6,H14,H16
D15	111743	Clinton	IL	40.11667	-88.96670	W6,W7,W9,H3,H8
D16	112193	Decatur	IL	39.81667	-89.01670	W9,H3,H13
D17	112223	De Kalb	IL	41.95000	-88.77000	W3,W8,H2,H9,H15
D18	112736	Elgin	IL	42.02000	-88.27000	W3,W8,H2,H9,H15
D19	112993	Farmer City	IL	40.25000	-88.65000	W6,W7,H3,H8,H14
D20	113320	Galesburg	IL	40.95000	-90.37000	W2,W4
D21	113335	Galva	IL	41.17000	-90.05000	W4,W6
D22	113413	Gibson City	IL	40.46667	-88.36670	W6,W7,H3,H8,H14
D23	113530	Golden	IL	40.08333	-91.01670	W2,H12
D24	113572	Grafton	IL	38.91667	-90.43330	W14,H1,H4
D25	113940	Havana	IL	40.33000	-90.02000	W2,W6
D26	114013	Hennepin	IL	41.28333	-89.31670	W3,W6,W7,H6,H16
D27	114198	Hoopeston	IL	40.47000	-87.67000	W7,W13
D28	114442	Jacksonville	IL	39.71667	-90.18330	W9,H5
D29	114489	Jerseyville	IL	39.08333	-90.33330	W14,H1,H4
D30	114530	Joliet	IL	41.50000	-88.08000	W3,W7,H15,H16
D31	114603	Kankakee	IL	41.12000	-87.87000	W7
D32	114710	Kewanee	IL	41.25000	-89.90000	W4,W6
D33	114805	Lacon	IL	41.01667	-89.40000	W3,W6,W7,H6,H16
D34	114823	LaHarpe	IL	40.56667	-90.96670	W1,W2,H7
D35	115079	Lincoln	IL	40.15000	-89.40000	W6,W9,H3,H8
D36	115272	Mackinaw	IL	40.51667	-89.36670	W6,W7,H3,H8,H14
D37	115280	Macomb	IL	40.47000	-90.67000	W2,W6
D38	115326	Marengo	IL	42.25000	-88.58000	W3,W8,W17,H9,H15
D39	115372	Marseilles	IL	41.32000	-88.75000	W3,W7,H15,H16
D40	115413	Mason City	IL	40.20000	-89.71670	W6,W7,H3,H8,H14
D41	115539	Medora	IL	39.16667	-90.11670	W14,H1,H4
D42	115712	Minonk	IL	40.90000	-89.05000	W6,W7,H6,H14,H16
D43	115768	Monmouth	IL	40.92000	-90.62000	W2,W4
D44	115792	Monticello	IL	40.01667	-88.58330	W7,W9,H3,H8,H13

Table 4. (Concluded)

Station	*Coop ID*	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**	*WDM & NOAA Hourly** stations used for disaggregation*
D45	115917	Mount Olive	IL	39.06667	-89.68330	W14,H1,H10
D46	115927	Mount Pulaski	IL	40.01667	-89.26670	W9,H3,H8
D47	115935	Mount Sterling	IL	39.96667	-90.76670	W2,H12
D48	115950	Moweaqua	IL	39.61667	-89.01670	W5,W9,H13
D49	116526	Ottawa	IL	41.32000	-88.92000	W3,W7,H15,H16
D50	116579	Pana	IL	39.36667	-89.06670	W5,W9,H5,H10,H13
D51	116616	Park Forest	IL	41.50000	-87.67000	W3,W7,H15,H16
D52	116661	Paw Paw	IL	41.70000	-88.97000	W3,W8,H2,H9,H15
D53	116670	Payson	IL	39.81667	-91.25000	W2,H5,H12
D54	116725	Peotone	IL	41.32000	-87.80000	W3,W7,W12
D55	116753	Peru	IL	41.31667	-89.11670	W3,W6,W7,H6,H16
D56	116910	Pontiac	IL	40.86667	-88.61670	W6,W7,H6,H14,H16
D57	117004	Princeville	IL	40.92000	-89.77000	W4,W6
D58	117150	Rantoul	IL	40.31667	-88.16670	W6,W7,H3,H8,H14
D59	117551	Rushville	IL	40.11667	-90.55000	W2,H5,H12
D60	118353	Streator	IL	41.08333	-88.81670	W3,W6,W7,H6,H16
D61	118740	Urbana	IL	40.08333	-88.21670	W7,H3,H13
D62	118756	Utica	IL	41.31667	-88.96670	W3,W6,W7,H6,H16
D63	118860	Virden	IL	39.51667	-89.76670	W9,H1,H4,H5,H10
D64	118870	Virginia	IL	39.95000	-90.21670	W2
D65	119021	Watseka	IL	40.77000	-87.77000	W7
D66	119029	Waukegan	IL	42.33333	-87.86670	W3,W8,W17,H9,H15
D67	119221	Wheaton	IL	41.82000	-88.07000	W3,W8,H2,H9,H15
D68	119241	White Hall	IL	39.41667	-90.36670	W9,W14,H4,H5,H11
D69	121940	Crown Point	IN	41.42000	-87.33000	W3,W12
D70	124008	Hobart	IN	41.53000	-87.27000	W3,W12
D71	124527	Kentland	IN	40.77000	-87.43000	W7,W13
D72	124837	La Porte	IN	41.57000	-86.72000	W7,W12
D73	125174	Lowell	IN	41.27000	-87.42000	W3,W7,W12
D74	126989	Plymouth	IN	41.32000	-86.30000	W10,W11,W12
D75	127298	Rensselaer	IN	40.92000	-87.15000	W7,W12
D76	129222	Wanatah	IN	41.42000	-86.92000	W7,W12
D77	129511	Wheatfield	IN	41.25000	-87.07000	W12
D78	129670	Winimac	IN	41.03000	-86.58000	W10,W11,W12
D79	471205	Burlington	WI	42.67000	-88.27000	W8,W16,W17,H9
D80	473058	Germantown	WI	43.22000	-88.12000	W8,W16,W17,H9
D81	474457	Lake Geneva	WI	42.58000	-88.42000	W3,W8,W17,H9,H15
D82	476200	Oconomowoc	WI	43.08000	-88.50000	W8,W16,W17,H9
D83	478723	Union Grove	WI	42.70000	-88.02000	W8,W16,W17,H9
D84	478937	Waukesha	WI	43.02000	-88.22000	W8,W16,W17,H9
D85	479046	West Allis	WI	43.02000	-87.97000	W8,W16,W17,H9
D86	479190	Whitewater	WI	42.83000	-88.72000	W8,W16,W17,H9

Notes:
*DD – Decimal degrees.
**WDM and hourly station serial numbers shown in this column are taken from Tables 2 and 3.

Sub-watershed and Land-Use Delineation

The automatic delineation tool of BASINS was used to subdivide each watershed into smaller, hydrologically connected sub-watersheds, stream reaches, and respective outlets. This process assigns a reach of acceptable uniformity to each sub-watershed. Because there are several sub-watersheds, a representative meteorological station can be assigned to each one. The watershed outlet was defined to correspond to a USGS streamflow gaging station used for model calibration or validation. The automatic delineation process uses DEM data in an ArcInfo grid format and a pre-digitized stream network data layer (Reach File version 1.0, or National Hydrography Dataset, NHD) in ArcView shape format. The area of each sub-watershed and each land-use type within each sub-watershed also is computed. Characteristics of the stream reach within each sub-watershed, such as length, average elevation, and change in elevation, are determined based on the DEM data. The FTABLES (giving depth, area, volume, and outflow of a reach) computed by BASINS based on reach characteristics are used for level-pool routing of flows through reaches. Complete information is saved in the UCI input file when the WinHSPF interface is invoked after the watershed delineation step, and is used during HSPF model runs.

The distribution of pervious and impervious land-use types is determined in each sub-watershed based on the land-use coverage. A segment of land that permits enough infiltration to affect the water budget is considered pervious; otherwise, it is considered impervious. The percentages of impervious and pervious area each were kept as 50 percent for urban and built-up land use because imperviousness can vary from 25 percent for residential land use to 70 percent for commercial land use (Brun and Band, 2000). Most watersheds being analyzed have remained predominantly as agricultural land for the period of analysis, 1970-1995, and the BASINS-HSPF land-use database does not differentiate between different types of agricultural land use. Although there have been some changes over this period in management of agricultural land, model test results using scenarios of land-use change indicate that noticeable impacts on flow quantity are more likely to be observed for smaller watersheds than for larger watersheds such as those being calibrated in the present study. Thus, land use is considered to be stationary over the period used for model calibration and verification. Greater detail on agricultural land use will be added to the Illinois River BASINS model as it is developed further, calibrated for use on smaller watersheds, and applied to address issues of land-use change.

Model Calibration and Validation Procedures

Calibration and validation are essential steps in the development of any watershed model. Model calibration involves the improvement of the model output to match observed hydrologic data through the progressive adjustment of selected model parameters that represent poorly known or unmeasurable hydrologic properties. Model validation involves testing the credibility of the new parameter values by comparing model output to a separate, independent set of observed hydrologic data. The most common and effective approach to calibration and validation of continuous-simulation watershed models is to split the available hydrologic data into two samples or periods of years. The model validation generally is considered successful if the parameters developed for the set of calibration years can be used to simulate the streamflows under a wide range of events during the set of validation years with a level of accuracy similar to that achieved in calibration.

The standard methods recommended in the flow calibration tutorial in BASINS (Lumb et al., 1994) were followed to calibrate the HSPF model. The tutorial lists 22 calibration scenarios that represent possible discrepancies between simulated and observed streamflow series. It provides guidelines on the relevant parameters that should be modified to correct the discrepancies associated with each of the different scenarios. Calibration scenarios in the tutorial are derived from the algorithms used by the HSPF Expert System for Calibration (HSPEXP) and are grouped into four categories:

- **Annual Trends and Water Balance.** The first goal of calibration is accurate replication of annual trends and water balance in the watershed. In this step, it is necessary to adjust the long-term simulated flow volume so it is not less or greater than the observed flow volume. This is performed by adjusting the simulated ET if it is less than the potential ET. Other possible losses to consider prior to adjusting ET are unaccounted flow diversions and recharge to deep aquifers. The key parameters that can be adjusted at this stage are those that control the evaporation rates from the different storages (CEPSC, UZSN, LZETP, LZSN, and BASETP). The storage CEPSC is the amount of rainfall (inches) retained by vegetation that does not reach the land surface, and that eventually evaporates. The storage UZSN is the nominal upper zone soil moisture storage (inches), which varies with topography and surface characteristics. The storage LZSN is the lower zone nominal soil moisture storage (inches), which is related to both precipitation patterns and soil characteristics in the region. The storage LZETP is the adjustable parameter for the vigor with which vegetation transpires; it affects ET from the lower zone. The storage BASETP is the fraction of potential ET that can be drawn from baseflow by riparian vegetation as active groundwater enters the streambed. Increasing any of these parameters has the effect of increasing simulated ET and decreasing simulated flows. The fraction of the potential ET occurring in areas having vegetation drawing directly from groundwater, such as marshes or wetlands, is called AGWETP.

  At this point, the lag between simulated and the observed peaks is evaluated. Three key parameters that control the timing of peakflows are associated with flow routing: LSUR, SLSUR, and NSUR. The parameter LSUR is the length of the overland flow plane, and increasing LSUR will delay the time to peak. The parameter SLSUR is the average slope of the overland flow path. Reducing the slope will result in decreased flow velocity and will allow more infiltration to take place, thus decreasing the time to peak and the peak value. The parameter NSUR is the Manning's n value for overland flow. Different NSUR values were used for overland flow for agricultural and urban areas in the present study based on the range of values suggested in the literature. However, for very large watersheds, such as those studied in this work, the NSUR value for the similar land-use types is not expected to have a large impact on either peakflows or volumes.

- **High/Low Flow Distribution.** After reproducing the annual water balance, the next step is to adjust the simulated flow distribution between high and low periods, if needed, to better match the observed flow. The key parameters used to change this distribution are INFILT and AGWRC. The parameter INFILT controls the distribution of water between upper and lower storage volumes so that lower INFILT values reduce baseflow and increase interflow and surface runoff volumes. The parameter AGWRC is the groundwater recession rate parameter; an increase of this parameter flattens the baseflow recession limb.

- **Storm Flow.** At this stage, the simulation of peaks and volumes of the major storm flows is analyzed. Key parameters to adjust simulated peak and storm volumes are INTFW and IRC. The parameter INTFW determines the portions of water that become interflow, surface flow, and upper zone storage. Increasing INTFW shifts surface runoff to interflow, decreasing peakflows and, to some degree, storm volumes. The parameter IRC, interflow recession coefficient, needs to be changed when the simulated peakflows need to be adjusted without modifying the storm volumes. An increase in IRC flattens the recession limb of the hydrograph and decreases the peakflows.

- **Seasonal Discrepancies.** The goal of this stage is to adjust for observed seasonal discrepancies by checking if differences between simulated and observed flows are different for different seasons. In that case, it is necessary to check if the values of the interception storage parameter (CEPSC), the index to lower zone ET (LZETP), and the upper zone nominal storage (UZSN) have been adjusted to use monthly values. Another parameter that corrects seasonal discrepancies is the nonlinear groundwater recession flow parameter (KVARY). A value different other than zero makes KVARY nonlinear and increases the rate of flow during wet periods.

The simulation of snow accumulation and melt is important to obtain a correct water balance, but initial calibration parameters can be obtained without considering the snowpack and then later incorporating the snow parameters. Several snow parameters are used in the HSPF model to model snow accumulation, aging, heat exchange, melt, and the influence of the frozen soils in the snowpack. The parameter SNOWCF is the factor by which precipitation is multiplied to account for poor gage catch efficiency. Changing SNOWCF from 1.0 to 1.1 will increase snow catch by 10 percent; physically meaningful values are in the 1.0-1.5 range (Crawford, 1999). The parameter TSNOW, the wet bulb air temperature below which precipitation occurs as snow under saturated conditions, is the most obvious parameter to change to increase or reduce snow accumulation (Crawford, 1999). Increasing TSNOW values increases modeled snow accumulation. The parameter SNOWEVP adjusts sublimation from the snowpack; this loss can be significant where windy, low humidity conditions are common.

The empirical parameter COVIND is used to estimate the areal coverage of snow on a land segment. Typical values are in the 1.0-6.0 range (Donigian and Davis, 1978); the values should be lowest in flat topographic areas where snow events are common. The parameter RDCSN, the density of new snow, is set by observations of regional snow conditions, where available. The parameter SHADE controls the short-wave solar radiation that reaches the snowpack and is increased by forest cover and slope. The parameter CCFACT adjusts the rate of heat transfer from the atmosphere to the snowpack, thereby controlling both convection and condensation melt. The parameter MGMELT is the rate of daily snowmelt (inches or millimeters (mm) due to heat transfer from the earth to the bottom of the snowpack. Areas with deep frost, frozen ground, or both have small MGMELT values (Donigian and Davis, 1978). The parameter ICEFG is a flag that instructs the HSPF model to calculate ice at the bottom of the snowpack or on frozen ground; a value of zero indicates that ice formation was not simulated.

Precipitation and Flow Records Used for Calibration and Validation

The hydrologic component of the HSPF model was calibrated and validated separately for the Kankakee River and Spoon River watersheds in the second phase of this study plotting time-series data and also quantitative data. Hydrologic calibration required adjustment (within reasonable limits) of various model parameters describing watershed properties until agreement between simulated and observed daily streamflow at the watershed outlet was obtained. Agreement between observed and simulated streamflow data on an annual, seasonal (monthly), and continuous (daily) basis was determined by plotting time-series data and also quantitative data.

Complete precipitation datasets for the Illinois River basin were available for the 25-year period 1970-1995. For both watersheds selected for calibration, streamflow data for an 11-year period (1985-1995) were used to calibrate the HSPF model. This period was chosen because it represents a combination of dry, average, and wet years. The first two years (1985 and 1986) were used to stabilize model runs; therefore, only 1987-1995 data were used for comparison purposes. Observed and simulated streamflows were compared on a daily, monthly, and annual basis to determine any seasonal trends and to evaluate any long-term discrepancies. Each calibrated watershed model then was validated for the 16-year period 1971-1986.

Observed streamflows at or near the watershed outlet and meteorological data records were available at six of the seven tributary watersheds (all but the Des Plaines watershed) for 1970-1995. Complete streamflow records for the Des Plaines River watershed were available only from July 1984 to December 1995. Therefore, the HSPF model was run for six tributary watersheds for 1970-1995, but for the Des Plaines River watershed only from July 1984 to December 1995. Because simulated streamflow outputs from all nine major tributary watersheds were used as input to the model of the entire Illinois River basin, hydrologic simulation for the latter therefore was restricted to the period from July 1984 to December 1995 only.

Hydrologic simulations performed in the third phase of this study used the HSPF model for the following regions of the Illinois River basin:

- Watersheds of the other seven major tributaries: Des Plaines, Fox, Vermilion, Mackinaw, Sangamon, La Moine, and Macoupin.
- The entire Illinois River basin.

For each region, the parameter sets from the two previously calibrated watersheds were used, and simulation results were compared to observed streamflows using subjective and quantitative measures, as described above.

Measures of Model Performance

The GenScn post-processor tool in BASINS was used to calculate the coefficient of correlation (R), intercept, and slope of linear regression fit between observed and simulated data. The coefficient of determination (R^2) calculated from these data was reported along with the intercept and slope of the linear regression fit. The Nash-Sutcliffe Efficiency or NSE (Nash and

Sutcliffe, 1970), which measures the relative magnitude of the residual variance noise to the variance of the flows information, also was computed. The NSE indicates how well the plots of observed versus simulated data fit the 1:1 line. An NSE value of 1.0 indicates that the simulated flow perfectly matches the observed flow, and a value equal to 0.0 indicates that the model provides absolutely no useful information such that the mean observed flow is a better predictor than the model. The following equation is used to determine the NSE:

$$NSE = 1 - \sum_{i=1}^{n} (P_i - O_i)^2 / \sum_{i=1}^{n} (O_i - \overline{O})^2$$

where O_i and P_i are the observed and model predicted values for the *i*th event, respectively, $\overline{O}$ is the mean observed value, and n is the number of events. Each calibrated model also was validated using observed data other than those used for calibration. Error statistics described above also were computed for the model validation output data. The NSE was the primary performance measure for model calibration and validation.

Based on a literature review of calibrated HSPF models, Duncker and Melching (1998) suggest that HSPF model calibration can be considered satisfactory if the NSE value for monthly flows exceeds 0.80. According to Donigian et al. (1984), monthly and annual simulations are very good when percentage error is less than 10, good when it is between 10 and 15, and fair when it is between 15 and 25.

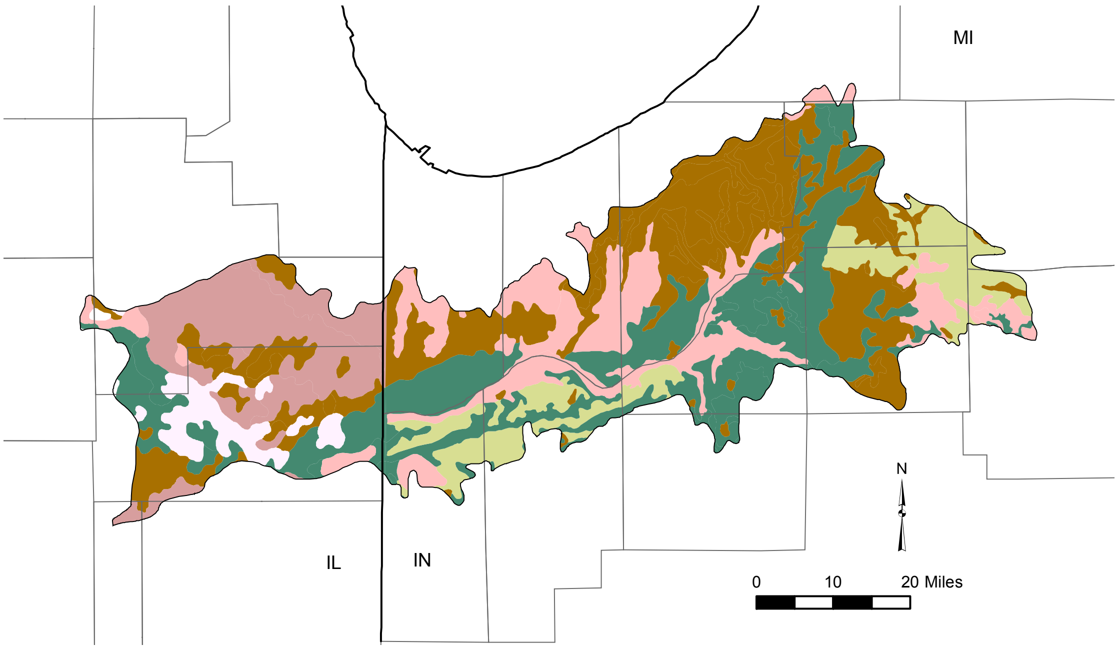
Donigan (2002) provides value ranges for the coefficient of determination (R^2) for assessing HSPF model performance. For daily flows, the R^2 is considered to be very good when it is greater than 0.8, good when it is between 0.7 and 0.8, fair when it is between 0.6 and 0.7, and poor when it is less than 0.6. For monthly flows, the R^2 is considered to be very good when it is greater than 0.85, good when it is between 0.75 and 0.85, fair when it is between 0.65 and 0.75, and poor when it is less than 0.65.

Hydrologic Modeling of the Kankakee River Watershed

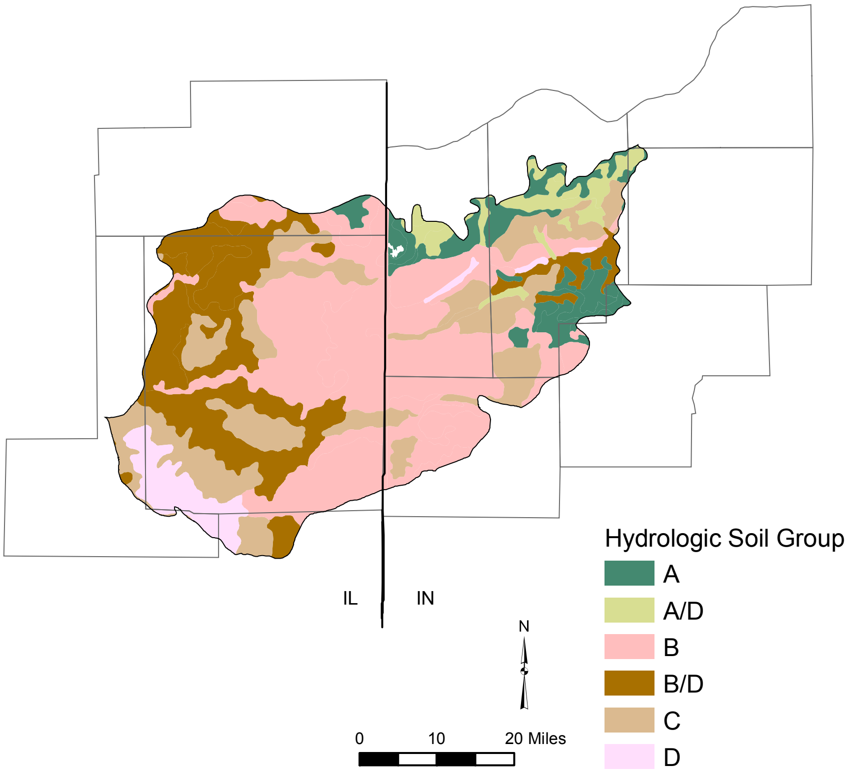
Watersheds of two of the nine major tributaries of Illinois River basin, specifically the Kankakee and Spoon Rivers, were selected for HSPF model calibration and validation in the second phase of this hydrologic modeling study. The Kankakee River watershed (8-digit USGS Cataloging Units 07120001 and 07120002) is located in northeastern Illinois and northwestern Indiana (Figure 1). The 5,165-square-mile (sq mi) watershed covers portions of 22 counties in the two states. The largest tributary of the Kankakee River is the Iroquois River, which flows west into Illinois from Indiana. The Iroquois River watershed (8-digit USGS Cataloging Unit 07120002) alone drains about 2,137 sq mi in eastern Illinois and western Indiana. The 140-mile Kankakee River is joined by the 94-mile Iroquois River at Aroma Park, Illinois, flows northwest for 38 miles, and then merges with the Des Plaines River to form the Illinois River.

The Kankakee River watershed consists primarily of level to gently undulated plains underlain by unconsolidated sands and gravels deposited from the outwash from a glacial lake. A large portion of the watershed originally was prairie, with nearly level to gently sloping topography and poor drainage. The soil, a heterogeneous mix of silts or clays, also has some deposits of sand in the Indiana portion and in Illinois (northern Iroquois County). Sub-surface water inputs come from the lakebed ditch and tile systems in the Pella soils. Figure 4 shows the distribution of various soil types in the Kankakee and Iroquois River watersheds based on the hydrologic soil group; soil group A indicates well-drained soil that generates very little runoff, whereas soil group D is very poorly drained and generates most runoff. The maps in Figure 4 were created using the State Soil Geographic Data Base (STATSGO) soils database available in the BASINS 3.0 dataset for the two watersheds. As shown in this figure, a mixture of soil groups A-C covers the Kankakee River watershed. Soil groups B and C are predominant in the Iroquois River watershed, however. Maps of various land-use types in the two watersheds are shown (Figure 5). These maps were created based on the land-cover/land-use database of BASINS 3.0 for the two watersheds. Agriculture, the predominant land use in both watersheds, covers 88 percent of the Kankakee River watershed area and 95 percent of the Iroquois River watershed area. Forest and urban land use cover 6.3 percent and 3.1 percent of the Kankakee River watershed area and 2.9 percent and 1.2 percent of the Iroquois River watershed area, respectively.

For the purpose of this study, the entire Kankakee River watershed was modeled in three sections (Figure 6): 1) upper Kankakee River watershed: upstream of USGS streamgage (05520500) at Momence, Illinois (2,294-sq-mi drainage area), 2) Iroquois River watershed: upstream of USGS streamgage (05526000) near Chebanse, Illinois (2,091-sq-mi drainage area), and 3) lower Kankakee River watershed: Kankakee/Iroquois River watershed upstream of USGS streamgage (05527500) near Wilmington, Illinois (5,150-sq-mi drainage area). Total streamflow at the Wilmington gage is the sum of the streamflows from all three sections. The HSPF model was calibrated separately only for the first two sections. Parameters obtained from the upper Kankakee River watershed calibration study were used to simulate the hydrology of the lower Kankakee River watershed. More details about model calibration and validation are given in the following sections.

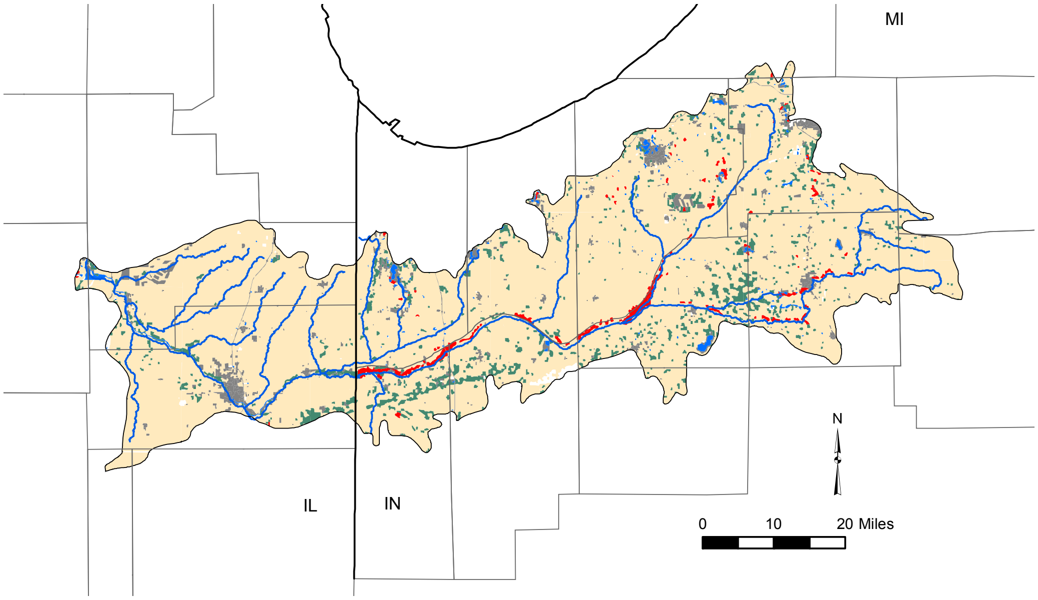


a) Kankakee River watershed

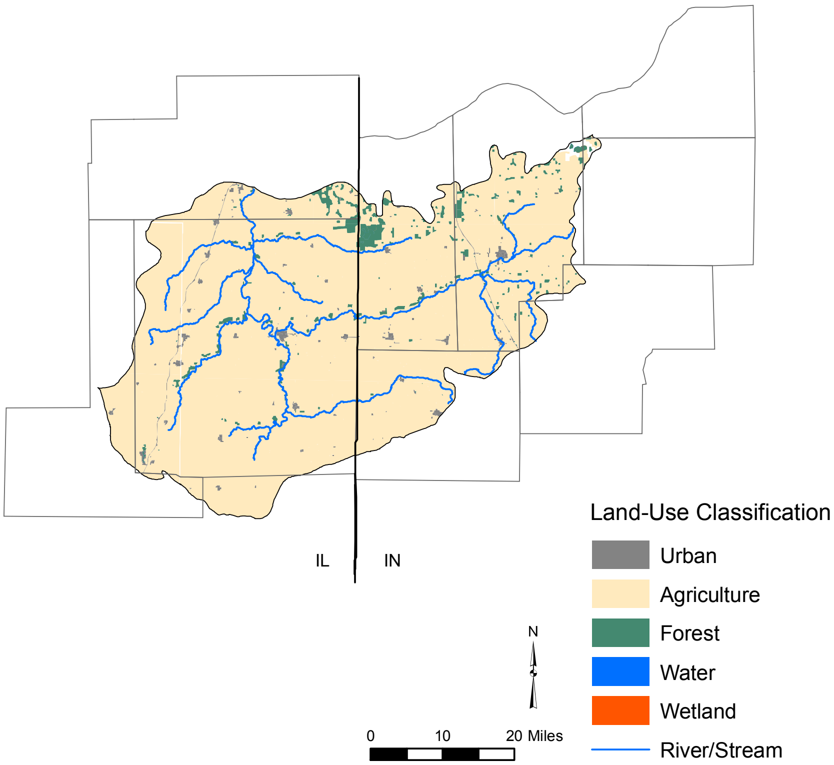


b) Iroquois River watershed

Figure 4. Soil types based on the hydrologic soil groups in the a) Kankakee and b) Iroquois River watersheds.



a) Kankakee River watershed



b) Iroquois River watershed

Figure 5. Land uses in the a) Kankakee River watershed and b) Iroquois River watershed.

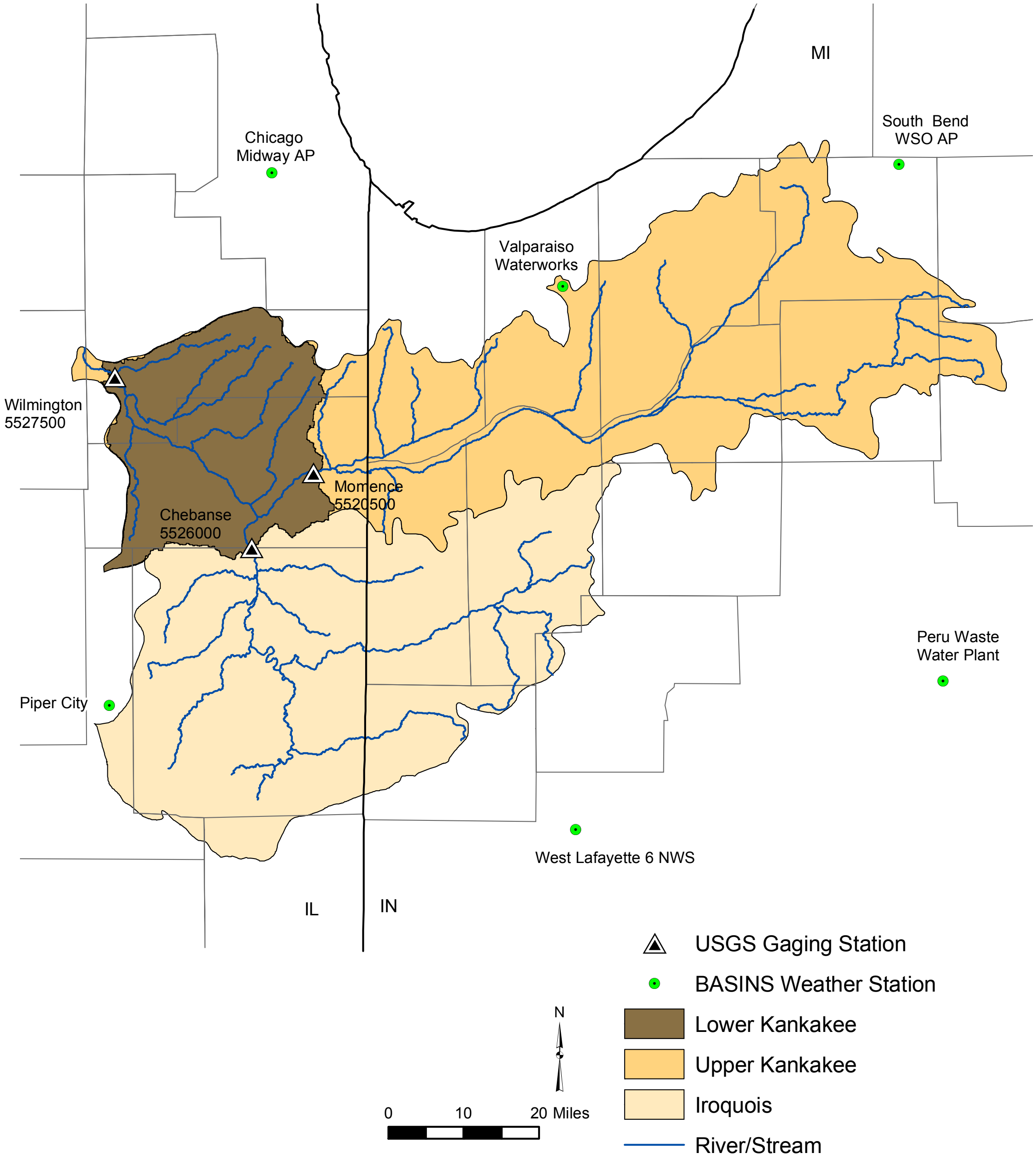


Figure 6. Lower and upper Kankakee, and Iroquois sections of entire Kankakee River watershed model.

Sub-watershed Delineation

Each of the three sections of the Kankakee River watershed was divided into smaller sub-watersheds using the automatic delineation tool of BASINS 3.0. The outlets of the upper Kankakee and Iroquois River watersheds were specified as inlets to the lower Kankakee section of the watershed to enable routing of simulated daily streamflows from the two inlet-watersheds through the lower Kankakee River watershed. The NHD stream coverage was used for the Iroquois River watershed, but the RF1 was used for the upper and lower Kankakee River watersheds because of the poor quality of NHD for those watersheds. Sub-watersheds for the three Kankakee River regions and respective stream reaches are shown (Figures 7-9). The USGS streamgaging stations used in those watersheds also are shown. An outlet in each watershed was chosen during delineation to nearly coincide with the USGS streamflow gaging station. The upper Kankakee and Iroquois River watersheds had 22 and 19 sub-watersheds, respectively, whereas the lower Kankakee River watershed had 13 sub-watersheds. The total number of land segments in each watershed was 131, 91, and 74, respectively.

Input Data

Of the eight required hourly meteorological input time series, six are used to simulate hydrology when snow is a consideration. These time series are saved in the WDM file for various weather stations. Figures 10-12 show various USEPA-WDM and local daily precipitation stations located within the entire Kankakee River watershed, lower Kankakee River watershed, and Iroquois River watershed, respectively. Daily precipitation data available at the local stations were disaggregated into hourly data using nearby USEPA-WDM reference stations. Tables 5-7 list all weather stations used for hydrologic modeling of each of the three sections of the Kankakee River watershed. The last column in each table lists various reference USEPA-WDM stations that were used to disaggregate daily precipitation data at local daily data stations. As shown in Figure 10 and Table 5, five USEPA-WDM weather stations were used to disaggregate daily precipitation data from seven daily precipitation stations identified for the upper Kankakee River watershed. Three USEPA-WDM stations were used to disaggregate daily precipitation data from three daily precipitation stations identified for the lower Kankakee River watershed (Figure 11 and Table 6). Three nearby USEPA-WDM weather stations were used to disaggregate daily precipitation data for five stations located in or near the Iroquois River watershed (Figure 12 and Table 7). Other hourly time-series data for local stations also were obtained from the closest USEPA-WDM station. A representative weather station was specified for each sub-watershed during HSPF model setup using the WinHSPF interface. The interface extracted appropriate information from land use, sub-watershed, stream, and outlet GIS layers of BASINS to develop the user-controlled input (*.UCI) file for the HSPF model. It also assigned a default set of parameters for hydrologic simulations. Some of these parameter values were modified during model calibration.

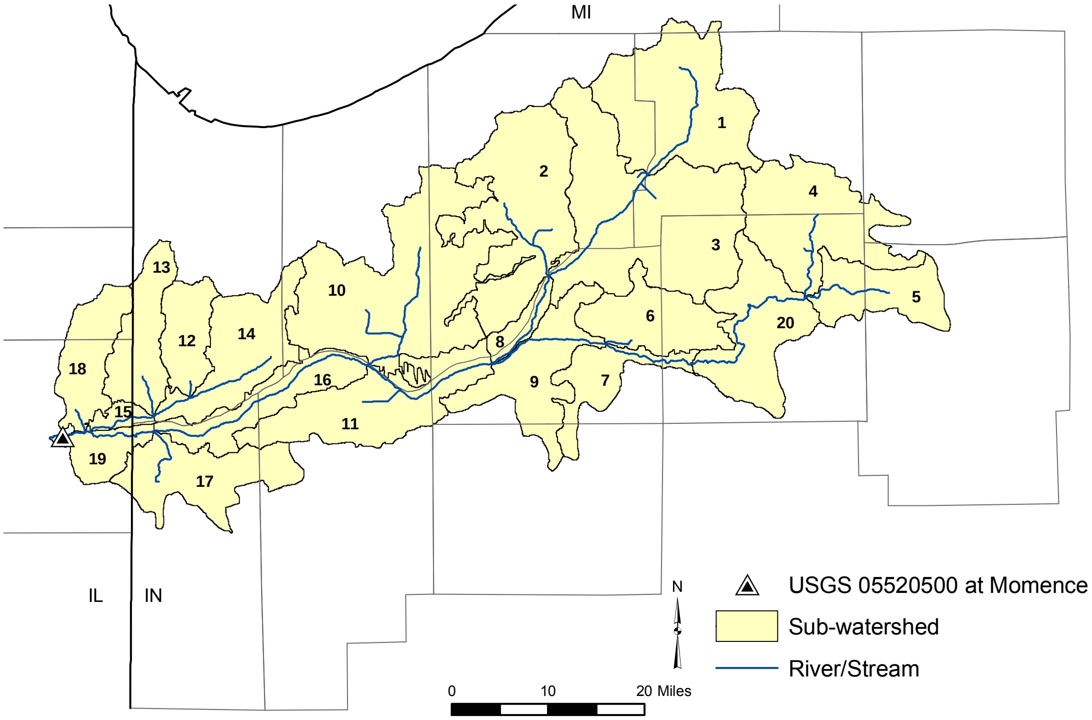


Figure 7. The 22 sub-watersheds of the upper Kankakee River watershed after delineation.

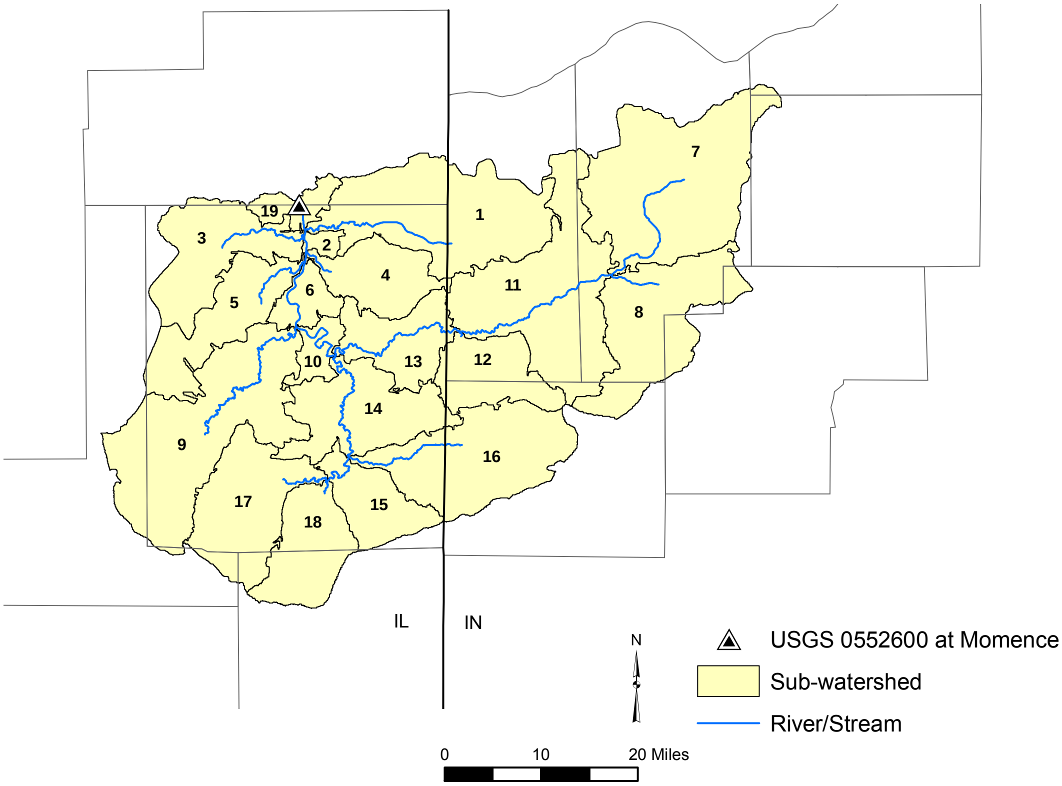


Figure 8. The 19 sub-watersheds of the Iroquois River watershed after delineation.

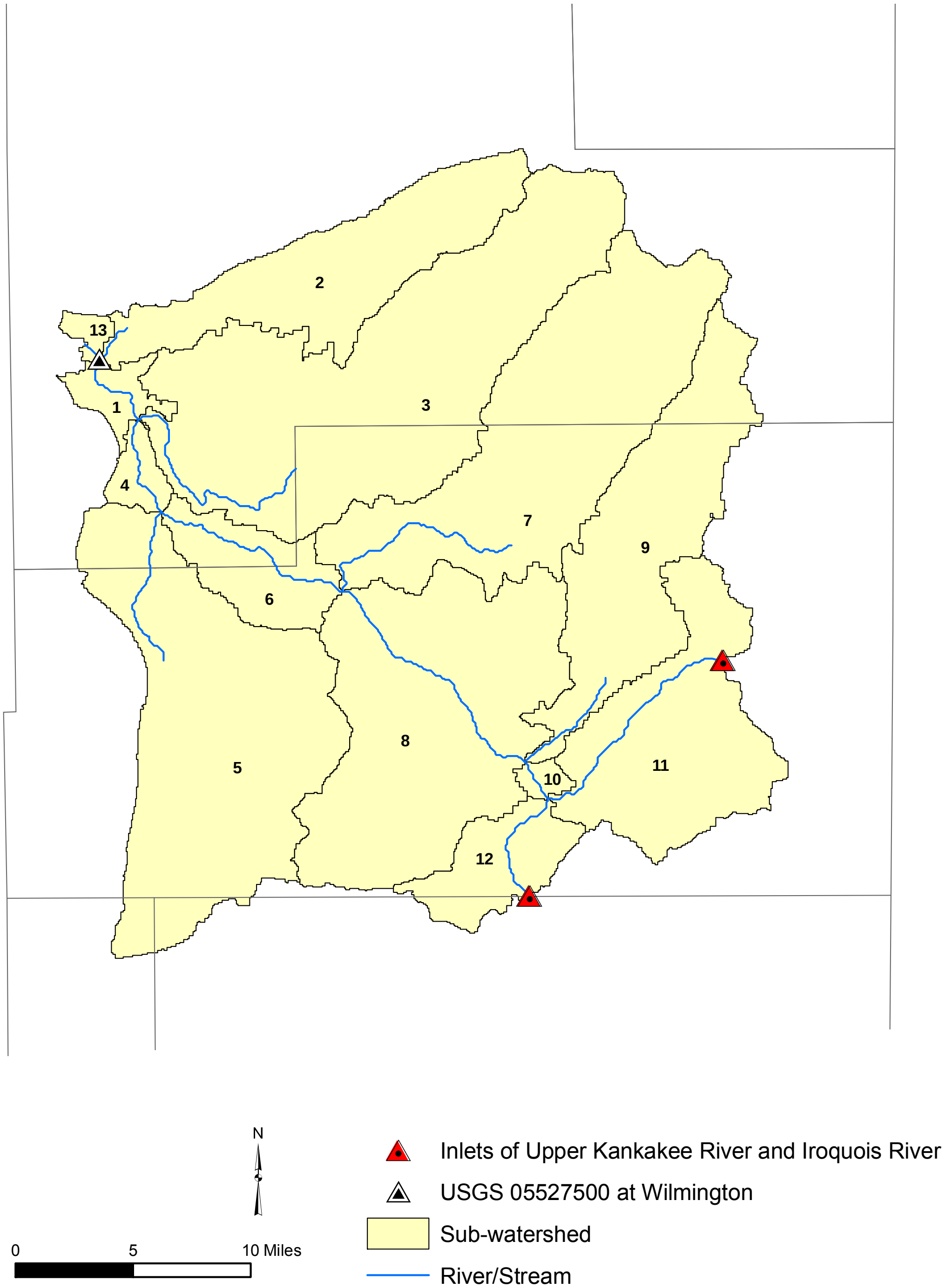


Figure 9. The 13 sub-watersheds of the lower Kankakee River watershed after delineation.

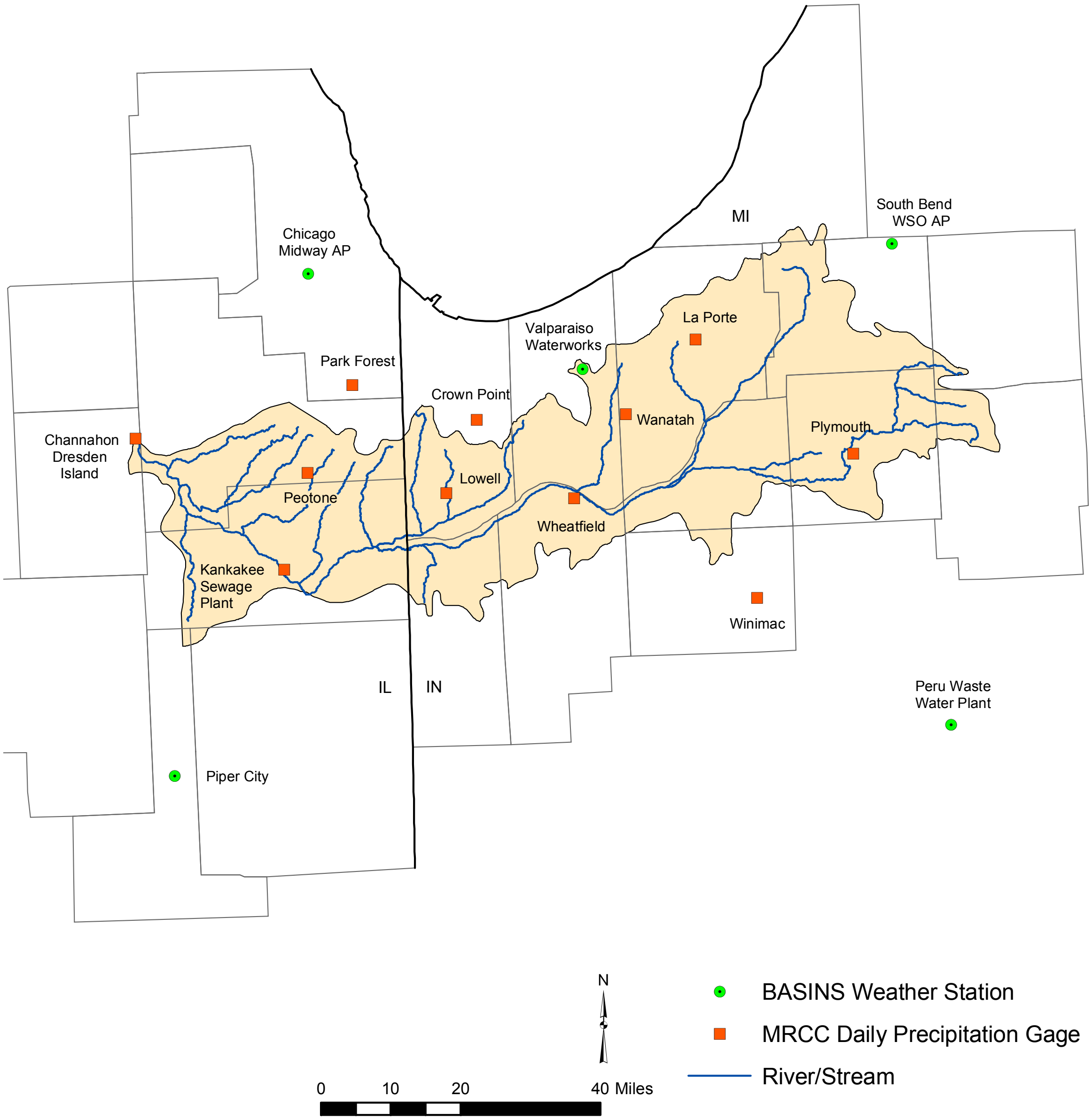


Figure 10. The BASINS weather stations and MRCC daily precipitation stations located in or near the upper Kankakee River watershed.

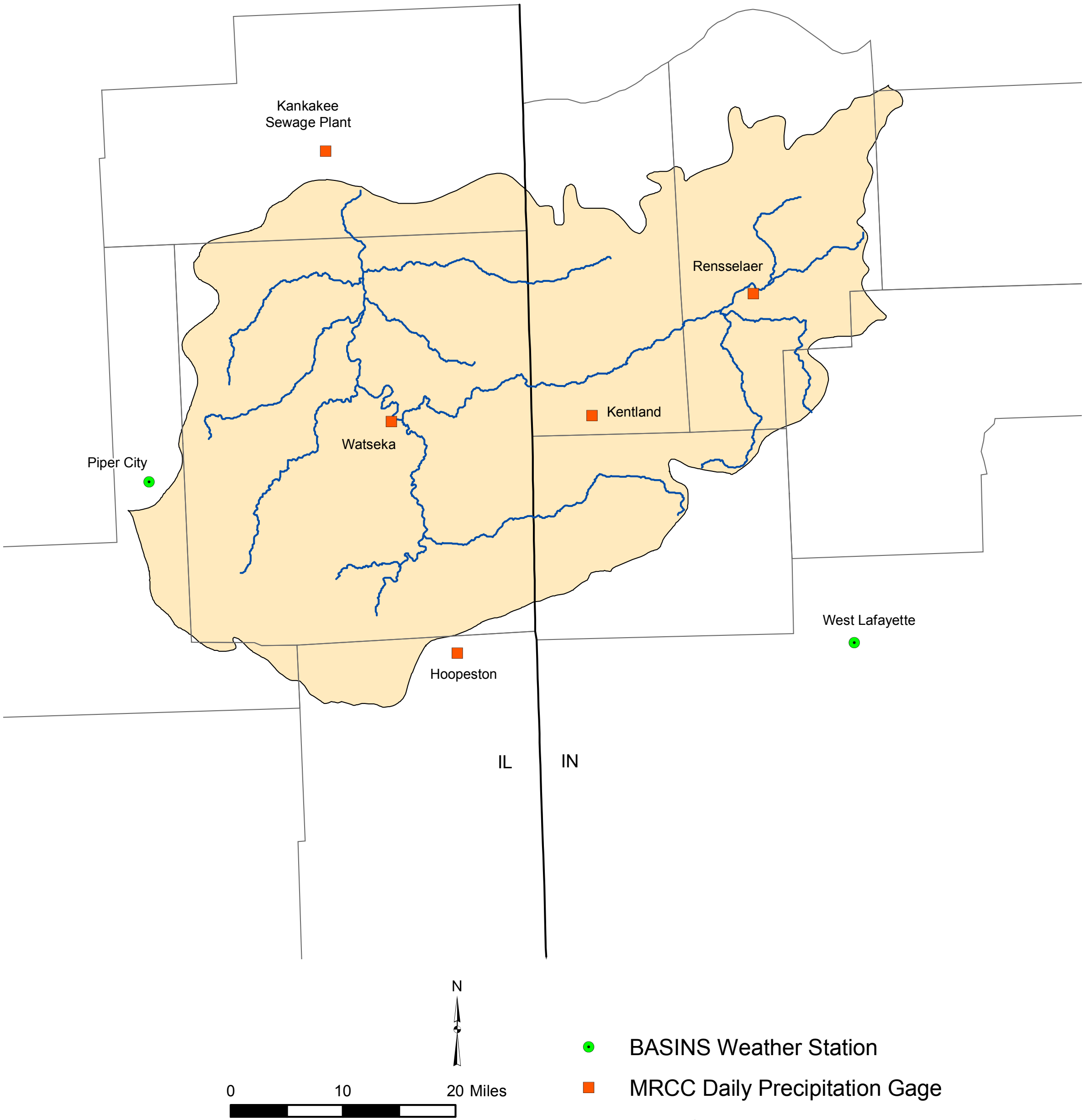


Figure 11. The BASINS weather stations and MRCC daily precipitation stations located in or near the Iroquois River watershed.

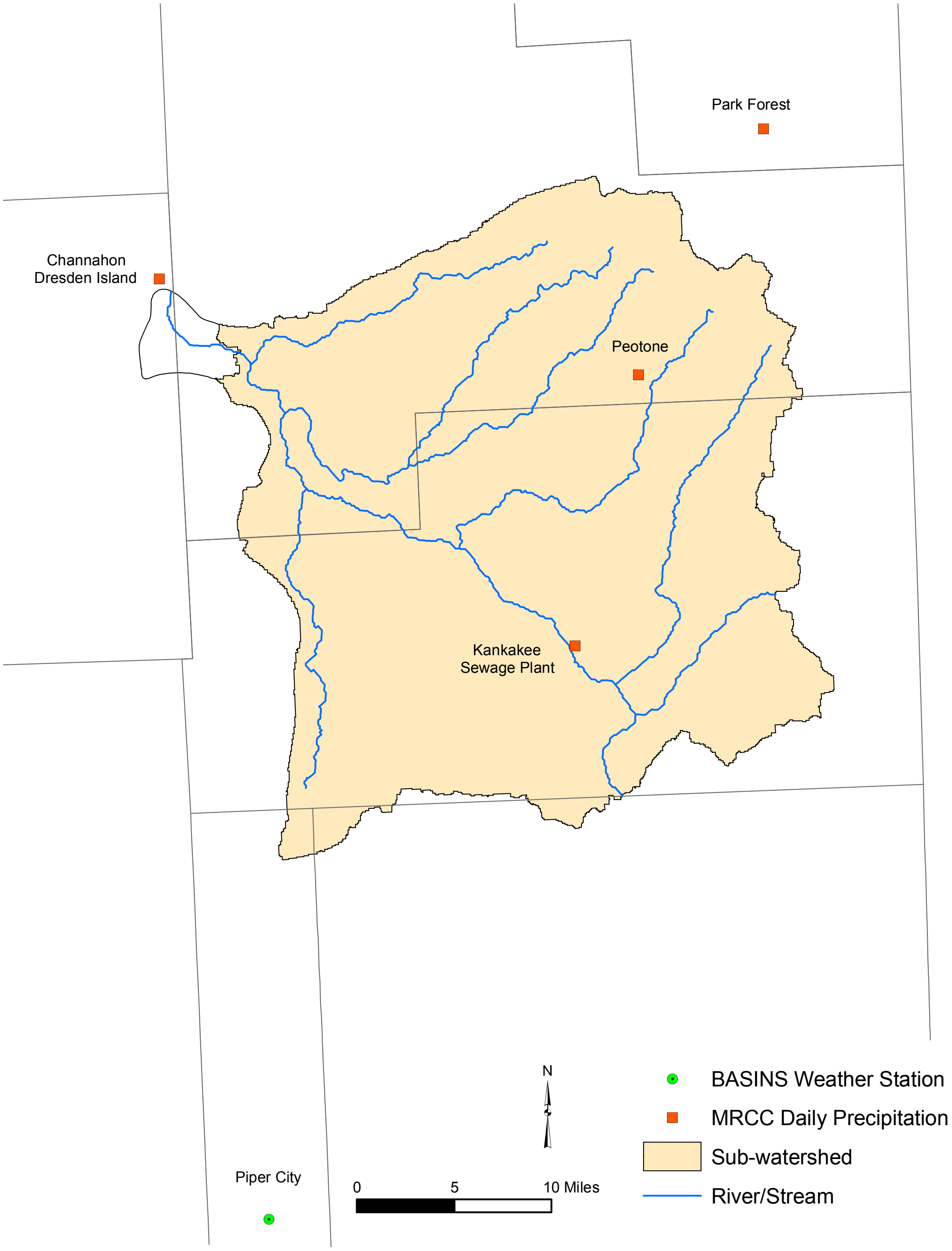


Figure 12. The BASINS weather stations and MRCC daily precipitation stations located in or near the lower Kankakee River watershed.

Table 5. Weather Stations Used for Upper Kankakee River Watershed Hydrologic Simulations

Coop ID	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**	*WDM & Hourly** stations used for disaggregation*
116725	Peotone	IL	41.32000	-87.80000	W3,W7,W12
124837	La Porte	IN	41.57000	-86.72000	W7,W12
125174	Lowell	IN	41.27000	-87.42000	W3,W7,W12
126989	Plymouth	IN	41.32000	-86.30000	W10,W11,W12
129222	Wanatah	IN	41.42000	-86.92000	W7,W12
129511	Wheatfield	IN	41.25000	-87.07000	W12
129670	Winimac	IN	41.03000	-86.58000	W10,W11,W12
008999	Valparaiso WW**	IN	41.51670	-87.03330	--
008187	South Bend WSO AP**	IN	41.75000	-86.16670	--

Notes:
*DD – Decimal degrees.
**WDM and hourly station serial numbers shown in this column are taken from Tables 2 and 3.

Table 6. Weather Stations Used for Iroquois River Watershed Hydrologic Simulations

Coop ID	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**	*WDM & Hourly** stations used for disaggregation*
114198	Hoopeston	IL	40.47000	-87.67000	W7,W13
114603	Kankakee SP	IL	41.12000	-87.87000	W7
119021	Watseka	IL	40.77000	-87.77000	W7
124527	Kentland	IN	40.77000	-87.43000	W7,W13
127298	Rensselaer	IN	40.92000	-87.15000	W7,W12
006819	Piper City**	IL	40.70000	-88.18330	--

Notes:
*DD – Decimal degrees.
**WDM and hourly station serial numbers shown in this column are taken from Tables 2 and 3.

Importance of Adding Additional Precipitation Gages to Database

Figure 13 compares observed and simulated daily streamflows for the upper Kankakee River watershed generated using the uncalibrated HSPF model and precipitation data from a) one USEPA-WDM station, and b) multiple precipitation stations that were available after

Table 7. Weather Stations Used for Lower Kankakee River Watershed Hydrologic Simulations

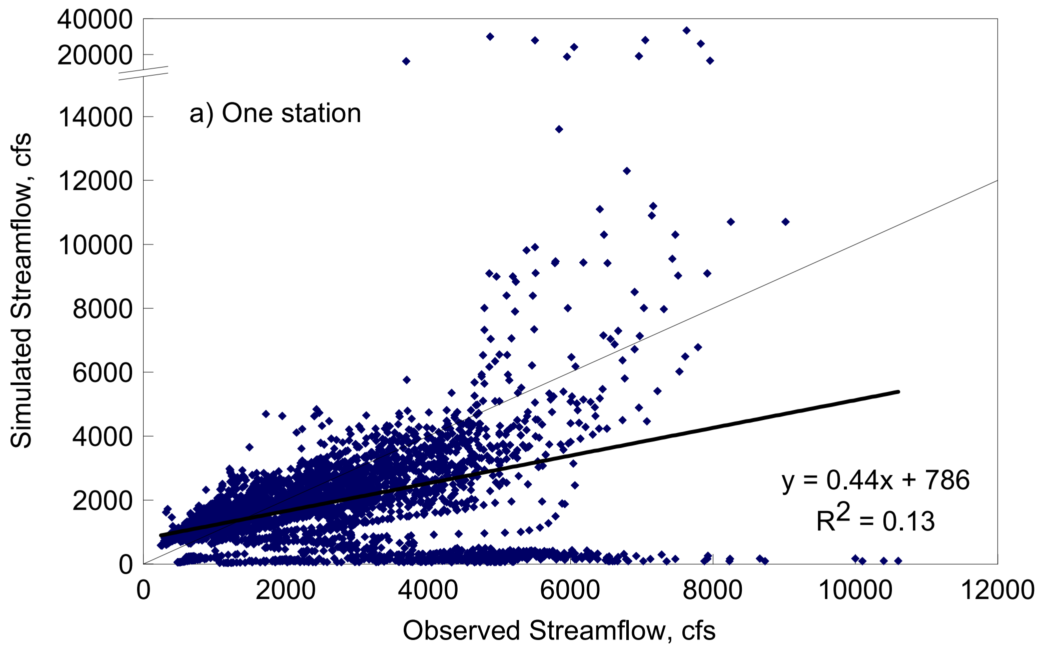
Coop ID	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**	*WDM & Hourly** stations used for disaggregation*
111420	Channahon Dres Isl	IL	41.40000	-88.27000	W3,W7
114603	Kankakee SP	IL	41.12000	-87.87000	7
116725	Peotone	IL	41.32000	-87.80000	W3,W7,W12
006819	Piper City***	IL	40.70000	-88.18330	--

Notes:
*DD – Decimal degrees.
**Based on Tables 2 and 3.
***Hourly precipitation data station (USEPA-WDM station) from BASINS 3.0 database.

disaggregation of daily data at the local weather stations into hourly data. It is evident that effect of spatial variability of rainfall over the large watershed area can be reduced by using multiple weather stations for different parts of the watershed. Agreement between observed and simulated daily streamflows improved significantly when precipitation data from six different precipitation gages were assigned to various sub-watersheds (Figure 13b), versus using only one USEPA-WDM weather station (Figure 13a) for the entire watershed. Similar improvements were observed for monthly and annual data, and also for the Iroquois River watershed.

HSPF Model Calibration and Validation

During model calibration, values of several sensitive model parameters were varied within a reasonable range to obtain the best practical agreement between observed and simulated streamflow data. Runoff responses to precipitation events were calibrated by adjusting various pervious land segment (PWATER) parameters (CEPSC, INFILT, UZSN, INTFW, LZSN, LZETP, BASETP, IRC, KVARY, AGWRC, and DEEPFR). The model was calibrated for snowmelt by adjusting HSPF snow parameters SHADE, SNOWCF, COVIND, TSNOW, and SNOEVP. Values of CEPSC, UZSN, INTFW, IRC, and LZETP were varied on a monthly basis, but only one value of other parameters was specified for the whole year. Two values of the Manning's surface roughness factor NSUR were used: 0.1 for pervious urban land use, and 0.2 for other pervious land surfaces. Similarly, an AGWETP value of 0.20 was used for wetlands, but a value of 0.00 was used for all other land uses. Only default parameter values were used for the impervious land segments. The same snow parameter values were used for pervious and impervious land segments. Because a major portion of the watershed is used for agriculture, no adjustments were made to the model parameters for hydrologic simulation of other types of pervious land-use segments.



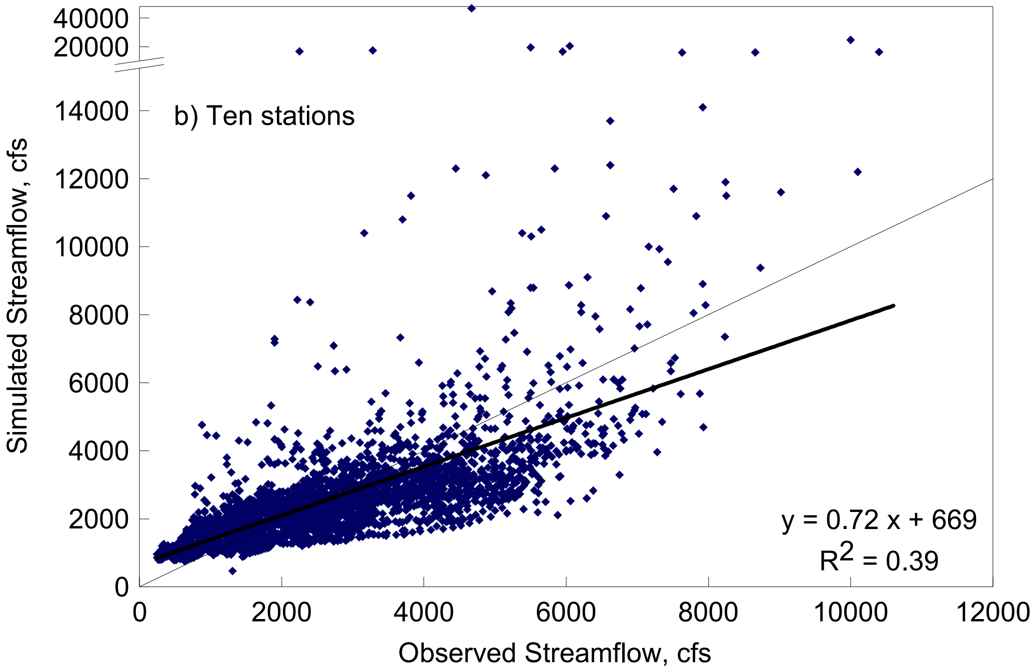


Figure 13. Observed and simulated streamflows from the uncalibrated model for the upper Kankakee River watershed, 1987-1995, using a) only one hourly precipitation station, and b) ten different hourly precipitation stations.

Calibration and Validation for Upper Kankakee River Watershed

Observed streamflow data at the Momence gage on the Kankakee River and simulated streamflow data at a watershed outlet that corresponds to this gage were compared during various calibration trials for the upper Kankakee River watershed. Figure 14 compares the daily simulated streamflow from the uncalibrated model of this watershed with observed streamflow at the Momence gage. Figure 14a is a scatter plot, and Figure 14b compares the time-series data for simulated and observed streamflows. It is clear from Figure 14a that the uncalibrated model overestimated some very low and very high streamflows, but overall it underestimated the flows. From a comparison between observed and simulated daily time-series data, it was found that the model poorly simulated the baseflow and overestimated some hydrograph peaks. Also, a comparison of average monthly data showed that most model overestimates were during the first five months of all years, and most model underestimates were during the other seven months. However, average annual streamflows show good agreement between observed and simulated values. Several calibration trials were performed to minimize these differences between observed and simulated flow values.

During model calibration, values of INFILT and INTFW parameters were increased to reduce the surface runoff and also the hydrograph peaks. The UZSN and LZETP parameters were varied on a monthly basis to increase ET during the first five months and decrease it for the rest of the months. An increase in the AGWETP parameter also resulted in some ET losses from groundwater. To increase baseflow, the LZSN parameter was reduced so that less water was stored in this zone and more baseflow was produced. To better match the shape of the recession limb of simulated streamflow hydrograph with that of the observed one, the IRC and AGWRC parameters were adjusted. The TSNOW parameter was found to be most critical in controlling the snow simulation. The final values of the model parameters that were adjusted during calibration are given (Table 8).

Figures 15a and 15b show a scatter plot and a time-series plot, respectively, of the daily observed and simulated streamflows (from calibrated model) for 1987-1995. After calibration, R^2 increased from 0.39 to 0.77 (Figure 15a), slope of the regression line increased from 0.72 to 0.98, whereas the intercept value decreased from 669 cubic feet per second (cfs) to 116 cfs. The NSE value also increased from 0.12 before calibration to 0.72. Thus, a much better agreement between observed and simulated data was obtained by calibrating the model. Figure 15b also shows better agreement between hydrograph peaks and shape for observed and simulated data. Some discrepancies were seen between high daily simulated and observed streamflows. It was not practical to recalibrate the model for every individual storm during the nine-year calibration period. Rather, it is the objective and standard procedure of long-term continuous simulation modeling to use *a priori* information to simulate individual storms as part of the complete range of flow conditions. Common discrepancies between high daily simulated and observed streamflows can be related to various factors, including inadequate data on the intensity and spatial variability of rainfall over the watershed, measurement error, and other unique characteristics of individual storms. The depth-discharge relationships (FTABLES) for streams in the tributary watersheds were not modified in this study, which also may have affected the simulated streamflow results.

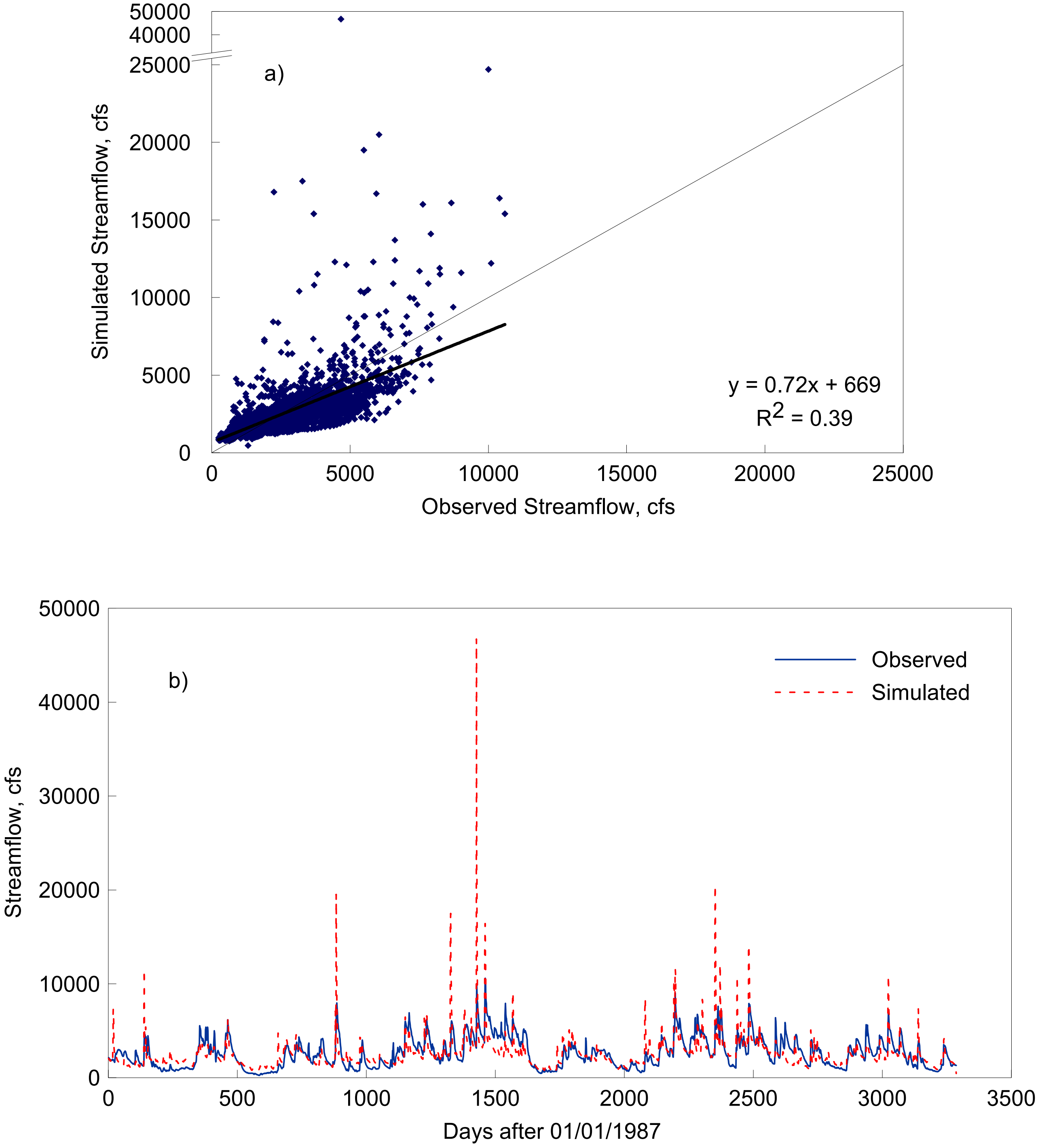


Figure 14. Comparison of observed and simulated daily streamflows from the uncalibrated model for the upper Kankakee River watershed, 1987-1995:
a) scatter plot and b) time series.

Table 8. Annual and Monthly Model Parameters for Upper Kankakee River Watershed

Annual parameter values

Hydrology parameters		*Snow parameters*	
KVARY(1/in)	0.05	SHADE	0.10
INFILT (in/h)	0.30	SNOWCF	1.20
AGWRC (1/d)	0.95	COVIND (in)	4.00
LZSN (in)	5.00	TSNOW (°F)	33.00
BASETP	0.10	SNOEVP	0.10
NSUR*	0.20 (0.1)		
DEEPER**	0.07		
AGWETP	0.20 (0.0)		

Monthly parameter values

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
CEPSC (inches)	0.01	0.01	0.01	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.30
UZSN (inches)	0.70	0.70	0.90	0.90	1.00	1.40	1.40	1.40	1.40	1.40	1.00	1.00
INTFW	2.30	2.30	2.30	2.30	2.30	1.80	1.80	2.30	2.30	2.30	2.30	2.30
IRC	0.98	0.98	0.98	0.90	0.70	0.50	0.50	0.60	0.60	0.80	0.98	0.98
LZETP	0.10	0.10	0.10	0.30	0.40	0.60	0.60	0.50	0.50	0.40	0.30	0.30

Notes:

*The NSUR value is 0.20 for pervious land-use types, and 0.10 for impervious land-use types.

** The AGWETP value is 0.20 for wetlands, and 0.00 for all other land uses.

A comparison of different statistics for daily, average monthly, and average annual streamflows prior to and after calibration is shown (Table 9). Comparison of average monthly flows for calibration years 1987-1995 with observed flows (Figure 16) shows good agreement. The scatter plot of average monthly streamflows (Figure 17a) and average annual streamflows (Figure 17b) also show good agreement between observed and simulated values. Percentage differences between the observed and simulated average annual streamflow values are presented in a bar chart (Figure 17c). The model slightly overestimated in six years and underestimated in three years. The percentage difference varied from 1.1 percent in 1990 to 17.8 percent in 1992. Of the nine years for which the model was calibrated, the percentage difference was less than 10 percent for six years and less than 15 percent for eight years, indicating a good fit in the annual values.

For validation purposes, the calibrated model was run for 1970-1986 without changing any parameter values. Simulated daily, average monthly, and average annual streamflows were compared with respective observed data values for 1971-1986. The results are shown (Figures 18-19, and Table 9). As shown in Figure 18, very few daily high-flow values were overestimated or underestimated. The performance measures indicate that fair to good agreement was obtained between observed and simulated daily, monthly, and annual data. Figure 19c shows a bar chart of

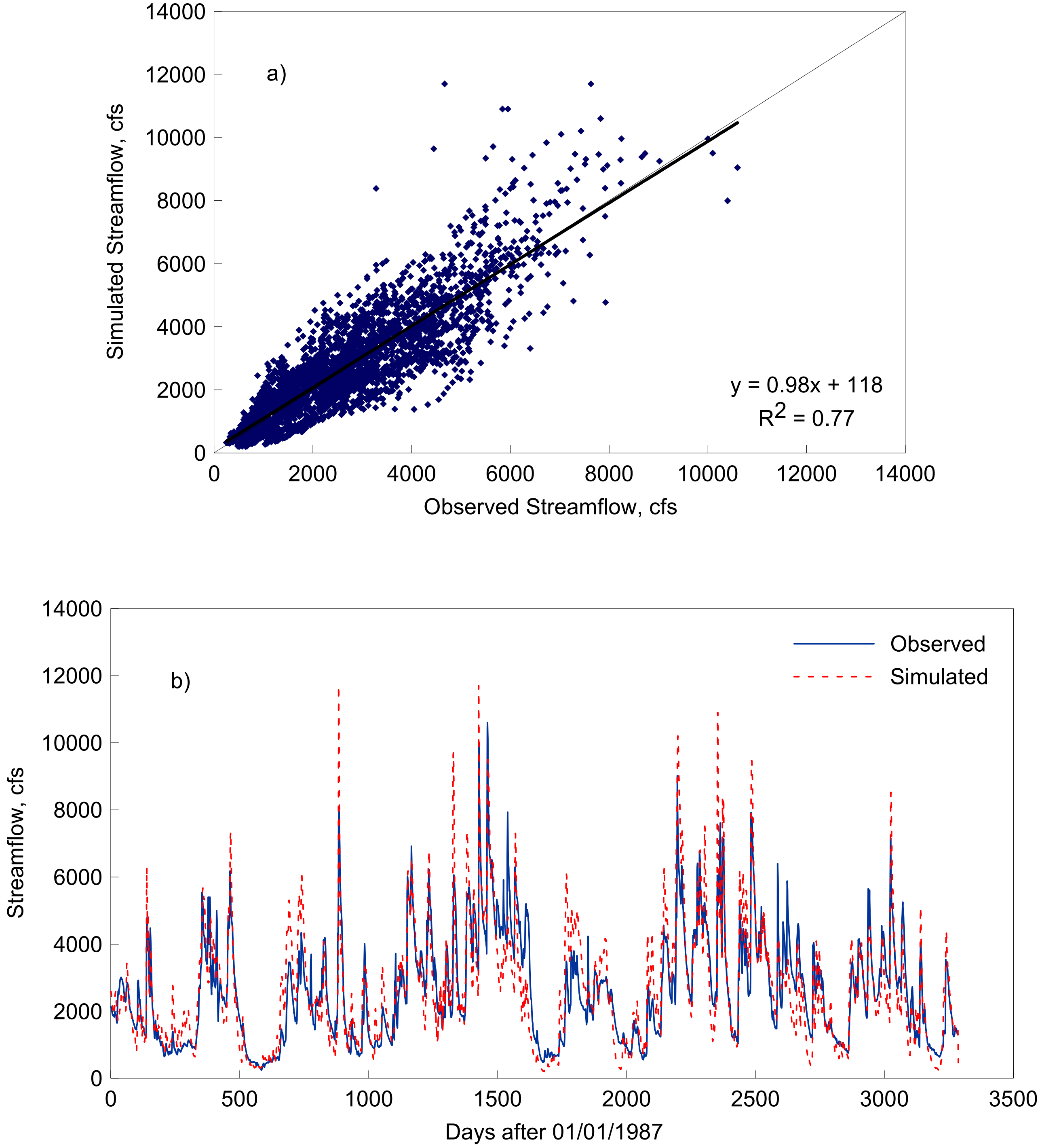


Figure 15. Observed and simulated streamflows from the calibrated model for the upper Kankakee River watershed, 1987-1995: a) scatter plot and b) time series.

Table 9. Statistics from Linear Regression Fit and NSE Values of Observed and Model-Simulated Streamflow Data before and after Calibration (1987-1995), and from Validation Period (1971-1986) for Upper Kankakee River Watershed

Streamflow data	*NSE*	*R^2*	*Slope*	*Intercept*
Uncalibrated model (1987-1995)				
Daily	0.12	0.39	0.72	669
Model calibration (1987-1995)				
Daily	0.72	0.77	0.98	116
Average monthly	0.78	0.82	0.99	85
Average annual	0.89	0.90	0.97	146
Model validation (1971-1986)				
Daily	0.71	0.75	0.92	264
Average monthly	0.78	0.81	0.90	308
Average annual	0.77	0.82	0.97	156

the percentage differences for 1971-1986. The model slightly overestimated in 12 years and underestimated in four years. The percentage difference varied from 2.1 percent in 1980 to 15.2 percent in 1982. During the 16-year validation period, the percentage difference was less than 10 percent for 12 years and less than 15 percent for 15 years, again indicating a good fit in the annual values.

Calibration and Validation for Iroquois River Watershed

Observed streamflow data at a USGS gaging station on the Iroquois River at Chebanse, Illinois, was compared with the HSPF-simulated streamflow data at a watershed outlet that corresponds to this gage during various calibration trials. The scatter plot of HSPF-simulated daily streamflows from the uncalibrated model and observed daily streamflows for the Iroquois River watershed shows that the model overestimated some low flows but generally underestimated streamflows (Figure 20a). The plot of time-series data for 1987-1995 showed that mostly baseflow was overestimated while peaks were underestimated (Figure 20b). It also was found that average monthly flows were overestimated from August to November, but underestimated in other months for different years.

In order to better match the hydrograph peaks, contributions from surface runoff and interflow to streamflow needed to be increased. This was achieved by reducing the INFILT, IRC, and INTFW parameter values, which also reduced the baseflow. Monthly UZSN values were lowered to reduce ET and increase streamflow. The shape of the recession limb of the simulated streamflow hydrograph was matched to the observed hydrograph by changing the KVARY parameter value. Using the same snow parameter values for the upper Kankakee River watershed resulted in an improved fit between observed and simulated streamflow values during winter months. The final values of the parameters modified during calibration are given (Table 10).

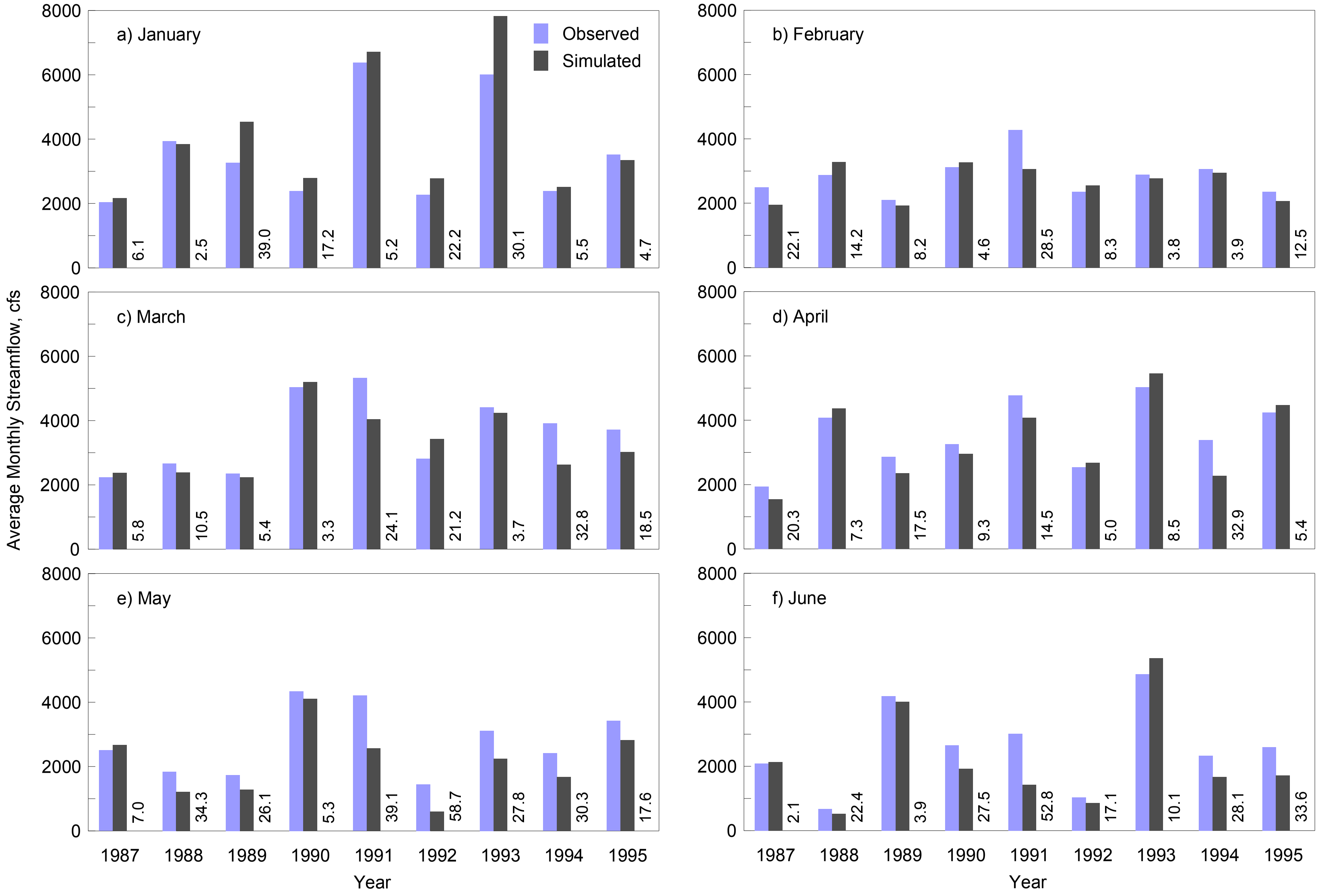


Figure 16a. Observed and simulated average monthly streamflows for the upper Kankakee River watershed, January-June 1987-1995 calibration period. Data labels indicate percent relative difference between simulated and observed values.

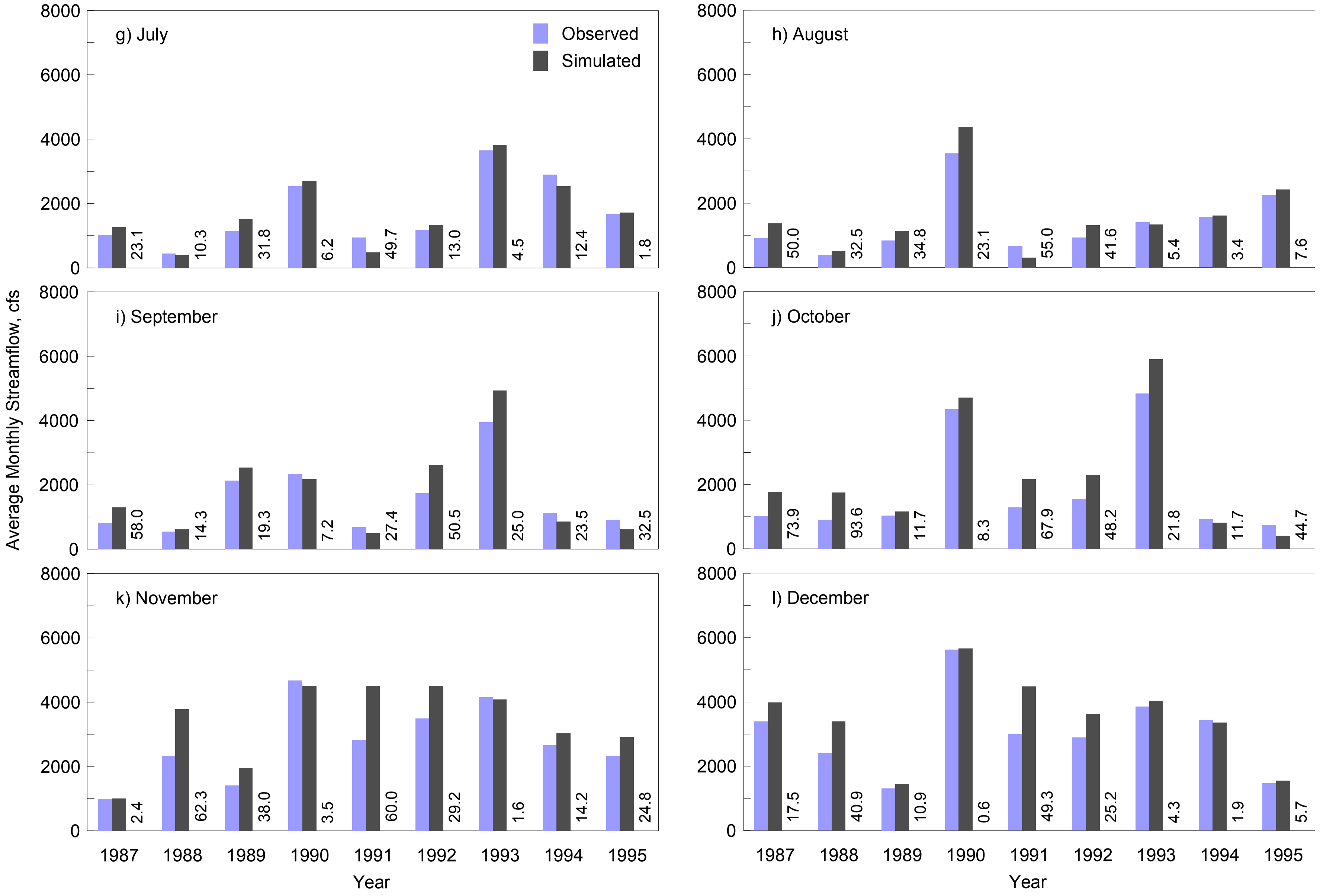


Figure 16b. Observed and simulated average monthly streamflows for the upper Kankakee River watershed, July-December 1987-1995 calibration period. Data labels indicate percent relative difference between simulated and observed values.

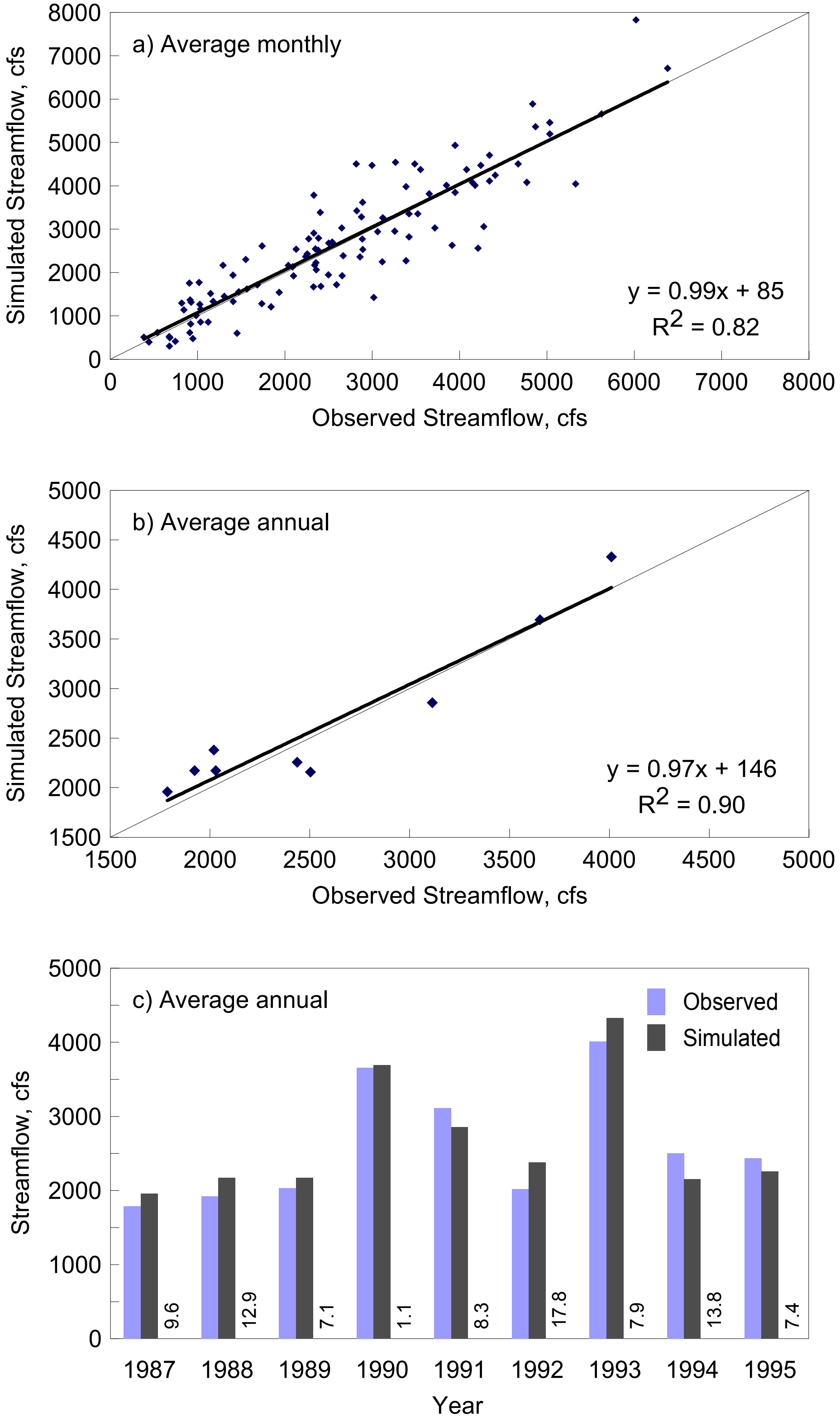


Figure 17. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, upper Kankakee River watershed, 1987-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

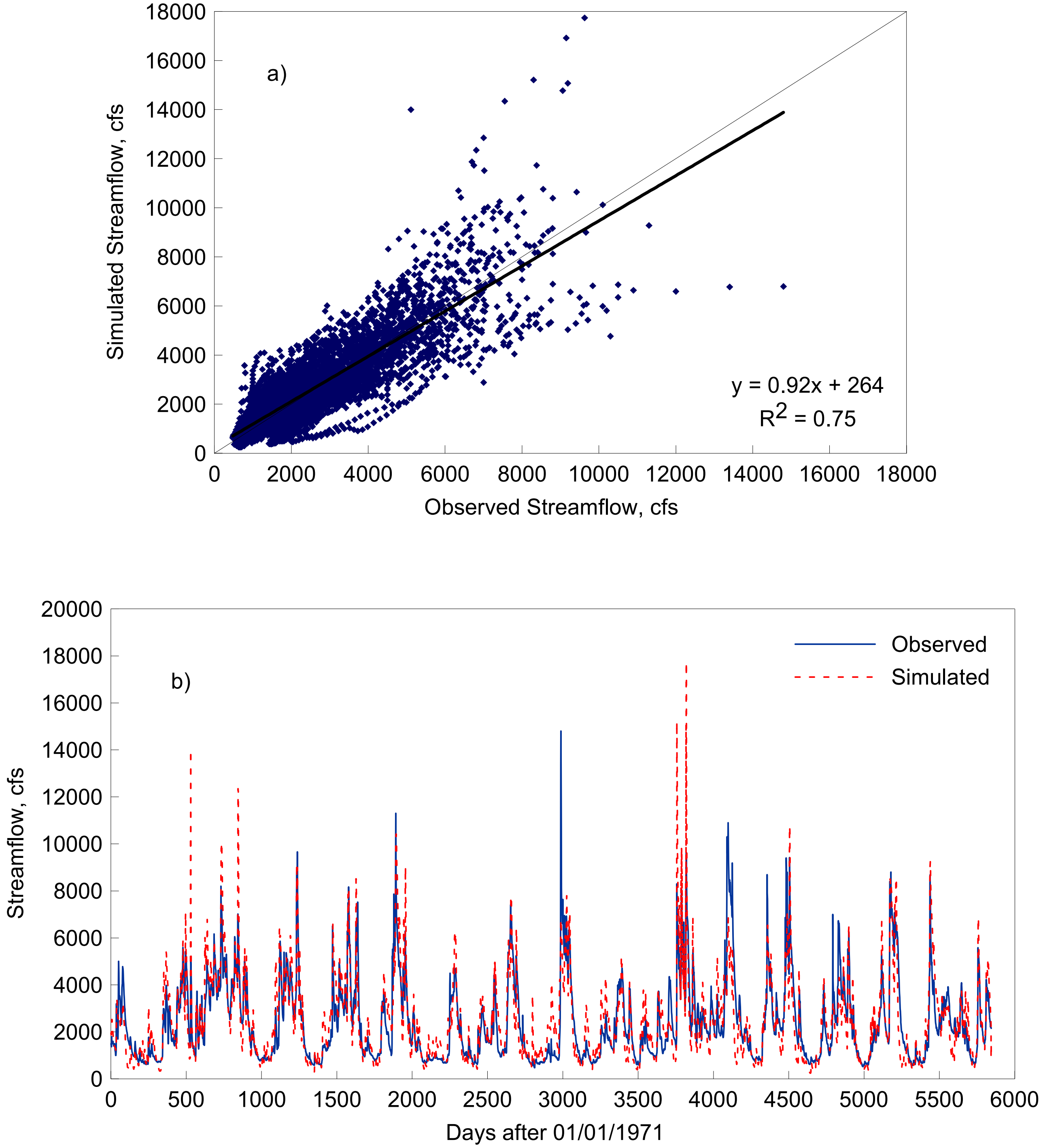


Figure 18. Observed and simulated streamflows, upper Kankakee River watershed, 1971-1986 validation period: a) scatter plot and b) time series.

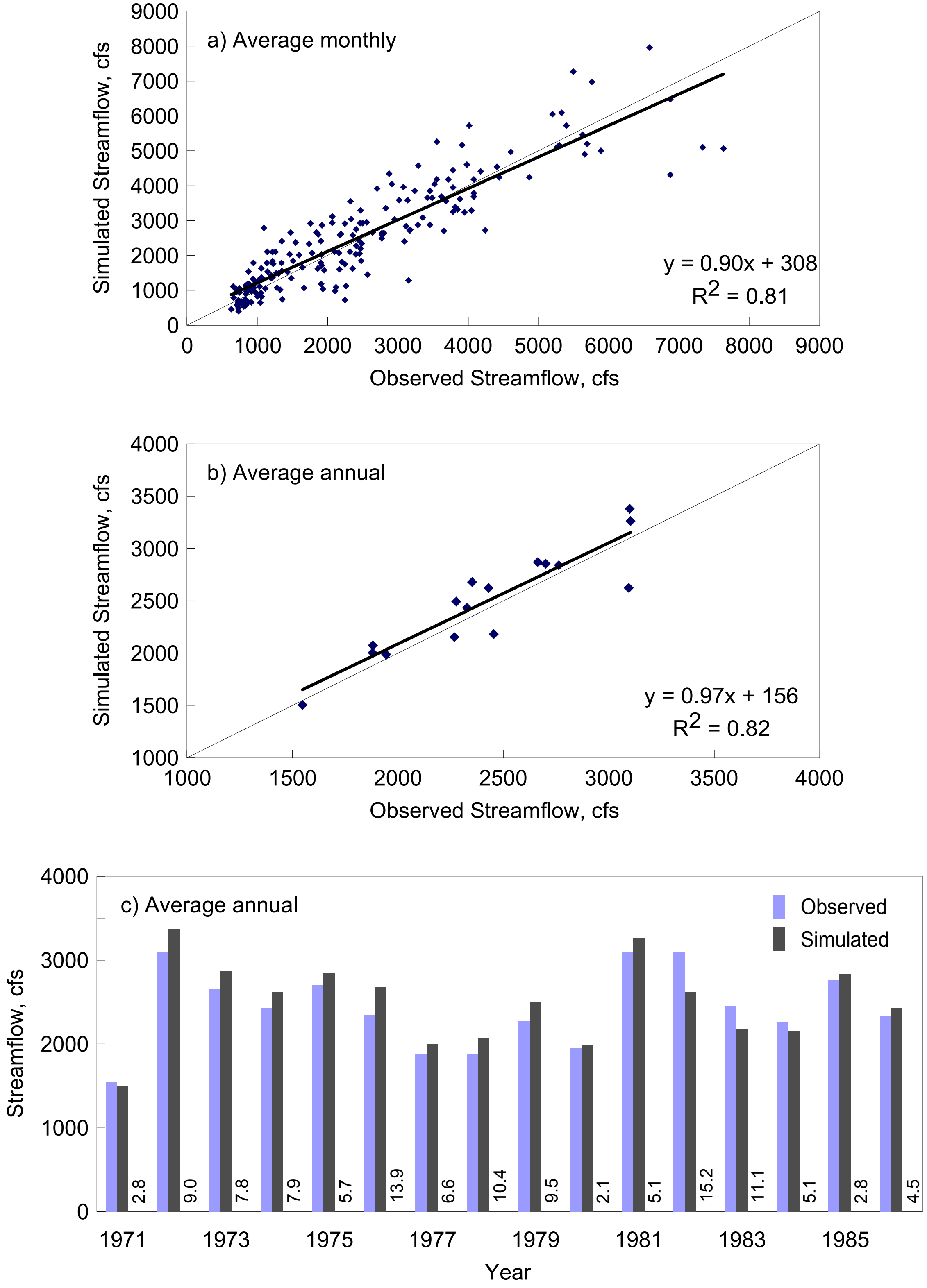


Figure 19. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, upper Kankakee River watershed, 1971-1986 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

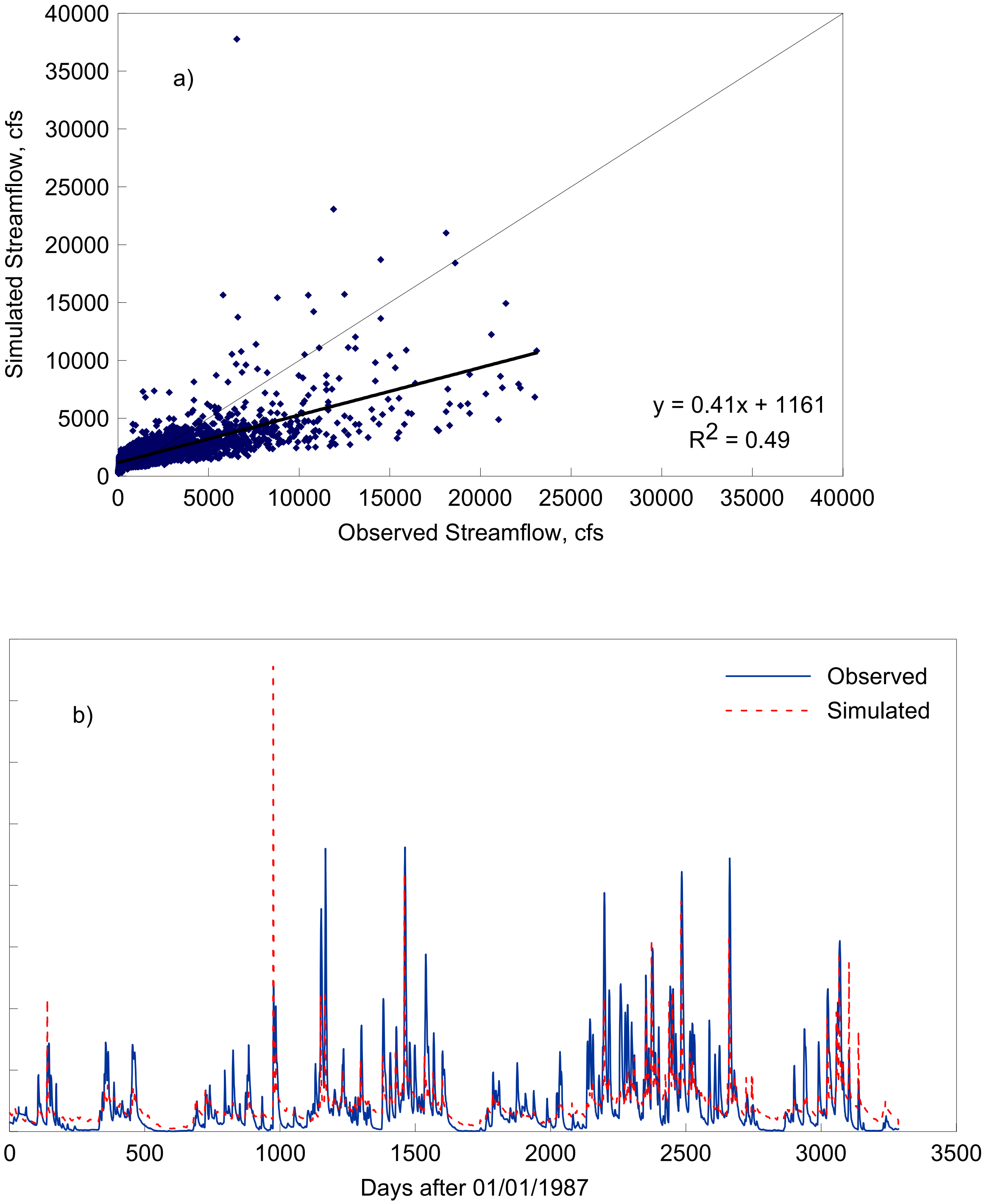


Figure 20. Observed and simulated daily streamflows from the uncalibrated model for the Iroquois River watershed, 1987-1995: a) scatter plot and b) time series.

Table 10. Annual and Monthly Model Parameters for Iroquois River Watershed

Annual parameter values

Hydrology parameters		*Snow parameters*	
KVARY (1/in)	3.00	SHADE	0.10
INFILT (in/h)	0.20	SNOWCF	1.20
AGWRC (1/d)	0.98	COVIND (in)	4.00
LZSN (in)	5.00	TSNOW (°F)	33.00
BASETP	0.10	SNOEVP	0.10
NSUR*	0.20 (0.1)		
DEEPER	0.05		
AGWETP**	0.20 (0.0)		

Monthly parameter values

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
CEPSC (inches)	0.10	0.00	0.00	0.00	0.02	0.10	0.10	0.10	0.10	0.10	0.10	0.10
UZSN (inches)	0.20	0.20	0.20	0.20	0.50	1.40	1.40	1.40	1.40	0.95	0.70	0.70
INTFW	1.60	1.60	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.40	1.80
IRC	0.80	0.80	0.70	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.70	0.80
LZETP	0.10	0.10	0.10	0.10	0.25	0.50	0.50	0.75	0.70	0.50	0.30	0.30

Notes:
*The NSUR value is 0.20 for pervious land-use types, and 0.10 for impervious land-use types.
**The AGWETP value is 0.20 for wetlands, and 0.00 for all other land uses.

A comparison of these final calibrated parameter values with those for the upper Kankakee River watershed (Table 8) revealed that the value of the INFILT parameter is higher (0.3 in/h) and that of the KVARY parameter is lower (0.05) for the upper Kankakee River watershed. The most likely reason may be relatively well-drained soils, and an underlying deposit of unconsolidated sand and gravel in the upper Kankakee River watershed may have resulted in a greater tendency for water to infiltrate and to flow towards the stream as baseflow. A higher value of the DEEPFR parameter (0.07) for the upper Kankakee River watershed was also most likely due to the same reasons. The fact that higher baseflow occurred in the upper Kankakee River watershed is also evident from comparison of Figures 14b and 20b.

Figures 21a and 21b show a scatter plot and a time-series plot, respectively, of the daily observed and simulated streamflows (from the calibrated model). A comparison of daily observed and simulated streamflows revealed that after calibration R^2 increased from 0.49 (Figure 21a) to 0.82, the slope of the regression line increased from 0.41 to 0.87, and the intercept value decreased from 1,161 cfs to 389 cfs. The NSE value also increased from 0.48 before calibration to 0.81. Thus, a satisfactory agreement between observed and simulated daily data was obtained by calibrating the model. A comparison of different statistics for daily, average monthly, and average annual streamflows prior to and after calibration is shown (Table 11). Figure 22 compares average monthly flows for calibration years 1987-1995 with observed

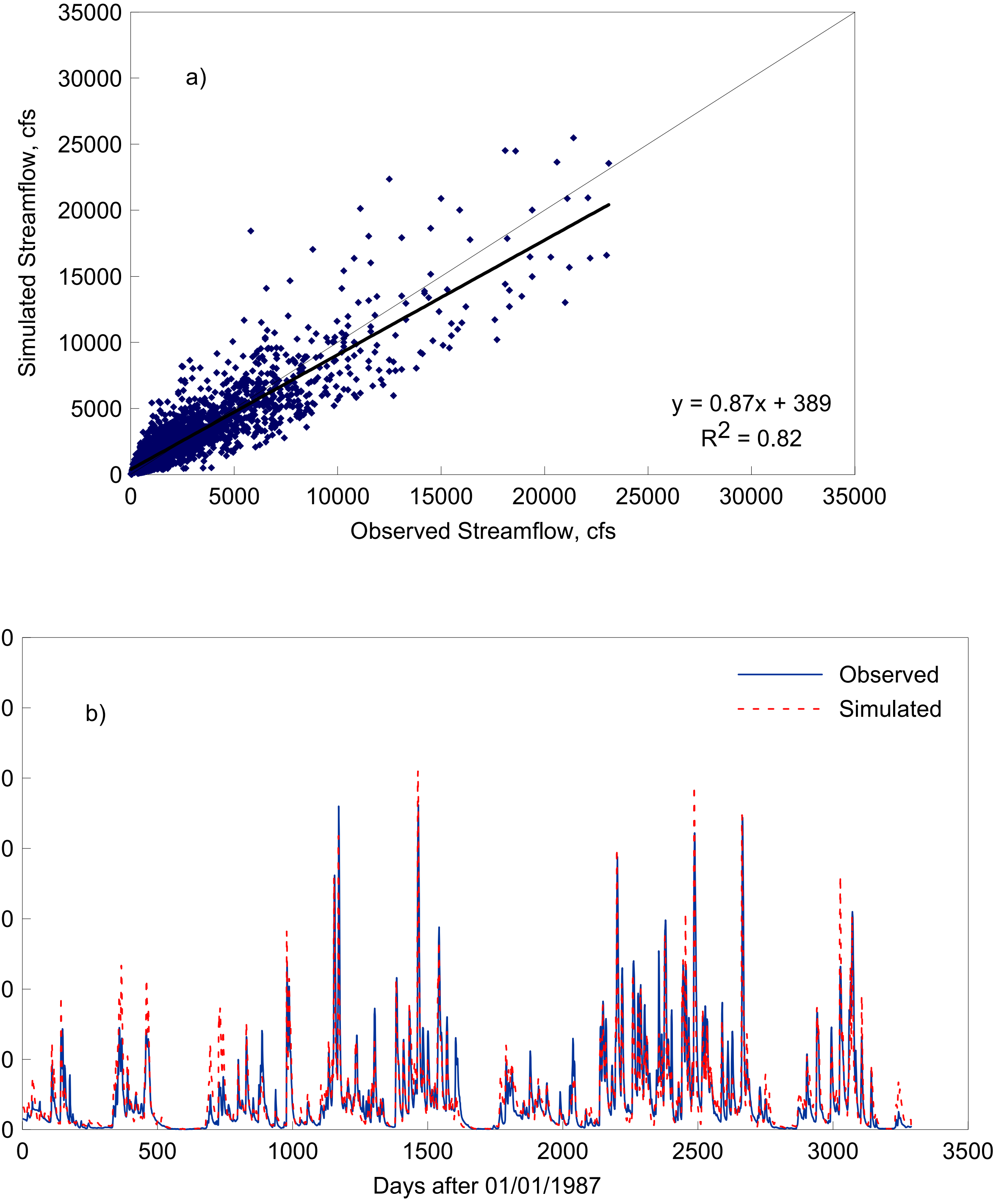


Figure 21. Observed and simulated streamflows from the calibrated model for the Iroquois River watershed, 1987-1995: a) scatter plot and b) time series.

Table 11. Statistics from Linear Regression Fit and NSE Values of Observed and Model-Simulated Streamflow Data before and after Calibration (1987-1995), and from Validation Period (1971-1986) for Iroquois River Watershed

Streamflow data	*NSE*	*R^2*	*Slope*	*Intercept*
Uncalibrated model (1987-1995)				
Daily	0.48	0.49	0.41	1161
Model calibration (1987-1995)				
Daily	0.81	0.82	0.87	389
Average monthly	0.88	0.88	0.88	369
Average annual	0.92	0.98	0.75	648
Model validation (1971-1986)				
Daily	0.70	0.70	0.77	614
Average monthly	0.82	0.82	0.81	519
Average annual	0.62	0.68	0.70	761

flows. Scatter plots of average monthly and average annual observed and simulated streamflow data are shown (Figures 23a and 23b). Figure 23c shows a bar chart of the percentage differences between the observed and simulated average annual streamflow values for the nine calibration years. The model slightly overestimated in seven years and underestimated in two years. The percentage difference varied from 2 percent (underprediction) in 1991 to about 49 percent (overprediction) in 1988. Of the nine years for which the model was calibrated, the percentage difference was less than 10 percent for three years and less than 15 percent for seven years, indicating a good fit between the annual values.

In order to run the HSPF model for the validation period (1970-1986), the UCI file from the calibrated model was modified by changing only the start and finish dates of simulation. All the parameter values were left unchanged, and the model was run for the new time period. Simulated daily, average monthly, and average annual streamflow values obtained from this new model run were compared with the respective observed data values for years 1971-1986. Results of this comparison are shown (Figures 24-25, and Table 11). Percentage differences between the observed and simulated average annual streamflow values for the 16- year period (1971-1986) are shown (Figure 25c). The model slightly overestimated in 12 years and underestimated in four years. The percentage difference varied from 2.9 percent in 1983 to 35 percent in 1977. Of the 16-year validation period, the percentage difference was less than 10 percent for 10 years and less than 15 percent for 11 years, indicating a good fit in the annual values.

Hydrologic Simulations for Lower Kankakee River Watershed

As explained earlier, simulated daily streamflows from the outlets of the upper Kankakee and Iroquois River watersheds were used as input to the lower Kankakee River watershed at the appropriate locations corresponding to the location of USGS gaging stations at Momence,

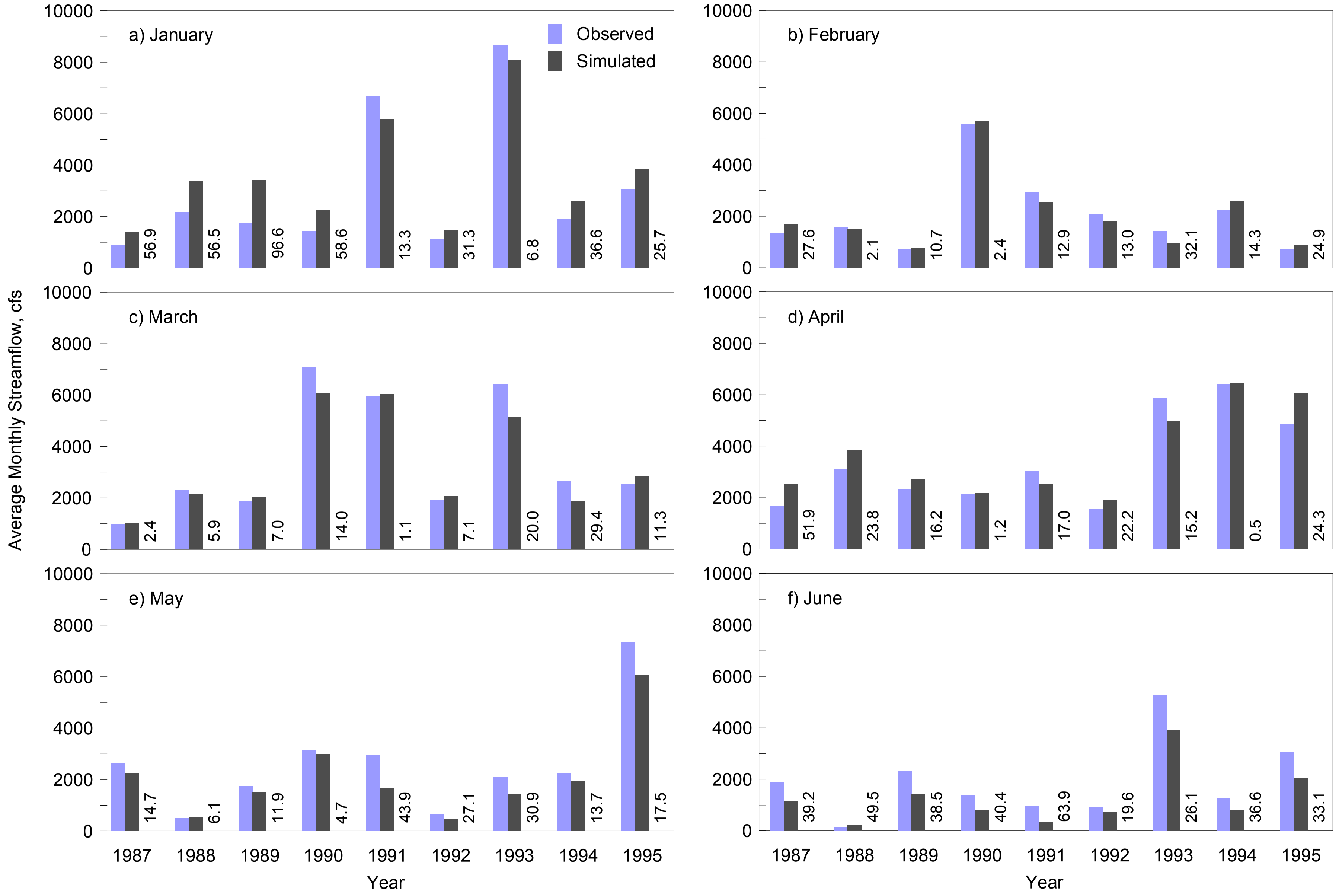


Figure 22a. Observed and simulated average monthly streamflows for the Iroquois River watershed, January-June 1987-1995 calibration period. Data labels indicate percent relative difference between simulated and observed values.

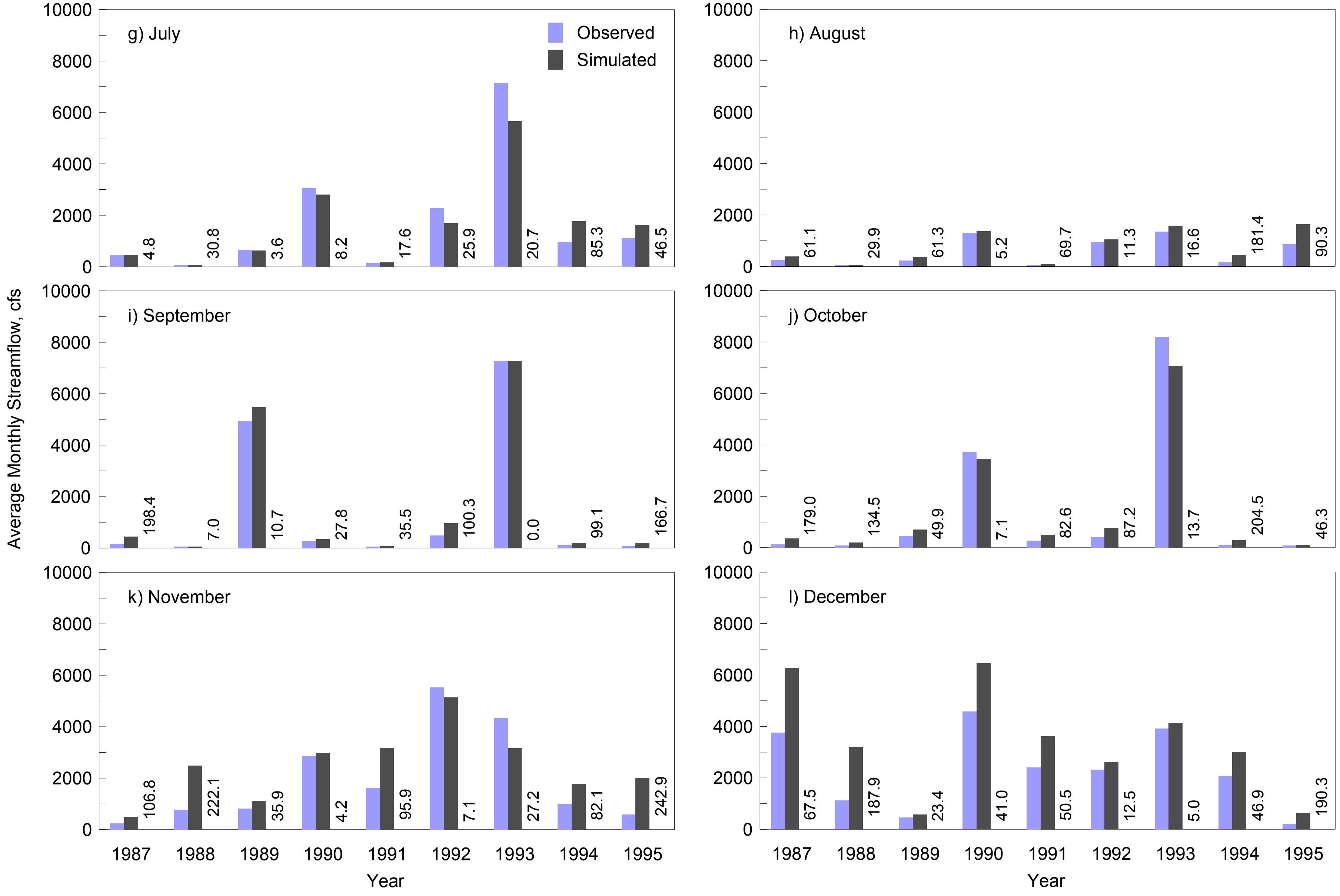


Figure 22b. Observed and simulated average monthly streamflows for the Iroquois River watershed, July-December 1987-1995 calibration period. Data labels indicate percent relative difference between simulated and observed values

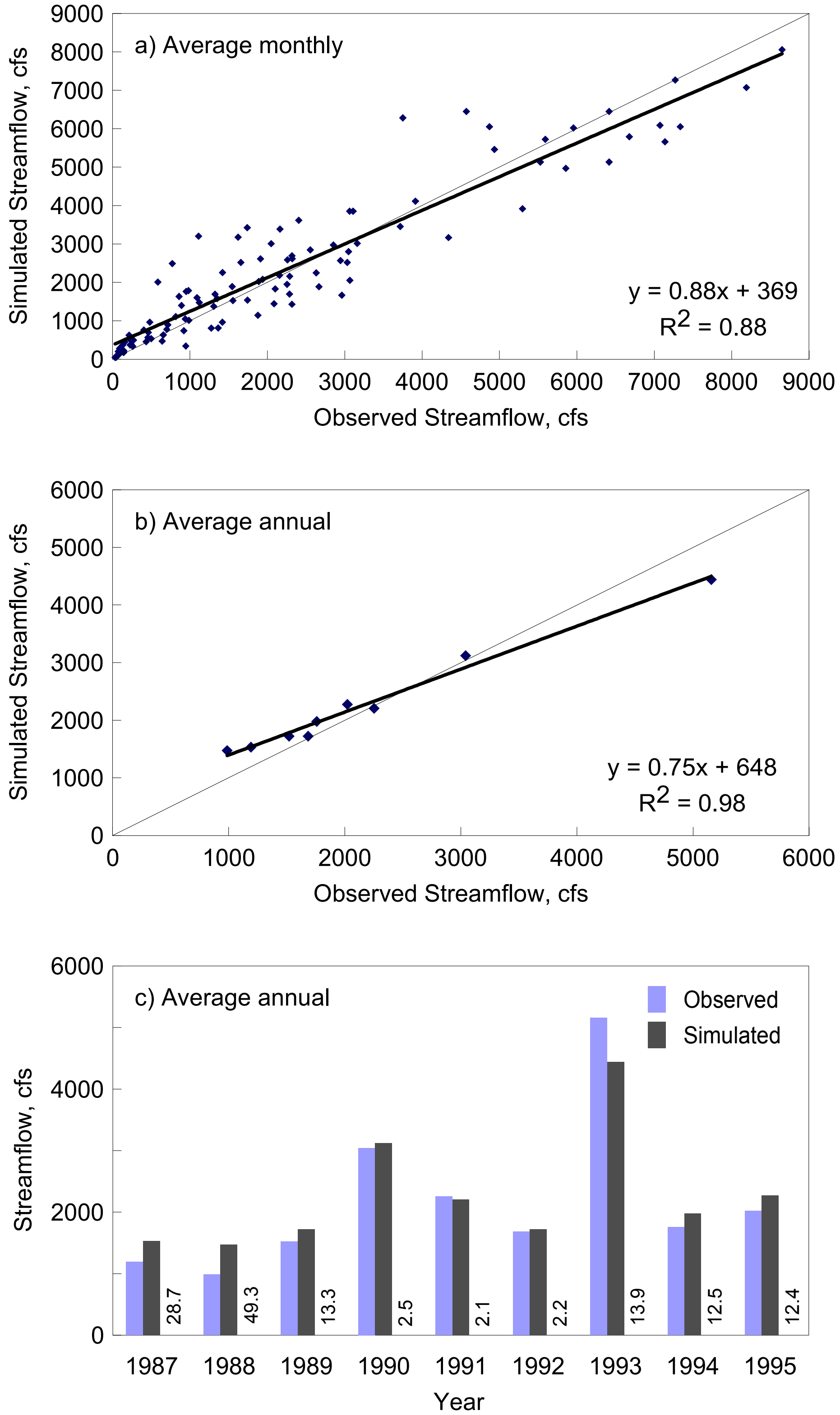


Figure 23. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Iroquois River watershed, 1987-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

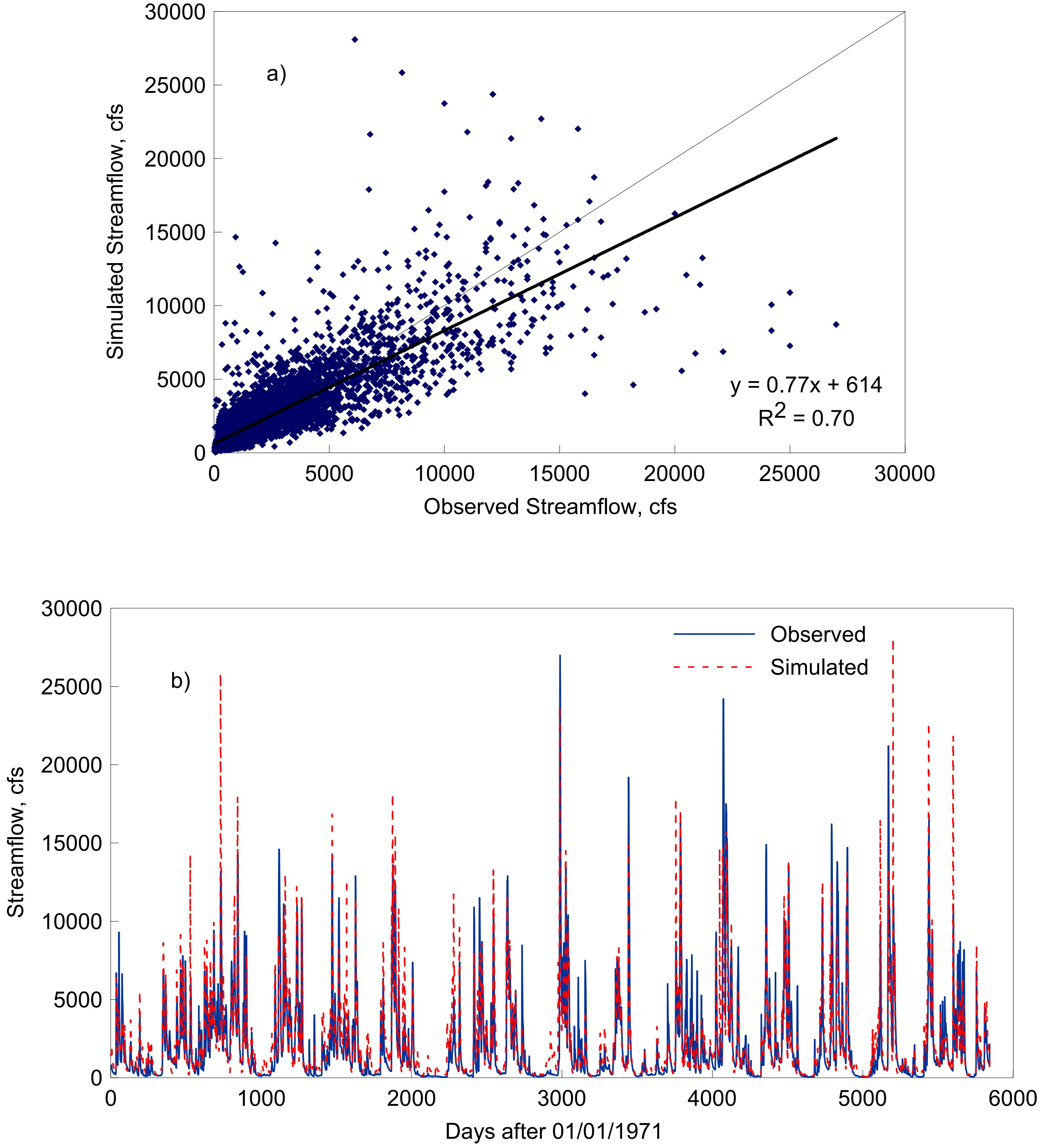


Figure 24. Observed and simulated streamflows, Iroquois River watershed, 1971-1986 validation period: a) scatter plot and b) time series.

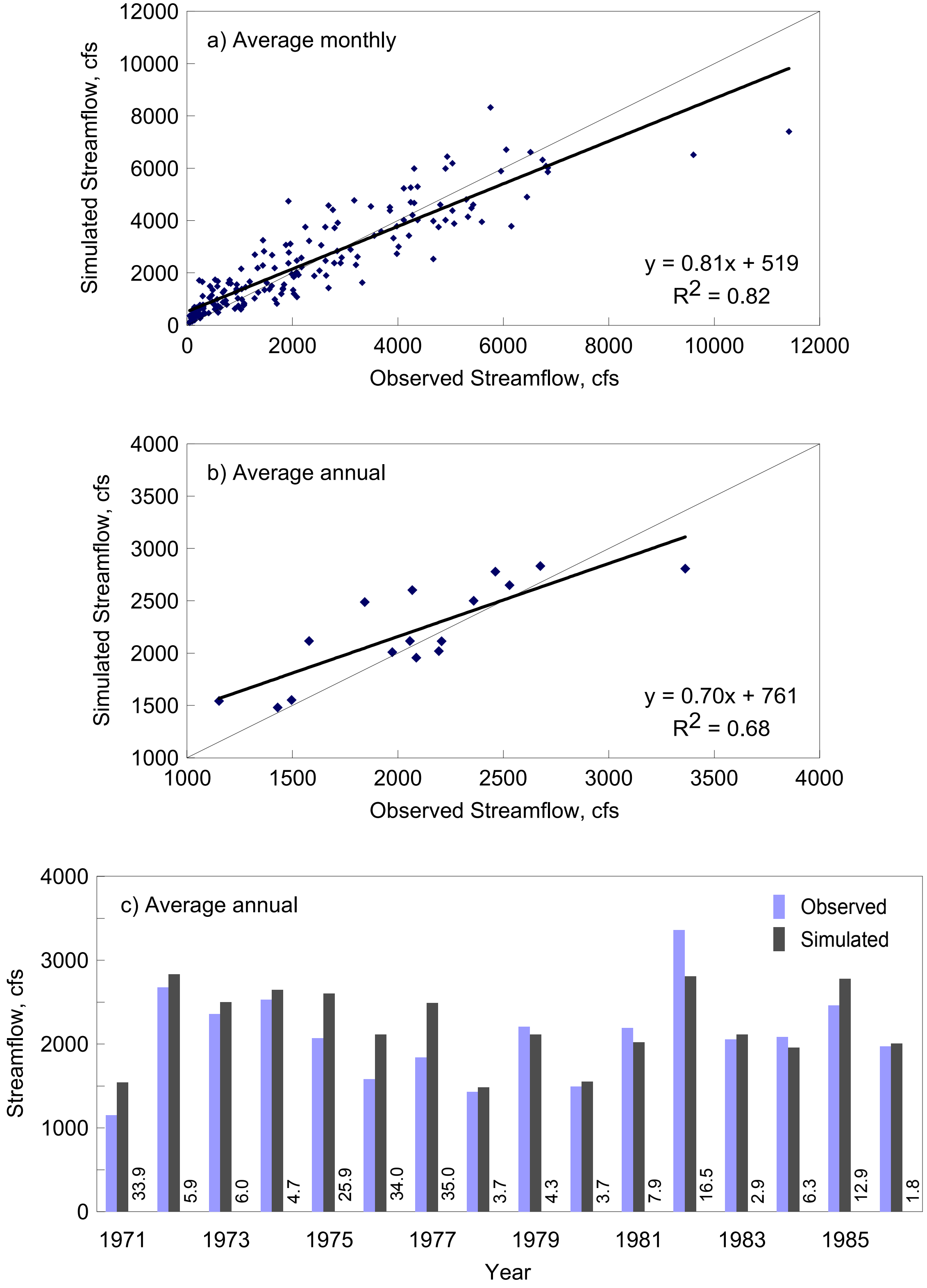


Figure 25. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Iroquois River watershed, 1971-1986 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

Illinois, and Chebanse, Illinois, respectively. Input streamflows then were routed through the lower Kankakee River, along with the streamflow from its own watershed, towards the watershed outlet that matched the USGS stream gaging station located near Wilmington, Illinois. Thus, the results of this watershed provide an overall view of HSPF model performance for simulating streamflow for the entire 5200-sq-mi Kankakee River watershed.

The final UCI file from the upper Kankakee watershed calibration run was modified and used to generate HSPF-simulated streamflows from the lower Kankakee River watershed. However, HSPF model parameter values were kept the same as shown in Table 8. The model was run for the same calibration period as the other two watersheds, and the simulated streamflow was compared with the observed data for 1987-1995. The results are shown (Figures 26-28 and Table 12). An R^2 value of 0.86 and an NSE value of 0.85 were obtained on a daily basis (Table 12). Because daily, monthly, and annual values of all the error statistics computed for this watershed (when simulated flow was generated using the same parameters as for the upper Kankakee River watershed) were comparable with similar statistics for the upper Kankakee River watershed, model calibration was not performed on this section of the watershed. The scatter plot and time-series plot of daily observed and simulated flows (Figure 26) show that the HSPF model had a tendency to underestimate a few very high observed flows. However, simulated low flows and baseflows corresponded very well with observed values. Comparison of average monthly simulated and observed streamflow data in the form of bar charts (Figure 27) and as a scatter plot (Figure 28a) also show good agreement. A scatter plot of average annual observed and simulated streamflow data (Figure 28b) shows good agreement between observed and HSPF-simulated data for 1987-1995. Figure 28c shows a bar chart of the percentage differences between the observed and simulated average annual streamflow values for the nine years. The model slightly overestimated in two years and underestimated in seven years. The percentage difference varied from 2.7 percent (overprediction) in 1995 to about 15 percent (underprediction) in 1991. During the nine years, the percentage difference was less than 10 percent for five years, and less than 15 percent for eight years, indicating a good fit between the annual values.

The model was run for the same time period and simulated results were compared with observed data to assess HSPF model performance for the 1970-1986 period (the validation period for the other two sections of the watersheds above) on this section of the watershed. These results are shown (Figures 29-30, and Table 12). There was good agreement between observed and simulated daily, monthly, and annual data. As shown in the bar chart in Figure 30c, the model slightly overestimated the average annual streamflow in ten years and underestimated in six years. The percentage difference varied from 3.6 percent (overpredicted) in 1980 to 21.5 percent in 1976. During the 16-year period, the percentage difference was less than 10 percent for eight years and less than 15 percent for 11 years, indicating a good fit between the annual values.

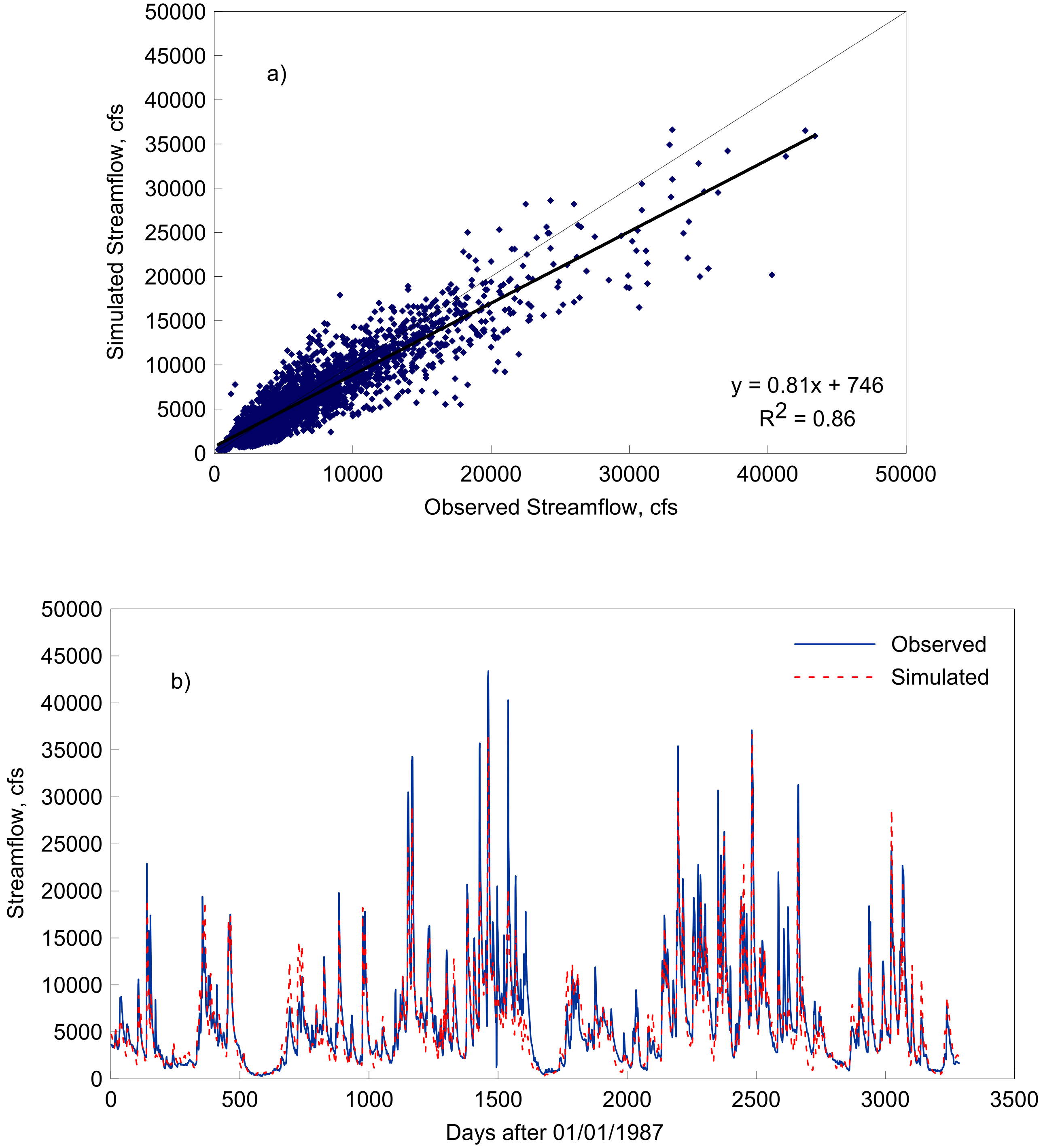


Figure 26. Observed and simulated streamflows from the calibrated model
for the entire Kankakee-Iroquois River watershed, 1987-1995: a) scatter plot and b) time series.

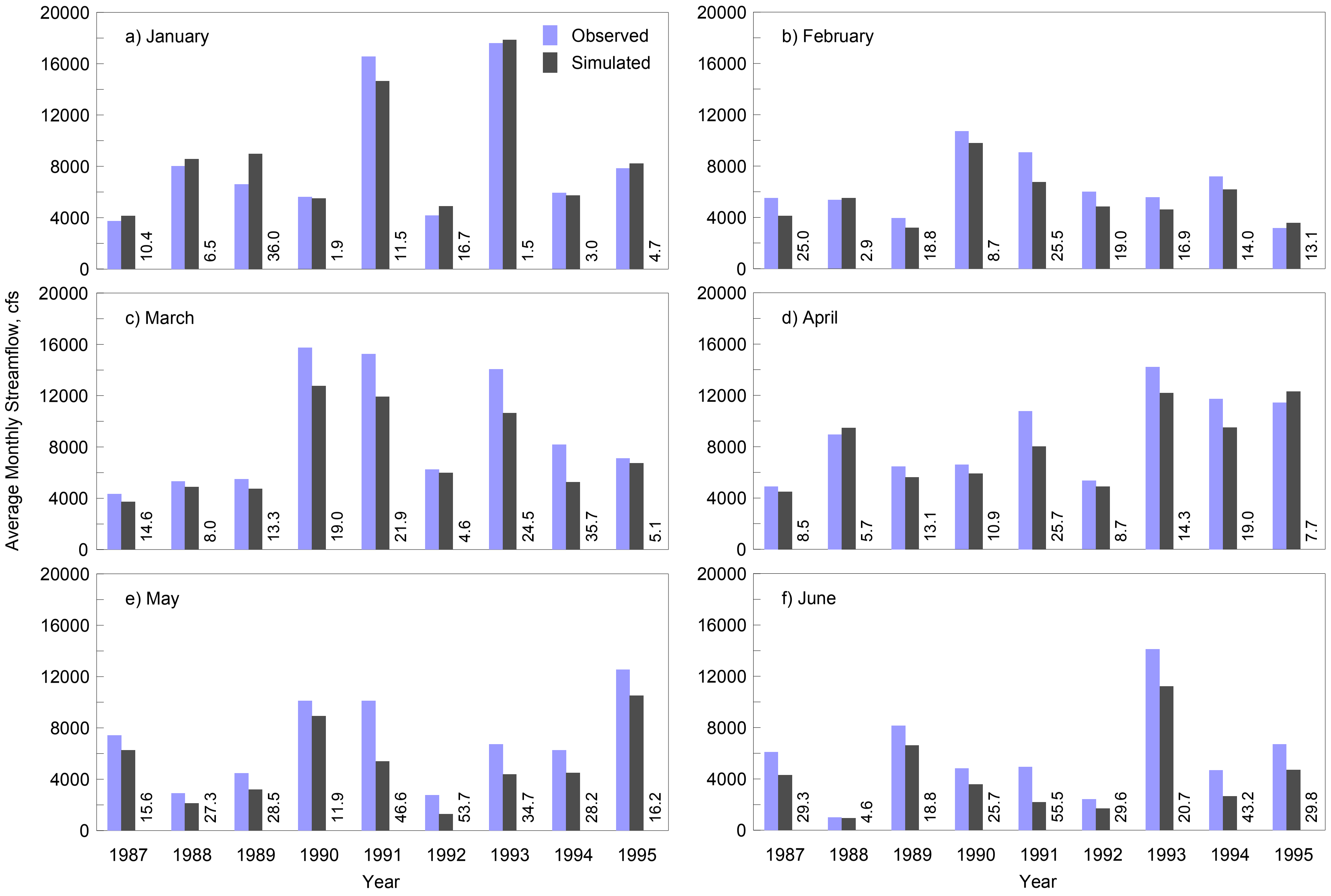


Figure 27a. Observed and simulated average monthly streamflows for the entire Kankakee-Iroquois River watershed, January-June 1987-1995. Data labels are percent relative difference between simulated and observed values.

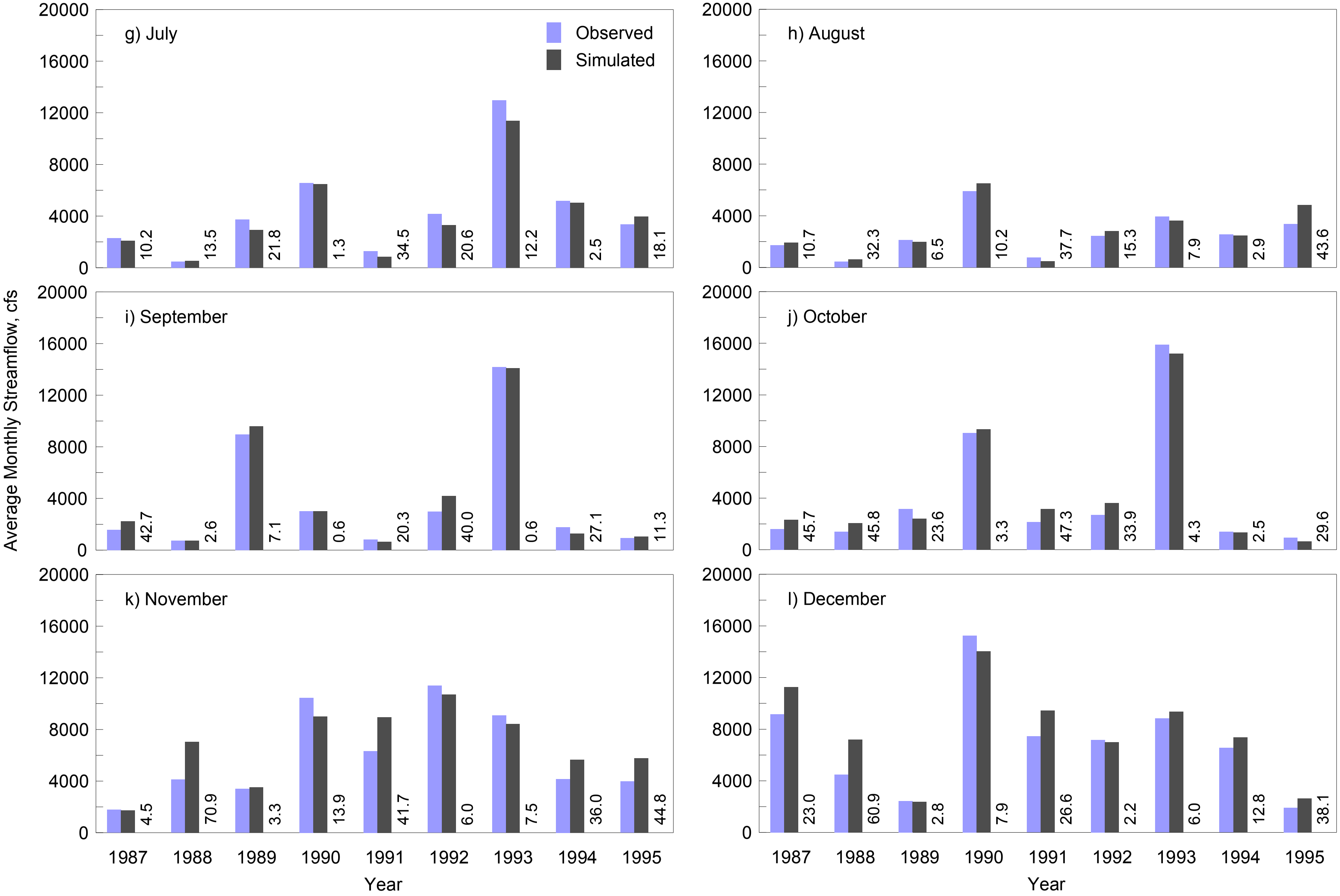


Figure 27b. Observed and simulated average monthly streamflows for the entire Kankakee-Iroquois River watershed, July-December 1987-1995. Data labels are percent relative difference between simulated and observed values.

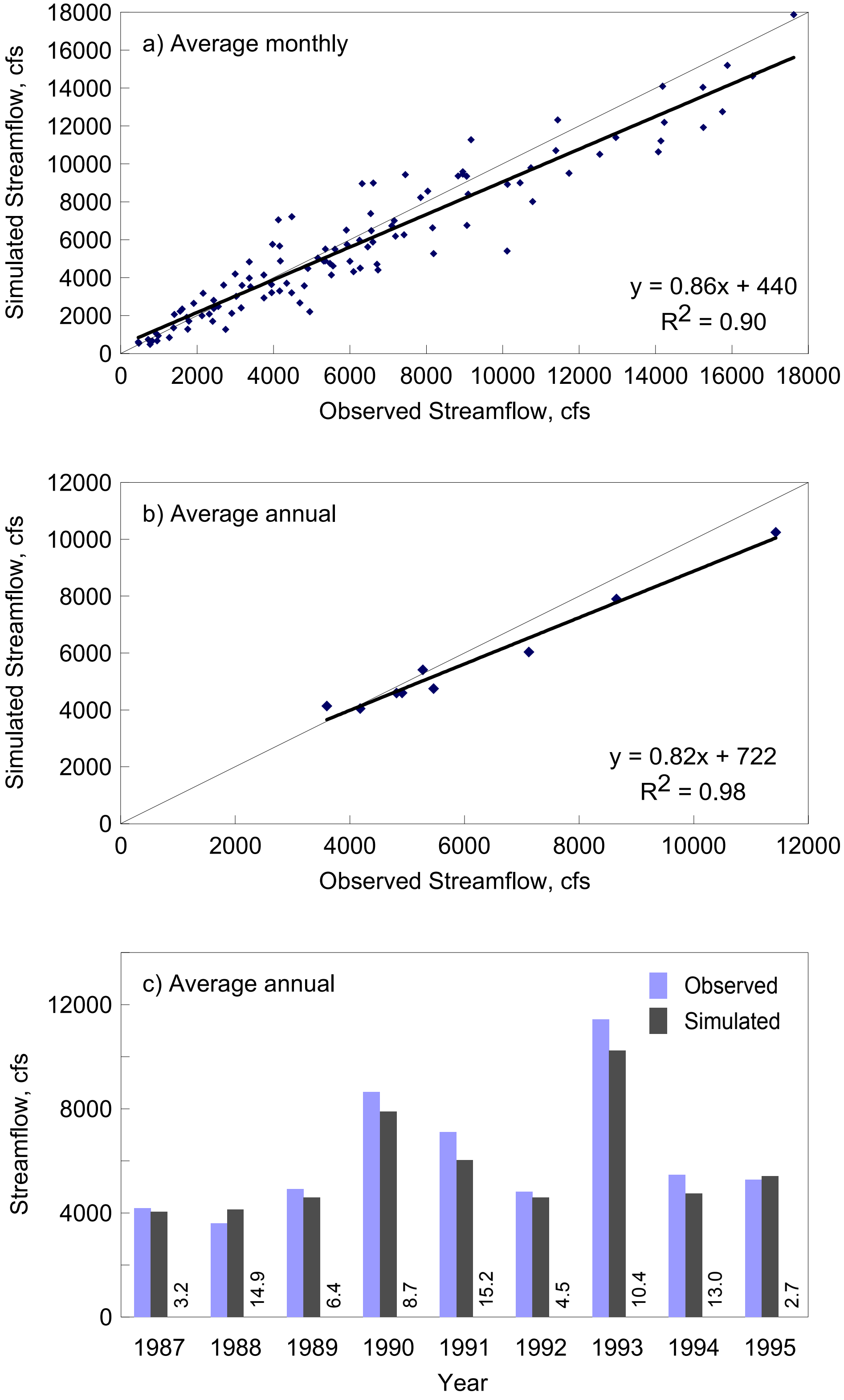


Figure 28. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, entire Kankakee-Iroquois River watershed, 1987-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

Table 12. Statistics from Linear Regression Fit and NSE Value of Observed and Model-Simulated Streamflow Data for Entire Kankakee River Watershed

Streamflow data	*NSE*	*R^2*	*Slope*	*Intercept*
Model simulations (1987-1995)				
Daily	0.85	0.86	0.81	746
Average monthly	0.89	0.90	0.86	440
Average annual	0.92	0.98	0.82	722
Model simulations (1971-1986)				
Daily	0.76	0.76	0.76	1374
Average monthly	0.83	0.83	0.80	1178
Average annual	0.69	0.69	0.67	1861
Model simulations (1971-1995)				
Daily	0.79	0.79	0.78	1168
Average monthly	0.85	0.85	0.82	945
Average annual	0.85	0.86	0.75	1315

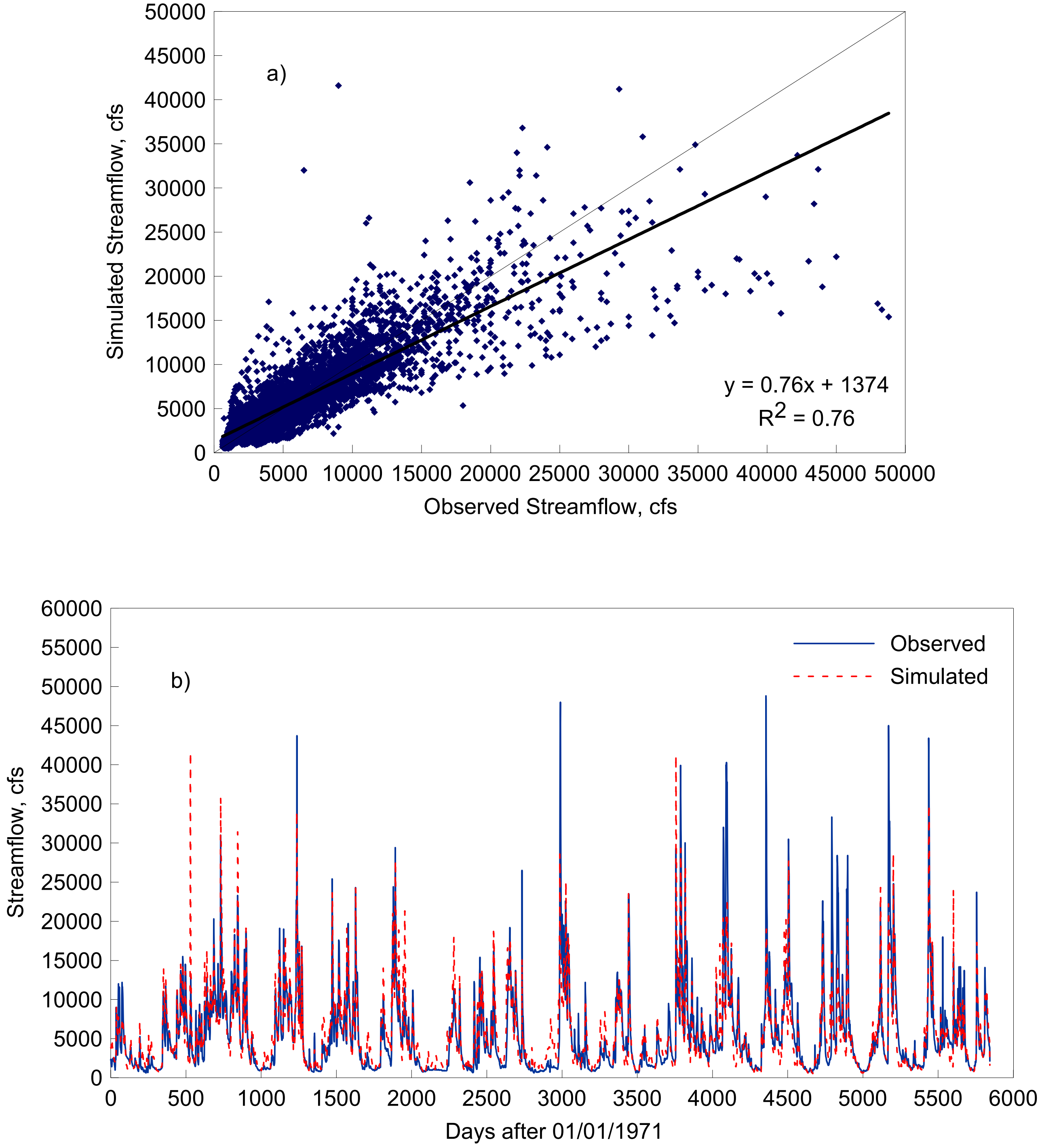


Figure 29. Observed and simulated streamflows for the entire Kankakee-Iroquois River watershed, 1971-1986 simulation period: a) scatter plot and b) time series.

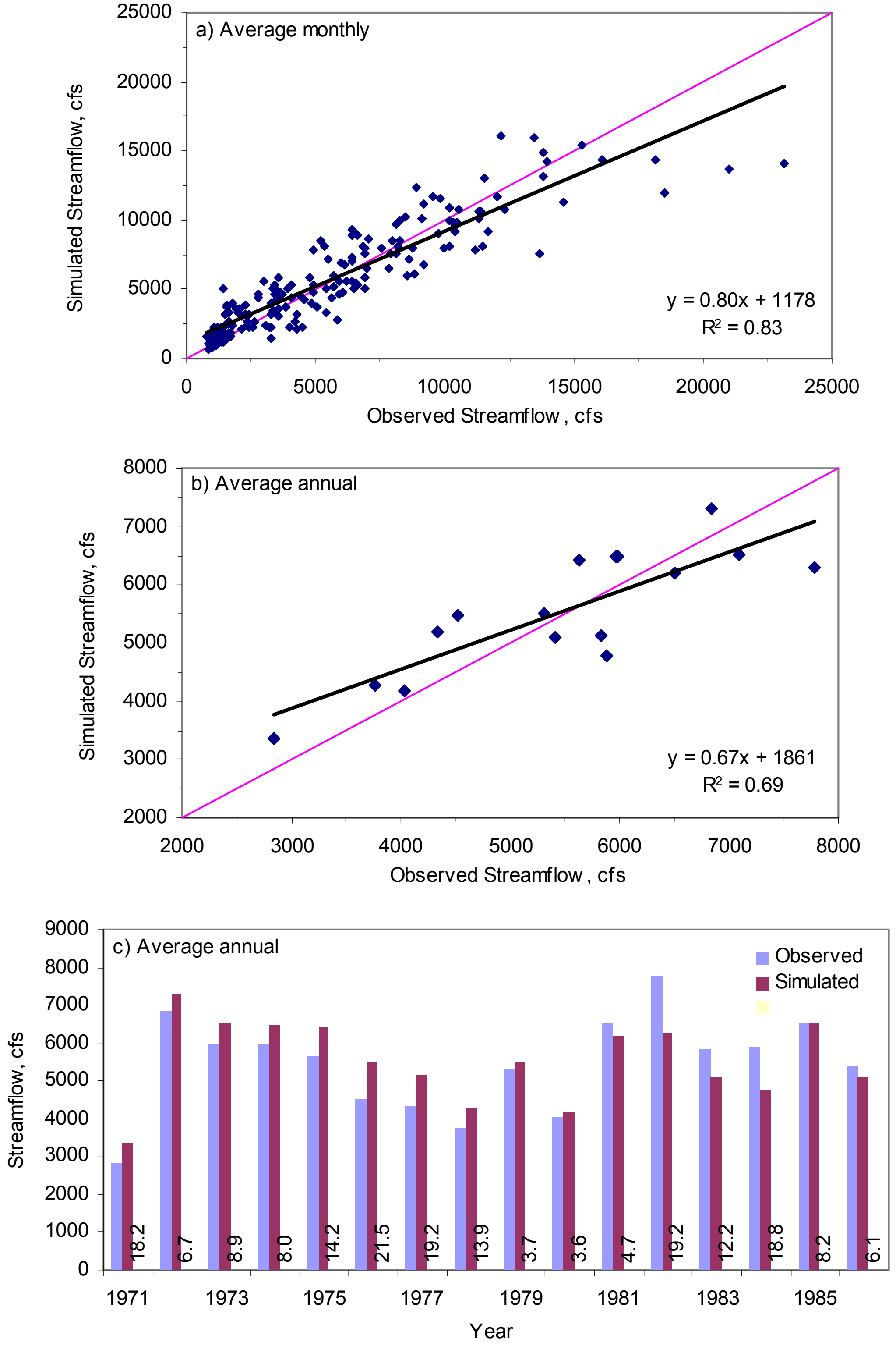


Figure 30. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, entire Kankakee-Iroquois River watershed, 1971-1986 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

Hydrologic Modeling of the Spoon River Watershed

Introduction

The Spoon River watershed (eight-digit USGS Cataloging Unit 07130005) located in western Illinois drains an area of 1,860 sq mi and includes portions of Bureau, Fulton, Henry, Knox, Marshall, McDonough, Peoria, Stark and Warren Counties. The location of this watershed in the Illinois River basin is shown in Figure 1. The watershed falls within the Galesburg Till Plain physiographic area (Leighton et al., 1948). The main topographic features are rolling upland prairies (IDNR, 1998b) with elevations from 850 feet in the northern part of the watershed to 420 feet at the confluence with the Illinois River.

The total length of the mainstem of the Spoon River is 124 miles, but the watershed has a total of about 2,750 miles of rivers and streams. The main channel is characterized by a deep and narrow cross section with steep banks and moderate channel slope (IDNR, 1998b). Only 21 stream miles within this watershed were identified as channelized (Mattingly and Herricks, 1991), making the Spoon River watershed one of the least channelized large watersheds in Illinois. The majority of the soils in the watershed are loess (windblown silts) with a thickness that varies from 5 feet deep to 15 feet deep close to the Illinois River (IDNR, 1998a). Silty clay loams underlie the loess throughout the region.

The soils distribution for the Spoon River watershed using the STATSGO soils database available in BASINS 3.0 is shown (Figure 31). According to this dataset, the soils in the watershed can be classified as predominantly type B soils, with only a small percentage of type B/D and C soils. The lack of drainage dissection combined with the slow permeability of many of the soils in the flat upland and floodplain areas give rise to high water tables, severe stream erosion, and sedimentation in streams and lakes. Steeper slopes located near the floodplains are prone to soil erosion through sheetwash and gully development. This watershed contributes the largest amount of sediment yield per unit area to the Illinois River (Demissie et al., 1992).

The predominant land use in the Spoon River watershed is agriculture, which constitutes about 85 percent of the total drainage area. The dominant crops in the area are corn and soybeans. Forest and barren and urban land uses cover 8 percent, 5 percent, and 2 percent of the area, respectively. Figure 32 shows the distribution of land uses in the watershed using the land coverage in the BASINS dataset. Surface mining for coal affects some portions of this watershed. This activity has an important impact on streamflows and watershed hydrology, which is particularly noticeable at sub-watersheds directly affected by this land use; that is, Big Creek, Evelyn Branch, and Slug Run (see IDNR, 1998a, b for more details).

Input Data and Model Preparation

As shown in Figure 33, the Spoon River watershed has three nearby meteorological stations that measure hourly precipitation data (USEPA-WDM weather stations) and ten local stations that measure daily data. Daily time-series data for the local precipitation stations were

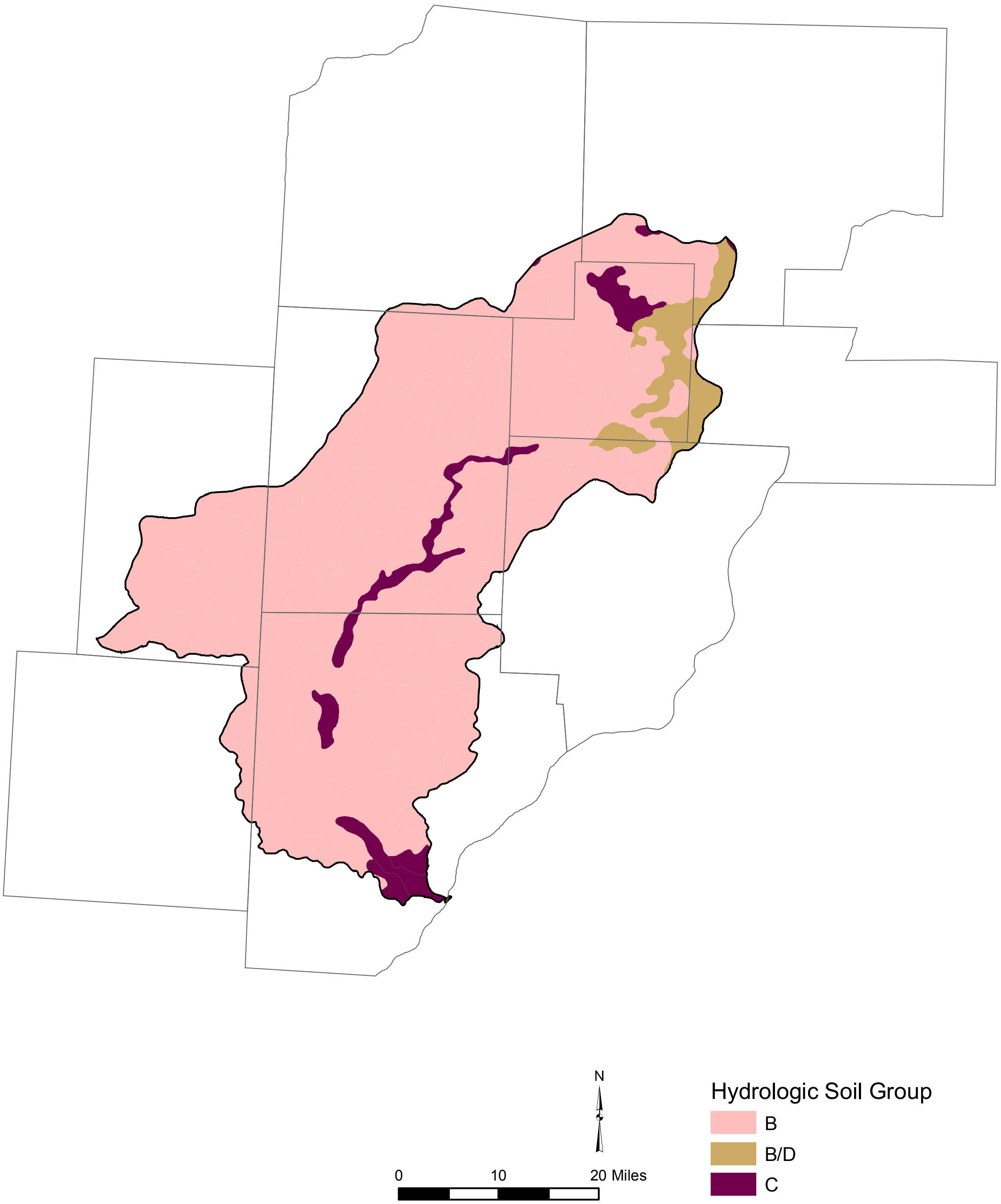


Figure 31. Soil type classification based on the hydrologic soil groups in the Spoon River watershed.

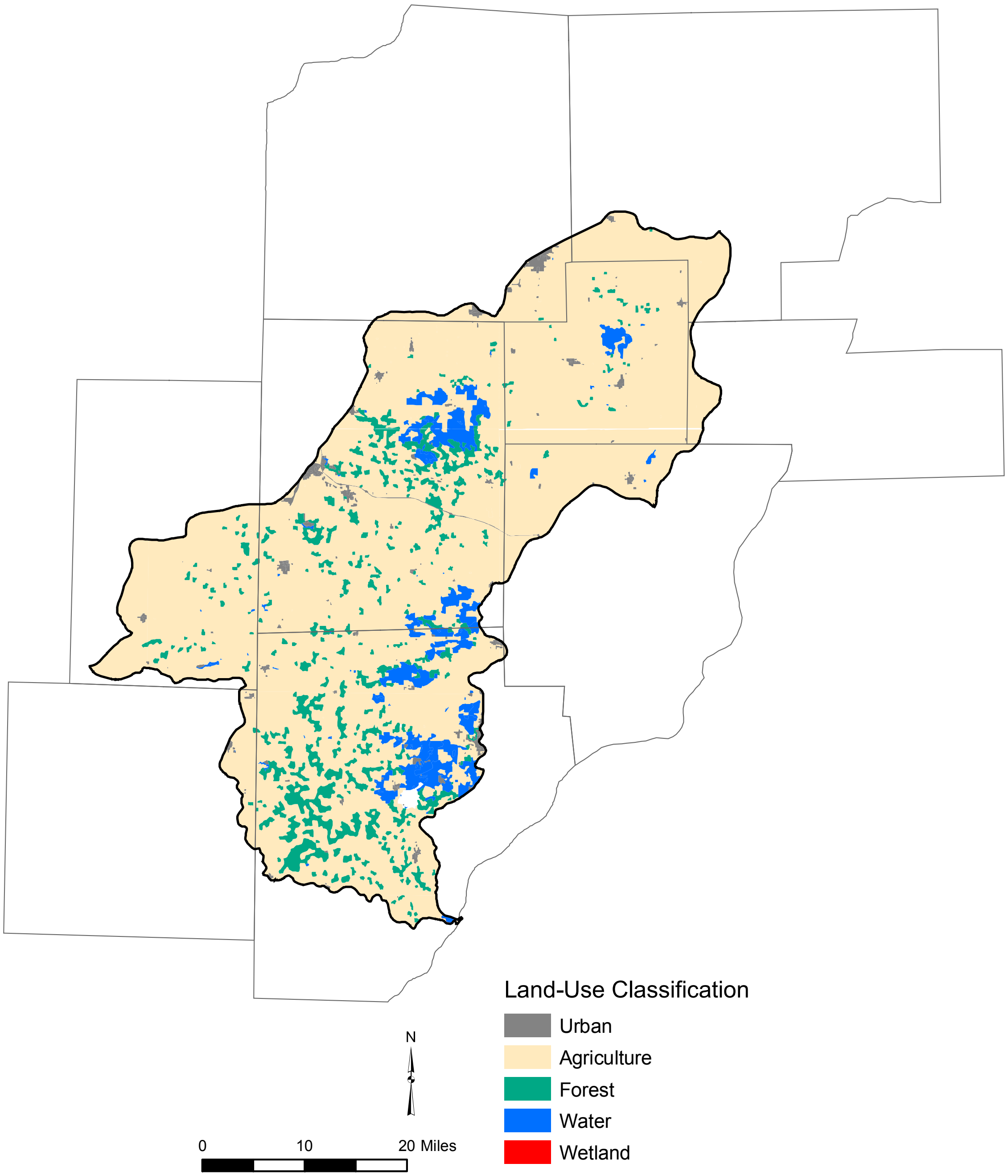


Figure 32. Land-use types in the Spoon River watershed.

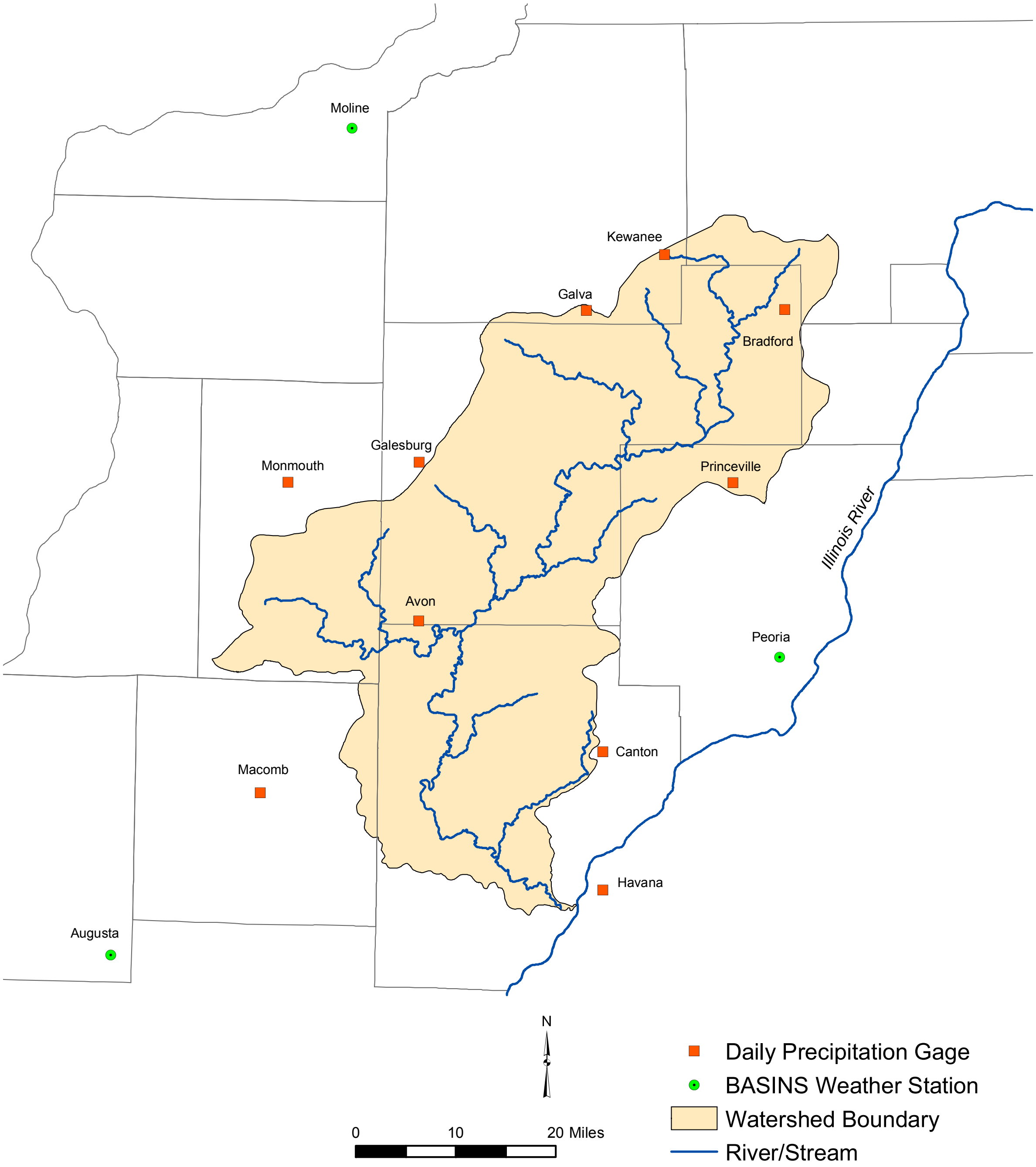


Figure 33. The USEPA-WDM and local weather stations located in or near the Spoon River watershed.

disaggregated into hourly intervals using the methodology available in the WDMUtil module of the BASINS 3.0 model. Table 13 lists all local stations used for hydrologic modeling. This same table also shows the WDM weather stations used to disaggregate each local station. Hourly potential ET for local stations was not available. Values used in this study were obtained from the closest BASINS station.

The NHD was used during automatic delineation for the Spoon River watershed. The complete watershed was divided into 27 sub-watersheds and 148 land segments. Figure 34 shows the sub-watersheds, stream reaches, and the USGS streamgaging station at Seville (05570000) used for calibration. The WinHSPF interface was used to create the model's UCI file. It extracted appropriate information from land-use, sub-watershed characteristics, and stream datasets to create the different land segments in the UCI file.

Calibration and Validation for Spoon River Watershed

Figures 35a and b show the time-series and scatter plots, respectively, comparing the observed and simulated flow for the Spoon River watershed before calibration of the HSPF model. Observed flow corresponds to the USGS gaging station at Seville, and simulated flow corresponds to that same location (outlet of sub-watershed #22 in Figure 8) obtained with the set of initial (uncalibrated) parameters. Comparison of both time-series data (Figure 35a) shows that low flows (especially baseflows) are consistently overestimated and high flows are underestimated. This also is reflected in the scatter plot of Figure 35b, and the slope of the regression line is very small.

Several parameters were modified to correct for these discrepancies. As a first step, the annual water balance was corrected. Evapotranspiration from the different soil moisture reservoirs was increased by increasing CEPSC, UZSN, LZSN, LZETP, BASETP, and AGWETP parameters. The discrepancies between observed and simulated flows (underprediction of high flows/overprediction of low flows) partially were corrected by decreasing the INFILT value and adjusting the IRC and INTFW values. Better correlation between observed and simulated flows was obtained after increasing the KVARY value. Monthly values of CEPSC, UZSN, LZETP, and IRC that reflect seasonal effects improved the calibration. Snowmelt was calibrated by adjusting the snow parameters SHADE, SNOWCF, COVIND, RDCSN, TSNOW, SNOEVP, and CCFACT. As noted earlier, the land use in the watershed is predominantly agriculture; therefore the parameters were not calibrated for individual land uses. Table 14 shows the values of the parameters adjusted during calibration.

Figures 36a and b show the scatter and time-series plots of the observed and simulated daily flows following the initial calibration (1987-1995) of the Spoon River model. Figures 37a and b show the daily time-series and regression plots for the calibration period. The simulated flows have improved substantially during the calibration process, the R^2 increased from 0.43 to 0.81, the slope of the regression increased from 0.49 to 0.88, and the intercept value decreased from 884 to 69. The NSE value also improved substantially after calibration (0.41 to 0.8). Table 15 shows the statistics corresponding to the objective function for daily, average monthly, and average annual streamflows before and after calibration. Figure 37 shows good agreement

Table 13. Weather Stations Used for Spoon River Watershed Hydrologic Simulations

Coop ID	*Station name*	*State*	*Latitude, DD**	*Longitude, DD**	*WDM & Hourly* Stations Used for Disaggregation*
110356	Avon	IL	40.72000	-90.37000	W2,W4,W6
110868	Bradford	IL	41.17000	-89.67000	W2,W4
111250	Canton	IL	40.53000	-90.02000	W6
113320	Galesburg	IL	40.95000	-90.37000	W2,W4
113335	Galva	IL	41.17000	-90.05000	W4,W6
113940	Havana	IL	40.33000	-90.02000	W2,W6
114710	Kewanee	IL	41.25000	-89.90000	W4,W6
115280	Macomb	IL	40.47000	-90.67000	W2,W6
115768	Monmouth	IL	40.92000	-90.62000	W2,W4
117004	Princeville	IL	40.92000	-89.77000	W4,W6

Note:
*Based on Tables 2 and 3

Table 14. Annual and Monthly Model Parameters for the Spoon River Watershed

Annual parameter values

Hydrology parameters		*Snow parameters*	
KVARY (1/in)	3.45	SHADE	0.27
INFILT (in/h)	0.06	NOWCF	1.10
AGWRC (1/d)	0.95	OVIND (in)	4.00
LZSN (in)	9.30	TSNOW (°F)	33.80
BASETP	0.20	SNOEVP	0.80
NSUR	0.30		
DEEPER	0.05		
INTFW	10.00		
AGWETP	0.18		

Monthly parameter values

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
CEPSC (inches)	0.10	0.10	0.10	0.10	0.05	0.07	0.09	0.18	0.18	0.15	0.13	0.12
UZSN (inches)	1.80	1.70	1.60	1.60	1.40	1.25	1.20	1.30	1.50	1.75	1.90	2.00
IRC	0.45	0.45	0.50	0.50	0.55	0.62	0.68	0.75	0.65	0.60	0.50	0.50
LZETP	0.40	0.40	0.40	0.50	0.50	0.60	0.70	0.80	0.80	0.75	0.60	0.60

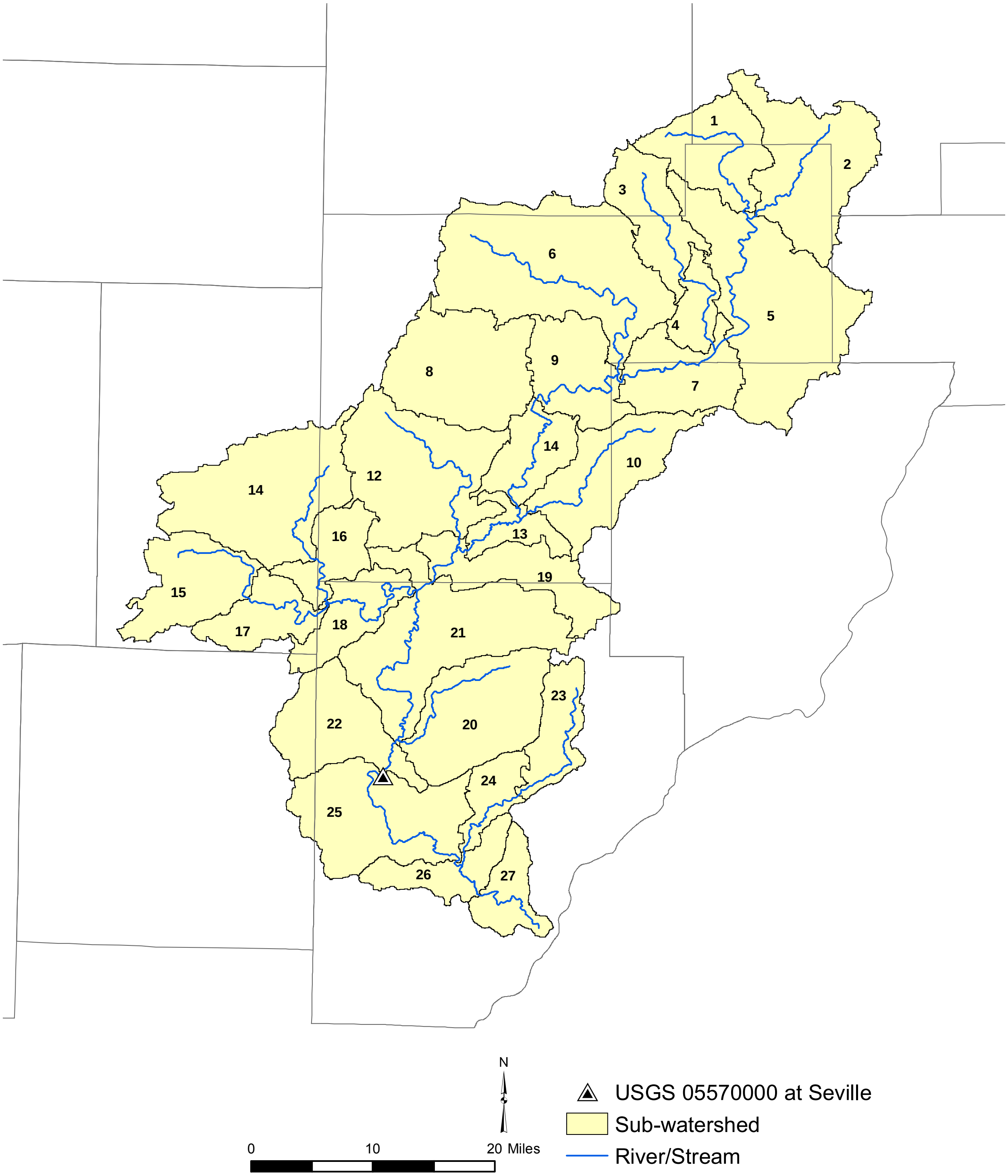


Figure 34. The 27 sub-watersheds of the Spoon River watershed after delineation.

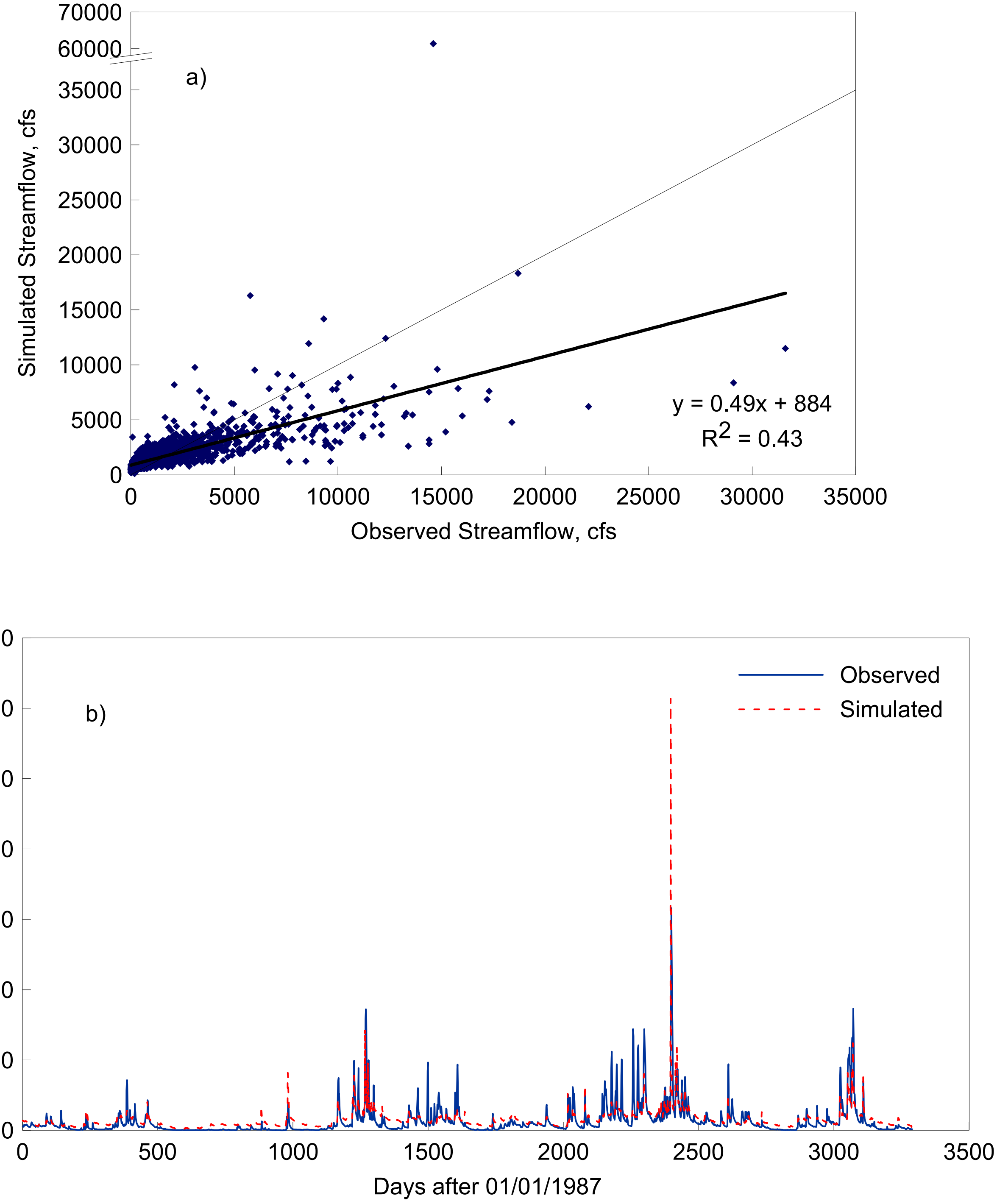


Figure 35. Observed and simulated daily streamflows from the uncalibrated model for the Spoon River watershed, 1987-1995: a) scatter plot and b) time series.

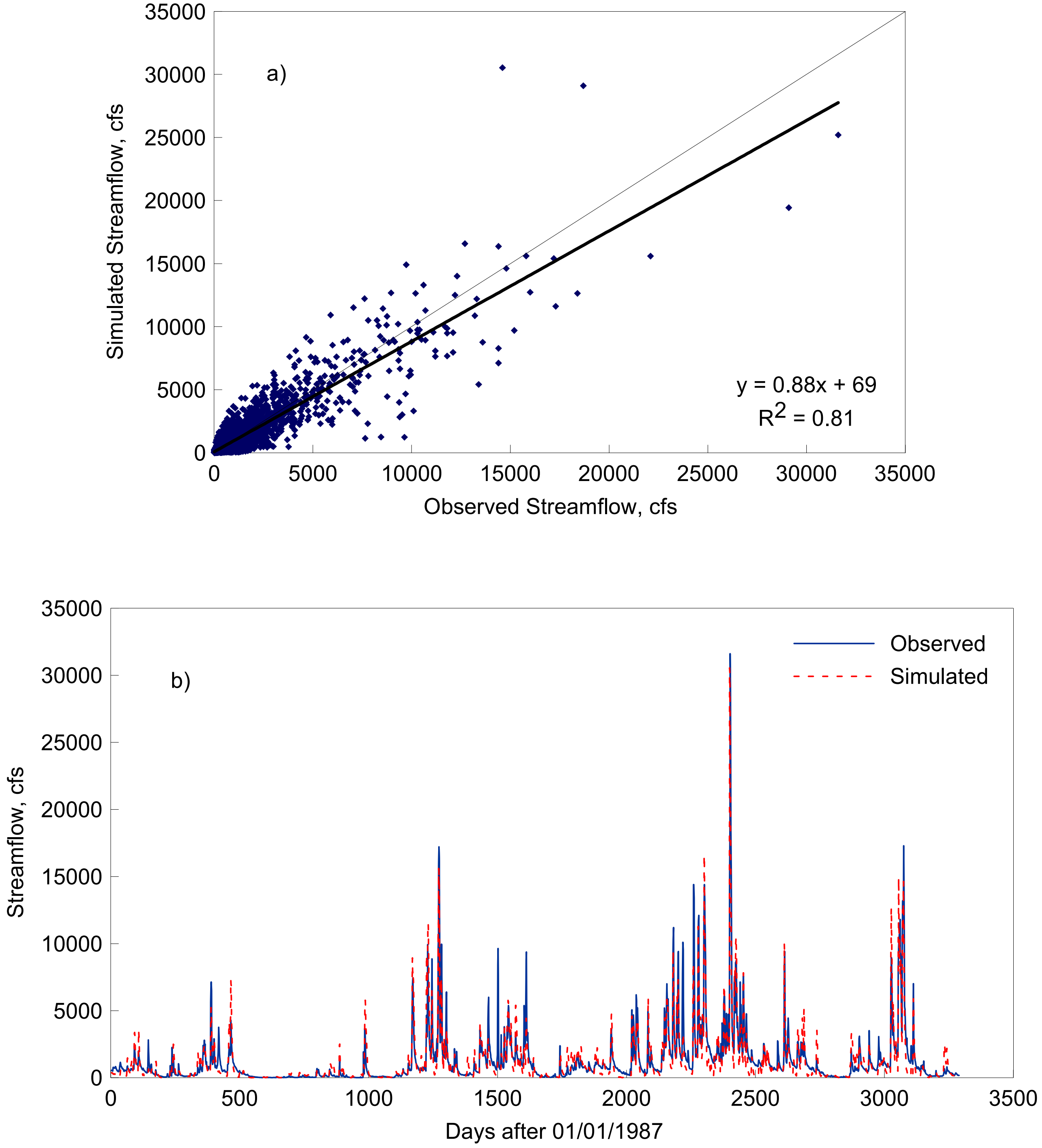


Figure 36. Observed and simulated streamflows from the calibrated model for the Spoon River watershed, 1987-1995: a) scatter plot and b) time series.

Table 15. Statistics from Linear Regression Fit and the NSE values of Observed and Model-Simulated Streamflow Data before and after Calibration (1987-1995), and from Validation Period (1972-1986) for Spoon River Watershed

Streamflow data	*NSE*	*R^2*	*Slope*	*Intercept*
Uncalibrated model (1987-1995)				
Daily	0.41	0.43	0.49	884
Model calibration (1987-1995)				
Daily	0.80	0.81	0.88	69
Average monthly	0.91	0.92	0.90	38
Average annual	0.93	0.98	0.77	169
Model validation (1972-1986)				
Daily	0.71	0.75	0.92	79
Average monthly	0.87	0.88	0.95	27
Average annual	0.93	0.94	0.94	42

Notes:

*The NSUR value is 0.20 for pervious land-use types, and 0.10 for impervious land use types.

**The AGWETP value is 0.20 for wetlands, and 0.00 for all other land uses.

between both the observed and simulated average monthly flows. The corresponding regression plot is shown (Figure 38a). Regression and bar plots of observed and simulated total accumulated annual flows are shown (Figures 38), and Figure 38b also shows the percentage differences between observed and simulated flows. This difference in 1989 was close to 90 percent. The recorded total streamflow for 1989 was extremely low, and the absolute difference would be considered relatively small for other years. However, this is not the driest year in terms of precipitation; lower precipitation occurred at all stations in this watershed in 1988. Therefore, it was necessary to increase the soil storage parameters in order to simulate the extremely low flows of 1989. Parameters associated with evaporation from the different reservoirs also required special attention to simulate years 1989 and 1993 correctly. The chosen set of parameters simulated 1989 as well or better than any other dataset, despite the relatively high discrepancy. For the rest of the years, the percentage of discrepancy between observed and simulated mean annual flows varied from 2.8 percent in 1987 to 17.5 percent in 1993.

As can be seen from Figure 36b, the calibrated model failed to correctly simulate some of the higher peakflows (e.g., ~1500 and 2200 days after 01/01/1987) correctly. Some reasons that could be responsible for the underestimation of these flow events are:

- **Incomplete precipitation records.** Some daily records were incomplete and were completed using data from nearby stations; some events were not represented as well as other events in the calibration period.

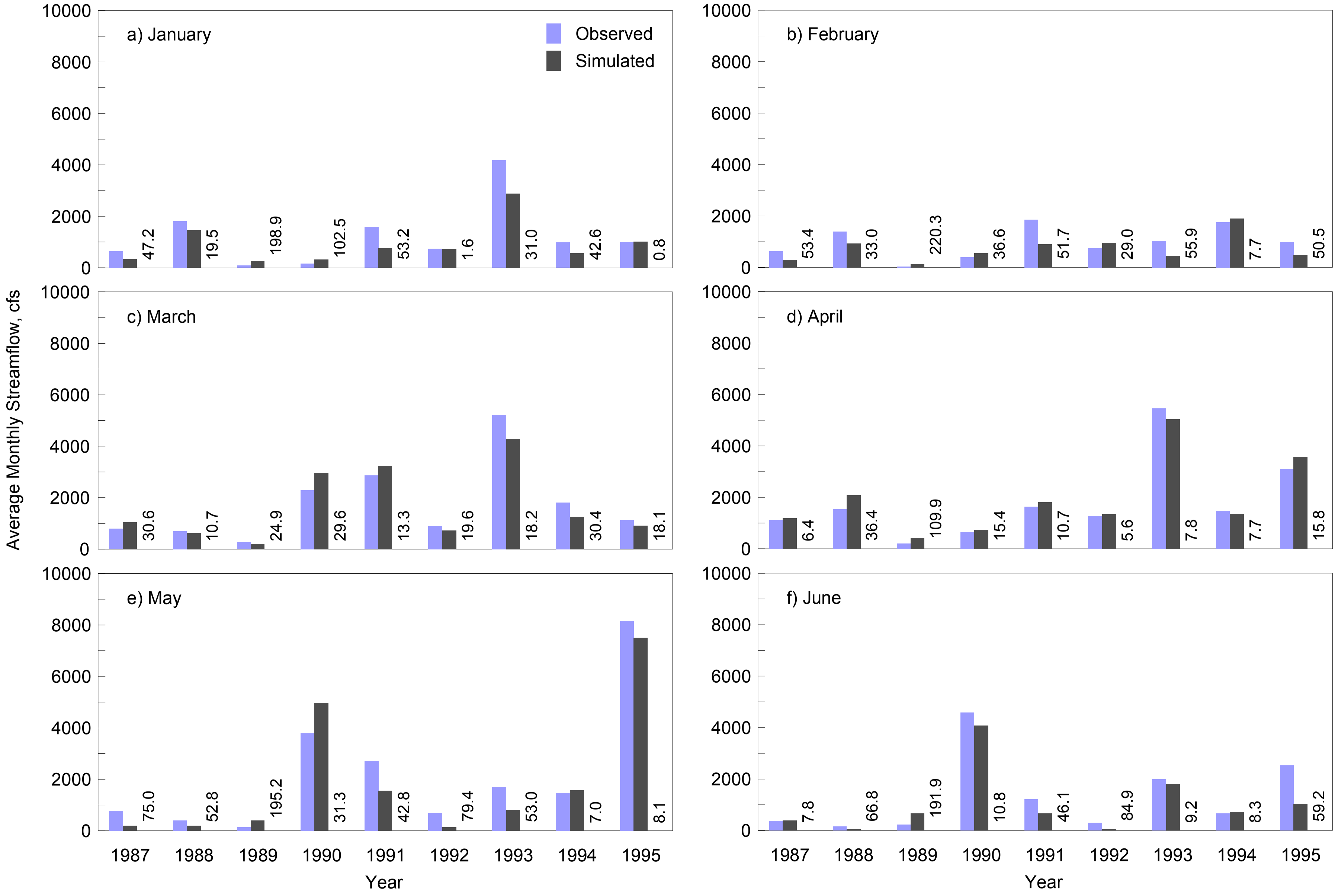


Figure 37a. Observed and simulated average monthly streamflows for the Spoon River watershed model, January-June 1987-1995 calibration period. Data labels indicate percent relative difference between simulated and observed values.

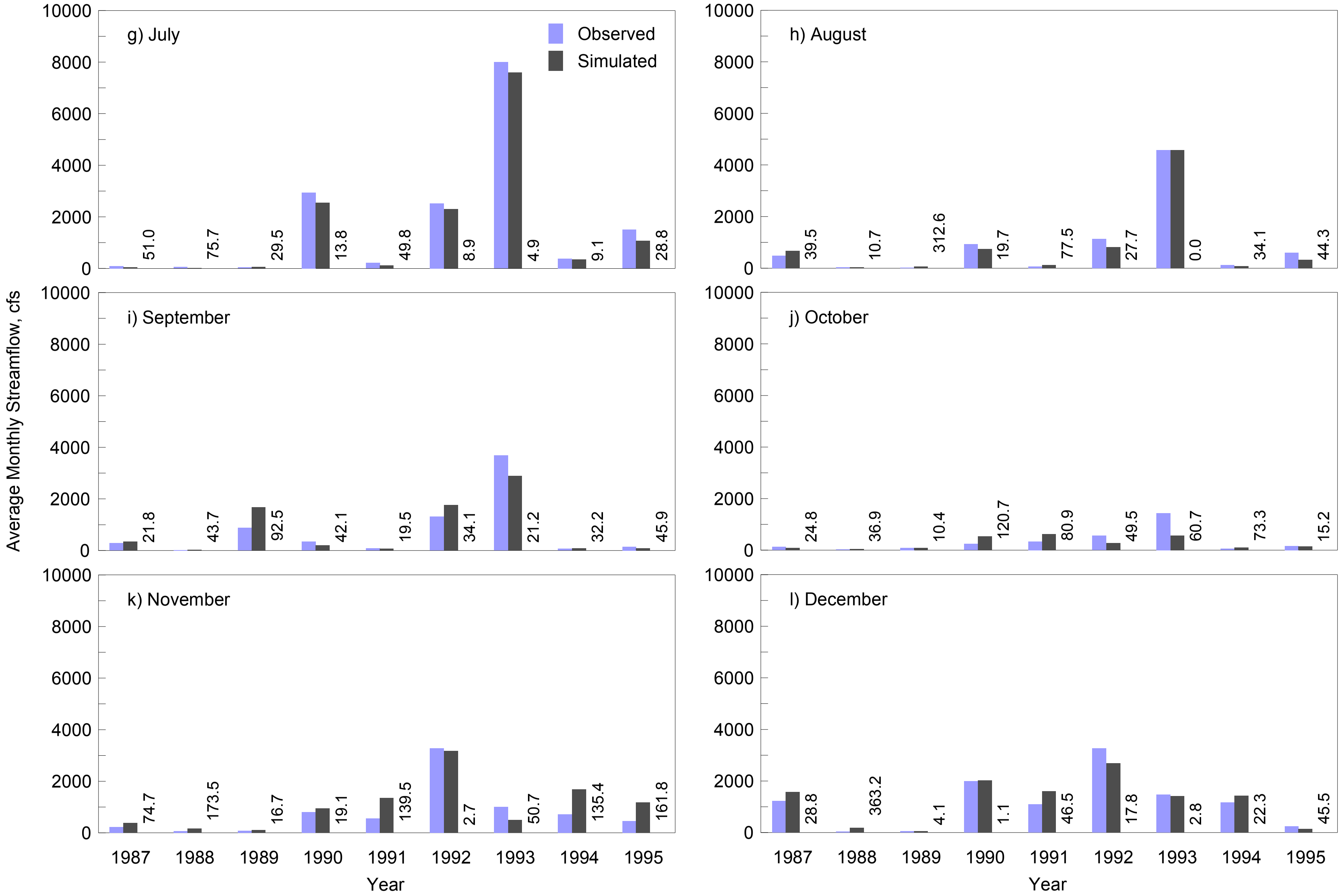


Figure 37b. Observed and simulated average monthly streamflows for the Spoon River watershed model, July-December 1987-1995 calibration period. Data labels indicate percent relative difference between simulated and observed values.

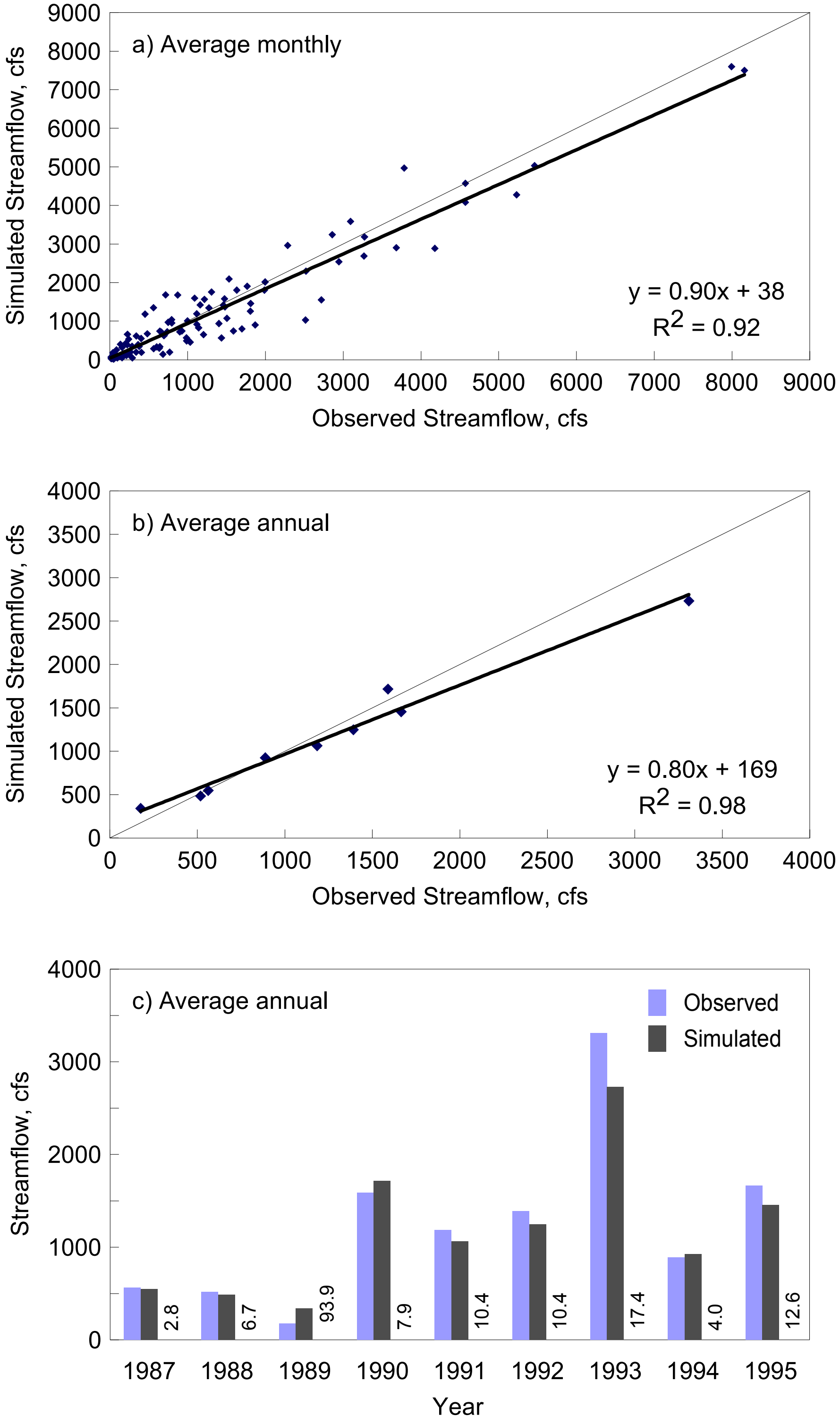


Figure 38. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Spoon River watershed, 1987-1995 calibration period. Values along bar graphs are absolute percentage differences between simulated and observed streamflows.

- **Localized storm events.** Although the areal coverage of precipitation gages is good (10 gages), it is possible that some localized storm events are not represented well.

- **Calibration issues.** The model was calibrated for a period of several years for which most of the larger flows corresponded to precipitation events with specific characteristics. It is possible that when the model parameters are adjusted to reproduce the high flows associated with the most frequent precipitation events, they may fail to simulate other events with the same accuracy. That is, most of the high flows and flood events in the Spoon River watershed (at Seville) occur during spring and summer when precipitation is convective and associated with short storms (IDNR, 1998b). High flows and flood events that occur during other periods (for example, the peak at ~1500 days during February) are associated mainly with precipitation of longer duration produced by synoptic-scale weather systems and may not be simulated as well.

For validation purposes, the calibrated model was run for years 1972-1986 with the parameter values calibrated from the 1987-1995 record. Figure 39 shows the scatter and time-series plots of the observed and simulated streamflows for this period. As can be seen from Figure 39a, the regression coefficient for the validation period is smaller than that for the calibration period, but the slope and intercept of the regression line have improved. Figure 40 shows a good agreement between observed and simulated values for monthly and annual mean flows. As seen in Figure 40c, the percentage error between mean annual observed and simulated flows varies from 0.2 percent for 1985 to 20.8 percent for 1977. The errors are lower than those obtained for the calibration period, because the extremely low-flow conditions during 1987-1989 are not included in the validation period. Annual mean flows are over estimated for seven and underestimated for eight years. Discrepancies were less than 10 percent in 10 out of 15 years. Table 15 summarizes the statistics for this period. Good fit was obtained between observed and simulated streamflows even during the validation period as indicated by the NSE value of 0.71, 0.87, and 0.93 for daily, monthly, and annual data, respectively.

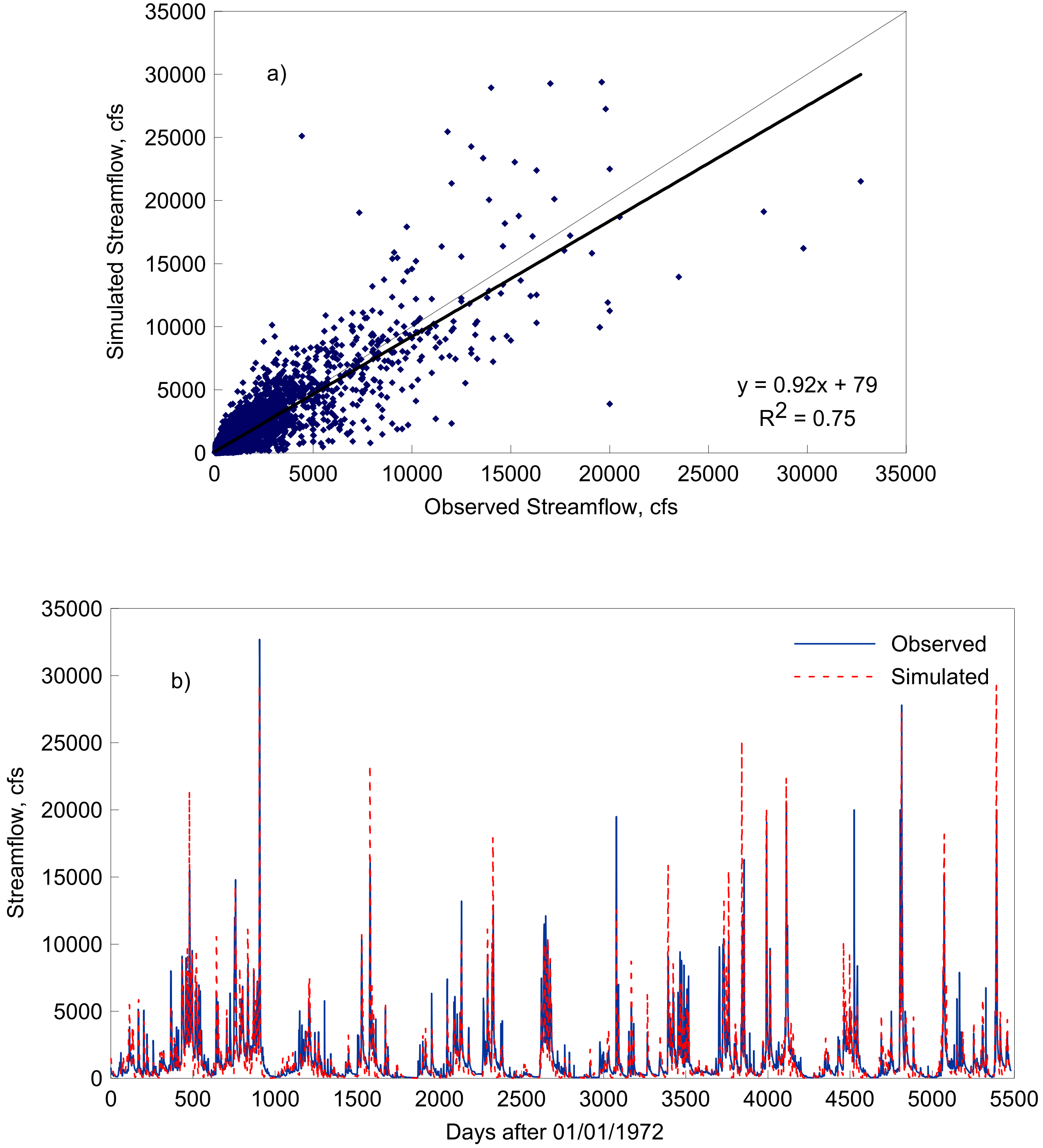


Figure 39. Observed and simulated daily streamflows for the Spoon River watershed model, 1972-1986 validation period: a) scatter plot and b) time series.

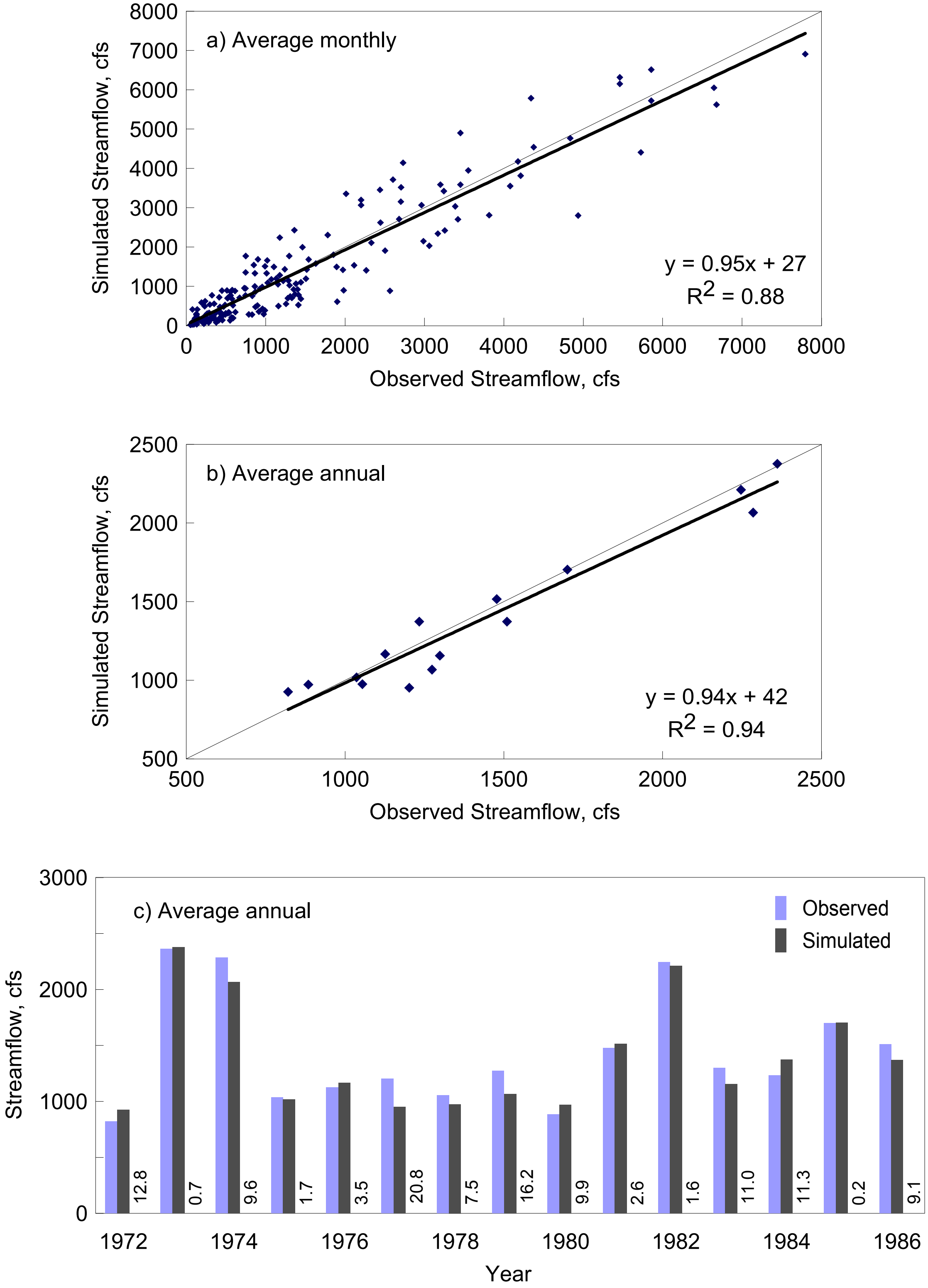


Figure 40. Scatter plots of a) average monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Spoon River watershed, 1971-1986 validation period. Values along bar graphs are absolute percentage differences between simulated and observed streamflows.

Physical Significance of Calibrated HSPF Parameters

This section compares the calibrated HSPF parameters for the three previously described tributary watersheds (Kankakee, Iroquois, and Spoon) and discusses the possible relationship between these parameters and physical characteristics of the watersheds. The three calibrated watersheds provide a limited perspective on the potential range of HSPF parameters in the Illinois River basin, and calibrating more of the major tributary watersheds would provide better insights about these parameter sets. As will be discussed later in this report, the parameters for the Spoon River watershed produce better streamflow estimates for all remaining regions of the Illinois River basin when compared with parameters developed for the Kankakee and Iroquois watersheds. Thus, it will be necessary to calibrate parameters for some of the remaining major tributary watersheds for a more complete analysis of regional characteristics of HSPF parameters for the entire basin. This issue will be addressed in future work.

The HSPF model and its predecessors were not originally designed as physically based models. Although most parameters can be linked directly to physical characteristics of the watershed, some parameters normally are used as calibration parameters, making sure that during the calibration period they are kept within a reasonable range determined through many years of experience and numerous model applications (USEPA, 2000). It also is known that, due to the large number of parameters used in the HSPF model, many of them are interconnected. Therefore, it is possible to obtain somewhat similar streamflow results using different sets of parameters, such that there is no unique “best” set of parameters for a given model application. Bearing that in mind, the following discussion attempts to explain the physical significance of the calibrated parameters by comparing the values obtained in the three calibrated watersheds and shown in Tables 8 (upper Kankakee River watershed), 10 (Iroquois River watershed), and 14 (Spoon River watershed).

Snow Parameters

The SHADE and SNOEVP snow parameters exhibit the largest difference among the three calibrated watersheds. The SHADE parameter is the fraction of land segment shaded from solar radiation by trees or slope, and this parameter is higher for the Spoon River watershed (0.27) than for the upper Kankakee-Iroquois River watersheds (0.1), reflecting differences in watershed slopes. The SNOEVP parameter is the factor used to adjust evaporation from the snowpack; it is not large in most watersheds, but it can be important for windy locations with low humidity (Crawford, 1999). This factor is much higher for the Spoon River watershed (0.8) than for the Kankakee-Iroquois River watersheds (0.1). Given that the climatic conditions are similar for these watersheds, the difference is mostly due to calibration issues. In particular, the value for the Spoon River watershed had an important impact on the water balance during the calibration process.

To determine the overall importance of snow simulation on model results, the HSPF models for the upper Kankakee, Iroquois, and Spoon River watersheds also were calibrated without activating the models snow simulation processes. Table 16 compares the NSE and R^2

Table 16. Effect of Including Snow Simulation on Model Results (NSE and R^2 for Fit between Observed and Simulated Streamflows) on Daily and Monthly Basis during Model Calibration and Validation

Time period		*Spoon*		*Iroquois*		*Upper Kankakee*	
		Snow On	*Snow Off*	*Snow On*	*Snow Off*	*Snow On*	*Snow Off*
Daily	model calibration	0.80 (0.81)	0.72 (0.72)	0.81 (0.82)	0.78 (0.79)	0.72 (0.77)	0.75 (0.78)
	model validation	0.71 (0.75)	0.64 (0.65)	0.70 (0.70)	0.58 (0.58)	0.71 (0.75)	0.71 (0.72)
Monthly	model calibration	0.91 (0.92)	0.84 (0.85)	0.88 (0.88)	0.80 (0.81)	0.78 (0.82)	0.80 (0.83)
	model validation	0.87 (0.88)	0.76 (0.76)	0.82 (0.82)	0.65 (0.65)	0.78 (0.81)	0.75 (0.76)

Notes:
Snow ON = snow was simulated during model run.
Snow OFF = snow was not simulated during model run.
Values within the parentheses are R^2 values.

performance measures of model results with and without snow simulation. Results are shown for both calibration and verification periods. In general, noticeably better results were obtained with snow simulation; however, slightly better results were obtained for the upper Kankakee River watershed without snow simulation. Snow simulation appeared to cause the greatest improvement in the timing and volume of simulated streamflows during snowmelt periods.

PWATER Parameters

The hydrologic behavior of the calibrated tributary watersheds is very different, as reflected in the streamflow series for the USGS reference stations. This can be observed by comparing daily time-series data in Figures 15a (Kankakee), 21a (Iroquois), and 36a (Spoon), and average annual flows in Figures 17c (Kankakee), 23c (Iroquois), and 38c (Spoon).

About 40 percent of the upper Kankakee River watershed is covered by well-drained loamy sand, loamy fine sand, and fine sand (soil groups A and A/D), with the remaining area in moderately well to poorly drained silty clay-loam or silt loam soils (soil groups B, C, B/D, and D). As can be observed in the daily time-series data, low flows are very high in the upper Kankakee River watershed because well-drained soils and underlying deposits of unconsolidated sand and gravel give rise to higher baseflows. Accordingly, the INFILT parameter value is high (0.3 inches/hour) for this watershed. The IRC parameter values for the upper Kankakee River watershed, given in Table 8, are also high because the interflow can be expected to behave as baseflow. The INTFW parameter value determines the distribution of water between interflow, direct overland flow and upper zone storage, and its value is relatively low (1.8 - 2.3) for the Kankakee River watershed due to more permeable soils. The nonlinear groundwater recession rate, KVARY, was modified after all other PWATER parameters were changed, and for this reason is essentially a calibration parameter. The low value of KVARY (0.05) for the Kankakee River watershed results in a fast recession of simulated groundwater flow during wet periods.

About 75 percent of the Iroquois River watershed contains B and C soils, but the remaining 25 percent has well-drained soils (soil groups A and A/D) mainly near the headwaters of the watershed. The baseflow in this watershed is not as high as in the Kankakee River watershed, but it is higher than that in the Spoon River watershed, and the overall INFILT parameter value in the watershed is 0.2 inches/hour. The IRC value for this watershed (Table 10) is also somewhat lower than in the upper Kankakee River watershed. The presence of porous soils in this watershed results in low INTFW values (1.2-1.8). The high KVARY value (3.0) for this watershed indicates slower recession of simulated groundwater flow during wet periods.

Land use on the Spoon River watershed is 85 percent agricultural on moderately well to poorly drained soils (soil groups B, B/D, and D). As can be observed in the daily time-series data, baseflow is much smaller for this watershed, and the INFILT value is relatively low (0.06 inches/hour). The INTFW parameter has a larger influence on the storm hydrograph for watersheds with a shallow, less permeable soil layer that retards vertical percolation. Its value is relatively high (10.0) for the Spoon River watershed, which has mainly loessian topsoils over a layer of less permeable soils. The high KVARY value (3.45) for this watershed indicates slower recession of simulated groundwater flow during wet periods.

Examination of the observed streamflow series for the Spoon River watershed (Figure 36b) shows that the Spoon River flow record includes extended periods of low flow. In particular, 1988-1989 represents the drought of record, with the lowest measured flows in the 87-year flow record for the Spoon River at Seville. Low-flow conditions persisted and intensified in 1989, despite more rainfall than in the preceding year. This suggests that sub-surface storage continued to be depleted throughout 1989, further reducing baseflow. Considerable effort was spent in trying to calibrate the model to match the observed flows for 1989. Higher storage values for both LZSN and UZSN parameters, combined with higher values of LZETP (the parameter that controls evaporation from the lower zone), were used to better simulate the extreme low flows of the observed streamflow series. Although results were improved, the HSPF model still did not simulate this low-flow condition satisfactorily. It was concluded that the HSPF model has limited capacity to simulate this particular record drought condition, at least within the range of parameter values normally accepted as reasonable. The persistence of low streamflow conditions during 1989 was not restricted just to the Spoon River, however. These conditions also affected much of western Illinois, as evidenced by long-term flow records on the La Moine River, Edwards River, and other streams.

The parameter corresponding to interception by vegetation cover (CEPSC) for the three watersheds is within the range specified for cropland (0.10-0.25 inches). The seasonal variation obtained during calibration is only slightly different for the three watersheds. Differences obtained during calibration in the rest of the parameters (AGWRC, BASETP, AGWETP, DEEPFR, and NSUR) are not significant.

Hydrologic Model for Entire Illinois River Basin

Introduction

The study plan to develop a calibrated and verified HSPF model for the entire Illinois River basin describes three different phases. This section discusses work performed during the third phase using lessons learned for the calibration of the Spoon and Kankakee River watersheds to develop a model for the entire Illinois River basin.

Two different approaches were pursued to develop a preliminary HSPF model of the Illinois River basin:

- **HSPF model using a single UCI data file.** An HSPF model for the entire Illinois River basin was developed by delineating the entire basin into 215 sub-watersheds (Figure 41). However, the current version of the HSPF model is limited to a maximum number of 500 operations, which is the total number of land segments plus the number of reaches in this study. After several trials, it was found that 60 sub-watersheds are, for practical purposes, the most that can be used to model the Illinois River basin. Three points on the mainstem of the Illinois River (Marseilles, Kingston Mines, and Valley City) were used to compare the simulated and the observed flows at the USGS discharge gaging stations. The precipitation station that was closest to the center of each sub-watershed was assigned to that sub-watershed and its reach. Because of the relatively coarse size of the sub-watersheds, the model used only 56 of the 95 precipitation gaging stations.

- **HSPF model using a modular approach.** A second approach modeled each of the nine main sub-watersheds (Des Plaines, Kankakee, Fox, Vermilion, Mackinaw, Spoon, Sangamon, La Moine, and Macoupin) of the Illinois River basin separately. Individual HSPF projects for the Spoon and Kankakee/Iroquois sub-watersheds were created, calibrated, and verified as described earlier in this report. The HSPF projects for the remaining seven sub-watersheds were created using the calibration parameters obtained for the Spoon, Kankakee, and Iroquois River watersheds. Figure 42 shows the nine main sub-watersheds of the Illinois River basin (shaded areas) and also the sub-watershed draining directly to the mainstem of the Illinois River (white area). An independent HSPF project was created to model the hydrologic response of the watershed of the mainstem Illinois River (MIR). Simulated daily streamflow series obtained at the outlet of each sub-watershed were used as external input flow series for the HSPF model of the MIR area (Figure 43).

The HSPF model of the Illinois River basin developed in this study is the first comprehensive hydrologic model developed for the entire basin to analyze large-scale planning issues. The model provides solid groundwork for developing and refining future basin modeling efforts in support of the Illinois River Ecosystem Restoration Project. Salient, useful model features developed are as follows:

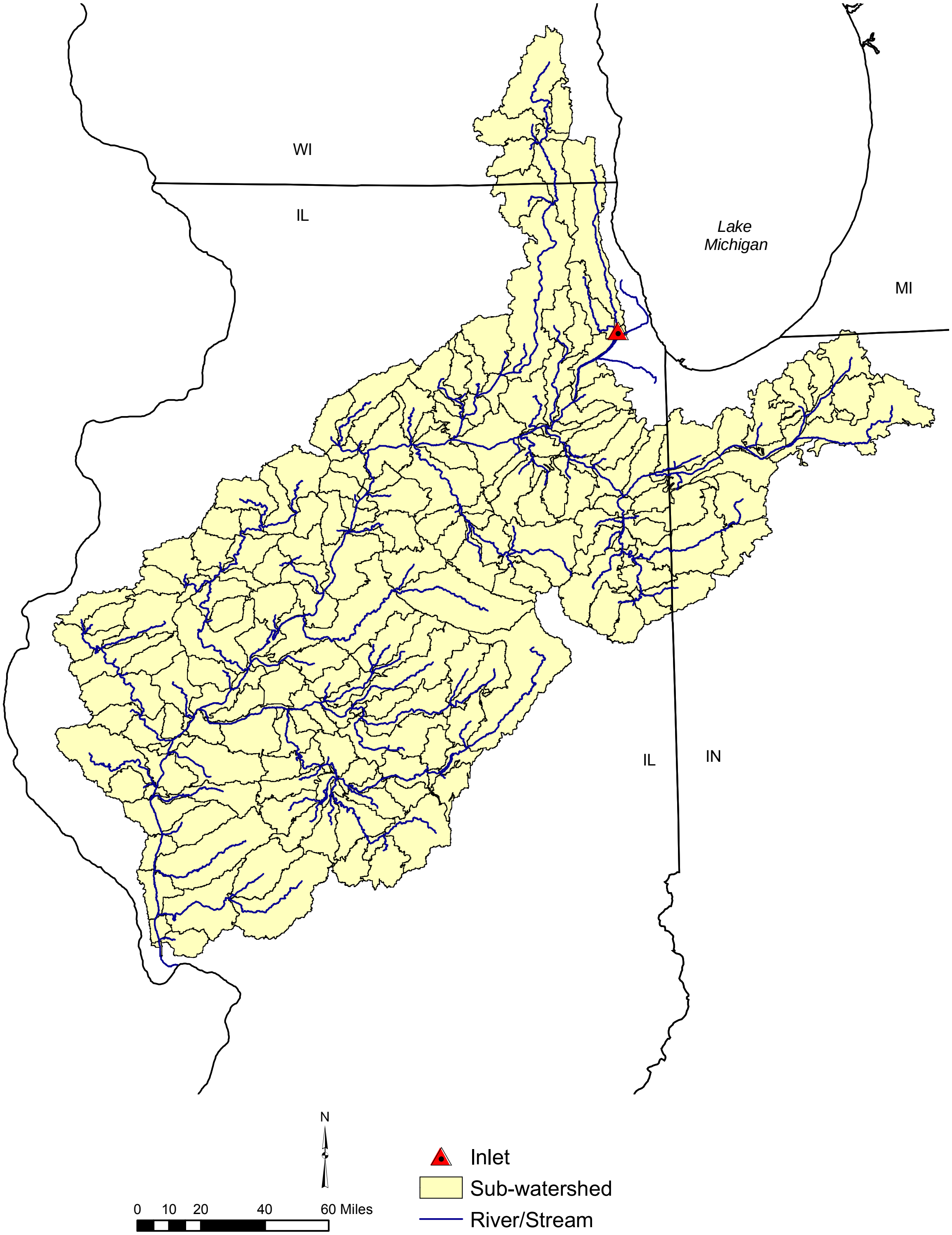


Figure 41. Illinois River basin after initial delineation into 215 sub-watersheds.

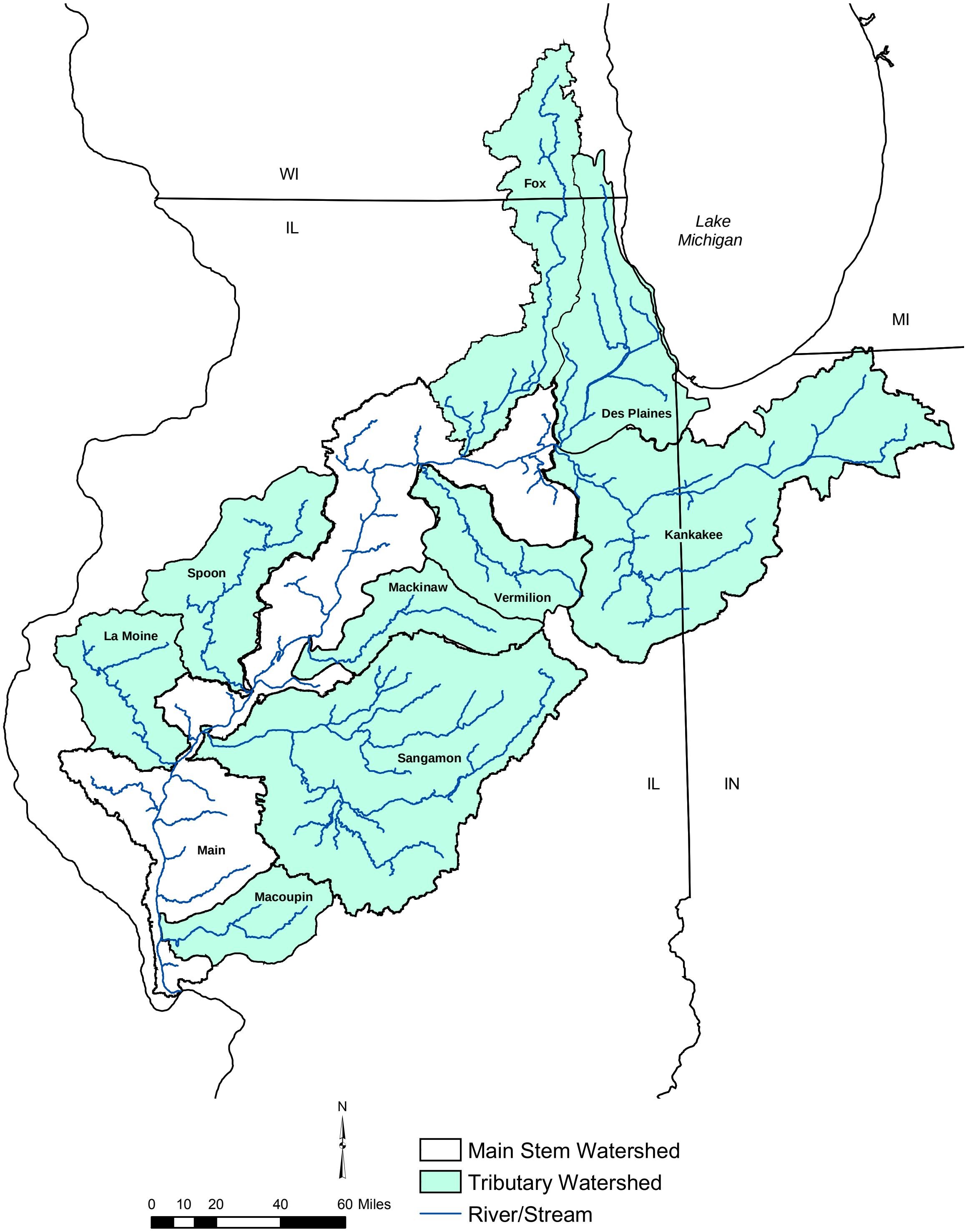


Figure 42. Location of the nine main sub-watersheds of the Illinois River basin (shaded areas) and the mainstem sub-watershed (white area).

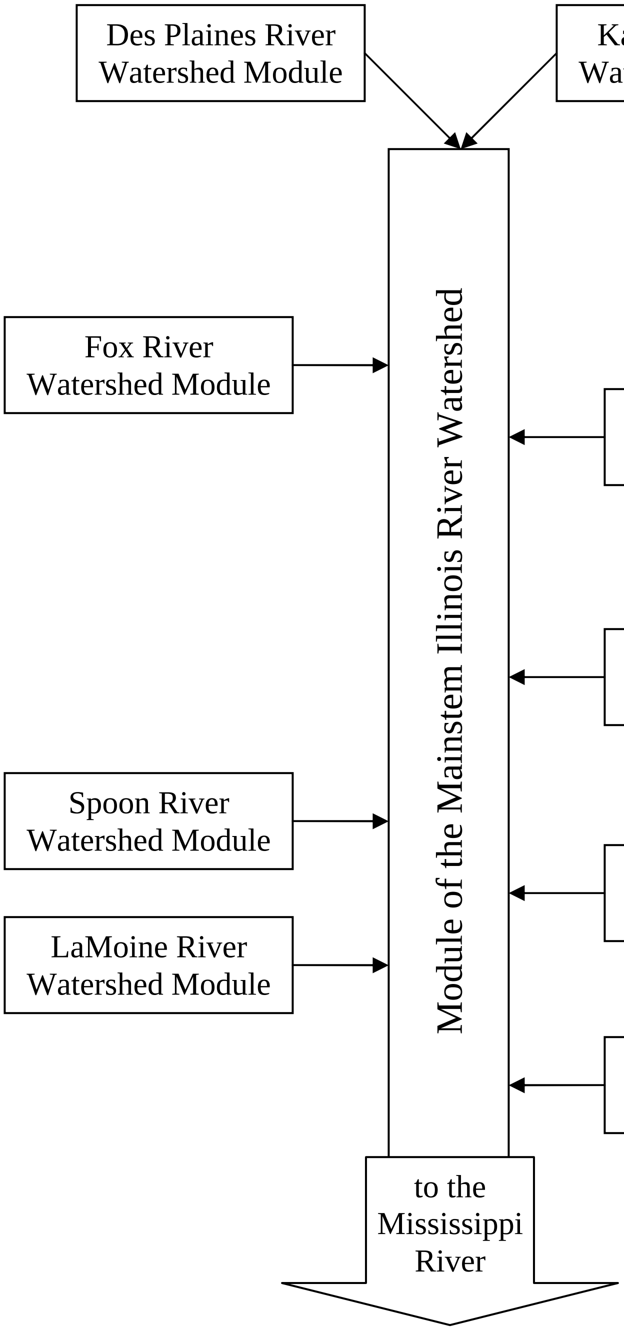


Figure 43. Schematic of the modular approach for modeling the Illinois River basin using individual HSPF models of different watersheds.

- The climatic database originally developed for BASINS was expanded to include precipitation data for 97 gaging stations throughout the Illinois River basin for 1970-1995. This database provides a complete set of available precipitation data for this time period in a usable format for further watershed modeling of any portion of the basin. It should be noted here that the USEPA's BASINS database has only five such climate stations for use with the Illinois River basin.
- Calibrated models of the Kankakee-Iroquois and Spoon River watersheds were prepared to simulate hydrology in these major tributaries, and can be used to study large-scale effects of alternative land-use and climate conditions. More detailed calibration may be appropriate when applying these models to smaller sub-watersheds. These models also can be expanded for use in simulating sediment and water quality in these tributaries with adequate calibration.
- Preliminary individual HSPF models of the major tributary watersheds and of the MIR area were created and are included in the current model of the basin. Model input files for these watersheds have been prepared and are available for future development and calibration. Although most of these tributary models are not yet calibrated, analysis has shown that they can give a reasonable but coarse representation of simulated flows for each major tributary using parameters from the calibrated tributary watersheds and climatic inputs created in this study.

General Description of the Illinois River Basin

The Illinois River basin drains an area of about 29,000 sq mi. Most of the watershed area is located in the State of Illinois, but small portions extend into Wisconsin (1,000 sq mi) and Indiana (3,200 sq mi). The Illinois River begins at the confluence of the Des Plaines and the Kankakee Rivers and has a total length of 270 miles up to its outlet to the Mississippi near Grafton, Illinois. The river flows through a narrow valley in the upper portion and through several lakes and backwaters in the lower portion, which has numerous levees for flood control.

More than 90 percent of the land use in the Illinois River basin is agricultural. Urban land use is about 3 percent and concentrated around the Chicago area (Des Plaines sub-watershed). Only 4 percent of the basin has forested areas. Figure 44 shows the land-use distribution obtained using GIS land coverage available in the BASINS dataset. Figure 45 shows the soil classification, based on the hydrologic soil group, in the Illinois River basin, and Table 17 shows the percentage of basin area corresponding to each soil group. Table 17 indicates that 46 percent of the soils are type B, and more than 92 percent are either types B, B/D, or C, meaning that most of the soils in the basin have moderate to slow infiltration rates.

The HSPF Model Using a Single UCI Data File

The Illinois River basin was divided into 60 sub-watersheds for the single UCI model. Figure 46 is a schematic of sub-watersheds, reaches, inlets, and outlets for the HSPF model

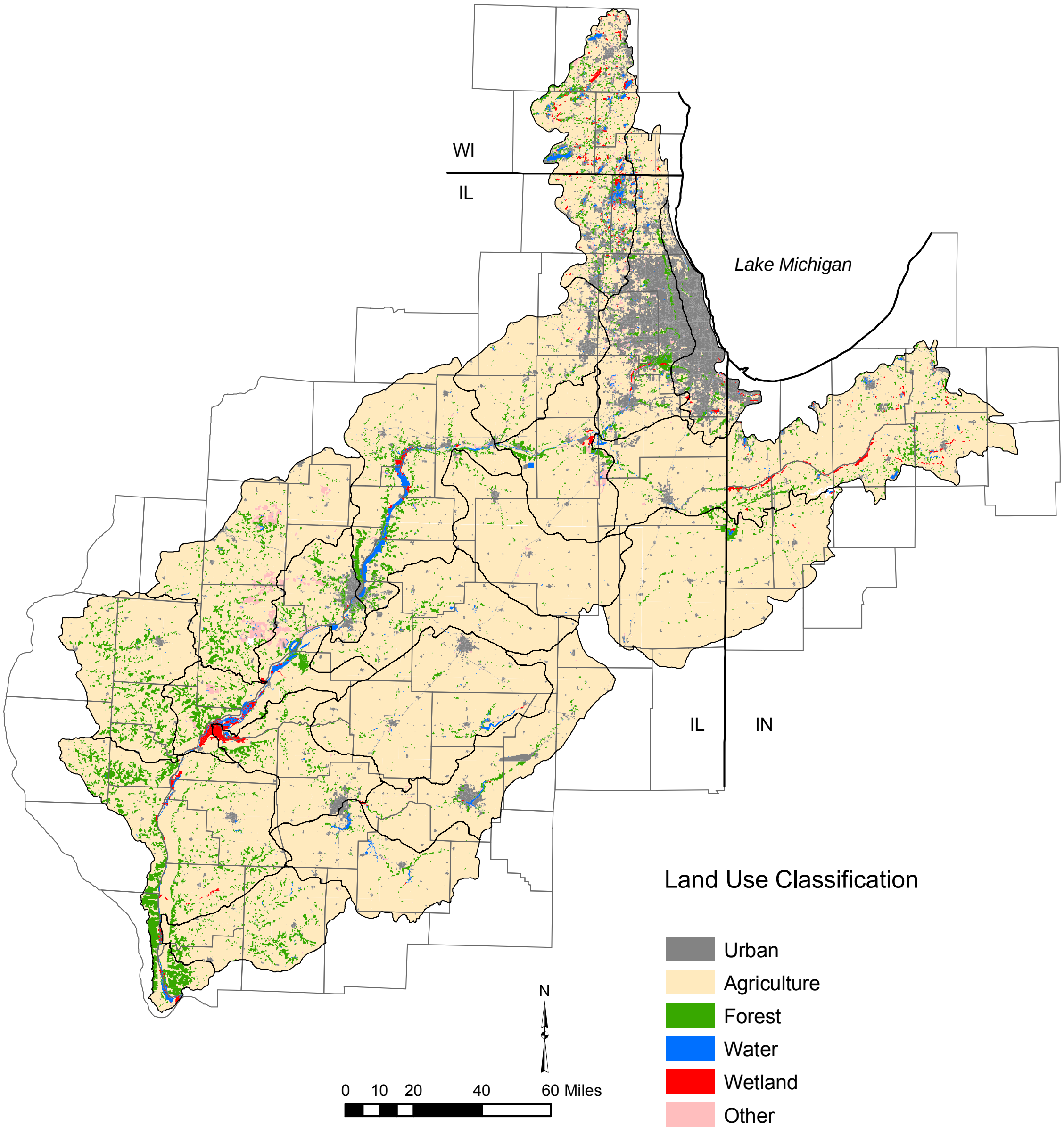


Figure 44. Land uses in the Illinois River basin.

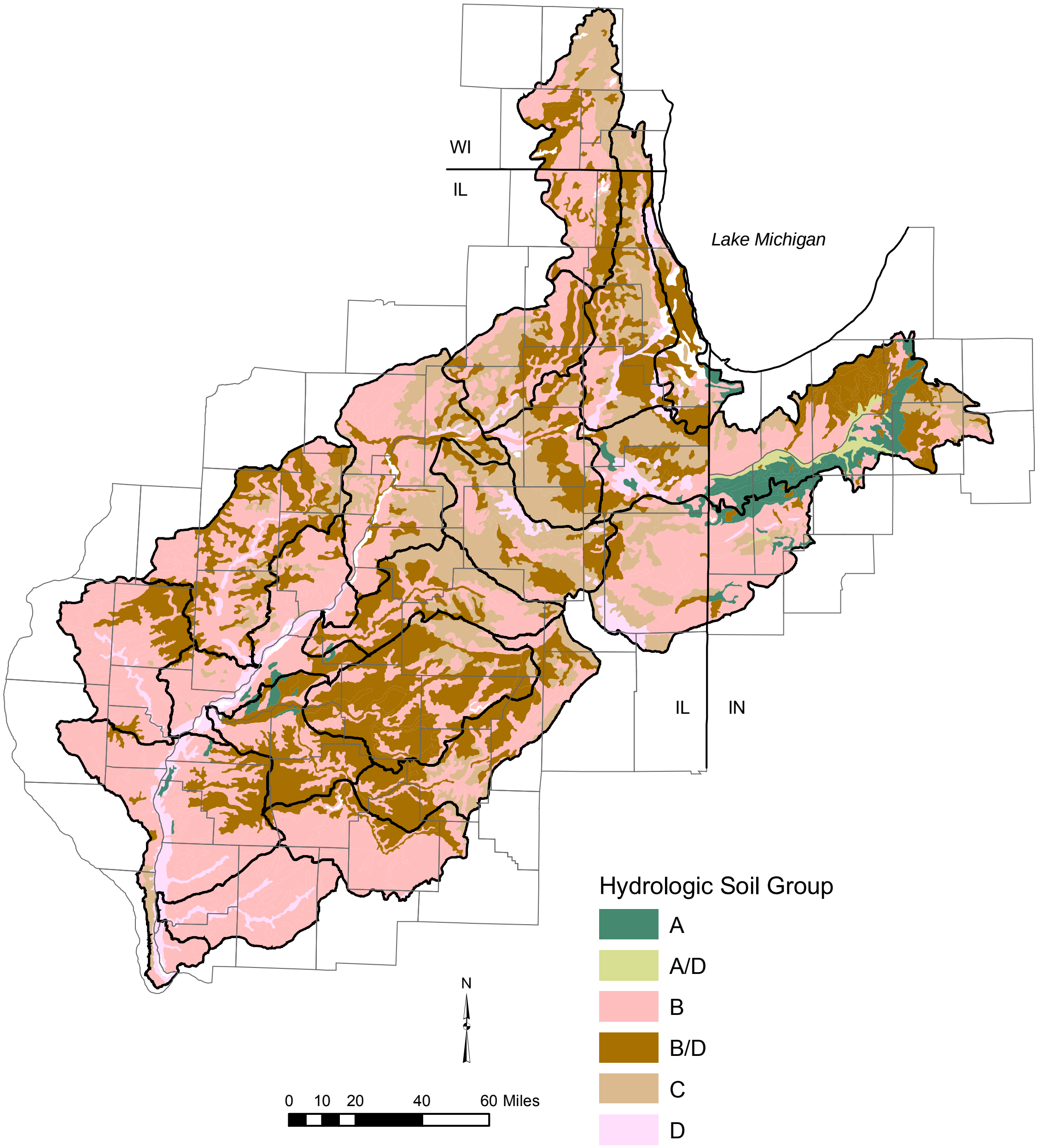


Figure 45. Soil type classification based on the hydrologic soil groups in the Illinois River basin.

Table 17. Soil Type Classification Based on Hydrologic Soil Groups in Illinois River Basin

Soil Type	*Area, %*
A	3.10
A/D	0.28
B	45.70
B/D	21.80
C	24.90
D	2.70

delineated using the BASINS modeling system. The BASINS system created 119 sub-watersheds using a threshold value watershed size of 5500 square meters. Of the initial 119 sub-watershed outlets, almost half delineated small tributaries or sub-watershed areas that were considered insignificant and were combined in the model to reduce the total number of sub-watersheds. In addition, flows from much of the Des Plaines River and Chicago-Calumet River drainage were represented by combined observed flows at two USGS gaging stations: the Chicago Sanitary and Ship Canal at Romeoville (gage #05536995) and the Des Plaines River at Riverside (gage #05532500). These observed flows were introduced as inlet locations in the model for two reasons: 1) the Chicago area is highly urbanized, and the watershed characteristics are dissimilar to the three calibrated watersheds, and 2) the Lake Michigan flow diversion provides an additional source of flow to the Chicago Sanitary and Ship Canal.

Three points on the mainstem of the Illinois River (Marseilles, Kingston Mines, and Valley City) were used to compare simulated and observed flow at USGS streamflow gaging stations. The final delineation of the Illinois River basin had 60 sub-watersheds, and the final version of the HSPF model had a total of 60 reaches, 409 land segments (Hydrologic Response Units), and one inlet. The total modeled area of 27,509 sq mi does not include the portion of the Des Plaines River watershed that is represented as a model inlet. About 6,923 sq mi of the modeled watershed, or 25 percent of the total area, drains to Marseilles; 12,354 sq mi (45 percent) drains to Kingston Mines, and 25,402 sq mi (92 percent) drains to Valley City. Grafton is the outlet of the entire Illinois River basin. The precipitation station closest to the center of the sub-watershed was assigned to each sub-watershed and its reach. Because of the relatively coarse size of the sub-watershed, the model used only 56 of the 95 precipitation gaging stations. The locations of precipitation gaging stations used for the model are shown (Figure 47).

This HSPF model tested the parameters calibrated from three individual watersheds. The sets of calibrated parameters developed for the Kankakee, Iroquois, and Spoon River watersheds were tested, comparing simulated and observed flows at gaging stations on six large tributaries to the Illinois River (La Moine, Sangamon, Mackinaw, Vermilion, and Fox Rivers, and Macoupin Creek). For all six watersheds, the Spoon River watershed parameters better simulated USGS observed flows than the parameter sets for the Kankakee and Iroquois River watersheds. As a result, the parameters of Spoon River watershed were used to simulate flows for the remainder of the Illinois River basin.

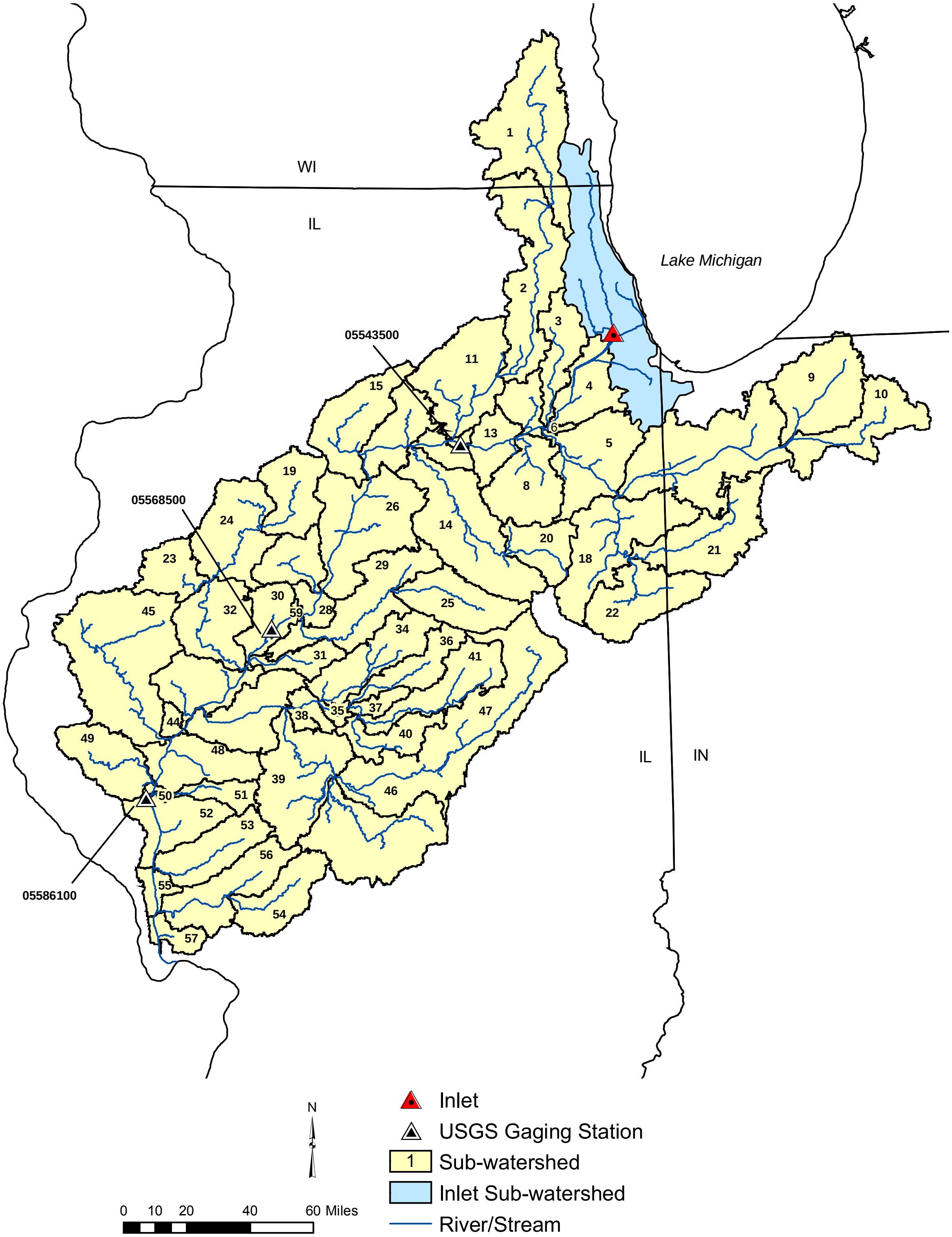


Figure 46. Sub-watersheds of the Illinois River basin after delineation into 60 sub-watersheds, and location of the USGS streamflow gages in the watershed.

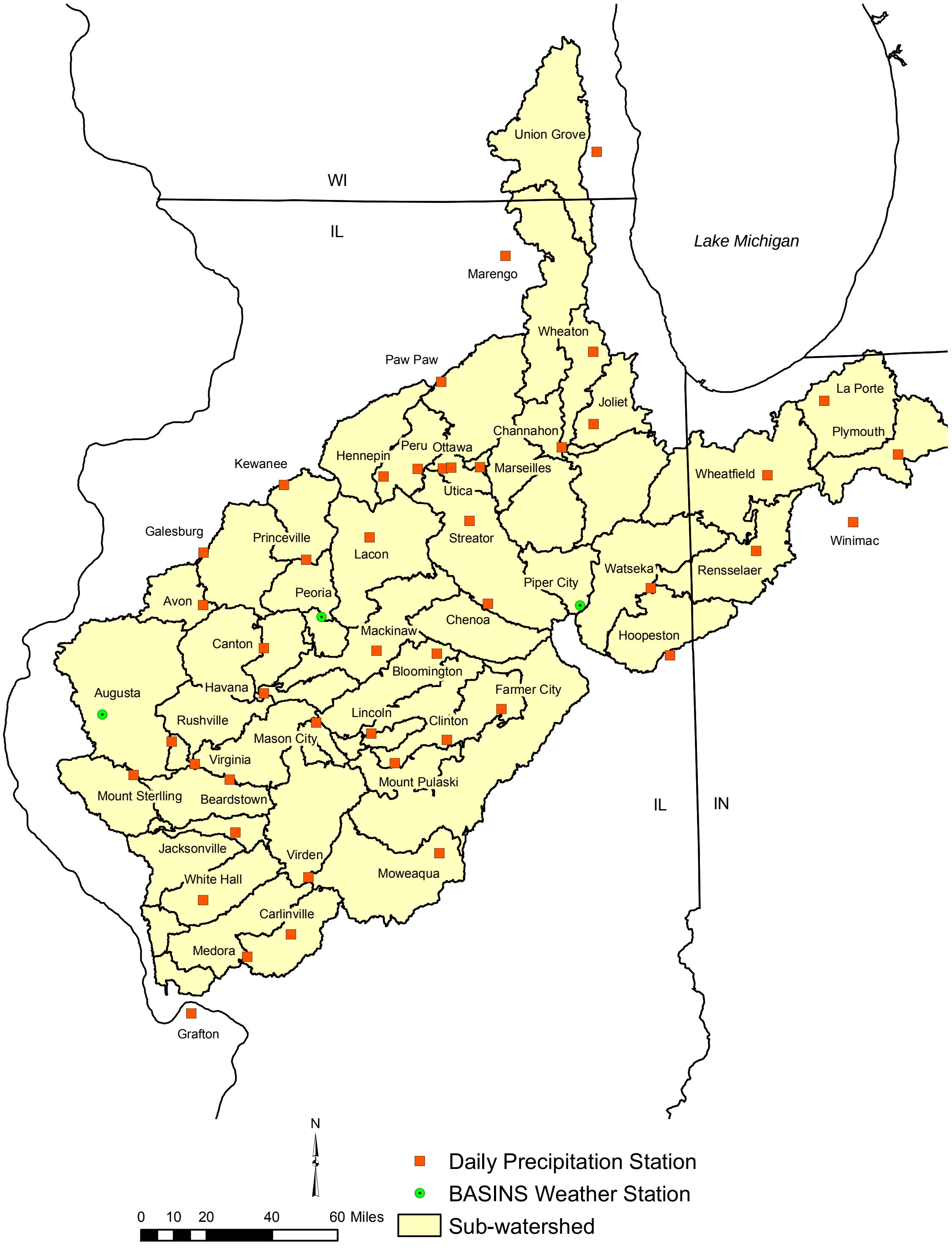


Figure 47. The USEPA-WDM weather stations and local precipitation stations in or near the 60 Illinois River basin sub-watersheds.

Because the observed discharge was used for the inflow from Lake Michigan flow diversion and flow from the Chicago area, and the period of record of the observed discharge started in July 1984; the simulation period for the model was January 1985 - December 1999. Figure 48 compares the simulated and observed daily flows at Marseilles. Although the simulated flow is higher than the observed flow for many high-flow events, the overall correlation between simulated and observed flows is good. The monthly comparisons of simulated flow with observed flow at Marseilles are shown (Figure 49). In general, the relative errors for the months from January to July are fairly low. The simulated flows tend to be higher than observed flows from August to December. Calibration may improve poor matches, such as those in August 1990 (70.7 percent error) and October 1996 (51.4 percent error). The correlation between simulated and observed flows is better on a monthly basis (Figure 50b) than on a daily basis (Figure 50a). Except for 1987, 1988, and 1990, the relative errors of the annual water balances are all below 10 percent (Figure 50c).

The Kingston Mines gage had an increasing amount of scatter between daily estimated and observed flows (Figure 51a), and the simulated peakflows are much higher than the observed peakflows (Figure 51b). As indicated earlier, the HSPF model was not adjusted to better simulate mainstem river flows, and there is no attempt to account for the impact of river storage on the simulated peakflows. The difference between the simulated and observed peakflows probably would improve with the addition of reservoir routing in the HSPF model, or through the use of a more detailed unsteady flow routing process for the Illinois River. The monthly flow correlation coefficient decreased from 0.86 at Marseilles to 0.79 at Kingston Mines (Figure 52a). However, the average annual simulated and observed flows correlate fairly well, $R^2 = 0.96$ (Figure 52b), and the relative error in annual flows for all years is below 15 percent (Figure 52c).

Flows draining to the outlet at Valley City cover about 92 percent of the entire basin, so the results from Valley City can be a reflection of the entire Illinois River basin. As seen in Figure 53a, the correlation between daily flows is much more scattered, and the correlation is about 0.52, mostly due to the overestimation of peakflows (Figure 53b) caused by routing deficiencies of the uncalibrated model. Backwater from the Mississippi River sometimes affects the Illinois River at Valley City. Although the slope measurements at the Valley City gage were adjusted for this effect, discharge estimates are of fair quality and estimation errors occasionally may influence the comparison of observed and simulated values. The correlation between monthly averaged flows (Figure 54a) is a little lower than for the upper stream locations. The correlation is also good for average annual flows (Figure 54b), with a relative error in all years of less than 15 percent (Figure 54c).

The 60 sub-watersheds represent the practical limit that can be developed and still model the entire Illinois River basin in a single HSPF project. If a higher number of sub-watersheds were delineated, the total number of HSPF operations in the project would exceed the practical limit (500 operations), and the model would not run. Future development of the HSPF model is expected to increase model capacity and the WinHSPF interface to be more user friendly and operationally interactive. Nevertheless, the modular approach is preferred for the reasons discussed in the next section.

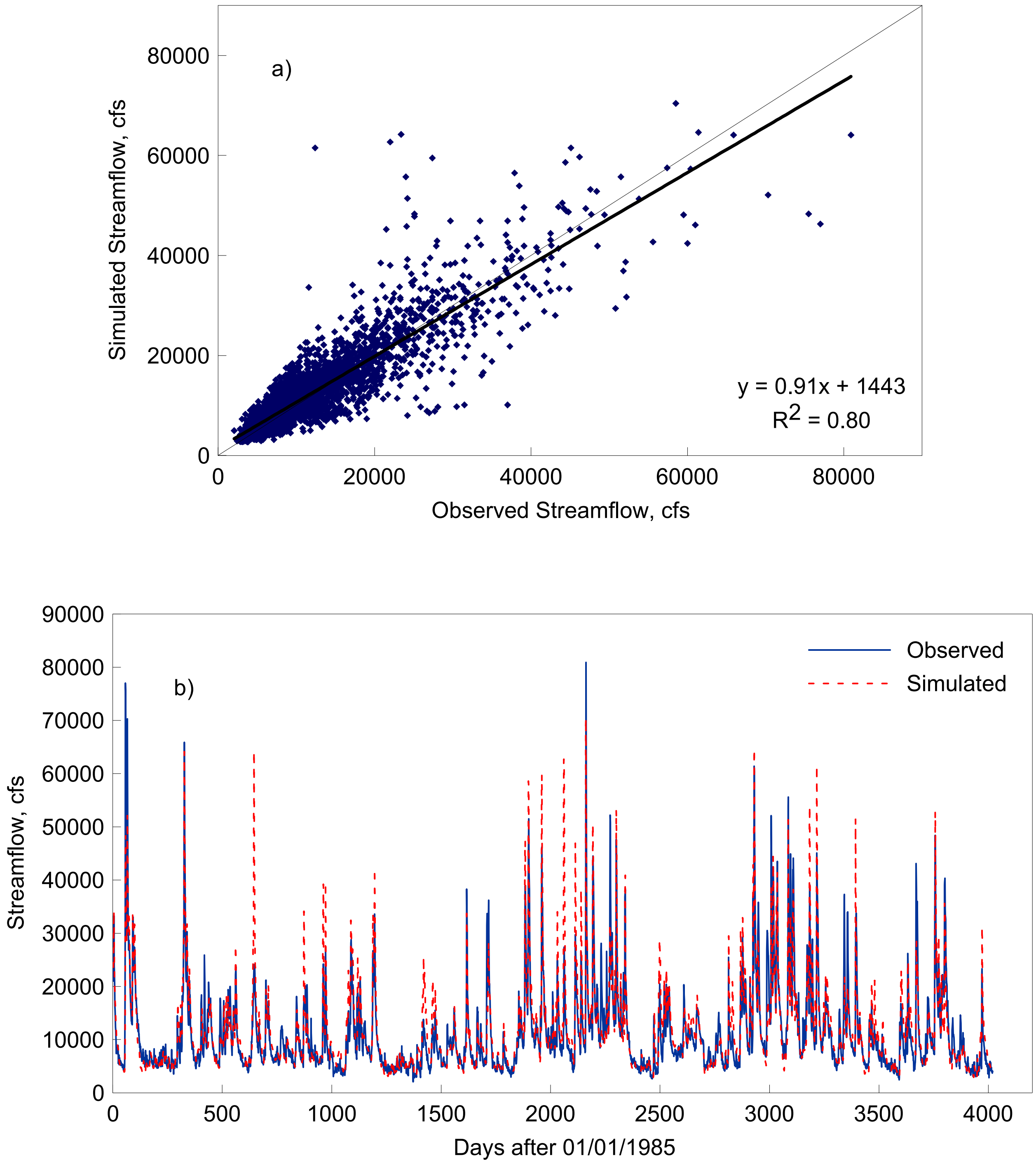


Figure 48. Observed and simulated streamflows from the Single UCI modeling approach at the USGS gaging station near Marseilles, IL,1985-1995: a) scatter plot and b) time series.

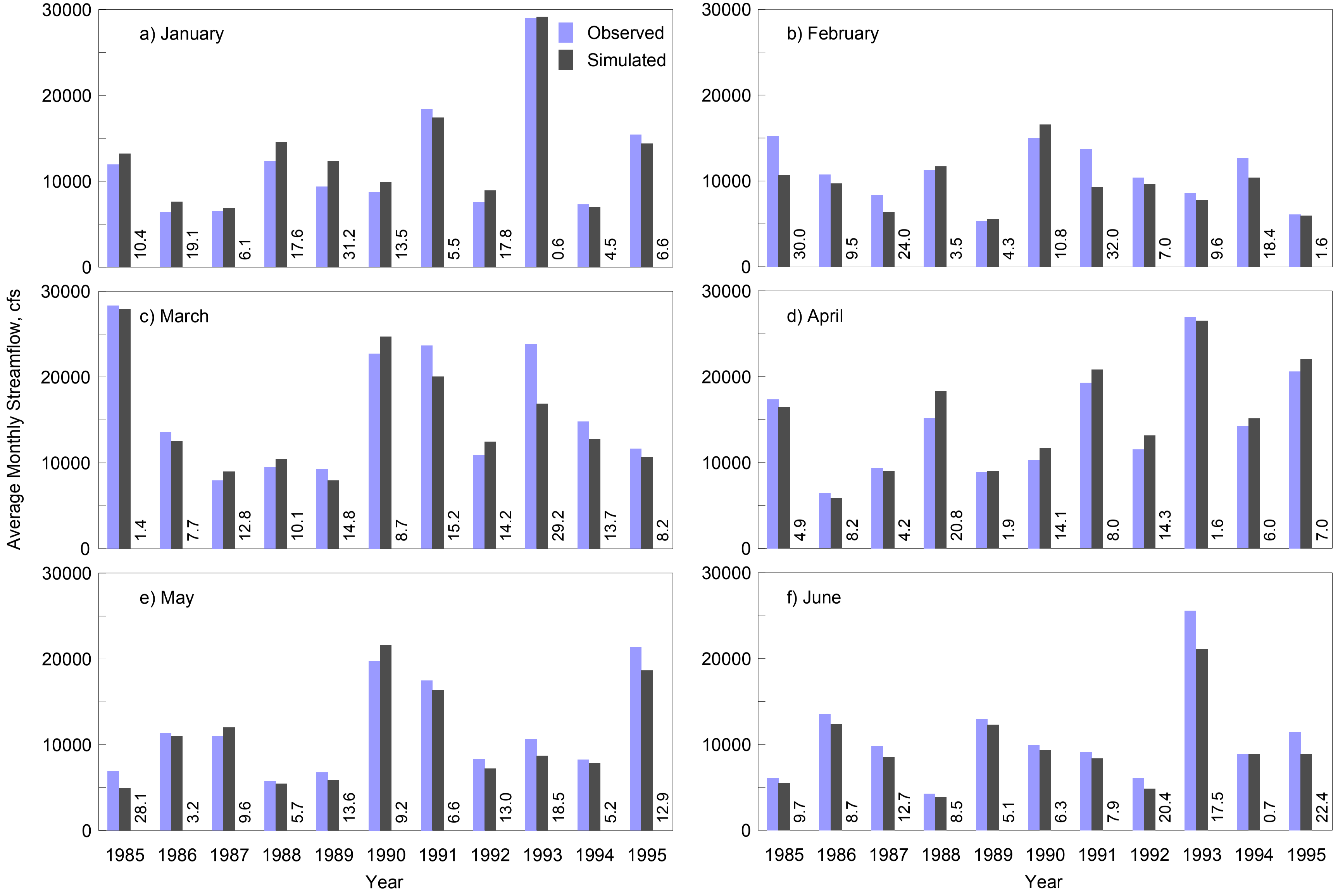


Figure 49a. Observed and simulated streamflows based on the single UCI modeling approach at the USGS streamgage near Marseilles, IL, January-June 1985-1995. Data labels indicate percent relative difference between simulated and observed values.

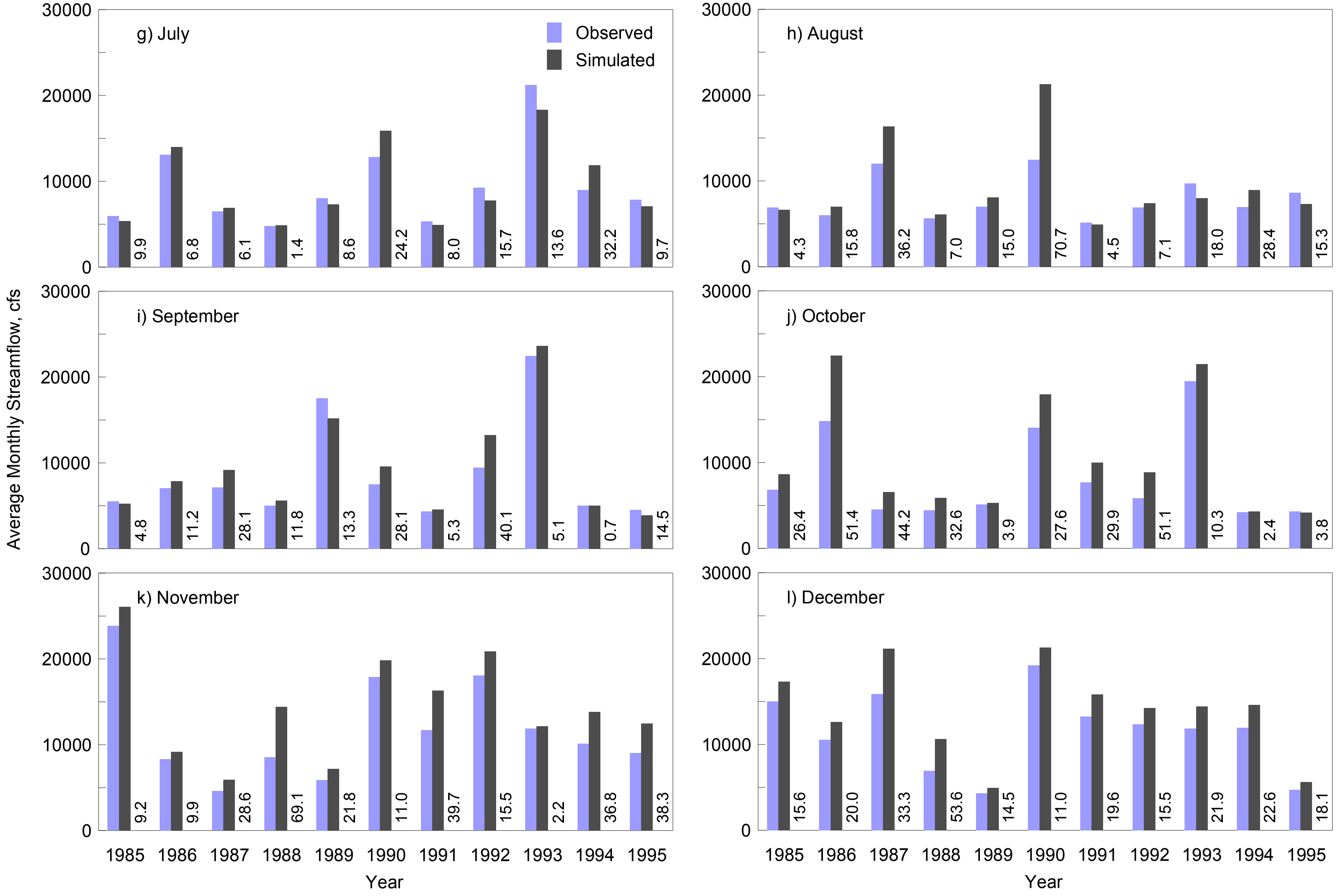


Figure 49b. Observed and simulated average monthly streamflows based on the single UCI modeling approach at the USGS streamgage near Marseilles IL, July-December 1985-1995. Data labels indicate percent relative difference between simulated and observed values.

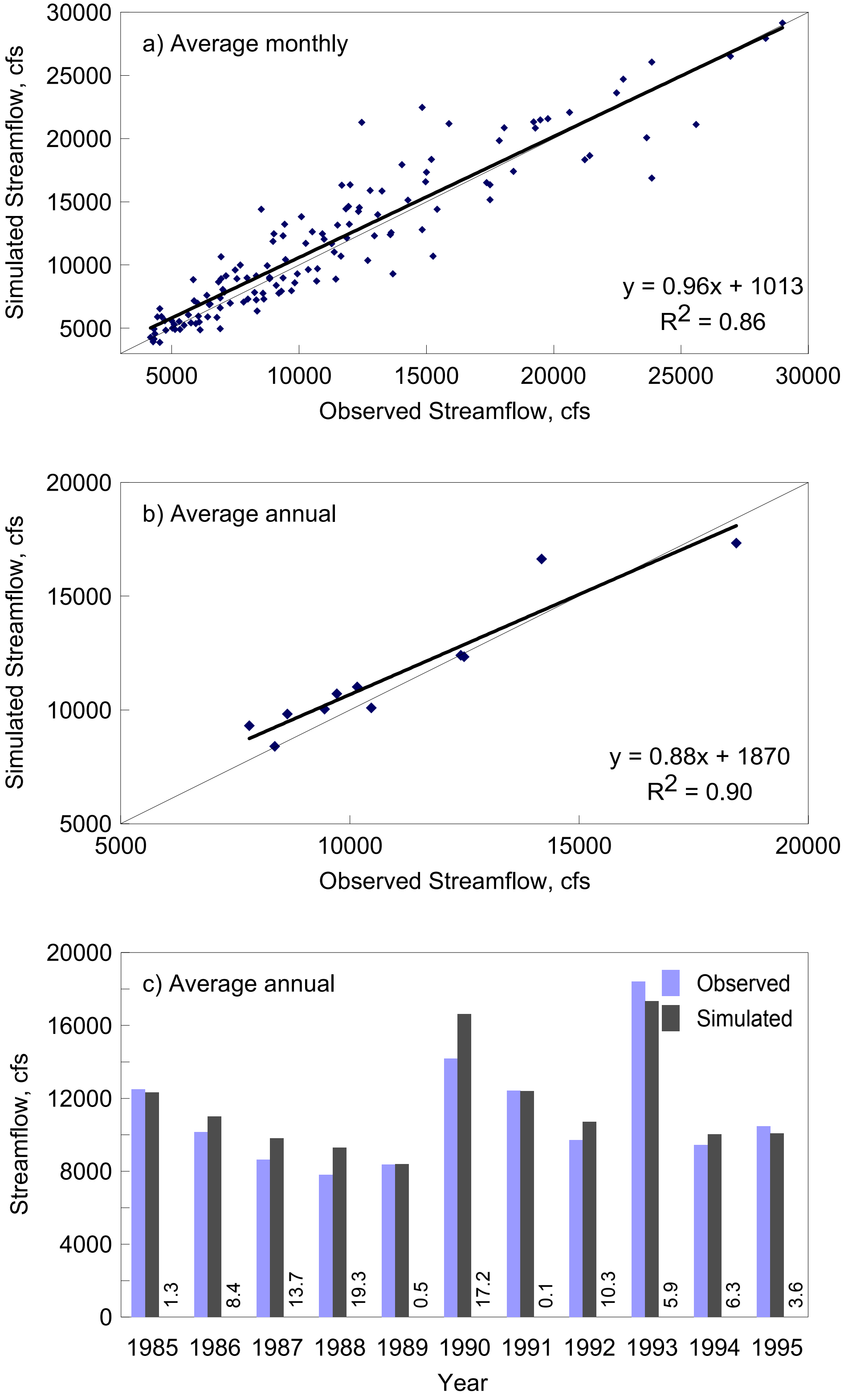


Figure 50. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Marseilles on the Illinois River, 1985-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

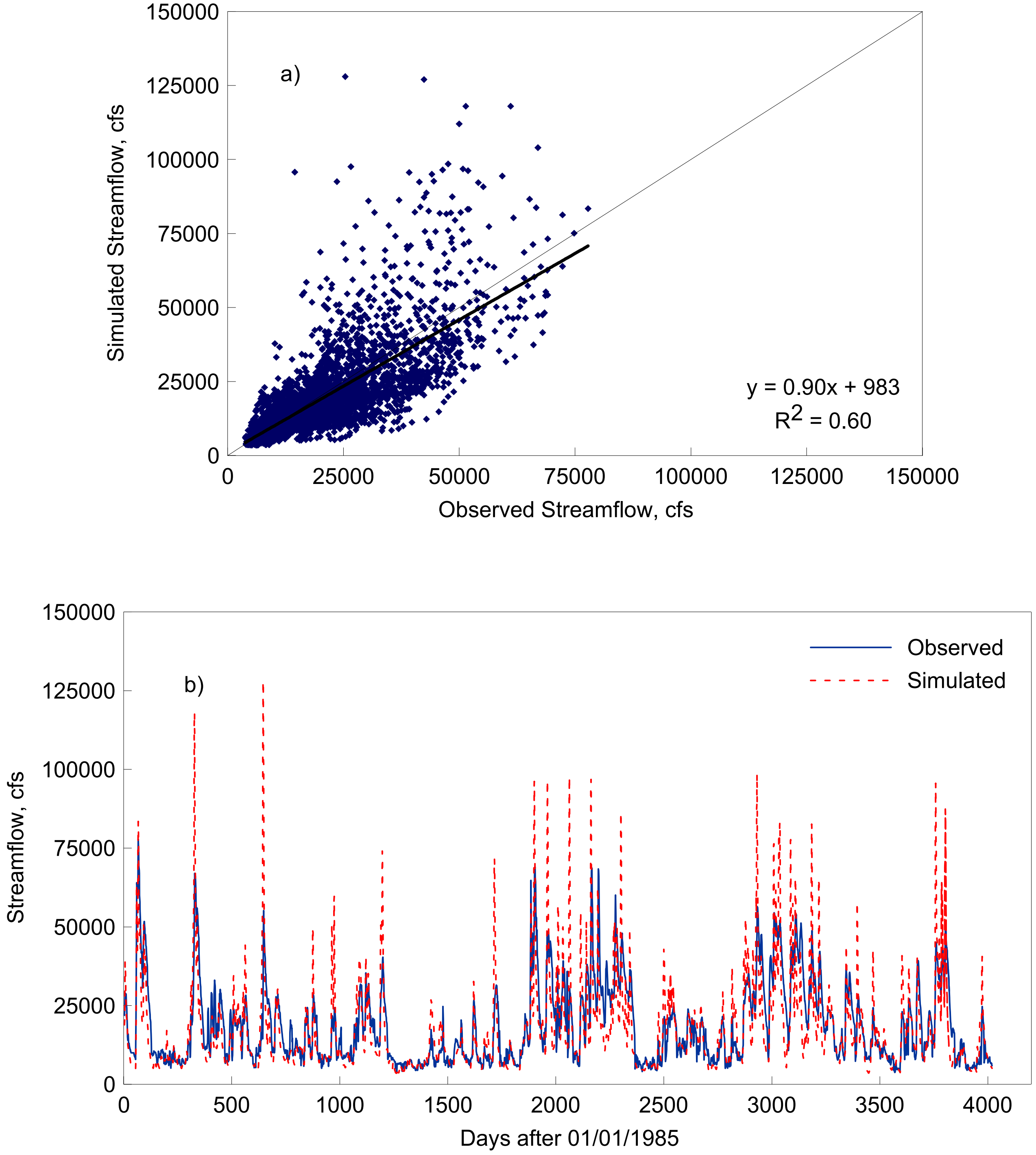


Figure 51. Observed and simulated streamflows
from the single UCI modeling approach at the USGS gaging station
near Kingston Mines, IL, 1985-1995: a) scatter plot and b) time series.

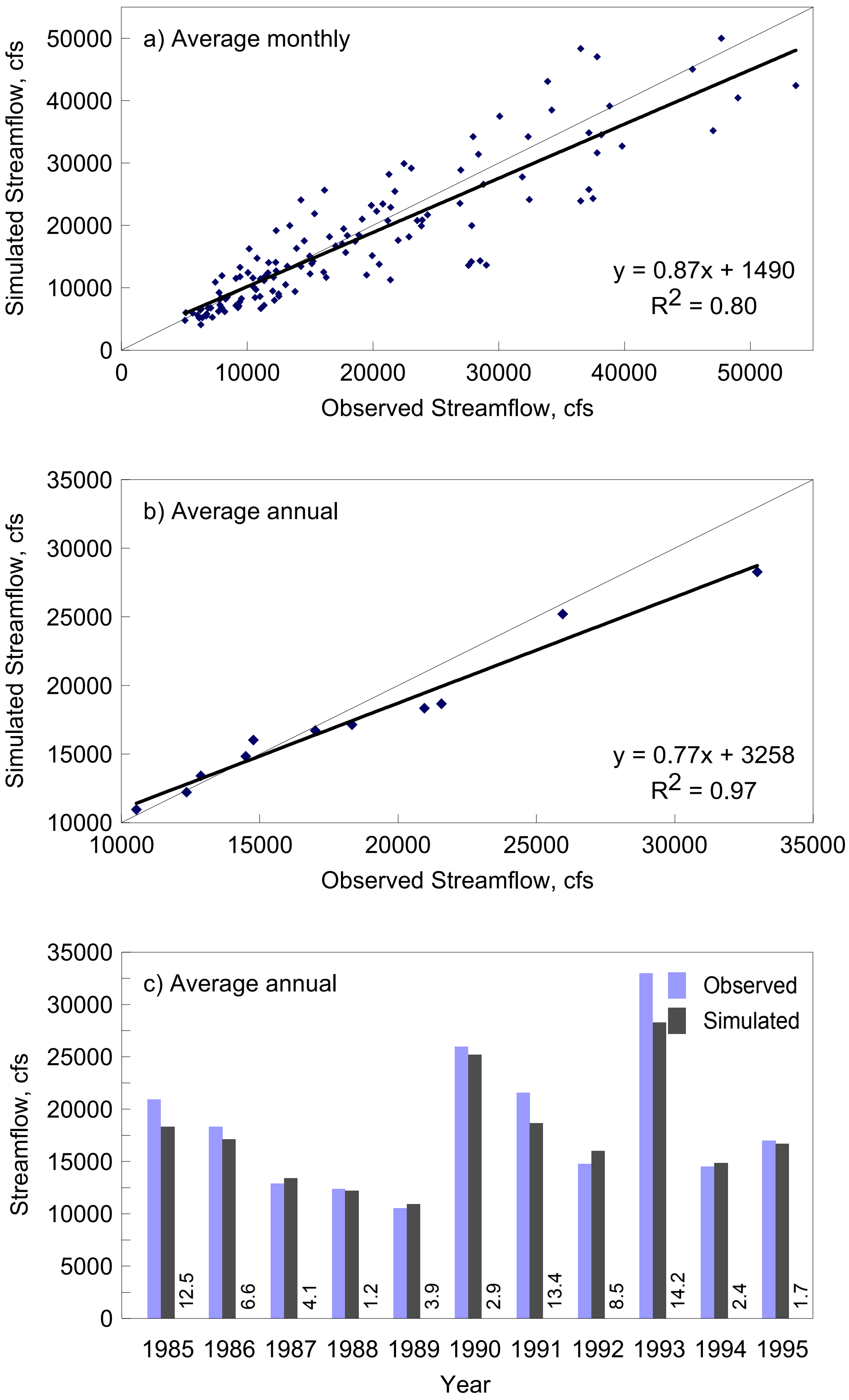


Figure 52. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Kingston Mines on the Illinois River, 1985-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

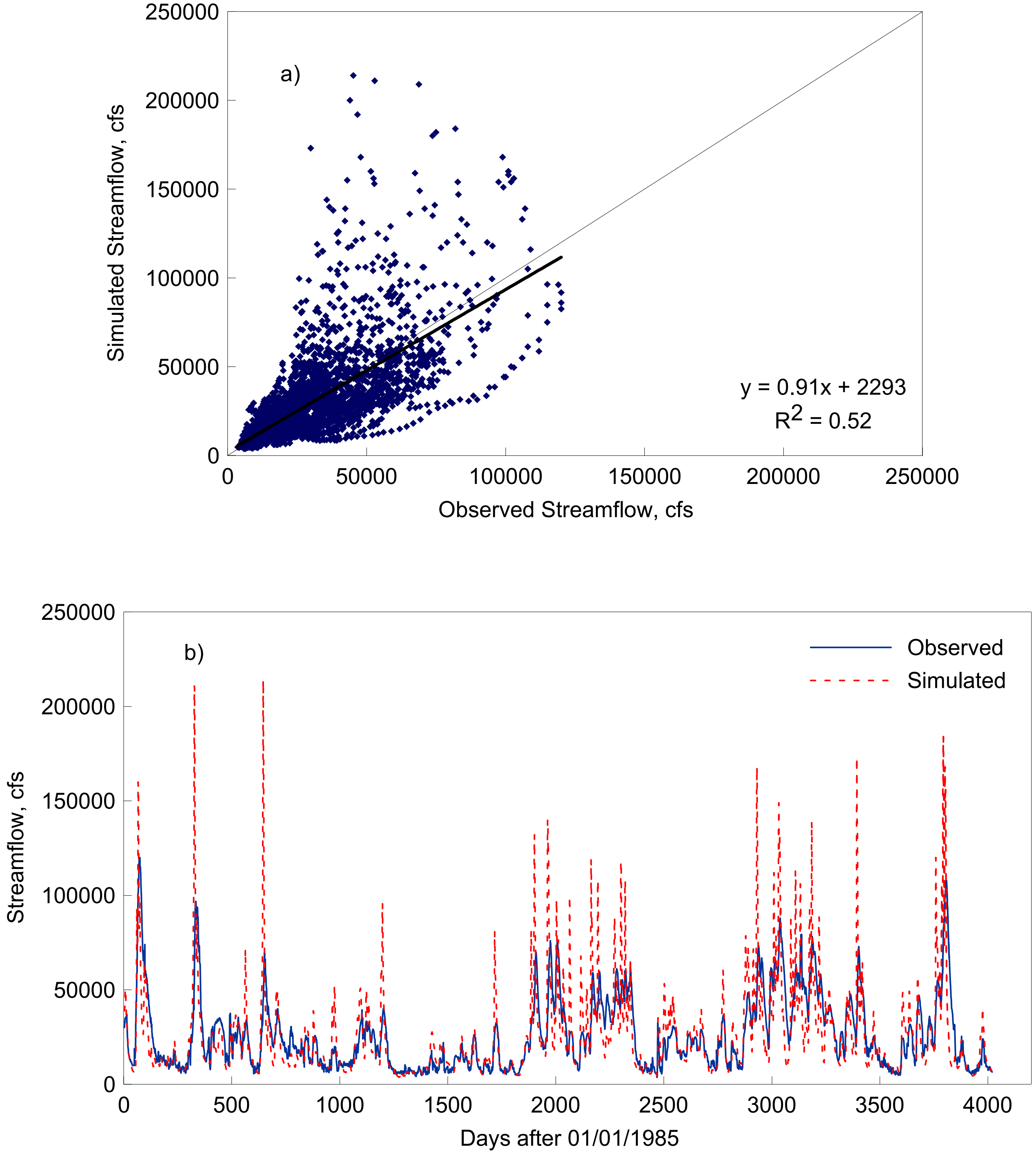


Figure 53. Observed and simulated streamflows from the single UCI modeling approach at the USGS gaging station near Valley City, IL, 1985-1995: a) scatter plot and b) time series.

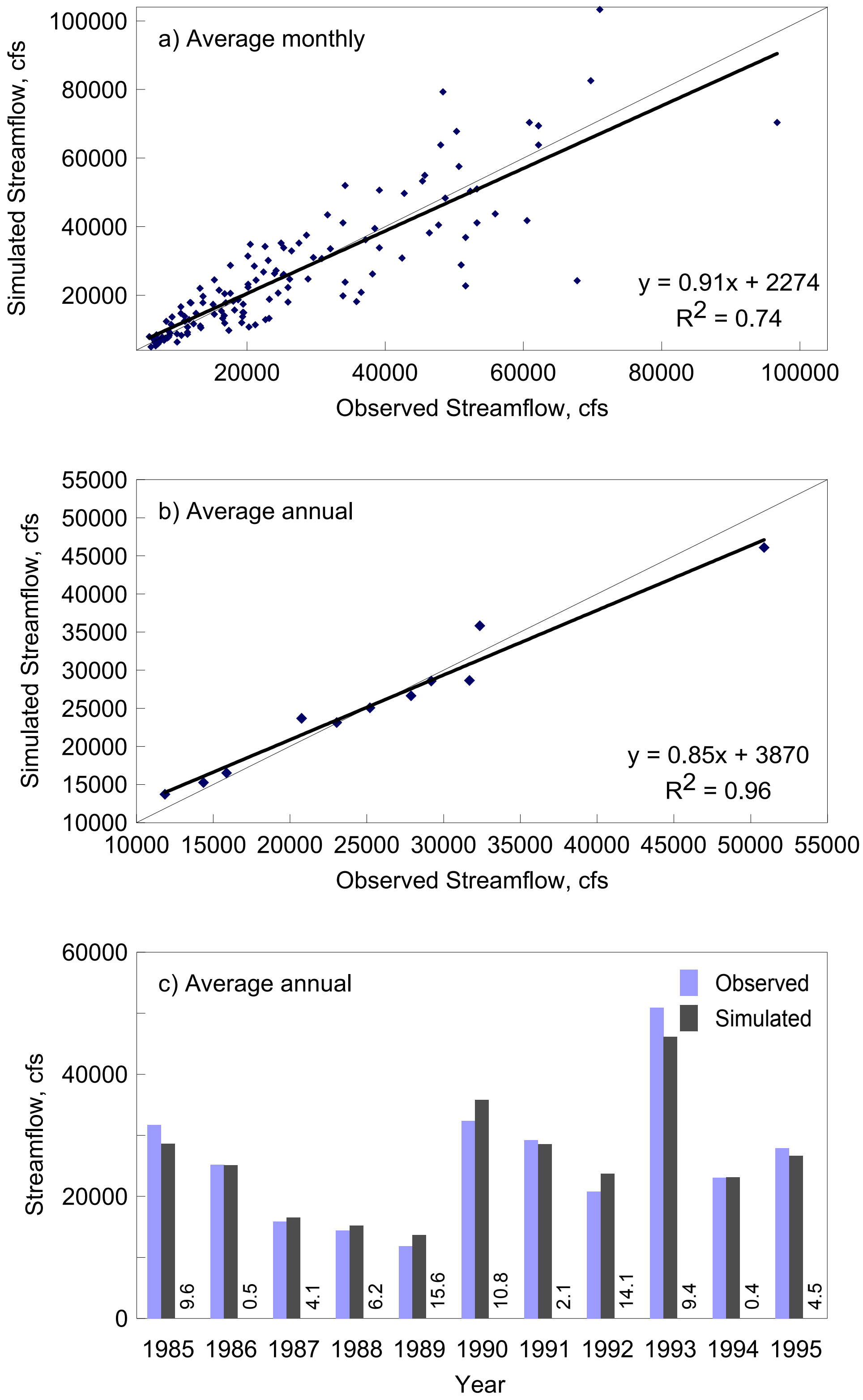


Figure 54. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Valley City on the Illinois River, 1985-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

The HSPF Model Using a Modular Approach

An alternative modular approach was implemented to model the entire Illinois River basin with more sub-watershed units and use as many precipitation gaging stations as possible from the current available data. This approach set up eight more separate HSPF modeling projects for different regions of the Illinois River basin: one model for each of the remaining seven major tributaries and an eighth model for the MIR watershed (Figures 42 and 43). Hydrologic modeling results for the two other tributary watersheds i.e., the Kankakee and Spoon River watersheds, were presented earlier in this report. This modular approach was the preferred approach for several reasons:

- It is anticipated that an HSPF model for the Illinois River basin will provide a base or umbrella for future modeling work, leading to more detailed applications for major tributaries and sub-watersheds, such as may be needed for the evaluation of watershed management practices and other applications. Use of the modular approach provides a framework for model expansion for more detailed watershed characterizations. A single UCI model of the Illinois River basin may be sufficient for many applications, but this approach may lead to separate or parallel modeling efforts.
- Representation of the Illinois River basin using a single UCI approach was limited to 60 sub-watersheds and precipitation gages because the modeling process used in this study treated each pervious land-use type separately. It is possible to increase the number of sub-watersheds by reducing the number of land segment types included in the model. For many applications, the restricted number of land segments is not a limitation; however, future work in defining hydrologic response based on soil type differences and parameter regionalization likely will lead to an increase in the number of land segments.
- The single UCI approach does not create a complete model for the Illinois River basin. Anticipated links to HSPF models developed for urban northeastern Illinois, needed for a complete model, would use a modular approach.
- It would be inefficient for a modeler to analyze the effect of land-use management or other changes in a particular part of the watershed using a single UCI model of the entire basin. The single UCI model has many land segment types, which would require substantial computer time to execute multiple modeling runs, but the use of a particular module could save substantial computer time and modeling effort.

The modular approach delineates the watersheds of the seven tributaries and the MIR area individually. This approach allowed representation of all eight regions by approximately 170 sub-watersheds in addition to the 80 sub-watersheds used to model the Kankakee and Spoon River watersheds. There were from 10 to 60 sub-watersheds in any single region, and the total number of HSPF operations did not exceed the maximum limit of 500. All 95 weather stations were used. Having a large number of sub-watersheds in each tributary watershed allows the modeler to input more details about the watershed and will facilitate studying changes in a particular part of the watershed.

Hydrologic Simulations for Seven Major Tributaries of the Illinois River Basin Using the HSPF Model

Individual HSPF projects were created for the watersheds of the seven tributaries, but the model was not calibrated. Instead, calibrated parameters from the three previously calibrated watersheds were used in three different HSPF model runs for each tributary. Flow was simulated for 1970-1995, and 1972-1995 data were used during analysis of modeling results graphically. The best simulation results in every uncalibrated tributary were obtained by using calibrated parameters from the Spoon River watershed; therefore, only these results are presented in the following sections. The simulated daily streamflow time-series data from HSPF model runs at all the seven major tributaries were saved in a WDM file.

Fox River Watershed

The 2,660-sq-mi Fox River watershed is located in northern Illinois and southern Wisconsin (Figure 42). This watershed comprises two eight-digit USGS Cataloging Units: upper Fox (07120006) and lower Fox (07120007). Starting at its headwaters near Waukesha, Wisconsin, the Fox River drains 940 sq mi in Wisconsin and 1720 sq mi in Illinois before merging into the Illinois River near Ottawa, Illinois. Glacial action that formed the landscape of the Fox River and its tributaries created more than 400 lakes, many with surface areas larger than 100 acres. The Fox Chain O' Lakes in Lake County, Illinois, contains nine of these prominent lakes, with a combined surface area of 7,700 acres. The Chain O' Lakes area of the watershed is one of the top three recreational waterways in the nation. Other large lakes in Wisconsin include Lake Geneva, Muskego Lake, Lake Pewaukee, Twin Lakes, Lake Tichigan, Lake Como, and Wind Lake. In its 115-mile run through northeastern Illinois, the Fox River flows over 15 dams that range in size from a few feet high to nearly 30 feet high. Most of these dams were built around the beginning of the 20th Century and were used mainly for power-generating plants. Some dams were built by the first settlers in the area to run private grain and lumber mills.

Agriculture, the dominant land use in the Fox River watershed, covers 93 percent of its area. Other land uses include urban area (4 percent), forest (2 percent), and lakes/reservoirs (0.5 percent). Soils of hydrologic groups B and B/D cover 69 percent area, and group C covers 31 percent area of this watershed. Many of the group B soils in the upper Fox watershed are underlain by sandy sub-strata and thus provide a considerable sub-surface component to streamflow. As shown in Figure 55 and Table 4, 14 local weather stations and 5 USEPA-WDM stations were located in or near this watershed. Daily precipitation data for local stations were converted into hourly data using reference WDM and additional NOAA hourly weather stations, as listed in the last column of Table 4. As shown in Figure 56, the watershed was divided into 15 sub-watersheds. Simulated streamflow was compared with the observed data at the USGS gaging station (05552500) at Dayton, Illinois (Table A1), which is situated very near the outlet of this watershed. Meteorological data from ten local weather stations and one USEPA-WDM weather station were used as model input.

Modeled streamflows using Spoon River parameters were compared with observed USGS gage flows on a daily, monthly, and annual basis, and results are shown (Table 18). Figures 57 and 58 compare observed flows with simulated flows obtained from model runs using Spoon River watershed parameters. The model underestimated or overestimated some high flows

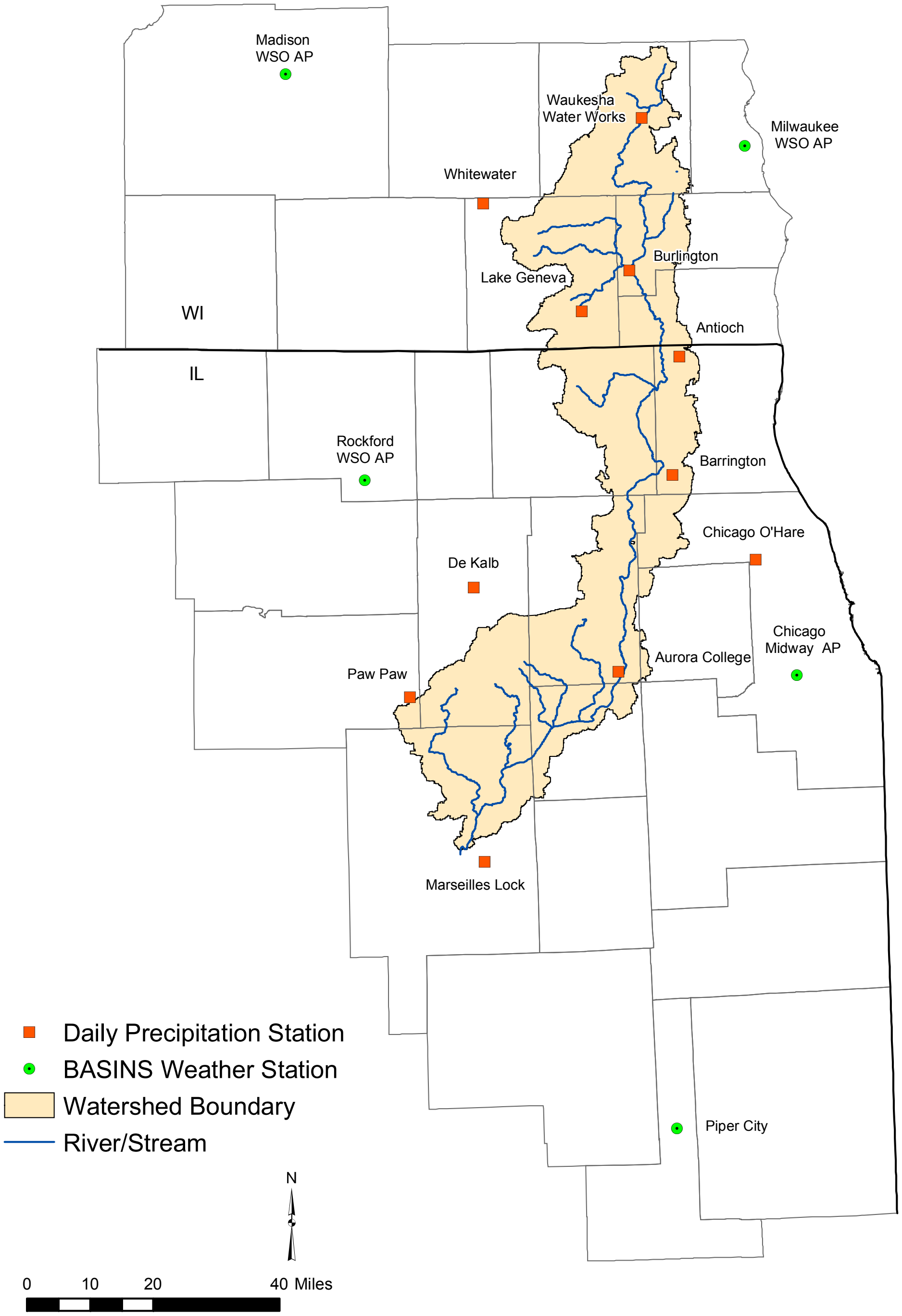


Figure 55. The USEPA-WDM weather stations and local precipitation stations in the Fox River watershed.

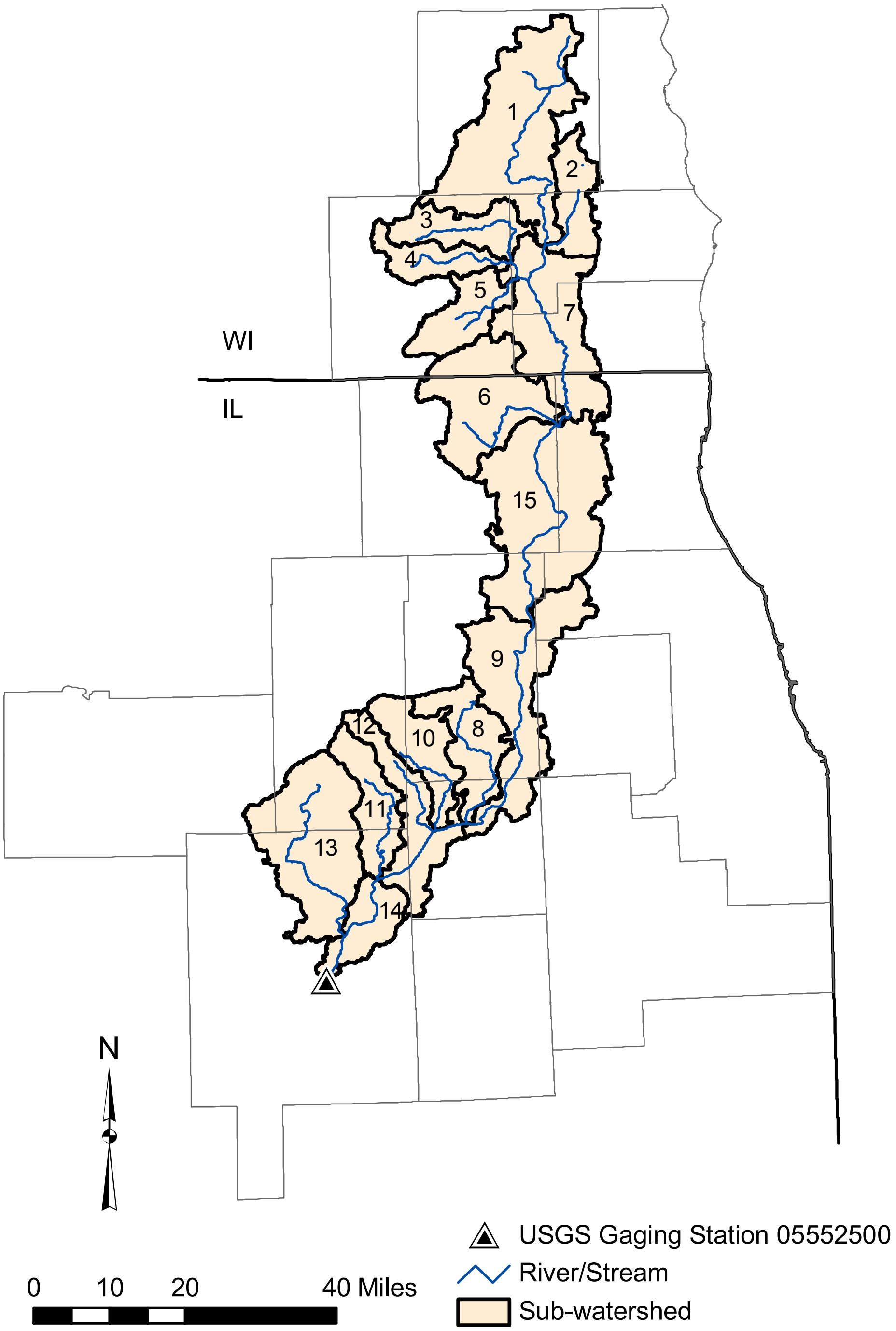


Figure 56. The 15 sub-watersheds of the Fox River watershed after delineation.

Table 18. Observed and Simulated Daily, Average Monthly, and Average Annual Streamflow Data for Watersheds of Six Major Tributaries of Illinois River

Watershed	*NSE*	*R^2*	*Slope*	*Intercept*
Daily (1972-1995)				
Fox	0.32	0.63	1.10	-334
Vermilion	0.74	0.76	0.67	186
Mackinaw	0.70	0.71	0.65	178
Sangamon	0.52	0.68	1.10	29
LaMoine	0.72	0.72	0.79	198
Macoupin	0.75	0.76	0.81	205
Average monthly (1972-1995)				
Fox	0.73	0.78	0.95	-65
Vermilion	0.84	0.89	0.74	115
Mackinaw	0.82	0.84	0.73	123
Sangamon	0.87	0.88	0.97	236
LaMoine	0.89	0.89	0.86	120
Macoupin	0.84	0.86	0.94	129
Average annual (1972-1995)				
Fox	0.80	0.89	0.82	245
Vermilion	0.69	0.87	0.69	162
Mackinaw	0.84	0.90	0.72	131
Sangamon	0.93	0.94	0.96	274
LaMoine	0.92	0.92	0.88	101
Macoupin	0.85	0.94	0.99	97

Note:
Simulated streamflow data were generated using calibrated model parameters from Spoon River watershed.

(Figure 57), resulting in a low R^2 (0.63) and NSE (0.32), but a slope of best-fit line close to one (1.06). Average monthly flows show fair correlation, and annual flows mostly are underestimated (Figure 58). As seen in Figure 58c, average annual flows were underestimated for 19 years (1-18 percent range) and overestimated for 5 years (3-10 percent range). The comparatively poor performance of the HSPF model using the Spoon River watershed parameters for the Fox River watershed may be due to diverse physiographic characteristics of the Fox River watershed, improper storage routing of most of the lakes, particularly the Chain O' Lakes, misrepresentation of considerable sub-surface storage in the soils, and incomplete modeling of the rapidly urbanizing areas of the watershed. More accurate and detailed future modeling of the watershed should take these sources of improvement into account.

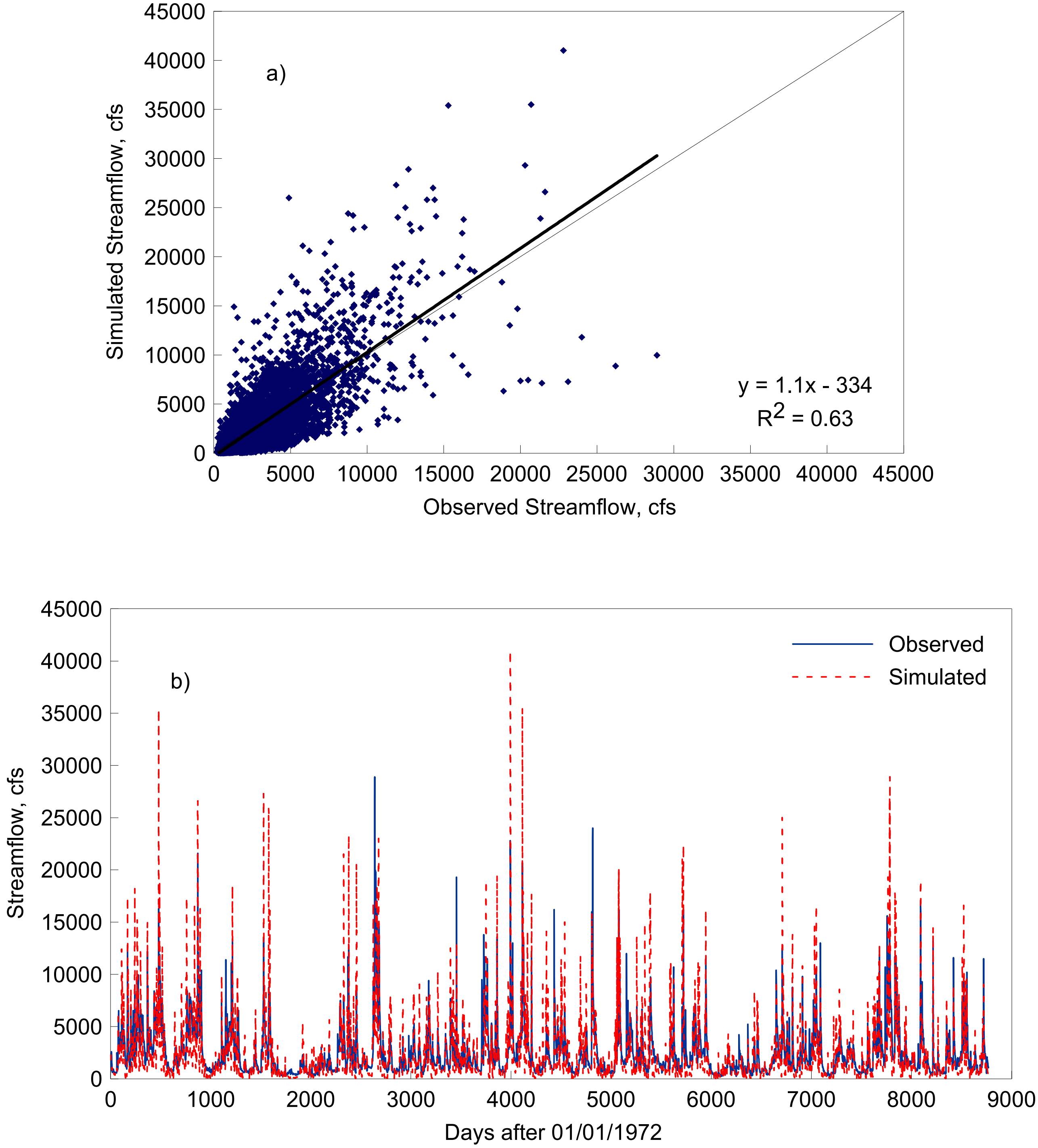


Figure 57. Daily observed and simulated streamflows at USGS gaging station 05552500 in the Fox River watershed, 1972-1995: a) scatter plot and b) time series. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

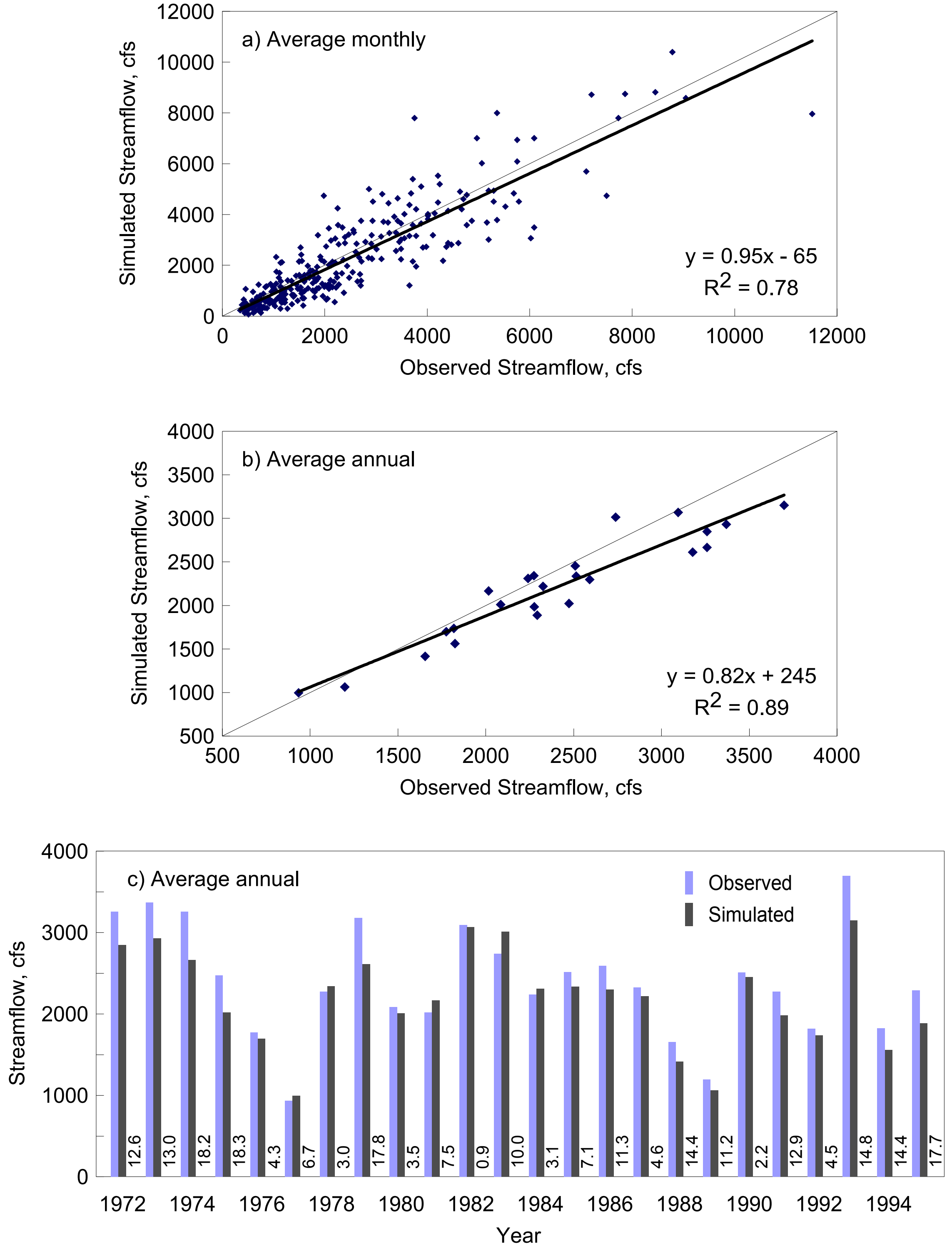


Figure 58. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Fox River watershed at Dayton, 1972-1995 calibration period. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

Vermilion River Watershed

The Vermilion River watershed (eight-digit USGS Cataloging Unit 07130002) is located in east-central Illinois and covers a 1330-sq-mi area. The Vermilion River merges with the Illinois River near Oglesby (LaSalle County, Illinois). Most of the land in this watershed is agricultural (99 percent), as shown in Figure 44. Forests and urban lands share the remaining area. Group C soils cover 70 percent of the drainage area, group B (16 percent), and groups B/D (12.5 percent) as shown (Figure 45). Hourly meteorological time-series data from five local stations and one USEPA-WDM station at Piper City, Illinois (Figure 59) were used as model input. The 11 sub-watersheds obtained by automatic delineation of the Vermilion River watershed are shown (Figure 60). The USGS gaging station 05555300 on the Vermilion River near Leonore drains nearly 1251 sq mi and is closest to the watershed outlet (Figure 60 and Table A1). Model-simulated streamflow data at an outlet corresponding to this gage were compared with observed data from this gage to evaluate model performance for this watershed. Simulated daily streamflow time-series data at the watershed outlet also were saved in a WDM file and later used as input for the MIR watershed hydrologic simulations.

Model performance results using calibrated parameters of the Spoon River watershed study are given (Table 18, and Figures 61 and 62) for daily, average monthly, and average annual data. The NSE values were 0.74, 0.84, and 0.69, respectively, and the R^2 values were 0.76, 0.89, and 0.87, respectively, for those three time scales. The model mostly underestimated the daily, monthly, and annual streamflows. This may be because this watershed has predominantly group C soils (70 percent area), which are noticeably less permeable than much of the remainder of the Illinois River basin. For the 24-year simulation period, the model underestimated average annual flows for 17 years (5-39 percent range) and overestimated average annual flows for 7 years (0.7-12 percent range). Overall model performance on this watershed was better than that for the Fox River watershed.

Mackinaw River Watershed

The Mackinaw River watershed (eight-digit USGS Cataloging Unit 07130004) is located south of Vermilion River watershed in east-central Illinois and drains a 1160-sq-mi area. The 130-mile long Mackinaw River originates near Sibley (Ford County, Illinois) and runs west before it merges with the Illinois River near Mapleton (Peoria County, Illinois). About 98 percent of the watershed area is agricultural land (Figure 44). Other land uses, such as urban, forest, and reservoir/water cover 0.8 percent, 0.7 percent, and 0.3 percent of watershed area, respectively. Soil groups B and B/D cover 67 percent area, group C covers 23 percent, and group D covers 9 percent area (Figure 45). Of the five local and two USEPA-WDM weather stations available for this watershed (Figure 63), hourly meteorological time-series data from the five local stations and the USEPA-WDM station at Peoria (WSO AP, IL) were used as model input.

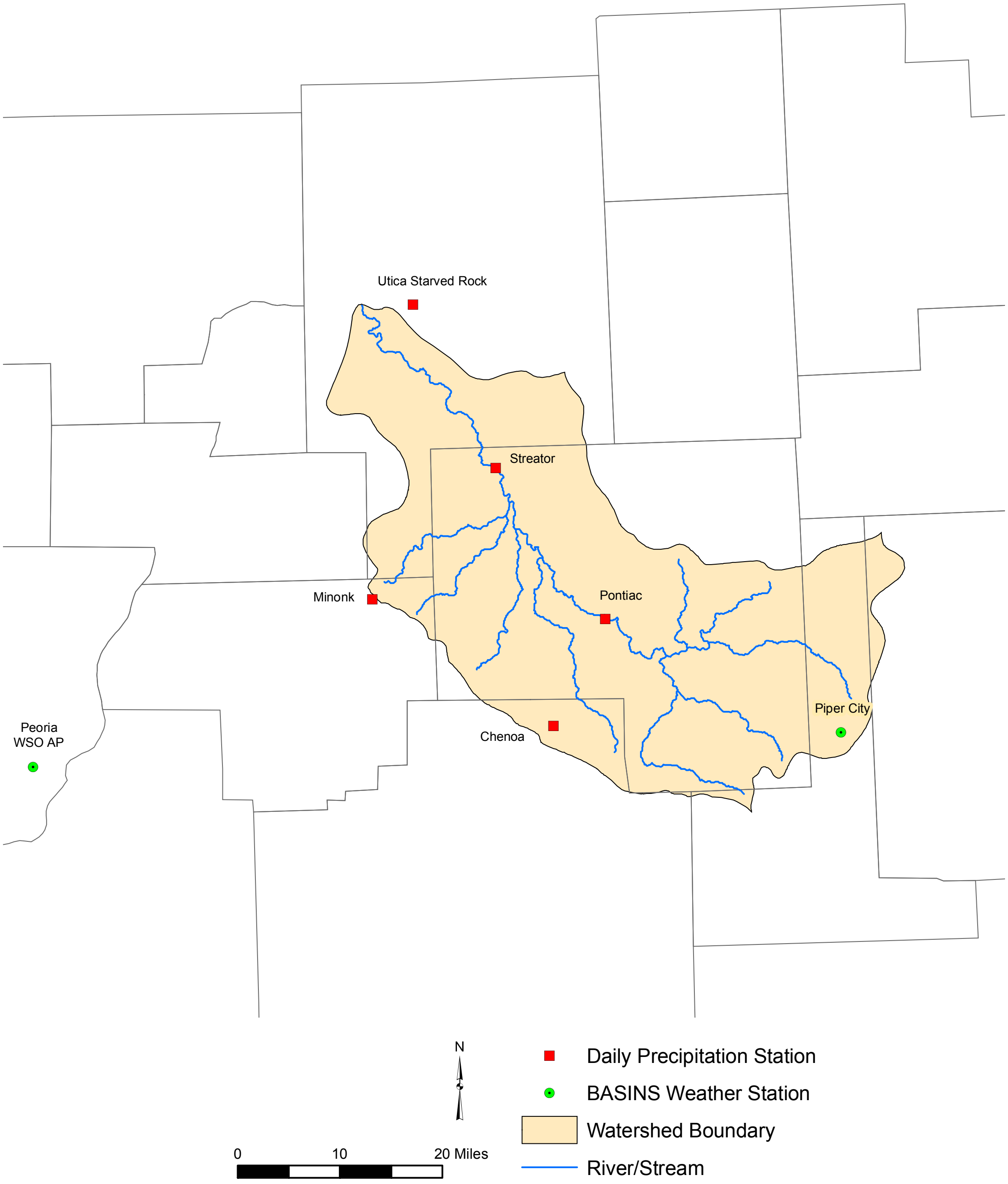


Figure 59. The USEPA-WDM weather stations and local precipitation stations of the Vermilion River watershed.

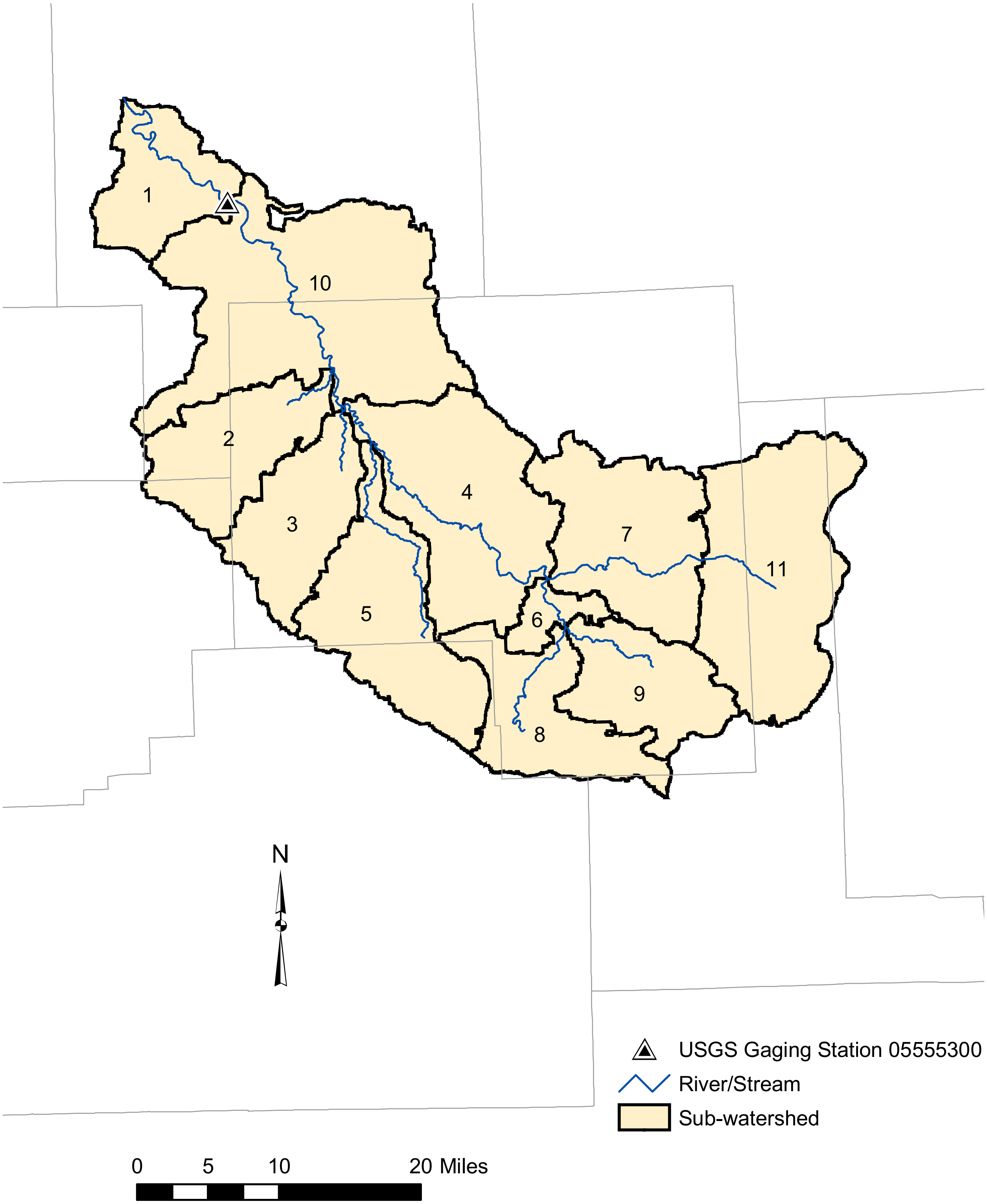
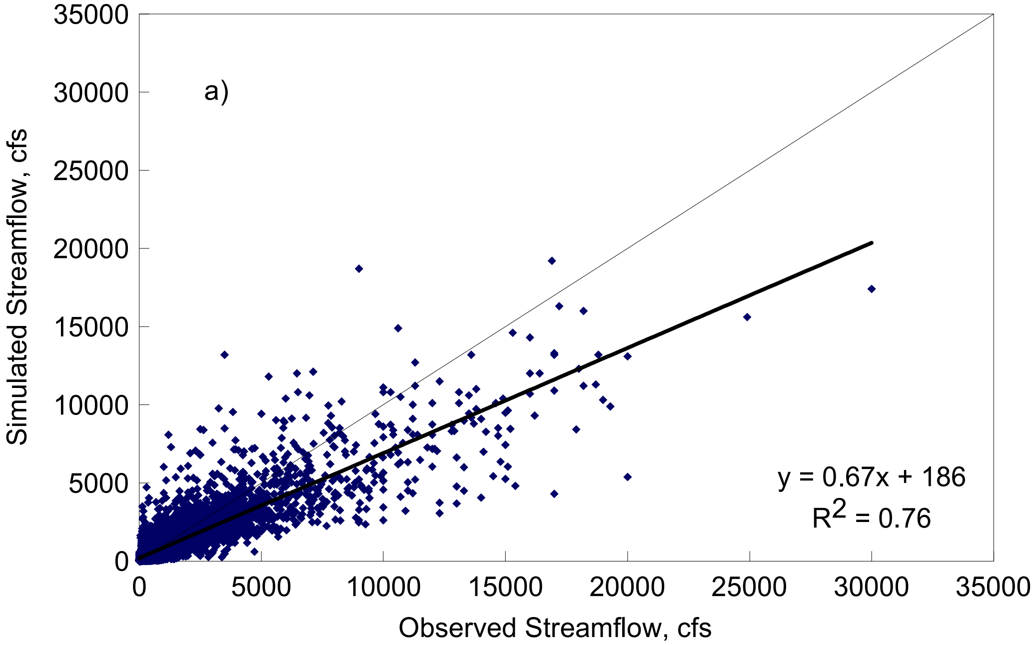


Figure 60. The 11 sub-watersheds of the Vermilion River watershed after delineation.



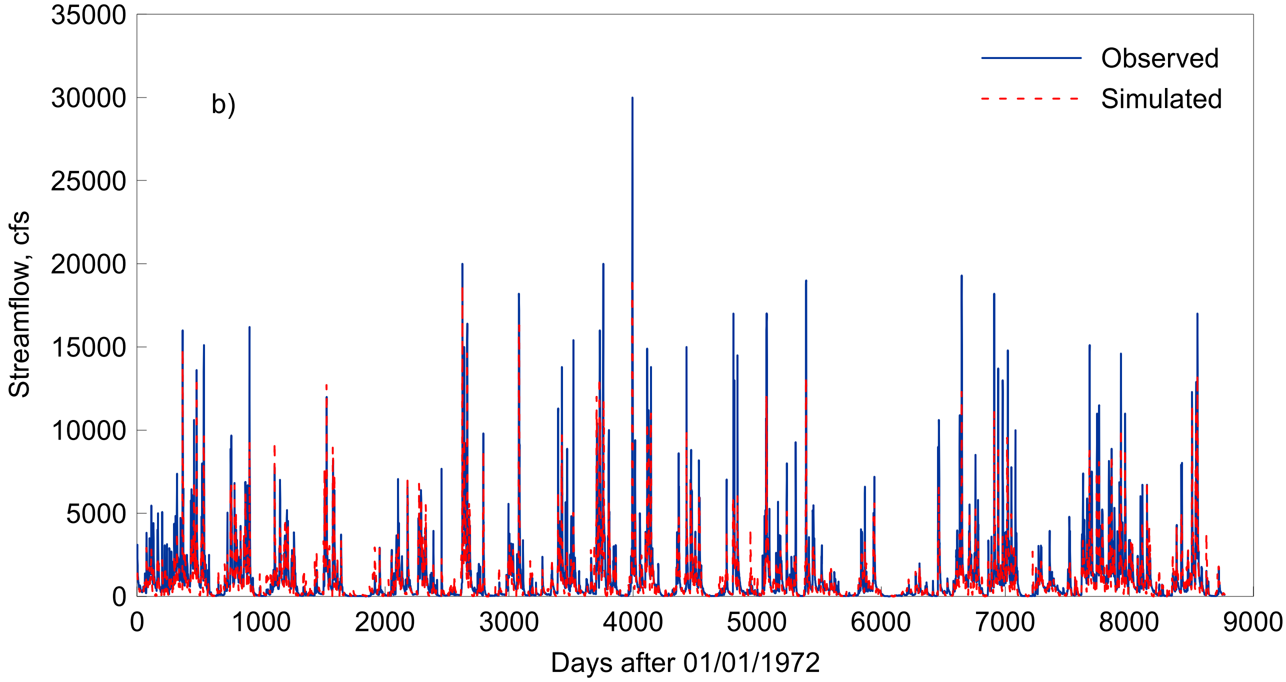


Figure 61. Daily observed and simulated streamflows at USGS gaging station 05555300 in the Vermilion River watershed, 1972-1995: a) scatter plot and b) time series. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

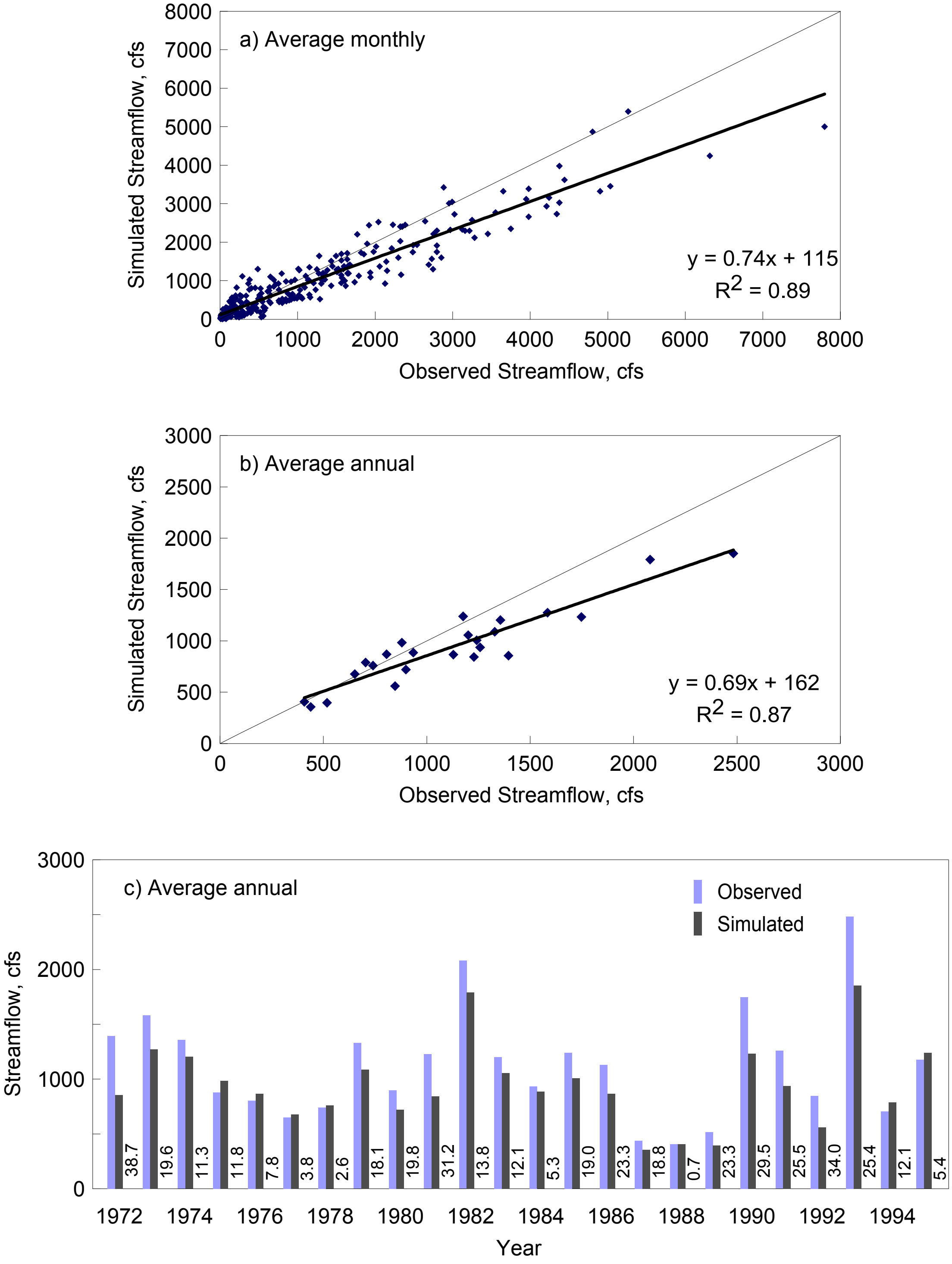


Figure 62. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed streamflows, Vermilion River watershed near Leonore, 1972-1995 calibration period. The HSPF-simulated streamflows are based on calibrated parameter set for the Spoon River watershed.

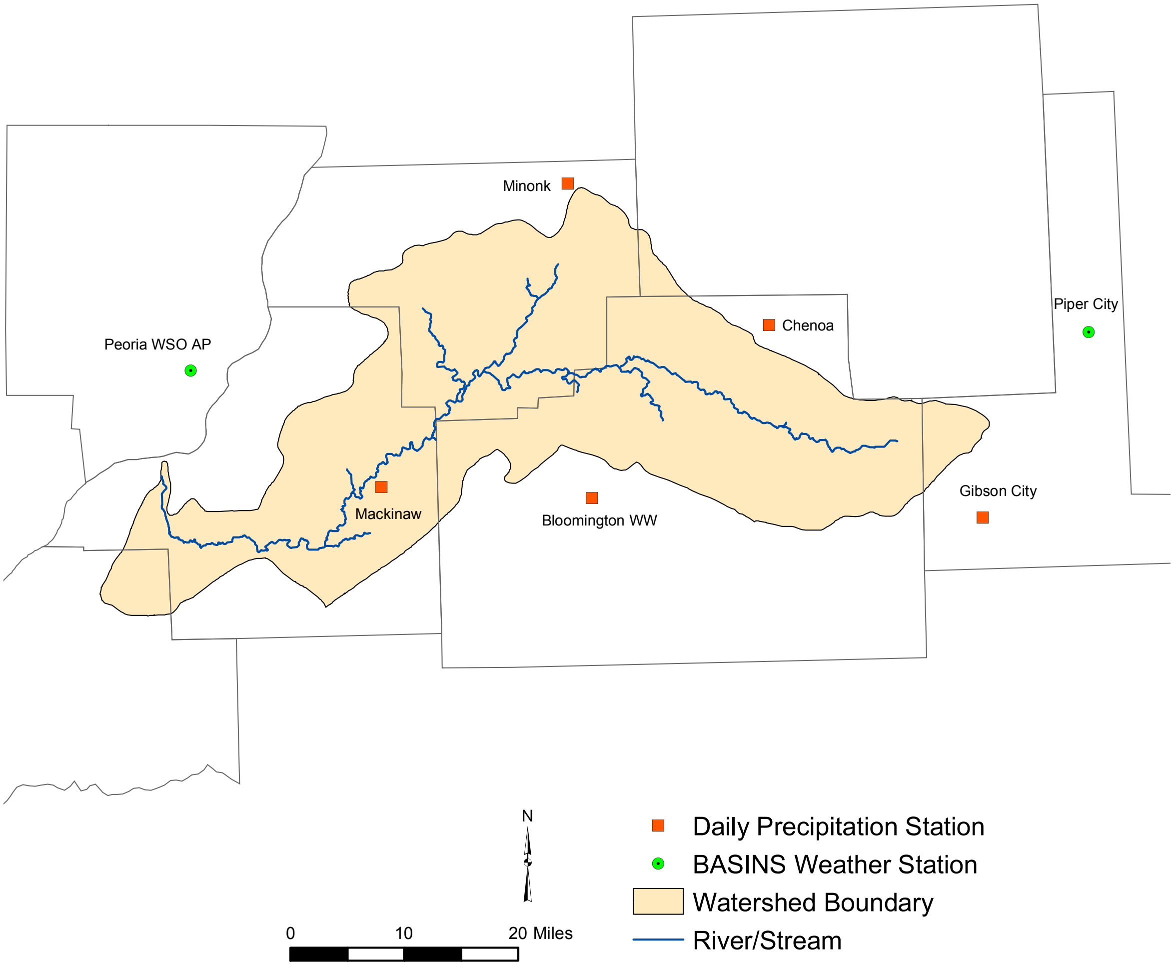


Figure 63. The USEPA-WDM weather stations and local precipitation stations in the Mackinaw River watershed.

The watershed was divided into 20 sub-watersheds, and outlets specified in the model project corresponded to USGS gaging station 05567500 at the Mackinaw River near Congerville, Illinois (Figure 64), and the main watershed outlet. Simulated daily streamflow time-series data at the watershed outlet were saved in a WDM file that later was used as input for the MIR watershed hydrologic simulations.

Table 18 presents model performance evaluation statistics that were computed based on simulated and observed streamflow at USGS gaging station 05567500. Figures 65 and 66 compare simulated and observed streamflows for 1972-1995. The NSE values were 0.70, 0.82, and 0.84, respectively, and the R^2 values were 0.71, 0.84, and 0.90, respectively, for daily, average monthly, and average annual data. The model mostly underestimated daily, monthly, and annual streamflows. For the 24-year simulation period, the model underestimated, average annual flows for 14 years (2.5-29 percent range) and overestimated for 10 years (2-147 percent range). The percentage difference between observed and simulated average annual flows was less than 10 percent for 7 of the 10 years. The overall results are very similar to those for the Vermilion River watershed, and better results may be obtained through calibration with data for the less permeable soils within these two watersheds.

Sangamon River Watershed

The Sangamon River basin in central Illinois is the largest tributary to the Illinois River basin. It has an area of 5,420 sq mi and a length of 206 miles. Salt Creek and South Fork are the largest tributaries to the Sangamon River. This watershed is comprised of four different eight-digit USGS Cataloging Units: upper Sangamon (07130006), South Fork Sangamon (07130007), the lower Sangamon (07130008), and Salt Creek (07130009). Most of this watershed is in agriculture land (96 percent), as shown in Figure 44. Other land uses such as urban/commercial, forest, reservoir/water, and wetlands cover 1.9 percent, 1.3 percent, 0.3 percent, and 0.3 percent of watershed area, respectively. Group C soils cover 39 percent drainage area, followed by group B soils (28 percent) and B/D soils (26 percent), shown in Figure 45. There are several large reservoirs, including Clinton Lake, Lake Taylorville, Sangchris Lake, and Lake Springfield. Lake Decatur, although not as large, is an important water-supply lake in the watershed and has a considerable effect on low flows in the Sangamon River.

As shown in Figure 67 and Table 4, 6 WDM stations and 19 local daily precipitation gages are located in or near this watershed. Daily precipitation data from the local stations was disaggregated into hourly data using the six WDM stations and the additional nearby NOAA hourly weather stations shown in Figure 2. The last column of Table 4 lists the stations used to disaggregate each of the 19 local stations. The meteorological time-series data from these 19 local stations and the USEPA-WDM station at Springfield were used as model input. The watershed was divided into 19 sub-watersheds using the BASINS automatic delineation tool (Figure 68). Model results were evaluated using the USGS gaging station (05583000) on the Sangamon River near Oakford, Illinois (Table A1), near the confluence of the Illinois River.

As with the other watershed models, three sets of calibrated parameters from the upper Kankakee, Iroquois, and Spoon River watersheds were used to run the HSPF model. The simulated streamflow from each run was compared with the observed streamflow at USGS

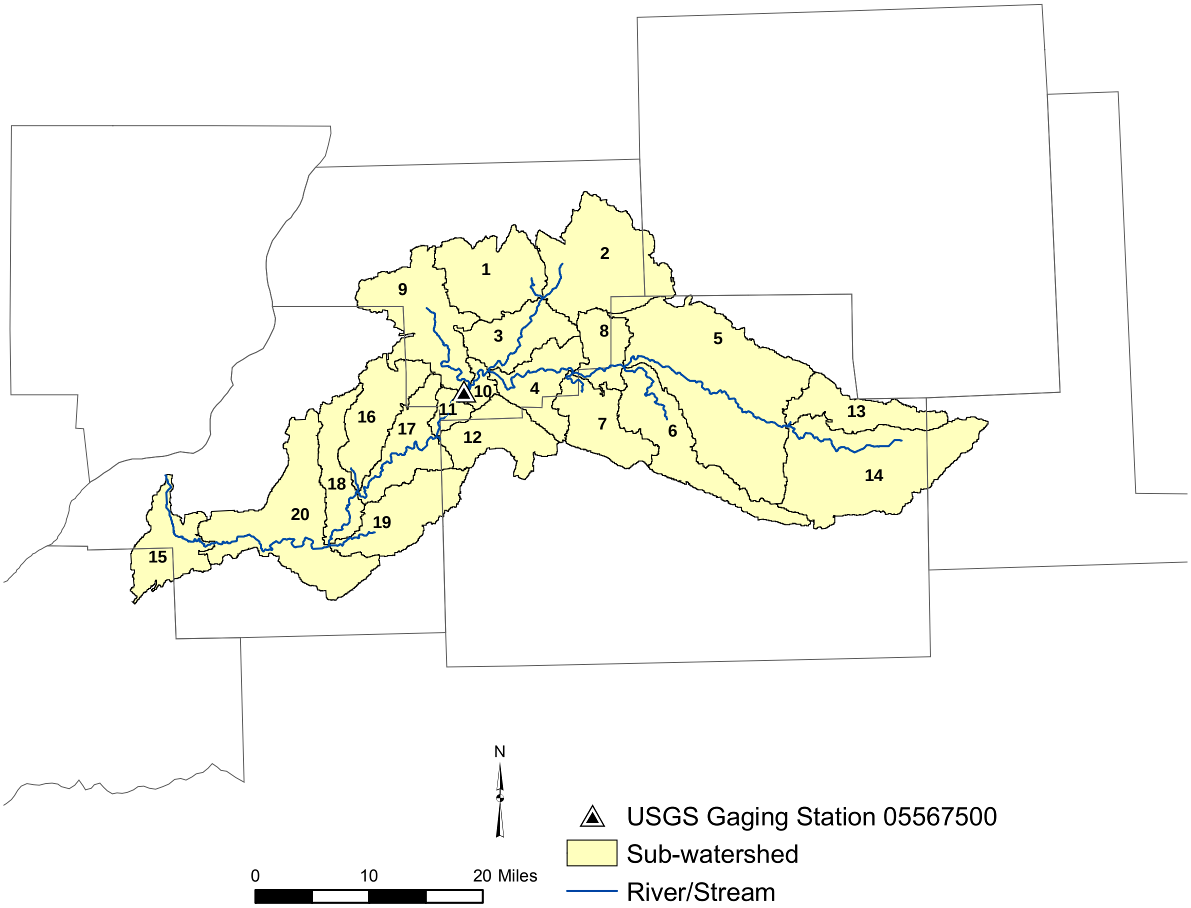


Figure 64. The 20 sub-watersheds of the Mackinaw River watershed after delineation.

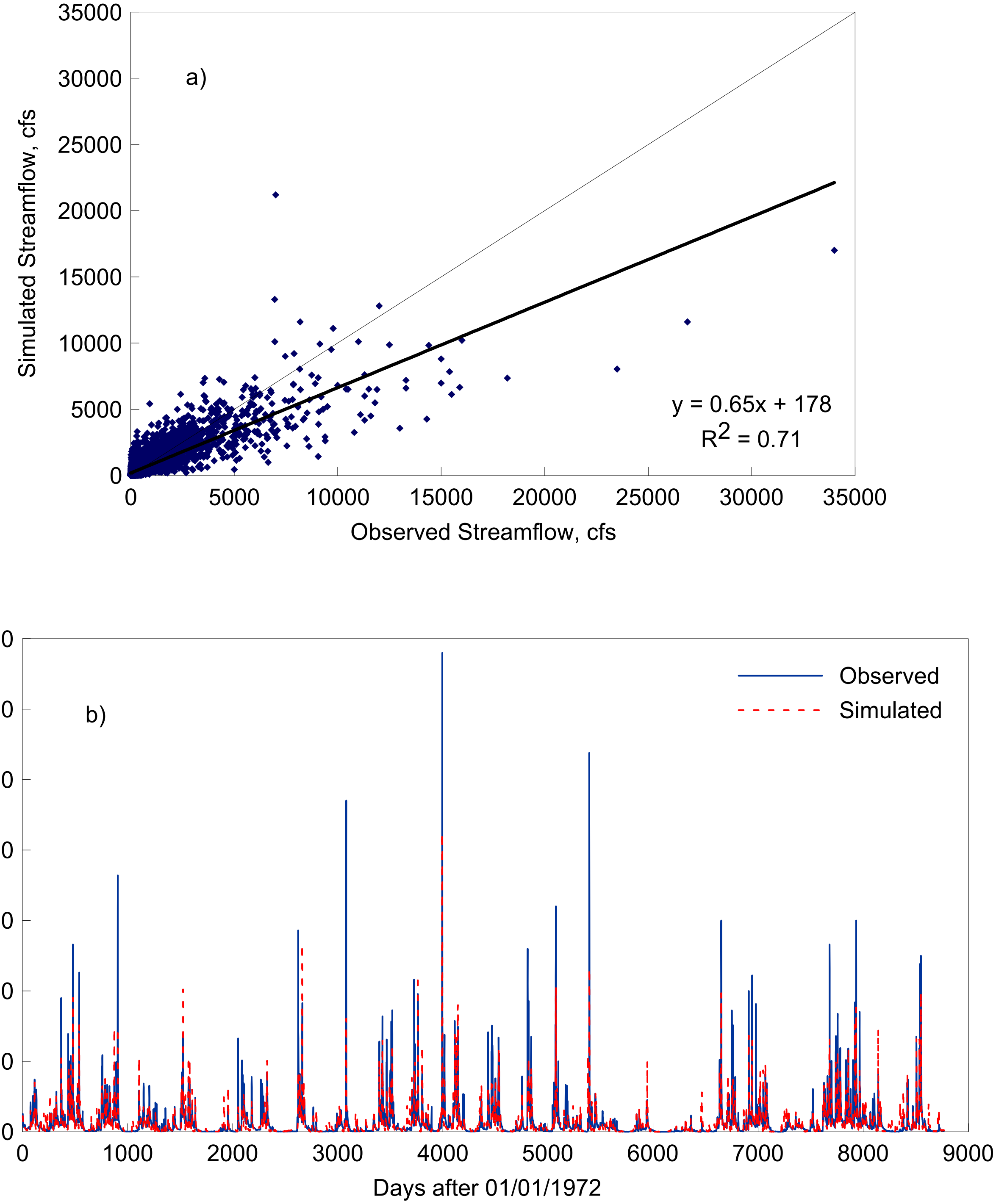


Figure 65. Daily observed and simulated streamflows at USGS gaging station 05567500 in the Mackinaw River watershed, 1972-1995: a) scatter plot and b) time series. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

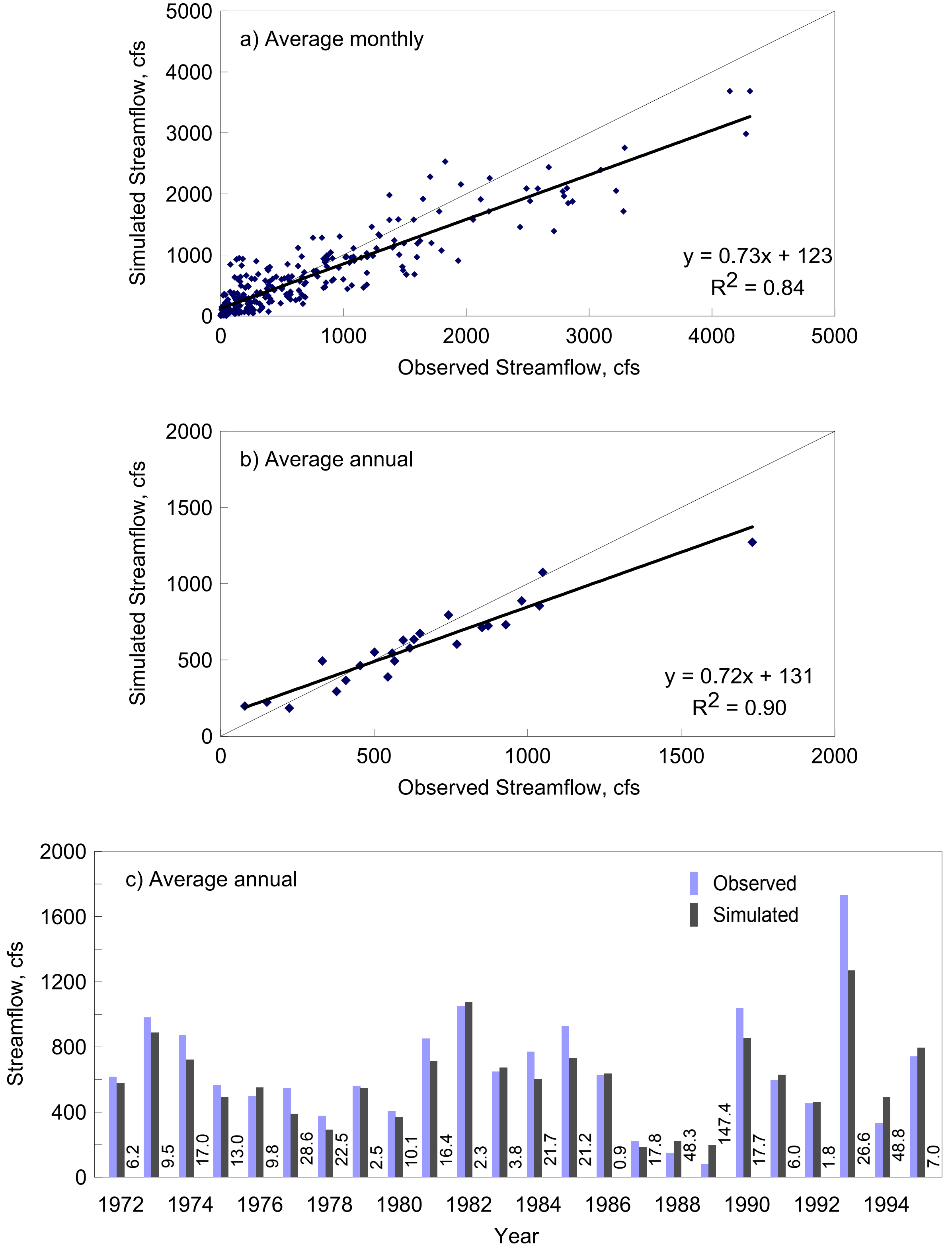


Figure 66. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Mackinaw River watershed near Congerville, 1972-1995 calibration period. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

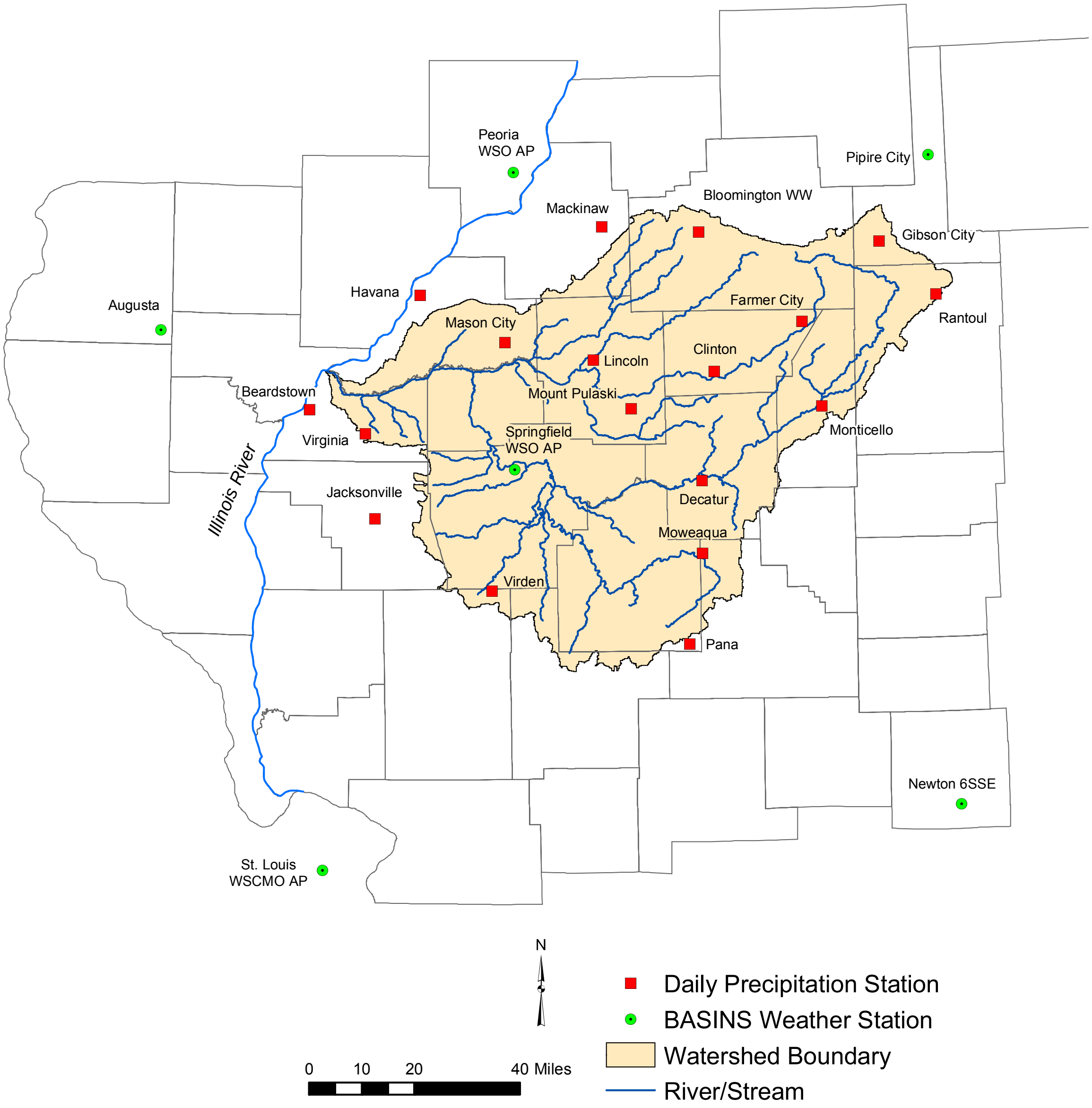


Figure 67. The USEPA-WDM weather stations and local precipitation stations in the Sangamon River watershed.

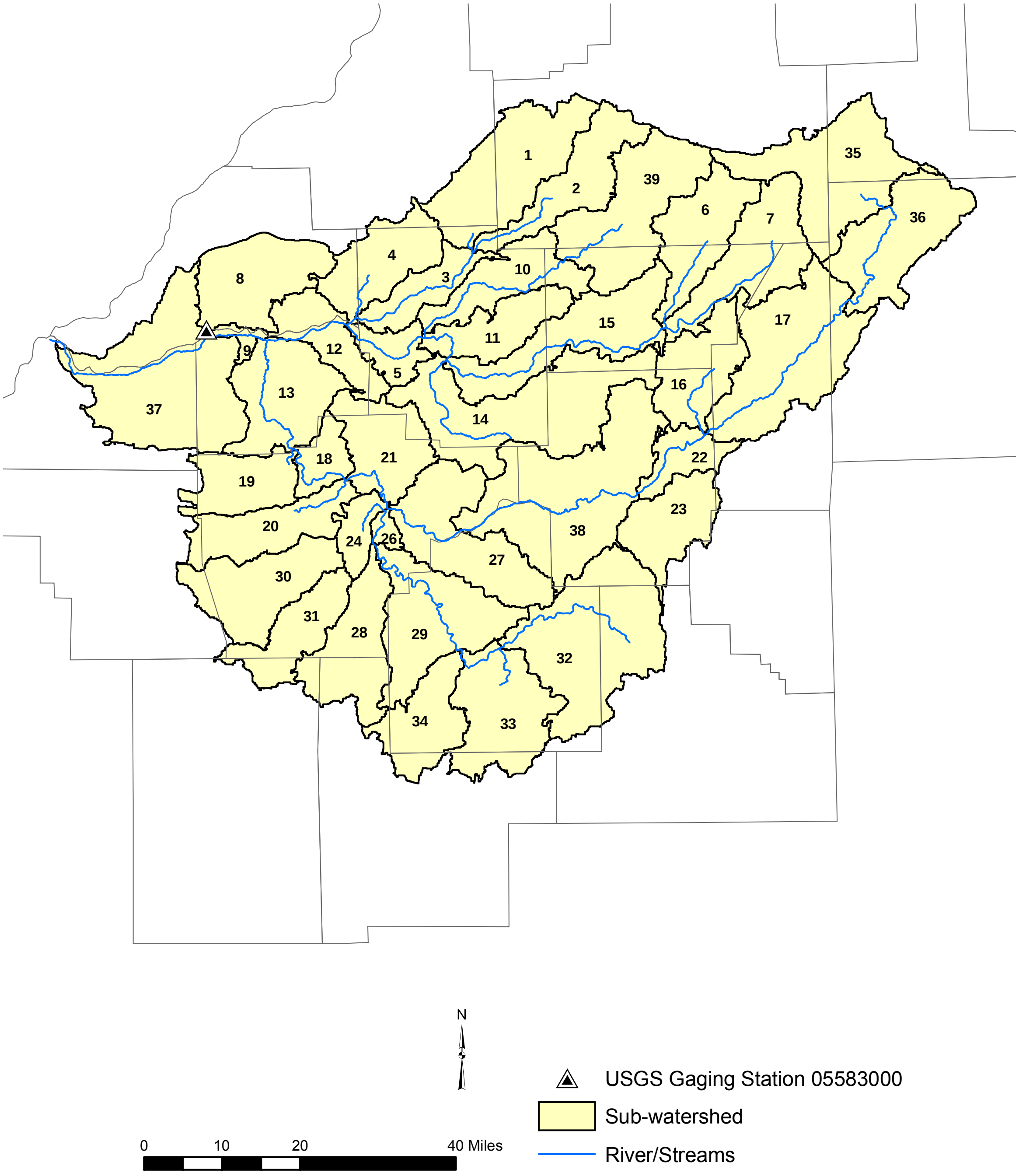


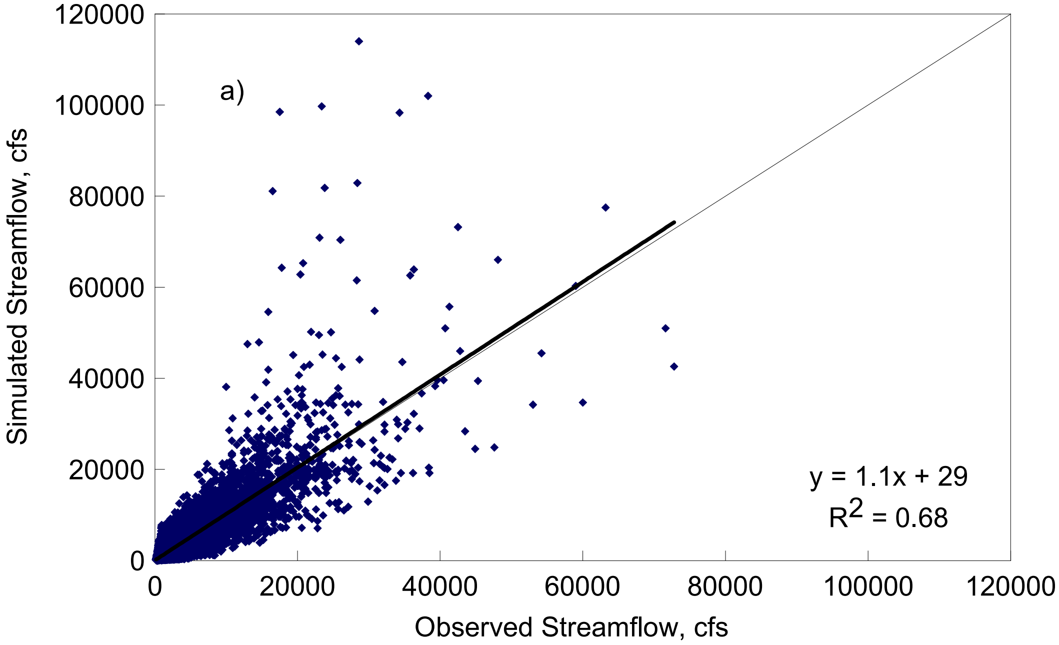
Figure 68. The 38 sub-watersheds of the Sangamon River watershed after delineation.

gaging station 05583000. The Spoon River watershed parameters gave the best results, which are summarized in Table 18 for daily, monthly, and annual mean simulated flows. Figures 69 and 70 compare observed flows and simulated flows obtained from model runs using the Spoon River watershed parameters. As seen in Figure 69, the model overestimated many of the high peaks. The R^2 is 0.68, the slope is 1.1 and the intercept is 29 for daily simulated flows, with an NSE of 0.52, indicating that the simulated results are reasonable but not as good as for many of the other uncalibrated sub-watersheds. On the other hand, the results for the monthly and annual simulated flows are good (Figure 70), particularly the simulated annual mean flows, which result in an NSE of 0.93. As seen in Figure 70a, the average annual flows were overestimated for 14 of the 24 years, underestimated for 10 years, and show a very good regression fit (Figure 70b). Model performance for this watershed can be improved by taking into account the storage and operation of large reservoirs in the watershed and their impacts on low and high flows. Because the Mason County portion of the watershed is underlain by well-drained, highly permeable soils, using parameters similar to those for the Kankakee River watershed for this part of the watershed probably would result in better hydrologic simulation of this particular sub-region.

La Moine River Watershed

The La Moine River basin (eight-digit USGS Cataloging Unit 07130010) has an area of 1,350 sq mi in west-central Illinois. Agriculture, the dominant land use in this tributary watershed, covers 96 percent of the area. Other land uses include urban (0.5 percent) and forest (3.2 percent). Soils of hydrologic groups B and B/D cover 90 percent and group D covers 9.5 percent of this watershed. Figure 71 shows the eight local daily precipitation gages and the USEPA-WDM station at Augusta in or near this watershed that were used as model input. The last column of Table 4 lists the WDM and the NOAA hourly stations used to disaggregate the daily records of the eight local stations into hourly time-series data. The streamgage closest to the watershed outlet is USGS gaging station (05585000) at Ripley (Table A1), which was used to evaluate model results. In this case, the watershed was divided into 11 sub-watersheds (Figure 72).

As in the previous watersheds, simulated flows obtained from the HSPF model runs using the Spoon River watershed parameters were closer to the observed flows than those obtained using the other two sets of parameters. Figures 73 and 74 compare observed flows and simulated flows obtained from model runs using Spoon River watershed parameters, and the results are summarized (Table 18). It can be observed from this table that the daily, average monthly, and average annual results obtained for the La Moine River basin are the best among the different uncalibrated watersheds. This is not surprising considering the proximity between the Spoon and the La Moine River basins and their similar soil types and physiography. Figure 73 displays the regression and the time-series plots for simulated and observed daily flows, which show good results as reflected in the values of R^2 (0.72), slope (0.79), and intercept (198) of the regression line. In general, the underprediction of daily flows may be due to the model's poor representation of channel flow characteristics that may have affected flow routing. Although the statistics for the mean annual flows are good, Figure 74c displays some important discrepancies that range from more than 20 percent and up to 48 percent for six years.



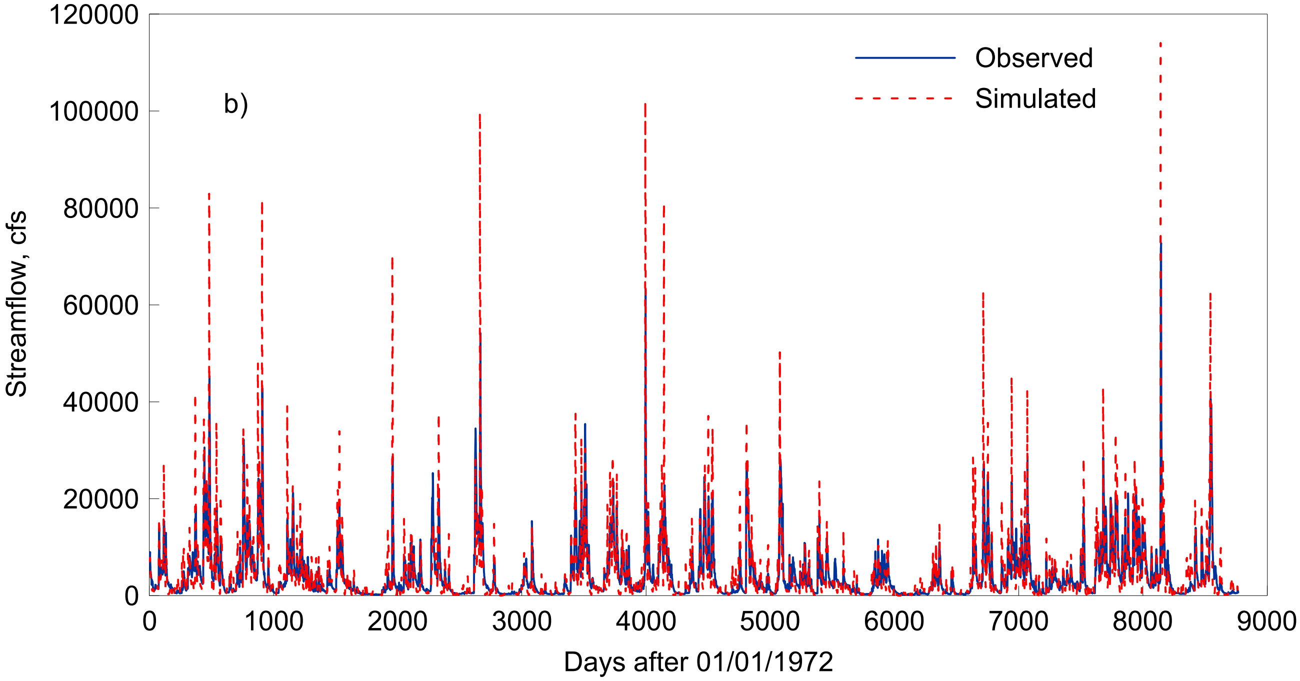


Figure 69. Daily observed and simulated streamflows at USGS gaging station 05583000 in the Sangamon River watershed, 1972-1995: a) scatter plot and b) time series. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

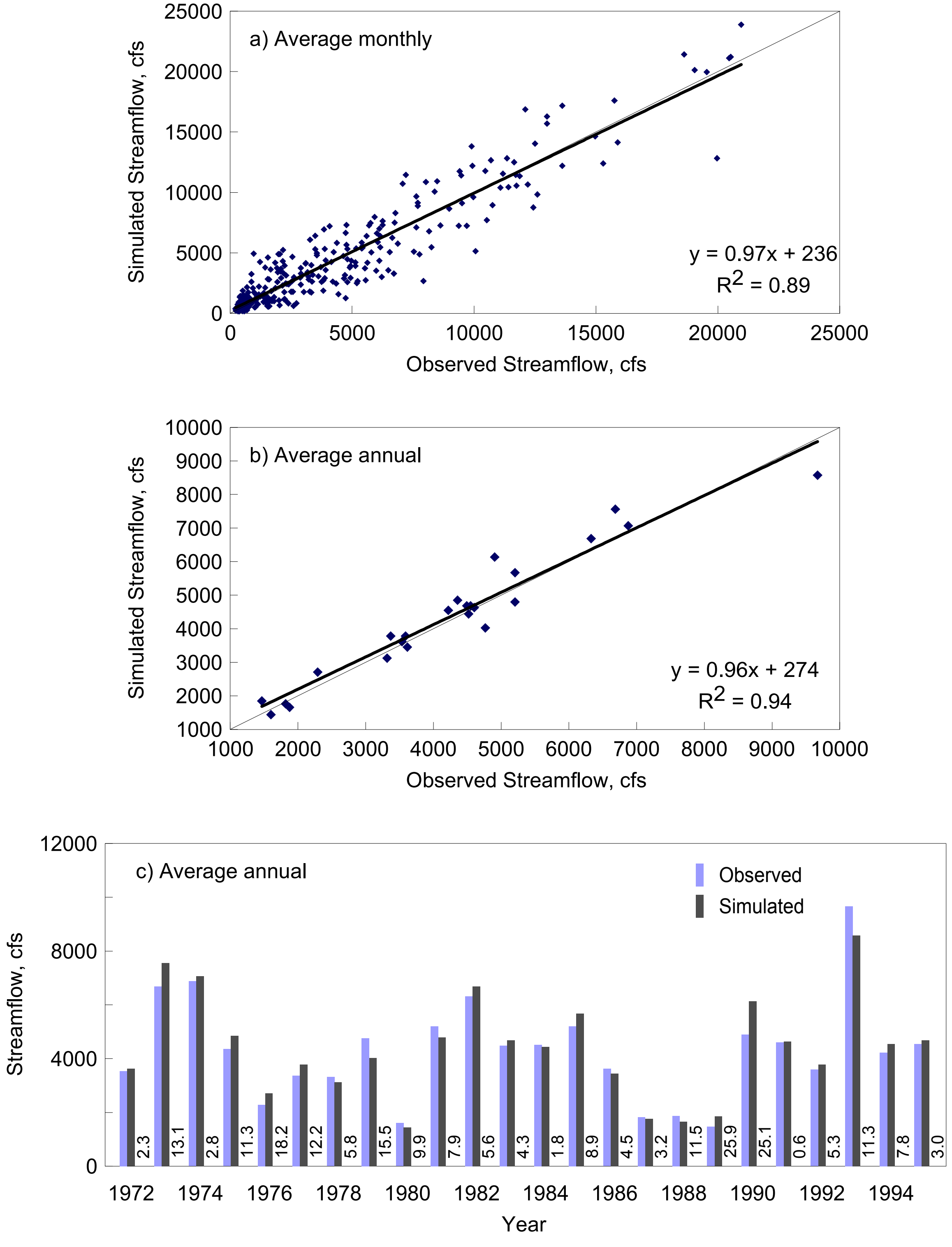


Figure 70. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of annual observed and simulated streamflows, Sangamon River watershed near Oakford, 1972-1995 calibration period. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

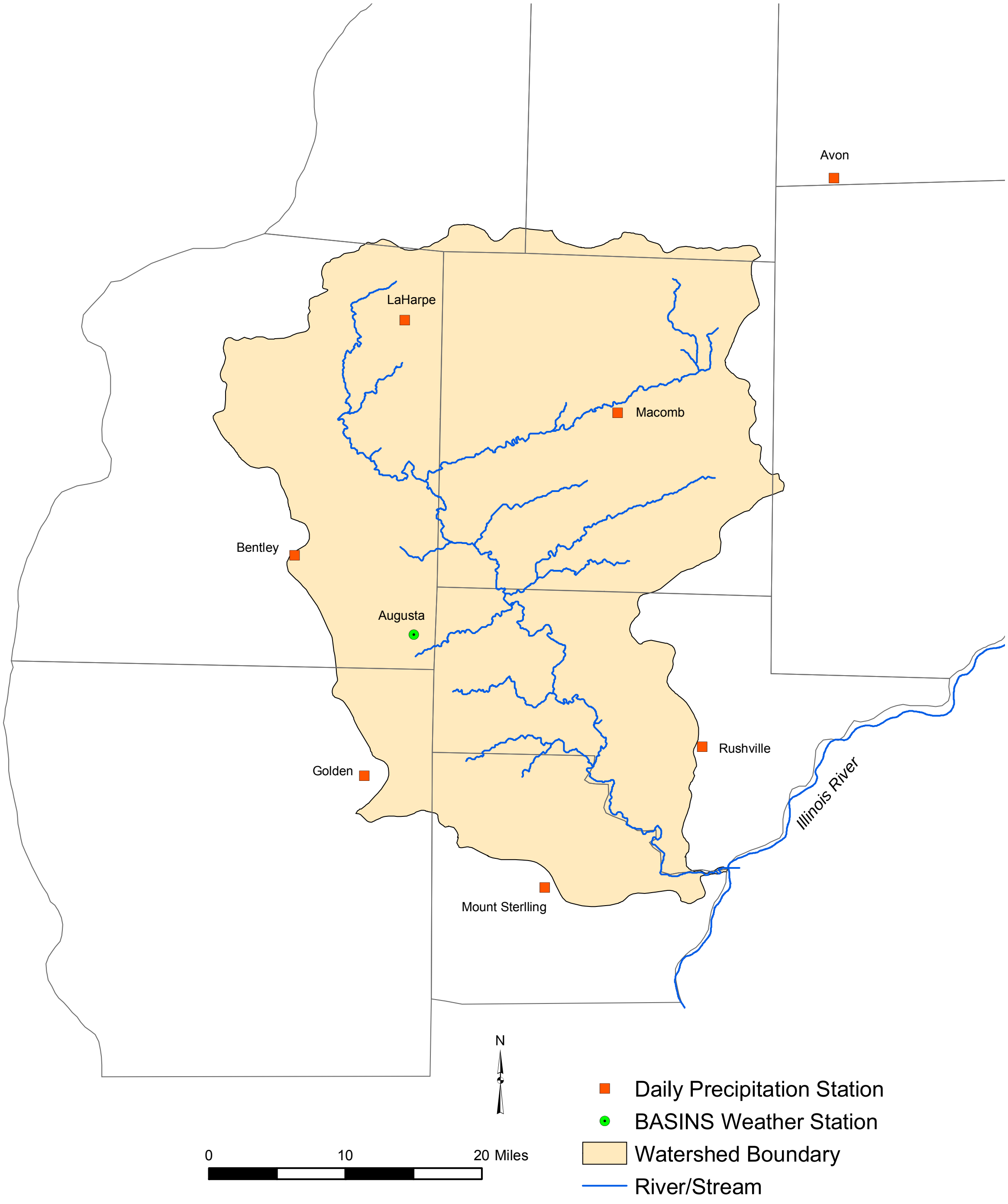


Figure 71. The USEPA-WDM weather stations and local precipitation stations in the La Moine River watershed.

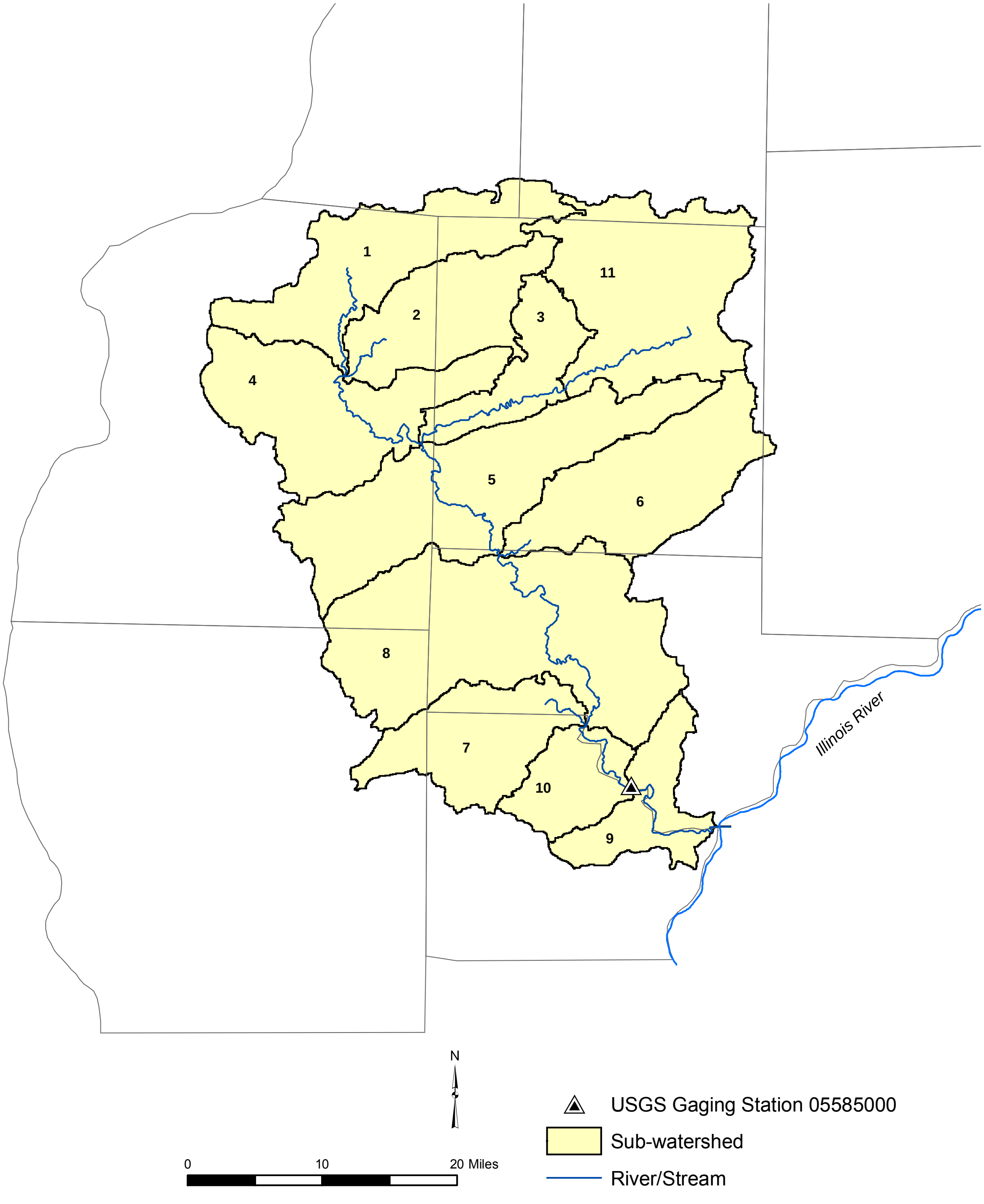


Figure 72. The 11 sub-watersheds of the La Moine River watershed after delineation.

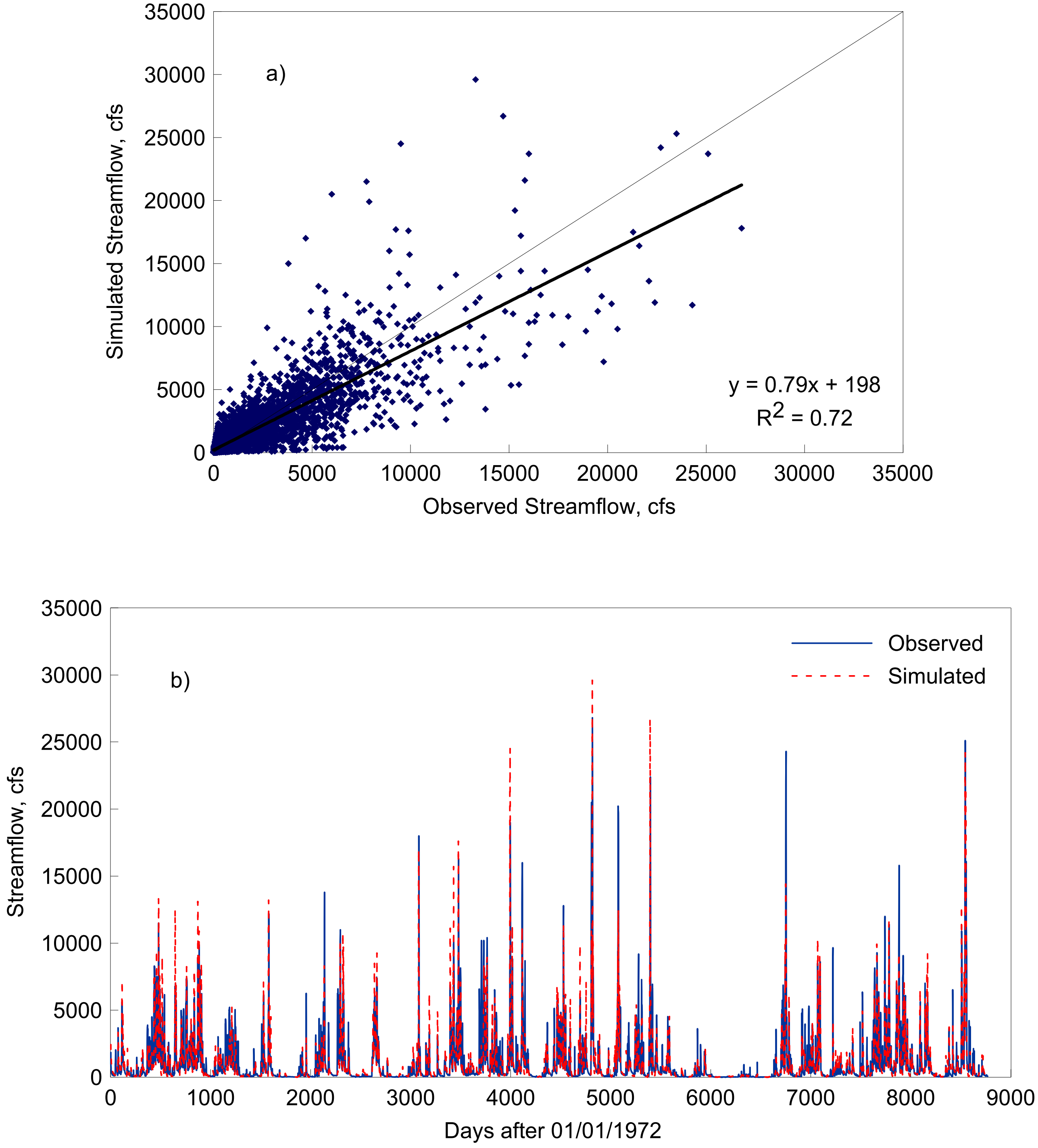


Figure 73. Daily observed and simulated streamflows at USGS gaging station 05585000 in the La Moine River watershed, 1972-1995: a) scatter plot and b) time series. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

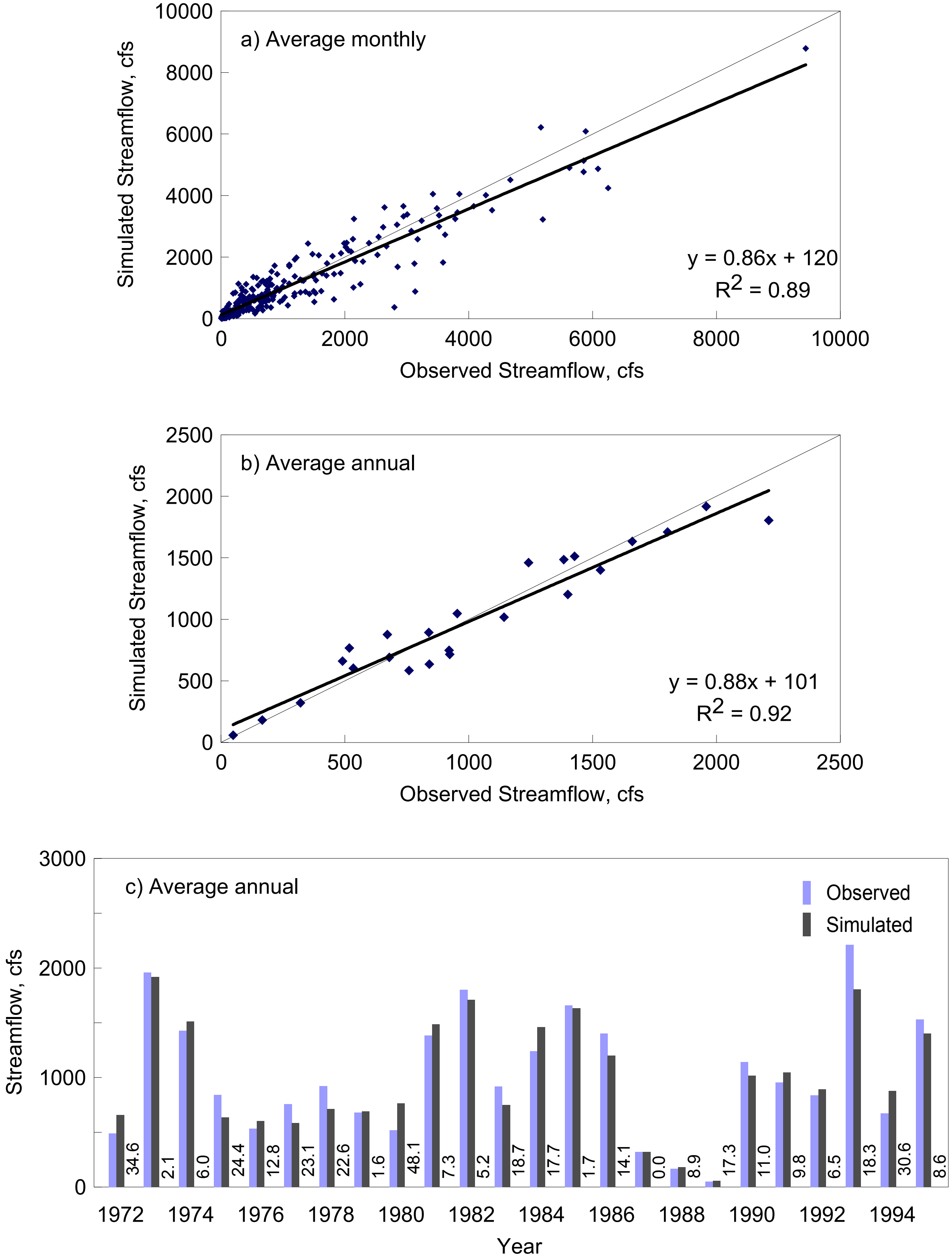


Figure 74. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of annual observed and simulated streamflows, La Moine River watershed at Ripley, 1972-1995 calibration period. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

Macoupin Creek Watershed

The Macoupin Creek watershed (eight-digit USGS Cataloging Unit 07130012) located in southern Illinois is very close to the confluence of the Illinois River with the Mississippi River. It has an area of 1,040 sq mi and is the smallest tributary watershed modeled in this study. This watershed, along with the watershed of the South Fork Sangamon River, falls within the physiographic region called the Springfield Plain, which has a different topographic character than much of the Illinois River basin. About 96 percent of the watershed area is agricultural land (Figure 44), and 3.8 percent is forest cover. Soil groups B and D cover 79 percent and 21 percent of the watershed, respectively (Figure 45). Figure 75 shows the six local daily precipitation gages and the two USEPA-WDM stations in or near this watershed. Table 4 lists the WDM and the NOAA hourly stations used to disaggregate the data from the six local stations into the hourly series, which were used as model input. The watershed was divided into 10 sub-watersheds using the NHD in the automatic delineation tool provided with BASINS (Figure 76). The USGS gaging station (05587000) at Macoupin Creek near Kane, Illinois (Table A1), is the streamgage closest to the outlet and was used to evaluate model results.

The plots of mean daily, monthly, and annual simulated flows (using Spoon River watershed parameters) versus observed flows are shown (Figures 77 and 78). The statistics in Table 18 show that the results of the simulation are reasonable at all scales, but as seen in Figure 78b, the water balance for this basin needs to be improved because average annual flows were consistently overpredicted. This last result is reflected in the NSE value (0.85) that is not as good as the values of R^2 (0.94), slope (0.99) and intercept (97) of the corresponding regression plot for the annual flows. Better modeling of this watershed may be possible through additional regional parameterization of the HSPF model to better represent the unique topographic character of this region.

Des Plaines River Watershed

As shown in Figure 44, most of the Des Plaines River watershed is urbanized. Urban and commercial land use together cover about 22 percent of total watershed area, a significantly larger area than the urban/commercial land use in any other tributary watersheds of the Illinois River basin. In addition there is considerable modification of flows from both effluent discharges in the Chicago metropolitan area and the diversion of Lake Michigan water into the Chicago Sanitary and Ship Canal. Thus, it was not practical to model this watershed using the calibrated parameters from any of the three watersheds in which the major land use was agriculture and only 1-3 percent area was urban land. Therefore, a different approach was used to obtain daily streamflow estimates for the outlet of this watershed, whereby observed flow records from the most urbanized areas were used in place of model simulations. The HSPF model was used to simulate flows for only a smaller ungaged area, referred to as the lower Des Plaines sub-basin (Figure 79).

Figure 80 shows the USGS streamflow gaging stations with available records that account for most of the flow in the watershed. The Des Plaines River at Riverside (05532500), the Chicago Sanitary and Ship Canal at Romeoville (05536995), and the Du Page River at Shorewood (05540500), had flow data in the time period 1970-1995, but Hickory Creek at Joliet

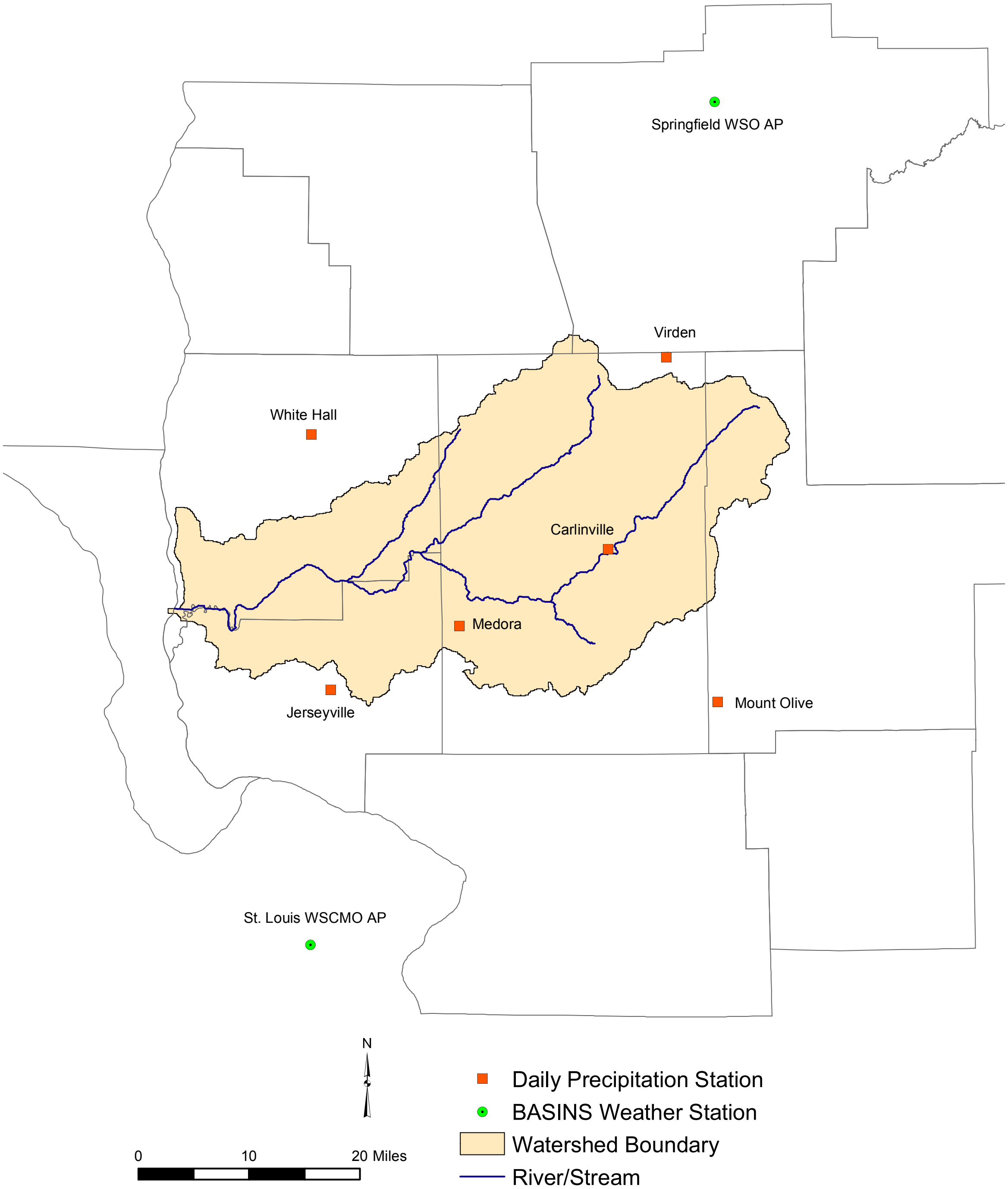


Figure 75. The USEPA-WDM weather stations and local precipitation stations in the Macoupin Creek watershed.

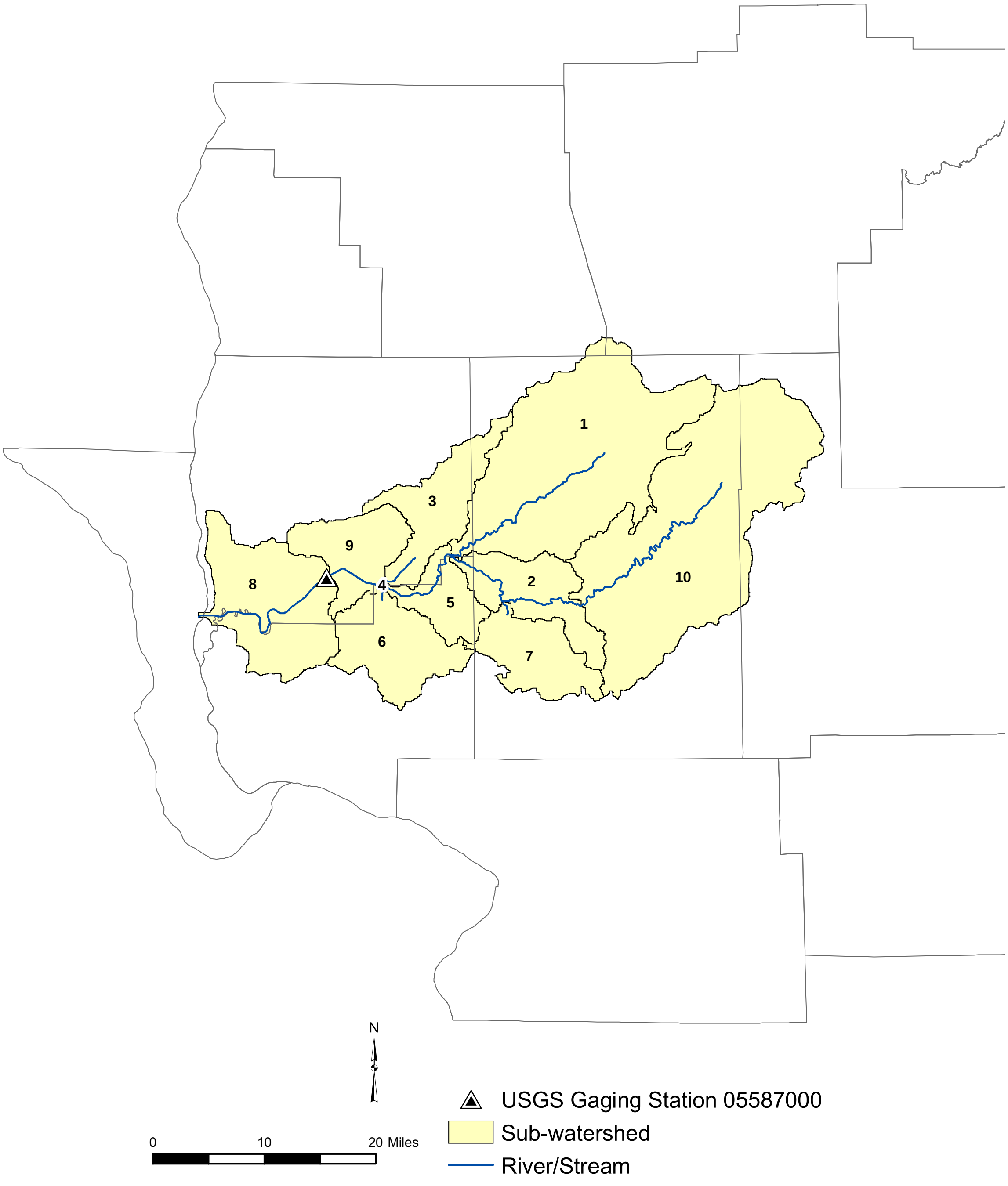


Figure 76. The 10 sub-watersheds of the Macoupin Creek watershed after delineation.

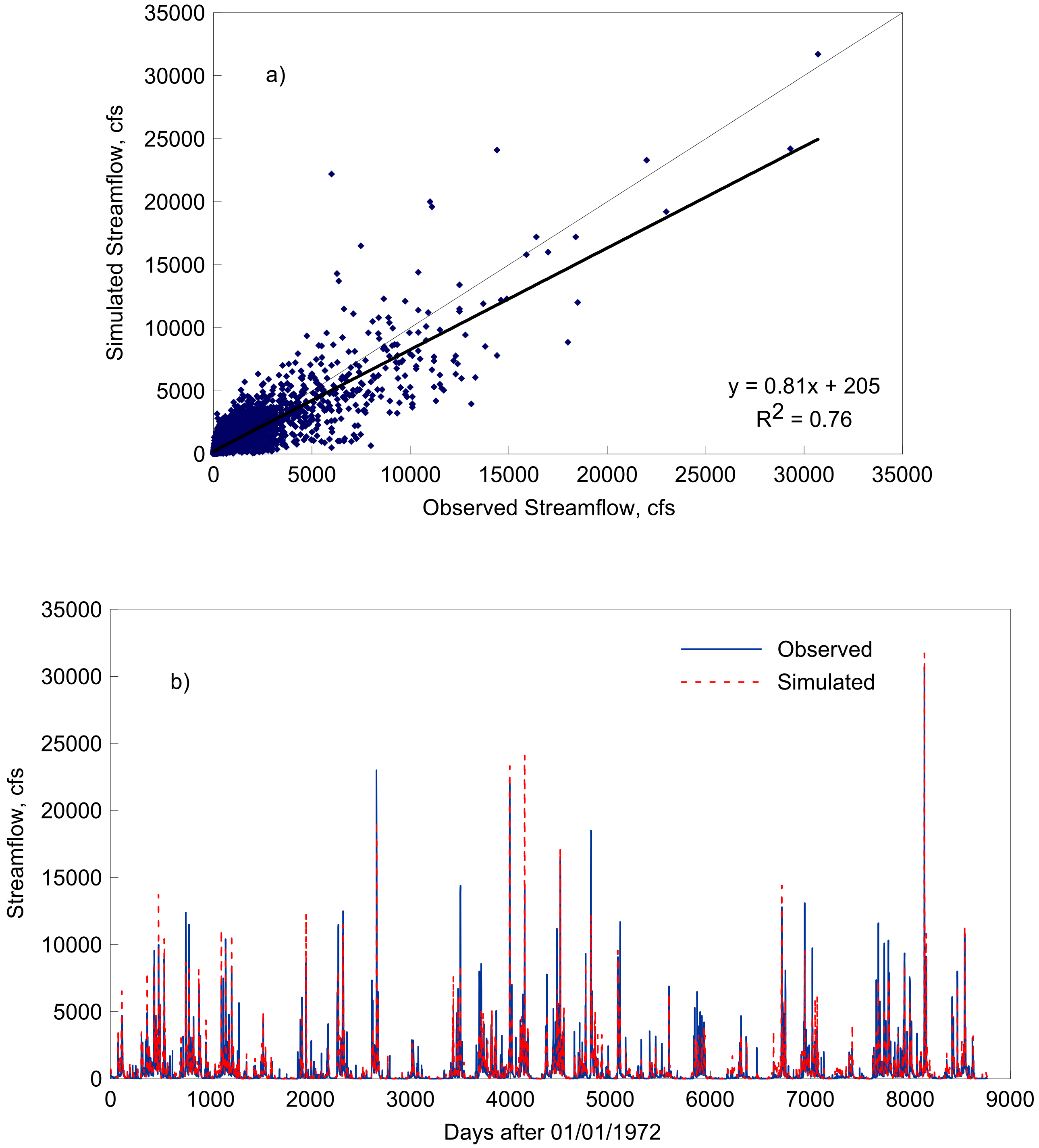


Figure 77. Daily observed and simulated streamflows at USGS gaging station 05587000 in the Macoupin Creek watershed, 1972-1995: a) scatter plot and b) time series. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

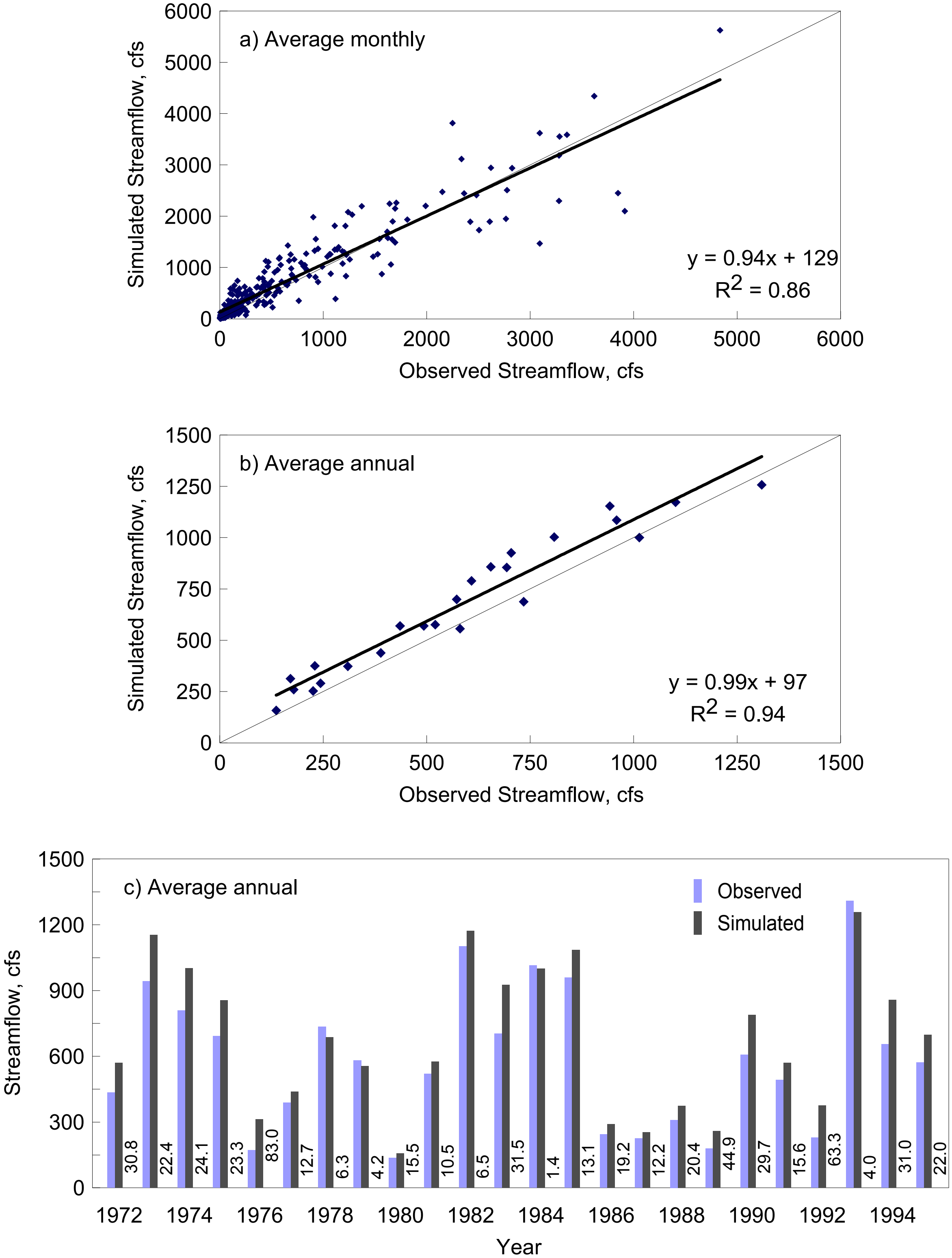


Figure 78. Scatter plots of a) monthly and b) average annual streamflows, and (c) bar chart of annual observed and simulated streamflows, Macoupin Creek watershed near Kane, 1972-1995 calibration period. The HSPF-simulated streamflows are based on the calibrated parameter set for the Spoon River watershed.

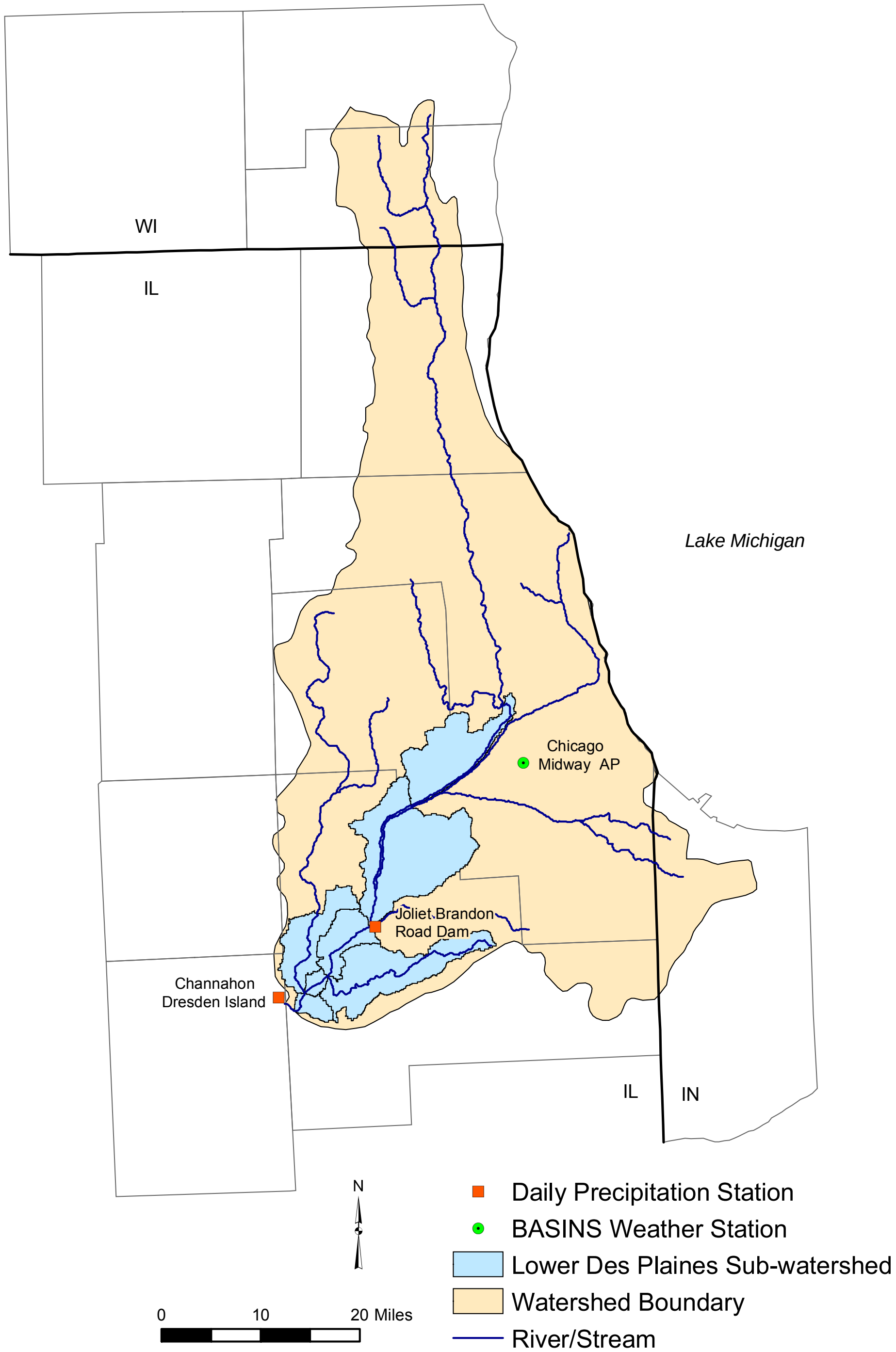


Figure 79. The USEPA-WDM weather stations, local precipitation stations, and USGS streamgages in the Des Plaines River watershed.

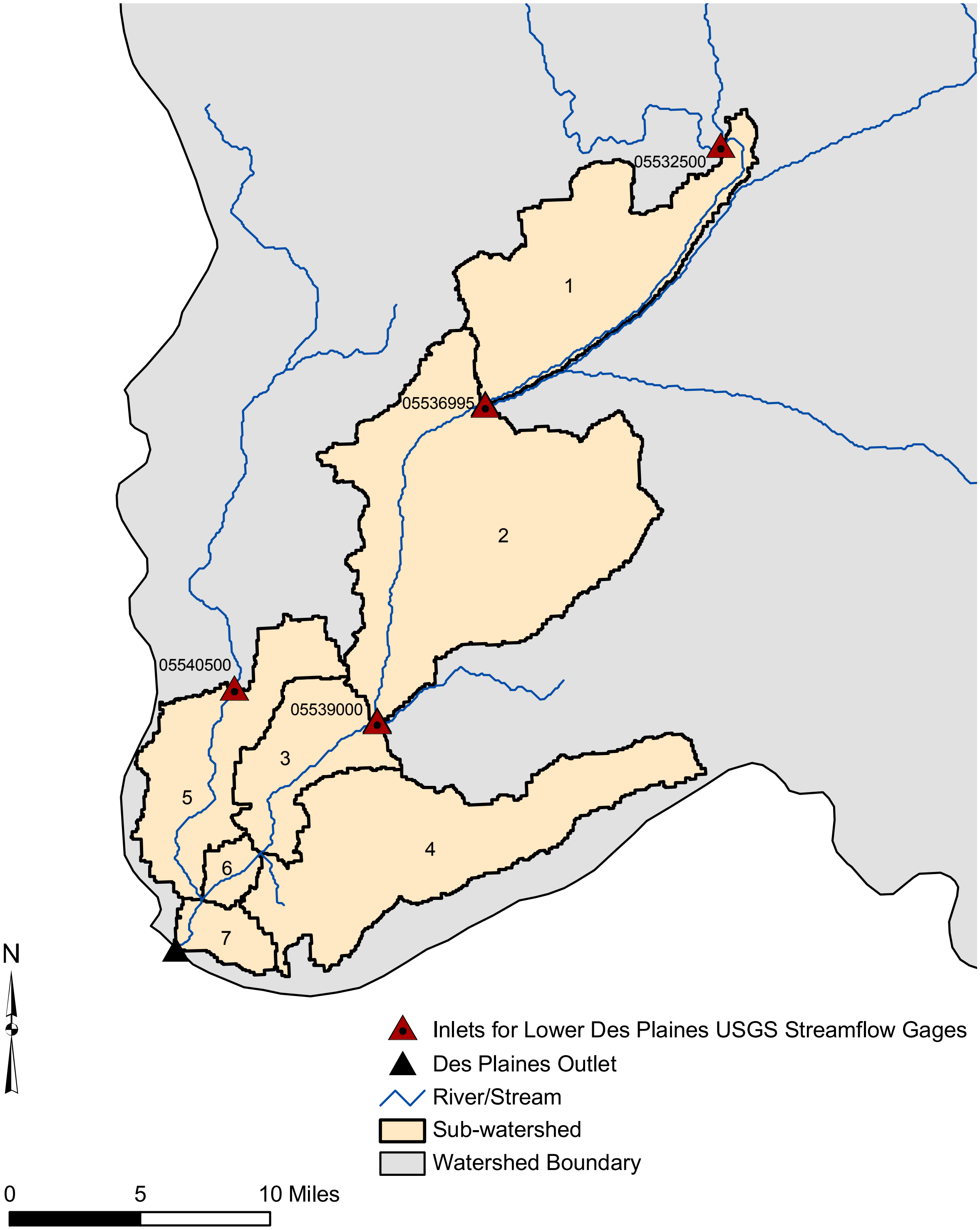


Figure 80. The seven sub-watersheds of the lower Des Plaines after delineation.

(05539000) had data only for June 1984-1995. All four gaging stations accounted for the runoff from the most densely urbanized areas of the watershed. The USGS gaging station on the Chicago Sanitary and Ship Canal also accounted for the water diverted from the Lake Michigan. Observed daily streamflows from these stations were used as inputs to the less urbanized lower Des Plaines sub-basin. An HSPF project for hydrologic simulation of the lower Des Plaines sub-basin used calibrated parameters for the Spoon River watershed. The model was run for the period from June 1984 to December 1995, and the simulated daily streamflow time-series data generated at the outlet of Des Plaines River watershed were saved in a WDM file for later use as input to the MIR watershed. The HSPF model performance on this watershed could not be evaluated because observed streamflow data were not available for the Des Plaines River at or near the watershed outlet.

As explained above in the sections for the six tributary watersheds, the correlation between observed and simulated streamflows obtained using the calibrated parameter set for the Spoon River watershed was not as high as that obtained for the Spoon River watershed itself. This is mainly due to spatial variability of some parameters between tributary watersheds, which was not considered by applying the same set of parameters to each of the six watersheds. Best results for all the tributary watersheds can be obtained if the HSPF model is calibrated individually for each of these watersheds using a global optimization method such as the Parameter ESTimation method or PEST (Doherty, 2002) and the Shuffled Complex Evolution method or SCE (Duan et al., 1992) to find a globally optimized set of parameters for each watershed.

Mainstem Illinois River (MIR) Watershed

After the hydrologic simulation results were obtained for all major tributaries of the Illinois River, an HSPF project was created for the MIR watershed. As shown in Figure 81, hourly meteorological time-series data from 25 local stations and one USEPA-WDM station were used as model input. These stations were assigned based on their proximity to the 60 different sub-watersheds after automatic delineation of the MIR watershed (Figure 82). Model parameters that affect runoff from sub-watersheds were not calibrated; the parameters for the Spoon River watershed were applied to the MIR as they were to the other uncalibrated tributary watersheds. Many minor tributaries that drain directly into the Illinois River basin are “bluff” streams that have high vertical relief and steep channel slopes. Because of the unique character of these watersheds, it would be beneficial for future work to calibrate hydrologic parameters for these watersheds.

The output time-series data of daily streamflow from the nine major tributaries were input in this HSPF project by specifying an inlet for each tributary corresponding to the point where it flows into the Illinois River. Because the input time-series data from the Des Plaines River were available only from June 1984 to December 1995, the model only could be run for this time period, and 1985-1995 data were used during analysis of modeling results. The best correlation between observed and simulated streamflow for all seven major tributaries was obtained using calibrated parameters from the Spoon River watershed; thus, it was decided to use the Spoon River parameter set for the MIR watershed. During watershed delineation, outlets

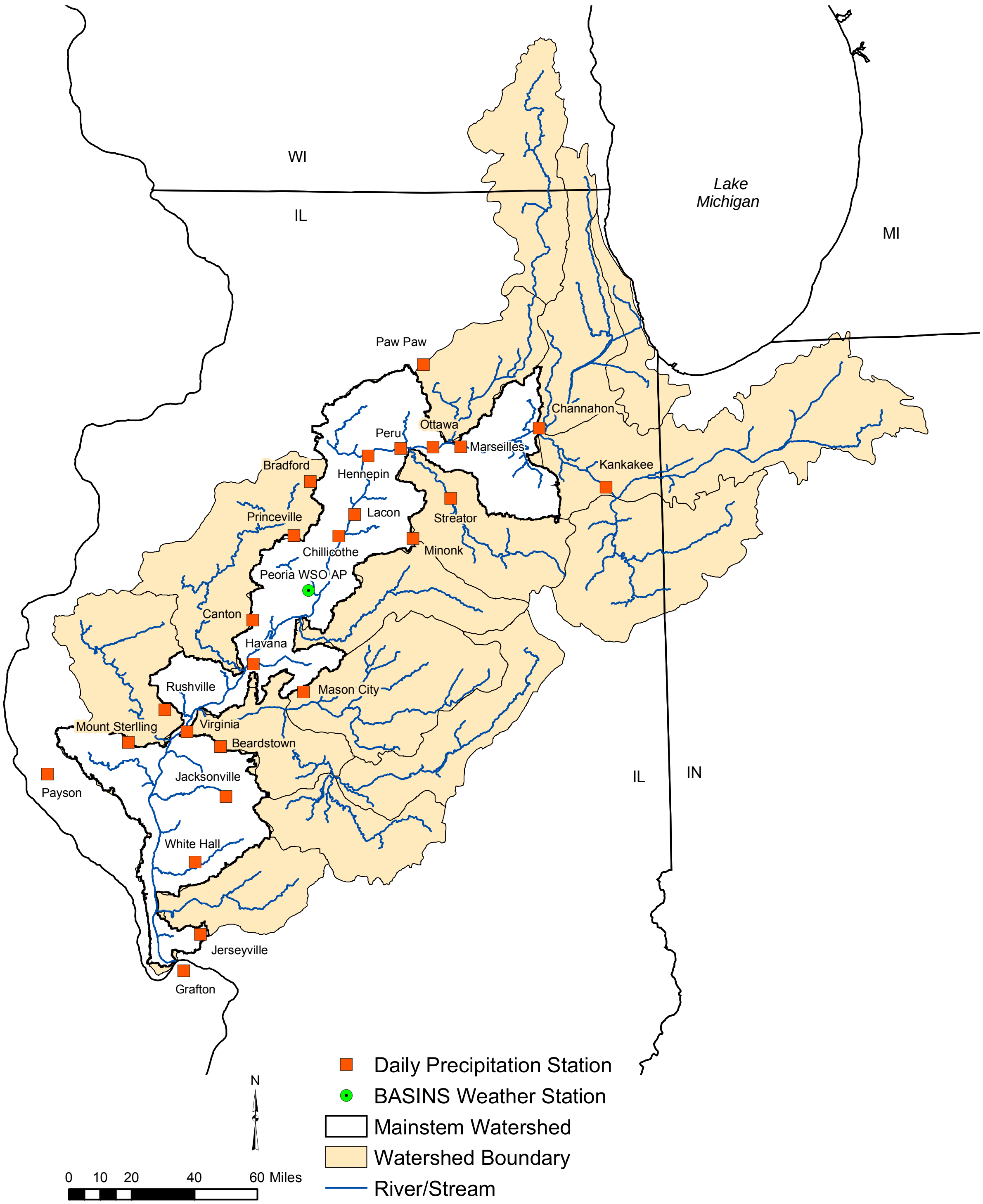


Figure 81. The USEPA-WDM weather stations and local precipitation stations in the watershed of the mainstem Illinois River.

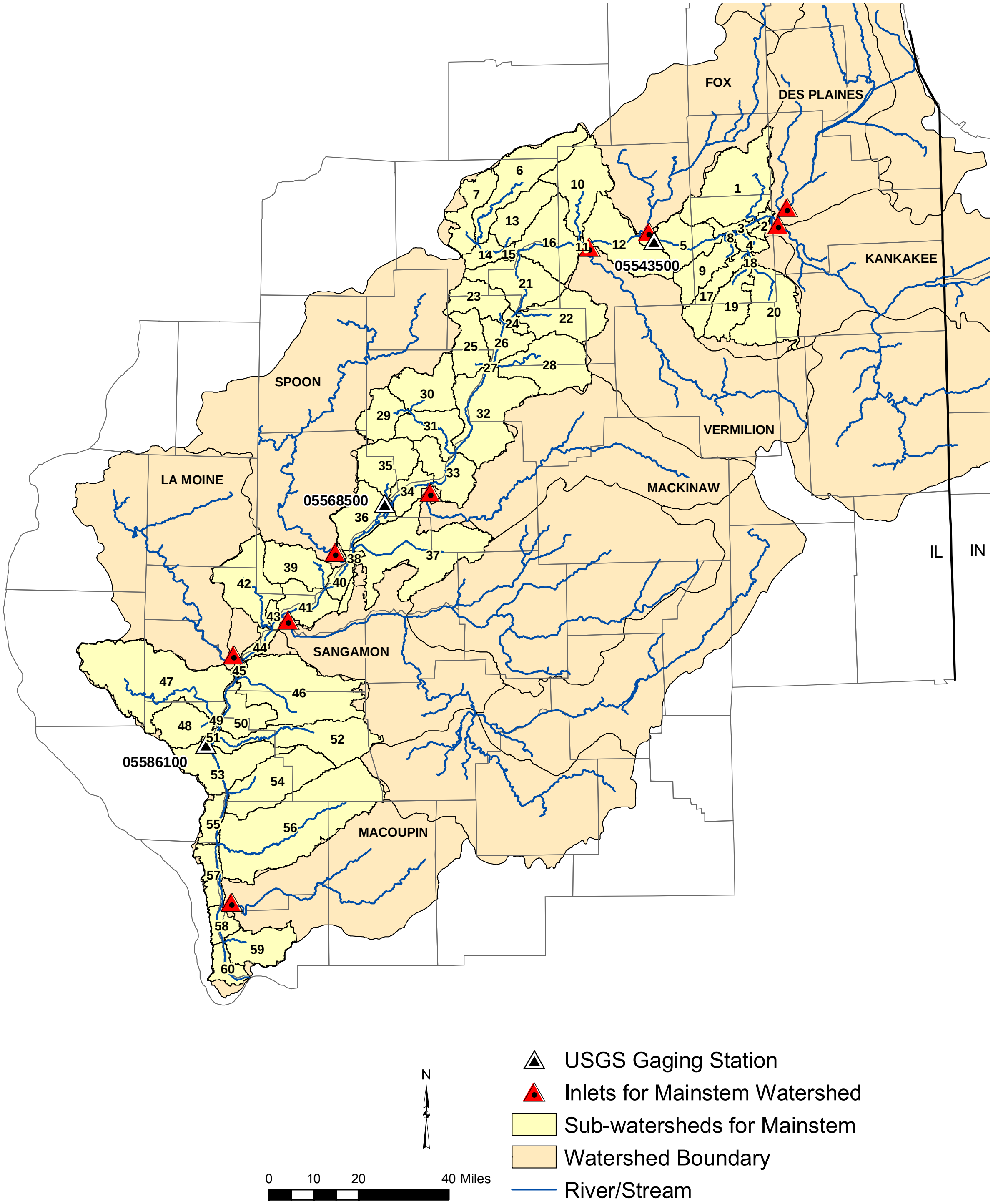


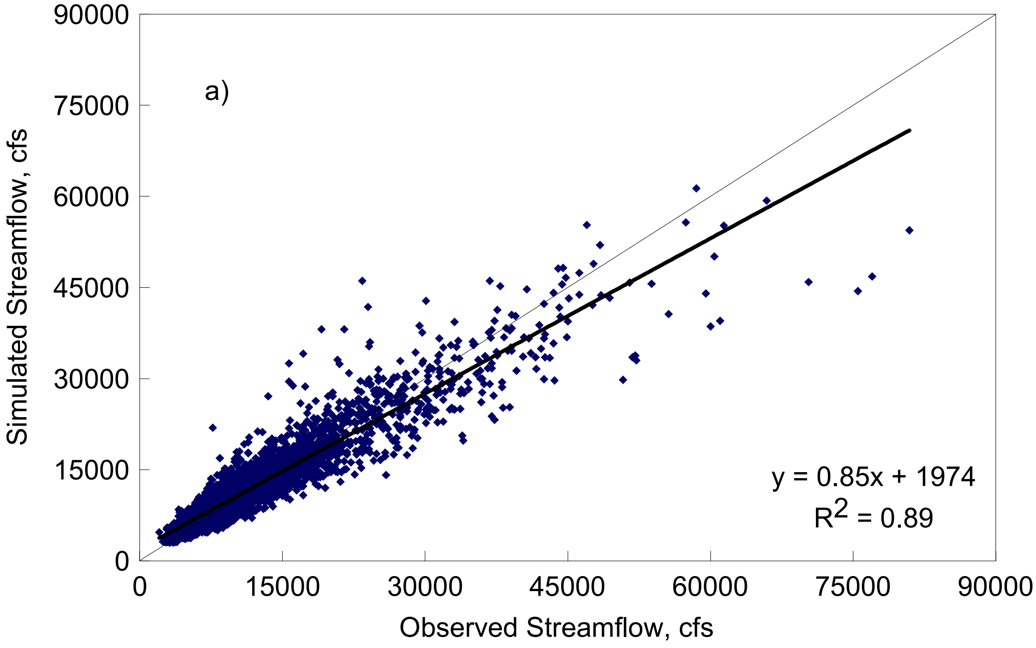
Figure 82. The 59 sub-watersheds in the watershed of the mainstem Illinois River after delineation, three USGS streamflow gaging stations, and inlet points from the nine other major tributaries of the Illinois River.

were specified corresponding to three gage locations on the Illinois River (Figure 82 and Table 19), and simulated streamflows at these three outlets were compared with the observed streamflows.

Figures 83 shows a scatter plot and a time-series plot of the daily observed and simulated streamflow for 1985-1995 corresponding to USGS streamgaging station 05543500 at Marseilles. Good agreement between daily observed and simulated flow was obtained at this gage as indicated by high R^2 (0.89) and NSE (0.88) values. As shown in Figure 83, some high flows were underestimated, but most simulated flows generally matched well with the observed flows. A comparison of different statistics for daily, average monthly, and average annual streamflow is shown (Table 19). Comparison of average monthly flows for the1985-1995 model simulation period with observed flows (Figure 84) shows a good correlation. The scatter plot of average monthly streamflow (Figure 85a) and average annual streamflow (Figure 85b) also show a good agreement between observed and simulated values. Percentage differences between the observed and simulated average annual streamflow values are presented in a bar chart (Figure 85c). The model slightly overestimated in nine years and underestimated in two years. The percentage difference varied from 1.6 percent in 1992 to 15.8 percent in 1988. The percentage difference was less than 10 percent for 9 years and less than 15 percent for all 11 years for which the model was calibrated, indicating a good fit between the annual values.

It should be noted that for the 11-year period, on average, the sum of observed average annual flows at four inlet gages (05532500, 05536995, 05539000, and 05540500) accounted for 44 percent of the estimated average annual flows at Marseilles. The percentage of the estimated flow at Marseilles from the four inlet gages ranged from 32 percent in 1993 to 53 percent in 1987. For this reason, there is an increased likelihood that estimated flows closely will match the observed flows at Marseilles. It is evident here that the flow from the unmodeled portions of the Illinois River basin, that being the Des Plaines and Chicago-Calumet River watersheds, significantly influences the function of the upper portions of the Illinois River. For certain model applications for the upper Illinois River, it will be important to include accurately simulated flows from those two unmodeled watersheds by linking the present model to HSPF models developed for the urban area of northeastern Illinois.

Hydrologic simulation results corresponding to USGS streamgage 05568500 at Kingston Mines also are shown (Table 19 and Figures 86 and 87). Figure 86b shows that several medium to high flows were overestimated. Simulated daily flow peaks also were found to be slightly higher than the observed flow peaks over time, suggesting that the model does not adequately represent the effect of storage in the Illinois River upstream of Kingston Mines. Scatter plots for average monthly and annual observed and streamflow (Figure 87) show that the model slightly underestimates high flows at these time scales. Figure 87c shows a bar chart of the percentage differences between the observed and simulated average annual streamflow values for the 11 years. The model slightly overestimated in four years and underestimated in seven years. The percentage difference varied from 0.3 percent in 1992 to 15.1 percent in 1991. The percentage difference was less than 10 percent for 7 years and less than 15 percent for 10 years, indicating a good fit between the annual values.



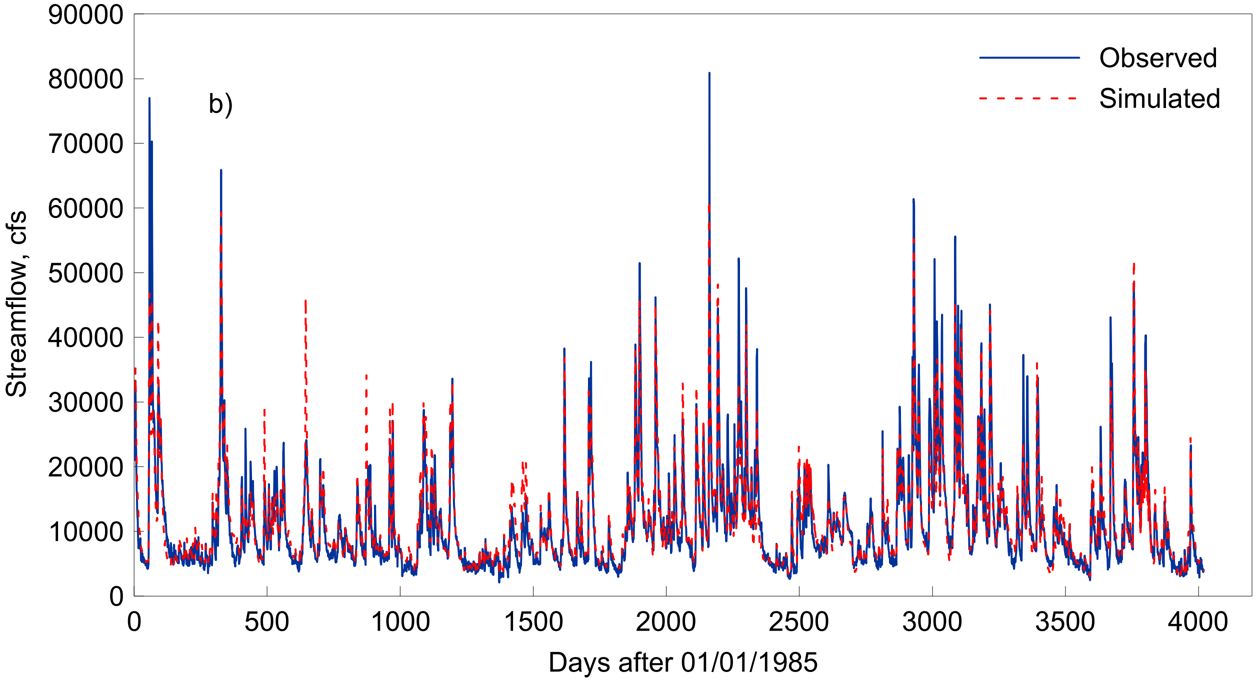


Figure 83. Observed and simulated monthly streamflows at the USGS gaging station near Marseilles (reach #8), 1985-1995: a) scatter plot and b) time series.

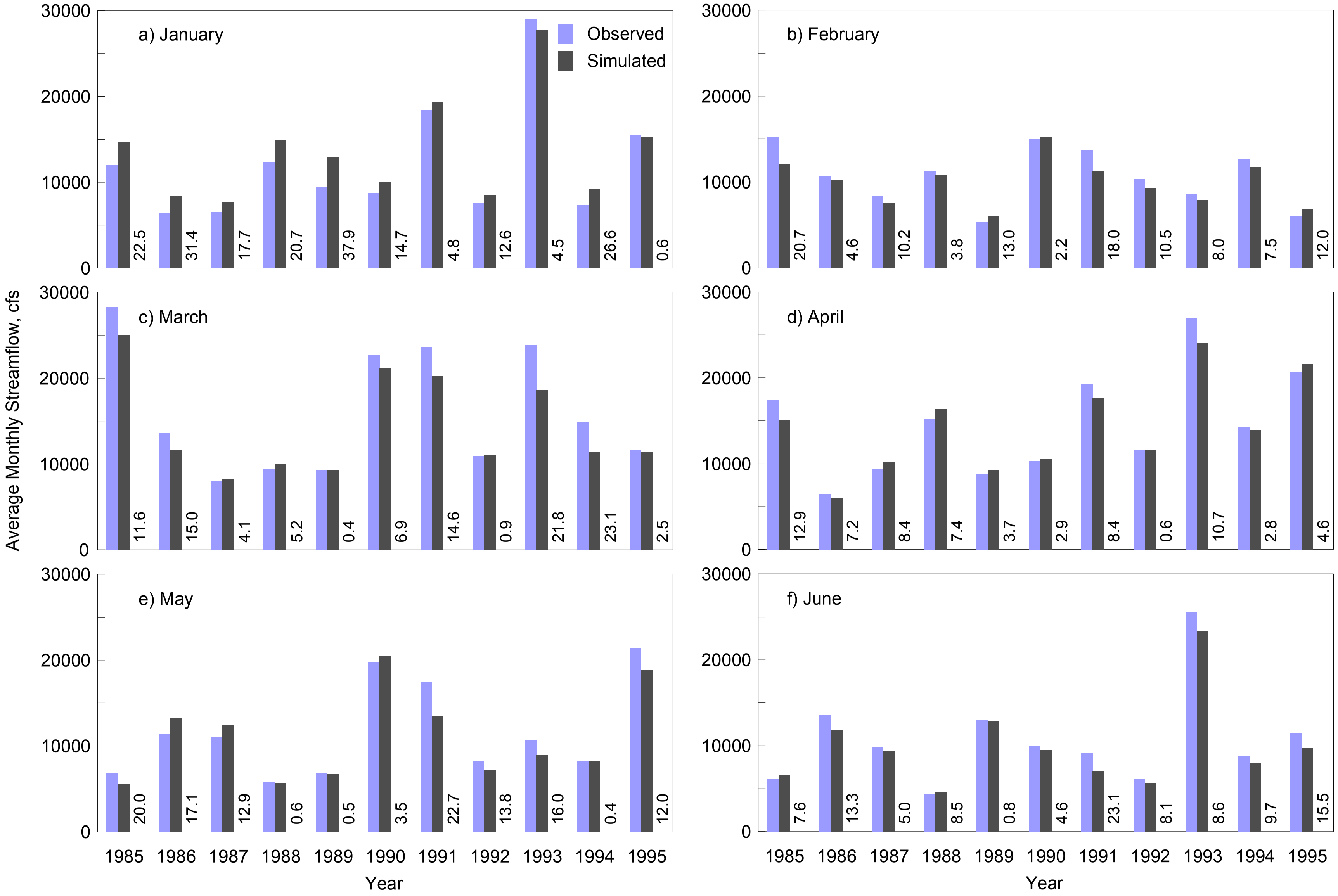


Figure 84a. Observed and simulated monthly streamflows at the USGS streamgage near Marseilles, IL, January-June 1985-1995. Data labels indicate percent relative difference between observed and simulated values.

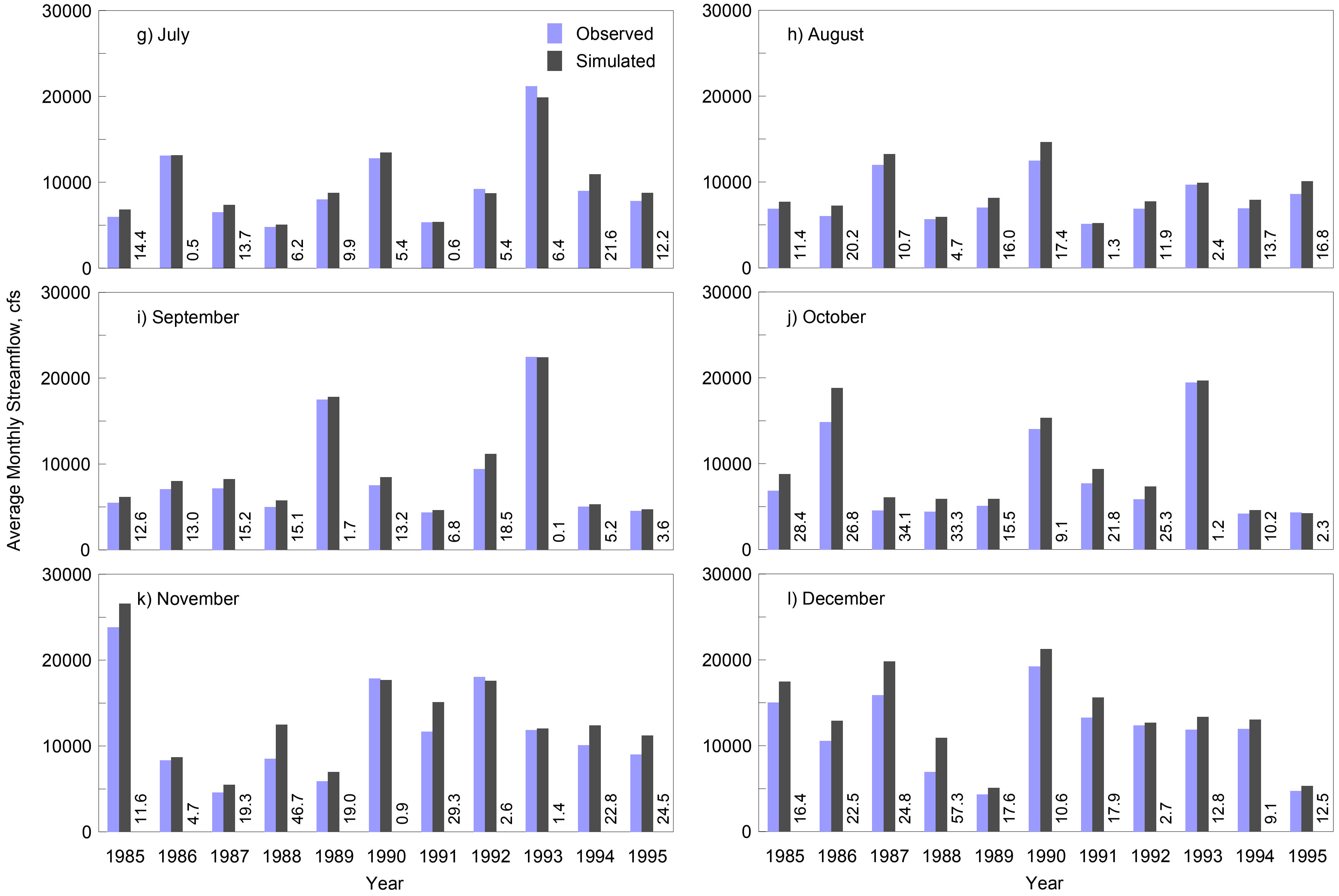


Figure 84b. Observed and simulated monthly streamflows at the USGS streamgage near Marseilles, IL, July-December 1985-1995. Data labels indicate percent relative difference between observed and simulated values.

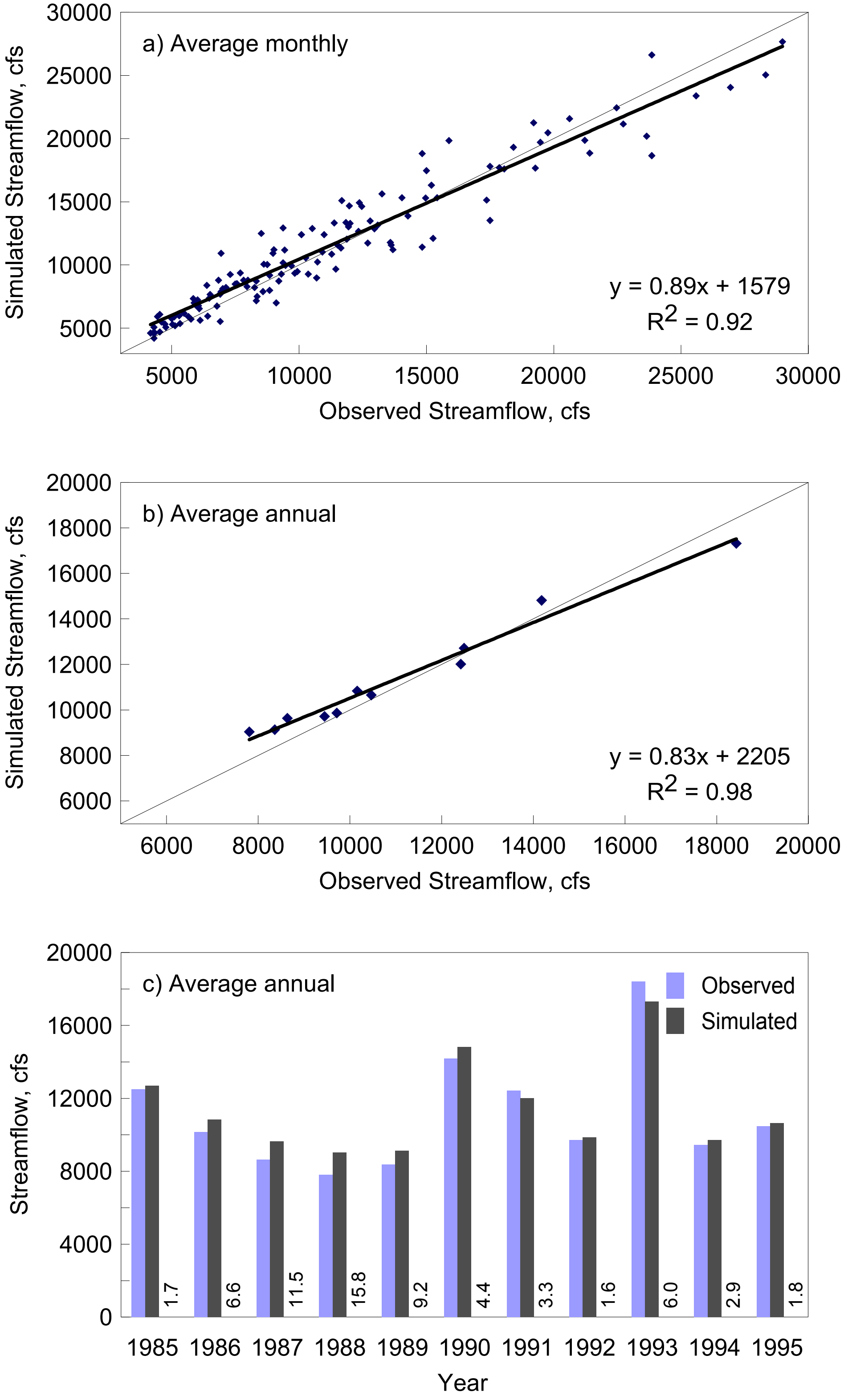


Figure 85. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of annual observed and simulated streamflows, Marseilles on the Illinois River, 1985-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

Table 19. Simulated and Observed Daily, Average Monthly, and Average Annual Streamflow Data at Three USGS Gages on Illinois River

USGS gage					
Name	*ID*	*NSE*	*R^2*	*Slope*	*Intercept*
Daily (1985-1995)					
Marseilles	05543500	0.88	0.89	0.85	1974
Kingston Mines	05568500	0.33	0.52	0.82	2344
Valley City	05586100	-0.02	0.44	0.89	3042
Average monthly (1985-1995)					
Marseilles	05543500	0.91	0.92	0.89	1579
Kingston Mines	05568500	0.78	0.79	0.82	2247
Valley City	05586100	0.64	0.70	0.90	2817
Average annual (1985-1995)					
Marseilles	05543500	0.94	0.98	0.83	2205
Kingston Mines	05568500	0.90	0.98	0.74	3744
Valley City	05586100	0.97	0.99	0.87	3536

Note:
Simulated streamflow data were generated using calibrated model parameters from Spoon River watershed, and no FTABLE for the MIR was modified.

The hydrologic simulations results corresponding to the USGS streamgage 05586100 at Valley City are shown (Table 19 and Figures 88 and 89). The correlation between daily observed and simulated streamflows at this gage was poorer than at the Kingston Mines gage. It can be seen from Figure 88b that many medium to high flows were overestimated. The extent of overestimation is greater at the Valley City gage than at the Kingston Mines gage, which again suggests inadequate model representation of river storage. The model also does not account for the backwater effects from the Mississippi River, leading to additional error in the simulated flows at Valley City. Model-simulated daily peakflows also were found to be slightly higher than the observed peak flows over time. Observed and simulated monthly flows did not correlate as well as annual flows (Figures 89a and b). Figure 89c shows a bar chart of the percentage differences between the observed and simulated average annual streamflow values for the 11 years. The model slightly overestimated in seven years and undersimulated in four years. The percentage difference varied from 0.1 percent in 1985 to 21.8 percent in 1989. The percentage difference was less than 10 percent for 10 years, indicating a relatively good fit between the annual values. Average annual and daily simulated streamflows for 1985-1995 at the main outlet of the Illinois River basin (Figure 82), near Grafton, Illinois, are shown (Figure 90).

As indicated by the NSE and R^2 values corresponding to the three USGS gages along the MIR (Table 19), the correlation between daily simulated and observed streamflows became poorer with greater distance downstream from the headwaters of the Illinois River. Values corresponding to the gage at Marseilles were high (NSE = 0.88 and $R^2 = 0.89$), but much lower for the gages at Kingston Mines (NSE = 0.33 and $R^2 = 0.52$), and Valley City (NSE = -0.02 and

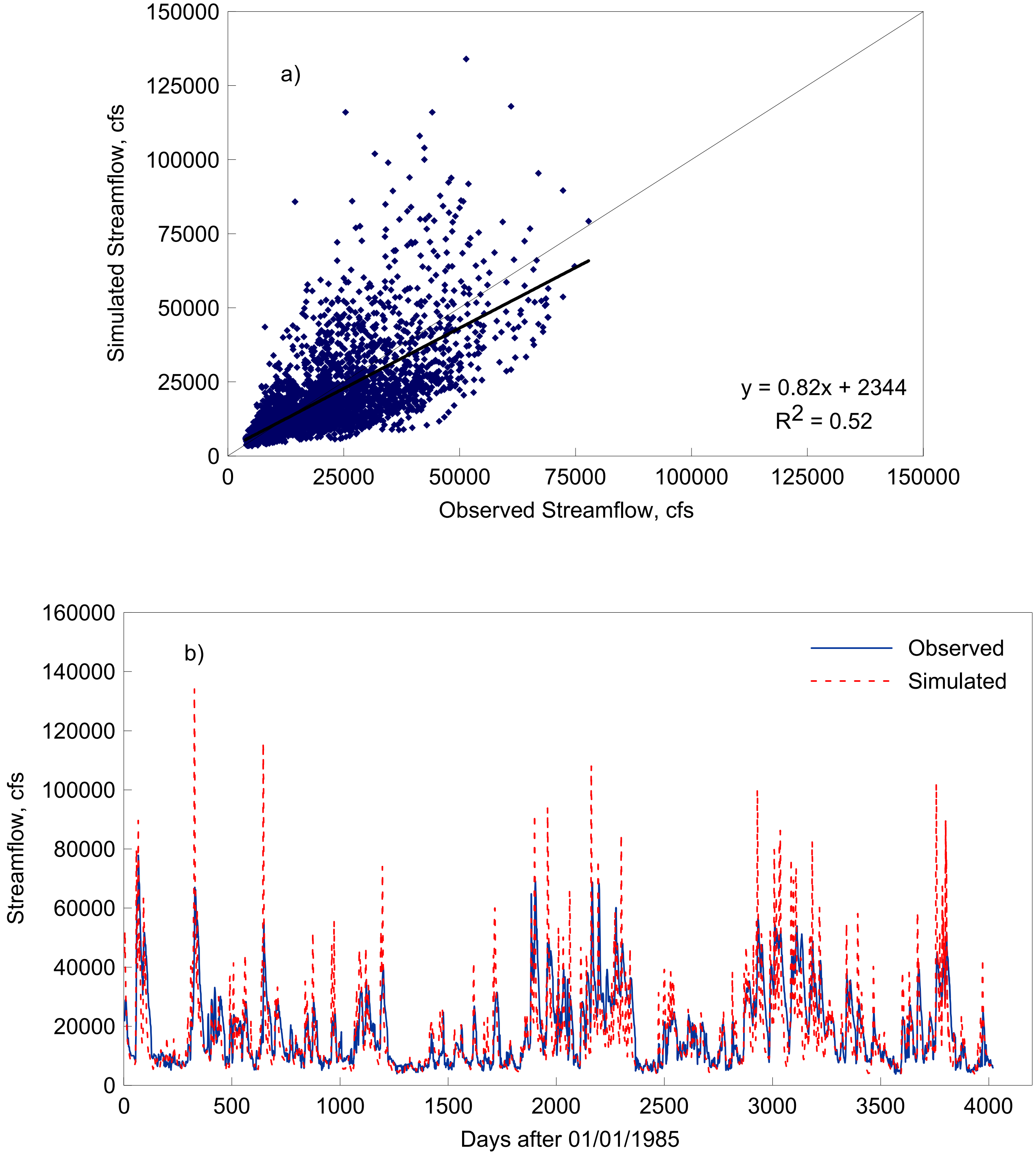


Figure 86. Observed and simulated daily streamflows at the USGS gage near Kingston Mines (reach #34), 1985-1995: a) scatter plot and b) time series.

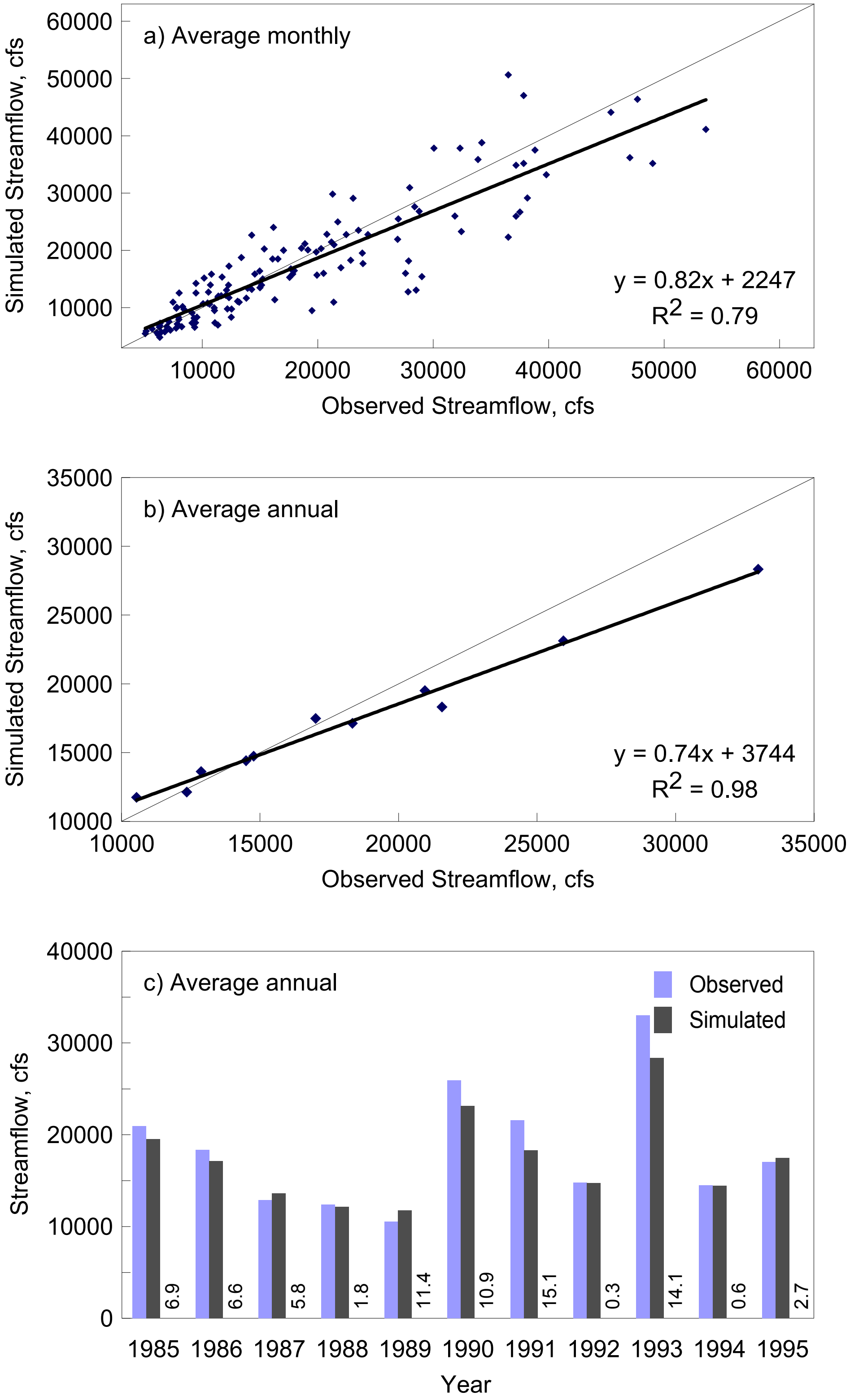


Figure 87. Scatter plot of a) monthly and b) averge annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Kingston Mines on the Illinois River, 1985-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

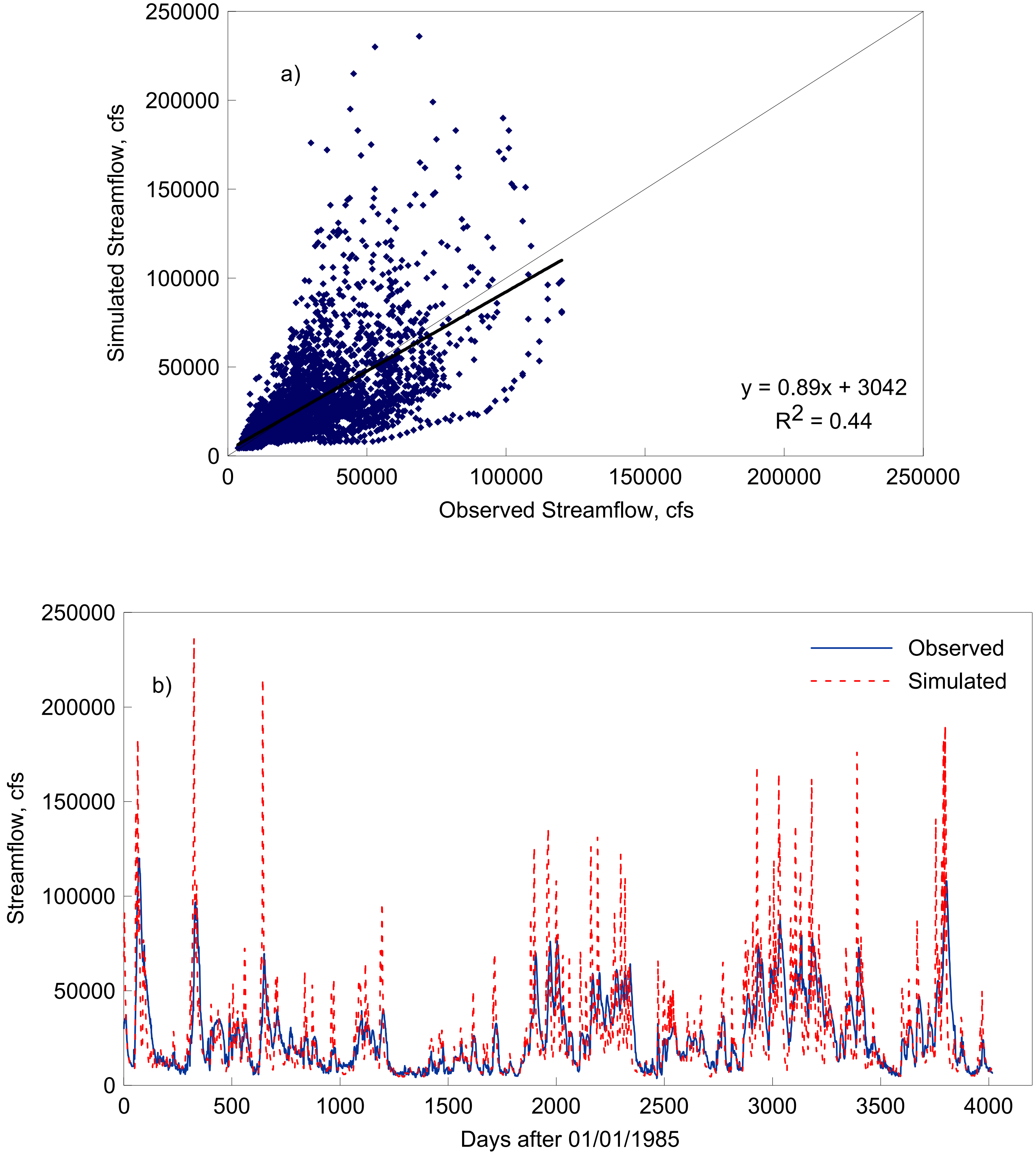


Figure 88. Observed and simulated streamflows at the USGS gaging station near Valley City (reach #51), 1985-1995: a) scatter plot and b) time series.

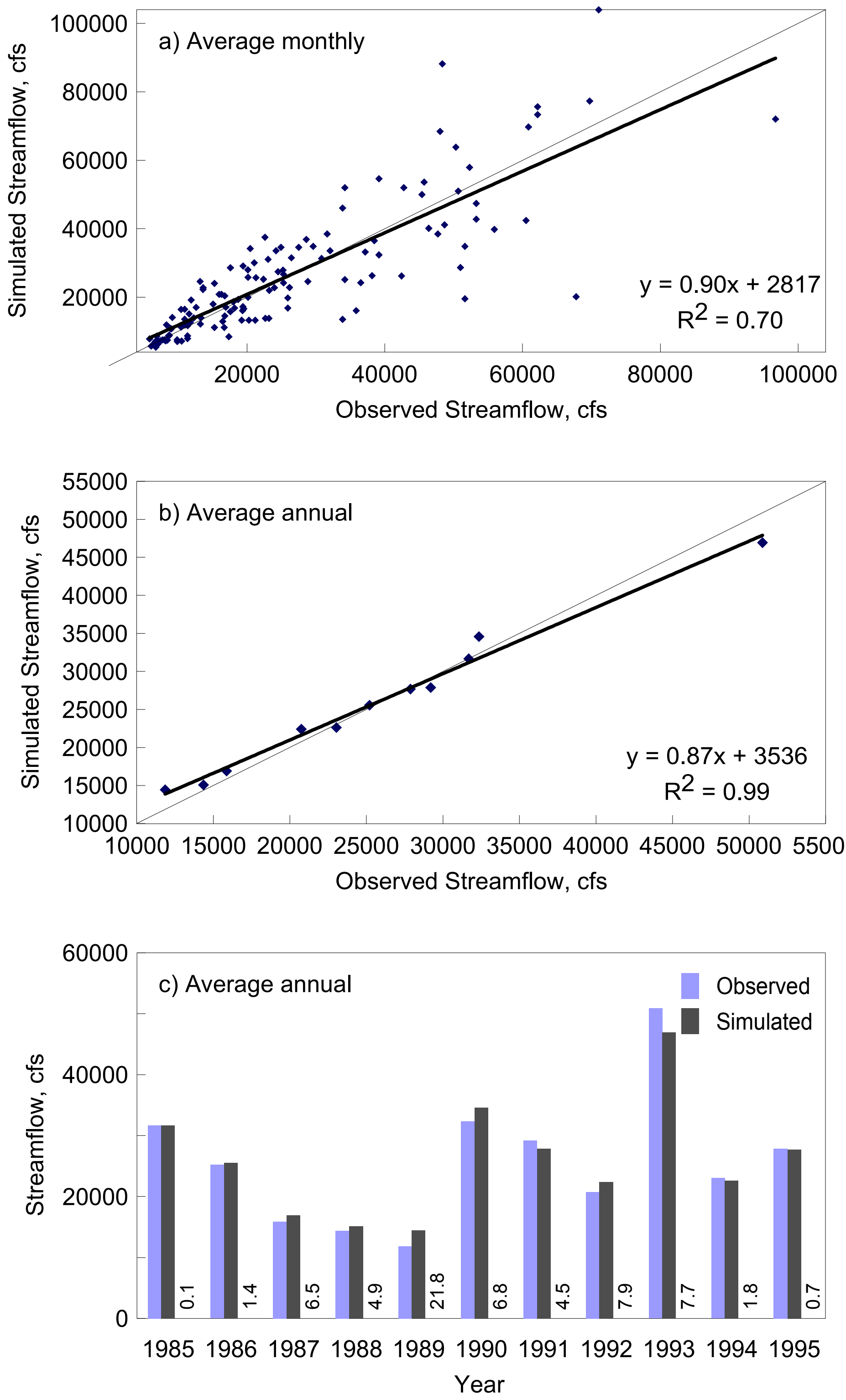


Figure 89. Scatter plots of a) monthly and b) average annual streamflows, and c) bar chart of average annual observed and simulated streamflows, Valley City on the Illinois River, 1985-1995 calibration period. Values along bar graphs are absolute percentage differences between observed and simulated streamflows.

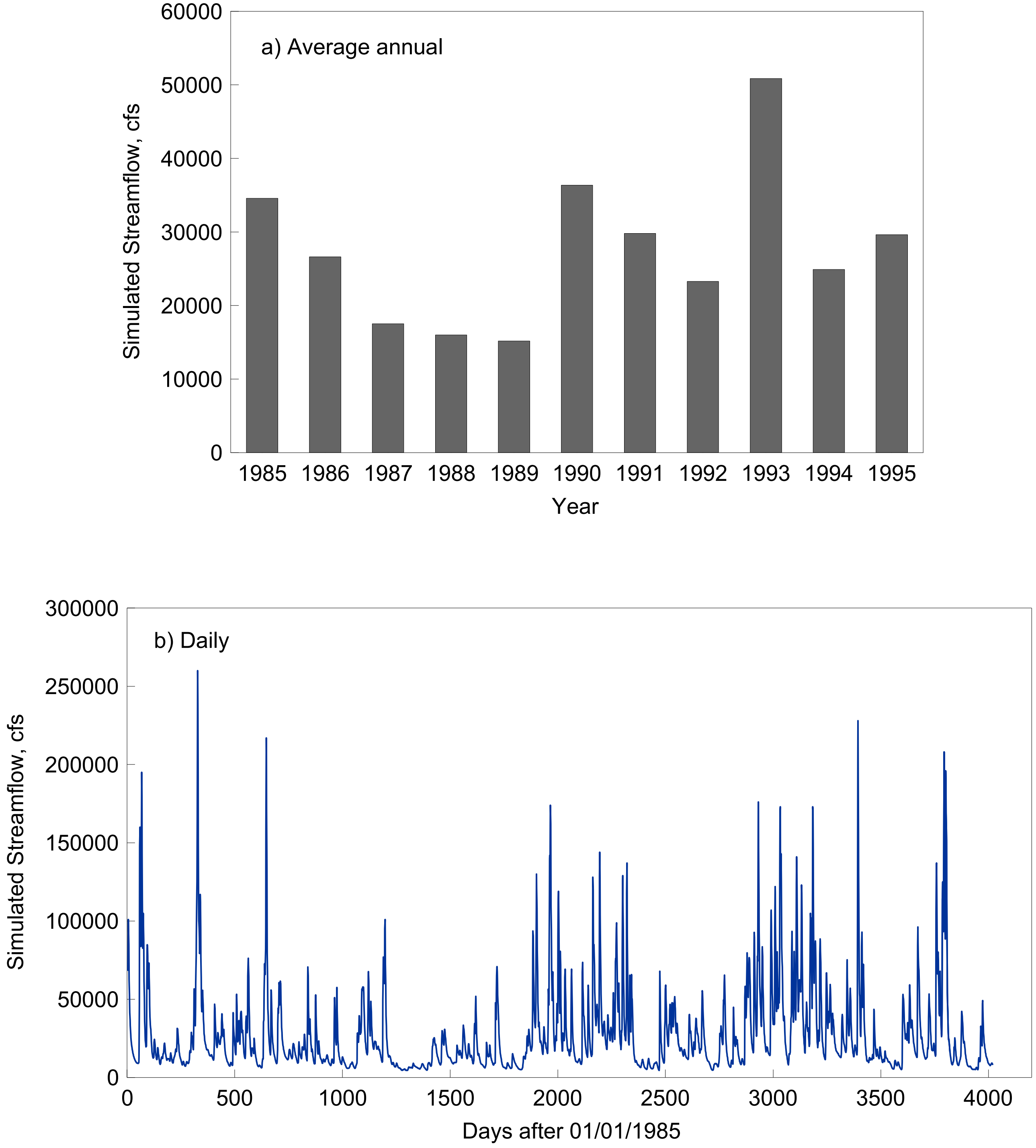


Figure 90. Average a) annual and b) daily simulated streamflows at the main outlet of the Illinois River basin, near Grafton, IL (outlet of reach #60 as shown in Figure 82).

$R^2 = 0.44$). A comparison of observed and simulated daily flows for the Valley City gage (Figure 88) indicates that:

- Simulated peakflows were mostly larger than observed peak flows.
- Simulated flow hydrographs had relatively steeper rising and recession limbs than the observed streamflow hydrographs.
- Simulated peakflows mostly occur before the observed peak flows.
- Backwater affects some flow events at Valley City.

The first three discrepancies are due, in part, to the fact that the effects of lakes and other storage elements along the Illinois River between Marseilles and Valley City are not simulated directly in the uncalibrated HSPF model of the MIR. Only the values calculated by BASINS using the DEM and the river reach file (RF1) were used to develop routing parameters for the uncalibrated model. Detailed information on cross section, slope, surface roughness, rating curves, and other pertinent factors for the various river reaches were not taken into consideration. Use of more detailed flow-routing information can be expected to improve the estimates of daily flow and, to a lesser degree, also improve monthly flow estimates. Although there is generally poor correlation between observed and simulated daily flows at Valley City, the comparison between observed and simulated monthly flows is better, and there is a consistently good correlation between observed and simulated annual flows.

Effect of Storage Routing for the Peoria Lake Reach

The HSPF model uses a hydraulic function table (FTABLE) to represent the hydraulic properties of river reaches. The default values in this BASINS-created table are rudimentary and often do not adequately describe the routing characteristics of the river reaches. It is expected that better, more detailed information in the FTABLE will improve the simulated flows for the Illinois River. The FTABLE for reach #32 on the Illinois River (Figure 82), which represents the Peoria Lake reach (length = 24.5 miles), was modified using measured channel geometry for that reach to investigate how this change would affect the daily flow simulations at the Kingston Mines and Valley City gages. Two representative cross sections of the reach at River Miles 164 and 184 were taken from surveyed cross sections obtained from the U.S. Army Corps of Engineers (USACE), Rock Island District, Illinois. Reach geometry (cross-sectional area and hydraulic radius) at each cross section was calculated for different water surface elevations corresponding to 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals (USACE, 1992). The average value of the water surface slope for these flood events was calculated. The Manning's equation with a roughness value (n) of 0.05 was used to calculate outflow for different depths; and average values of channel depth, surface area, volume, and outflow were determined from the two cross sections for use in the FTABLE for reach #32. The values in the last three rows of the new FTABLE correspond to extrapolated channel depth values of 51.7 feet, 67.0 feet, and 97.5 feet, respectively. Table 20 shows the default FTABLE for reach #32 generated by BASINS and the new FTABLE created using the cross section and flood profile information. Comparison between the two FTABLEs corresponding to similar depth values shows the new FTABLE estimates and an increase in water storage volume has decreased outflow for a given depth.

Table 20. The FTABLE Created by the HSPF Model and the Modified FTABLE for Reach #32

Default FTABLE Generated by HSPF Model

Depth, ft	*Surface area, acres*	*Volume, acre-ft*	*Outflow, cfs*
0.0	6517.6	0.0	0.0
2.8	6534.2	18272.6	8376.1
28.0	6683.9	184820.8	387917.5
35.0	6933.2	231753.6	562370.8
43.8	20197.0	408023.0	697187.8
52.5	20300.9	585201.6	1266870.0
901.3	30379.2	22092594.0	401513088.0
1750.0	40457.5	52153948.0	1371917440.0

New Customized FTABLE

Depth, ft	*Surface area, acres*	*Volume, acre-ft*	*Outflow, cfs*
0.0	0.0	0.0	0.0
6.5	1163.6	5018.2	457.8
15.8	2400.0	21854.5	3011.3
26.3	26472.7	202181.8	25635.0
29.9	26718.4	297567.8	46523.7
32.6	26933.7	366380.6	65818.0
36.9	27313.1	484164.5	103405.6
39.5	27540.6	555474.4	129131.2
42.3	27785.6	632931.1	159419.7
51.7	28614.0	898562.2	279676.1
67.0	29988.4	1354718.4	536687.7
97.5	32680.0	2315774.2	1238363.4

The HSPF module for the MIR was re-run using new FTABLE values for reach #32. A scatter plot and a time-series plot comparing the daily observed and simulated streamflow values at the USGS gaging station (05568500) on the Illinois River at Kingston Mines are shown (Figure 91). Similar results for the Kingston Mines gage using the default FTABLE are shown (Figure 86). A comparison of Figures 86 and 91 indicates that simulated daily streamflows using the new FTABLE (Figure 91) provide a much better fit to observed flows than the simulated flows from the default FTABLE (Figure 86). Various statistics comparing modeled data with observed daily, monthly, and annual data using the new FTABLE for reach #32 are shown for the Kingston Mines and Valley City gages (Table 21). The NSE value using the default FTABLE was 0.33 for Kingston Mines, whereas it more than doubled (0.69) using the new FTABLE. The improvement is directly attributed to the better representation of water storage in Peoria Lake by the new customized FTABLE for reach #32.

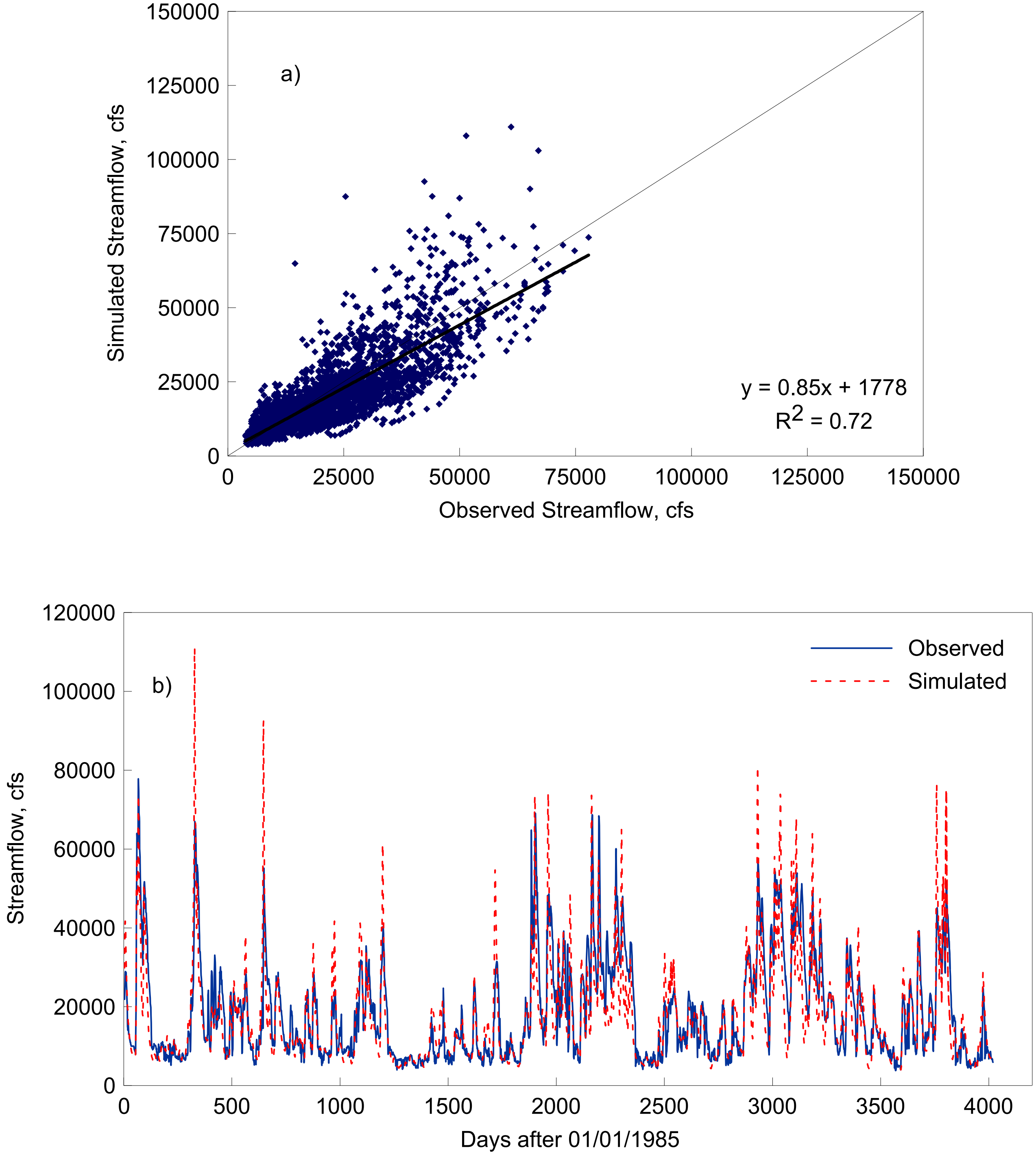


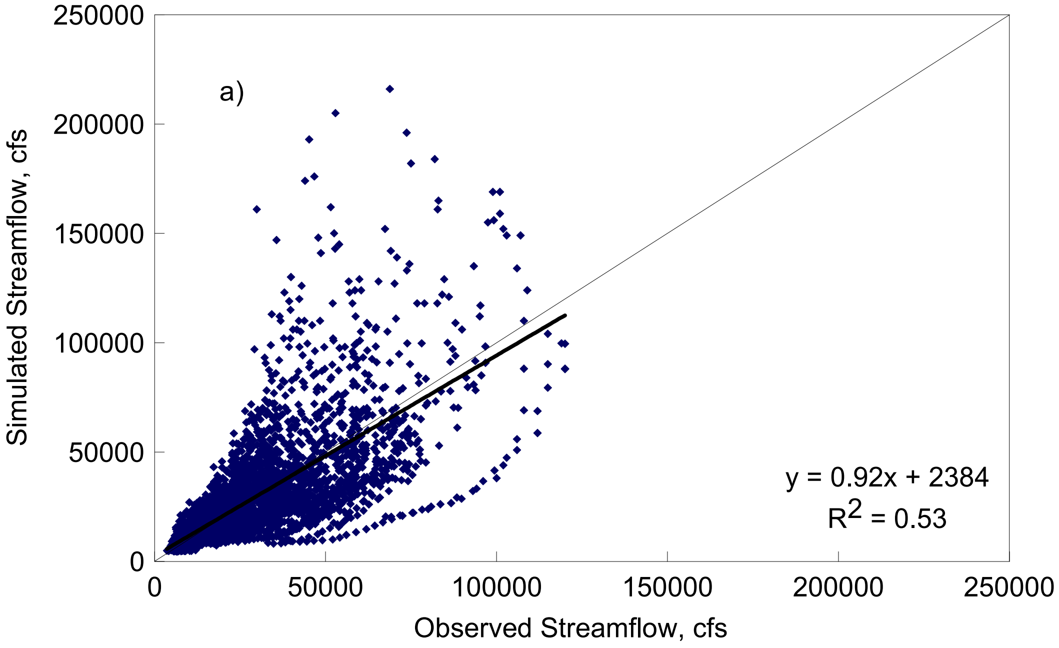
Figure 91. Observed and simulated daily streamflows at the USGS gaging station near Kingston Mines (reach #34) when new FTABLE was used for reach #32, 1985-1995: a) scatter plot and b) time series.

Table 21. Simulated and Observed Daily, Average Monthly, and Average Annual Streamflow Data at Kingston Mines and Valley City USGS Gages on the MIR

USGS gage					
Name	*ID*	*NSE*	*R^2*	*Slope*	*Intercept*
Daily (1985-1995)					
Kingston Mines	05568500	0.69	0.72	0.85	1778
Valley City	05586100	0.24	0.53	0.92	2384
Average monthly (1985-1995)					
Kingston Mines	05568500	0.83	0.84	0.83	2123
Valley City	05586100	0.69	0.73	0.91	2560
Average annual (1985-1995)					
Kingston Mines	05568500	0.90	0.99	0.74	3780
Valley City	05586100	0.97	0.99	0.88	3521

Note:
Simulated streamflow data were generated using calibrated model parameters from Spoon River watershed, and FTABLE for reach #32 of the MIR was modified.

Some effect of this modification also was seen with the simulated daily flows for the USGS gaging station (05586100) at Valley City. A scatter plot and a time-series plot comparing the daily observed and simulated streamflow values at the Valley City gage using the new FTABLE are shown (Figure 92). Results using the default FTABLE can be seen in Figure 88. The NSE value using the default FTABLE for reach #32 was -0.01 compared to 0.24 with the new FTABLE (Table 21). Even with the adjusted FTABLE, there are still considerable differences between the simulated and observed flows; however, the results in Figure 92 are associated only with an improvement in the routing characteristics for Peoria Lake (reach #32). The results at Valley City can be further improved by developing customized FTABLEs for all reaches along the Illinois River, particularly the reaches between the Kingston Mines and Valley City gages. However, it is important to recognize that improvements to storage routing in the HSPF model may not adequately simulate all flow dynamics in the Illinois River, particularly those associated with backwater effects from the Mississippi River. A hydraulic model such as the one-dimensional unsteady flow through a full network of open channels (UNET) may be needed to model the full range of flow conditions for river segments affected by backwater.



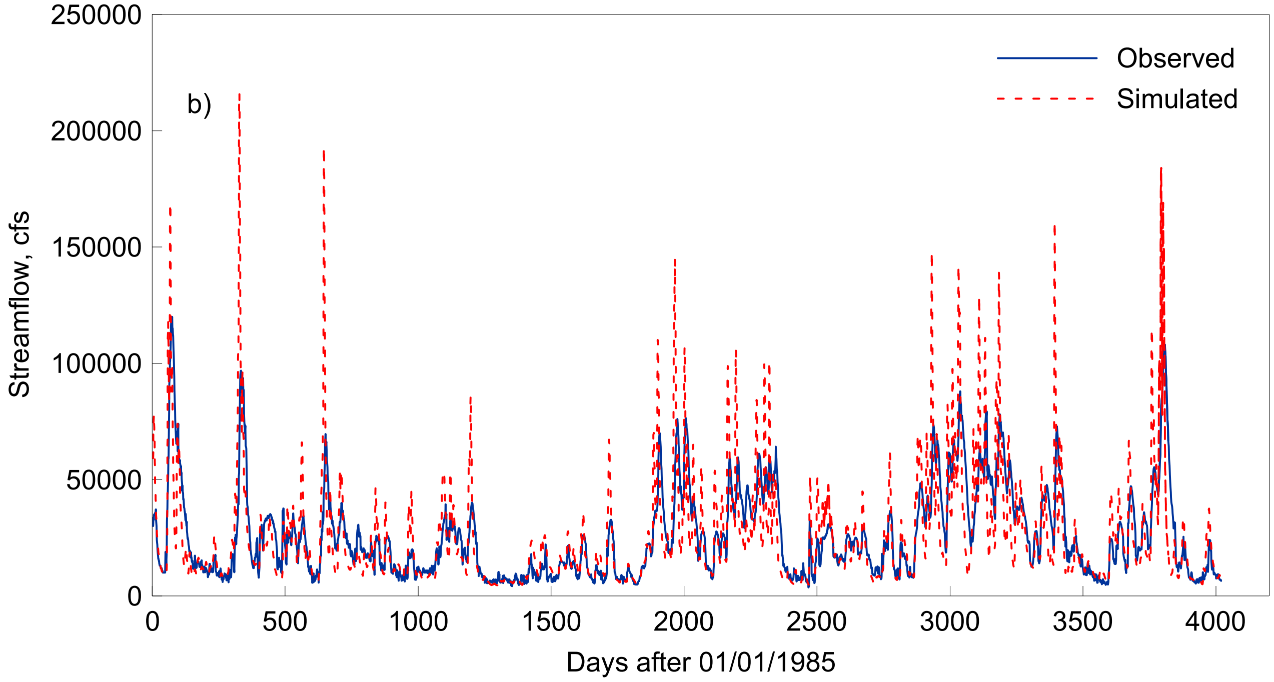


Figure 92. Observed and simulated streamflows at USGS gaging station near Valley City (reach #51) when new FTABLE was used for reach #32, 1985-1995: a) scatter plot and b) time series.

Plans for Future Improvements

The model constructed for the entire Illinois River basin provides a strong framework for additional development and refinement, but at present it is considered only a preliminary hydrologic model. Although the model provides a reasonable representation of basin hydrology for large-scale planning purposes, it has several limitations:

- Simulated flows for most major tributaries have not been calibrated. Only models corresponding to the Spoon and Kankakee River watersheds have been calibrated and validated, and the simulated streamflow series for the remainder of the major sub-watersheds were obtained with extrapolated parameters. Calibration should be performed for more major tributaries.
- In the calibrated watersheds (i.e., the Spoon and Kankakee River watersheds), observed flows were used at four major outflow sites (Kankakee River at Momence and Wilmington, Iroquois River at Chebanse, and Spoon River near Seville). More complete calibration of each of these and other watersheds requires matching simulated and observed flows at more streamflow gages, including smaller tributaries. Calibration for more locations within each watershed also will improve the understanding of regional variations in model parameters.
- The initial HSPF model derived for the mainstem Illinois River (MIR) poorly simulated flow routing through the Illinois River, in part, because detailed information on flow routing characteristics associated with lakes and pooled areas in the MIR were not included. However, modifying the FTABLE of the Illinois River reach segment representing Peoria Lake showed that modeled flows downstream could be improved. Better simulation of flows on the Illinois River requires creation of FTABLEs for the entire MIR using more detailed stream geometry and storage information for each reach, which also should involve creating more reach segments along the river. This will be helpful in analyzing specific river management issues. However, it is envisioned that best results can be obtained by linking HSPF model output for the nine main sub-watersheds (Des Plaines, Kankakee, Fox, Vermilion, Mackinaw, Spoon, Sangamon, La Moine, and Macoupin) with a hydraulic model such as UNET.

Regional Variation in Parameters and Designation of Hydrologic Response Units

The three sets of calibrated parameters (for the upper Kankakee, Iroquois, and Spoon River watersheds) are not sufficient to provide a complete perspective on the potential range of HSPF parameters in the Illinois River basin. Calibrating parameters for more tributary watersheds and the MIR watershed will provide better insight into these parameter sets and a broader understanding of parameter variation and their potential application in regional parameterization for the entire basin. Future work also should investigate how well the calibrated parameters for the major tributary watersheds can be applied to smaller sub-watersheds.

The current model may be refined further by more rigorously classifying the landscape based on significant differences in soil types and land uses, and the regionalization of model parameters based on these soil types and land uses. Within each delineated watershed, there can be hydrologic response units (HRUs) or land segments with distinctly different runoff characteristics. These land segments usually are defined using differences in land use and soil types within a watershed. Runoff responses from each HRU are computed separately and then routed to simulate the overall flow from the watershed. The HRUs can be defined by different approaches, depending on the specific model application and associated watershed characteristics. Jones and Winterstein (2000) state that "experience with HSPF and the Stanford Watershed Model (the forerunner of HSPF) has shown that soil type is secondary to land use as a partitioning factor in HSPF simulations" (p. 24).

Land use affects the development of HRU parameters for the Illinois River basin. Agriculture accounts for roughly 90 percent of all land use over most of the basin. However, there are distinct differences in agricultural land use across the Illinois River basin, including variability in the spatial distribution and types of row crops, rural grassland, small grains, and other agricultural uses. The model's representation of hydrologic responses within the basin can be improved with further discretization and parameterization for separate agricultural land-use categories. In addition, there is noticeable variation in soil characteristics in the basin. As shown in Figures 4 and 31, and as given in the STATSGO soils database of BASINS 3.0, fine-textured soils (soil groups D, C, B, and B/D) together cover about 60 percent area of the Kankakee River watershed, 75 percent of the Iroquois River watershed, and 100 percent of the Spoon River watershed, respectively. The remaining area in the first two watersheds is coarser textured soils, such as loamy sand, loamy fine sand, and fine sand (soil groups A and A/D). Thus, in areas of relatively homogeneous land use, soil type may be expected to be a significant factor in the regional differences in hydrologic response.

Although the BASINS model automatically designates HRUs based on land-use type, unfortunately, the HSPF model does not provide unique parameter values for each HRU, and these parameter values must be calibrated. Also, the HSPF model cannot define HRUs using soil type. To accomplish this, the modeler must use GIS software to overlay the sub-watersheds, soils, and land-use data layers, manually define HRUs, and then develop corresponding parameter values for input in the UCI file. Calibration of parameters based on HRUs is best accomplished using smaller watershed areas with homogenous hydrologic responses; it become problematic when calibrating larger watersheds that may contain a combination of several HRU types. Unfortunately, aside from the metropolitan northeastern Illinois area, the Illinois River basin has relatively few gages on smaller watersheds that can aid in calibrating parameters for individual HRUs for the HSPF model.

Although the inputs to the HSPF model can be adjusted manually to create additional HRUs based on various combinations of land uses and soil types, for long-term usefulness, it may be desirable to examine if the existing WinHSPF interface can be modified (or an additional interface created) to create a model input file (*.UCI file) automatically with the full range of HRU combinations. Parameterization of the various HRU combinations for the Illinois River basin also should be a key modeling effort, with the goal of developing regionally applicable parameters for the primary HRU types within the basin.

Update of BASINS Datasets

Over the past ten years, there have been significant advances in the resolution and accuracy of many datasets used by hydrologic models. In many cases, more current datasets may be available now that could be used in place of the datasets developed at a national level for use in the BASINS model. For example, land-use data contained in the BASINS model were developed in the 1980s; and 1998 land-use data for Illinois are now available at a finer resolution. Soil type information and DEMs are also now available at a finer resolution. Updates in databases used by the BASINS model should significantly improve the Illinois River basins model as a framework for detailed calibration of sub-watersheds and also may improve the regional parameterization process and designation of HRUs. Such improvements will not only benefit the Illinois River basin model, but also additional modeling efforts in the basin by other modelers. Meteorological datasets also should be updated to provide for BASINS modeling beyond the year 1995. Development of meteorological datasets for years prior to 1970 also should be considered because the availability of older meteorological records provides the potential for model calibration using many additional discontinued streamflow gages on smaller watersheds.

Summary

The objective of this study was to initiate the development of a preliminary continuous-simulation hydrologic model of the entire Illinois River basin. This model will be used to conduct analyses in support of the Restoration Needs Assessment for the Illinois River Ecosystem Restoration project. The model also will be useful in assessing flow characteristics throughout the basin, the effects of changes in land use and climate, changes due to project alternatives, and potential problem areas and restoration alternatives.

The BASINS modeling system, developed by the USEPA, was selected for this study for several reasons.

- It was designed for multiple purposes in environmental and hydrologic practices.
- It is based on state-of-the-art ARCVIEW technology for easy data processing.
- It incorporates widely accepted models to simulate watershed hydrology and the transport of nutrients, pesticides, and sediments.
- It has a user-friendly interface to generate hydrologic parameters.
- It has an existing database of DEMs, land uses, streams, and soils for the Illinois River basin.

The Hydrologic Simulation Program – FORTRAN (HSPF, version 12) was used to simulate daily watershed streamflow. It was accessed through the WinHSPF graphical user interface, which interacts with the BASINS 3.0 utilities and datasets to aid in project development. The HSPF model requires spatial information about watershed topography, river/stream reaches, land use, and meteorology to simulate streamflows accurately. It uses hourly precipitation, potential evapotranspiration, temperature, wind speed, and solar radiation time-series data to perform hydrologic simulations when snow also is simulated. The HSPF comprehensive and dynamic watershed model simulates nonpoint source hydrology and water quality in combination with point source contributions and performs flow and water quality routing in watershed reaches. It has been used widely for hydrologic simulations on a watershed scale that assess the effects of land-use changes on hydrology and water quality.

The study plan to develop an HSPF model for the entire Illinois River basin involved tasks performed in different phases. The initial phase involved preparation of data that would be used for model development throughout the study. The HSPF model was developed during the second phase, and parameters were calibrated for the Kankakee River and Spoon River watersheds. In that process, the Kankakee River watershed was divided into two portions, the upper Kankakee and Iroquois River watersheds, and parameters were calibrated for the upper Kankakee, Iroquois, and Spoon River watersheds. During the third phase of study, a model for the entire Illinois River basin was developed, parameters from the three calibrated watersheds were tested in other tributary watersheds, appropriate parameter values were adopted, and the HSPF model was run to simulate flows for the entire Illinois River watershed. This report discusses the work performed in all three phases.

Preparation of Input Data

Of the USEPA-WDM stations for which meteorological data are given in the BASINS database, only 17 stations are located in the general vicinity of the Illinois River basin. More precipitation data stations were needed to reduce the effect of spatial variability of rainfall over the large area of the watersheds studied. Numerous additional weather stations in the Illinois River basin for which daily precipitation data were available for the study period were identified, and these data were extracted from the MRCC's database. Hourly precipitation data for 16 more stations located in the watershed also were extracted from the NOAA-NCDC database. All hourly stations were used as reference stations to disaggregate daily precipitation data available at local stations into hourly precipitation.

Model Calibration and Validation for Two Watersheds

The hydrologic component of the HSPF model was calibrated and validated separately for the Kankakee and Spoon River watersheds during the second phase of the study. The entire Kankakee River watershed was modeled in three sections: upper Kankakee River watershed upstream of Momence, Illinois; Iroquois River watershed upstream of Chebanse, Illinois; and the remainder of the watershed up to its outlet near Wilmington, Illinois. During calibration of the Kankakee and Spoon River watersheds, values of several sensitive model parameters were varied within a reasonable range to improve the agreement between the observed and simulated streamflow data. Calibration and validation were based on data from the 25-year period, 1970-1995, for which complete streamflow and meteorological data were available. Data from the 11-year period, 1985-1995, were used to calibrate the HSPF model, which was verified separately for a 16-year period, 1971-1986. Agreement between observed and simulated streamflow data on an annual, seasonal (monthly), and continuous (daily) basis was determined objectively (by plotting time-series data) and quantitatively. This was done to determine any trends due to seasonality and to find any discrepancies in long-term data values. Quantitative comparison was based on calculation of objective functions such as Nash-Sutcliffe efficiency (NSE), and coefficient of determination (R^2), intercept, and slope of linear regression fit between observed and simulated data. Relative percent difference between observed and simulated monthly and annual flows also was calculated and reported.

Model Development for Entire Illinois River Basin

In the third phase of this study, hydrologic simulations were performed using the HSPF model for the entire Illinois River basin using two different approaches: a) the HSPF model using a single UCI data file, and b) the HSPF model using a modular approach. The first approach delineated the entire Illinois River basin into 60 sub-watersheds using meteorological data from 56 gaging stations. The 60 sub-watersheds represent the practical limit that can be developed and still model the entire Illinois River basin in a single HSPF project. The second approach created individual HSPF projects for the watersheds of seven additional major tributaries (Des Plaines, Fox, Vermilion, Mackinaw, Sangamon, La Moine, and Macoupin) and the MIR. The modular approach divided the entire Illinois River basin into approximately 250 sub-watersheds, and the simulation used data from all 95 available precipitation gages.

Model calibration was not performed for the entire Illinois River basin for either approach. Instead, calibrated parameters from the three previously calibrated watersheds (upper Kankakee, Iroquois, and Spoon River watersheds) were tested over the entire Illinois River basin to determine which set of parameters worked best for various portions of the basin. The best results consistently were obtained by using calibrated parameters for the Spoon River watershed for all remaining portions of the Illinois River basin.

Both approaches removed much of the Des Plaines River watershed from the HSPF model and replaced this by an inlet location, from which flows observed were used to represent the Des Plaines River and Chicago Sanitary and Ship Canal rather than model simulation. This was done for two reasons: 1) the Chicago area is highly urbanized, and the watershed characteristics are totally different than those of the three calibrated watersheds; thus, it would not be appropriate to use any one of the three calibrated sets of the parameters; and 2) the Lake Michigan flow diversion provides an additional source of flow to the Chicago Sanitary and Ship Canal. Eventually, a detailed HSPF model that includes the Des Plaines River watershed and Chicago-Calumet drainage could be linked with the model for the remainder of the Illinois River basin.

The modular approach for modeling the entire Illinois River basin is preferred because it provides a broader framework for future modeling work, leading to more detailed applications in the major tributaries and sub-watersheds. Such an approach may be needed for the evaluation of watershed management practices and other applications.

Plans for Future Improvements

In addition to providing a useful tool for analyzing broad-scale restoration issues for the entire Illinois River basin, it is envisioned that the Illinois River BASINS-HSPF model will provide a framework for expansion into more detailed modeling within each sub-watershed. The model constructed for the entire Illinois River basin is at present considered only a preliminary hydrologic model. At this stage, it is not expected that this model gives reliable hydrologic predictions throughout the watershed for several reasons.

- Simulated flows for most major tributaries have not been calibrated.
- Calibration has been performed only using observed flows at four major outflow sites (Kankakee River at Momence and Wilmington, Iroquois River at Chebanse, and Spoon River near Seville).
- The initial HSPF model derived for the MIR poorly simulates the routing of flows through the Illinois River, in part, because detailed information on flow routing characteristics associated with MIR lakes and pooled areas were not included. Flow routing for the Illinois River can be improved by creating more model segments to the MIR, and adding greater detail to their respective hydraulic function tables. It is

envisioned that best results can be obtained by linking the HSPF model output for the nine main sub-watersheds to a dynamic hydraulic model.

Three sets of calibrated parameters for the upper Kankakee, Iroquois, and Spoon River watersheds are not sufficient to provide a complete perspective on the potential range of HSPF model parameters in the Illinois River basin. Parameters for the Spoon River watershed produced better streamflow estimates for all remaining regions of the Illinois River basin when compared with the parameters developed for the Kankakee and Iroquois River watersheds. It will be necessary to calibrate parameters for more tributary watersheds and the MIR watershed to obtain better insights into these parameter sets, and a broader understanding of parameter variation and their potential application in regional parameterization for the entire basin. The current model may be refined further by more rigorously classifying the landscape based on significant differences in soil types, land uses, and the regionalization of model parameters based on these soil types and land uses. Future work also should investigate whether the calibrated parameters for the major tributary watersheds can be applied to smaller sub-watersheds and the level of accuracy they provide.

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Appendix

Table A1. Details of Various USGS Streamgaging Stations Used in This Study

Watershed/River	Station ID	Station name	Location			Drainage area (sq mi)
			County	Latitude	Longitude	
Spoon	05570000	Spoon River at Seville	Fulton	40°29'24"	90°20'25"	1636
Iroquois	05526000	Iroquois River Near Chebanse	Kankakee	41°00'32"	87°49'24"	2091
Kankakee	05520500	Kankakee River at Momence	Kankakee	41°09'36"	87°40'07"	2294
Kankakee-Iroquois	05527500	Kankakee River Near Wilmington	Will	41°20'48"	88°11'11"	5150
Fox	05552500	Fox River at Dayton	La Salle	41°23'04"	88°47'21"	2642
Vermilion	05555300	Vermilion River Near Leonore	La Salle	41°12'30"	88°55'51"	1251
Mackinaw	05567500	Mackinaw River Near Congerville	Woodford	40°37'25"	89°14'30"	767
Sangamon	05583000	Sangamon River Near Oakford	Mason	40°07'26"	89°59'06"	5093
La Moine	05585000	La Moine River at Ripley	Brown	40°01'29"	90°37'54"	1293
Macoupin	05587000	Macoupin Creek Near Kane	Greene	39°14'03"	90°23'40"	427
DesPlains-1	05532500	Des Plaines River at Riverside	Cook	41°49'20"	87°49'15"	630
DesPlains-2	05536995	Chicago Sanit. & Ship Canal at Romeoville	Will	41°38'27"	88°03'35"	739
DesPlains-3	05539000	Hickory Creek at Joliet	Will	41°31'08"	88°04'10"	107
DesPlains-4	05540500	Du Page River at Shorewood	Will	41°31'20"	88°11'33"	324
IL River -1	05543500	Illinois River at Marseilles	La Salle	41°19'37"	88°43'03"	8259
IL River -2	05568500	Illinois River at Kingston Mines	Peoria	40°33'11"	89°46'38"	15818
IL River -3	05586100	Illinois River at Valley City	Pike	39°42'12"	90°38'43"	26744

Note: All counties listed are in Illinois.

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