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Fox River Watershed Investigation: Stratton Dam to the Illinois River PHASE II

Hydrologic and Water Quality Simulation Models

Part 4: Fox River Watershed Hydrology using the HSPF Model

Alena Bartosova, Mustafa Rahim, and Sally McConkey

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Illinois State Water Survey
Institute of Natural Resource Sustainability
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Champaign, Illinois

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Abstract

This report documents the development of the Fox River watershed hydrologic model using the Hydrological Simulation Program - FORTRAN (HSPF). The Fox River HSPF model simulates rainfall runoff processes for watersheds adjacent to the Fox River from Stratton Dam to the mouth of the Fox River at the Illinois River. Runoff is simulated from 31 separate tributary watershed models and is used as an input to the mainstem model. Observed flows at Stratton Dam are used as the upstream boundary condition defining inflow from the Fox River watershed above Stratton Dam.

Calibration is based on Hydrologic Response Units (HRUs). These units represent homogeneous areas of land use, soil type, and slope. Parameter values from prior calibration of Blackberry and Poplar Creek models were initially used for the same HRUs in the other 29 tributary watershed models and the mainstem model. However, additional calibration was needed to simulate flow at the Fox River mainstem gages accurately.

Calibration was simplified to determine model parameters for dominant HRUs covering more than 10 percent of drainage area. The model parameters for dominant HRUs and reported literature values guided development of model parameters for other major and minor HRUs. Parameter values were developed through calibration of the mainstem model using observed flows from United States Geological Survey gages at Algonquin, South Elgin, and Dayton. The Fox River mainstem model was calibrated for water years 1991–1999 and validated for water years 2000–2003.

Simulation results are presented in graphics, and model accuracies were evaluated through graphical comparisons and statistical measures such as the Nash-Sutcliffe efficiency coefficient and coefficient of determination. Exceedence probabilities of simulated and observed flows were compared to assess the simulation accuracy for high-, low-, and middle-range flows at three Fox River mainstem gaging stations.

The integrated model simulates flow at the mainstem gages adequately based on specified calibration criteria. Model performance for the two pilot watersheds, Blackberry and Poplar Creek, worsened slightly, but overall performance for all seven gaged tributary watersheds improved.

Acknowledgments

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Introduction

The Fox River watershed is located in southeastern Wisconsin and northeastern Illinois. The Illinois State Water Survey (ISWS) is participating in a study of the Fox River watershed within Illinois, below Stratton Dam to the confluence of the Fox River with the Illinois River. This report is one of a series of reports on the Fox River Watershed Investigation prepared by the ISWS. Working with the Fox River Study Group (FRSG), the ISWS prepared a plan to investigate water quality in the surface waters of the watershed. The plan has four phases. The first phase included a comprehensive inventory of studies and data for the watershed. The second phase outlines the development of a suite of hydrologic and water quality models to simulate hydrologic and water quality conditions in the watershed. The third phase focuses on data collection and model calibration. In the fourth phase, the tools developed will be used to guide planning. This work is being conducted for and in consultation with the FRSG and the Illinois Environmental Protection Agency (IEPA).

Project Overview

The Fox River in northeastern Illinois is the focal point of many communities along the river, providing an aesthetically pleasing area and opportunities for fishing, canoeing, and boating. The Fox River is also a working river. Two major cities, Elgin and Aurora, withdraw water for public water supplies, and the river serves as a receptor for stormwater and treated waste water. This highly valued river, however, has been showing signs of impairment over an increasing geographic area.

The IEPA in their *Illinois Water Quality Report 2000* (IEPA, 2000) listed parts of the Fox River in McHenry and Kane Counties and part of Little Indian Creek as impaired. The 2002 IEPA report (IEPA, 2002) listed the entire length of the Fox River in Illinois as impaired, as well as Nippersink, Poplar, Blackberry, and Somonauk Creeks, and part of Little Indian Creek, all tributaries to the Fox River. The IEPA has included the Fox River and these tributaries on their list of impaired waters, commonly called the 303(d) list (IEPA, 2003). In the 2004 IEPA water quality report (IEPA, 2004), the upper and parts of the lower Fox River are listed as not meeting or only partially meeting aquatic life use. Poplar, Flint, and Little Indian Creeks are also listed as only partially supporting aquatic life.

The 2006 IEPA report (IEPA, 2006) lists the entire length of the Fox River, Nippersink Creek, Tyler Creek, Crystal Lake outlet, Poplar Creek, Ferson Creek, and Blackberry Creek as impaired. The most prevailing potential sources for listing were hydromodification and flow regulation, urban runoff, and combined sewer overflows. The most prevailing potential causes for listing were flow alterations, habitat, sedimentation/siltation, dissolved oxygen, suspended solids, excess algal growth, fecal coliform bacteria, and PCBs. The 2008 and 2010 IEPA reports have not been finalized and/or approved prior to completion of this report, but continue to list Fox River and its tributaries as impaired.

In response to local concerns about the Fox River water quality, the Fox River Study Group organized in 2001. The FRSG comprises a diverse group of stakeholders representing municipalities, county government, water reclamation districts, and environmental and watershed groups from throughout the watershed. The goal of the FRSG is to address water quality issues in the Fox River watershed and assist with implementing activities to improve and maintain water quality. The FRSG has initiated activities to more accurately characterize the water quality of the Fox River, including data collection and preparation of comprehensive water quality models.

Reporting Structure

This section provides a short description of the various reports that have been published documenting the progress of the watershed investigation through different phases of the project.

The Phase I report (McConkey et al., 2004) reviews the available literature and data for the study area and includes recommendations for developing a suite of models to simulate hydrology and water quality to address key water quality issues in the targeted watershed. The Hydrological Simulation Program - FORTRAN version 12 model (HSPF, Bicknell et al., 2001) was selected to simulate watershed loading and delivery and routing of nonpoint and point sources of pollution from the entire watershed. The QUAL2 model was selected to simulate dissolved oxygen diurnal processes during steady-state low-flow conditions along the Fox River mainstem. The HSPF and the QUAL2 models are referred to as watershed loading and receiving stream models, respectively. A database was constructed to house water quality, sediment quality, habitat, and biological data (included in Phase II) available within the watershed; this database is called FoxDB. The structure of the database is described in the Part I report.

A series of reports have been prepared describing the Phase II work.

The report *Overview of Recommended Phase II Water Quality Monitoring, Fox River Watershed Investigation* (Bartosova et al., 2005) outlines a plan for monitoring to collect data for improved model calibration.

The Phase II, Part 1 report (Singh et al., 2007) describes methods and procedures used in developing the HSPF models. It also discusses sources of uncertainty in these models, as well as the data assimilation procedure conducted to prepare watershed loading models for the study area, and identifies statistical and graphical methods used in evaluating confidence in the model. It serves as a guide for model development, parameterization, calibration, and validation of the watershed loading models for all tributary watersheds and the Fox River mainstem.

The Phase II, Part 2 report (Bartosova et al., 2007a) presents the specific development of watershed loading models (HSPF) for two pilot watersheds (Blackberry and Poplar Creek) in the Fox River watershed. These pilot watersheds represent contrasting land use and soil conditions. The HSPF models were calibrated to simulate daily streamflow and selected water quality constituents.

The Phase II, Part 3 report (Bartosova et al., 2007b) describes the validation of hydrologic model parameters. Model parameters developed for the pilot watersheds were transferred to five tributary watersheds with flow data available for at least part of the study period: Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek. At this stage, these tributary watersheds were not used in the calibration process, but were used to test the transferability of model parameters to other watersheds. This report provides background on these five watersheds and compares HSPF-simulated discharges with observed discharges.

Biological data collected within the watershed were inventoried and the FoxDB was expanded to house those data. An assessment of the biological indicators and changes to the database structure are reported in Bartosova, 2008.

This Phase II, Part 4 report documents the hydrologic model for the Fox River mainstem. Model parameters developed for pilot watersheds and tested on the five validation watersheds were transferred to all remaining tributary watersheds and the Fox River mainstem watershed. The parameters were further adjusted as needed to reflect the changing conditions among the watersheds. This report presents results of calibration and validation.

Future reports will document the development of water quality components of the HSPF model as well as development of the receiving water quality model (QUAL2).

Fox River Watershed Model

Overview

The Fox River flows from Wisconsin through northeastern Illinois and joins the Illinois River at Ottawa. The Fox River drains 938 square miles in Wisconsin and 1720 square miles in Illinois. The river and land in the watershed are used for agriculture, industry, recreation, and urban development. The mainstem of the Fox River and the Chain of Lakes region are used for recreation. The Fox River is a source of potable water for public water supplies, and the Fox River and its tributaries carry stormwater and receive permitted discharges from wastewater treatment plants, combined sewers, and industry. There is increasing population growth and development pressure in the Fox River watershed west of the Chicago metropolitan area. In Illinois, the population of the Fox River watershed by 2020 is expected to increase dramatically (about 30 percent) from the 2000 total, with much of the growth in McHenry and Kane Counties. Land cover, soil type, water use, topography, and population density all have an impact on the watershed hydrology and, in combination, affect runoff and ultimately flows in the Fox River.

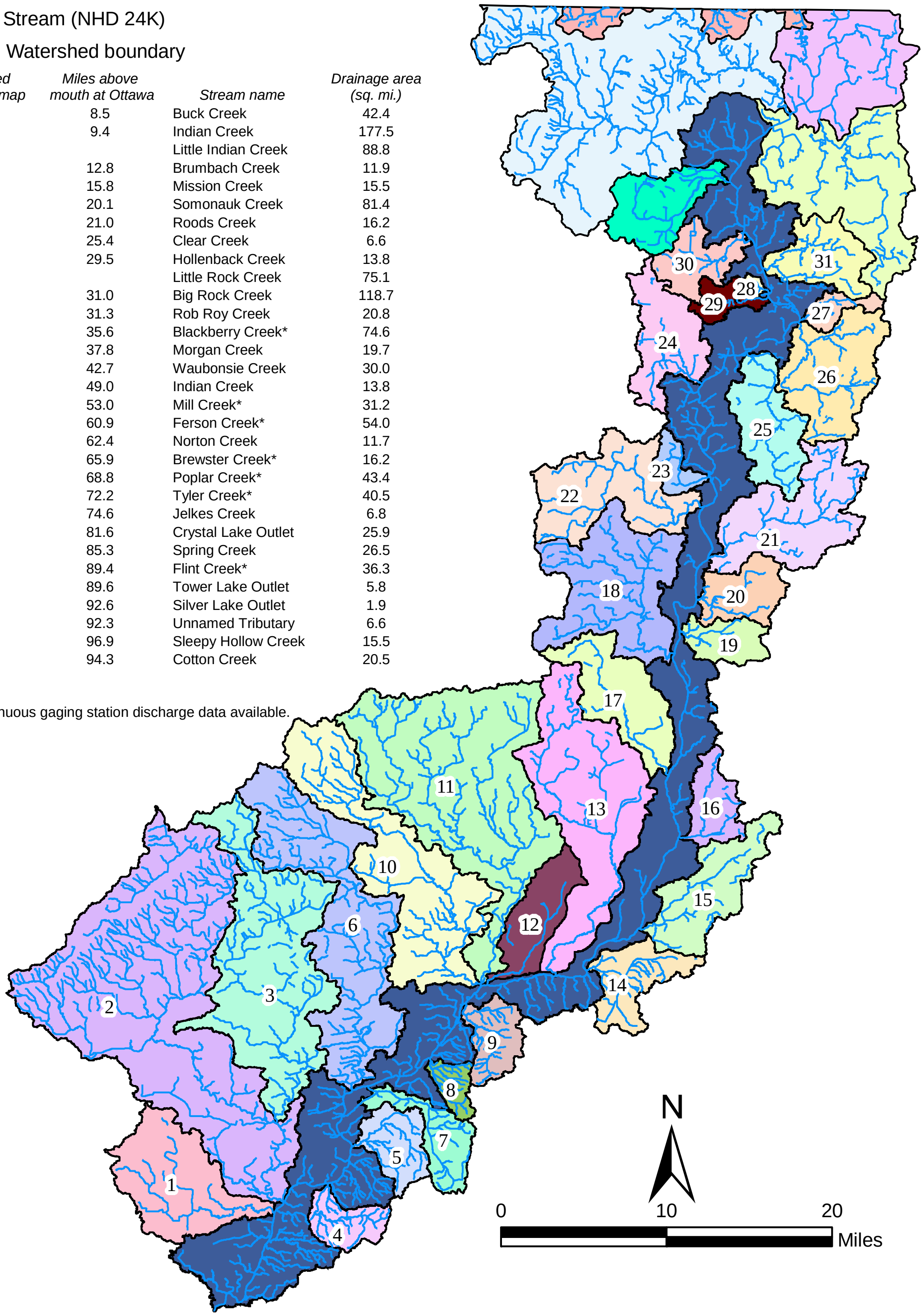
This report focuses on the calibration and validation of hydrologic components of the HSPF model. The integrated HSPF model includes the Fox River mainstem and 31 tributary watersheds downstream from the Chain of Lakes (Figure 1). The framework for the models was created using Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), version 3.1, a multipurpose environmental analysis system developed by the U.S. Environmental Protection Agency (USEPA, 2001). Protocols for model calibration and validation were developed for this project. These are described in the Phase II, Part 1 report: *Methodology and Procedures for Development of HSPF Models* (Singh et al., 2007).

Long-term, continuous observations of discharge available at gaging stations are used for model calibration and validation. Continuous discharge data are available for three gaging stations on the mainstem of the Fox River: Algonquin, South Elgin, and Dayton. Continuous discharge data are also available for seven tributaries for at least a portion of the simulation period: Blackberry Creek, Poplar Creek, Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek. Data from Water Years (WY) 1990–2003 were used for model development, calibration, and validation. A Water Year is the 12-month period from October 1 through September 30 of the following year and is designated by the calendar year in which it ends. Models were executed using an hourly time step to preserve the time step needed to simulate fast reaction times in smaller watersheds.

Model development was an iterative process, with the goal of establishing a set of model parameters that provides simulation results that best replicate observed flows. Initially, two pilot watersheds (Blackberry and Poplar Creek) were selected for simulation. These two watersheds were selected because long-term continuous discharge data and some water quality data were available. Furthermore, these two watersheds represent diverse land uses, rural and urban. The other five watersheds either have incomplete discharge records or lack water quality data that will be needed for later calibrations. During the calibration process for the pilot watersheds, a set of parameters for hydrologic response units (HRUs) was developed. An HRU represents a unique combination of land use, soil type, and slope category. Next, model parameters developed during calibration of the pilot watersheds were used to parameterize models of other tributary watersheds in the study area that did not have sufficient data for calibration. The five watersheds (Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek) were used initially to evaluate the model parameters outside the pilot watersheds and to test the efficiency of the parameter transfer (Bartosova et al., 2007b).

Since models of the five watersheds produced results consistent with calibration and validation, the remaining tributary watershed models were executed, followed by an execution of the mainstem model. Simulated discharges were compared with observed discharges at three United States Geological Survey (USGS) gaging stations on the mainstem of the Fox River. It was found that further adjustment to the HRU parameters was needed for calibration and validation of the model at the mainstem USGS gage locations. Therefore the integrated model was calibrated and validated at these gages; simultaneously they were also examined and recalibrated at the gages on the seven watersheds where discharge data were available (Blackberry Creek, Poplar Creek, Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek). The objective of the calibration was to establish parameter values that resulted in simulated model discharges that match observed flows at the three USGS gage stations on the mainstem within certain statistical requirements (as described later in this report), while also maintaining good simulation results at gages on tributary watersheds that met less rigorous statistical limits.

A revised set of HRU parameter values was determined for the integrated Fox River watershed model using data from the calibration period (WY 1991–1999). The models were then run for the validation period (WY 2000–2003) and the output was compared to observations to assess model capability to simulate conditions outside the calibration period. The revised set of model parameters differs from the parameter values used in the pilot study of Blackberry and Poplar Creeks (Bartosova et al., 2007a) and tested for Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek watersheds (Bartosova et al., 2007b).



Watershed number on map	Miles above mouth at Ottawa	Stream name	Drainage area (sq. mi.)
1	8.5	Buck Creek	42.4
2	9.4	Indian Creek	177.5
3		Little Indian Creek	88.8
4	12.8	Brumbach Creek	11.9
5	15.8	Mission Creek	15.5
6	20.1	Somonauk Creek	81.4
7	21.0	Roods Creek	16.2
8	25.4	Clear Creek	6.6
9	29.5	Hollenback Creek	13.8
10		Little Rock Creek	75.1
11	31.0	Big Rock Creek	118.7
12	31.3	Rob Roy Creek	20.8
13	35.6	Blackberry Creek*	74.6
14	37.8	Morgan Creek	19.7
15	42.7	Waubonsie Creek	30.0
16	49.0	Indian Creek	13.8
17	53.0	Mill Creek*	31.2
18	60.9	Ferson Creek*	54.0
19	62.4	Norton Creek	11.7
20	65.9	Brewster Creek*	16.2
21	68.8	Poplar Creek*	43.4
22	72.2	Tyler Creek*	40.5
23	74.6	Jelkes Creek	6.8
24	81.6	Crystal Lake Outlet	25.9
25	85.3	Spring Creek	26.5
26	89.4	Flint Creek*	36.3
27	89.6	Tower Lake Outlet	5.8
28	92.6	Silver Lake Outlet	1.9
29	92.3	Unnamed Tributary	6.6
30	96.9	Sleepy Hollow Creek	15.5
31	94.3	Cotton Creek	20.5

Notes:
* Continuous gaging station discharge data available.

Figure 1. Fox River watershed in Illinois and 31 major tributary watersheds

Study Watersheds

Table 1 and Figure 2 show the distribution of land use in the Fox River watershed and its 31 tributary watersheds. Land cover for Illinois from the Illinois Interagency Landscape Classification Project, or IILCP (Illinois Department of Agriculture, 2003), was used to determine and specify different land-use categories. In the broad-spectrum, the Fox River watershed appears to be primarily agricultural or rural in nature (51 percent crop and 13 percent rural grassland), but it still has some significant urban areas (urban high density, 2 percent; urban low/medium density, 9 percent; and urban open spaces, 10 percent). Urban areas are concentrated in the north and central areas, while southern tributary watersheds are primarily agricultural (Figure 2).

Table 2 reports the distribution of hydrologic soil groups in the Fox River mainstem watershed and its tributary watersheds. Hydrologic soil groups and the estimated percentage area they represent in the Illinois portion of the Fox River watershed and all tributary watersheds were estimated using the most detailed soil data available. The hydrologic soil group classification is from the U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey Manual* (Soil Survey Division Staff, 1993). The description of each soil group is provided in Table 3-9 of the manual. Soils of hydrologic soil group A are highly permeable (e.g., sand); soil groups B and C represent decreasing permeability, while soils of hydrologic soil group D have a very low permeability (e.g., clay). Soil type B is the prevalent soil type in the Fox River watershed. Figure 3 illustrates the hydrologic soil groups in the Fox River watershed. Singh et al. (2007) provides detailed descriptions of these datasets.

State Soil Geographic (STATSGO) data (Natural Resource Conservation Service [NRCS], 2003a) were uniformly available across the Fox River watershed study area. At the time of model development, more detailed Soil Survey Geographic (SSURGO) data (NRCS, 2003b) were available only for some counties. Both STATSGO and SSURGO data represent generalized categories of soil types; soil components in one map unit (polygon) are not necessarily in the same hydrologic soil group. Map units had to be clipped to watershed boundaries and, because the exact location of an individual soil component within a map unit was not specified, it was necessary to assume that the individual soil components were uniformly distributed throughout each map unit.

Alternate sources for soils data were used in some areas when SSURGO data were not available, although their geographic scope is limited. The ISWS digitized soil survey data for Kendall County (County Soil Association Maps, CSAM) as part of the Illinois Streamflow Assessment Model (ILSAM) project development. The resolution of this dataset is not as high as the resolution of SSURGO, but significantly higher than the resolution of STATSGO. Similarly, Cook County soil survey data were digitized for the Illinois Department of Transportation. This dataset was created on a single soil series level with a resolution comparable to SSURGO data, although the accuracy of the line work was lower. Table 2 lists the sources used to describe soils by watershed.

Table 1. Representation of Land Use Categories in the Study Area (Percent Watershed Area)

Watershed	*Corn*	*Forest*	*Rural Grass-land*	*Soy-beans*	*Water*	*Wetland*	*Urban High Density*	*Urban Low/ Medium Density*	*Urban Open Space*
Blackberry	30	7	20	27		<1	<1	7	9
Big Rock	45	3	12	37		<1	<1	1	1
Brewster	6	16	11	2	<1	1	7	19	38
Brumbach	34	6	16	42		2			
Buck	46	1	3	49	<1	<1			
Clear	35	8	20	29		1		3	4
Cotton	12	20	24	7	6	7	2	14	9
Crystal	9	8	3	6	5		5	27	38
Ferson	18	13	37	18			2	7	5
Flint	1	34	11	1	3	4	1	16	30
Fox River*	21	12	12	20	1	<1	3	18	13
Hollenback	39	5	16	39		<1		<1	
Indian (Kane, DuPage)	5	7		7			9	28	45
Indian (LaSalle, DeKalb, Lee)	45	2	9	43	<1	1		<1	<1
Jelkes	5	18	18	8			5	17	28
Little Indian	49	1	5	45					
Little Rock	50	2	8	35		<1	1	1	2
Mill	17	7	28	20			2	12	13
Mission	39	5	10	45		1			
Morgan	30	9	21	34	1	<1		1	3
Norton	5	24	6	3	<1		4	15	43
Poplar	3	15		2	2	1	6	31	40
Rob Roy	46	2	10	41		<1			1
Roods	37	1	14	47		1			
Silver Lake		30	28	2	4	2		10	24
Unnamed Tributary (downstream of Silver Lake)	4	23	28	4			7	22	12
Sleepy Hollow	6	30	30	6	1	2	2	7	17
Somonauk	44	4	11	38	1	1		1	0
Spring	4	40		1		<1		4	50
Tower Lake		31	29	4	6	5		16	9
Tyler	27	9	20	24			2	11	7
Waubonsee	19	2	7	17			8	24	23
Combined study area	30	9	12	28	1	1	2	8	10

Notes: * mainstem watershed only
Values are rounded.

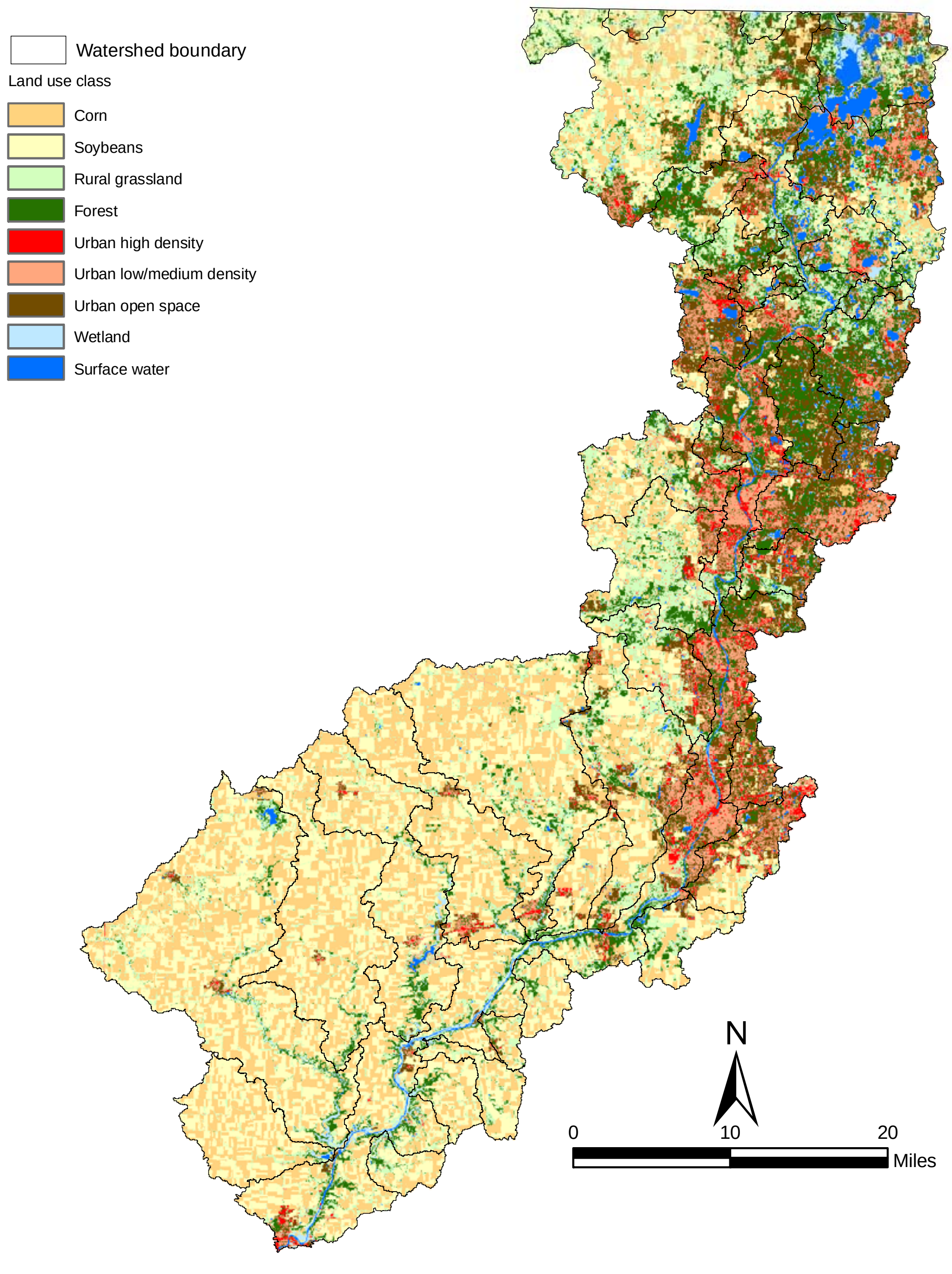


Figure 2. Land use categories in the Fox River watershed

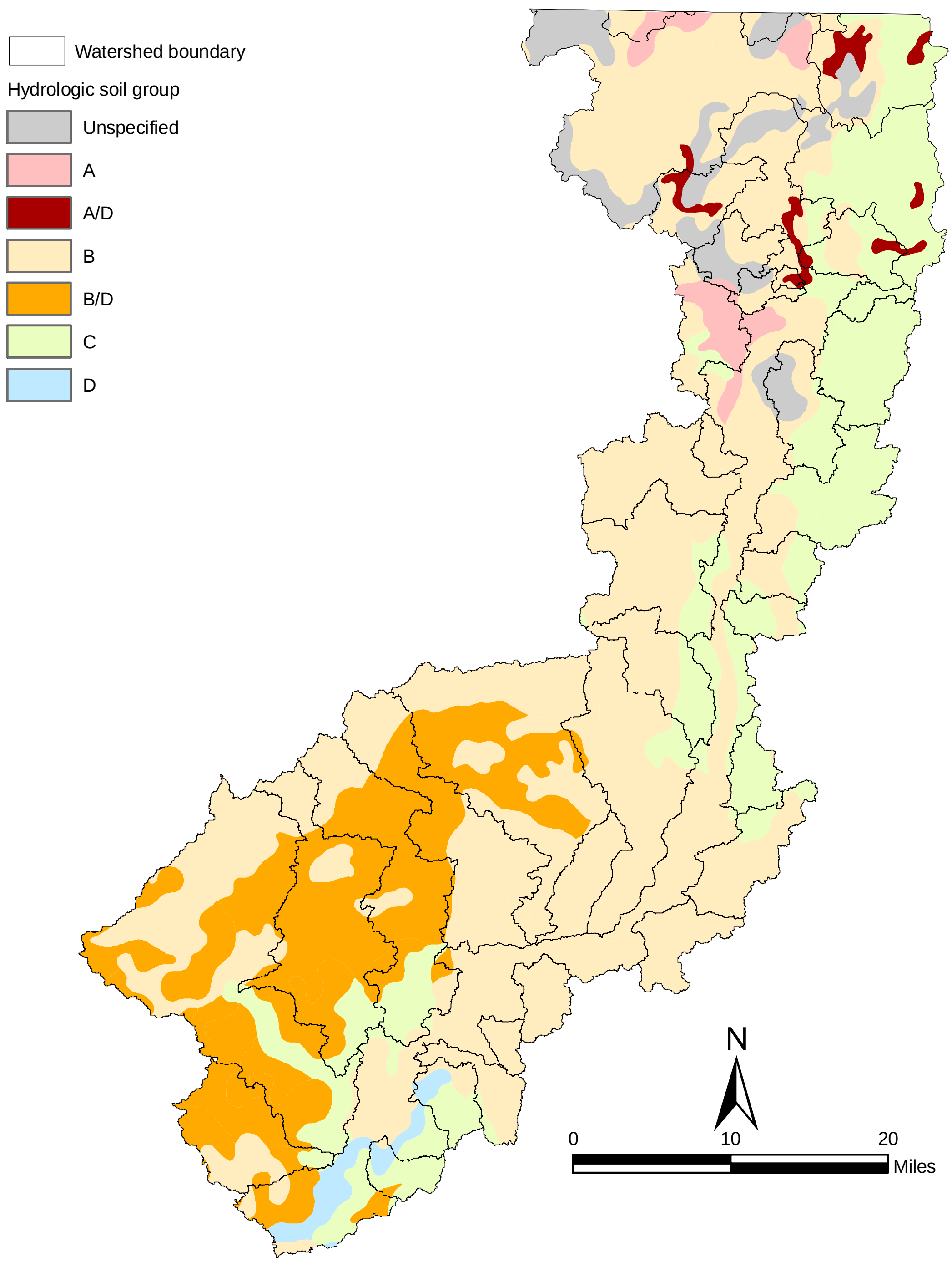


Figure 3. Soil types in the Fox River watershed

Table 2. Representation of Soil Groups and Soil Data Sources Used for Tributary and Mainstem Models

Watershed	*Impervious land*	*A*	*B*	*C*	*D*	*Soil Data Sources*
		Hydrologic soil group				
Blackberry	3	2	84	6	5	SSURGO (Kane), CSAM (Kendall)
Big Rock	1		98		2	STATSGO
Brewster	12	<1	41	36	10	SSURGO(Kane, DuPage), CSAM (Cook)
Brumbach			4	74	22	STATSGO
Buck			95		5	STATSGO
Clear	1		87		12	STATSGO
Cotton	6	7	39	35	13	SSURGO (McHenry, Lake)
Crystal	13	4	60	21	2	SSURGO (McHenry, Kane)
Ferson	4	3	84	9		SSURGO (Kane)
Flint	6	8	15	57	14	SSURGO (McHenry, Lake), CSAM (COOK)
Fox River*	**	3	75	19	3	STATSGO
Hollenback	<1		95		5	STATSGO
Indian (Kane, DuPage)	17	<1	41	43	<1	SSURGO (Kane, DuPage)
Indian (LaSalle, DeKalb, Lee)	<1		100		<1	STATSGO
Jelkes	10	3	86	<1	1	SSURGO (Kane)
Little Indian			100			STATSGO
Little Rock	1		99			STATSGO
Mill	6	<1	71	23		SSURGO
Mission			27	55	19	STATSGO
Morgan	1		95		5	STATSGO
Norton	8	<1	52	34	5	SSURGO (Kane, DuPage), CSAM (Cook)
Poplar	15		19	51	14	SSURGO, CSAM (COOK)
Rob Roy			96		4	SSURGO (Kane), CSAM (Kendall)
Roods			91	9		STATSGO
Silver Lake	3	24	40		33	SSURGO (McHenry)
Unnamed Tributary (downstream of Silver Lake)	13	8	75		4	SSURGO (McHenry)
Sleepy Hollow	4	2	75	<1	19	SSURGO (McHenry)
Somonauk	<1		99		<1	STATSGO
Spring	1		25	44	30	SSURGO (McHenry, Lake, Kane), CSAM (Cook)
Tower Lake	6	9	19	56	10	SSURGO (Lake)
Tyler	5	3	90	0	1	SSURGO (Kane)
Waubonsee	14	<1	65	18	3	SSURGO (Kane, DuPage, Will), CSAM (Kendall)
Combined study area	3	1	80	12	4	

Notes: * mainstem watershed only
** impervious area was not simulated separately due to the HSPF computational limits
Values are rounded.

Table 3 shows the distribution of watershed slope categories in the study area as simulated. The average slope of each subwatershed is calculated by the BASINS system during the watershed delineation from digital elevation model raster data distributed by the USGS.

Table 3. Model Representation of Slope Categories in the Study Area (Percent Watershed Area)

Watershed	*Slope Categories*			
	<2%	*2-4%*	*4-6%*	*>6%*
Blackberry	70	30		
Big Rock	76	24		
Brewster	9	87	4	
Brumbach		88		12
Buck	93	2		5
Clear		92	8	
Cotton	19	73	8	
Crystal	35	35	21	10
Ferson	12	67	21	<1
Flint	1	73	26	
Fox River*	6	63	31	
Hollenback		76	24	
Indian (Kane, DuPage)	95	5		
Indian (LaSalle, DeKalb, Lee)	49	50	1	
Jelkes		16	74	10
Little Indian	94	6		
Little Rock	95	5		
Mill	19	77	4	
Mission	35	63		2
Morgan	43	47	10	
Norton	60	28	7	5
Poplar	8	84	8	
Rob Roy	97		3	
Roods		100		
Silver Lake	5		57	38
Unnamed Tributary (downstream of Silver Lake)		44	19	38
Sleepy Hollow	11	60	29	
Somonauk	76	24		
Spring	15	53	27	6
Tower Lake		23	72	5
Tyler	44	56		<1
Waubonsee	88	12		
Combined study area	45	44	10	1

Notes: * mainstem watershed only
Values are rounded. Average slope was used for each subwatershed.

Climate Data

Various climate data are required for hydrologic model development, calibration, and validation. Time series of climate data provide the input necessary for the HSPF model to simulate the continuous hydrologic and water quality response of the watershed. Appropriate representation of precipitation, temperature, wind speed, potential evapotranspiration (PET), potential surface evaporation, solar radiation, dew point temperature, and cloud cover are required to develop a valid model. As a group, these time series allow the HSPF model to represent changing weather conditions in the study watershed for the simulation. Climate data were compiled from all available stations for the period of interest, stored in the HSPF Watershed Data Management (WDM) format, and resolved in an hourly time step to accommodate the algorithm in the HSPF model.

To achieve the best representation of spatial variability of precipitation, data from multiple climate stations located in or near the study area were incorporated into the models. (Note that the remaining climate data were recorded at a very limited number of stations.) Information from several data sources was combined to obtain the most complete dataset. Table 4 lists the available data for stations located within or in close proximity (10 miles or less) to the Fox River watershed. The data recorded at each climate station were reviewed for consistency with data recorded at nearby stations. Whenever any ambiguity was found for a station compared to the nearby stations, those data were further evaluated and excluded if necessary. For example, significant differences were found in annual precipitation reported at the St. Charles Illinois Climate Network (ICN) station compared to annual precipitation at the Aurora COOP and Wheaton 3 SE stations; therefore St. Charles ICN precipitation data were not used for any tributary watershed or mainstem. Similarly, DeKalb ICN and Aurora Airport station precipitation were purged from the model input (see Singh et al., 2007, and Bartosova et al. 2007a).

A representative climate station was assigned to each subwatershed within a tributary or mainstem watershed based on the Thiessen polygon method (Figure 4), as only one station can be assigned to a subwatershed. Any missing data were replaced using values from nearby stations.

Table 5 shows which nearby climate stations were used to replace missing values and in what order. Mendota 2 SE station is excluded from climate tables as it did not dominate any subwatershed. Other climate data were provided from the three stations that had required information. Cloud cover data were assigned from the Chicago O’Hare International Airport station. Evaporation data were supplied by the St. Charles ICN station. Evaporation data for the St. Charles ICN station used for the pilot watershed calibration were replaced with new updated data. All other climate data were assigned from the two ICN stations in St. Charles and DeKalb (Table 6).

Table 7 shows lists of hourly stations that were used to disaggregate daily precipitation data. Before disaggregating daily data as hourly, several adjustments were necessary. Hourly data are recorded with calendar day and hour when precipitation occurs. However, NCDC COOP daily data recording starts at 7 a.m. the day before and continues to 6:59 a.m. of the reporting day, so it consists of 7 hours of precipitation from the reporting day as well as 17 hours from the previous day.

Another aspect of the disaggregation is the algorithm in the WDM Utility Tool that performs this task. The algorithm uses a triangular distribution routine that may result in assignment of hourly precipitation that is not proportionally allocated. When the daily data is not proportionately distributed, total daily values may differ from the original data. On the other hand, hourly stations may not have data or may have no precipitation for certain days or hours, but daily stations may have precipitation for that time period, so proportional disaggregation will not be ideal for those data.

A methodology was developed to cope with these issues. It was necessary to temporarily shift the time stamps on the hourly data to correspond with the daily data reporting period prior to disaggregating the daily data. The time-shifted data disaggregated into hourly time steps were then adjusted using the developed FORTRAN scripts to ensure that the precipitation was proportionally assigned consistent with the hourly station data. The corrected proportional data were then shifted back to match actual time.

Table 8 shows average, high, and low precipitation for all stations within and/or near the Fox River Watershed between WY 1991 and WY 2003. The highest annual precipitation of 50.9 inches was observed at Aurora COOP station for WY 1996. The Elburn station showed the same precipitation because missing data for year 1996 were substituted with data from the Aurora COOP station. The lowest annual precipitation of 18.3 inches was observed at St. Charles ICN station for WY 2003; however, the precipitation data recorded at this station were not consistent with nearby stations and thus were excluded from the modeling. Mean annual precipitation for WY 1991–2003 ranges from 30 inches (at DeKalb ICN station) to 37.8 inches (at Barrington COOP station).

Table 4. Data Available for Stations Located at or Within 10 Miles of the Fox River Watershed

Station Name	*Precipitation*	*Temperature*	*Wind speed*	*Solar radiation*	*Dew point*	*Potential evapotranspiration*	*Evaporation*
Antioch+	D	D					
Aurora Airport+	H*	H*/D	H*/D	D	H*/D	D	
Aurora (Coop)	D	D					
Barrington 3 SW	D	D					
Compton 1 NW	D*	D*					
Crystal Lake 4 NW (Coop)	D*						
Dayton River	D*						
De Kalb ICN+	H*/D*	H*/D*	H*	H*	H*	H*	
De Kalb (Coop) +	D	D					
DuPage	H/D	H/D	H/D	D	H/D		
Earlville 3 S	D*						
Elburn	D*						
Elgin	D	D					
Elk Grove+	D*						
Gurnee Public Works+	D						
Hampshire 8 SE	D*						
Lake Villa 2 NE+	D	D					
Marengo+	D	D					
Marseilles Lock+	D	D*					
McHenry Stratton L&D	H/D	D					
Mendota 2 SE+	D*						
Morris 1 NW+	D	D					
Mount Prospect+	D*						
Mundelein 4 WSW	D*	D*					
Newark 2 SSE	D*						
Ottawa 5 SW	D	D					
Paw Paw 2 NW	D	D					
Plainfield 3 NE	D						
Plano	D*						
Shabbona 3 S	H/D						
Spring Grove+	D*						
St. Charles ICN+	H*	H*	H*	H*	H*	H*	H
St. Charles 7 NW (Coop)	D						
Streamwood	D	D					
Utica Starved Rock Dam+	D	D*					
Waterman	H*						
Wheaton 3 SE+	D	D					
Woodstock 5 NW+	D*						
Yorkville 3 SW	D*						

Notes: * Period of record does not cover the full calibration/validation period (1990–2003)
+ Station was not assigned directly to any subwatershed, but data were used to replace missing data or to disaggregate daily data to hourly
D = daily data, H = hourly data

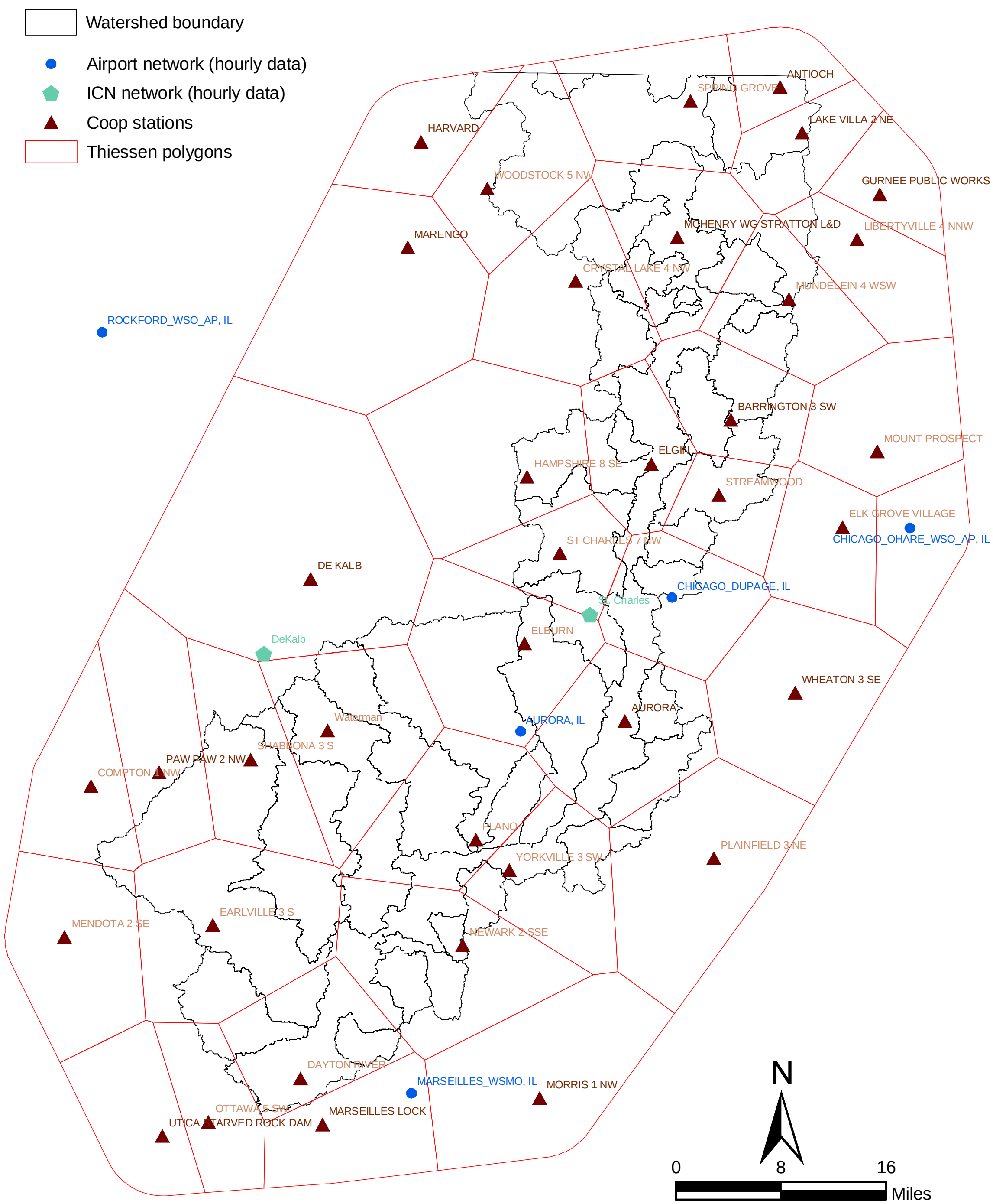


Figure 4. Location of climate stations

Table 5. List of Climate Stations and Their Nearby Stations Used to Replace Missing Values

Station Name	*1st*	*2nd*	*3rd*	*4th*	*5th*
Aurora (Coop)	Elburn	Plainfield	Wheaton 3 SE		
Barrington 3 SW	Streamwood	Elgin	Mundelein 4 WSW	Mount Prospect	Elk Grove
Compton 1 NW	Paw Paw 2 NW	Mendota 2 SE	Shabbona 3 S	Earlville 3 S	De Kalb (Coop)
Crystal Lake 4 NW (Coop)	McHenry Stratton L&D	Woodstock 5 NW	Marengo	Elgin	Hampshire
Dayton River	Marseilles Lock	Ottawa 5 SW	Utica Starved Rock Dam	Earlville 3 S	
DuPage	St. Charles ICN	Streamwood	St. Charles 7 NW (Coop)	Elgin	Aurora (Coop)
Earlville 3 S	Mendota 2 SE	Paw Paw 2 NW	Shabbona 3 S	Dayton River	Compton 1 NW
Elburn	Aurora (Coop)	St. Charles 7 NW (Coop)	Hampshire 8 SE	Plano	Elgin
Elgin	Streamwood	Barrington 3 SW	Hampshire 8 SE	St. Charles 7 NW (Coop)	Crystal Lake 4 NW (Coop)
Hampshire 8 SE	St. Charles 7 NW (Coop)	Elgin	St. Charles ICN	Elburn	DuPage
McHenry Stratton L&D	Crystal Lake 4 NW (Coop)	Mundelein 4 WSW	Spring Grove	Lake Villa 2 NE	Antioch
Mundelein 4 WSW	Libertyville	McHenry Stratton L&D	Gurnee Public Works	Barrington 3 SW	Lake Villa 2 NE
Newark 2 SSE	Yorkville 3 SW	Plano	Morris 1 NW	Dayton River	
Ottawa 5 SW	Utica Starved Rock Dam	Dayton River	Marseilles Lock	Earlville 3 SW	
Paw Paw 2 NW	Compton 1 NW	Shabbona 3 S	Earlville 3 S	De Kalb ICN	Mendota 2 SE
Plainfield 3 NE	Aurora (Coop)				
Plano	Yorkville 3 SW	Newark 2 SSE	Aurora (Coop)	Aurora Airport	Elburn
Shabbona 3 S	Paw Paw 2 NW	De Kalb ICN	Compton 1 NW	Earlville 3 S	De Kalb (Coop)
St. Charles 7 NW (Coop)	St. Charles ICN	Hampshire 8 SE	Elburn	DuPage	Elgin
Streamwood	Elgin	Barrington 3 SW	DuPage	Elk Grove	Mount Prospect
Waterman	Shabbona 3 S	De Kalb ICN	Aurora (Coop)	St. Charles ICN	DuPage
Yorkville 3 SW	Plano	Newark 2 SSE	Aurora Airport	Aurora (Coop)	Plainfield

Table 6. List of Stations and the Stations that Provide Certain Climate Data: Wind Speed, Solar Radiation, Dew Point, and PET

Station using wind speed, solar radiation, dew point, and PET data from	
St. Charles ICN	*De Kalb ICN*
Aurora (Coop)	Compton 1 NW
Barrington 3 SW	Dayton River
Crystal Lake 4 NW (Coop)	Earlville 3 S
DuPage	Newark 2 SSE
Elburn	Ottawa 5 SW
Elgin	Paw Paw 2 NW
Hampshire 8 SE	Shabbona 3 S
McHenry Stratton L&D	Waterman
Mundelein 4 WSW	
Plainfield	
Plano	
St. Charles 7 NW (Coop)	
Streamwood	
Yorkville 3 SW	

Table 7. List of Hourly Stations That Were Used to Disaggregate Daily Precipitation Data

Daily Station	*Hourly station 1*	*Hourly station 2*
Aurora (Coop)	St. Charles ICN	
Barrington 3 SW	Chicago O'Hare	
Compton 1 NW	Shabbona 3 S	De Kalb ICN
Crystal Lake 4 NW (Coop)	McHenry Stratton L&D	
Dayton River	Shabbona 3 S	
De Kalb (Coop)	De Kalb ICN	
Earlville 3 S	Shabbona 3 S	Waterman
Elburn	St. Charles ICN	
Elgin	St. Charles ICN	
Hampshire 8 SE	St. Charles ICN	
Mundelein 4 WSW	McHenry Stratton L&D	
Newark 2 SSE	Shabbona 3 S	Waterman
Ottawa 5 SW	Shabbona 3 S	
Paw Paw 2 NW	Shabbona 3 S	De Kalb ICN
Plainfield 3 NE	St. Charles ICN	
Plano	Waterman	
St. Charles 7 NW (Coop)	St. Charles ICN	
Streamwood	St. Charles ICN	
Yorkville 3 SW	Waterman	

Table 8. Annual Precipitation (Inches) at Stations and Watershed Assignments (WY 1991–2003). Final data are shown as used in simulation after replacing any missing data.

Station	*Watersheds*	*Statistics*	*Precipitation (in) Time period (WY)*
Aurora (Coop) (ID 110338)	Blackberry Creek, Indian Creek*, Mill Creek, Wabaunsee Creek	Mean annual	37.7
		High (Year)	51.0 (1996)
		Low (Year)	29.8 (1994)
Barrington 3 SW (ID 110442)	Flint Creek, Poplar Creek, Spring Creek	Mean annual	37.8
		High (Year)	49.4 (1993)
		Low (Year)	26.3 (2003)
Compton 1 NW (ID 111835)	Indian Creek	Mean annual	37.7
		High (Year)	47.6 (1993)
		Low (Year)	28.9 (2003)
Crystal Lake 4 NW (Coop) (ID 112048)	Crystal Creek, Sleepy Hollow Creek	Mean annual	37.4
		High (Year)	48.7 (1999)
		Low (Year)	26.1 (2003)
Dayton River (ID 112178)	Brumbach Creek, Buck Creek, Indian Creek	Mean annual	37.1
		High (Year)	46.6 (1993)
		Low (Year)	28.2 (1994)
DuPage	Brewster Creek, Ferson Creek, Mill Creek, Norton Creek	Mean annual	33.4
		High (Year)	49.9 (1993)
		Low (Year)	23.3 (2003)
Earlville 3 S (ID 112510)	Buck Creek, Indian Creek, Little Indian Creek	Mean annual	35.0
		High (Year)	48.8 (1993)
		Low (Year)	24.8 (2003)
Elburn (ID 112709)	Big Rock Creek, Blackberry Creek, Mill Creek, Tyler Creek	Mean annual	37.2
		High (Year)	50.9 (1996)
		Low (Year)	27.9 (2003)
Elgin (ID 112736)	Crystal Creek, Ferson Creek, Jelkes Creek, Poplar Creek	Mean annual	37.0
		High (Year)	49.3 (1993)
		Low (Year)	25.8 (2003)
Hampshire 8 SE (ID 113782)	Ferson Creek, Tyler Creek	Mean annual	37.4
		High (Year)	49.3 (1993)
		Low (Year)	27.5 (2003)
McHenry Stratton L&D (ID 115493)	Cotton Creek, Silver Lake Outlet, Unnamed Tributary (next to Silver Lake), Sleepy Hollow Creek	Mean annual	34.0
		High (Year)	45.0 (1993)
		Low (Year)	25.4 (2003)
Mundelein 4 WSW (ID 115961)	Cotton Creek, Flint Creek, Tower Lake Outlet	Mean annual	35.4
		High (Year)	50.7 (1993)
		Low (Year)	25.2 (2003)
Newark 2 SSE (ID 116065)	Clear Creek, Hollenback Creek, Mission Creek, Roods Creek, Somonauk Creek	Mean annual	35.1
		High (Year)	46.6 (1993)
		Low (Year)	28.2 (1994)
Ottawa 5 SW (ID 116526)	Buck Creek	Mean annual	33.3
		High (Year)	45.3 (1993)
		Low (Year)	25.1 (2003)
Paw Paw 2 NW (ID 116661)	Indian Creek	Mean annual	35.1
		High (Year)	48.9 (1993)
		Low (Year)	27.7 (1997)
Plainfield 3 NE	Morgan Creek, Wabaunsee Creek	Mean annual	37.7
		High (Year)	51.0 (1996)
		Low (Year)	28.9 (2001)

Table 8. (Continued)

Station	Watersheds	Statistics	Precipitation (in) Time period (WY)
Plano (ID 116855)	Big Rock Creek, Hollenback Creek, Little Rock Creek, Rob Roy Creek, Somonauk Creek	Mean annual	37.4
		High (Year)	50.4 (1996)
		Low (Year)	28.7 (1997)
Shabbona 3 S (ID 117833)	Indian Creek, Little Indian Creek	Mean annual	36.2
		High (Year)	43.1 (1996)
		Low (Year)	24.3 (2003)
St. Charles 7 NW (Coop) (ID 117586)	Ferson Creek, Mill Creek	Mean annual	36.1
		High (Year)	48.4 (1993)
		Low (Year)	28.0 (2003)
Streamwood (ID 118324)	Brewster Creek, Poplar Creek	Mean annual	35.8
		High (Year)	49.3 (1993)
		Low (Year)	25.7 (2003)
Waterman (ID 119010)	Big Rock Creek, Little Indian Creek, Little Rock Creek, Somonauk Creek	Mean annual	36.2
		High (Year)	43.1 (1996)
		Low (Year)	24.3 (2003)
Yorkville 3 SW (ID 119827)	Blackberry Creek, Hollenback Creek, Morgan Creek	Mean annual	37.5
		High (Year)	50.4 (1996)
		Low (Year)	28.7 (1997)

Notes: Replaced missing values in precipitation series affected total precipitation for water years
* Indian Creek by Aurora

Streamflow Data Available for Calibration

There are four USGS streamflow gages on the Fox River mainstem within the study area from Stratton Dam to the junction of the Fox River and the Illinois River. These gages are located at Algonquin (USGS ID 05550000), South Elgin (USGS ID 05551000), Montgomery (USGS ID 05551540), and Dayton (USGS ID 05552500). Table 9 lists streamflow statistics for the Algonquin, South Elgin, and Dayton gaging stations available for WY 1991–2003. The Montgomery gaging station became operational in 2002; there are insufficient data to compute meaningful statistics for the simulation period of this study. Streamflow statistics for the seven tributary gages are reported in the Phase II, Part 3 report (Bartosova et al., 2007b).

The Algonquin gage is located in McHenry County. It has daily streamflow records from WY 1915 to the present. The drainage area of the Fox River at the Algonquin gage is 1403 square miles (sq. mi.). Recorded mean flow for the simulation period, WY 1991–2003, at the Algonquin gage is 1105 cubic feet per second (cfs). Mean annual streamflows are plotted in Figure 5. Figure 6 shows mean monthly flows recorded at the Algonquin gage during the simulation period. Streamflow is lowest in July through October and highest in March through June.

The USGS gaging station at South Elgin in Kane County has daily streamflow records for WY 1990–1998. This means data were available during a large portion of the calibration period but not during the validation period. The drainage area of the Fox River at the South Elgin gage is 1556 sq. mi. Recorded mean daily flow for the record period at the South Elgin gage is 1289 cfs. Mean annual streamflows are plotted in Figure 7. Figure 8 shows mean monthly flows recorded at the South Elgin gage during the record period. Streamflow is lowest in August through October and highest in February through June.

The USGS gaging station at Dayton is located close to the mouth of the Fox River in LaSalle County. This station has data for WY 1915 to the present. Recorded mean daily flow at the Dayton gage for the simulation period is 2223 cfs. Mean annual streamflows are plotted in Figure 9. Figure 10 shows mean monthly flows recorded at the Dayton gage during the simulation period. Streamflow is lowest in August through October and highest from March to May.

Table 9. Streamflow Statistics for Dayton, Algonquin, and South Elgin

		Time period (WY)
Station	*Statistic*	*1991-2003*
Algonquin (USGS 05550000)	Mean annual flow, cfs	1105
	High, cfs	1936
	(Year)	(1993)
	Low, cfs	513
	(Year)	(2003)
		1991-1998
South Elgin (USGS 05551000)	Mean annual flow, cfs	1289
	High, cfs	2245
	(Year)	(1993)
	Low, cfs	1001
	(Year)	(1994)
		1991-2003
Dayton (USGS 05552500)	Mean annual flow, cfs	2223
	High, cfs	3938
	(Year)	(1993)
	Low, cfs	974
	(Year)	(2003)

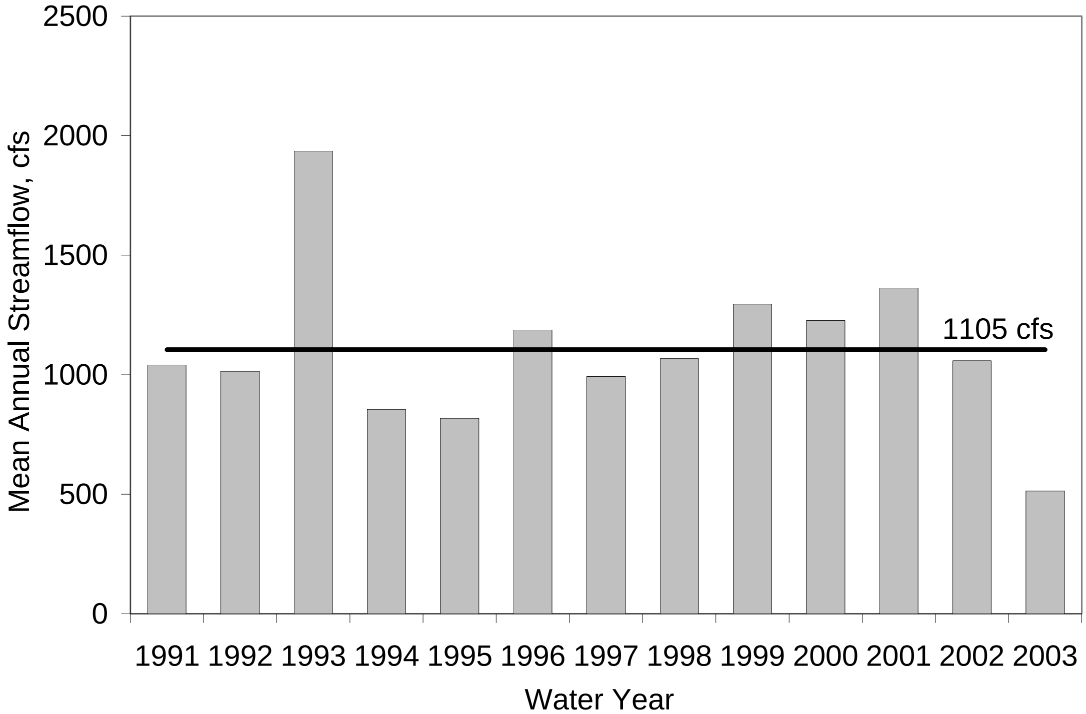


Figure 5. Mean annual streamflows, Algonquin (USGS 05550000)

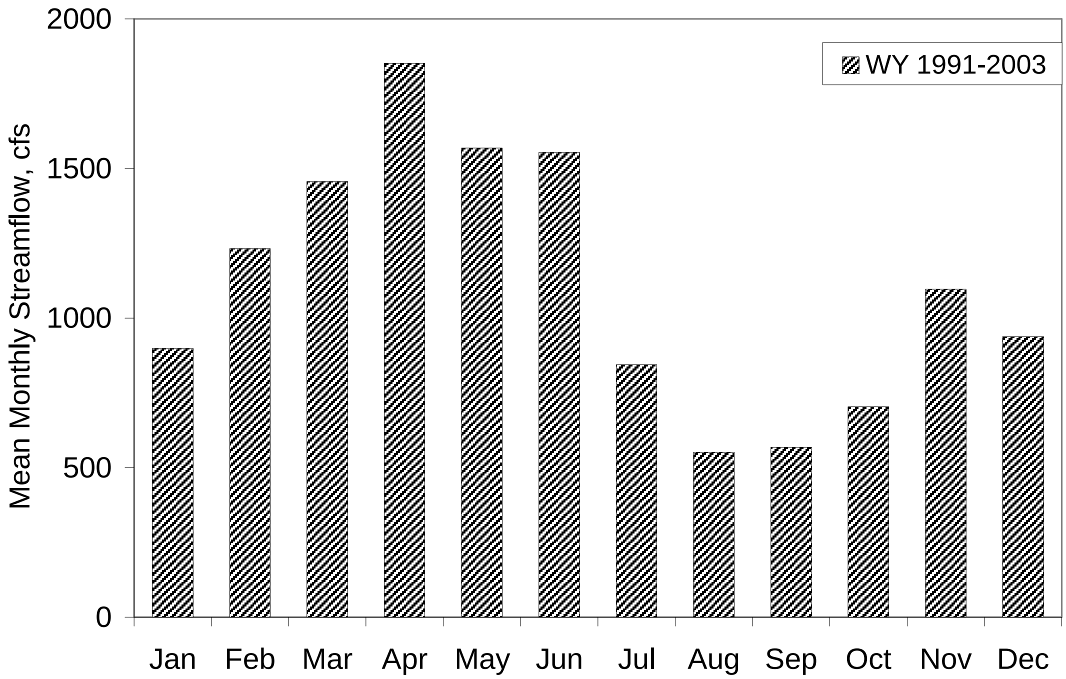


Figure 6. Mean monthly streamflows, Algonquin (USGS 05550000)

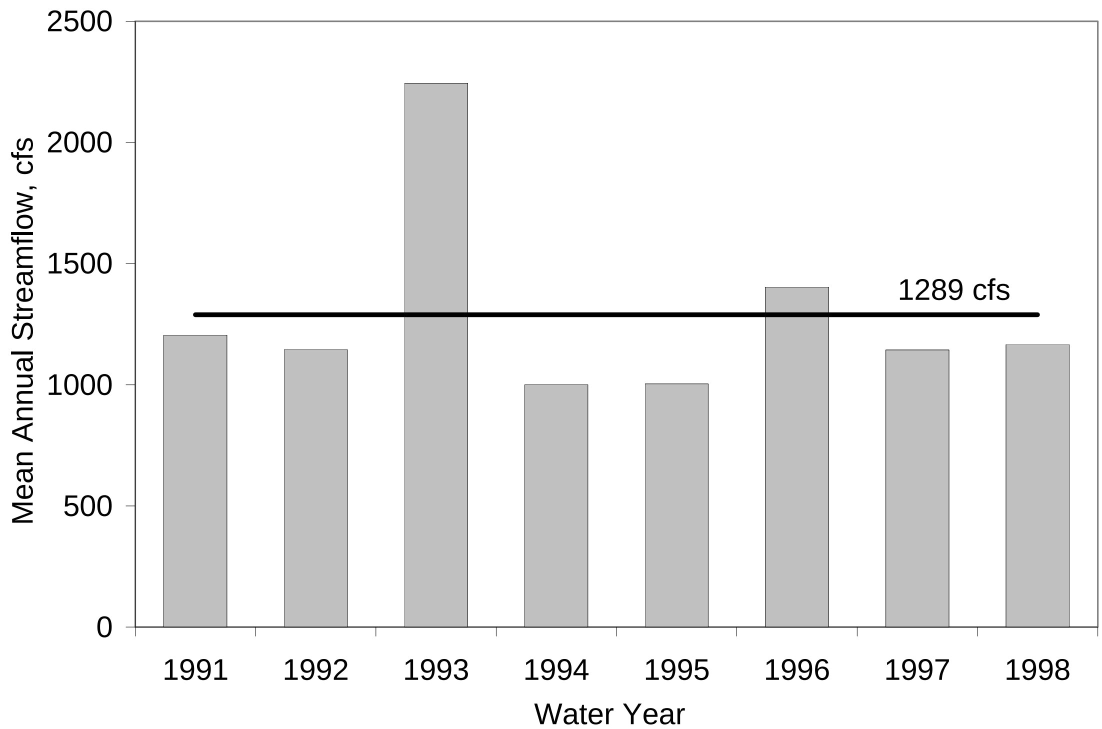


Figure 7. Mean annual streamflows, South Elgin (USGS 05551000)

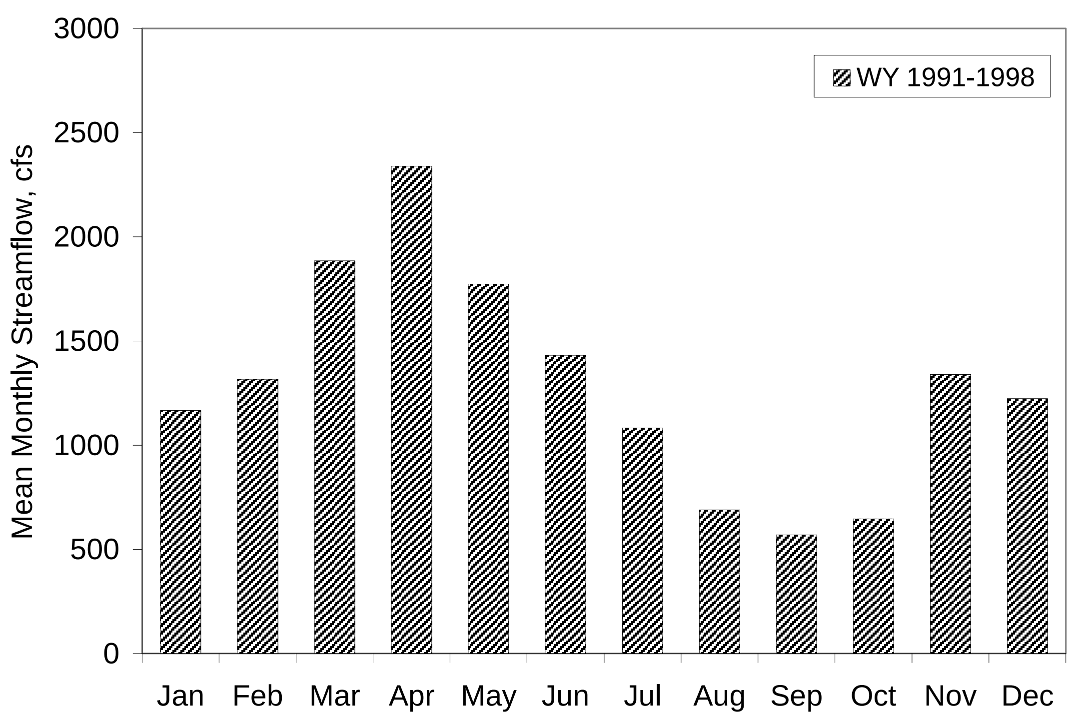


Figure 8. Mean monthly streamflows, South Elgin (USGS 05551000)

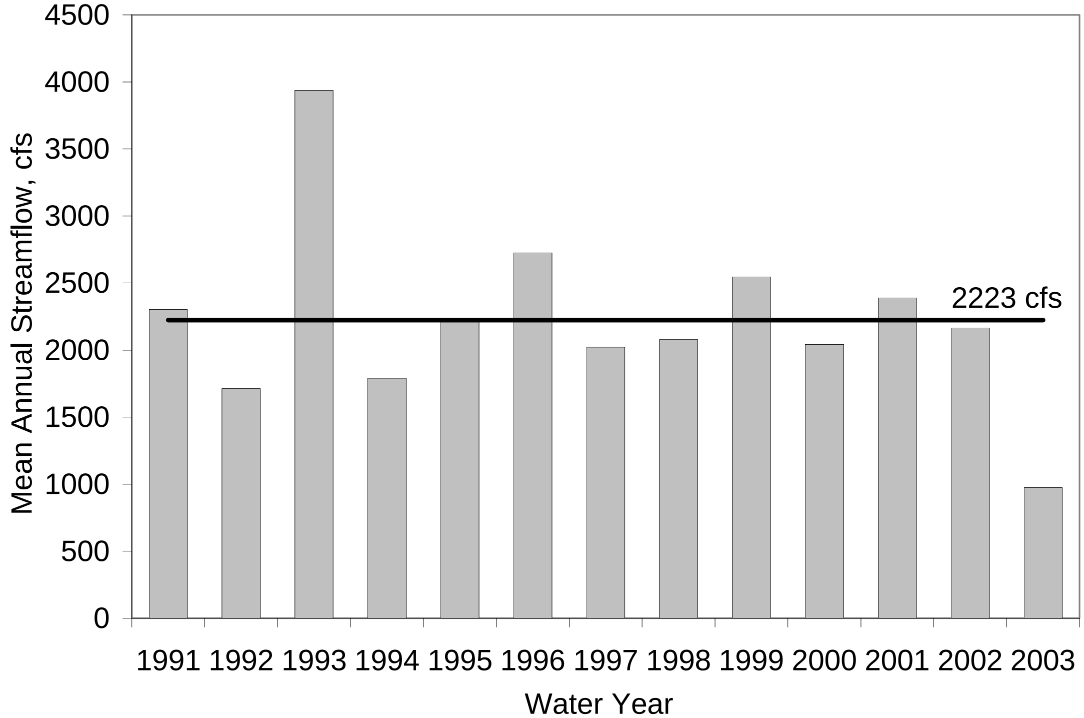


Figure 9. Mean annual streamflows, Dayton (USGS 05552500)

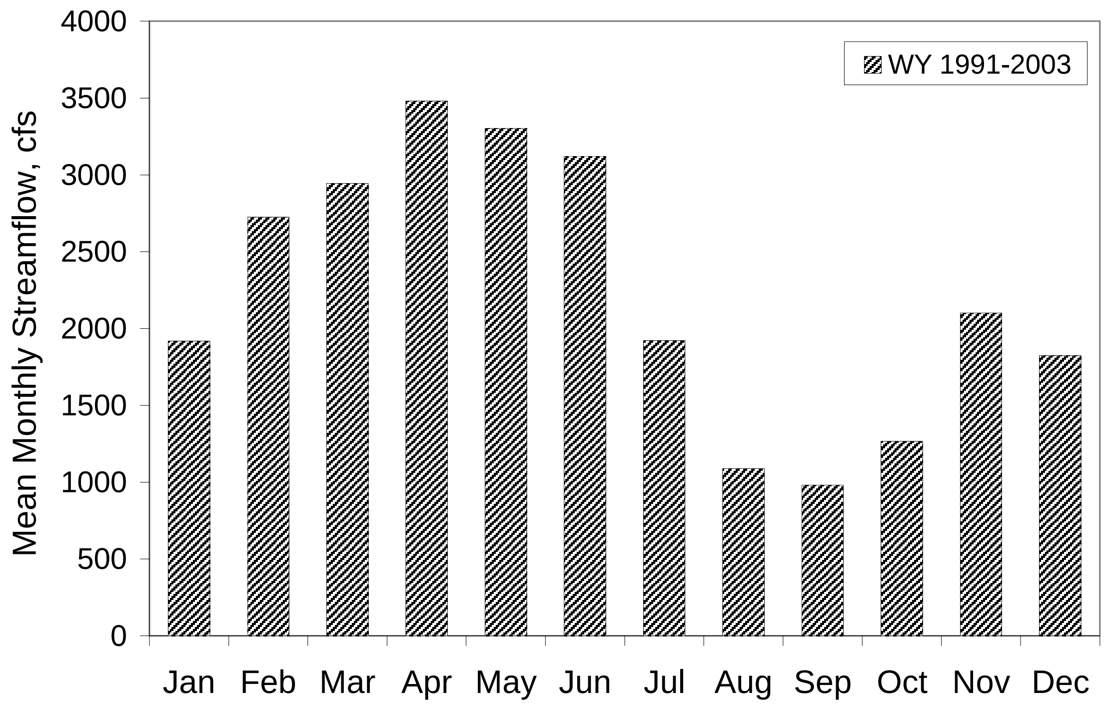


Figure 10. Mean monthly streamflows, Dayton (USGS 05552500)

Upstream Boundary Input: Stratton Dam

Stratton Dam serves as the upstream boundary of the study area. The area above Stratton Dam contributes a significant portion of flow to the Fox River, so accurate representation of Stratton Dam discharges is critical to simulate the correct volume in the Fox River. The drainage area of the Fox River at Stratton Dam is 1250 sq. mi., and at the USGS gage at Algonquin the drainage area is 1406 sq. mi. This means 88.9 percent of area contributing flows at Algonquin is upstream of Stratton Dam.

Stratton Dam has operational gates as well as a free flow weir. Outflow from Stratton Dam occurs either over the spillway, which is 282 feet wide, or under five sluice gates, each of which is 13.75 feet wide. The crest elevation of the spillway is at 736.76 feet above mean sea level (ft-msl). The sluice gates can be opened to a maximum height of 9.0 feet above their spill elevation of 731.15 ft-msl. The minimum low flow release is 89 cfs (Knapp, 1998).

Stratton Dam is considered an upstream boundary of the mainstem model. The Stratton Dam flow needs to be specified as an inflow to the model. Stage measurements and gate openings are recorded at 8 a.m. and 4 p.m. each day. On the basis of the relationships established between stage and gate openings, the discharge is computed and the average of these two measurements is taken as the daily average flow. These computed flows are available for the simulation period.

The accuracy in determining flow at this boundary condition has a significant effect on the accuracy of the model flow prediction. A regression analysis of flows reported at Stratton Dam and at the Algonquin gage shows a correlation coefficient (r) of 98.7 percent and coefficient of determination (R^2) of 97.4 percent, indicating that 97.4 percent of the variation in flow recorded at Algonquin is a function of the flow at Stratton Dam. A comparison of daily flows reported at Stratton Dam and Algonquin shows that there were a number of days when the flow reported at Algonquin was less than that reported at Stratton Dam. Some of these differences were expected in that the Algonquin gage is a continuous recording gage, while the Stratton Dam daily flows were estimated from two readings a day (not accurate when flow changes during the day).

Point Sources

There are more than 100 facilities with National Pollutant Discharge Elimination System (NPDES) permits identified in the Fox River watershed (Illinois portion). Daily discharges from these facilities range from 0.001 million gallons per day (MGD) to 32 MGD (0.0016 cfs to 50 cfs). Given the volume of flow in the Fox River, not all NPDES discharges would potentially have a measurable impact on the hydrologic model calibration. Mainstem NPDES facilities were limited to those discharging on average 0.2 MGD (0.31 cfs) or more (20 facilities). For comparison, an average daily flow of 100 cfs at Algonquin has a 99 percent chance of exceedence, and the lowest mean monthly streamflow (August) at Algonquin is 535 cfs. A threshold discharge of 0.3 cfs included in the model is less than 0.1 percent of this flow.

A total of 48 NPDES facilities were included in the model, 20 discharging directly to the mainstem and 28 discharging to tributaries. Flow time series for these facilities were completed to provide missing data before their incorporation into the hydrologic model. Although not all discharged volumes are included at this time, all known loadings reported for NPDES discharges will be considered for water quality model development at the next phase of the project.

Table 10 lists the NPDES facilities discharging more than 5 cfs at the Fox River mainstem. The NPDES data provided by the FRSG (CDM, 2006) were collected either directly from NPDES facilities or the U.S. EPA EnviroFacts database (USEPA, 2004). The data were processed into the WDM format required for the HSPF model, and any missing data were estimated based on actual known discharges. The average monthly discharge was used to approximate average daily flows when daily data were not available.

Two communities within the Fox River watershed have NPDES permits for their Combined Sewer Overflows (CSOs): Aurora and Elgin. Combined sewers carry stormwater in the same conduits as wastewater. CSOs are structures that allow the release of mixtures of stormwater and wastewater to a receiving stream once a certain threshold (usually specified by water depth) is exceeded. Any water above the CSO weir then overflows and relieves the sewer system of excess water. The CSOs are not modeled explicitly because there is no information on volumes or loads discharged to the Fox River through CSOs during the simulation period. The two-year intensive monitoring program carried out by the ISWS for the FRSG includes sampling of CSO discharges and water quality to provide missing information.

Table 10. Major NPDES Facilities in Fox River Watersheds Discharging More Than 5 cfs

NPDES	*Name*	*Receiving stream*	*Original permit issue date*	*City*	*Average daily discharge, cfs*
IL0020818	Fox Metro WRD	Fox River	12/13/1974	Oswego	45.1
IL0028657	Fox River WRD South	Fox River	6/23/1976	Elgin	23.1
IL0028665	Fox River WRD North	Fox River	10/10/1980	Elgin	7.8
IL0022705	St. Charles WWTF	Fox River	10/04/1976	St. Charles	7.3
IL0028282	Crystal Lake STP #2	Crystal Lake outlet	3/08/1984	Crystal Lake	5.5

Note: Average daily discharges were calculated for completed data series after replacing missing values.

Water Withdrawals

Elgin and Aurora both withdraw water from the Fox River for their public water supply. Elgin began withdrawing water for most of its public water supply in 1983, and Aurora began in 1992. While much of this water is returned to the river as treated effluent, these withdrawals must be accounted for in the river segment in which they occur. Average annual withdrawal data are available for each community. Average withdrawal rates were computed and included in the HSPF model. In 2002 Elgin withdrew an average of 10.6 MGD (16.5 cfs) and Aurora withdrew an average of 9.7 MGD (15.1 cfs).

Groundwater Interactions

A study conducted by Meyer et al. (2009) in northeastern Illinois identified areas of significant interactions between surface water and groundwater where pumping from shallow aquifers can result in reduced groundwater discharge to streams. The pumped water can be either groundwater that would otherwise be discharged to streams or water induced to seep from stream channels by pumping wells. Model simulations (Meyer et al., 2009) suggest the greatest reduction in natural groundwater discharge in the Fox River watershed occurred in Mill Creek (68 percent reduction), Fox River upstream of Algonquin, including Spring Creek and Flint Creek (46 percent reduction), Poplar Creek (41 percent reduction), and Fox River between Montgomery and Algonquin (25 percent reduction) (Figure 11). This information was used to adjust HSPF model parameters affecting simulation of baseflow. The baseflow model parameters were varied on a tributary watershed basis for Fox River tributaries and on a reach segment basis for the Fox River mainstem, reflecting subsurface characteristics that are not included in HRU determination. HRUs only consider land use, hydrologic soil type, and slope.

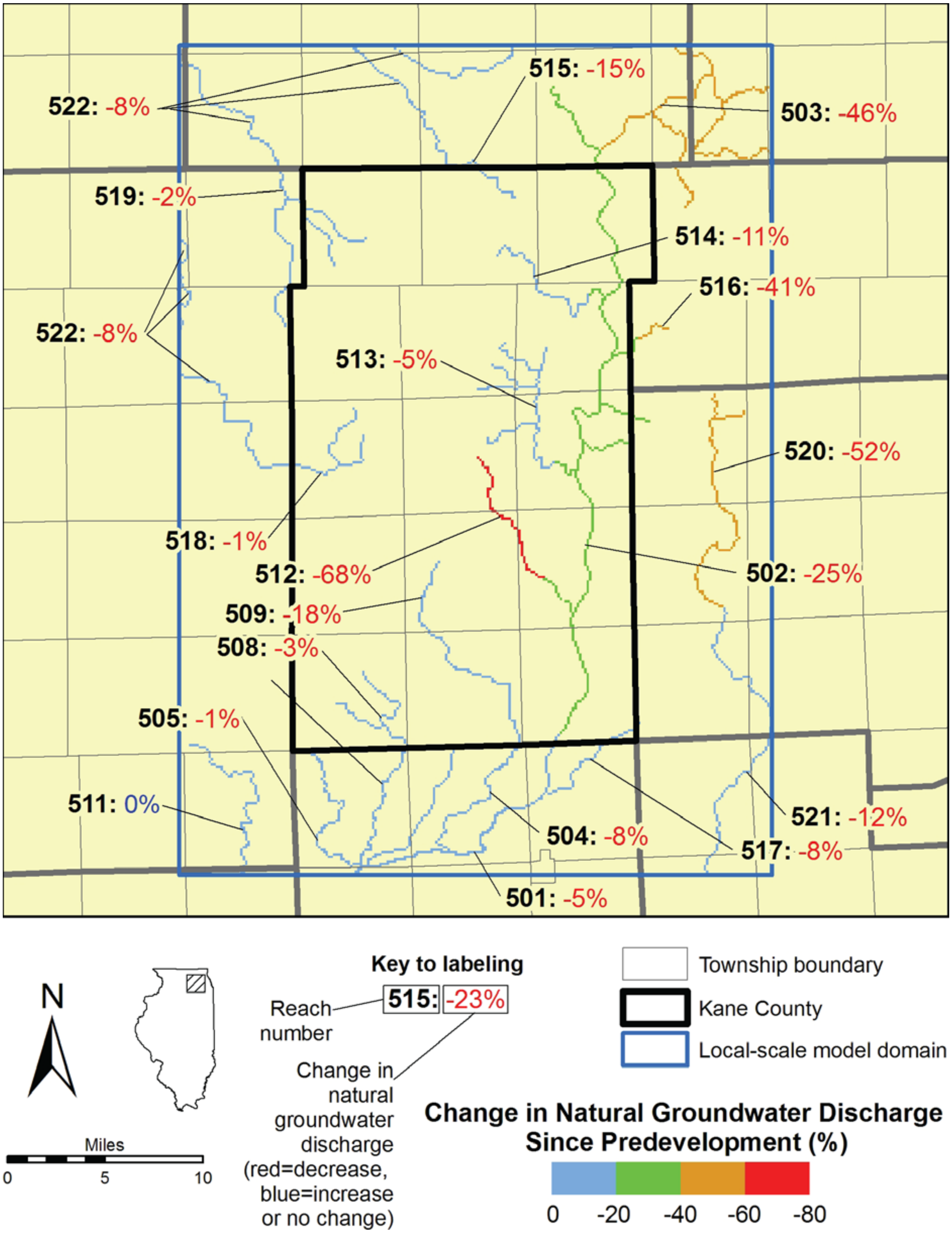


Figure 11. Estimated total change in natural groundwater discharge caused by pumping, by stream reach, at the end of 2003 (from Meyer et al., 2009)

Watershed Model Structure

The first and very important step towards model development is to divide a watershed into subwatersheds and streamlines that define the internal structure of the model and the location of possible calculation or outlet points for which model output can be exported and reviewed. As illustrated in Figure 1, for modeling purposes the study area was divided into 31 tributary watersheds and the Fox River mainstem. The BASINS Automatic Delineation Tool was used to delineate watershed boundaries and to subdivide each tributary watershed into smaller, hydrologically connected subwatersheds. Stream reaches and outlets were defined for each tributary watershed based on predefined criteria, such as location of monitoring point or NPDES facility, change in physical characteristics of the stream, and so forth (Singh et al., 2007).

The watershed and subwatershed boundaries were delineated by enforcing streamlines from the high-resolution National Hydrography Dataset (NHD) (USGS, 2004) on the National Elevation Dataset (NED) (USGS, 2005). The BASINS delineation algorithm also considers a stream threshold number specifying a drainage area needed to form a channel. Those numbers were specified for each tributary watershed to match the network of perennial streams in the high-resolution NHD and to prevent delineation of intermittent streams or artificial streams not in the NHD or visible on orthophotography (USGS, 2005).

The NHD has companion watershed boundaries for various watershed scales. The boundaries are designated by Hydrologic Unit Codes (HUC), followed by a number that indicates the relative scale of the watersheds delineated. HUC-8 watershed boundaries show major river watersheds; HUC-12 boundaries have a much denser set of smaller subwatersheds. During the delineation process, tributary watershed boundaries delineated from the NED were compared to the HUC-12 boundaries where possible. The resolution of boundary differences is described in the Phase II, Part 1 Report (Singh et al., 2007).

A number of characteristics are computed by BASINS from the elevation data and other spatial data for each delineated subwatershed. These include subwatershed area, flow path length (longest path within the subwatershed), slope in a percentage, latitude of the subwatershed centroid, elevation of the subwatershed centroid, cumulative drainage area, stream length, stream slope, stream average width, stream average depth, and minimum and maximum elevation of the stream. These characteristics were used to develop input for the HSPF model to characterize each subwatershed.

Stream Reaches and Outlets

The HSPF model structure requires a segmentation of a stream or river into reaches that have similar hydraulic characteristics and to isolate specific inputs to the system such as a major tributary or point source. Stream reaches represent physical segments along the river in the model, and model computations are based on the assumption of constant hydraulic characteristics and rate coefficients within each reach. Thus, reaches must be selected carefully. Physical geometry of the channel defines relationships among water depth, flow, surface area, and volume in a reach. Mixing of constituents and travel time along the stream are influenced by channel slope, cross-sectional area, velocity, channel roughness, and other physical characteristics or structures, such as dams. Those parameters play an important role in the fate and transport of modeled water quality constituents.

Another consideration in model development is to determine at what locations output from the model would be useful. Before delineating each tributary watershed, possible outlet locations (where output could be retrieved) were identified based on criteria such as junctions of perennial tributaries, locations of USGS flow gages, location of water quality sampling stations, slope changes, impoundments, significant changes in soil and land uses, and availability of climate data. A description of the criteria and selection of outlet locations are presented in the Phase II, Part 1 Report (Singh et al., 2007).

Hydraulic characteristics are stored in hydraulic function tables (FTABLEs) in the HSPF input sequence and describe a river reach or reservoir segment by defining the functional relationship among water depth, surface area, water volume, and outflow in the segment. The BASINS model can derive FTABLEs automatically, but the procedure uses simplified assumptions on river geometry and does not consider effects of impoundments. The required variables for the Fox River mainstem were calculated using the Hydrologic Engineering Centers River Analysis System (HEC-RAS) program with data from the Flood Insurance Study (FIS) model. Originally, the FIS models of the Fox River were developed for flood insurance purposes and were calibrated for flood flows. The following recurrence intervals were used: 1, 2, 5, 10, 20, 50, 100, and 500 years. Available channel cross-section data were assembled from FIS models in both electronic and paper format and then transferred into an electronic data table in a consistent format. Model outputs were analyzed to derive a functional relationship for the FTABLEs.

Tributary Watersheds and Subwatersheds

The 31 tributary watersheds delineated within the study area drain from 1.9 to 177.5 square miles (Figure 1). The number of subwatersheds in each tributary watershed varies as shown in Table 11. The number of subwatersheds ranges from four in the Roods Creek watershed and Unnamed Tributary watershed (downstream of Silver Lake) to 36 in the Poplar Creek watershed.

Areas adjacent to and draining directly to the Fox mainstem (i.e., do not drain to a modeled tributary) were delineated based on a reach segmentation scheme of the mainstem (Singh et al., 2007). The subwatersheds of the Fox mainstem collectively form the Fox mainstem model. The Fox mainstem model has the highest number of subwatersheds (60) of all individual watershed models in this study due to the high number of tributary inflows, NPDES discharge locations, dams, and channel geometry changes. The subwatershed immediately downstream of Montgomery Dam was divided into two, allowing for better simulation of water quality upstream and downstream of the Fox Metro Water Reclamation District outfall. Segmentation of the Fox River mainstem and those areas that drain directly to the mainstem are shown in Figure 12.

Areas that drain directly to the Fox River mainstem must also be identified and included in the model. These are direct inflows to each reach designated along the mainstem in addition to inflows from tributaries entered as a point inflow to the mainstem. A detailed scheme was determined for designating reaches of the Fox River mainstem from Stratton Dam to the confluence with the Illinois River.

Table 11. Watershed Area and Number of Subwatersheds Delineated in Each Watershed

Watershed Name	*Area (acres)*	*Number of subwatersheds*
Big Rock Creek	76,083	17
Blackberry Creek	47,767	28
Brewster Creek	10,369	14
Brumbach Creek	7,597	6
Buck Creek	27,108	9
Clear Creek	4,201	5
Cotton Creek	13,188	19
Crystal Lake	16,606	13
Ferson Creek	34,584	26
Flint Creek	23,233	24
Fox Mainstem	164,887	60
Hollenback Creek	8,864	5
Indian Creek (Kane and DuPage County)	8,864	9
Indian Creek (LaSalle, DeKalb, Lee County)	113,605	26
Jelkes Creek	4,393	12
Little Indian Creek	56,899	11
Little Rock Creek	48,046	11
Mill Creek	19,984	10
Mission Creek	9,899	8
Morgan Creek	12,636	9
Norton Creek	7,485	13
Poplar Creek	27,793	36
Rob Roy Creek	13,287	8
Roods Creek	10,387	4
Silver Lake Outlet	1,239	7
Sleepy Hollow Creek	9,936	12
Somonauk Creek	52,096	9
Spring Creek	16,980	17
Tower Lake Outlet	3,722	10
Tyler Creek	25,966	20
Unnamed tributary (downstream of Silver Lake)	4,207	4
Waubansee Creek	19,227	7

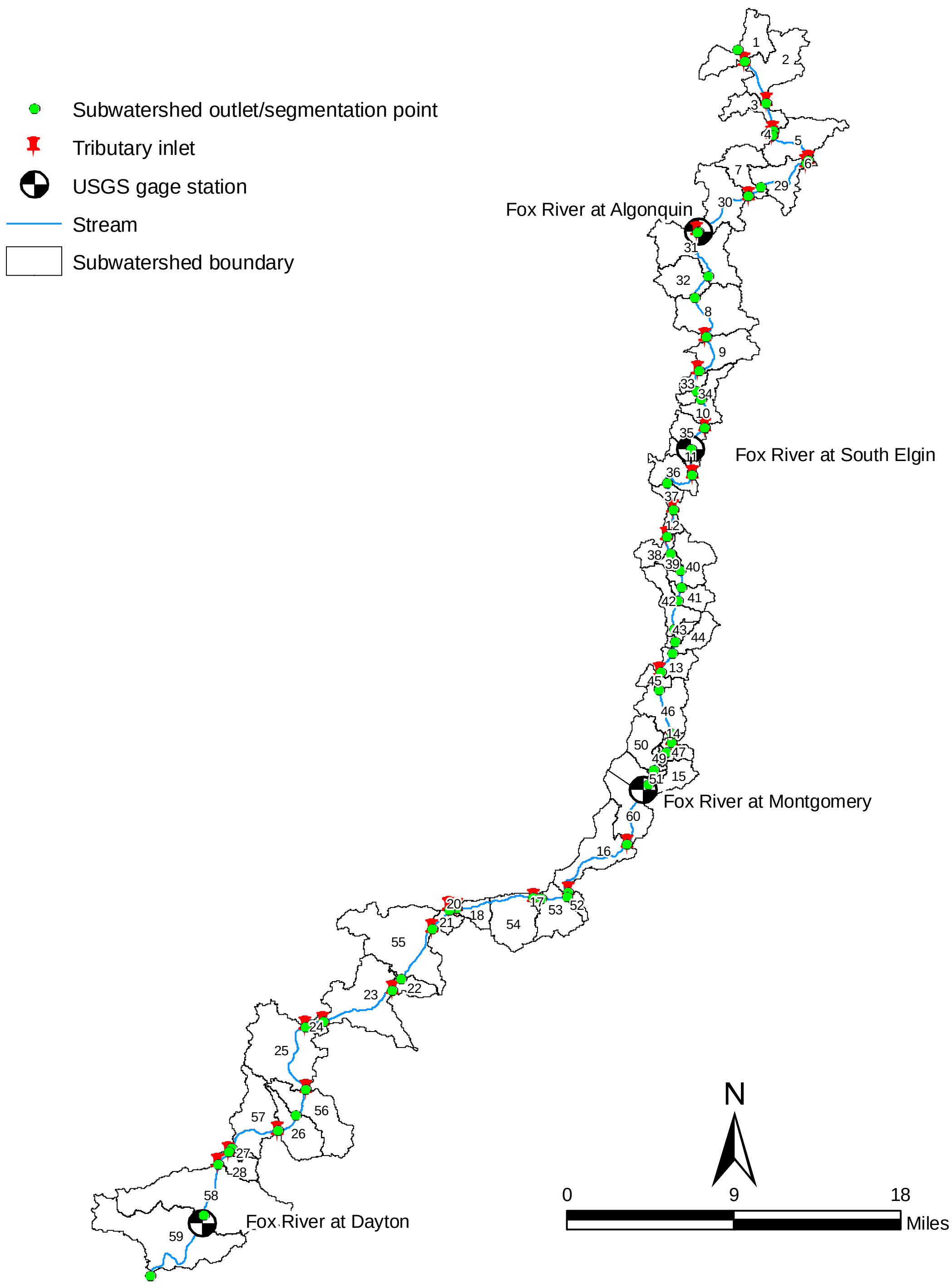


Figure 12. Subwatershed delineation of the Fox mainstem

Hydrologic Response Units (HRUs)

Subwatersheds were characterized by further subdivision into homogeneous areas called HRUs. An HRU is an area within a subwatershed that is expected to have a similar hydrologic response to inputs of precipitation and evapotranspiration. A subwatershed may be partitioned into different HRUs to account for the spatial variability in land use, soil, and physiographic features. The number of possible unique HRUs is a product of the number of categories used: land use/land cover, soil types, and land slope. Details are described in the Phase II, Part 1 Report (Singh et al., 2007). Within the Fox River watershed, nine pervious and four impervious land use categories, four soil groups, and three land slope categories were identified; this resulted in 156 unique combinations based on these physical features. Not all HRUs were present in the study area. The list of 152 HRUs defined for the model is given in Appendix A. Since the BASINS-HSPF model interface does not create these unique HRUs automatically (only land use is considered when BASINS interface creates the HSPF input file), they were created by spatially integrating land use, soil, and surface slope categories outside the interface using geographic information system (GIS) tools and custom developed Excel macros. Relevant model parameters were specified in the model's User Control Input (UCI) file. Each unique HRU can be assigned a set of parameter values determined through the model calibration process to define runoff characteristics, as well as loading of various constituents from the HRU.

Land use in the models was classified as pervious or impervious; agricultural, forest, and grassland areas were considered pervious, whereas urban areas were considered partly impervious. The urban high density (UHD) or low/medium density (ULM) areas were divided into pervious and impervious fractions for all tributary watershed models. An imperviousness of 75 percent and 35 percent was used for the UHD and ULM areas, respectively, based on previous calibration of the Poplar Creek watershed model (Bartosova et al., 2007a). Impervious areas were divided into effective and non-effective areas to simulate different processes happening on impervious areas overflowing to pervious areas (non-effective areas, e.g., roof tops draining to lawns) and impervious areas draining directly to sewers or receiving streams (effective areas, e.g., parking lots).

The division of urban areas into pervious and impervious portions was not performed for areas draining directly to the Fox River mainstem due to computational limits of the model. The HSPF software cannot handle more than 500 operations. This number would have been exceeded, considering the number of segments, HRUs, and other operations in the mainstem model. All land uses in the mainstem model are thus simulated as pervious. This assumption affects only areas draining directly to the Fox River mainstem (i.e., all tributary watersheds are simulated with appropriate imperviousness). The Fox River mainstem within the study area drains directly about 165,000 acres, or 18 percent of the study area and 10 percent of the watershed area. Impervious surfaces cover about 15,000 acres or 9 percent of the Fox River mainstem area using the imperviousness of 75 percent and 35 percent for the UHD and ULM areas, respectively. This would represent an additional 1.7 percent imperviousness of the study area and less than 1 percent of the whole Fox River watershed area.

The effects of simulating urban areas as all pervious were tested on the Poplar Creek watershed. Nearly 15 percent of the 43.5-square-mile (27,793-acre) Poplar Creek watershed is impervious (30 percent ULM and 6.8 percent UHD). Table 12 shows information on imperviousness for both Poplar Creek watershed and Fox River mainstem watershed. The calibrated and verified HSPF model of Poplar Creek watershed was modified by setting all impervious areas to zero and adding the impervious areas to corresponding pervious areas.

After running the simulation, results were compared (Table 13). Long-term average flow simulated for Poplar Creek with imperviousness was 23 percent higher than when simulated as all pervious. Annual average flows simulated with imperviousness were 14 to 47 percent higher than when simulated as all pervious. The difference in annual average flows decreases with increasing flow (Figure 13). Monthly average flows simulated with imperviousness were 11 to 69 percent higher than when simulated as all pervious (Table 14). Note that the largest difference was associated with summer months during which flow is typically lower (Figure 14).

Table 12. Comparison of Poplar Creek and Fox River Mainstem Watersheds

Watershed	*Poplar Creek*	*Fox River mainstem*
Total area, acres	27,800	165,000
% study area	3.1	18
% Fox R. watershed area	1.6	9.7
UHD, % watershed area	6.8	4.4
ULM, % watershed area	30	17
Imperviousness, % watershed area	15	9.3
% study area	0.47	1.7
% Fox R. watershed area	0.25	0.91

Table 13. Comparison of Flows (cfs) Simulated for Poplar Creek With and Without Imperviousness

Statistic	*Simulation*		*Difference*, %*	
	With imperviousness	*All as pervious*	*Annual Average*	*Average from Annual Differences*
Long-term average	33.2	26.9	23.2	-
Annual average				
Minimum	15.4	11.4	36.0	14.0
Average	33.3	27.0	23.3	26.2
Median	28.4	23.2	22.6	25.7
Maximum	63.7	55.8	14.1	47.0

Notes: * Percent difference calculated for “all as pervious” simulation
** First number is calculated from annual flow statistics, second number is calculated from statistics of annual differences

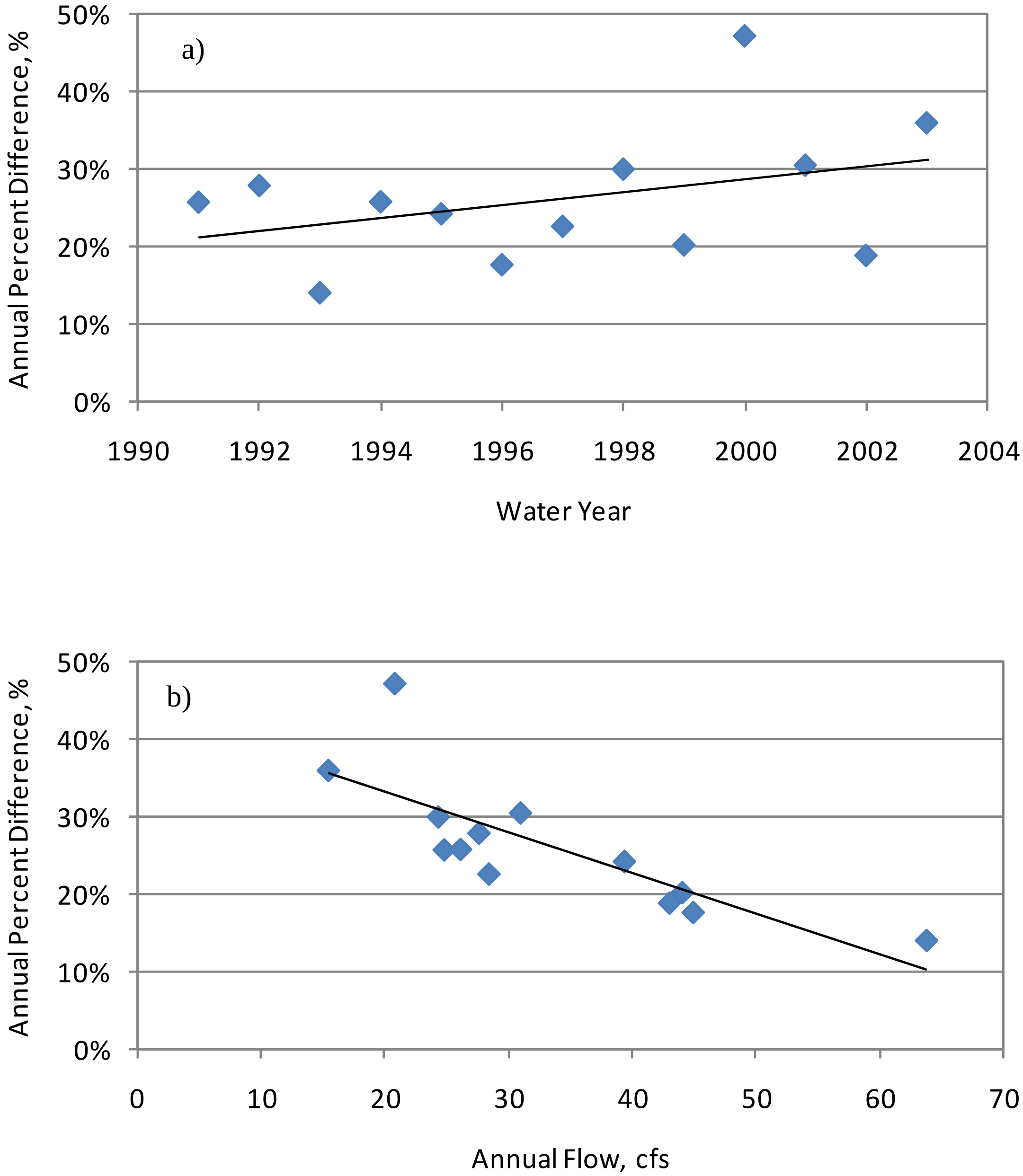


Figure 13. Variation of percent difference between Poplar Creek annual flows simulated with and without imperviousness with a) water year and b) annual flow

Table 14. Comparison of Monthly Flows (cfs) Simulated for Poplar Creek With and Without Imperviousness

Statistic	*Simulation*		*Difference**
	With imperviousness	*All as pervious*	%
Monthly averages			
January	24.7	21.8	13.6
February	40.5	35.5	14.2
March	42.9	38.6	10.9
April	59.0	52.2	13.0
May	48.9	42.0	16.5
June	40.6	33.3	21.9
July	17.8	12.3	45.0
August	24.2	15.2	59.4
September	19.2	11.3	69.2
October	28.9	20.6	39.8
November	31.4	22.7	38.4
December	20.9	18.1	15.7

For simplification, a linear relationship between imperviousness and an increase in long-term average flow is assumed. Under this assumption, a 14 percent increase in long-term average flow can be expected within the Fox River mainstem with 9.3 percent imperviousness. As Fox River mainstem represents 18 percent of the study area and 9.7 percent of the watershed area, a 2.6 percent increase in long-term average flow simulated from the whole study area can be expected. This would represent a 1.4 percent increase in long-term average flow at the Fox River watershed outlet, i.e., including the outflow contributed by areas outside the study area (above Stratton Dam). Similarly, the largest increase in monthly flows for September (69.2 percent) would represent a 4.2 percent increase in flows simulated at the Fox River watershed outlet. While this is only a rough estimate, it indicates the decision will have a relatively small impact on simulated long-term averages but may affect summer months to a higher degree than winter months.

Test simulations using Poplar Creek watershed indicate that excluding imperviousness from hydrologic simulation lowers the average simulated flows during summer and early fall months. While the impact may vary seasonally, the total magnitude of the decrease in simulated Fox River flows is expected to be negligible. Although the impact on pollutant loads was not quantified, a decrease in simulated flow is typically associated with a decrease in pollutant load from the surface. However, the overall impact on pollutant load in the Fox River is not expected to be significant due to a small relative contribution from affected areas. The absence of impervious surfaces might affect simulated types and efficiencies of urban BMPs on a local scale. For this reason, the Fox mainstem model input file will be split into two and updated to include imperviousness in the next phase of the study.

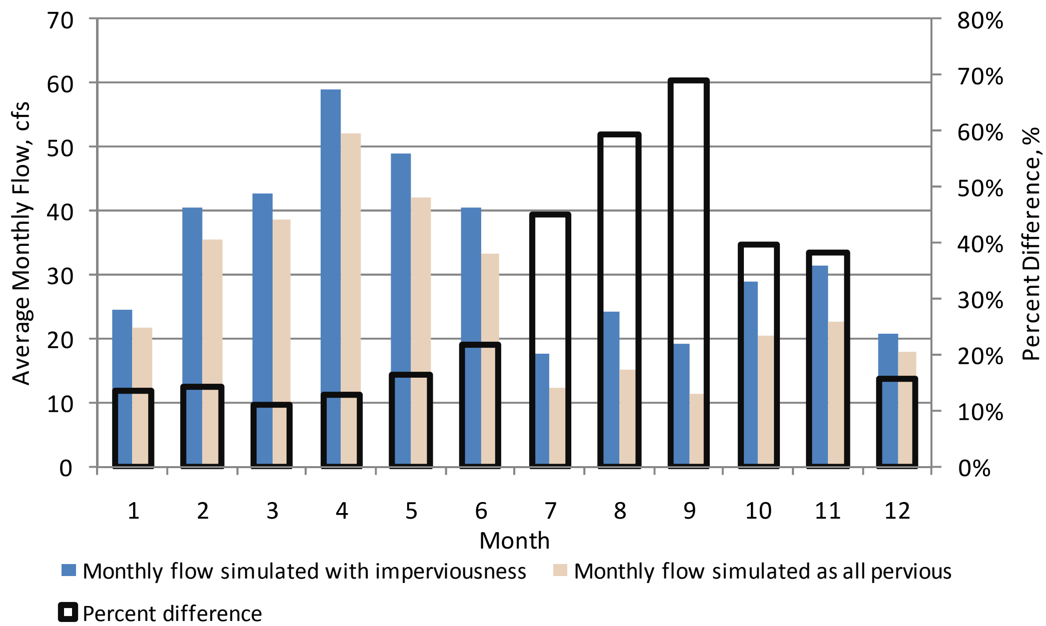


Figure 14. Variation of average monthly flow (cfs) and average monthly percent difference

Efficiency of model calibration largely depends on how well conditions in gaged watersheds reflect those in ungaged watersheds. To ascertain HRU types that dominate modeled watersheds, areas with unique land use and soil groups were determined while slope categories were grouped together to limit the number of types to analyze. Note that this grouping was solely to establish priorities during the calibration process, and the effect of slope on calibration parameters was included. In addition, areas under corn and soybeans were combined into agriculture land use. The area planted with corn and soybeans changes every year; the default distribution is based on year 1999. For the purpose of model calibration, all HRUs constituting 4 percent or more of drainage areas for any tributary or mainstem watershed are considered major HRUs. All HRUs constituting more than 10 percent of drainage area are considered dominant HRUs. Table 15 lists major HRU types identified in gaged watersheds and their representation.

All major HRUs represent 93–99 percent of drainage area for gages at tributary watersheds and 92–98 percent of modeled drainage area for mainstem gages excluding the area above the Stratton Dam. Dominant HRUs represent 62–90 percent of drainage area for gages at tributary watersheds and 72–87 percent of modeled drainage area for mainstem gages excluding the area above the Stratton Dam. Focusing calibration on dominant HRUs substantially helped to limit the number of individual HRU types.

Table 16 lists representation of major HRU types in ungaged watersheds. Dominant HRUs cover more than 60 percent of watershed areas for all watersheds except Brumbach Creek, Cotton Creek, Silver Creek, and Tower Lake outlet. Major HRUs cover more than 90 percent of watershed area for all watersheds except Cotton Creek, Silver Creek, and Tower Lake outlet. The thresholds of 60 percent and 90 percent represent conditions present in gaged watersheds. Watersheds with a low representation of dominant HRUs are expected to have lower accuracy of simulation than watersheds where dominant HRUs cover a significant portion of the watershed area.

Table 15. Percent Area Covered by Major HRUs for Gaged Watersheds

HRU Code	*Algonquin**	*South Elgin**	*Dayton**	*Blackberry Creek*	*Brewster Creek*	*Ferson Creek*	*Flint Creek*	*Mill Creek*	*Poplar Creek*	*Tyler Creek*
Dominant HRUs										
AGR2	4%	**11%**	**54%**	**51%**	0%	**34%**	1%	**31%**	3%	**51%**
FOR2	**13%**	**10%**	5%	7%	0%	**11%**	2%	6%	4%	7%
FOR3	**14%**	8%	2%	1%	**10%**	2%	**31%**	1%	8%	0%
RGR2	9%	7%	**10%**	**16%**	0%	**32%**	2%	**23%**	0%	**18%**
ULM3	3%	4%	2%	0%	8%	1%	**10%**	4%	**15%**	0%
ULMi	6%	9%	4%	3%	7%	2%	5%	4%	**10%**	4%
UOS2	8%	**12%**	5%	9%	0%	4%	1%	6%	7%	6%
UOS3	**11%**	**10%**	4%	2%	**22%**	1%	**28%**	7%	**24%**	0%
UOS4	3%	3%	1%	0%	**16%**	0%	1%	0%	9%	0%
Subtotal	72%	74%	87%	90%	62%	87%	81%	83%	79%	87%
Other major HRUs										
AGR3	2%	2%	3%	5%	3%	2%	1%	6%	3%	0%
AGR4	1%	0%	1%	0%	5%	0%	0%	0%	0%	0%
FOR4	5%	3%	1%	0%	7%	0%	0%	0%	3%	1%
RGR3	7%	3%	2%	2%	2%	4%	9%	5%	0%	0%
RGR4	2%	1%	1%	0%	9%	0%	0%	0%	0%	0%
UHDi	1%	2%	1%	1%	6%	1%	1%	1%	5%	1%
ULM2	3%	6%	2%	0%	0%	3%	0%	4%	5%	7%
ULM4	0%	0%	0%	0%	4%	0%	0%	0%	1%	0%
Subtotal	20%	18%	11%	8%	35%	10%	11%	16%	16%	9%
Total	92%	93%	98%	98%	97%	97%	93%	99%	96%	96%

Notes: Values are rounded to the nearest percent
* only area from Stratton Dam to the gage is included
Land use codes: AGR=Corn and soybeans, FOR=Forest, RGR=Rural grassland, ULM=Urban low/medium density, UOS=Urban open space, UHD=Urban high density
Hydrologic soil group code: 2=B, 3=C, 4=D, i=impervious area
Values greater than or equal to 10% are in bold

Table 16. Percent Area Covered by Major HRUs for Ungaged Watersheds

Watershed	*Dominant HRUs*	*Other major HRUs*	*Total*
Big Rock Creek	98%	2%	100%
Brumbach Creek	**5%**	93%	99%
Buck Creek	95%	4%	99%
Clear Creek	87%	12%	99%
Cotton Creek	**52%**	28%	**81%**
Crystal Lake outlet	68%	22%	90%
Hollenback Creek	95%	5%	100%
Indian Creek	99%	0%	99%
Indian Creek*	78%	20%	98%
Jelkes Creek	80%	15%	95%
Little Indian Creek	100%	0%	100%
Little Rock Creek	98%	1%	99%
Mission Creek	**27%**	72%	99%
Morgan Creek	94%	5%	99%
Norton Creek	86%	13%	99%
Rob Roy Creek	96%	4%	100%
Roods Creek	90%	9%	99%
Silver Creek	**42%**	27%	**69%**
Unnamed tributary downstream of Silver Creek	69%	21%	90%
Sleepy Hollow Creek	74%	21%	96%
Somonauk Creek	97%	1%	98%
Spring Creek	80%	20%	100%
Tower Lake outlet	**53%**	29%	**82%**
Waubonsie Creek	79%	19%	98%

Notes: * Indian Creek at Aurora
Values smaller than 60% and 90% for dominant and all major HRUs, respectively, are in bold.

Calibration and Validation of HSPF Models

Hydrologic processes in HSPF models must be calibrated and validated to observed streamflows before attempting to model the generation, transformation, and transport of water quality constituents. The goal of the hydrologic modeling was to simulate daily flow values as closely as possible. Flows of particular interest for this study are medium to low flows.

The study period, WY 1991–2003, was selected to provide a sufficiently long time series for model calibration and validation that represents contemporary watershed conditions. Study period data are separated into calibration (WY 1991–1999) and validation (WY 2000–2003) periods. The simulation period includes additional months (January–September 1990) at the beginning of the study period that allow the model calculations to stabilize. Calibration data are used to establish parameter values in the models. The models are then run using climate data for the validation period without adjustment to parameter values. The same statistical and graphic tests of fit are applied to both the calibration and the validation results. Results of the tests of fit ideally are within specified requirements for acceptable simulation and are similar for both calibration and validation datasets.

The basic assumption in the calibration process is that a given HRU will have the same parameter values throughout the study area; however, local conditions may need to be considered in some circumstances. In particular, additional adjustments to parameter values were warranted in watersheds where underlying groundwater conditions differed, particularly where impacted by groundwater pumping. In this case, parameters describing deep aquifer recharge were varied, not by HRU but by watershed, which allowed for more adequate spatial variation as the underlying geology was not considered in the HRU definition.

Given the limitation of data and time, each of the 156 HRUs could not be parameterized independently. Some model parameters vary with land use only, others with soil type or slope or a combination of categories. To make the calibration process transparent, the most spatially prevalent HRUs in the seven tributary watersheds and the three drainage areas contributing to mainstem gages were identified and calibration was focused on determining model parameters for these HRUs. Model parameters for HRUs with minor representation were derived from values of prevalent HRUs or literature values. Ultimately, identifying the fully integrated model that best simulates flows on the mainstem was the goal guiding the calibration.

Data needed to calibrate individual models were not available for all 31 tributary watersheds. Thus a stepwise approach to calibration was followed. Two tributary watersheds of the Fox River, Blackberry Creek and Poplar Creek, were initially chosen as pilot watersheds for detailed model development and to provide guidance for parameterization of other tributary watersheds (Bartosova et al., 2007a, b). These watersheds have the most abundant discharge and water quality datasets and also represent contrasting land uses. Blackberry Creek is primarily a rural watershed, and Poplar Creek is primarily an urban watershed. First, these models were calibrated to the extent possible with available data. Flow data were also available for additional five tributary watersheds: Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek. These watersheds were then used to test or validate the hydrologic parameters developed during the calibration of the pilot watersheds. Results of the calibration and validation appear in separate reports (Bartosova et al., 2007a, b). These steps prepared the foundation for calibration of the integrated Fox watershed model (31 tributary models and the mainstem model) described in this report.

The primary goal was to achieve the best possible calibration/validation of the integrated model to flows observed at the Fox River mainstem gages. The physical and climatological input data were prepared for the 31 tributary HSPF models and the mainstem model. The integrated model was parameterized using the parameter values from two pilot watersheds (Blackberry and Poplar). The calibration of the integrated models proceeded in a step-wise, iterative protocol.

Based on the simulation results, new sets of parameters were determined for the prevalent HRUs in the gaged areas. These new parameter values were then applied to all tributary watershed models and the mainstem model.

Statistical and graphic tests were performed to assess the model fit by comparing results to observed flows recorded at the three mainstem gages and the seven gaged tributaries.

This iterative procedure was repeated until satisfactory statistical and graphic results were achieved at gages on the mainstem and the seven watersheds. Since the model development was focused on the mainstem, requirements for the gages on the tributary watersheds were less stringent than for those on the mainstem to simplify calibration. Keeping constant calibration parameters for each unique HRU ensures internal consistency of the model and allows for better transferability of parameters during future scenario simulations.

Statistical and Graphical Tests for Calibration and Validation Results

Success of the calibration is tested using various statistical parameters comparing simulated and observed values. During calibration, parameters are adjusted to achieve the best results. These tests are repeated, comparing simulated and observed values from the validation period, which provides an independent test of the calibration. The standard statistical tests used are the Pearson product moment correlation coefficient, the Nash-Sutcliffe Efficiency, and the percent deviation.

The Pearson product moment correlation coefficient (r) is a standard measure of the strength of the linear relationship between two random variables (e.g., observed and simulated daily streamflows). The r is dimensionless and varies between -1.0 and +1.0, where -1.0 indicates perfect negative correlation, 0.0 indicates no linear relationship between variables, and 1.0 indicates perfect direct correlation. A value of r close to 1.0 is desirable in modeling as it indicates simulated streamflows are similar to those measured. Scatter plots of the data augment the interpretation of this test as they provide a visual means to see if a relationship exists between the two variables.

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 optimal value of NSE is 1.0, and values should be larger than 0.0 to indicate minimally acceptable performance; a value less than 0.0 indicates that mean observed flow is a better predictor than the model.

Percent deviation (Dv) was used to measure model overestimation (positive values) or underestimation (negative values) of a quantity (e.g., streamflow) over a long period such as a month, year, or period of study. This provides an idea about the net bias in model simulations over that period and was used to adjust the model parameters to simulate acceptable volumes. Simulation results are considered very good when Dv is within 10 percent, good when Dv is within 15 percent, and fair when Dv is within 25 percent (Donigian et al., 1984).

In addition to the statistical tests, graphical comparisons of observed and simulated streamflows were made. Comparison of annual volumes ensures reasonable water budgets. The ratio of simulated (S) and observed (O) average monthly flows is computed for each month. A comparison of the range of ratios (S/O) for each month provides insight to any seasonal bias. There does not appear to be any seasonal bias if the average S/O ratio is one (1), meaning the model does not overestimate or underestimate flows consistently during any month. The average variation was considered significant only when larger than ±5 percent. Model performance over a range of streamflow values also was investigated by plotting the ratio S/O versus average monthly streamflow to assess the fit in the range of interest.

Additional insight to model performance is provided by comparing flow duration curves generated by ranking all observed (or simulated) daily flows and determining flow values that correspond to the probability of exceedence. For example, a flow value corresponding to 10 percent probability of exceedence is a fairly high flow, with only 10 percent of flows being greater. Flow duration curves are shown on plots with flow on the vertical axis and probability of exceedence along the horizontal axis. Comparing the flow duration curve generated from observed values and that generated from simulated values provides a perspective on model ability to simulate the most commonly occurring flows and also those that occur less frequently irrespective of the day when flow occurred. This approach looks at statistical similarities between the observed and simulated series rather than comparing values during the exact day of simulation that may be influenced by less accurate timing of precipitation events associated with disaggregation of daily values into hourly values and by spatial variability of precipitation represented by a limited number of climate stations.

The simulation period was divided into calibration and validation periods. All statistics and graphics explained previously are derived separately for the calibration and the validation period. Only those statistics and graphics for the calibration period were examined during calibration. The calibrated model was validated using a separate period of observed data from that used for calibration.

Fox River Mainstem Model

The integrated Fox River model includes flows from 31 tributary watersheds and the 60 hydrologically connected subwatersheds that drain directly to the mainstem (Figure 12). The mainstem subwatershed size ranges from 114 acres (subwatershed 4) to 12,472 acres (subwatershed 58), as shown in Appendix B. Calculation points defined at the outlet of subwatersheds 30, 35, and 58 correspond to the locations of the USGS gages at Algonquin

(USGS 05551700) in McHenry County, South Elgin (USGS ID 05551000) in Kane County, and Dayton (USGS ID 05552500) in LaSalle County, respectively.

The HSPF hydrologic component was calibrated to best simulate observed daily streamflow at the USGS streamflow gages at Algonquin, South Elgin, and Dayton. Data from WY 1991–1999 were used for model calibration. The validation period is WY 2000–2003. The integrated model was calibrated at all three gage stations on the mainstem, but validated only on Algonquin and Dayton as discharge data were not available at South Elgin for the validation period.

Unknown initial conditions necessitate a substantial period (in some cases even more than a year) before the model stabilizes and achieves proper balance of various hydrologic processes. The simulation period always starts before the calibration or validation period. The period from January 1, 1990 to September 30, 1990 was used to stabilize model runs.

Development of an HSPF model that truly represents watershed hydrologic characteristics needs serious consideration of different sets of hydrologic parameters. This was accomplished by examining model results for four different cumulative time periods: annual, seasonal, monthly, and storm periods. First total runoff volume error or differences are minimized during the calibration process. The most sensitive parameters to adjust total runoff volumes are LZSN (lower zone storage nominal that is related to precipitation and soil characteristics in the watershed) and UZSN (upper zone storage nominal that is related to land surface characteristics, topography, and LZSN). Other parameters that may impact total runoff are FOREST (fraction of land covered by forest), PETMAX (temperature threshold that reduced plant evapotranspiration), PETMIN (temperature threshold where evapotranspiration is completely suspended), and DEEPFR (fraction of infiltrating water lost to deep aquifers), which were also adjusted. A sensitivity analysis was performed to identify those parameters that have the greatest influence on streamflow simulations (Bartosova et al., 2007a).

Once acceptable results were achieved to simulate runoff volume, parameters related to soil moisture storage and actual evapotranspiration for high and low flows were adjusted. Soil moisture storage controls the division between surface and subsurface flow and affects the timing of the runoff. The two most important parameters are INFILT (index to mean soil infiltration rate) and LZETP (index to lower zone evapotranspiration). These two parameters were carefully examined and adjusted. Hydrograph and peak flows were adjusted through INTFW (determines how much water will enter the ground from detention storage and become interflow and also has an effect on the timing of runoff by controlling the division of water between interflow and surface processes) and IRC (the interflow recession coefficient).

Table 17 gives the HSPF hydrologic calibration parameters and ranges of final values used in this study. During calibration, parameter values were adjusted within recommended model limits until an optimal fit was obtained between simulated and observed streamflows at USGS gages on the mainstem.

Table 17. Model Calibration Parameters for Fox River Watershed

Parameter	*Description*	*Unit*	*Values used*
Pervious HRUs			
AGWETP	Active groundwater evapotranspiration	*	0
AGWRC	Basic groundwater recession rate	1/d	0.95-0.993
BASETP	Baseflow evapotranspiration	*	0
CCFACT	Condensation/convection melt factor	*	1
CEPSC	Interception storage capacity	in	0-0.3
DEEPFR	Fraction of inactive groundwater	*	0-0.3
INFILT	Index to soil infiltration capacity	in/h	0.03-0.8
INTFW	Interflow inflow parameter	*	0.3-2
IRC	Interflow recession constant	*	0.5
KVARY	Variable groundwater recession flow	1/in	1-3
LZETP	Lower zone evapotranspiration	in	0.01-1
LZSN	Lower zone nominal storage	in	5-7.5
NSUR	Manning's n for overland flow	*	0.1 or 0.28[+]
SNOWCF	Snow gage catch correction factor	*	1.3
TSNOW	Temperature at which precipitation is snow	°F	31
UZSN	Upper zone nominal storage	in	0.05-1.2
Impervious HRUs			
NSUR	Manning's n for overland flow	*	0.1
RETN	Retention storage capacity	in	0.05-0.2
SNOWCF	Snow gage catch correction factor	*	1.3

Note: * Parameter is dimensionless or unit is complex
[+] Value 0.28 used only for corn and soybean land uses

Evaluation of the Fox River Mainstem Model

Table 18 presents model calibration statistics for the Algonquin, South Elgin, and Dayton gages and model validation statistics for the Algonquin and Dayton gages for annual, monthly, and daily flows. In interpreting the results, it is important to note that the inflow to the model is provided by the streamflow measurements at Stratton Dam, which accounts for 89 percent of the total watershed area at Algonquin. It appears that Stratton Dam flow derived from two daily readings underestimates total inflow to the model. Note that the absolute difference between simulated and observed long-term mean flows does not vary significantly among stations.

The total volume error between observed streamflows and simulated streamflows at the Algonquin gage was 3.5 percent over the calibration period (WY 1991–1999). On a yearly basis, this error was within ±10 percent (very good simulation) in all nine years (Table 18) at the Algonquin gage. During the calibration period, the model underestimated streamflow in all nine years, but by a very low margin (Figure 15): between 1 to 5 percent for six years and between 5 to 7 percent for three years. Mean annual streamflows were simulated with NSE=0.981.

Mean monthly streamflows were simulated with NSE=0.991 and r=0.997 (Table 18). The ratio of simulated and observed mean monthly flows was computed for each month in the calibration period (Figure 16). The plot shows that for any given month during the calibration period, the simulated values were scattered around the S=O line. Of the 108 months in the calibration period, the volume error between observed and simulated mean monthly values was within ±10 percent in 91 months (Table 18). The model did not consistently overestimate or underestimate flows during any month, and there is no appearance of any significant seasonal bias in the simulated results overall, but mean monthly streamflows during December through February and April are underestimated by 5 to 7 percent on average (Figure 17).

Statistics reported in Table 18 show fair agreement between observed and simulated daily streamflows for the calibration period (WY 1991–1999). The NSE=0.968 also indicates that the model simulates daily streamflows efficiently as well as mean monthly streamflows and annual streamflows. Observed and simulated daily streamflows show even scatter around the S=O line, suggesting a significant relationship (Figure 18). Flow duration curves for observed and simulated daily streamflows are shown in Figure 19. The model-simulated range of daily streamflows closely matches daily streamflows with a probability of exceedence below 25 percent (high flows) and overestimates daily streamflows with probability of exceedence above 90 percent (low flows). The highest 25 percent flows were underestimated by 0.7 percent, whereas the lowest 10 percent flows were overestimated by 5.8 percent.

Table 18. Statistics for the Model Calibration and Validation Periods at Mainstem Gages

	Algonquin		*South Elgin*	*Dayton**	
Statistics	*Calibration WY 1991-1999*	*Validation WY 2000-2003*	*Calibration WY 1991-1998*	*Calibration WY 1991-1999*	*Validation WY 2000-2003*
Long term					
Observed mean flow, cfs	1,131	1,037	1,287	2,329	1,886
Simulated mean flow, cfs	1,092	955	1,235	2,221	1,786
Dv, %	-3.5	-8.0	-4.1	-4.6	-5.3
Annual					
NSE	0.981	0.917	0.979	0.933	0.919
r	0.998	0.995	0.999	0.984	0.977
Years with Dv within ±10%	9	2	8	7	2
Years with Dv within ±25%	9	4	8	9	4
Monthly					
NSE	0.991	0.968	0.987	0.949	0.952
r	0.997	0.993	0.997	0.976	0.979
Months with Dv within ±10%	91	29	82	66	25
Months with Dv within ±25%	108	47	95	100	46
Daily					
NSE	0.968	0.956	0.962	0.823	0.893
r	0.985	0.984	0.983	0.909	0.947

Notes: Dv = error in simulated and observed streamflow volumes for a given period
* does not include July 1996

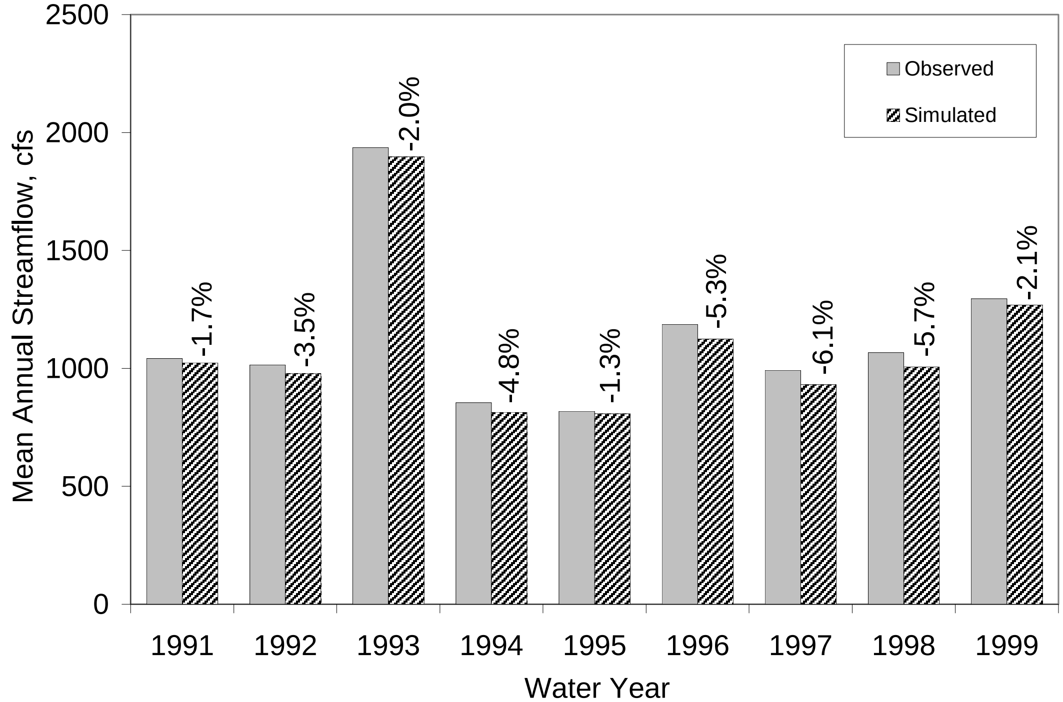


Figure 15. Observed and simulated mean annual streamflows during calibration, Algonquin (WY 1991–1999)

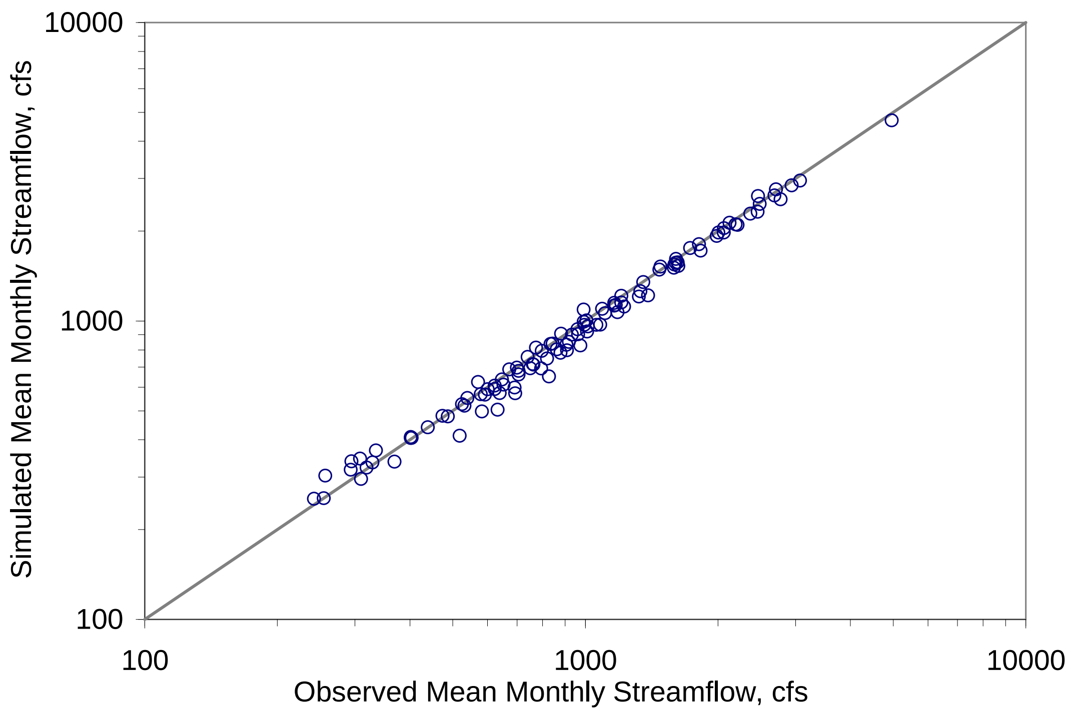


Figure 16. Observed and simulated mean monthly streamflows during calibration, Algonquin (WY 1991–1999)

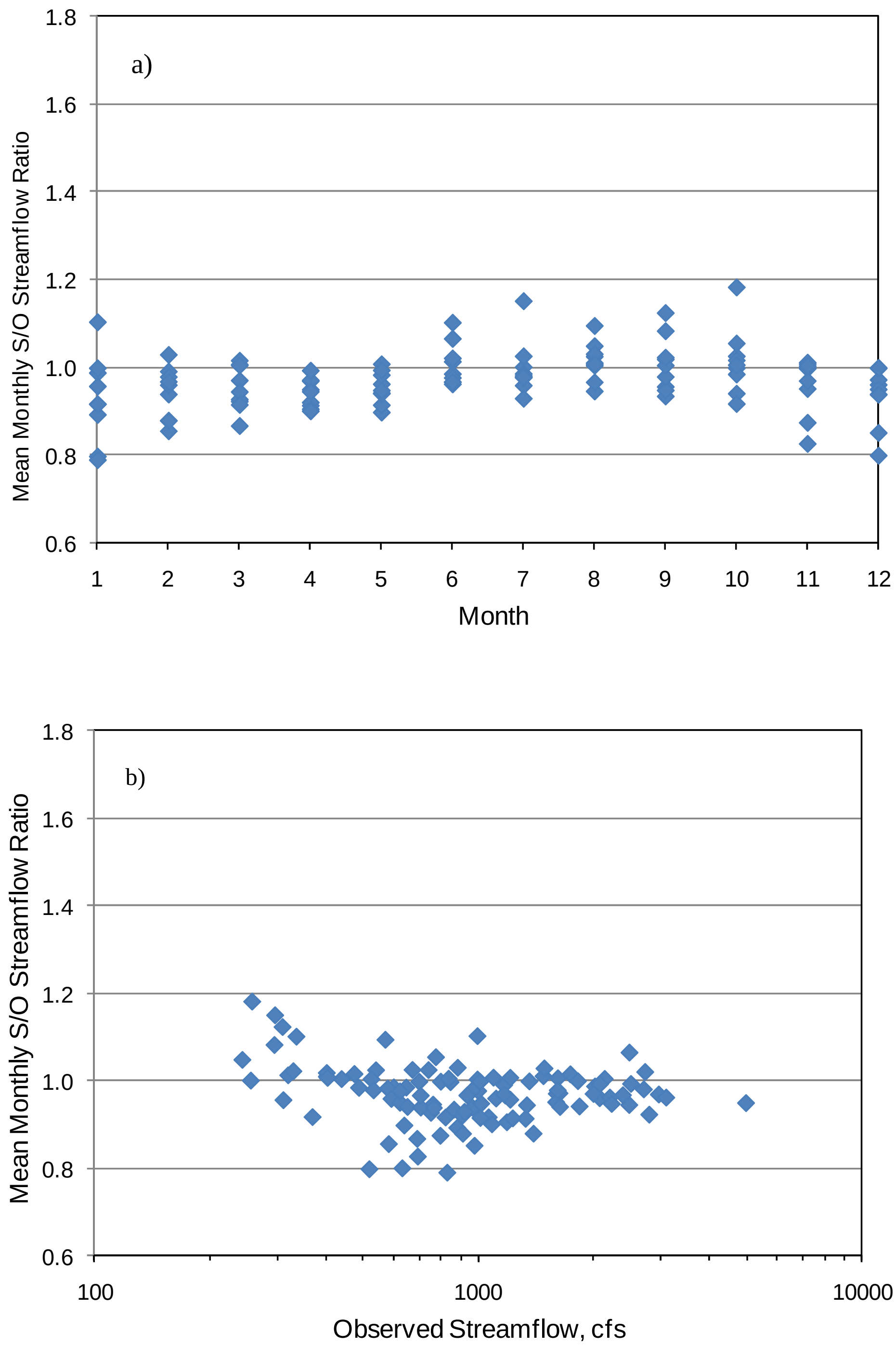


Figure 17. Comparison of simulated (S) and observed (O) mean monthly streamflow during calibration, Algonquin gage (WY 1991–1999): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow

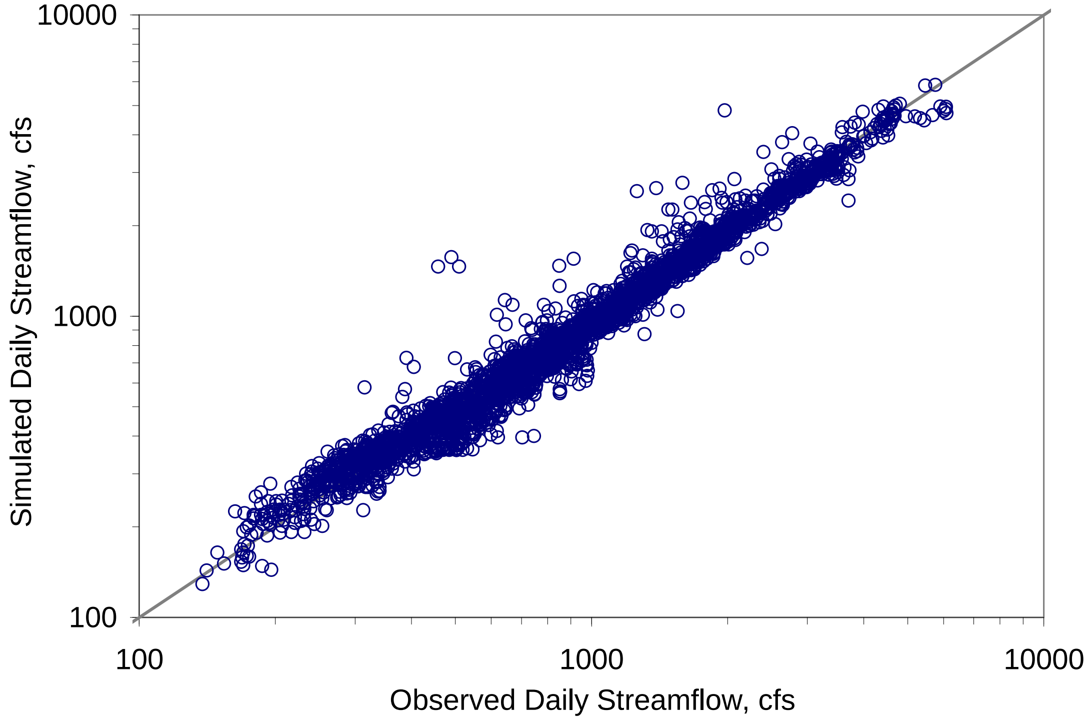


Figure 18. Observed and simulated daily streamflow during calibration, Algonquin (WY 1991–1999)

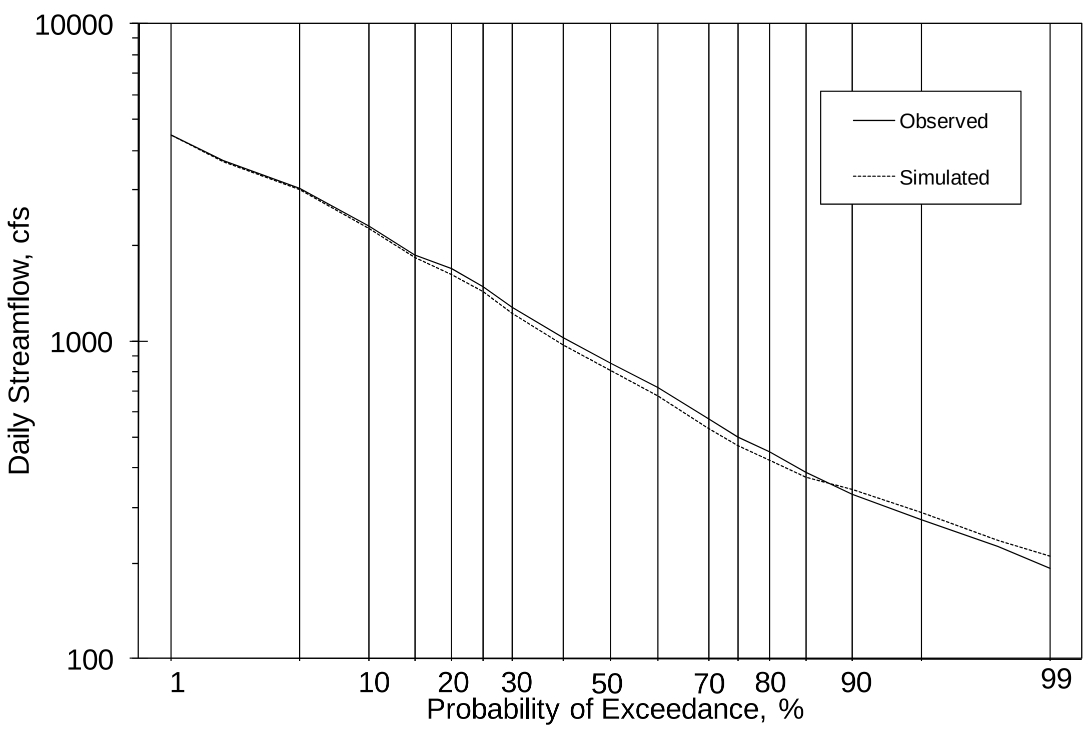


Figure 19. Flow duration curve for observed and simulated daily streamflow during calibration, Algonquin (WY 1991–1999)

At the South Elgin USGS gage, the total volume error between observed streamflows and simulated streamflows was -4.1 percent over the period of record (WY 1991–1998). On a yearly basis, this error was within ±10 percent (very good simulation) in all eight simulation years (Table 18). During the calibration period, the model underestimated streamflow in all eight years (Figure 20), but by a narrow margin (six years by less than 5 percent, and two years by 5–7 percent). Mean annual streamflows were simulated with NSE=0.979 with a very high correlation (r=0.999). Mean monthly streamflows were simulated with NSE=0.987 and r=0.997 (Table 18). Simulated versus observed mean monthly streamflows follow the S=O line, suggesting a significant relationship (Figure 21). The plot shows that for any given month during the calibration period, the S/O values were scattered around the S=O line. Of the 95 months in the calibration period, the volume error between observed and simulated mean monthly values was within ±10 percent in 82 months, as shown in Table 18. The ratio of simulated and observed mean monthly flows was computed for each month in the calibration period, and ratios are plotted for each month. The model underestimated monthly streamflow for November through May (Figure 22) by less than 7 percent in all months. The statistics reported in Table 18 show NSE=0.962 for daily flows, which indicates that the model simulates daily streamflows efficiently (Figure 23). Flow duration curves for observed and simulated daily streamflows are shown (Figure 24). The highest 10 percent flows were underestimated by 3.3 percent, whereas the lowest 10 percent flows were overestimated by 2.7 percent.

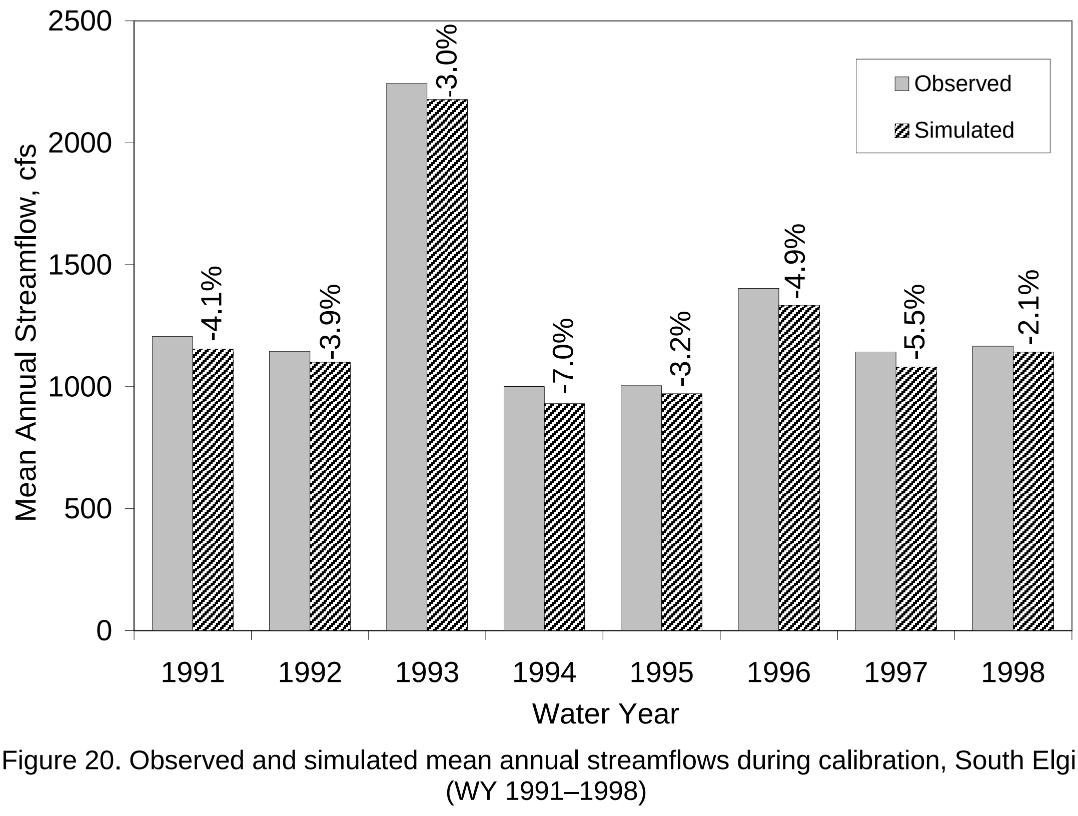


Figure 20. Observed and simulated mean annual streamflows during calibration, South Elgin (WY 1991–1998)

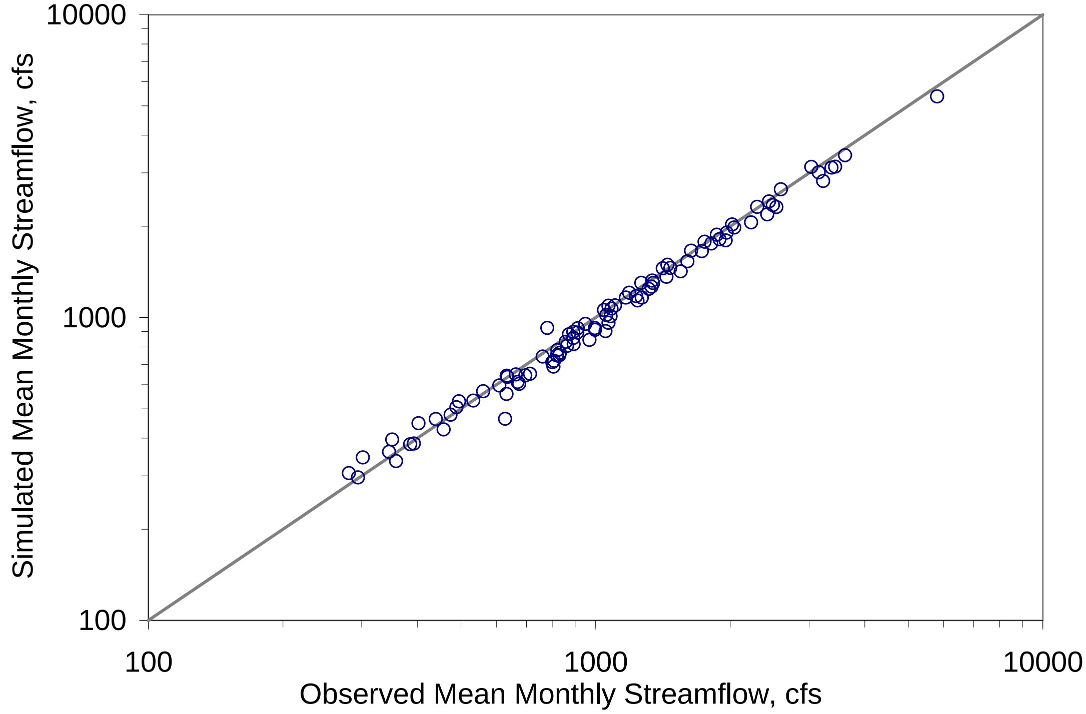
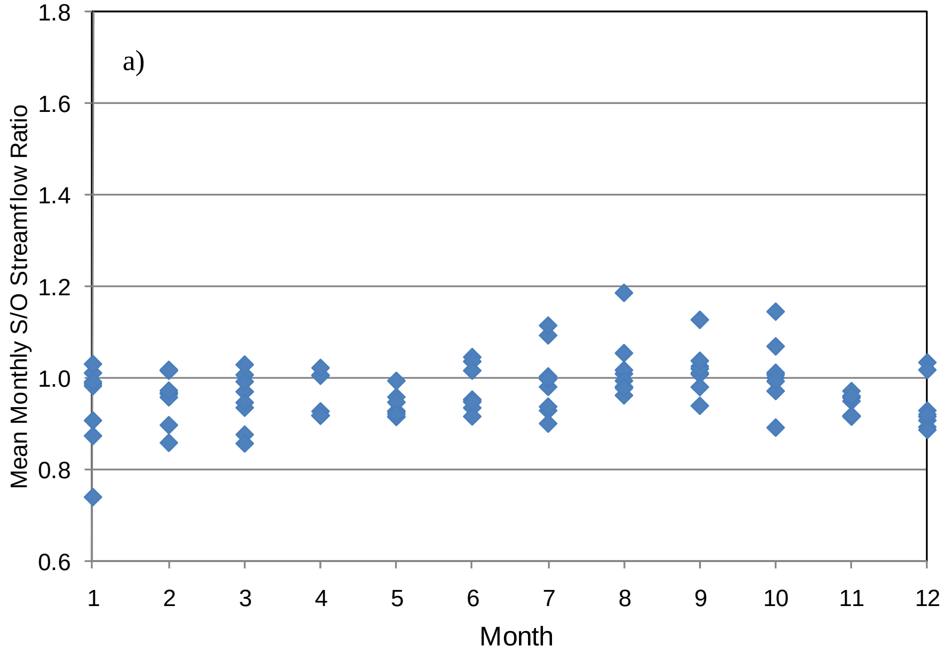


Figure 21. Observed and simulated mean monthly streamflows during calibration, South Elgin (WY 1991–1998)



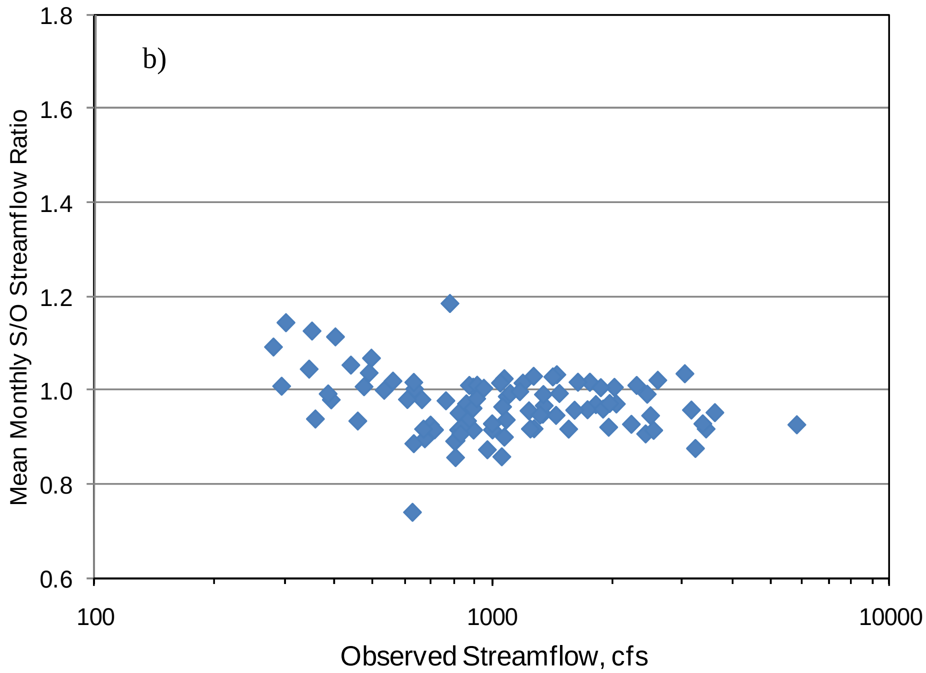


Figure 22. Comparison of simulated (S) and observed (O) mean monthly streamflow during calibration, South Elgin gage (WY 1991–1998): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow

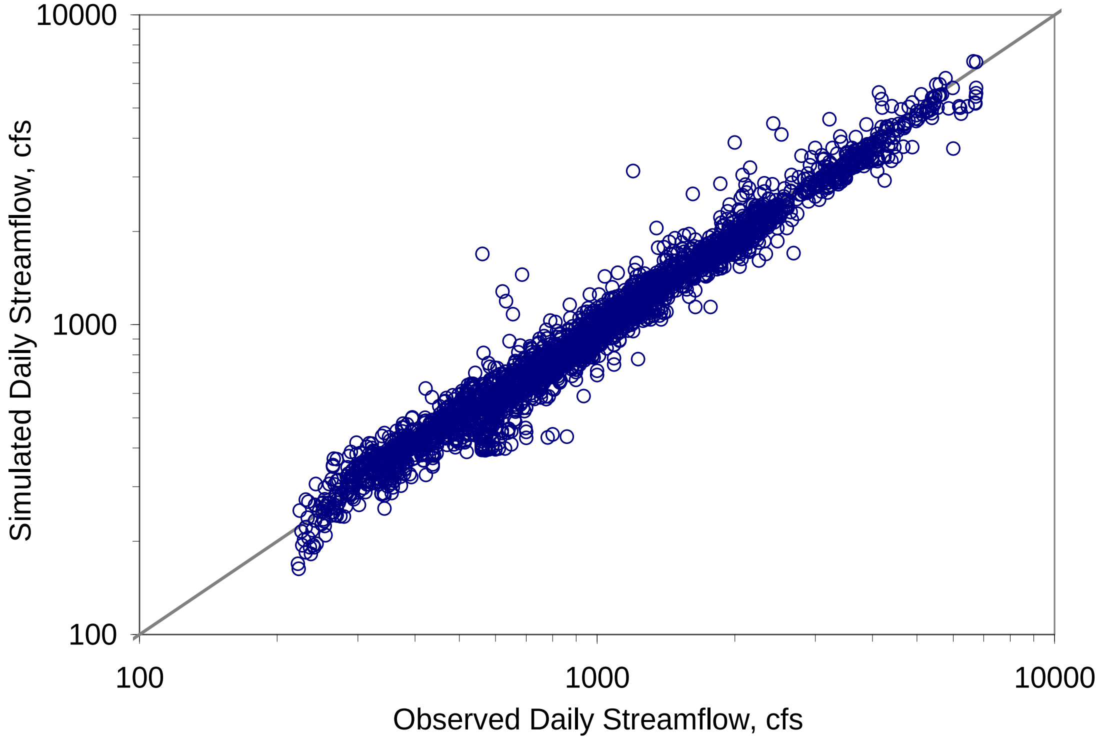


Figure 23. Observed and simulated daily streamflow during calibration, South Elgin (WY 1991–1998)

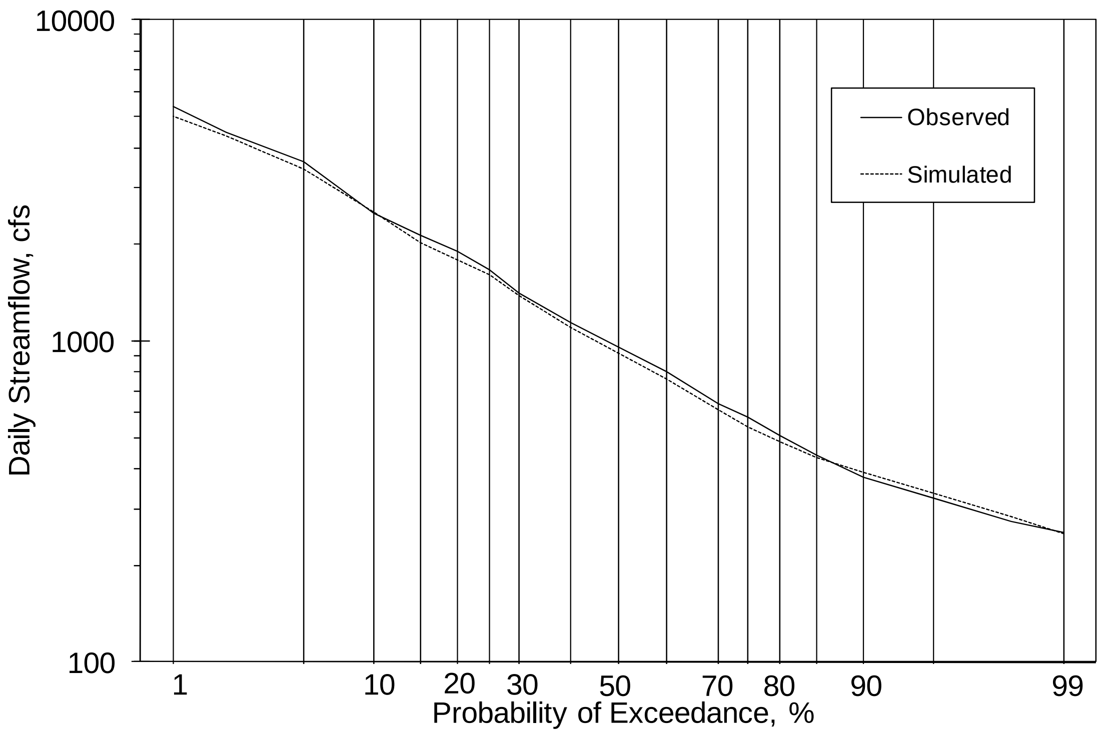


Figure 24. Flow duration curve for observed and simulated daily streamflow during calibration, South Elgin (WY 1991–1998)

The model simulation results for the most downstream gage at Dayton (near the mouth) show the total volume error between observed streamflows and simulated streamflows was -4.6 percent over the calibration period (WY 1991–1999). On a yearly basis, this error was within ±10 percent (very good simulation) in seven out of nine years of simulation (Table 18). Two years were between ±10 percent and ±25 percent. During the calibration period, the model overestimated streamflow in one year (Figure 25), but underestimated streamflow in the remaining years by a fair margin (seven years by less than 10 percent). Mean annual streamflows were simulated with NSE=0.92. Mean monthly streamflows were simulated with NSE=0.95 and r=0.98 (Table 18). Simulated versus observed mean monthly streamflows follow the S=O line, suggesting a significant relationship (Figure 26). The ratio of simulated and observed mean monthly flows was computed for each month in the calibration period, and ratios are plotted for each month (Figure 27). The model underestimated monthly streamflow for July through September by less than 7 percent, and for January, February, and May by 9 percent, 11 percent, and 8 percent, respectively. Of the 108 months in the calibration period, the volume error between observed and simulated mean monthly values was within ±10 percent in 66 months, as shown in Table 18. Statistics reported in Table 18 show fair agreement between observed and simulated daily streamflows for the calibration period. The NSE=0.89 also indicates that the model simulated daily streamflows well, although not as well as the mean monthly streamflows and annual streamflows. Observed and simulated daily streamflows show even scatter around the S=O line, suggesting a significant relationship (Figure 28). Flow duration curves for observed and simulated daily streamflows are shown in Figure 29. The model simulated the range of daily streamflows reasonably but underestimated daily streamflows. The highest 10 percent flows were underestimated by 5.9 percent, whereas the lowest 10 percent flows were underestimated by 7.6 percent.

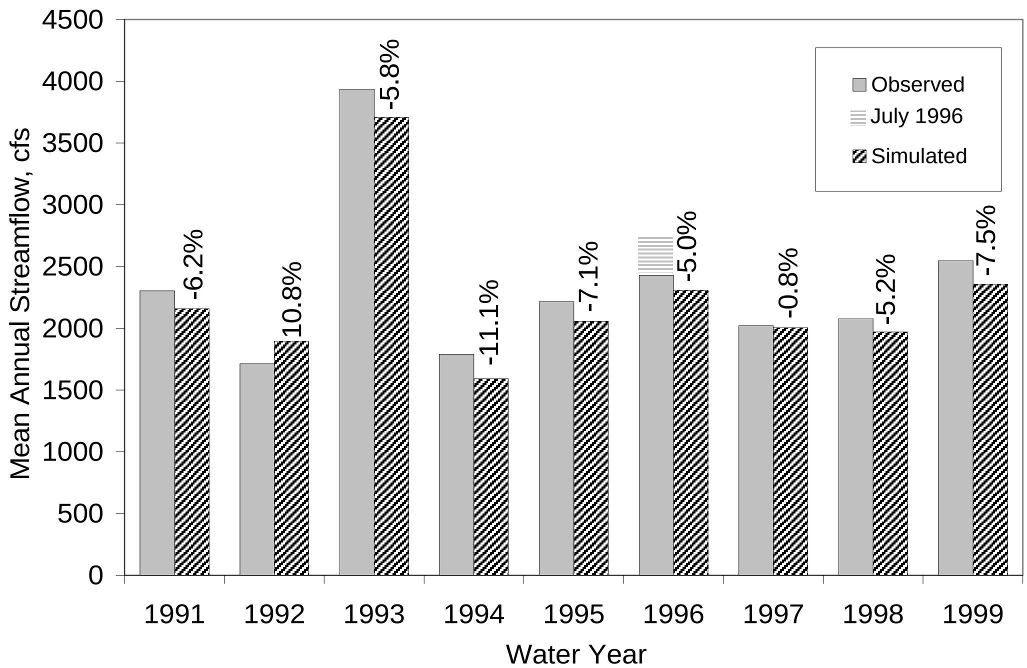


Figure 25. Observed and simulated mean annual streamflows during calibration, Dayton (WY 1991–1999)

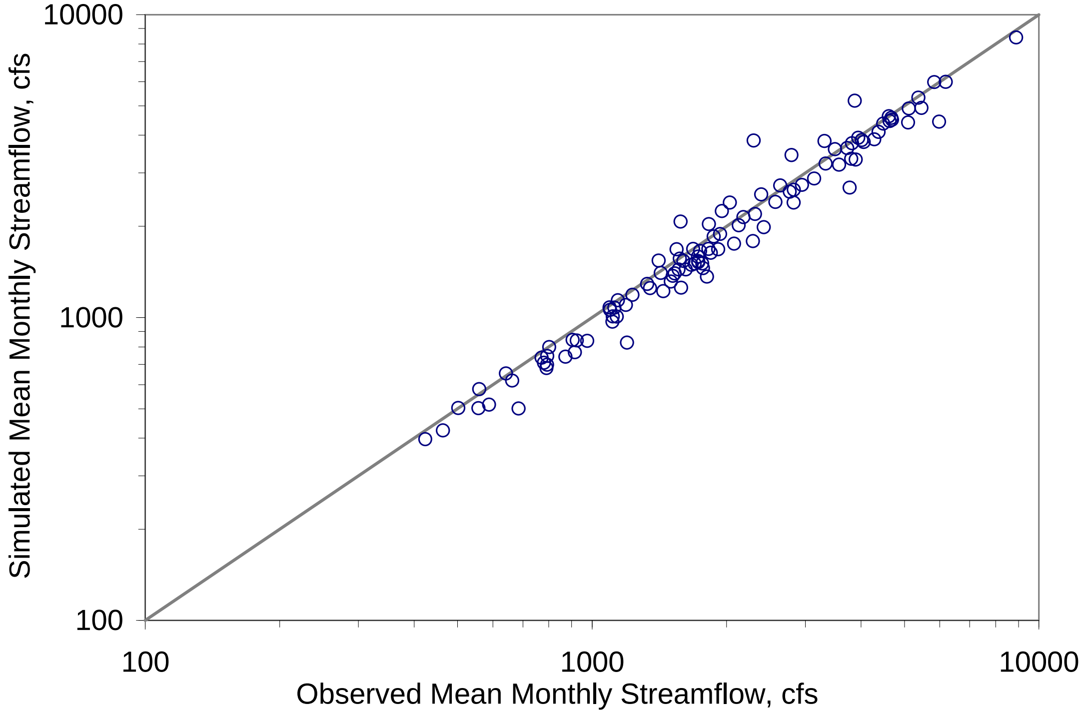
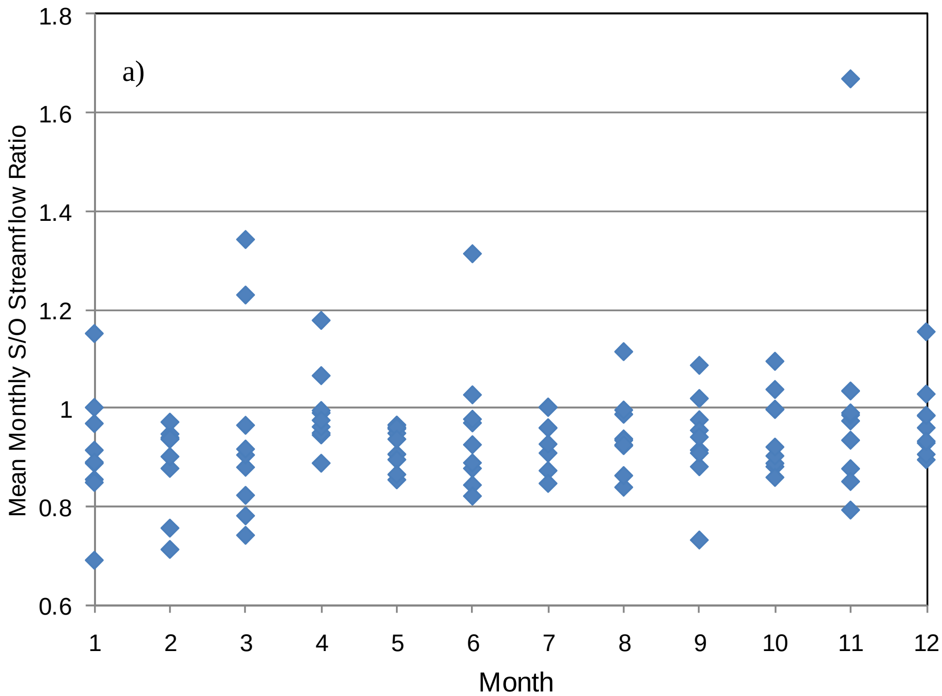


Figure 26. Observed and simulated mean monthly streamflows during calibration, Dayton (WY 1991–1999)



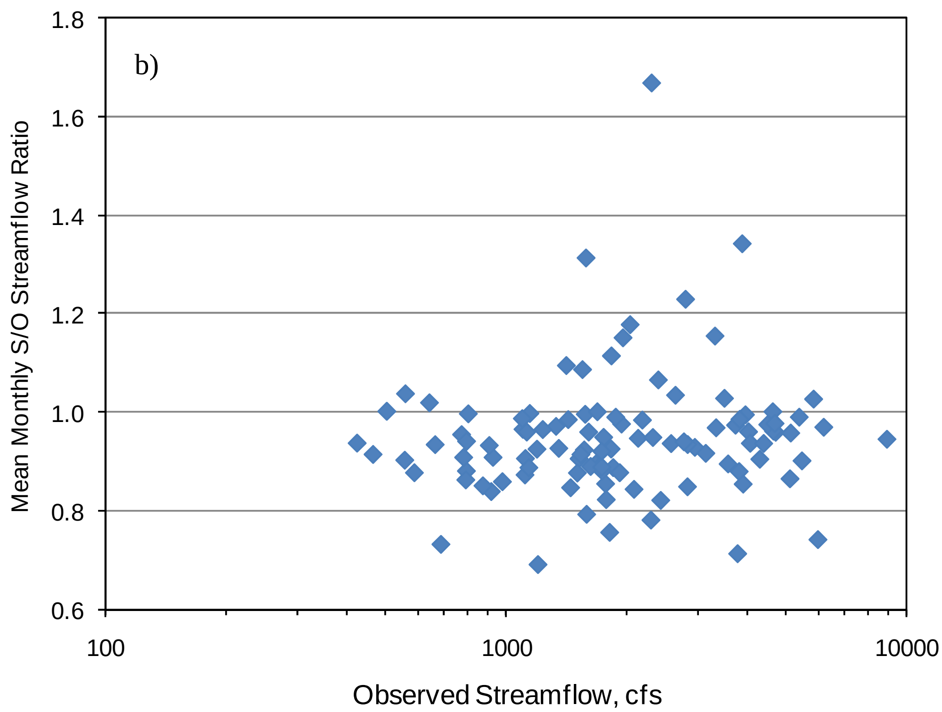


Figure 27. Comparison of simulated (S) and observed (O) mean monthly streamflow during calibration, Dayton gage (WY 1991–1999): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow

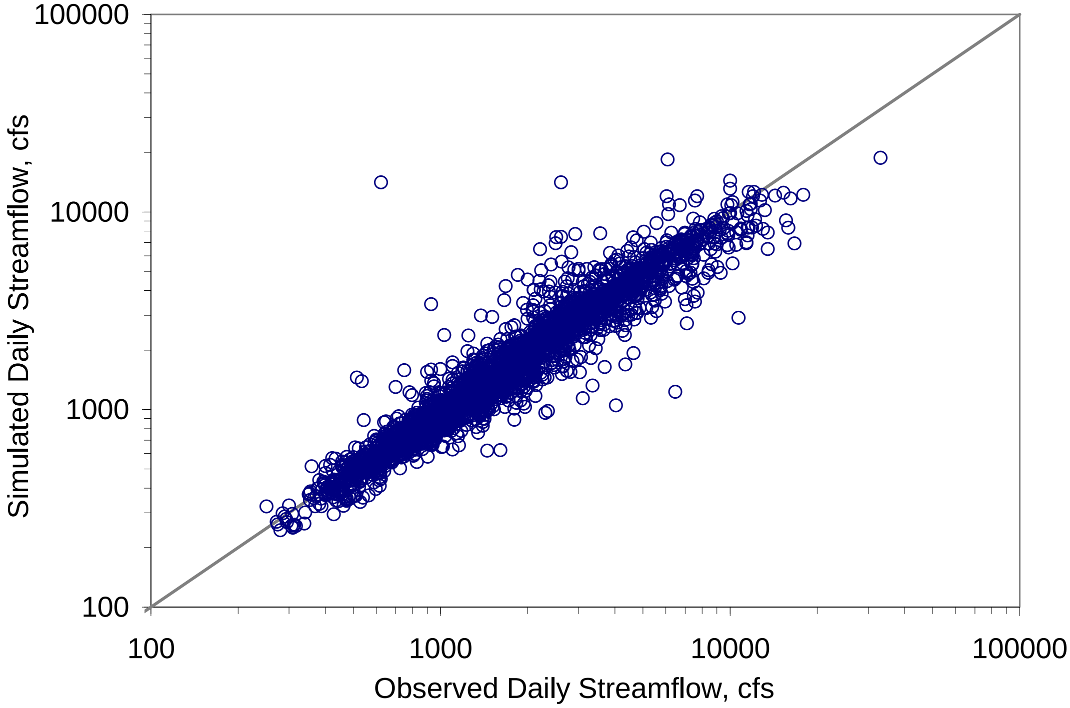


Figure 28. Observed and simulated daily streamflow during calibration, Dayton (WY 1991–1999)

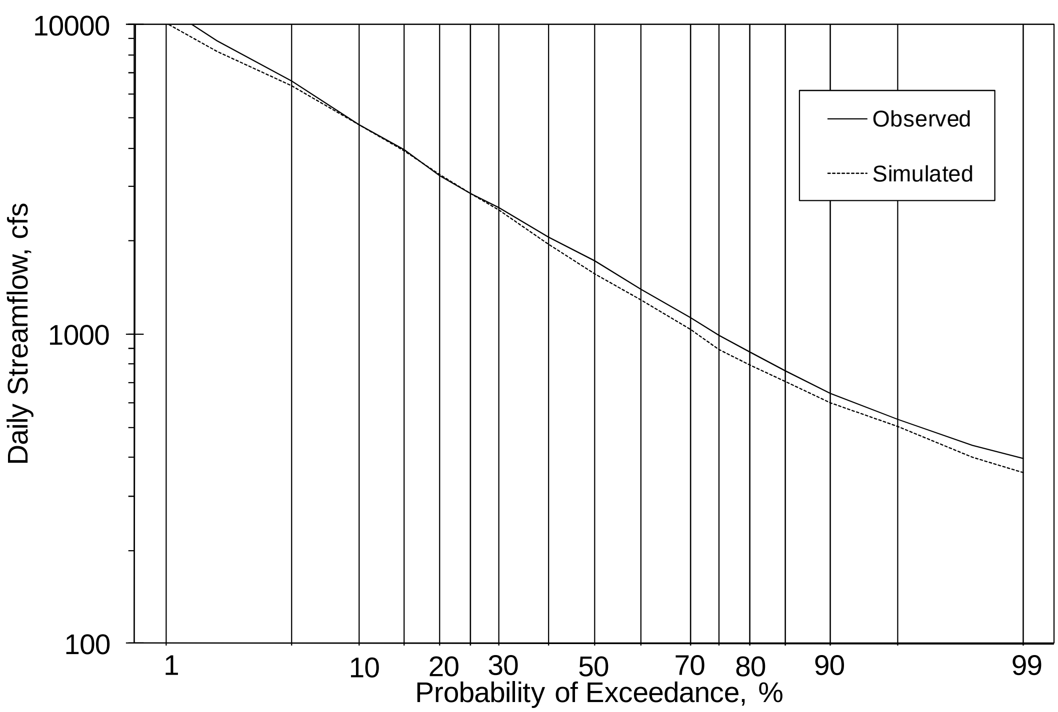


Figure 29. Flow duration curve for observed and simulated daily streamflow during calibration, Dayton (WY 1991–1999)

Validation of the Fox River Mainstem Model

Once the model was properly calibrated, the validation took place using observed streamflow data for the WY 2000–2003 time frame that was not used to calibrate the model. The ability of the model to simulate flows that correspond to observations without the additional need to adjust parameters illustrates a desirable result and validates the assigned parameter values. The same statistical and graphical comparisons used for the calibration period are used to compare flows for the validation periods. The integrated model was validated at Algonquin and Dayton USGS gage stations; the model could not be verified at South Elgin due to limited discharge data (the record ends in WY 1998, before the calibration period ends).

Total volume error between observed and simulated streamflow during the four-year validation period was -8.0 percent at Algonquin (Table 18, page 48). The model underestimates mean annual streamflow by -11.1 percent in WY 2001, which is the highest difference, and the smallest difference is -4.5 percent in WY 2002 (Figure 30). Mean annual streamflows were simulated with NSE=0.917. The NSE and r values for the monthly fit were 0.968 and 0.993, respectively. The scatter plot of simulated versus observed mean monthly streamflows (Figure 31) shows a similar bias toward slight underestimation of mean monthly streamflows. The plot of monthly S/O ratios versus month of year shows the model overestimates mean monthly flow in some years and months, but overall underestimates the flow (Figure 32). The volume error between observed and simulated mean monthly streamflows was within ±10 percent in 29 months and within ±25 percent in 47 months (Table 18). The simulated daily streamflows show fair agreement with observed values and resulted in model efficiency (NSE=0.956) and correlation coefficient (r=0.984) that are comparable to the calibration run. The scatter plot of observed and simulated daily streamflows given in Figure 33 shows the model tendency to underestimate daily streamflow. Flow duration curves (Figure 34) show that the model consistently underestimated daily streamflows during the four-year period. The highest 10 percent flows were underestimated by 9.1 percent, whereas the lowest 10 percent flows were underestimated by 3.1 percent.

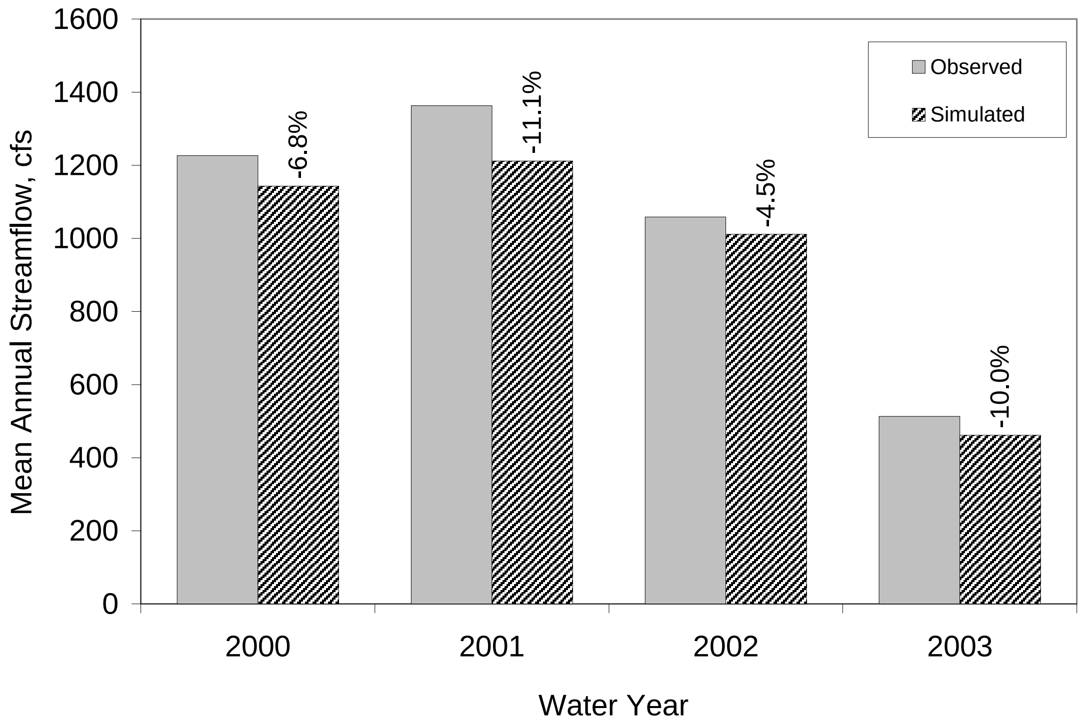


Figure 30. Observed and simulated mean annual streamflows during validation, Algonquin (WY 2000–2003)

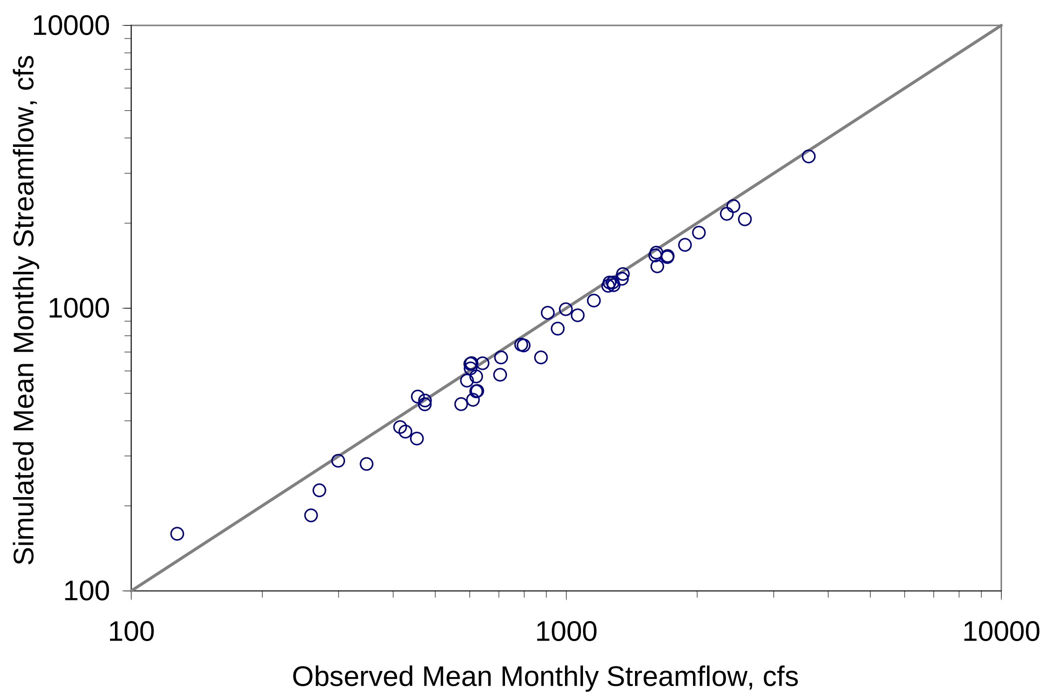
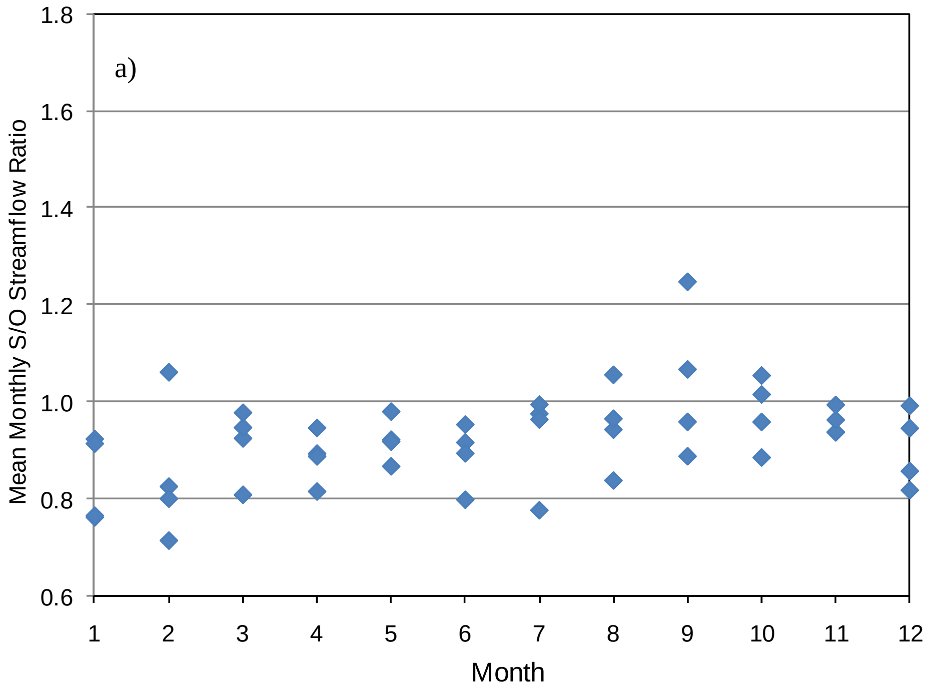


Figure 31. Observed and simulated mean monthly streamflows during validation, Algonquin (WY 2000–2003)



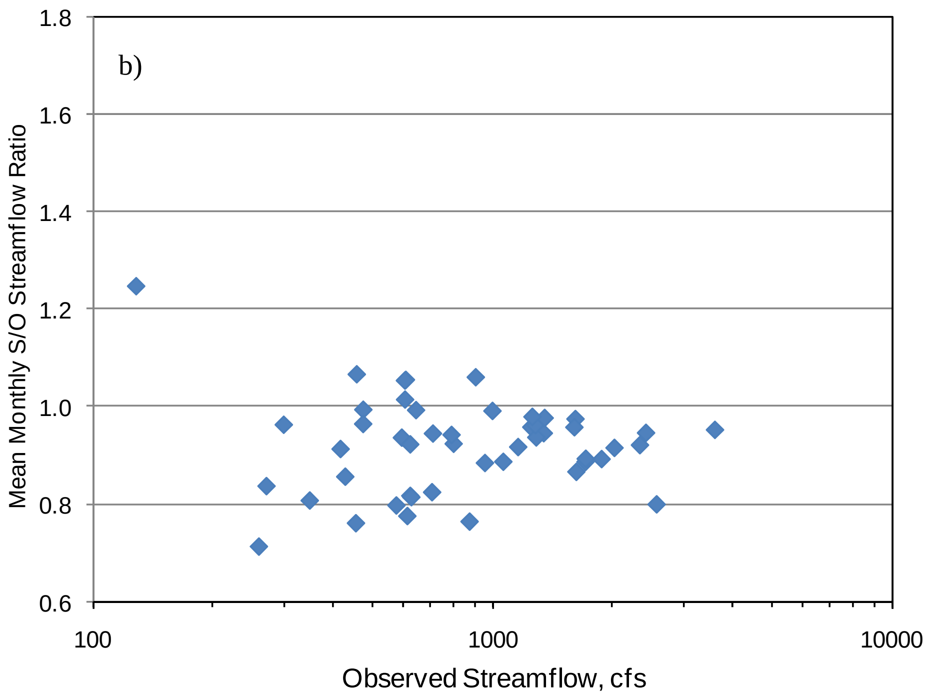


Figure 32. Comparison of simulated (S) and observed (O) mean monthly streamflow during validation, Algonquin gage (WY 2000–2003): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow

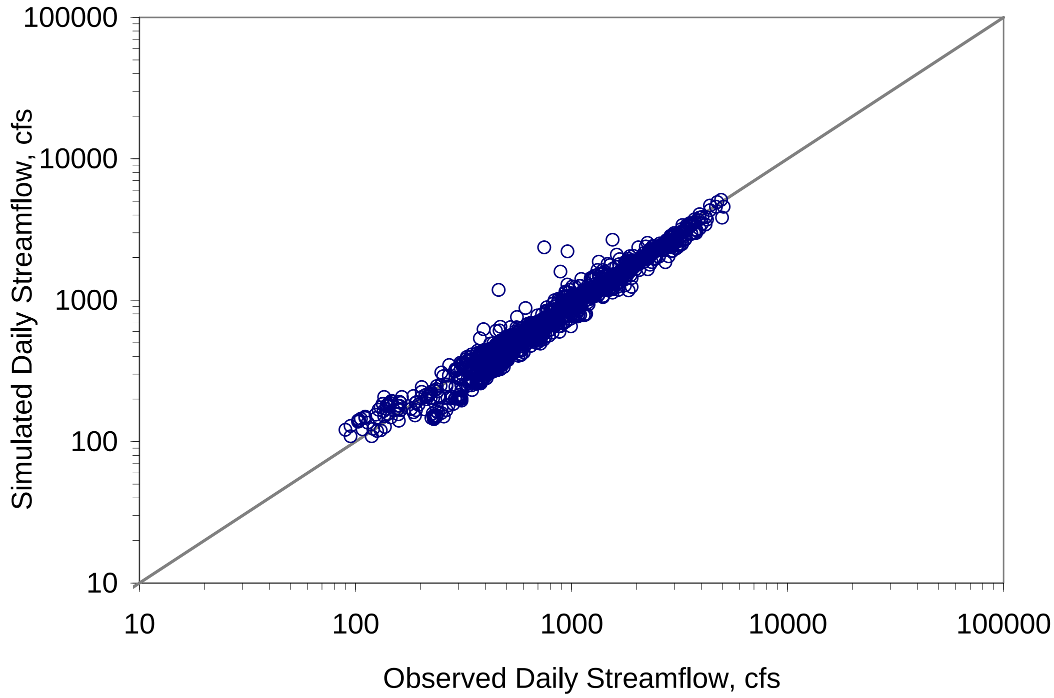


Figure 33. Observed and simulated daily streamflow during validation, Algonquin (WY 2000–2003)

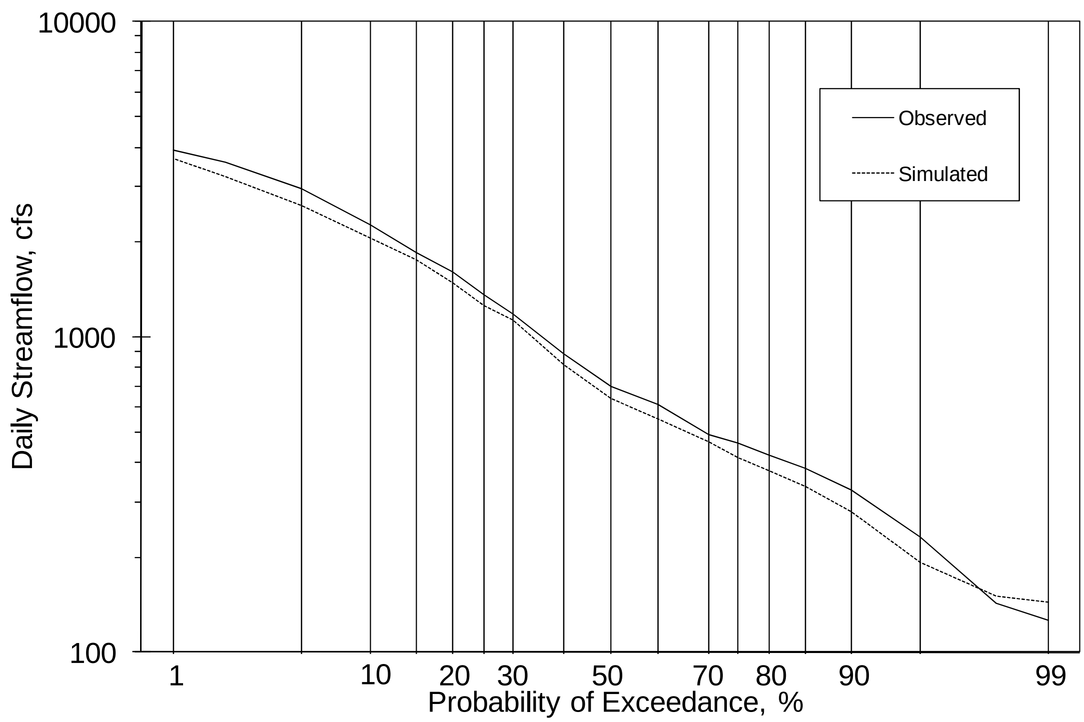


Figure 34. Flow duration curve for observed and simulated daily streamflow during validation, Algonquin (WY 2000–2003)

At the Dayton gage for the validation period, the total volume error between observed and simulated streamflow was -5.3 percent (Table 18). The model underestimates mean annual streamflow by 12.0 percent in WY 2003, which is the largest difference, and the smallest difference is 1.1 percent in WY 2002 (Figure 35). Mean annual streamflows were simulated with NSE=0.919. The NSE and r values for the monthly fits are 0.952 and 0.979, respectively. The volume error between observed and simulated mean monthly streamflows was within ±10 percent in 25 months and within ±25 percent in 46 months (Table 18, Figure 36). The plot of monthly S/O ratios versus month of year shows the model overestimates mean monthly flow in some years and months, but overall underestimates the flow (Figure 37). The simulated daily streamflows show fair agreement with observed values and resulted in model efficiency (NSE=0.893) and a correlation coefficient (r=0.947) comparable to the calibration run. The scatter plot of observed and simulated daily streamflows given in Figure 38 shows the model has a slight tendency to underestimate daily streamflow. Flow duration curves (Figure 39) show that the model consistently underestimated daily streamflows during the four-year period. The highest 10 percent flows were underestimated by 2.0 percent, whereas the lowest 10 percent flows were underestimated by 10.6 percent.

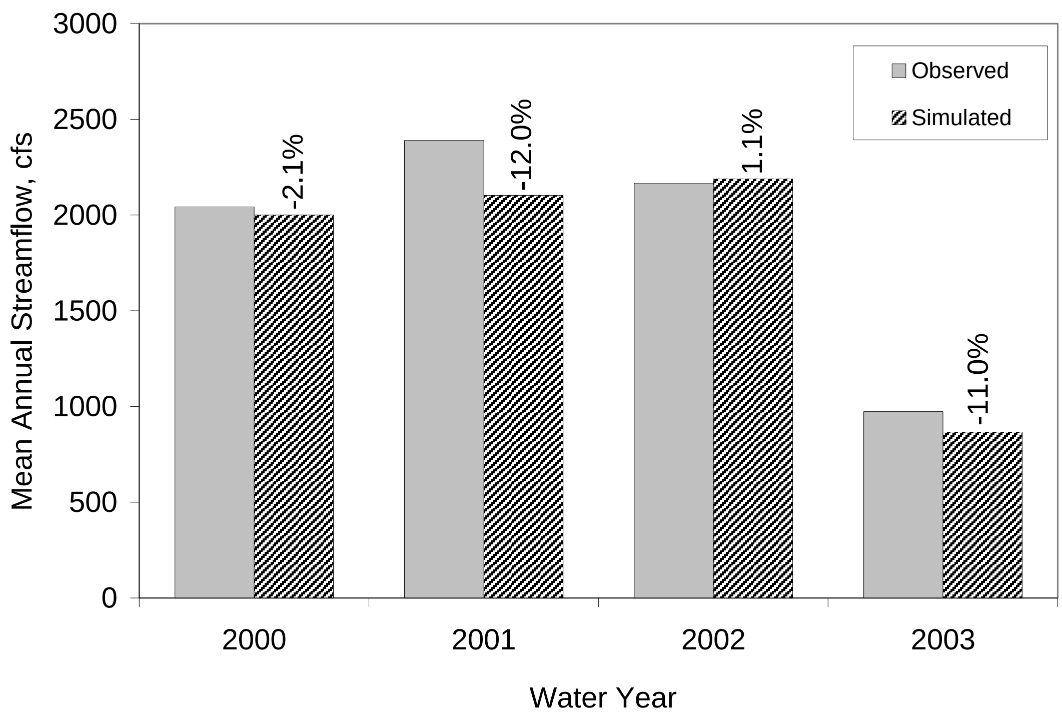


Figure 35. Observed and simulated mean annual streamflows during validation, Dayton (WY 2000–2003)

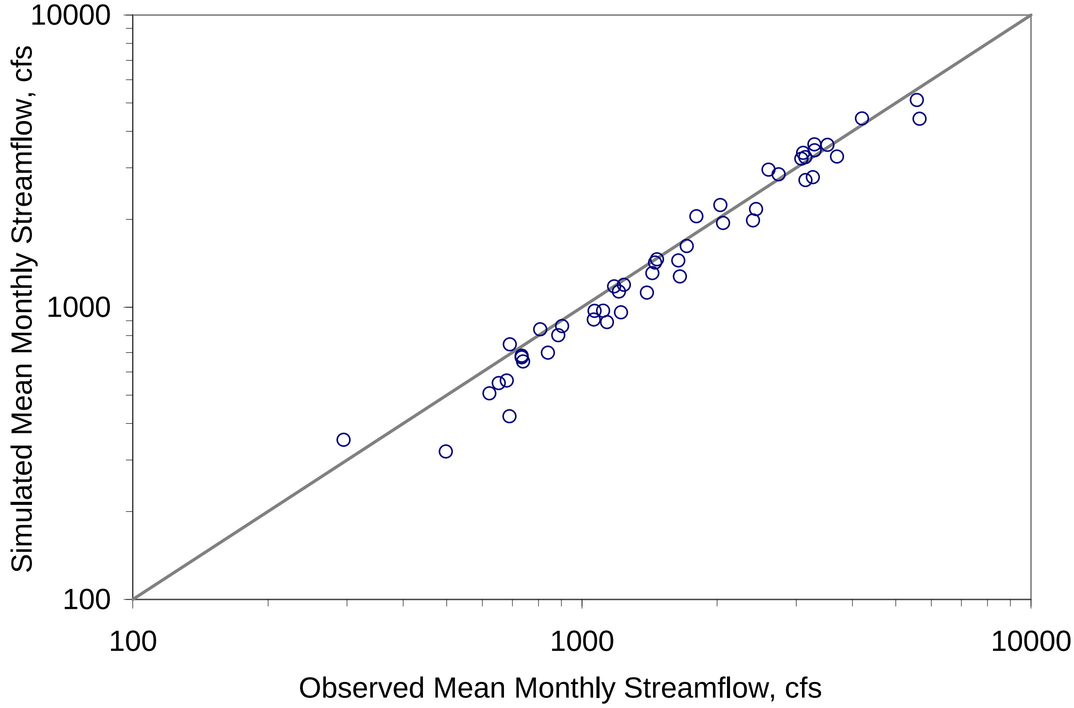
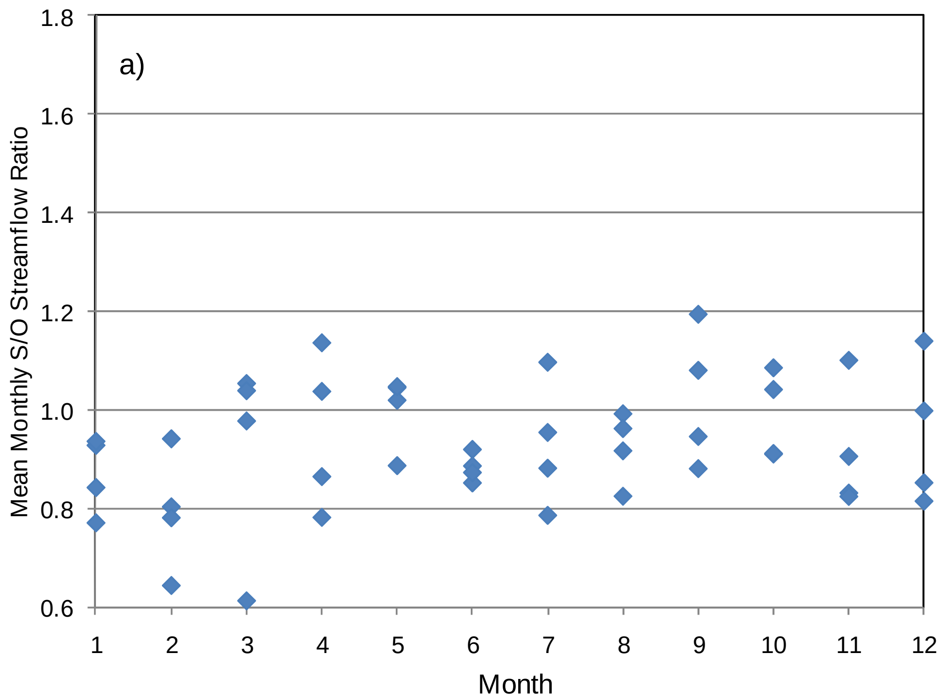


Figure 36. Observed and simulated mean monthly streamflows during validation, Dayton (WY 2000–2003)



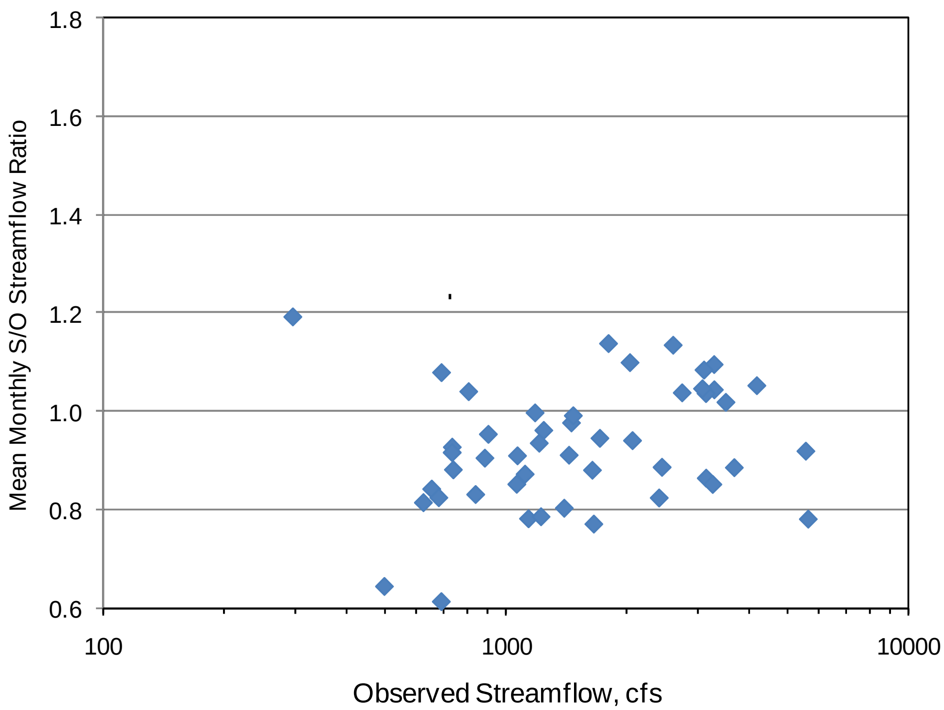


Figure 37. Comparison of simulated (S) and observed (O) mean monthly streamflow during validation, Dayton gage (WY 2000–2003): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow

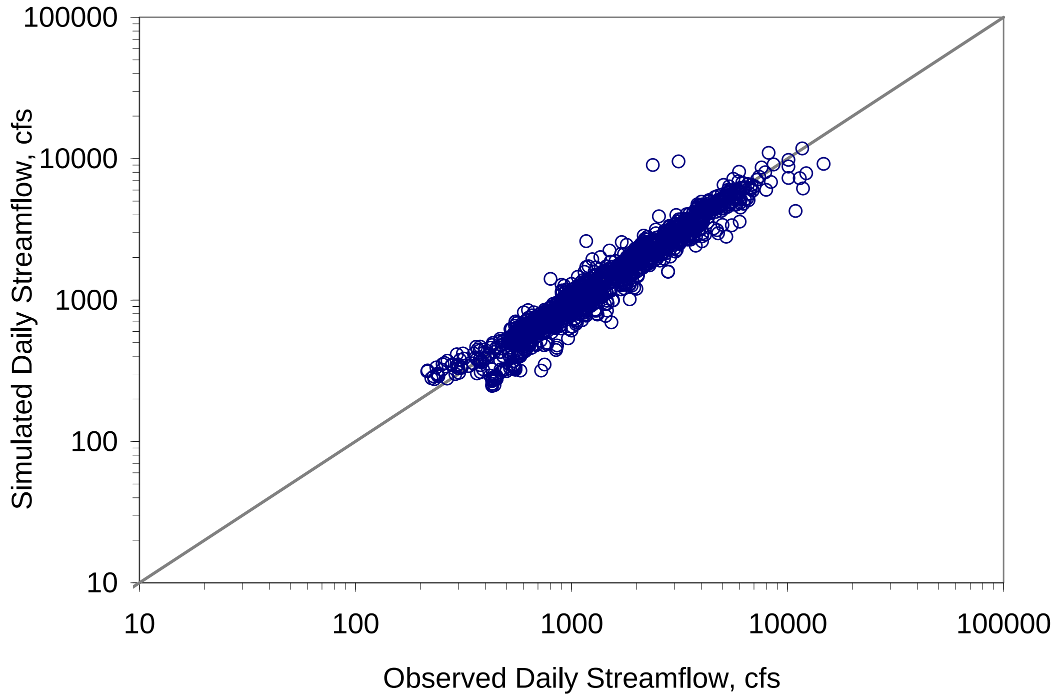


Figure 38. Observed and simulated daily streamflow during validation, Dayton (WY 2000–2003)

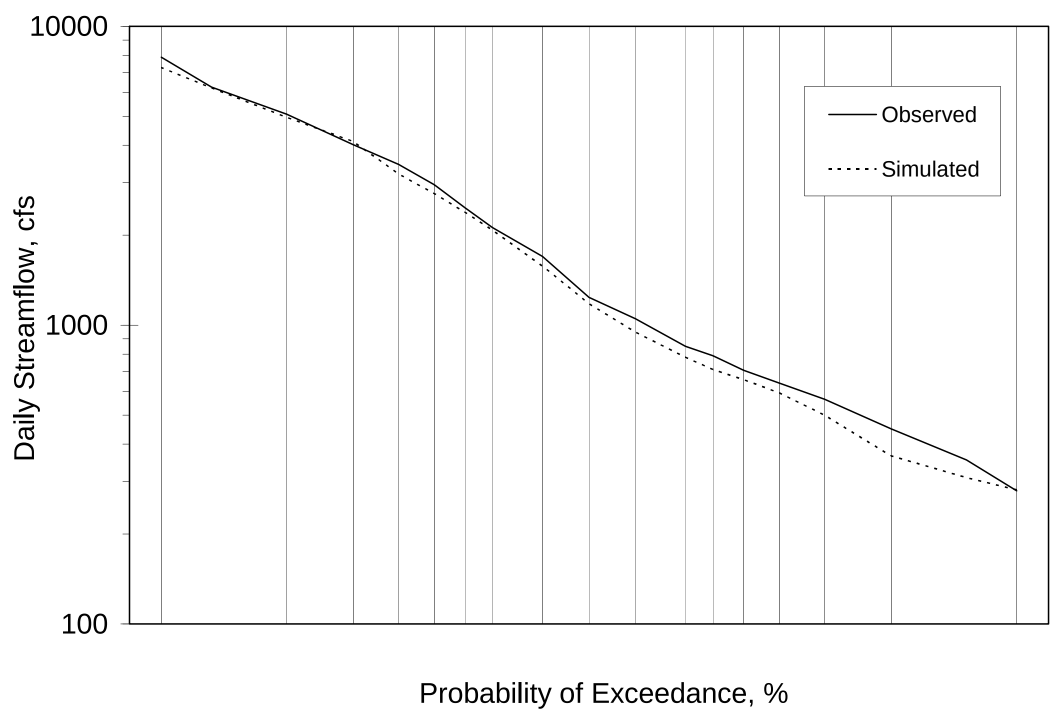


Figure 39. Flow duration curve for observed and simulated daily streamflow during validation, Dayton (WY 2000–2003)

Effects on Previously Calibrated and Validated Seven Tributary Watersheds

Before calibrating the integrated model at three gage stations on the mainstem, the two tributary watersheds (Blackberry Creek and Poplar Creek) were calibrated as pilot watersheds. Calibration parameters from these two watersheds were transferred to five other tributary watersheds (Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek) to validate the results. These studies were presented in the Part 2 and Part 3 reports (Bartosova et al., 2007a, b). However, those sets of parameters required further adjustment for an integrated model. Therefore, the integrated model was calibrated and validated on USGS gage stations on the mainstem as described in the previous sections. Since the model parameters were adjusted, new statistics are presented in this section.

Table 19 presents model simulation statistics for the annual, monthly, and daily flows of the tributary watersheds at their respective USGS gages. The results show that the calibrated and validated integrated model was also able to produce good simulation results for the previously calibrated models of tributary watersheds.

Statistics reported in Table 19 show fair agreement between observed and simulated daily streamflows for most watersheds. Total volume error is within 10 percent, and annual NSE more than 0.5 for all but the Brewster Creek watershed. Note that the Brewster Creek gage had data available only for 18 months; the shorter record makes statistics less reliable for evaluating model performance during the simulation period. Monthly NSE is above 0.8 for all but one gage (Blackberry Creek at Yorkville during the calibration period, NSE=0.607). Daily NSE is above 0.5 for several watersheds; two other watersheds (Blackberry Creek at Yorkville during the calibration period and Ferson Creek at St. Charles) have daily NSE just below 0.5. Three gages show NSE between 0.1 and 0.3 (Brewster Creek, Flint Creek, and Poplar Creek during the validation period). Although the model performance for the two pilot watersheds declined slightly from the initial calibration (Bartosova et al., 2007a,b), it improved for the remaining five watersheds, and overall, the updated set of model parameters gives better performance at the seven tributary watersheds and the three mainstem gages (see Appendix C for statistics prior to full mainstem calibration as published in Bartosova et al., 2007a,b).

Table 19. Statistics for the Model Calibration and Validation Periods at Tributary Gages

	Blackberry			*Brewster*	*Ferson*	*Flint*	*Mill*	*Poplar*		*Tyler*
Statistics	*Yorkville**		*Montgo-mery*	*Valley view*	*St. Charles**	*Fox River Grove*	*Batavia*	*Elgin*		*Elgin*
	WY 1991-1999	*WY 2000-2003*	*WY 2000-2003*	*WY 2002-2003*	*WY 1991-2003*	*WY 1991-1996*	*WY 1998-2003*	*WY 1991-1999*	*WY 2000-2003*	*WY 1998-2003*
Observed mean flow, cfs	58.9	43.3	36.2	7.1	43.7	33.9	20.5	33.6	29.4	29.8
Simulated mean flow, cfs	62.5	41.3	35.0	5.7	42.3	36.4	19.3	35.8	27.5	30.8
Dv, %	6.1	-4.6	-3.3	-19.9	-3.3	7.3	-5.9	6.3	-6.4	3.3
Annual										
NSE	0.616	0.653	0.704	0.126	0.902	0.720	0.682	0.656	0.909	0.964
r	0.830	0.837	0.882	1.000	0.963	0.949	0.867	0.963	0.990	0.985
Years with Dv within ±10%	4	2	4	2	8	3	2	3	2	5
Years with Dv within ±25%	7	3	4	2	13	6	4	9	4	6
Monthly										
NSE	0.607	0.802	0.816	0.850	0.865	0.828	0.808	0.808	0.875	0.908
r	0.812	0.899	0.909	0.952	0.936	0.914	0.902	0.923	0.942	0.954
Months with Dv within ±10%	24	11	12	3	44	15	9	27	11	15
Months with Dv within ±25%	53	25	27	7	96	28	32	57	29	32
Daily										
NSE	0.482	0.690	0.697	0.275	0.499	0.151	0.541	0.521	0.150	0.737
r	0.713	0.835	0.837	0.772	0.742	0.606	0.737	0.806	0.670	0.864

Notes: * excluding July 1996

Summary and Conclusions

Calibration of the hydrologic model of the Fox River watershed is a prerequisite to develop water quality simulation models, a principle objective of the Fox River Watershed Investigation. The integrated HSPF model prepared for the study area will serve as the basis for simulating the transport and fate of various pollutants in the watershed and in particular, their delivery to, and effect on, the Fox River. The integrated HSPF model consists of 31 individual HSPF models simulating the hydrology of all major tributaries to the Fox River. The simulated tributary watershed flows are input to the Fox mainstem model, which also includes the interbasin flow areas that drain directly to the Fox River. Such integration of individual models enables piece-wise improvement of the integrated model as more data or improved models become available on a tributary watershed basis. It also enables specific watershed groups to use the models of their respective watersheds without any additional manipulation. Thus 32 individual HSPF models have been developed together with a protocol for integrating model simulations within the integrated Fox watershed model.

The HSPF models prepared to simulate the hydrology of the Fox watershed are tools used to help assess the movement of water through a very complex system. The strength of the HSPF model is that various aspects of the hydrologic process are separated to allow for individual parameterization and characterization throughout diverse watersheds. However, these processes are only partially understood, and the simulation routines can only approximate them. Furthermore, many processes cannot be directly measured, and parameters must be calibrated on the basis of indirect measurement. Data requirements for calibration are intensive.

A stepwise, iterative procedure was established to assign model parameter values and achieve the best possible simulation of flows along the mainstem of the Fox River. Initially, model parameter values were determined from a study of two pilot watersheds. These parameter values were further tested by applying them to models of five other gaged tributaries. The parameter values were then adjusted to best simulate flows at all 10 gages and applied to the remaining ungaged watersheds and the integrated Fox River mainstem model. Additional calibration trials were performed to improve simulation results along the mainstem of the Fox River while maintaining acceptable results at the gaged tributaries. Simulation results were compared to flow observations at three stations on the Fox River mainstem and seven gages located on tributaries.

Model calibration and parameterization in this study were focused on dominant HRUs in each watershed, i.e., HRUs representing a significant portion of the drainage area contributing to respective gages. Parameter values for the non-dominant HRUs were assigned from dominant HRUs based on the HRU component (land use, soil, and/or slope) that has the most significant effect on a particular parameter. In the process of calibrating the integrated Fox River mainstem HSPF model, additional dominant HRUs that were not present in the two calibrated pilot watersheds (Blackberry Creek and Poplar Creek watersheds) were calibrated against the observed flows on the gaged tributaries and Fox River mainstem. The HSPF model can only simulate constant land use, assuming no change during the simulation period. This assumption inherently introduces uncertainty in model results, especially during longer simulation periods or times of rapid development.

Two factors that limit the accuracy of the model calibration are climate and streamflow data. A complete set of climate data (precipitation, temperature, potential evapotranspiration, cloud cover, etc.) is not available in sufficient spatial and temporal resolution for each tributary watershed and along the mainstem. Uncertainty in the inputs to the hydrologic model is introduced by a) approximation of the climate variables associated with the small number of climate stations available for the Fox River watershed, b) necessity to supply data during periods when a station does not have the data (missing data or data outside the station's period of record), and c) disaggregation of daily data into hourly data. Discharge observations at Stratton Dam serve as the upstream boundary condition; however, the daily flow is estimated from only two readings a day. Comparison to daily flow computed from hourly observations at the Algonquin gage clearly shows that the accuracy of discharge observations recorded at Stratton Dam greatly influences accuracy of model simulations since Stratton Dam flow constitutes 85 percent of flow on average at Algonquin. The contribution diminishes for downstream stations; Stratton Dam flow constitutes only 40 percent of flow at Dayton on average. The overall tendency of the model to underestimate Fox River flows can be attributed to discrepancies in Stratton Dam flow.

The simulation period consists of three distinct parts. The first nine months (January 1–September 30, 1990) are considered a warm-up period for the model. This period minimizes the influence of estimated initial conditions on the model simulation and is not used in any analyses. The calibration period for the integrated model is WY 1991 to 1999. The validation period, WY 2000–2003, provides additional data outside the calibration period to test model performance.

The integrated model simulates total volume with very good accuracy: total volume error is within 10 percent for all gages except the Brewster Creek gage. The Brewster Creek gage has only 16 months of data (June 2002–September 2003) with a prolonged low flow period. This strongly affects the simulation results since the model was calibrated to medium flows (days with extreme flows were excluded from statistics and graphical comparisons during calibration). The agreement between simulated and observed flows is confirmed by statistics (NSE and r) for annual, monthly, and daily flows on the mainstem. While model performance at the two pilot watersheds, Blackberry and Poplar Creek, is lower than during the initial calibration (Bartosova et al., 2007a), the overall performance at all gaged tributary watersheds improved (Bartosova et al., 2007b).

The integrated HSPF model of the Fox watershed between Stratton Dam and the Illinois River was developed using all available physical, climate, and streamflow data. The hydrologic simulation results show very good agreement when compared to flows observed on the mainstem of the Fox River. The next step in the Fox River investigation is to parameterize the water quality components of the integrated HSPF model.

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Appendix A. HRU Types Represented in the Study Area

HRU Code	*Land use*	*Soil type*	*Slope category*	*Study area*
COR11	Corn	A	<2%	<1%
COR12	Corn	A	2-4%	<1%
COR13	Corn	A	4-6%	<1%
COR14	Corn	A	>6%	<1%
COR21	Corn	B	<2%	18%
COR22	Corn	B	2-4%	10%
COR23	Corn	B	4-6%	<1%
COR24	Corn	B	>6%	<1%
COR31	Corn	C	<2%	<1%
COR32	Corn	C	2-4%	1%
COR33	Corn	C	4-6%	<1%
COR34	Corn	C	>6%	<1%
COR41	Corn	D	<2%	<1%
COR42	Corn	D	2-4%	<1%
COR43	Corn	D	4-6%	<1%
COR44	Corn	D	>6%	<1%
FOR11	Forest	A	<2%	<1%
FOR12	Forest	A	2-4%	<1%
FOR13	Forest	A	4-6%	<1%
FOR14	Forest	A	>6%	<1%
FOR21	Forest	B	<2%	<1%
FOR22	Forest	B	2-4%	3%
FOR23	Forest	B	4-6%	2%
FOR24	Forest	B	>6%	<1%
FOR31	Forest	C	<2%	<1%
FOR32	Forest	C	2-4%	1%
FOR33	Forest	C	4-6%	<1%
FOR34	Forest	C	>6%	<1%
FOR41	Forest	D	<2%	<1%
FOR42	Forest	D	2-4%	<1%
FOR43	Forest	D	4-6%	<1%
FOR44	Forest	D	>6%	<1%
RGR11	Rural grassland	A	<2%	<1%
RGR12	Rural grassland	A	2-4%	<1%
RGR13	Rural grassland	A	4-6%	<1%
RGR14	Rural grassland	A	>6%	<1%
RGR21	Rural grassland	B	<2%	4%
RGR22	Rural grassland	B	2-4%	5%
RGR23	Rural grassland	B	4-6%	1%

Appendix A. (continued)

HRU Code	*Land use*	*Soil type*	*Slope category*	*Study area*
RGR24	Rural grassland	B	>6%	<1%
RGR31	Rural grassland	C	<2%	<1%
RGR32	Rural grassland	C	2-4%	<1%
RGR33	Rural grassland	C	4-6%	<1%
RGR34	Rural grassland	C	>6%	<1%
RGR41	Rural grassland	D	<2%	<1%
RGR42	Rural grassland	D	2-4%	<1%
RGR43	Rural grassland	D	4-6%	<1%
RGR44	Rural grassland	D	>6%	<1%
SOY11	Soy	A	<2%	<1%
SOY12	Soy	A	2-4%	<1%
SOY13	Soy	A	4-6%	<1%
SOY21	Soy	B	<2%	16%
SOY22	Soy	B	2-4%	9%
SOY23	Soy	B	4-6%	<1%
SOY24	Soy	B	>6%	<1%
SOY31	Soy	C	<2%	<1%
SOY32	Soy	C	2-4%	1%
SOY33	Soy	C	4-6%	<1%
SOY34	Soy	C	>6%	<1%
SOY41	Soy	D	<2%	<1%
SOY42	Soy	D	2-4%	<1%
SOY43	Soy	D	4-6%	<1%
SOY44	Soy	D	>6%	<1%
SWA11	Surface water	A	<2%	<1%
SWA12	Surface water	A	2-4%	<1%
SWA13	Surface water	A	4-6%	<1%
SWA14	Surface water	A	>6%	<1%
SWA21	Surface water	B	<2%	<1%
SWA22	Surface water	B	2-4%	<1%
SWA23	Surface water	B	4-6%	<1%
SWA24	Surface water	B	>6%	<1%
SWA31	Surface water	C	<2%	<1%
SWA32	Surface water	C	2-4%	<1%
SWA33	Surface water	C	4-6%	<1%
SWA34	Surface water	C	>6%	<1%
SWA42	Surface water	D	2-4%	<1%
SWA43	Surface water	D	4-6%	<1%
SWA44	Surface water	D	>6%	<1%

Appendix A. (continued)

HRU Code	*Land use*	*Soil type*	*Slope category*	*Study area*
SWM12	Wetlands	A	2-4%	<1%
SWM13	Wetlands	A	4-6%	<1%
SWM21	Wetlands	B	<2%	<1%
SWM22	Wetlands	B	2-4%	<1%
SWM23	Wetlands	B	4-6%	<1%
SWM31	Wetlands	C	<2%	<1%
SWM32	Wetlands	C	2-4%	<1%
SWM33	Wetlands	C	4-6%	<1%
SWM34	Wetlands	C	>6%	<1%
SWM41	Wetlands	D	<2%	<1%
SWM42	Wetlands	D	2-4%	<1%
SWM43	Wetlands	D	4-6%	<1%
SWM44	Wetlands	D	>6%	<1%
UHDi1	Urban high density	impervious	<2%	<1%
UHDi2	Urban high density	impervious	2-4%	<1%
UHDi3	Urban high density	impervious	4-6%	<1%
UHDi4	Urban high density	impervious	>6%	<1%
UHD12	Urban high density	A	2-4%	<1%
UHD14	Urban high density	A	>6%	<1%
UHD21	Urban high density	B	<2%	<1%
UHD22	Urban high density	B	2-4%	<1%
UHD23	Urban high density	B	4-6%	<1%
UHD24	Urban high density	B	>6%	<1%
UHD31	Urban high density	C	<2%	<1%
UHD32	Urban high density	C	2-4%	<1%
UHD33	Urban high density	C	4-6%	<1%
UHD34	Urban high density	C	>6%	<1%
UHD42	Urban high density	D	2-4%	<1%
UHD43	Urban high density	D	4-6%	<1%
UHD44	Urban high density	D	>6%	<1%
ULMi1	Urban low/medium density	impervious	<2%	<1%
ULMi2	Urban low/medium density	impervious	2-4%	<1%
ULMi3	Urban low/medium density	impervious	4-6%	<1%
ULMi4	Urban low/medium density	impervious	>6%	<1%
ULM11	Urban low/medium density	A	<2%	<1%
ULM12	Urban low/medium density	A	2-4%	<1%
ULM13	Urban low/medium density	A	4-6%	<1%
ULM14	Urban low/medium density	A	>6%	<1%
ULM21	Urban low/medium density	B	<2%	1%

Appendix A. (concluded)

HRU Code	*Land use*	*Soil type*	*Slope category*	*Study area*
ULM22	Urban low/medium density	B	2-4%	2%
ULM23	Urban low/medium density	B	4-6%	1%
ULM24	Urban low/medium density	B	>6%	<1%
ULM31	Urban low/medium density	C	<2%	<1%
ULM32	Urban low/medium density	C	2-4%	1%
ULM33	Urban low/medium density	C	4-6%	<1%
ULM34	Urban low/medium density	C	>6%	<1%
ULM41	Urban low/medium density	D	<2%	<1%
ULM42	Urban low/medium density	D	2-4%	<1%
ULM43	Urban low/medium density	D	4-6%	<1%
ULM44	Urban low/medium density	D	>6%	<1%
UOS11	Urban open space	A	<2%	<1%
UOS12	Urban open space	A	2-4%	<1%
UOS13	Urban open space	A	4-6%	<1%
UOS14	Urban open space	A	>6%	<1%
UOS21	Urban open space	B	<2%	2%
UOS22	Urban open space	B	2-4%	2%
UOS23	Urban open space	B	4-6%	2%
UOS24	Urban open space	B	>6%	<1%
UOS31	Urban open space	C	<2%	<1%
UOS32	Urban open space	C	2-4%	2%
UOS33	Urban open space	C	4-6%	<1%
UOS34	Urban open space	C	>6%	<1%
UOS41	Urban open space	D	<2%	<1%
UOS42	Urban open space	D	2-4%	<1%
UOS43	Urban open space	D	4-6%	<1%
UOS44	Urban open space	D	>6%	<1%

Note: Effective and non-effective impervious areas are combined in this table into one impervious HRU.

Appendix B. Subwatershed Areas for the Mainstem Model

Subwatershed ID	*Total area, acre*	*Fraction of total watershed area, %*
1	3,700	2.24
2	4,662	2.83
3	1,937	1.17
4	114	0.07
5	4,361	2.64
6	31	0.02
7	2,776	1.68
8	5,547	3.36
9	3,386	2.05
10	1,260	0.76
11	1,050	0.64
12	665	0.40
13	1,561	0.95
14	238	0.14
15	7,204	4.37
16	4,890	2.97
17	240	0.15
18	1,362	0.83
19	11	0.01
20	114	0.07
21	949	0.58
22	1,298	0.79
23	7,590	4.60
24	547	0.33
25	8,279	5.02
26	3,442	2.09
27	296	0.18
28	1,414	0.86
29	3,176	1.93
30	6,326	3.84
31	5,913	3.59
32	2,909	1.76
33	815	0.49
34	1,452	0.88
35	1,726	1.05
36	2,260	1.37
37	829	0.50
38	1,360	0.82
39	572	0.35
40	3,039	1.84
41	1,502	0.91
42	2,544	1.54
43	521	0.32
44	1,786	1.08

Appendix B. (concluded)

Subwatershed ID	*Total area, acre*	*Fraction of total watershed area, %*
45	935	0.57
46	3,529	2.14
47	782	0.47
48	230	0.14
49	248	0.15
50	2,640	1.60
51	364	0.22
52	649	0.39
53	3,042	1.84
54	4,179	2.53
55	9,534	5.78
56	4,852	2.94
57	4,844	2.94
58	12,472	7.56
59	10,935	6.63
Total	164,887	100.0

Appendix C. Statistics for Tributary Gages as Published in Part 2 and 3 Reports (Prior to Full Calibration)

Statistics	*Blackberry*				*Brewster*	*Ferson*	*Flint*	*Mill*	*Poplar*		*Tyler*
	Yorkville+*			*Montgomery*	*Valley view*	*St. Charles**	*Fox River Grove*	*Batavia*	*Elgin*		*Elgin*
	WY 1993-2000	*WY 1991-1992*	*WY 2001-2003*	*WY 2000-2003*	*WY 2002-2003*	*WY 1991-2003*	*WY 1991-1996*	*WY 1998-2003*	*WY 1991-1999*	*WY 2000-2003*	*WY 1998-2003*
Observed mean flow, cfs	61.6	49.7	46.3	36.2	7.11	44.2	33.9	20.5	33.7	29.4	29.8
Simulated mean flow, cfs	61.9	57.5	43.6	35.5	6.58	37.8	27.1	17.9	33.6	27.0	29.3
Dv, %	0.6	15.8	-5.8	-1.9	-7.5	-14.4	-20.1	-12.3	<0.1	-8.2	-1.6
Annual											
NSE	0.82	0.59	0.66	0.72	0.88	0.64	0.25	0.67	0.95	0.89	0.97
r	0.92	1.00	0.88	0.92	1.0	0.91	0.87	0.87	0.98	0.98	0.997
Years with Dv within ±10%	5	0	2	2	2	4	2	2	7	3	4
Years with Dv within ±25%	8	2	2	4	2	10	5	5	9	4	4
Monthly											
NSE	0.74	0.63	0.75	0.77	0.84	0.77	0.73	0.57	0.87	0.88	0.89
r	0.92	0.85	0.88	0.93	0.94	0.90	0.89	0.77	0.93	0.95	0.95
Months with Dv within ±10%	27	5	5	13	0	31	11	6	26	12	16
Months with Dv within ±25%	56	13	14	22	5	79	27	16	61	27	34
Daily											
NSE	0.55	0.52	0.64	0.59	-0.30	0.52	0.39	0.37	0.76	0.67	0.72
r	0.72	0.75	0.78	0.80	0.69	0.73	0.67	0.61	0.87	0.82	0.86

Notes: These statistics were originally published in Part 2 and Part 3 reports (Bartosova et al., 2007a,b). They describe how the model performed after two pilot watersheds were calibrated and before the calibration of the integrated model described in this report.
* July 1996 is excluded
\+ Calibration and validation periods for Blackberry Creek watershed were different in the first part of the project as requested by the FRSG (Bartosova et al., 2007a).