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Fox River Watershed Investigation: Stratton Dam to the Illinois River

Phase II
Hydrologic and Water Quality Simulation Models

Part 2
Blackberry and Poplar Creek HSPF Models, Calibration and Initial Simulation Results

by
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Prepared for the
Fox River Study Group, Inc.

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Illinois State Water Survey
Center for Watershed Science
Champaign, Illinois

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

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Abstract

This report describes development of watershed loading models for two watersheds contributing to the Fox River: Blackberry Creek and Poplar Creek watersheds. These two tributary watersheds were used as pilot watersheds to develop a set of model parameters. Preceding report describes methodology, procedures, and data used in model development. Results of calibration and validation of the pilot watersheds' hydrologic and water quality modeling are presented. Subsequent reports will present the development of models for the remainder of the study area and discuss the model uncertainty.

Acknowledgments

The study was funded by the Fox River Study Group, Inc. through federal appropriation and local funds. The authors would like to express thanks to the United States Geological Survey for providing a copy of their model of Blackberry Creek watershed. The authors gratefully acknowledge contribution of several ISWS staff. Mike Machesky and Yanqing Lian reviewed the report, Sara Nunnery provided guidance and expert advice on all illustrations, and Eva Kingston edited the report.

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Introduction

The Fox River watershed is located in Wisconsin and 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. The model preparation is part of an ongoing investigation of water quality issues identified by the Illinois Environmental Protection Agency (IEPA). This work is being conducted for and in consultation with the Fox River Study Group, Inc. (FRSG).

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 supply, and the river serves as a receptor for stormwater and treated waste water. This highly valued river, however, has been showing increasing signs of impairment.

In response to local concerns about the Fox River water quality the FRSG organized in 2001. The FRSG is comprised of 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: data collection and preparation of comprehensive water quality models.

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. The IEPA has included the Fox River and these tributaries on their list of impaired waters, commonly called the 303(d) list (IEPA, 2003). The latest 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. A suite of water quality models has been envisioned to characterize the various sources and causes of impairment.

Reporting Structure

The Phase I report (McConkey et al., 2004) reviews the available literature and data for the study area and includes recommendations for development of a suite of models to simulate hydrology and water quality in the watershed targeted to key water quality issues identified in the watershed. The Hydrological Simulation Program FORTRAN version 12 (HSPF, Bicknell et al., 2001) model 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 model dissolved oxygen diurnal processes during steady state low flow conditions along the mainstem Fox River. These models are referred to as watershed loading and receiving stream models respectively.

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 Part 1 report (Singh et al., 2007) describes the structure of the HSPF hydrology and water quality model and methods used in developing the watershed loading models, discusses sources of uncertainty in these models and data assimilation conducted in preparation of 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.

Watershed models can provide insights about impacts of land use change, delivery of pollutants from nonpoint sources, and the hydrology of the watershed. These watershed models will be especially useful for tributary watersheds where benefits of preventative actions can be evaluated via reduction in pollutant loadings.

Two companion reports present the specific development of watershed loading models (HSPF). This report (Part 2) focuses on two tributary watersheds (Blackberry and Poplar Creek) in the Fox River watershed. These pilot watersheds represent contrasting land use and different soil conditions. The HSPF models were calibrated to simulate daily streamflow and selected water quality constituents.

The Part 3 report (Bartosova et al., 2007) describes the validation of hydrologic model parameters using flow observations from five tributary watersheds not used in the calibration process (Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek watersheds).

The hydrologic model for the Fox River mainstem and remaining tributary watersheds currently is under development and will be addressed in a separate report. Development of water quality components of the HSPF model as well as development of the receiving water quality model (QUAL2) is planned to begin subsequently.

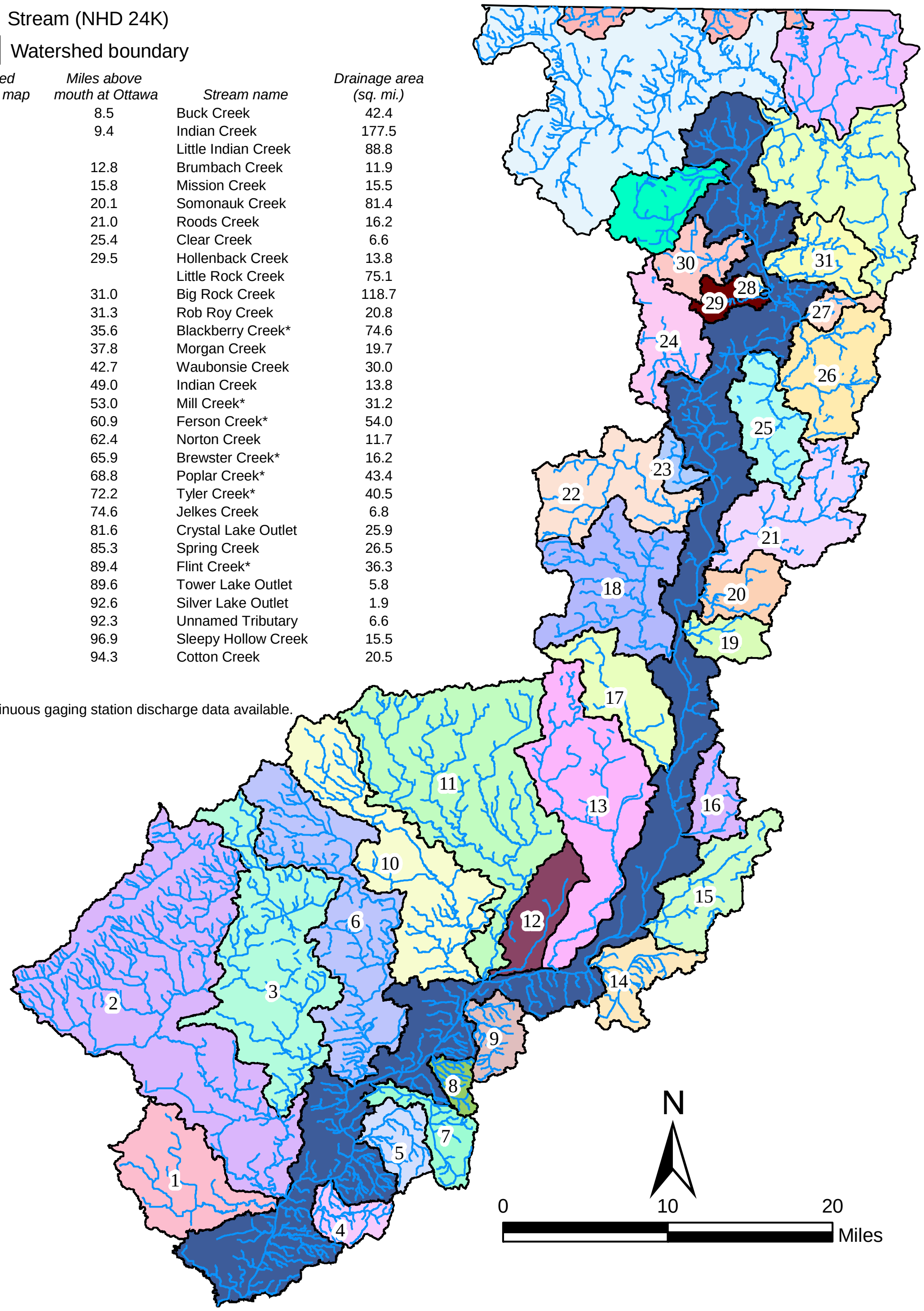
Pilot Watershed Models

This report describes calibration and validation of HSPF models for the Blackberry Creek and Poplar Creek watersheds. 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). These watersheds represent primarily agriculture (Blackberry Creek) and primarily urban (Poplar Creek) land uses in the Fox River watershed. Both watersheds have long-term discharge data and periodic measurements of water quality.

Two pilot watersheds were selected for preparation of HSPF models and development of parameter information for use in other tributary watershed models. Continuous discharge data are available for only seven tributary watersheds, and consistent water quality data are available for even fewer watersheds. The remaining five watersheds (Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek watersheds) were used to validate the model parameters outside the pilot watersheds and to test efficiency of the parameter transfer (Bartosova et al., 2007).

During the calibration process for the pilot watersheds, a set of parameters for hydrologic response units (HRUs) was developed for later use in preparing HSPF models for other tributary watersheds in the Fox River watershed (Figure 1). An HRU represents a unique combination of land use, soil type, and slope category. Model parameters developed during calibration of the pilot watersheds will be used to parameterize models of other tributary watersheds in the study area that do not have sufficient data for calibration. Model development and calibration procedures are described in Singh et al. (2007).

Available precipitation, streamflow, water quality, and other data from the Blackberry Creek and Poplar Creek watersheds were used to prepare the models. Data from Water Years (WY) 1990-2003 were used for model development, calibration, and validation. A Water Year (WY) is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends. Models were run on an hourly basis, and observed concentrations of different water quality constituents were compared with respective model output for the two watersheds. Model parameters were adjusted carefully during calibration based on other studies reported in the literature and the HSPFParm database, which consists of model parameter tables from various HSPF test studies conducted in different regions of the United States. The models then were run for the validation period and the output compared to observations to assess model capability to simulate conditions outside the calibration period.



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.

Data Specific to Blackberry and Poplar Creek Watersheds

Study Watersheds

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 supply; and the Fox River and its tributaries carry stormwater and receive permitted discharges from wastewater treatment plants, combined sewers, and industry. In Illinois, the population of Fox River watershed by 2020 is expected to increase dramatically (about 30%) from the 2000 totals, with much of the growth in McHenry and Kane Counties. The Fox River watershed is west of the Chicago metropolitan area, where there is increasing population growth and development pressure.

The 73-square-mile (46,720-acre) Blackberry Creek watershed is located in south-central Kane County and north-central Kendall County, Illinois. Blackberry Creek, a 32-mile-long stream, originates north of Elburn in central Kane County and drains to the Fox River near Yorkville in Kendall County. Nearly 54% of the Blackberry Creek watershed is planted in row crops such as corn and soybeans. Urban high or low/medium density areas and urban open space cover nearly 18% of the watershed area. Nearly 9% of land area in the watershed is impervious. Imperviousness was estimated from land use categories, assuming 35% and 75% imperviousness for urban low/medium density and urban high density areas, respectively. Forest and rural grassland cover approximately 8% and 19% of the Blackberry Creek watershed area, respectively. Soils of hydrologic soil groups B and C exist over nearly 90% of the watershed. Hydrologic soil groups classify soils based on the infiltration rate. Soils of hydrologic soil group A have a high infiltration rate (e.g., sand) while soils of hydrologic soil group D have a very low infiltration rate (e.g., clay). The average land surface slope of subwatersheds is 1-3.8%. About 87% of the watershed has slope less than 4%, and 50% of the watershed has slope less than 1.2%.

The 43.5-square-mile (27,793-acre) Poplar Creek watershed is located in east Kane County and west Cook County, Illinois. Poplar Creek, an 18-mile-long stream, originates northwest of South Barrington in Cook County and drains to the Fox River near Elgin in Kane County. Nearly 75% of the Poplar Creek watershed has urban high or low/medium density areas and urban open space. Nearly 15% of land area in the watershed is impervious. Forest and row crops cover approximately 14% and 6% of the Poplar Creek watershed area, respectively. Soils of hydrologic soil groups B and C exist in nearly 76% of the watershed. The average land surface slope of subwatersheds is 1.6-6.1%. About 76% of the watershed has slope less than 4%, and 50% of the watershed has slope less than 2%.

Table 1 shows the distribution of land use in the Fox River watershed and pilot watersheds. Land cover for Illinois from the Illinois Interagency Landscape Classification Project or IILCP (IDOA, 2003) was used to determine and specify different land use categories. Land use distribution in the Blackberry Creek watershed (Figure 2) more closely mimics that of the entire watershed while that in the Poplar Creek watershed (Figure 3) represents encroaching development from the Chicago metropolitan area.

Table 2 shows the distribution of hydrologic soil groups in the Fox River watershed and the pilot watersheds. Hydrologic soil groups and the estimated percentage area they represent in the Illinois portion of the Fox River watershed, Blackberry Creek watershed, and Poplar Creek watershed were estimated using the best soil data available as indicated in Table 2. State Soil Geographic (STATSGO) data were uniformly available across the Fox River watershed study area. More detail Soil Survey Geographic (SSURGO) data are available only for some counties. Both STATSGO and SSURGO data represent generalized categories. Soil components in one map unit (polygon) are not necessarily in the same hydrologic soil group. Because the exact location of an individual soil component within a map unit is not specified and map units had to be adjusted (clipped) to watershed boundaries, percentages of the various soil types were estimated assuming uniform representation of soil components in a given map unit. Given the composition of the soil data, the only option was to assume a constant ratio of individual soil components throughout a map unit. Soil type B is the prevalent soil type in the Fox River watershed. Figure 4 and Figure 5 illustrate the hydrologic soil groups in the Blackberry and Poplar Creek watersheds, respectively. These figures show the higher resolution soils data that were used in the actual model development. Singh et al. (2007) provide detailed descriptions of these datasets.

Figure 6 shows the distribution of watershed slopes in the Fox River, Blackberry Creek, and Poplar Creek watersheds. Poplar Creek watershed includes relatively more area with steeper slope. For example, while 50% of Poplar Creek watershed has a slope greater than 2%, the same slope category is found in only 38% of Fox River watershed and 32% of Blackberry Creek watershed.

Table 1. Representation of Land Use Categories in the Study Area

	Percent watershed area		
Model classification	*Fox River**	*Poplar Creek*	*Blackberry Creek*
Corn	26.5	3.7	28.6
Soybeans	24.5	2.5	25.4
Rural Grassland	13.1	0.0	18.7
Forest	10.4	13.6	7.8
Urban High Density	2.0	6.8	1.5
Urban Low/Medium Density	8.8	30.2	7.6
Urban Open Space	10.0	37.6	8.6
Wetland	2.3	2.7	1.3
Water	2.4	2.9	0.6

Note: *Illinois portion of watershed only.

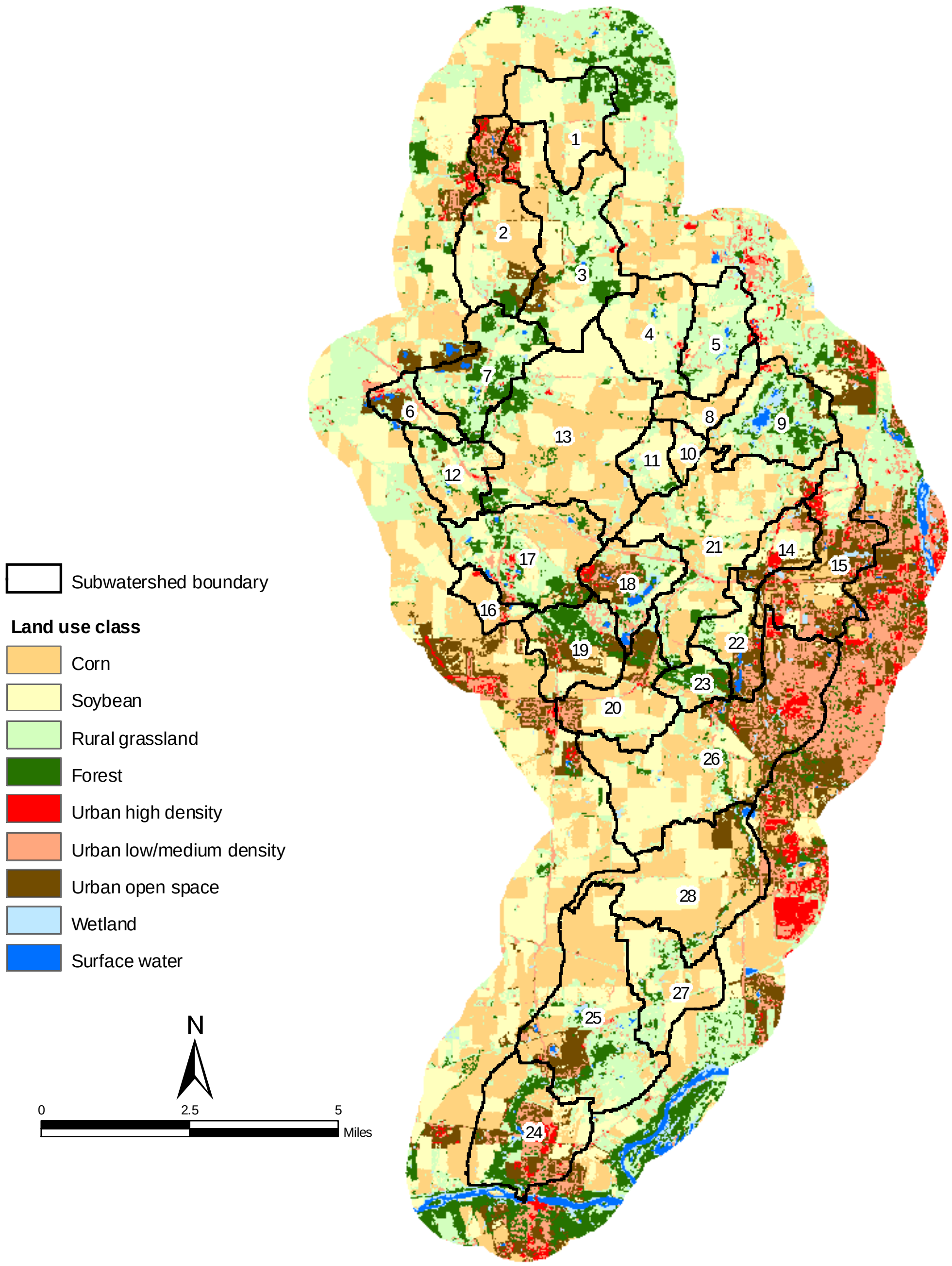


Figure 2. Land use categories in the Blackberry Creek watershed.

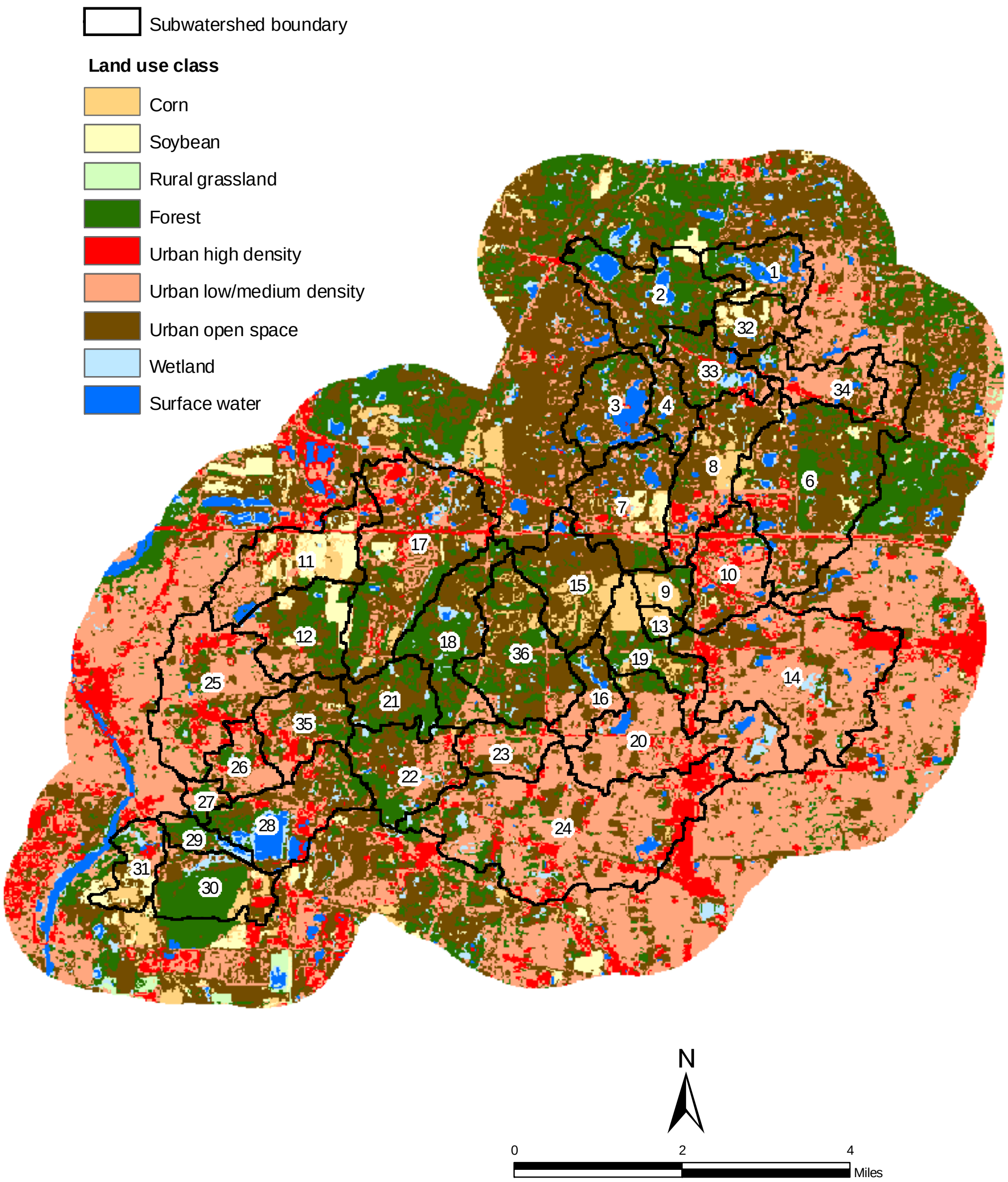


Figure 3. Land use categories in the Poplar Creek watershed.

Table 2. Representation of Soil Groups in the Study Area

	Percent watershed area		
Hydrologic soil group	*Fox River**	*Poplar Creek*	*Blackberry Creek*
A	1.6	0.9	2.9
A/D	2.5	4.4	0.0
B	59.1	17.9	79.9
B/D	20.9	20.4	4.0
C	13.6	43.4	6.4
C/D	0.3	0.2	0.0
D	1.3	0.7	0.5
Not specified or impervious surface	0.7	12.1	6.3
Source	STATSGO	SSURGO	STATSGO

Note: *Illinois portion of watershed only.

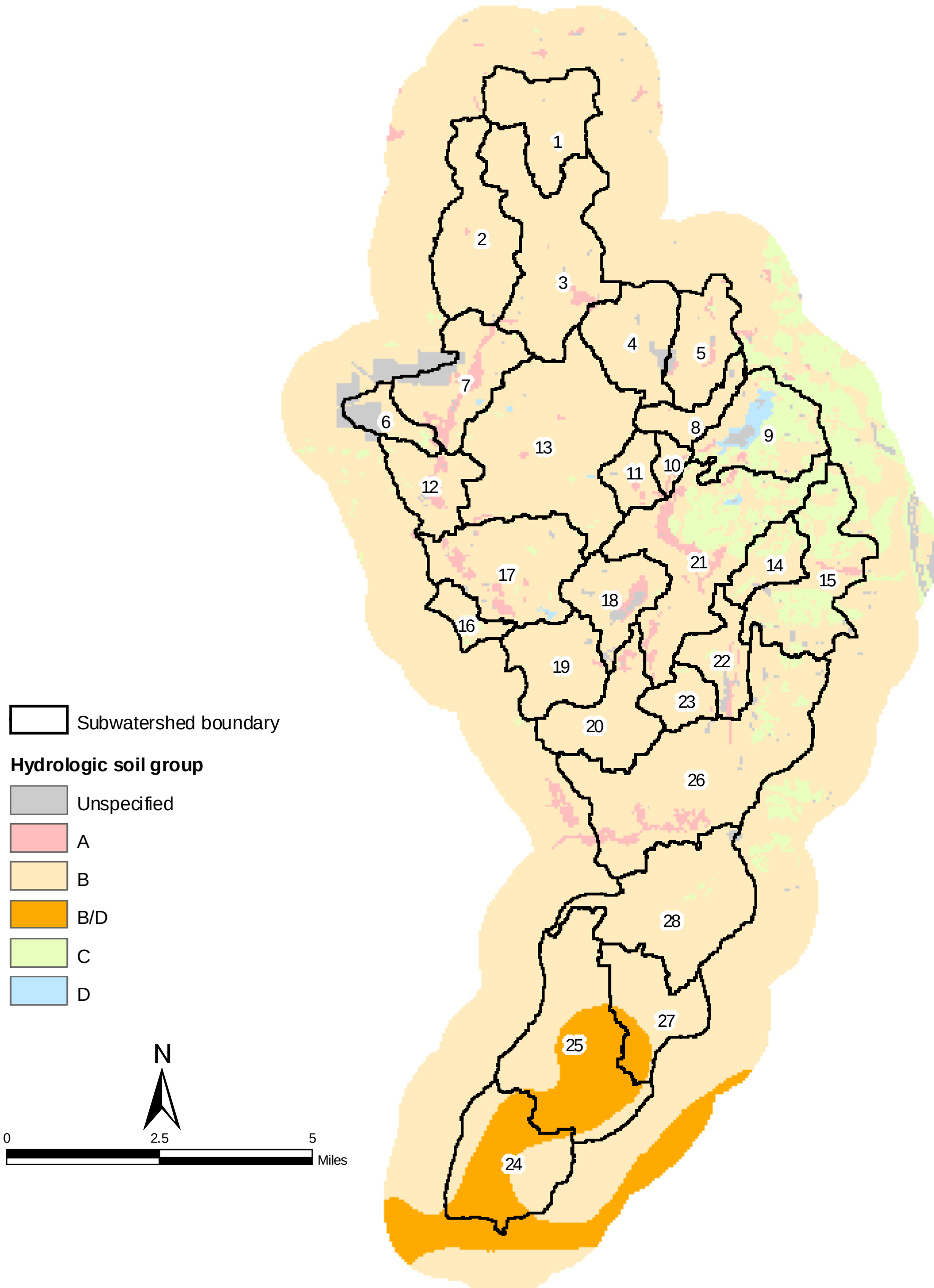


Figure 4. Soil types in the Blackberry Creek watershed.

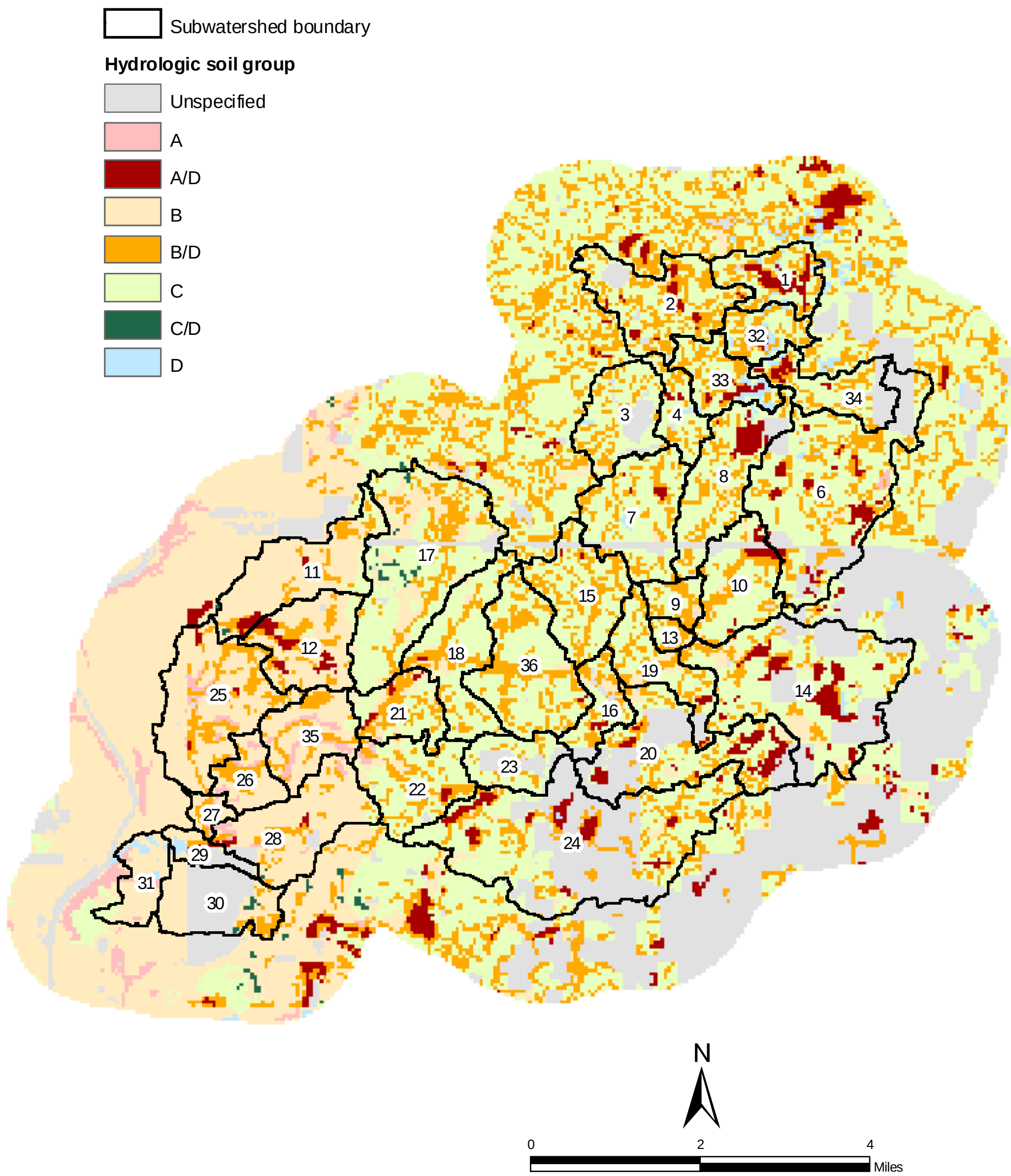


Figure 5. Soil types in the Poplar Creek watershed.

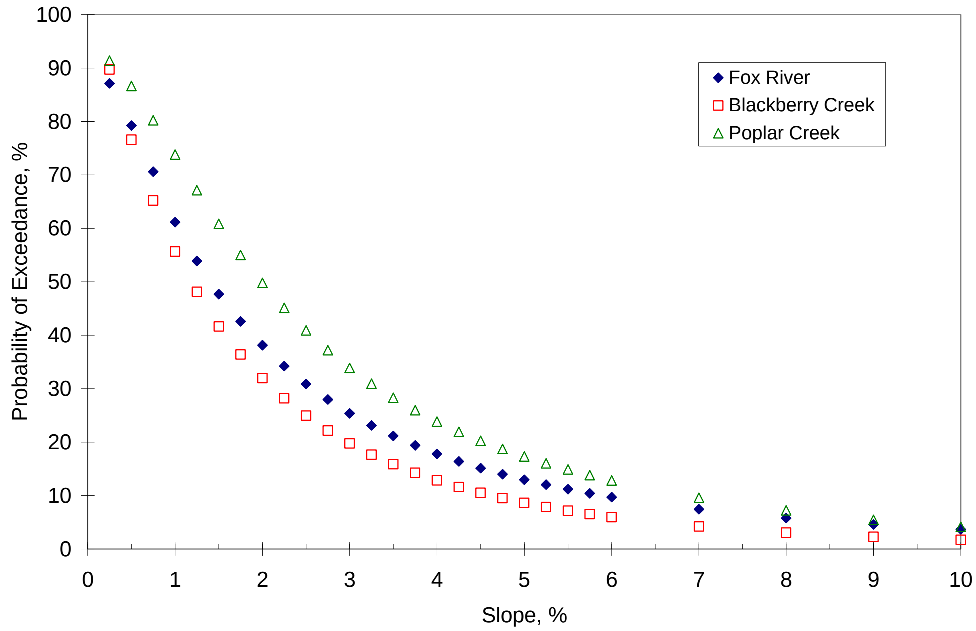


Figure 6. Distribution of land slope in the Fox River, Blackberry Creek, and Poplar Creek watersheds.

Land use and soil spatial datasets are analyzed to create unique combination HRUs for each subwatershed, that are categorized further based on subwatershed slope. Each physiographically unique HRU can be assigned a set of parameter values determined through the model calibration process to define runoff characteristics and loading of various water quality constituents from the HRU. The number of unique HRUs is a product of the number of land use/land cover, soil type, and land slope categories used. Within the Fox River watershed, nine pervious and two impervious land use categories, four soil groups, and three land slope categories were identified. There are 124 possible unique combinations based on these physical features. The actual number likely will be smaller as not all combinations are present.

Spatial Datasets

The BASINs framework provides tools for readily using digital, spatial datasets to develop model input parameters. These data define physical characteristics of the watershed, including land use/land cover, soil types, and slope. Data used are described briefly below.

Land cover for Illinois from the Illinois Interagency Landscape Classification Project or IILCP (IDOA, 2003) was the most recent, high-resolution dataset available at the time of study. It was used to determine and specify different land use categories throughout the watersheds. Figure 2 and Figure 3 show land use classifications and their distribution in Blackberry and Poplar Creek watersheds, respectively.

The Blackberry Creek watershed is located in Kane and Kendall Counties. SSURGO soil data have been developed for Kane County. As part of the Illinois Streamflow Assessment Model development (ISWS, 2005), the Illinois State Water Survey (ISWS) digitized soil survey data for Kendall County (County Soil Association Maps, or CSAM). Each map unit in SSURGO represents up to five soil components. The resolution of the CSAM dataset is between that of STATSGO and SSURGO data. Figure 4 shows the hydrologic soil groups found in the Blackberry Creek watershed.

The Poplar Creek watershed is located primarily in Cook County with a portion in Kane County. Published SSURGO data were not available for Cook County during the model development, but the ISWS digitized Cook County soil survey data for the Illinois Department of Transportation. This dataset uses one soil component. Its resolution is comparable to SSURGO data, but the accuracy of the line work is lower than that of SSURGO data. Figure 5 shows the hydrologic soil groups found in the Poplar Creek watershed.

Watershed slope was derived from digital elevation model raster data distributed by the U.S. Geological Survey (USGS) and described in Singh et al. (2007). The average slope of each subwatershed is calculated by the BASINS system during the watershed delineation.

Climate Data

There are two climate stations near the Blackberry Creek watershed (Figure 7). One climate station is located in St. Charles and operated by Illinois Climate Network or ICN (ICN ID STC, 1988-present). The other one is located in Aurora and operated as part of the National Climate Data Center (NCDC) Cooperative Stations (Coop) network (Coop ID 110338, 1887-present). Both stations have data for WY 1990-2003, which includes calibration and validation periods. Those data and long-term records were compared to determine the representativeness of the study period. The St. Charles gage has hourly data for all seven climate parameters required for the HSPF model, whereas only daily precipitation and temperature data are available at the Aurora station. Table 3 shows the mean annual precipitation recorded at Aurora (Coop ID 110338) is 37.4 inches for WY 1963-2003 and 37.8 inches for WY 1991-2003.

In the course of preparing input data for the Blackberry Creek model, significant differences were found in annual precipitation between the St. Charles and Aurora stations. Following this examination of the precipitation data, the correlations between annual observed precipitation at the St. Charles and Aurora stations and streamflow recorded at the Yorkville station for WY 1991-2003 were investigated. A higher correlation coefficient, r, was obtained using Aurora precipitation data (r=0.75) rather than using St. Charles precipitation data (r=0.27). This indicated that precipitation data from the Aurora station are more representative of the hydrology in the Blackberry Creek watershed than data from the St. Charles station. The Aurora station is near the center of the Blackberry Creek watershed and closer to the streamflow gage stations than the St. Charles station. Hourly precipitation data for the St. Charles station also were being revised by the network operator. Therefore, it was decided to use only the Aurora climate station in developing the hydrologic model for the Blackberry Creek watershed. It must be noted that precipitation is the driving force in the hydrologic modeling. Accurate representation of spatial variability of precipitation over the large study area is paramount to the development of an accurate hydrologic model and requires a dense network of gages.

Daily precipitation data at the Aurora station were disaggregated into hourly data using the Data Disaggregation Tool in the HSPF Watershed Data Management (WDM) Utility. Hourly precipitation time series from the St. Charles station were used as reference data during disaggregation. Hourly climate data from the St. Charles station were used for climate input throughout the Blackberry Creek watershed in the HSPF model, supplementing precipitation data from the Aurora station.

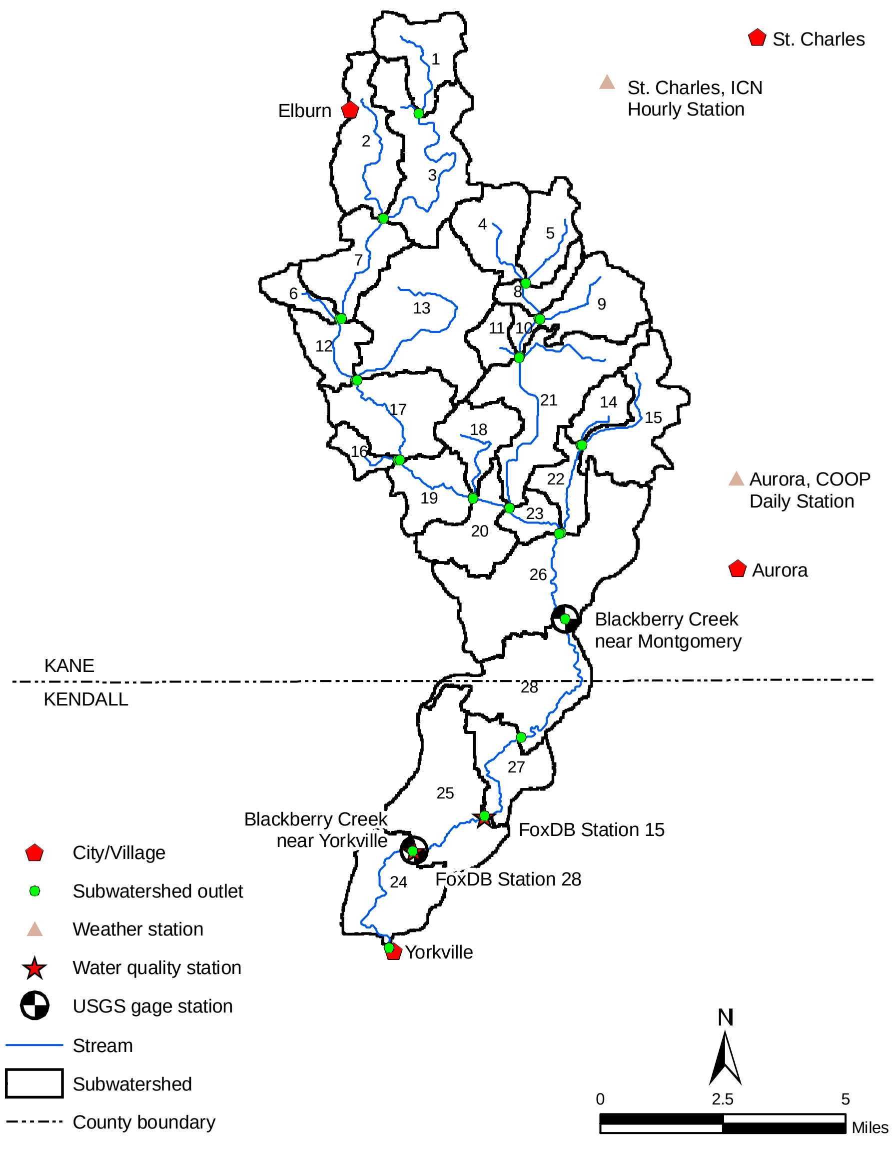


Figure 7. Delineation of the Blackberry Creek watershed and location of precipitation and streamflow gages.

There are three climate stations in or near the Poplar Creek watershed (Figure 8). Daily precipitation is recorded at the following stations: Barrington (ID 110442, 1962-present), Streamwood (ID 118324, 1994-present), and Elgin (ID 112736, 1898-present). The nearest stations with hourly precipitation data for the study period are the ICN station at St. Charles (ID STC) and NCDC stations at O'Hare International Airport (ID 111549) and Rockford (ID 117382).

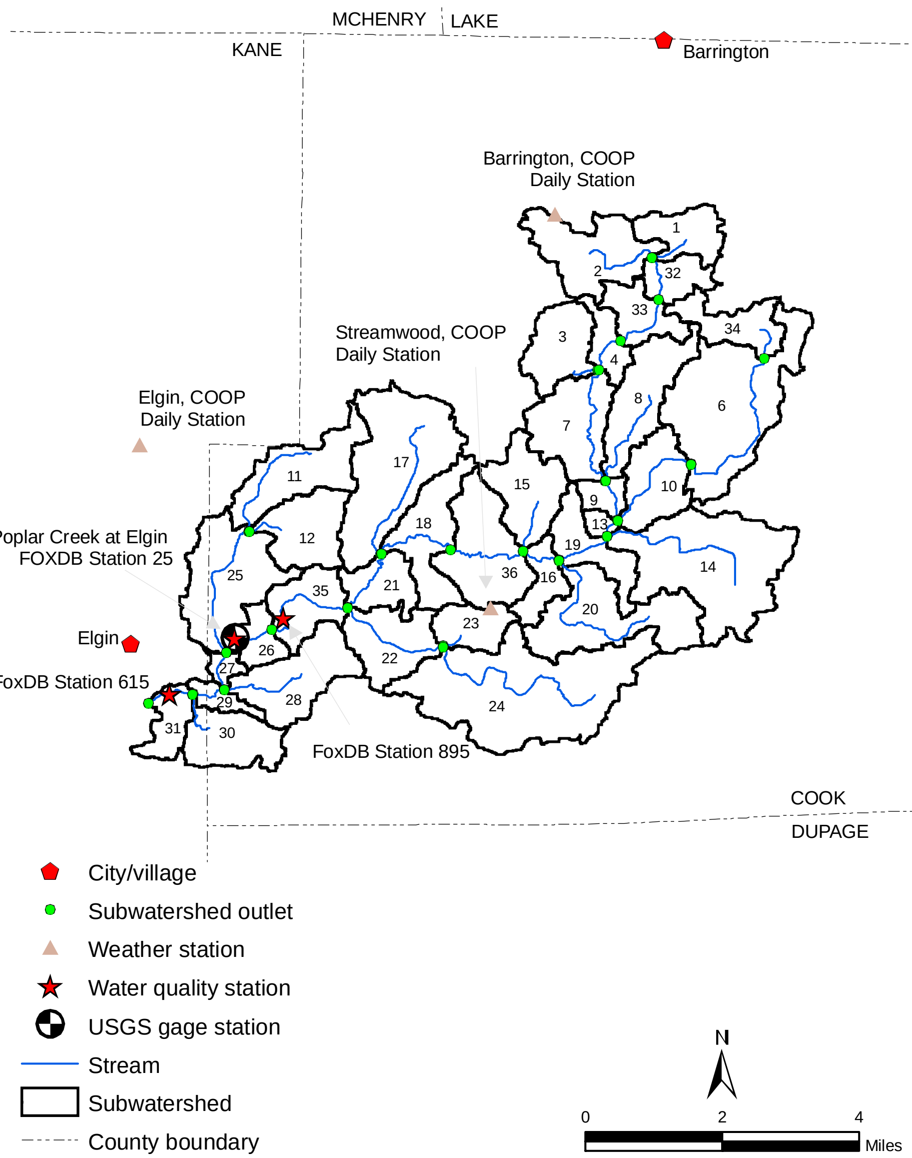


Figure 8. Delineation of the Poplar Creek watershed and location of precipitation and streamflow gages.

Observed mean annual precipitation at Elgin for WY 1963-2003 ranges from 20.2 inches in 1984 to 49.9 inches in 1972 with a long-term mean value of 35.9 inches (Table 3). The HSPF simulations require a continuous precipitation record. In order to use all available information from the three precipitation stations, missing data were replaced with data from the other stations. For example, the missing daily precipitation data records at the Barrington station were replaced with daily precipitation data from the Streamwood, Elgin, and O'Hare stations, in that order. This was repeated for the Elgin station using Streamwood and O'Hare station data. Daily precipitation data for WY 1990-1994 for the Streamwood station were borrowed from the Elgin station.

Daily precipitation data at the Barrington, Streamwood, and Elgin stations were disaggregated into hourly data using the Data Disaggregation Tool in the HSPF WDM Utility. Hourly precipitation time series from the O'Hare, St. Charles, and Rockford stations were used as references during disaggregation. The other required hourly climate data series for the three MRCC stations were transferred directly from the St. Charles station. The MRCC stations then were assigned to the respective subwatersheds based on the Thiessen polygon method.

Table 3 and Figure 9 show precipitation statistics for the Aurora gage and the Yorkville gage for WY 1963-2003. The mean annual precipitation increased by about 2% at both the Aurora and Elgin gages from WY 1963-1990 to WY 1991-2003.

Table 3. Precipitation (inches) at Stations in and near Blackberry and Poplar Creek Watersheds

				Time period (WY)	
Watershed	*Station*	*Statistic*	*1963-2003*	*1963-1990*	*1991-2003*
Blackberry Creek	Aurora (ID 110338)	Mean annual	37.4	37.1	37.8
		High	51.0	49.5	51.0
		(Year)	(1996)	(1972)	(1996)
		Low	25.8	25.8	29.9
		(Year)	(1971)	(1971)	(1994)
Poplar Creek	Barrington (ID 110442)	Mean annual	32.2	31.7	32.2
		High	48.3	48.3	44.7
		(Year)	(1983)	(1983)	(1999)
		Low	8.8	13.1	8.8
		(Year)	(1991)	(1971)	(1991)
	Streamwood (ID 118324)*	Mean annual			35.7*
		High			42.8
		(Year)			(1995)*
		Low			25.8
		(Year)			(2003)*
	Elgin (ID 112736)	Mean annual	35.9	35.7	36.5
		High	49.9	49.9	49.4
		(Year)	(1972)	(1972)	(1993)
		Low	20.2	20.2	25.9
		(Year)	(1984)	(1984)	(2003)

Notes: Missing values in precipitation series affected total precipitation for water years.
*Data for Streamwood station were available starting WY 1995.

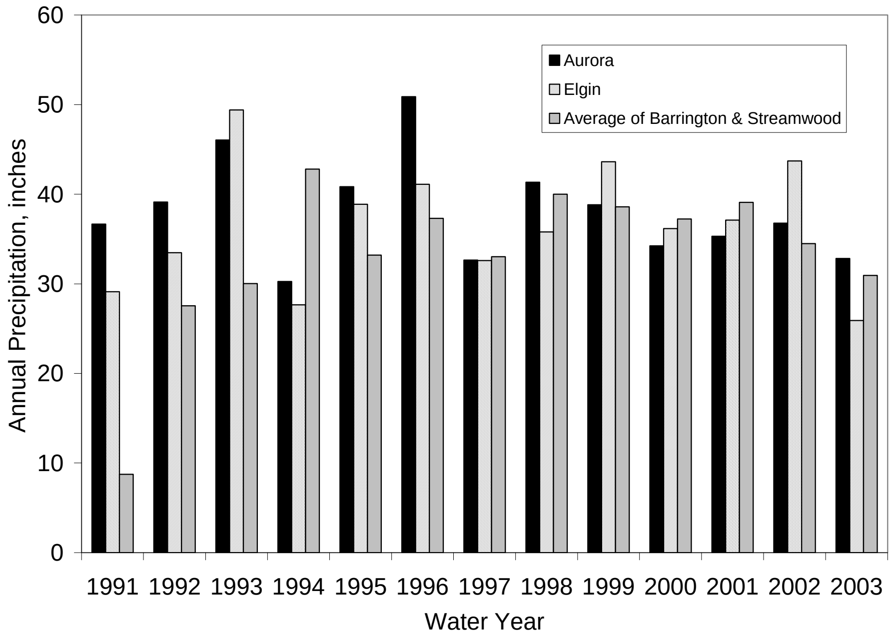


Figure 9. Annual precipitation at stations near Blackberry and Poplar Creek watersheds.

There is considerable variability in precipitation that falls on the two watersheds from year to year. Comparing the annual precipitation between gages in any year also shows notable differences, even across the Poplar Creek watershed. This is illustrated in Figure 9, which compares total annual precipitation for the study period (WY 1991-2003) at the precipitation stations available for modeling. The average of mean annual precipitation at the adjusted Barrington and Streamwood stations for the study period is compared with the annual precipitation at Elgin and Aurora. The Aurora gage recorded the highest precipitation in 4 of the 13 years. Stations used for Poplar Creek watershed simulations show three years in the study period as clearly wetter in Barrington and Streamwood than in Elgin, seven years as wetter in Elgin, and three years with similar values.

Calibration of the hydrologic components of the HSPF model depends on having precipitation records representative of conditions throughout each watershed. Without adequate precipitation data, calibration of the hydrologic components is impaired. Differences in precipitation illustrated by the comparison of annual totals at these three stations in Figure 9 are an indication of the potential inaccuracies in using precipitation from stations not truly representative of events within a watershed.

Streamflow Data

There are two USGS streamflow gages located in the Blackberry Creek watershed. The USGS gage at Yorkville (USGS ID 05551700) in Kendall County is near the mouth of Blackberry Creek and has a drainage area of 70 square miles (44,800 acres). The record for this station starts in 1961 and continues through the present. The USGS gage at Montgomery (USGS ID 05551675) in Kane County is farther upstream and has a drainage area of 55 square miles (35,200 acres). That gage became operational in 1998 and continues through the present.

Mean flow at the Yorkville gage is 54.2 cubic feet per second or cfs (10.5 inches over the drainage area) during WY 1963-2003, 53.2 cfs (10.3 inches over the drainage area) during WY 1963-1990, and 56.4 cfs (10.9 inches over the drainage area) during WY 1991-2003. Streamflow expressed in inches over the drainage area represents depth to which the drainage area would be covered if all the runoff for a year were uniformly distributed over the area. Streamflow in this format is directly comparable to annual precipitation. The ratio between annual precipitation and streamflow in inches over the drainage area indicates losses by evapotranspiration and evaporation. For WY 1963-2003, the mean annual streamflow at the Yorkville gage ranges from 16.8 cfs in 1977 to 97.6 cfs in 1993. Figure 10 compares mean annual streamflows for the study period (WY 1991-2003) and long-term mean streamflow for WY 1963-2003 at the Yorkville gage to identify the relatively wet, dry, and average streamflow years. Generally higher streamflows during the study period than in WY 1963-1990 may be due to an increase in precipitation and also due to an increase in impervious surface (and hence a reduction in evapotranspiration and infiltration), resulting from increased urbanization in the Blackberry Creek watershed.

Figure 11 shows mean monthly flows at the Yorkville gage (WY 1963-1990 and WY 1991-2003). Streamflow is lowest July through October and highest March through June. Higher flows in WY 1991-2003 compared to the earlier period generally are distributed uniformly throughout the year.

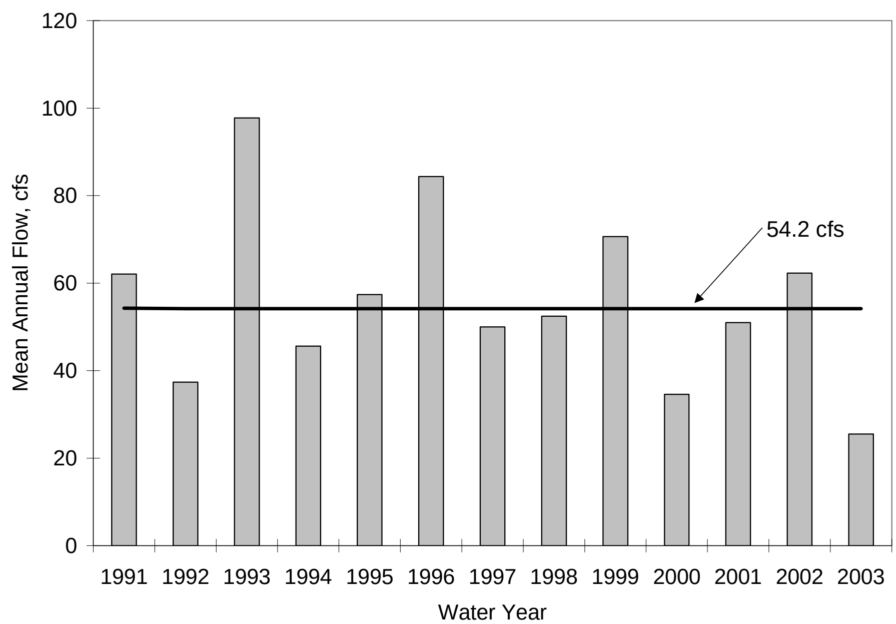


Figure 10. Mean annual streamflows, Blackberry Creek at Yorkville (USGS 05551700).

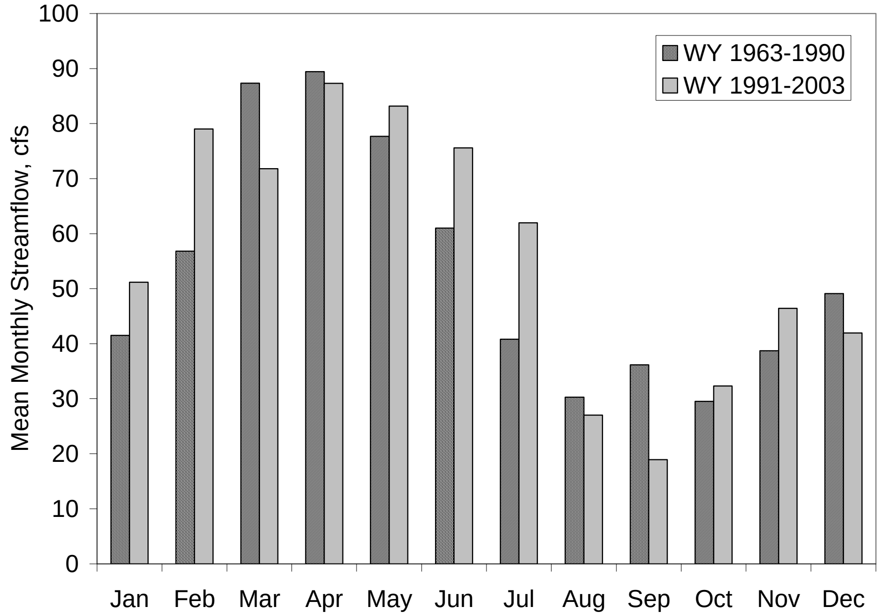


Figure 11. Mean monthly streamflows, Blackberry Creek at Yorkville (USGS 05551700).

There is one USGS streamflow gage in the Poplar Creek watershed (Figure 8). Daily streamflow data are measured at the Elgin gage (USGS ID 05550500), which has a drainage area of 35.2 square miles (22,530 acres). For WY 1963-2003, the observed mean annual streamflow at the Elgin gage ranges from 4.6 cfs in 1963 to 52.4 cfs in 1993 with the 40-year mean value of 29.0 cfs (11.2 inches over the drainage area). Figure 12 compares mean annual streamflows for the study period (WY 1991-2003) and long-term mean streamflow for WY 1963-2003 (29.0 cfs) at the Elgin gage to identify the relatively wet, dry, and average streamflow years.

Figure 13 shows mean monthly flows at the Elgin gage for WY 1963-1990 and WY 1991-2003. Streamflow is lowest July through October and highest February through June. High streamflows during winter months of February and March partially may have resulted from snowmelt events.

Table 4 shows streamflow statistics for the Elgin gage and the Yorkville gage for WY 1963-2003. The mean annual streamflow increased by 6% and 19% for the Yorkville and Elgin gages, respectively, between WY 1963-1990 and WY 1991-2003.

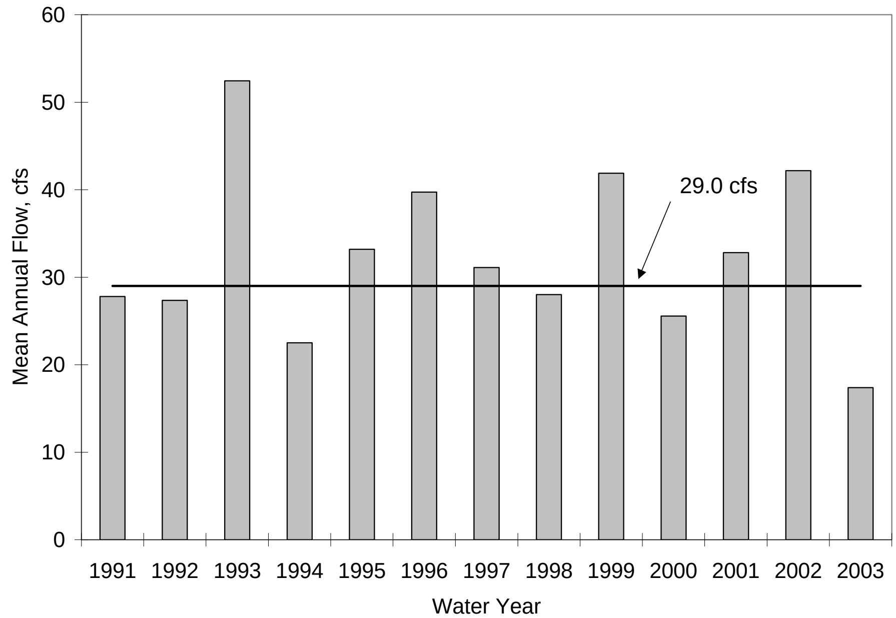


Figure 12. Mean annual streamflows, Poplar Creek near Elgin (USGS 05550500).

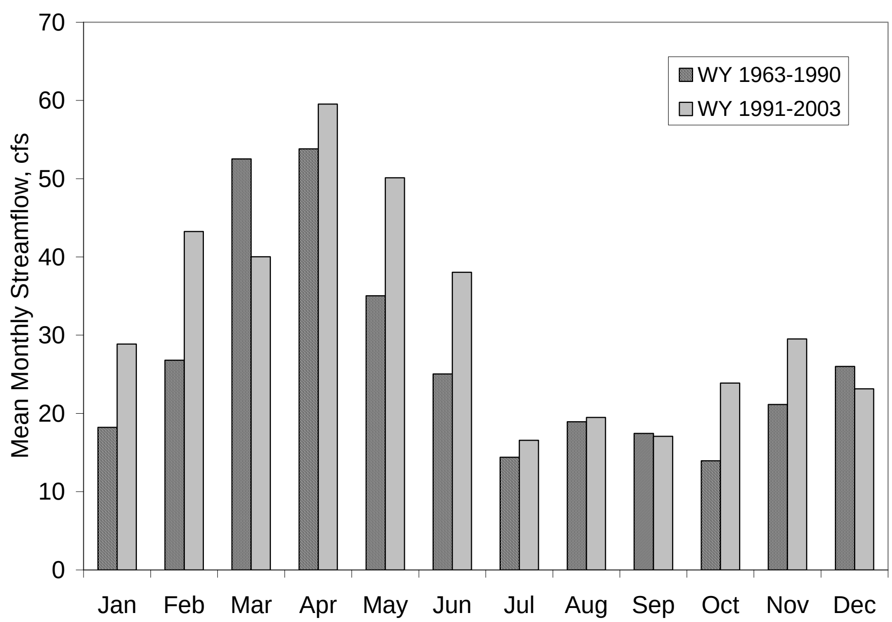


Figure 13. Mean monthly streamflows, Poplar Creek at Elgin (USGS 05550500).

Table 4. Streamflow Statistics for Blackberry and Poplar Creek Watersheds

Station	Statistic	Time period (WY) 1963-2003	1963-1990	1991-2003
Yorkville (USGS 05551700)	Mean annual flow (cfs/inches on drainage area)	54.2/10.5	53.2/10.3	56.4/10.9
	High, cfs	97.6	96.8	97.6
	(Year)	(1993)	(1983)	(1993)
	Low, cfs	16.8	16.8	25.3
	(Year)	(1977)	(1977)	(2003)
Elgin (USGS 05550500)	Mean annual flow (cfs/inches on drainage area)	29.0/11.2	27.4/10.6	32.5/12.5
	High, cfs	52.4	50.8	52.4
	(Year)	(1993)	(1974)	(1993)
	Low, cfs	4.6	4.6	17.4
	(Year)	(1963)	(1963)	(2003)

Water Quality Data

Information on water quality was obtained from the FoxDB, a relational database of water quality data in the Fox River watershed (McConkey et al., 2004). Water quality data are available for one station on Blackberry Creek and three stations on Poplar Creek. The IEPA samples Blackberry Creek near Yorkville (FoxDB Station 28), which corresponds to the HSPF model subwatershed outlet for HSPF Reach 26 (Figure 7). Stations on Poplar Creek (FoxDB Stations 25, 615, and 895) correspond to the HSPF model subwatershed outlet for HSPF reaches 26, 31, and 35, respectively (Figure 8). The IEPA samples FoxDB Station 25, the Fox River Water Reclamation District samples FoxDB Station 615, and the Metropolitan Water Reclamation District of Greater Chicago samples FoxDB Station 895. Appendices A1 and A2 show statistical analyses of various water quality constituents collected at these stations. While statistics are shown for the study period (WY 1991-2003), tables also include information about the span of years over which data were collected.

Point Sources

Table 5 lists the National Pollutant Discharge Elimination System (NPDES) facilities identified in the pilot watersheds (Blackberry Creek and Poplar Creek). Information on discharges reported by these permitted facilities to the USEPA and the IEPA are stored in the Permit Compliance System (PCS) database with recent data available online through EnviroFacts (USEPA, 2004). The PCS database includes monthly average discharges and concentrations as required for reporting by individual permit owners. Some discharge reports include total suspended solids (TSS), pH, Biochemical Oxygen Demand (BOD), and ammonia, but many permits require monitoring for TSS and pH only and information on nutrients or organic enrichment is limited. All data available in EnviroFacts for these NPDES permits were downloaded during the data compilation phase of the study reported in McConkey et al. (2004) and reformatted into HSPF input time series. The IEPA was contacted for any archived data.

Table 5. NPDES Facilities in Blackberry and Poplar Creek Watersheds

NPDES	*Name*	*Receiving stream*	*Issued*	*Last reported discharge[*]*	*City*	*Discharging as of July 2004 (Yes/ No)**
IL0068993	Mobil Oil Corp-Hoffman Estates	Poplar Creek	11/19/91	N/A	Hoffman Estates	No
IL0061051	Allstate Insurance Company	Poplar Creek	4/07/93	9/30/99	South Barrington	No
ILG840050	Chicago Gravel Co. - Bluff City LLC-Hammond Plant	Poplar Creek	10/03/97	10/31/03	Near Elgin	Yes**
IL0036641	Sugar Grove Sanitary Treatment Plant	Blackberry Creek	10/28/94	N/A	Sugar Grove	No
IL0038229	Waubonsee Community College	Blackberry Creek	8/07/02	5/31/04	Sugar Grove	No***
IL0048887	Fisherman's Inn	Blackberry Creek	7/30/97	N/A	Elburn	No
IL0072338	Blackberry Aquatic Center	Blackberry Creek	10/23/97	8/31/03	Aurora	Yes**

Notes: N/A = only last 5 years of data are available online through EnviroFacts. The facility was not operational more than 5 years before the data were downloaded.
*Data through July 2004 were acquired from the IEPA.
**Discharge occurs irregularly and/or infrequently.
***The facility stopped discharging to a receiving stream in September 2006.

Most of these facilities are currently not operational. Blackberry Aquatic Center typically discharges only during summer months (May-August). Waubonsee Community College was the only facility regularly reporting discharge at the time data were downloaded, but it closed as of September 2006. Although some facilities may be inactive at present, historical discharges during the study period are necessary to define conditions during the calibration period.

Hydrology Model

Hydrologic processes must be calibrated before attempting to model 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 BASINS Automatic Delineation Tool was used to divide the pilot watersheds into smaller subwatersheds, which were divided further into HRUs based on land use, soil type, and slope category as specified in Singh et al. (2007). Each subwatershed also is associated with a stream reach and an outlet that can be specified as a calculation point (i.e., the model will output results for the outlet only when specified as such). Calculation points were defined at locations of USGS streamflow gaging stations and water quality stations. Data from these stations were used later in model calibration and verification.

The Blackberry Creek watershed model (i.e., rural HRUs) was calibrated first. Relevant model parameters were transferred directly to the Poplar Creek watershed model for those HRUs present in both watersheds. Calibration parameters then were fine tuned. Model parameters for HRUs associated with urban land use and other HRUs not present in the Blackberry Creek watershed were calibrated in the Poplar Creek watershed model. The purpose of model calibration is to assign the best possible parameter values to each HRU and stream reach to estimate fluxes of water between upper soil zone, lower soil zone, and groundwater storages, and to the stream or atmosphere. Net output of these flows is the streamflow reaching the designated watershed or subwatershed outlet (i.e., a calculation point). The objective of model calibration is to simulate daily streamflows (and later the concentration of constituents) from each tributary watershed, which, in turn, serve as input for the Fox River watershed model. While there are many processes in the hydrologic cycle, only observed streamflow data are available for calibration. Precipitation data serve as model input.

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 tests used are as follows:

Regression or Pearson product moment correlation coefficient (r) quantifies the strength of the linear relationship between two random variables (e.g., observed and simulated daily streamflows). Data are plotted as a scatterplot to see if a relationship exists between the two variables. 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.

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.

The calibrated model was validated using observed data other than that used for calibration. All statistics explained above also were computed for the model validation period.

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 month, year, or period of study. This provides an idea about the net bias in model simulations over that period and helps model calibration to minimize bias. Simulation results are very good when Dv is within ±10%, good when Dv is within ±15%, and fair when Dv is within ±25% (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 model does not overestimate or underestimate flows consistently during any month. 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 exceedance. For example, a flow value corresponding to 10% probability of exceedance is a fairly high flow, with only 10% of flows being greater. Flow duration curves are shown on plots with flow on the vertical axis and probability of exceedance 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.

A sensitivity analysis was conducted for parameters used in the hydrologic simulation for the Blackberry and Poplar Creek watersheds. It was conducted to examine values assigned to various model parameters and to compute the response of model output to changes in those parameters.

Blackberry Creek Watershed

HSPF Model Development

The Blackberry Creek watershed was subdelineated into 28 hydrologically connected subwatersheds (Figure 7). Calculation points defined at the outlet of subwatersheds 26 and 24 correspond to the locations of the USGS gages at Yorkville and Montgomery, respectively. Subwatershed numbers (Figure 7) correspond to those listed in Appendix B that summarizes information on the total area of each subwatershed and area of pervious and impervious land use.

Subwatershed size ranges from 255 acres (subwatershed 10) to 4589 acres (subwatershed 26), as shown in Appendix B. The fraction of impervious area within a subwatershed is 0.5-13.9%. Impervious surface (combined from urban high density and urban low/medium density together) covers only 4% of watershed area. Unique combinations of land use, soil type, and drainage area in the Blackberry Creek watershed result in 22 different types of HRUs (Appendix C). There are 237 HRUs in the Blackberry Creek watershed model. Appendix D1 lists the HRUs in each subwatershed.

Data from WY 1993-2000 were used for model calibration. At the request of the FRSG, two different periods were used for model validation comparisons. The intent was to test if any effects could be discerned between the success of the validation for two time periods separated by a decade, modeled using the single land use dataset from 2003. The validation periods were WY 1991-1992 and WY 2001-2003 at the Yorkville gage. In addition, streamflow data available for WY 2000-2003 at the Montgomery gage provided an opportunity to validate model results at additional watershed location.

Calibration and Model Performance

The HSPF hydrologic component was calibrated to best simulate observed streamflow at the subwatershed outlet corresponding to the USGS streamflow gage at Yorkville. The model was calibrated using historical streamflow data for WY 1993-2000, from the USGS gage at Yorkville (USGS 05551700) in Kendall County near the mouth of Blackberry Creek. The calibration period represents a combination of dry, average, and wet years, with annual precipitation ranging from 29.9 inches to 51.0 inches. The model was run using data from January 1, 1990 through September 30, 2000. Unknown initial conditions necessitate 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. Only data from WY 1993-2000 were used for comparison purposes during model calibration and performance evaluation. Streamflow data were not collected at the USGS gage at Montgomery during the calibration period.

Table 6 gives the HSPF hydrologic calibration parameters and ranges of final values used in this study. During calibration, parameter values were adjusted within reasonable limits until an optimal fit was obtained between simulated and observed streamflows at the outlet of subwatershed 25 that coincides with the USGS gage at Yorkville.

Table 6. Model Calibration Parameters for the Blackberry Creek Watershed

Parameter	Description	Unit	Values used
Pervious HRUs			
AGWETP	Active groundwater evapotranspiration	*	0.005-0.01
AGWRC	Basic ground water recession rate	1/d	0.98
BASETP	Baseflow evapotranspiration	*	0
CCFACT	Condensation/convection melt factor	*	1.0
CEPSC	Interception storage capacity	in	0.05-0.42
DEEPFR	Fraction of inactive groundwater	*	0.05
INFILT	Index to soil infiltration capacity	in/h	0.03-0.23
INTFW	Interflow inflow parameter	*	1.75-2.5
IRC	Interflow recession constant	*	0.42-0.69
KVARY	Variable groundwater recession flow	1/in	0.85
LZETP	Lower zone evapotranspiration	in	0.1-1.1
LZSN	Lower zone nominal storage	in	7.0-10.0
NSUR	Manning's *n* for overland flow	*	0.1-0.35
SNOWCF	Snow gage catch correction factor	*	1.4
TSNOW	Temperature at which precipitation is snow	°F	30
UZSN	Upper zone nominal storage	in	0.15-1.2
Impervious HRUs			
NSUR	Manning's *n* for overland flow	*	0.15-0.20
RETN	Retention storage capacity	in	0.05-0.1
SNOWCF	Snow gage catch correction factor	*	1.4

Note: *Parameter is dimensionless or unit is complex.

USGS Blackberry Creek HSPF Model

The USGS conducted a flood study of the Blackberry Creek watershed, including development of revised hydrology and hydraulic models (Soong, 2001). The USGS provided a copy of the preliminary HSPF input file. The following disclaimer applies to the USGS model data: "This data is for preliminary review purposes only. The USGS or Kane County will not be held responsible for its use. The model results are slated to be enhanced through more thorough modeling techniques and improved data use in the next phase of this project."

The USGS input file was reviewed and its relevance to this project assessed. There are inherent differences in the USGS model and the ISWS model under development. The 1999-2000 land use/land cover data (IDOA, 2003) were not available when the USGS developed the HSPF model. The USGS model has 47 subwatersheds, compared to 28 subwatersheds in the ISWS model. Also, the USGS land use category cropland combined area under corn and soybeans. The ISWS model keeps corn and soybeans in separate categories to facilitate different parameter assignment, e.g., evapotranspiration (LZETP). Despite these differences, hydrologic parameter values from the USGS model provided an extremely useful starting point for calibration of the hydrologic components of the HSPF model. Input files (FTABLES) that represent stream channel characteristics for different stream sections from the USGS model also were used with some modification. Combining FTABLES from the USGS model made it possible to prepare representative characteristics for the larger channel sections corresponding to the larger subwatersheds in this model. A length-weighted value of the channel depth, sum of the channel surface area and volume, and discharge at the outlet of most downstream channel sections were used to populate the FTABLES for the ISWS model.

Model Calibration Results

Table 7 presents model calibration and validation statistics for the Yorkville gage and model validation statistics for the Montgomery gage for annual, monthly, and daily flows. The volume error between observed streamflows at the Yorkville gage and simulated streamflows was 0.6% over the calibration period (WY 1993-2000). On a yearly basis, this error was within ±10% (very good simulation) in 5 years but within ±25% (fair simulation) in all 8 years (Table 7 and Figure 14). During the calibration period, the model overestimated streamflow in 4 years (by 5.9% to 16.6%) and underestimated it in 4 years (by -1.5% to -23.1%). Mean annual streamflows were simulated with NSE=0.82.

During WY 1996, 16.9 inches of rainfall fell near Aurora in 24 hours on July 17. This excessive rainfall likely did not occur uniformly over the entire watershed (Angel et al., 1997). Because rainfall data from the Aurora station were used for the entire watershed, the model subsequently overestimated streamflow. In WY 1996, the simulated flow exceeded observed flow by 16.6%, in part, due to overestimation of streamflow for the July event.

Table 7. Statistics for the Model Calibration and Validation Periods at Yorkville and Montgomery Gages

		Yorkville		*Montgomery*
Statistics	*Calibration*	*Validation 1*	*Validation 2*	*Validation 3*
	WY 1993-2000	WY 1991-1992	WY 2001-2003	WY 2000-2003
Long term				
Observed mean flow, cfs	61.6	49.7	46.3	36.2
Simulated mean flow, cfs	61.9	57.5	43.6	35.5
Dv, %	0.6	15.8	-5.8	-1.9
Annual				
NSE	0.82	0.59	0.66	0.72
r	0.92	1.00	0.88	0.92
Years with Dv within ±10%	5	0	2	2
Years with Dv within ±25%	8	2	2	4
Monthly				
NSE	0.74	0.63	0.75	0.77
r	0.92	0.85	0.88	0.93
Months with Dv within ±10%	27	5	5	13
Months with Dv within ±25%	56	13	14	22
Daily				
NSE	0.55	0.52	0.64	0.59
r	0.72	0.75	0.78	0.80

Note: Dv = error in simulated and observed streamflow volumes for a given period.

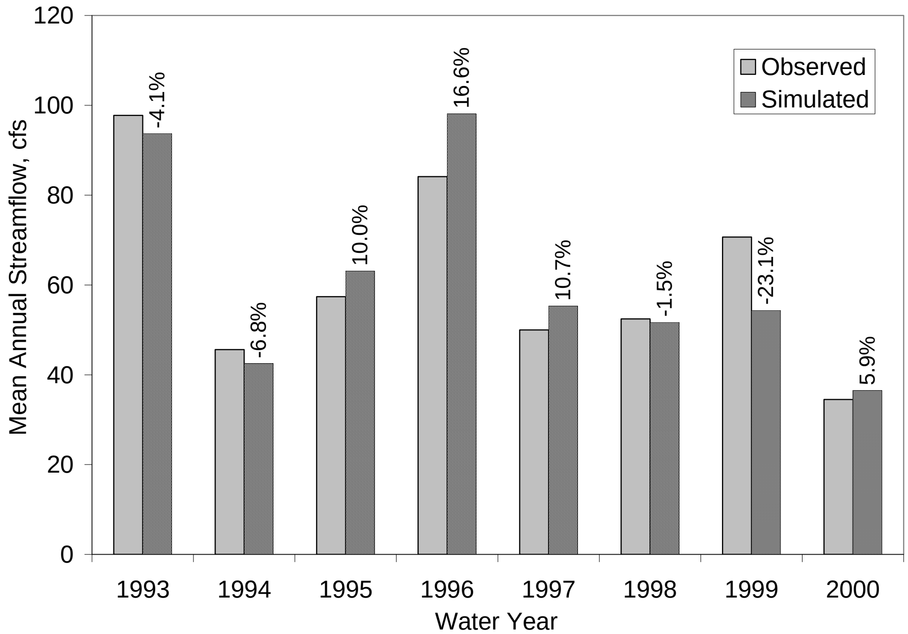


Figure 14. Observed and simulated mean annual streamflows during calibration, Yorkville gage (WY 1993-2000).

Mean monthly streamflows were simulated with NSE=0.74 and r=0.92 (Table 7). Simulated versus observed mean monthly streamflows follow the S=O line, suggesting a significant relationship (Figure 15). There is some scatter over the range of flows. The highest simulated mean monthly streamflow corresponds to the month of July 1996 that included the extreme rainfall event as stated before. 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 16a). The plot shows that for any given month during the calibration period, the S/O values were scattered around the S=O line. As the model did not consistently overestimate or underestimate flows during any month, there does not appear to be any significant seasonal bias in the simulated results, but mean monthly streamflow during April, July, and August tends to be slightly overestimated and mean monthly streamflow during November tends to be slightly underestimated on average. Of the 96 months in the calibration period, the volume error between observed and simulated mean monthly values was within ±10% in 26 months and within ±25% in 56 months, as shown in Table 7. The S/O ratios are plotted versus the observed mean monthly streamflow (Figure 16b), showing consistent model performance over the range of monthly average flows. The average S/O ratio is 1.04.

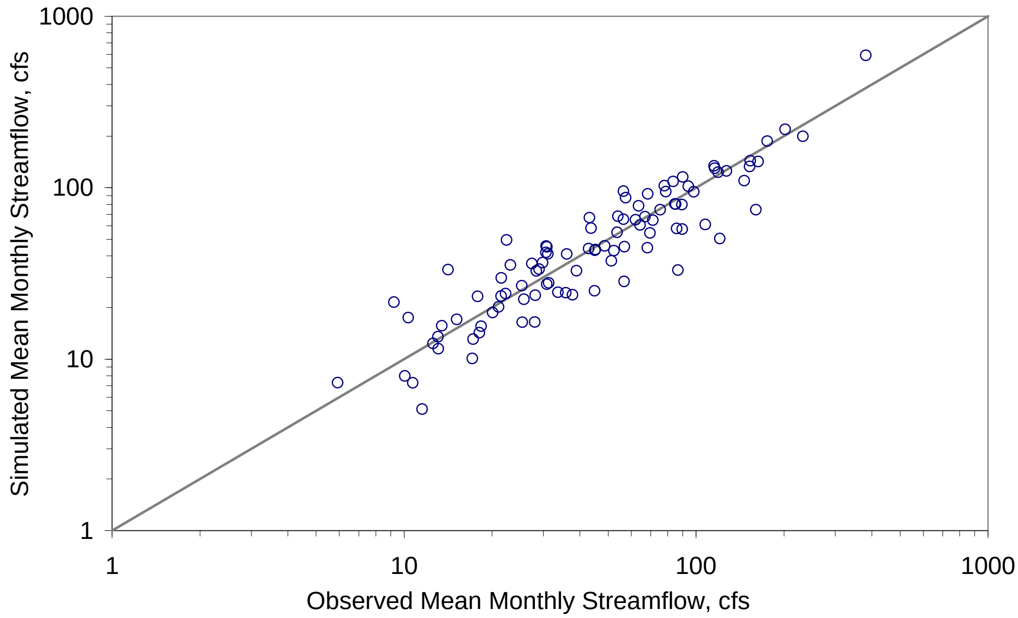


Figure 15. Observed and simulated mean monthly streamflows during calibration, Yorkville gage (WY 1993-2000).

Statistics reported in Table 7 show fair agreement between observed and simulated daily streamflows for the calibration period (WY 1993-2000). Lower model efficiency (NSE=0.55) and a lower correlation coefficient (r=0.72) indicate that the model does not simulate daily streamflows as well as mean monthly streamflows. Observed and simulated daily streamflows show even scatter around the S=O line, suggesting a significant relationship (Figure 17). Flow duration curves for observed and simulated daily streamflows are shown (Figure 18). The model simulated the range of daily streamflows reasonably but underestimated daily streamflows with probability of exceedance below 10% (high flows) and overestimated daily streamflows with probability of exceedance above 90% (low flows). The highest 10% flows were underestimated by 3.5%, whereas the lowest 50% flows were overestimated by 2.5%.

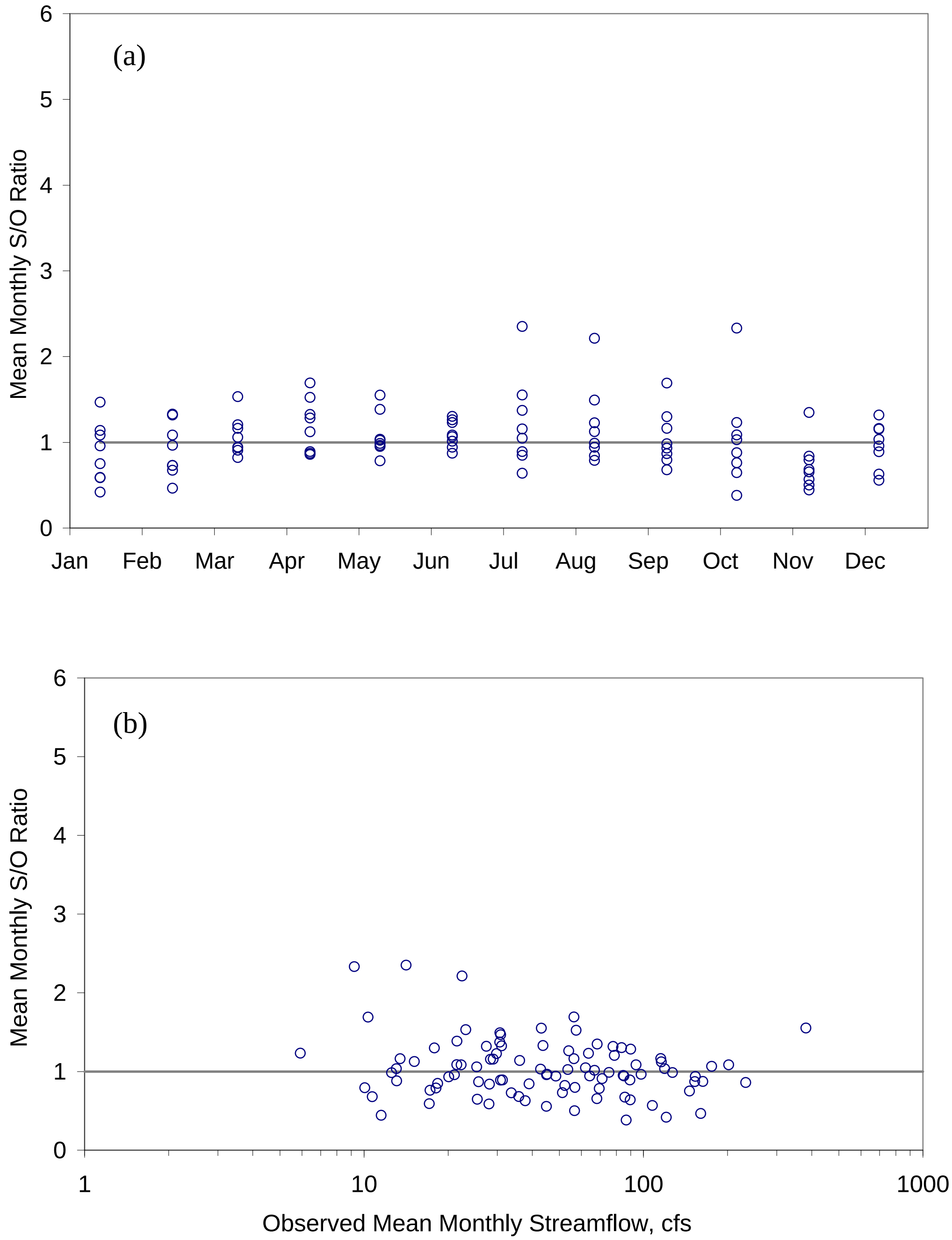


Figure 16. Comparison of simulated (S) and observed (O) mean monthly streamflow during calibration, Yorkville gage (WY 1993-2000): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow.

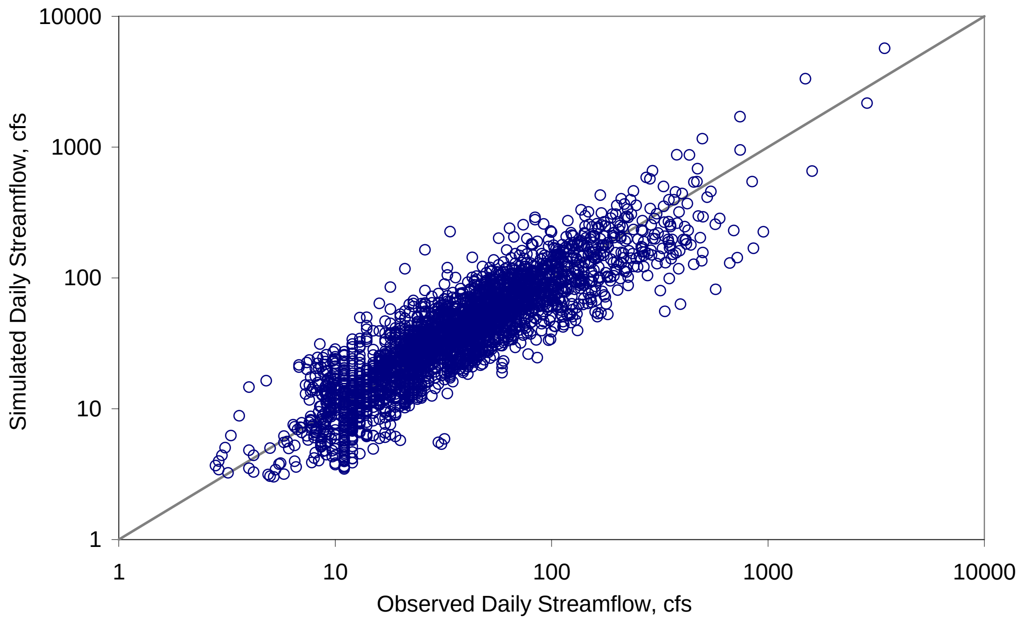


Figure 17. Observed and simulated daily streamflow during calibration, Yorkville gage (WY 1993-2000).

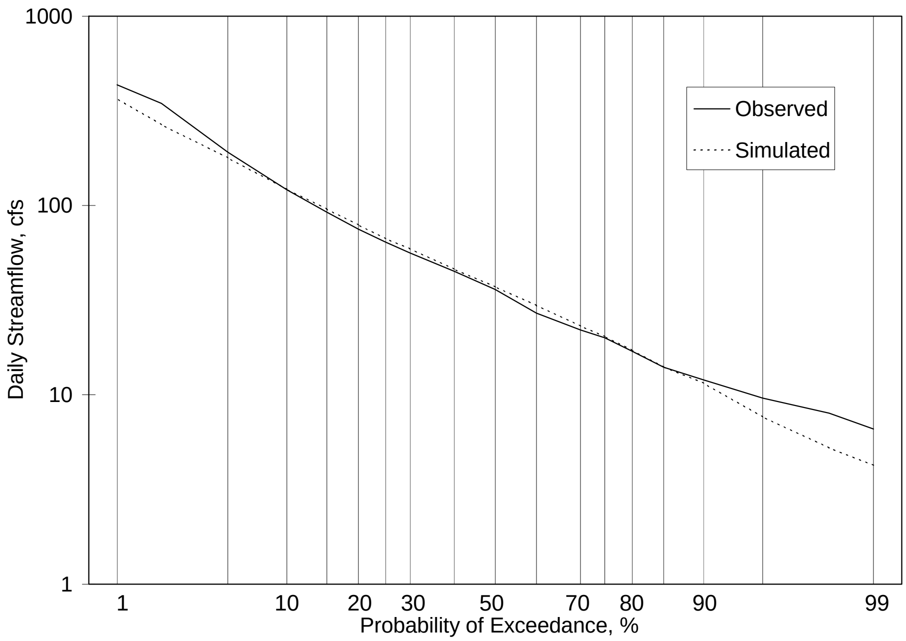


Figure 18. Flow duration curve for observed and simulated daily streamflow during calibration, Yorkville gage (WY 1993-2000).

Validation of Calibrated Model Parameters

The calibrated model was tested using observed streamflow data that were not used to calibrate the model. The ability of the model to simulate flows that correspond to observations without additional need to adjust parameters illustrates good model performance, thus validating the assigned parameter values. The same statistical and graphical comparisons used for the calibration period are used to compare flows for the validation periods. Three sets of observed daily streamflow data accompanied by climate data from the same period were used to validate the parameter set as follows:

- Validation Set 1: WY 1991-1992 at the Yorkville gage,
- Validation Set 2: WY 2001-2003 at the Yorkville gage, and
- Validation Set 3: WY 2000-2003 at the Montgomery gage.

Validation Set 1. Overall volume error between observed and simulated streamflow during the 2-year period was 15.8% (overestimation). The model overestimates mean annual streamflow by 10.6% and 24.4% in WY 1991 and WY 1992, respectively (Table 7 and Figure 19). Mean annual streamflows were simulated with NSE=0.59. The NSE and r values for the monthly fit were 0.63 and 0.85, respectively. The scatter plot of simulated versus observed mean monthly streamflows (Figure 20) shows similar bias toward overestimation of mean monthly streamflows. The plot of monthly S/O ratios versus month of year shows the model overestimates mean monthly in some months, particularly March, April, and July (Figure 21a). A similar bias also was seen in the plot of monthly S/O ratios versus observed mean monthly streamflows (Figure 21b). The average S/O ratio was 1.28. The volume error between observed and simulated mean monthly streamflows was within ±10% in 5 months and within ±25% in 13 months (Table 7). The simulated daily streamflows show fair agreement with observed values and resulted in model efficiency (NSE=0.52) and correlation coefficient (r=0.75) comparable to the calibration run. The scatter plot of observed and simulated daily streamflows given in Figure 22 shows the model tendency to overestimate daily streamflow. Flow duration curves (Figure 23) show that the model consistently overestimated daily streamflows during the two-year period. This validation period precedes the land use data used in the model by about 10 years. The highest 10% flows were overestimated by 10.3%, whereas the lowest 50% flows were overestimated by 32.6%.

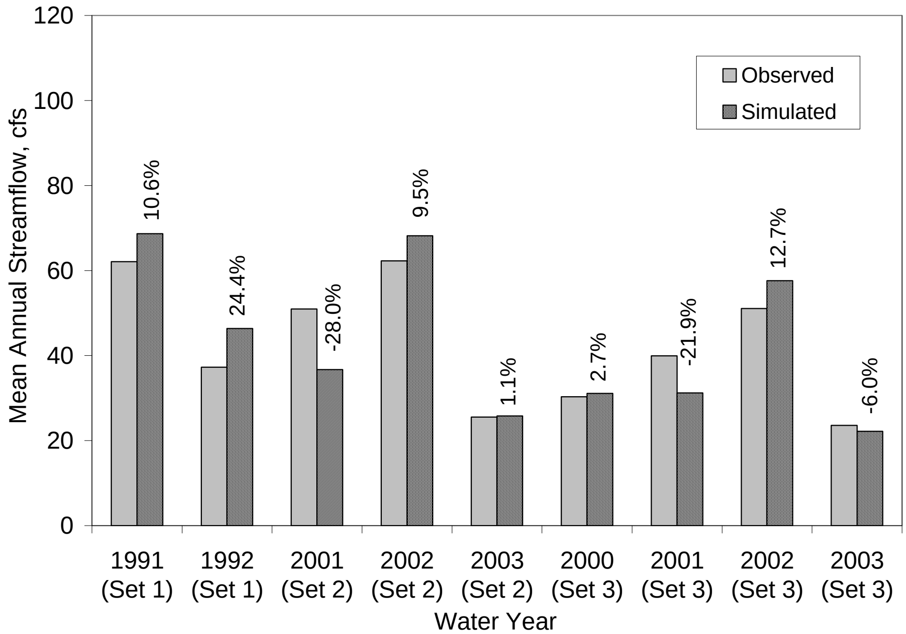


Figure 19. Observed and simulated mean annual streamflows during validation, Yorkville gage (Sets 1 and 2) and Montgomery gage (Set 3).

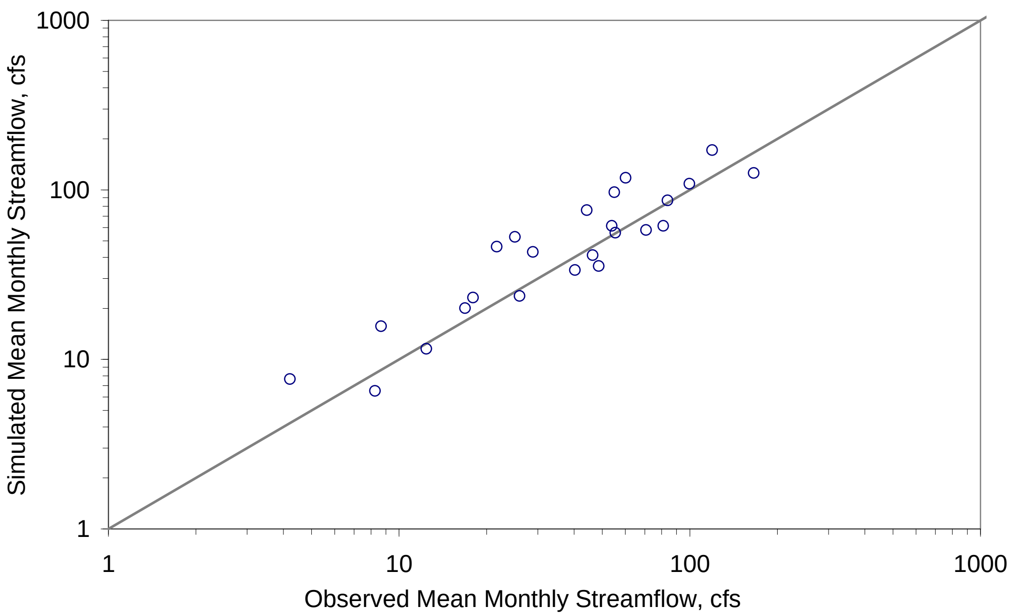
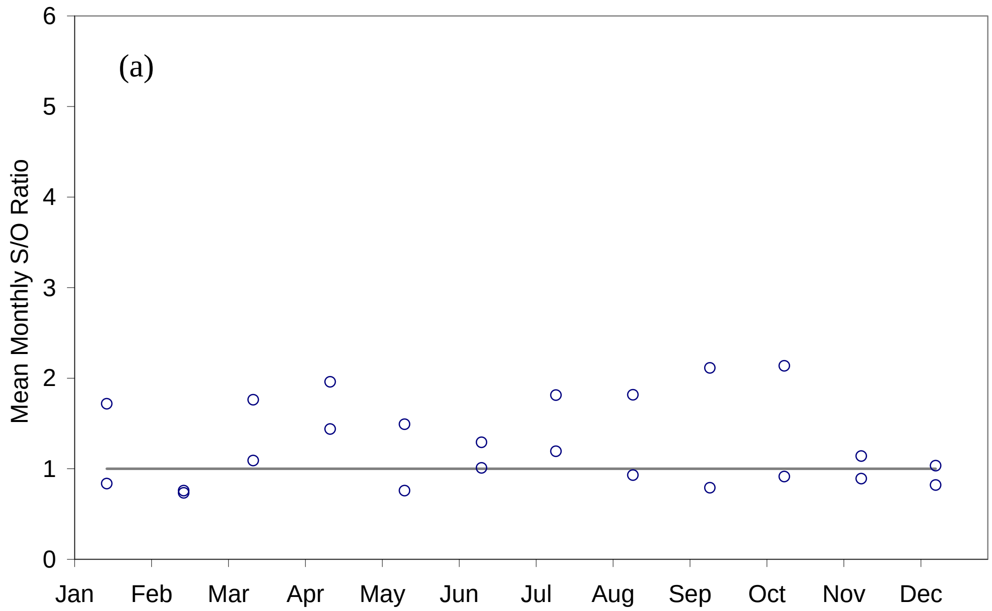


Figure 20. Observed and simulated mean monthly streamflows during validation Set 1, Yorkville gage (WY 1991-1992).



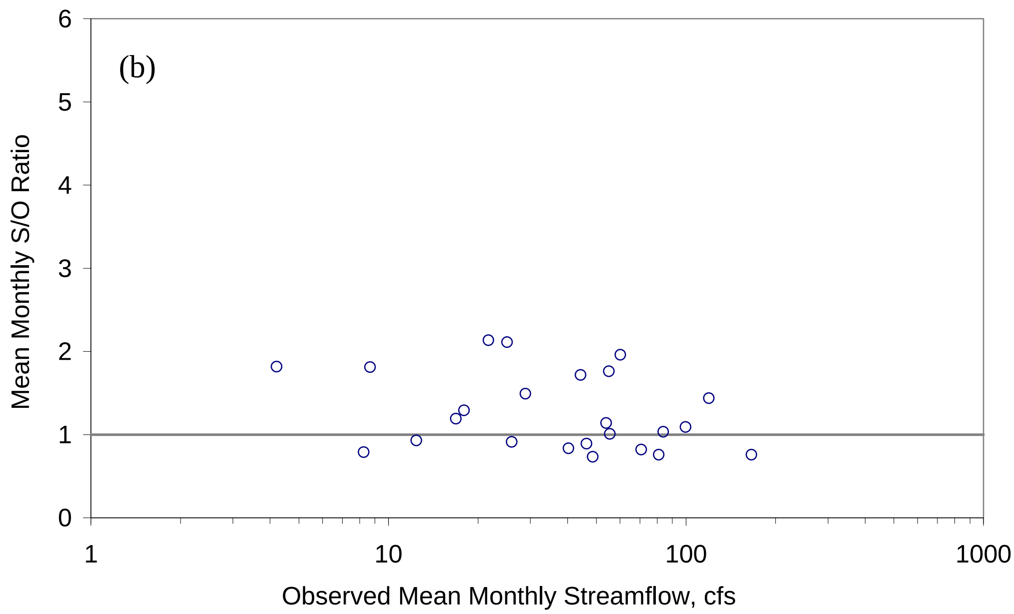


Figure 21. Comparison of simulated (S) and observed (O) mean monthly streamflow during validation Set 1, Yorkville gage (WY 1991-1992): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow.

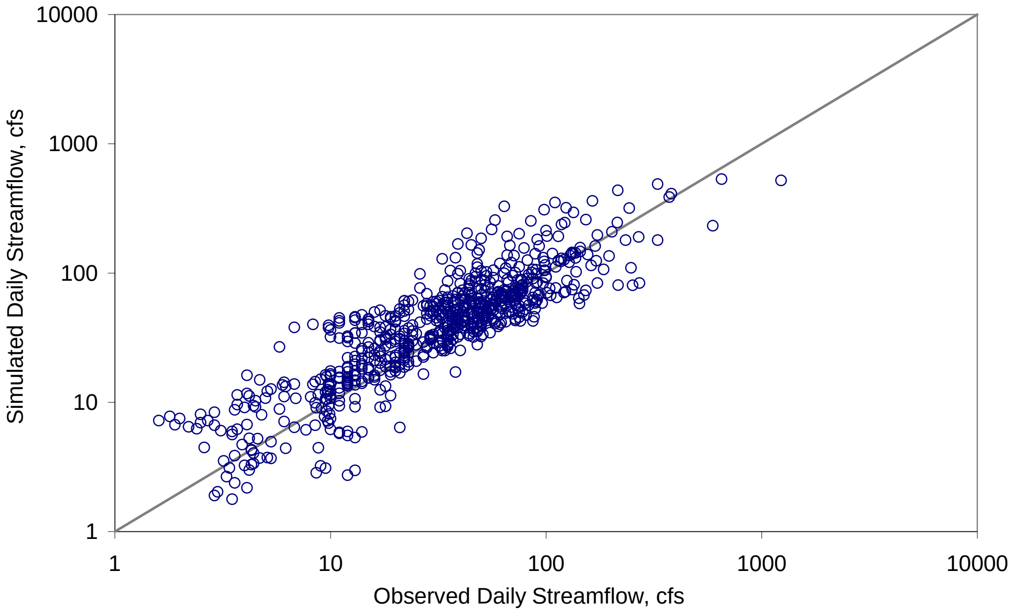


Figure 22. Observed and simulated daily streamflows during validation Set 1, Yorkville gage (WY 1991-1992).

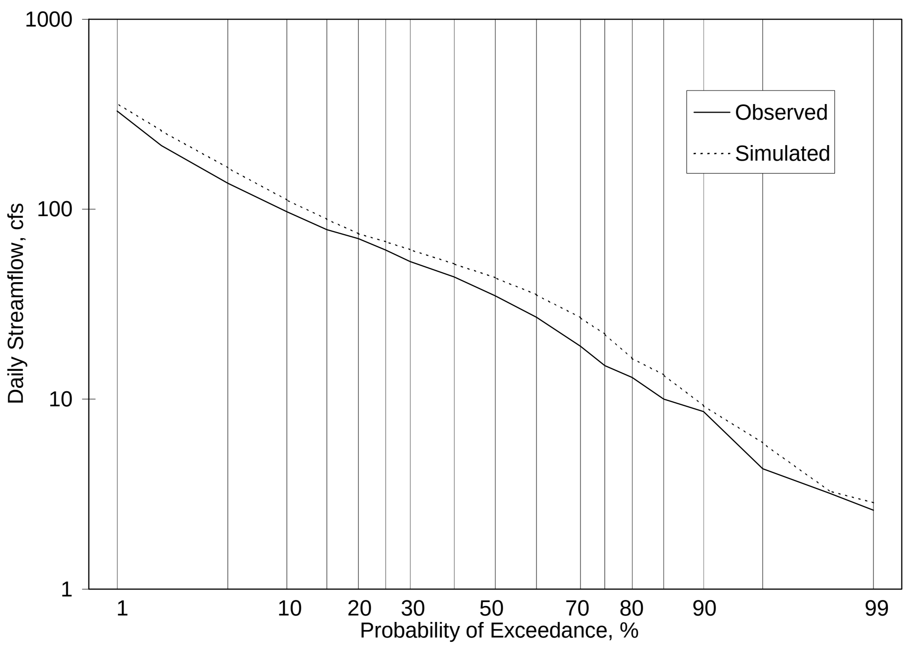


Figure 23. Flow duration curve for observed and simulated daily streamflow during validation Set 1, Yorkville gage (WY 1991-1992).

Validation Set 2. Overall volume error between observed and simulated streamflow during the 3-year period was -5.8% (underestimation). The model underestimated streamflow in WY 2001 by 28%, whereas in WY 2002 and WY 2003, it overestimated by a smaller error of 9.5% and 1.1%, respectively (Table 7 and Figure 19). Mean annual streamflows were simulated with NSE=0.66. The NSE and r values for the monthly fit were 0.75 and 0.88, respectively. The scatter plot of simulated versus observed mean monthly streamflows shows no bias (Figure 24). However, the plot of monthly S/O ratios versus month of year shows some seasonality (Figure 25a). The model overestimated streamflow in some months (May and July-September) but overestimated flows in other months (January, February, and October-December). The volume error between observed and simulated mean monthly values is within ±10% in 5 months and within ±25% in 14 months (Table 7). The plot of monthly S/O ratios versus observed monthly flows (Figure 25b) shows that, in general, datapoints are scattered evenly around the S=O line, but flows in the driest months (mean observed streamflow less than 30 cfs) are simulated with greater uncertainty as indicated by larger scatter of points from the S/O=1 line. The average S/O ratio was 1.02. Simulated daily flows show fair agreement with observed values and resulted in model efficiency (NSE=0.64) and correlation coefficient (r=0.78) comparable to the calibration run. The scatter plot of observed and simulated daily streamflows (Figure 26) shows data scatter from the S=O line greater at flows of 30 cfs or lower. Flow duration curves (Figure 27) show that simulated daily streamflows agree well with observed flows, but the model consistently underestimated the smallest flows in the exceedance range of 50% and above. The highest 10% flows were underestimated by 3.9%, whereas the lowest 50% flows were underestimated by 18%.

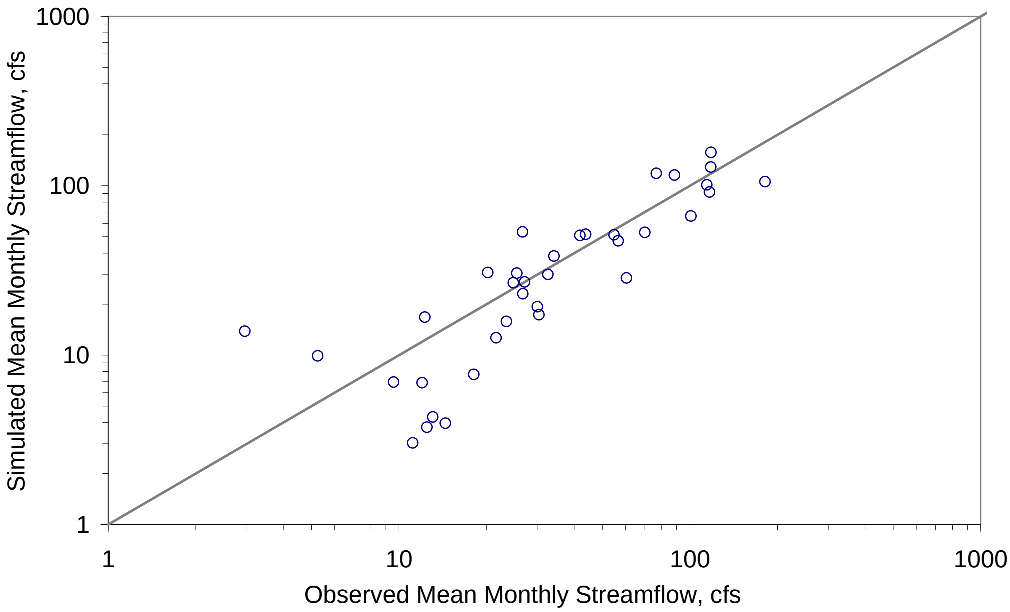
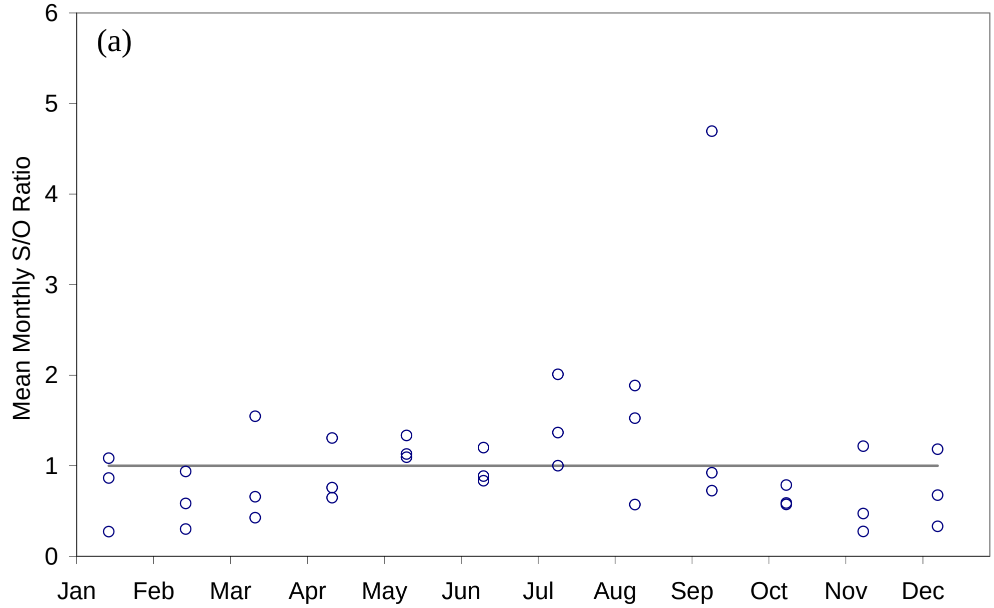


Figure 24. Observed and simulated mean monthly streamflows during validation Set 2, Yorkville gage (WY 2001-2003).



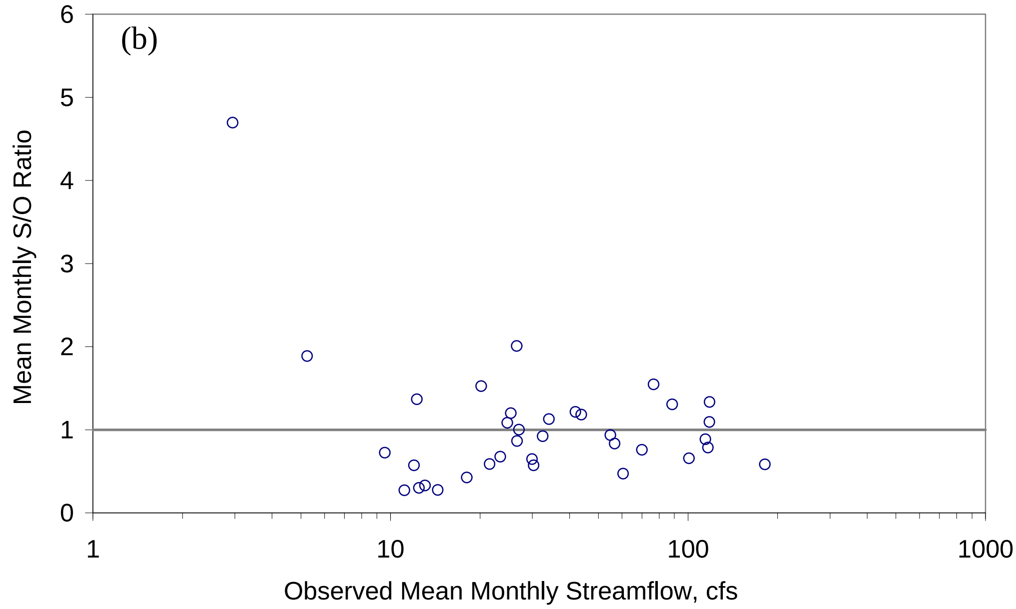


Figure 25. Comparison of simulated (S) and observed (O) mean monthly streamflow during validation Set 2, Yorkville gage (WY 2001-2003): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow.

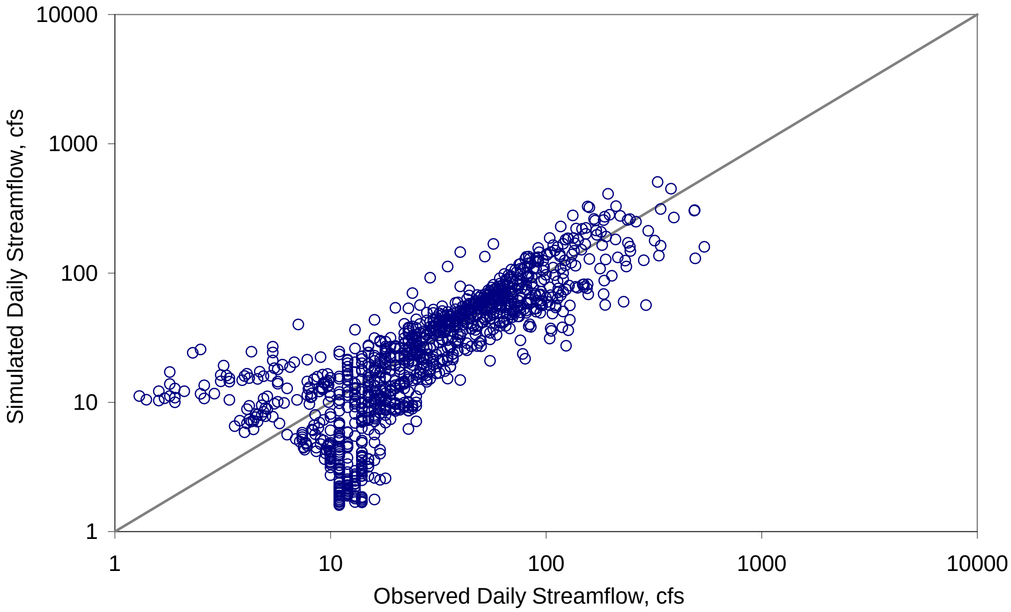


Figure 26. Observed and simulated daily streamflows during validation Set 2, Yorkville gage (WY 2001-2003).

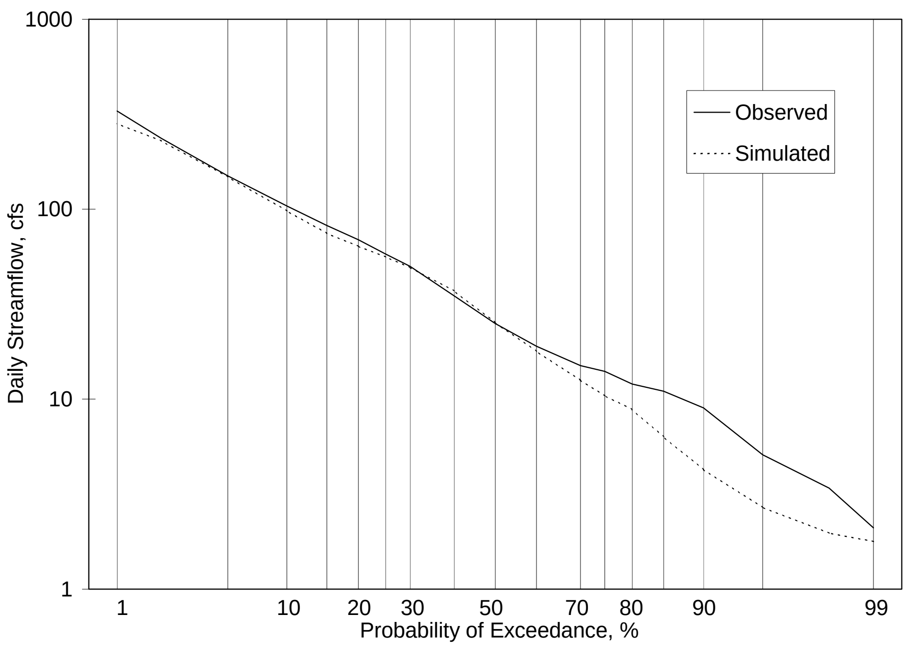


Figure 27. Flow duration curve for observed and simulated daily streamflows during validation Set 2, Yorkville gage (WY 2001-2003).

Validation Set 3. Volume error between observed and simulated streamflow during the 4-year period was -1.9% (underestimation). On an annual basis, this error was within ±10% (very good estimation) for 2 years and within ±25% (fair estimation) for all 4 years (Table 7 and Figure 19). Mean annual streamflows were simulated with NSE=0.72. The NSE and r values for the monthly fit were 0.77 and 0.93, respectively. The scatter plot of simulated versus observed mean monthly streamflows (Figure 28) shows no bias, but scatter around the S=O line is greater over low flows. The plot of monthly S/O ratios versus month of the year shows some seasonality (Figure 29a). The model generally overestimated streamflow in some months (May, July, and September) but underestimated streamflow in other months (January, February, October, and November). The volume error between observed and simulated mean monthly streamflows was within ±10% in 13 months and within ±25% in 22 months. The plot of monthly S/O versus observed monthly flows (Figure 29b) shows that datapoints are scattered evenly around the S/O=1 line, but scatter is greater for the driest months (mean observed streamflow less than 20 cfs). The average S/O ratio is 1.00. Simulated daily streamflows show fair agreement with observed values and resulted in model efficiency (NSE=0.59) and correlation coefficient (r=0.80) comparable to the calibration run. The scatter plot of observed and simulated daily streamflows (Figure 30) shows greater scatter at flows less than 20 cfs. Flow duration curves (Figure 31) show that simulated daily streamflows agree well with observed flows in the higher range. The model consistently underestimated lowest flows in the exceedance range of 50% and above. The highest 10% flows were underestimated by 0.8%, whereas the lowest 50% flows were underestimated by 20.5%.

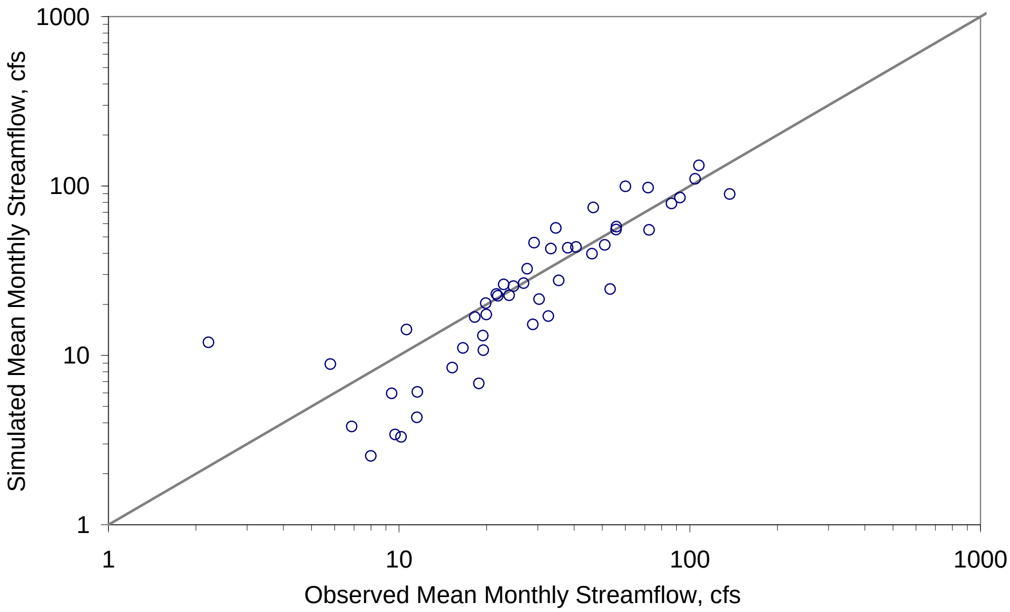


Figure 28. Observed and simulated mean monthly streamflows during validation Set 3, Montgomery gage (WY 2000-2003).

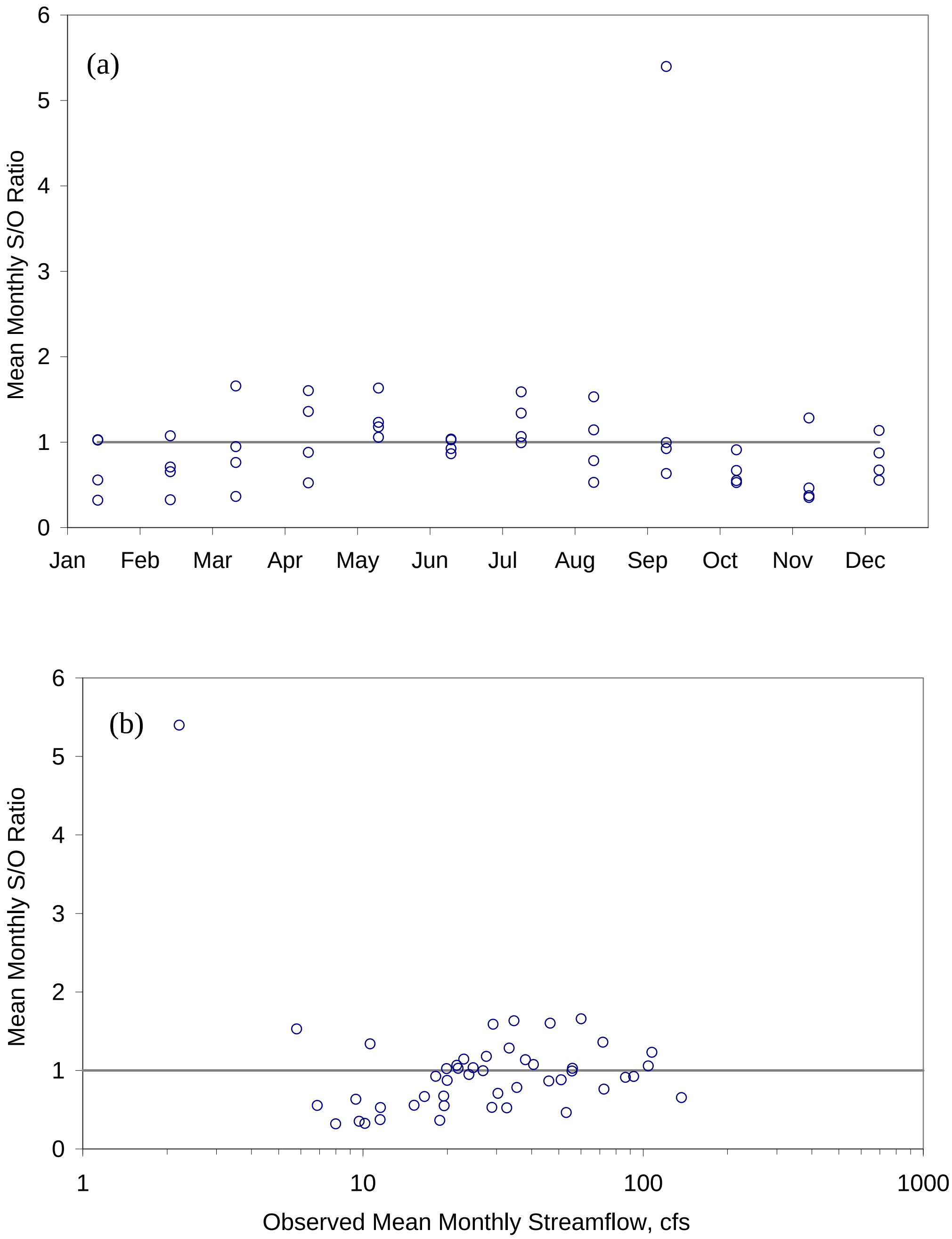


Figure 29. Comparison of simulated (S) and observed (O) mean monthly streamflow during validation Set 3, Montgomery gage (WY 2000-2003): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow.

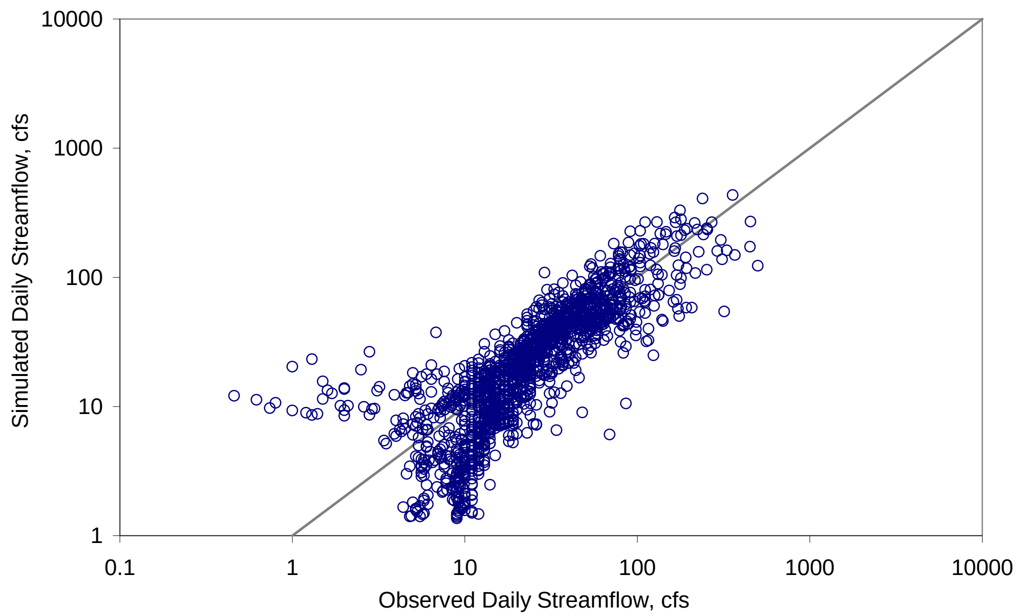


Figure 30. Observed and simulated daily streamflows during validation Set 3, Montgomery gage (WY 2000-2003).

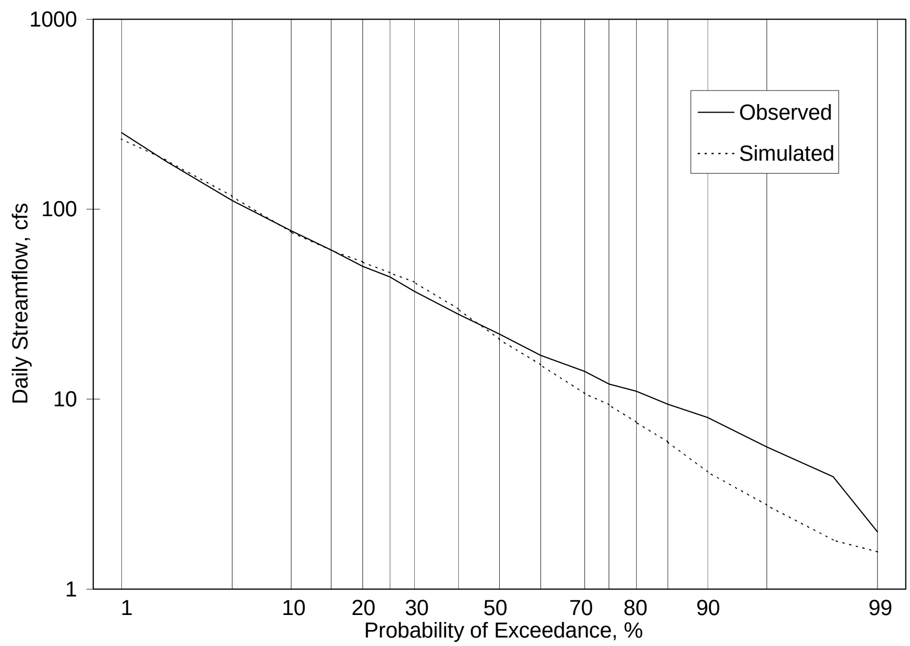


Figure 31. Flow duration curve for observed and simulated daily streamflows during validation Set 3, Montgomery gage (WY 2000-2003).

Poplar Creek Watershed

HSPF Model Development

The Poplar Creek watershed was divided into 36 hydrologically connected subwatersheds, their stream reaches, and respective outlets. Calculation points were defined at the outlet of subwatersheds 26, 31, and 35 (Figure 8). The outlet of subwatershed 26 corresponds to the location of the USGS gage in Elgin. Simulated daily streamflow data from this outlet point were used for comparison with observed data from the Elgin gage during model calibration and validation. Water quality data are also available for this location (FoxDB Station 25). Outlets of subwatersheds 31 and 35 correspond to locations of water quality stations (FoxDB Stations 615 and 895, respectively), but no streamflow data are available for these sites. Thus, results from these calculation points are used only in calibrating the water quality component of the HSPF model, not the hydrologic component. Subwatershed numbers (Figure 8) correspond to subwatershed numbers listed in Appendix B that summarizes information on the total area of each subwatershed and the area of pervious and impervious land use.

Subwatershed size ranges from 101 acres (subwatershed 13) to 2606 acres (subwatershed 24), as shown in Appendix B. The amount of impervious area within a subwatershed ranges from 9 acres (subwatershed 29) to 796 acres (subwatershed 24). Five subwatersheds have no impervious area, as shown in Appendix B. The fraction of impervious area within the remaining subwatersheds is 2.8-33.1%. Impervious surface (combined from urban high density and urban low/medium density) covers 15% of watershed area. Unique combinations of land use, soil type, and drainage area in the Blackberry Creek watershed result in 53 different types of HRUs (Appendix C). The Poplar Creek watershed model has 293 HRUs. Appendix D2 lists the HRUs in each subwatershed.

Data from WY 1991-1999 at the Elgin gage were used for model calibration. Data from WY 2000-2003 were used for model validation.

Calibration and Model Performance

The hydrologic component of the HSPF model was calibrated to best simulate the observed streamflow at the outlet of subwatershed 26 using observed streamflow data at Elgin (April 1991-WY 1999). This period represents a combination of dry, average, and wet years (annual precipitation ranges from 31 inches to 49 inches). The model was run using data from January 1, 1990-September 30, 1999. The period prior to April 1, 1991 was used to stabilize model runs. Only the simulated daily streamflow data for April 1991-WY 1999 were used for comparison purposes during model performance evaluation.

The initial model parameter set used was taken from the Blackberry Creek watershed model for each respective HRU type present in both watersheds. There are 22 and 53 unique HRU types in the Blackberry Creek and Poplar Creek watershed models, respectively, together accounting for 65 unique HRU types. However, only 16 HRU types are present in both watersheds and only seven of these 16 HRU types constitute at least 4% of area in one of the watersheds. Four unique HRU types account for nearly 60% of the Blackberry Creek watershed area, another four for about 20%, and the remaining 14 unique HRU types are distributed over 20% of the Blackberry Creek watershed area. Seven unique HRU types account for 62% of the Poplar Creek watershed area. The seven major HRU types for Poplar Creek watershed are all different from the eight major HRU types for Blackberry Creek watershed. During calibration of pilot watersheds, only major HRU types (Table 8) were calibrated consistently across the watersheds. It would be nearly impossible to determine a unique set of calibration parameters for each minor HRU type that could be directly transferable to other watersheds. Consequently, HRU types not identified as major cannot be considered properly calibrated outside their respective watersheds.

Due to constraints on time and resources, the difference in parameter values for minor HRU types between Blackberry and Poplar Creek watershed models was not resolved. Identifying a proper set of calibration parameters for HRU types present in such a small percentage in both watersheds would involve major effort but would not improve confidence in the model or its parameters adequately. This difference will be resolved during model development for the Fox River mainstem and all remaining tributaries. It can be expected that other unique HRU types will become important (major) in other tributary watersheds. Major HRU types then will be calibrated to streamflows on the Fox River mainstem during the next stage of the project.

Table 8. Major HRU Types Identified in Pilot Watersheds

				Percent watershed area, %	
Land use	*Hydrologic soil group*	*Slope, %*	*HRU Code*	*Blackberry Creek*	*Poplar Creek*
Corn	B	<2	COR21	**20.9**	0.5
Corn	B	2-4	COR22	**5.1**	0.9
Forest	B	<2	FOR21	**4.6**	0
Forest	C	2-4	FOR32	0	**6.9**
Soy	B	<2	SOY21	**17.7**	0.8
Soy	B	2-4	SOY22	**5.8**	0.6
Urban low/medium density	C	2-4	ULM32	0	**12.4**
Urban low/medium density (effective)	*	2-4	ULMIe2	0.5	**4.2**
Urban low/medium density (non-effective)	*	2-4	ULMIn2	0	**4.2**
Urban open space	B	<2	UOS21	**9**	0.9
Urban open space	B	2-4	UOS22	2.7	**4.8**
Urban open space	C	2-4	UOS32	0	**22.1**
Urban open space	D	2-4	UOS42	0	**7.4**
Rural grassland	B	<2	RGR21	**10.9**	0
Rural grassland	B	2-4	RGR22	**5.5**	0
		Total	*Major*	79.5	62.0
			Minor	3.2	3.7
			All	82.7	65.7

Note: *Hydrologic soil group is not determined for impervious surfaces.

Table 9. Model Calibration Parameters for the Poplar Creek Watershed

Parameter	*Description*	*Unit*	*Values used*
Pervious HRUs			
AGWETP	Active groundwater evapotranspiration	*	0.0-0.5
AGWRC	Basic ground water recession rate	1/d	0.87-0.98
BASETP	Baseflow evapotranspiration	*	0.0-0.5
CCFACT	Condensation/convection melt factor	*	1.0
CEPSC	Interception storage capacity	in	0.0-1.0
DEEPFR	Fraction of inactive groundwater	*	0.1
INFILT	Index to soil infiltration capacity	in/h	0.06-1.5
INTFW	Interflow inflow parameter	*	0.36-1.02
IRC	Interflow recession constant	*	0.33-0.64
KVARY	Variable groundwater recession flow	1/in	0.85
LZETP	Lower zone evapotranspiration	*	0.1-1.1
LZSN	Lower zone nominal storage	in	5.0-7.0
NSUR	Manning's *n* for overland flow	*	0.01-0.3
SNOWCF	Snow gage catch correction factor	*	1.2-1.4
TSNOW	Temperature at which precipitation is snow	°F	32
UZSN	Upper zone nominal storage	in	0.84-1.96
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	*	1.4

Note: *Parameter is dimensionless or unit is complex.

There is greater confidence in parameter values established for the Poplar Creek watershed model than in those for the Blackberry Creek watershed model because spatial distribution of precipitation is described better by the three stations in the Poplar Creek watershed model than by the single station in the Blackberry Creek watershed model. During calibration, values of different parameters for minor HRU types were adjusted within reasonable limits to obtain an optimal fit between simulated and observed streamflow data. Table 9 defines and provides final ranges of calibrated model parameters.

Table 10 presents model calibration statistics with respect to the Elgin gage. The volume error between observed streamflows and simulated streamflows was negligible (only -0.06%) over the calibration period (April 1991-WY 1999). On a yearly basis, this error was within ±10% (very good simulation) in 7 years but within ±15% (good simulation) in all years (Figure 32). The model overestimated streamflow in 4 years (by 3.1% to 11.1%) and underestimated it in 5 years (by -0.2% to -14.5%). Mean annual streamflows were simulated with an NSE=0.95.

Table 10. Statistics for the Model Calibration and Validation Periods at the Elgin Gage

Statistics	*Elgin* Calibration April 1991-WY 1999	*Elgin* Validation WY 2000-2003
Long-term mean		
Observed, cfs	33.7	29.4
Simulated, cfs	33.6	27.0
Dv, %	0.0	-8.2
Annual		
NSE	0.95	0.89
r	0.98	0.98
Number of years with Dv within ±10%	7	3
Number of years with Dv within ±25%	9	4
Monthly		
NSE	0.87	0.88
r	0.93	0.95
Number of months with Dv within±10%	26	12
Number of months with Dv within ±25%	61	27
Daily		
NSE	0.76	0.67
r	0.87	0.82

Note: Dv = error in the simulated and observed streamflow volumes for a given time period.

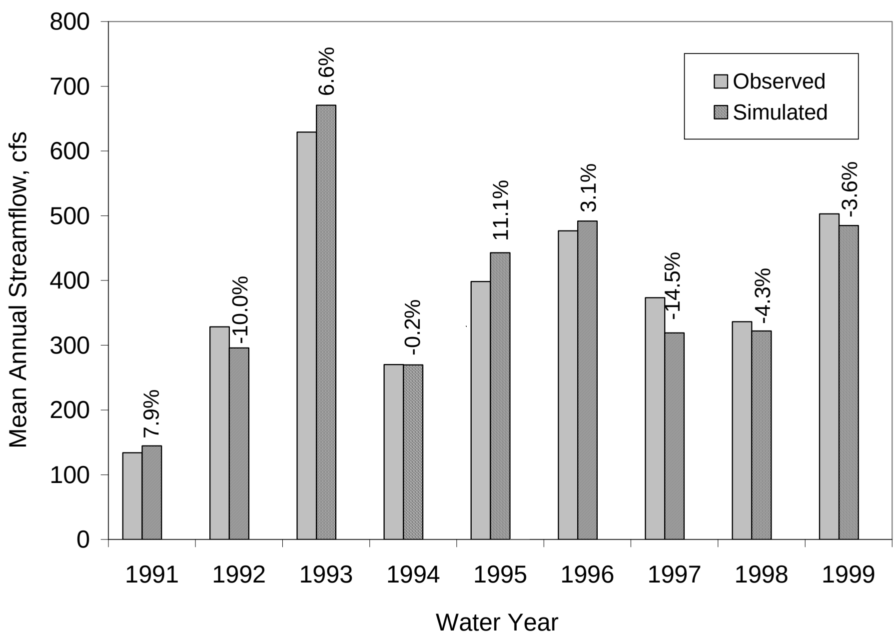


Figure 32. Comparison of mean annual streamflows during calibration, Elgin gage (WY 1991-1999). Values along the bars are the absolute percent difference between the observed and simulated values.

The mean monthly streamflows were simulated with an NSE=0.87 and r=0.93 (Table 10), indicating good correlation with observed data. Volume error between observed and simulated mean monthly streamflows was within ±10% in 26 months and within ±25% in 61 months. The scatter plot of observed versus simulated mean monthly streamflows (Figure 33) shows the model overestimated mean monthly streamflows below 10 cfs. The plot of monthly S/O ratios versus month of the year (Figure 34a) shows mean monthly streamflows during June-October are overestimated, and mean monthly streamflows during January-March are underestimated. Mean monthly streamflows during July-September are less than 20 cfs. Monthly S/O ratios plotted versus observed monthly streamflows (Figure 34b) show unbiased fit except for overestimated flows below 10 cfs. The average S/O ratio is 1.12.

Statistics reported in Table 10 show good agreement between observed and simulated daily streamflows for the calibration period (NSE=0.76 and r=0.87). The scatter plot and flow duration curves of the observed and simulated daily streamflows (Figure 35 and Figure 36, respectively) show that the calibrated model simulated the range of daily streamflows reasonably well. The highest 10% flows were underestimated by -8.1%, whereas the difference in the lowest 50% flows was negligible (only 0.02%).

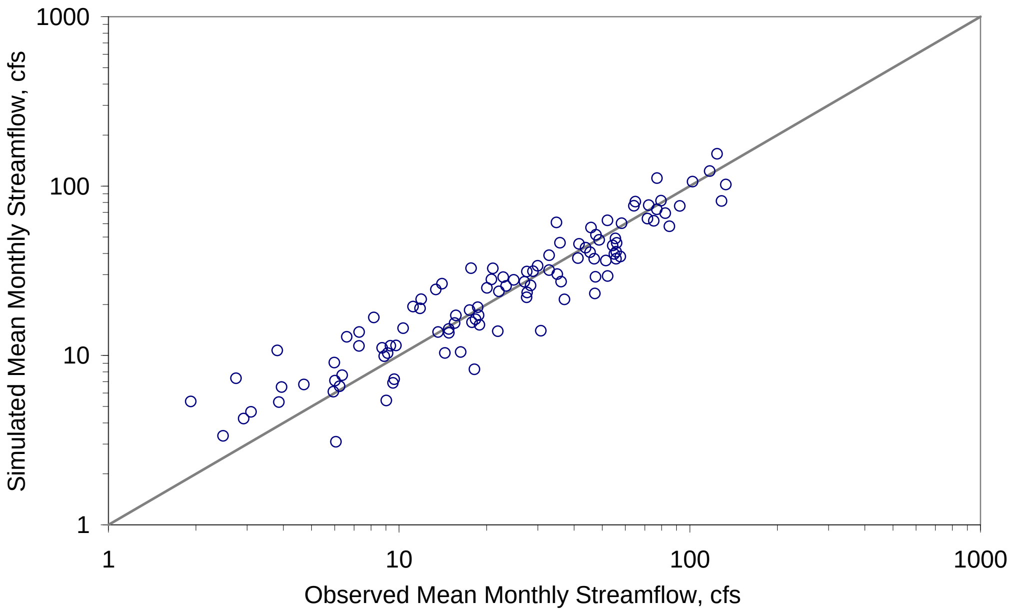


Figure 33. Observed and simulated mean monthly streamflows during calibration, Elgin gage (WY 1991-1999).

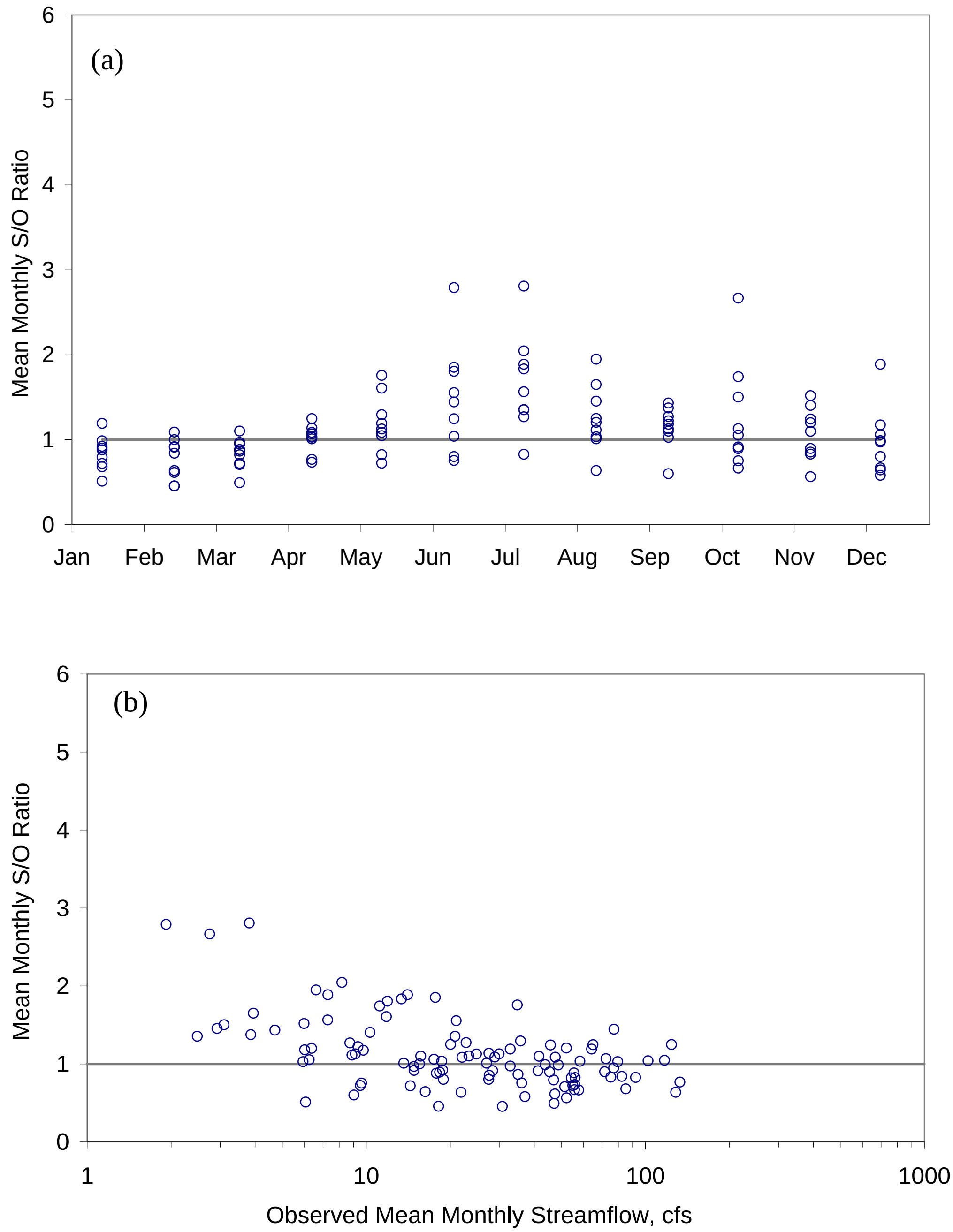


Figure 34. Comparison of simulated (S) and observed (O) mean monthly streamflow during calibration, Elgin gage (WY 1991-1999): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow.

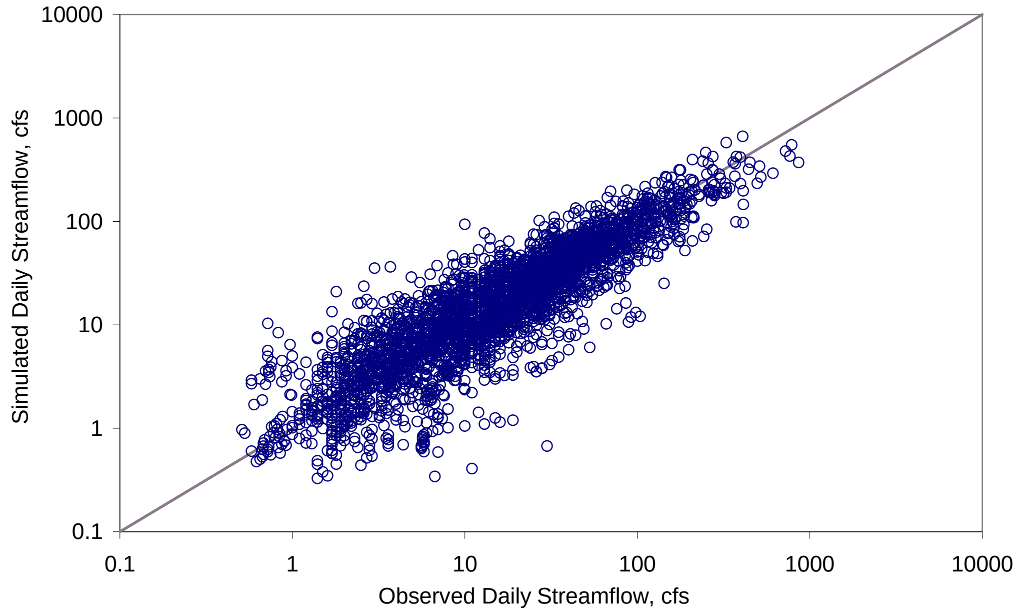


Figure 35. Observed and simulated daily streamflows during calibration, Elgin gage (WY 1991-1999).

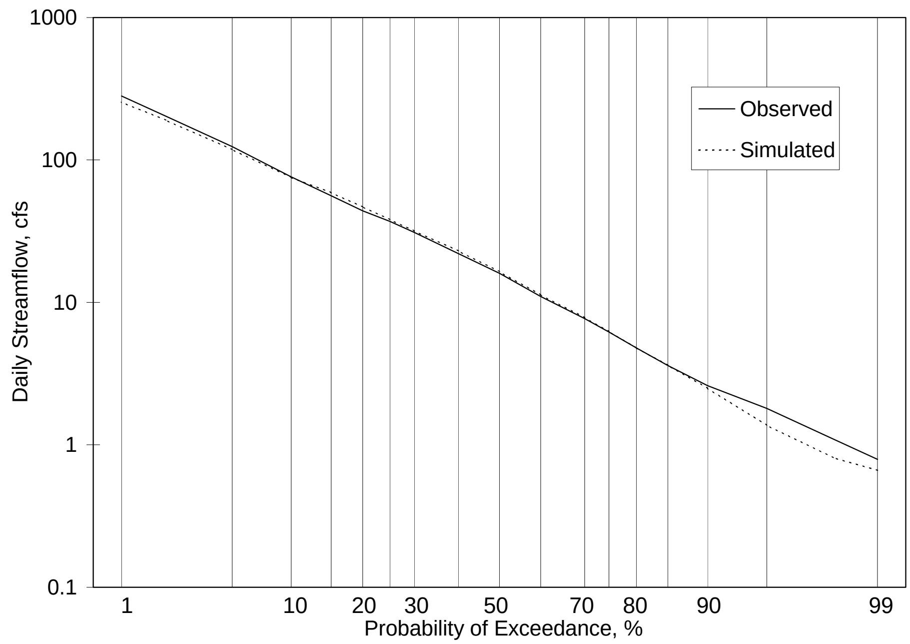


Figure 36. Flow duration curve for observed and simulated daily streamflows during calibration, Elgin gage (WY 1991-1999).

Validation of Calibrated Model Parameters

The calibrated model was validated for WY 2000-2003 to evaluate model ability to predict streamflows outside the calibration period. During validation, calibrated model parameters were not changed. The model was run for the validation period with corresponding climate data, and the fit between simulated and observed streamflows at the Elgin gage was evaluated in the same manner as for calibration.

Overall volume error between observed and simulated streamflow during the 4-year period was -8.2% (underestimation). Mean annual streamflows were simulated with NSE=0.89 (Table 10). The model underestimated streamflow in WY 2001 by 16.6%, whereas this difference was less than 10% in the other years (Figure 37).

The fit between observed and simulated mean monthly streamflows was very similar to that for the calibration period, as indicated by high NSE and r value, 0.88 and 0.95, respectively (Table 10). The scatter plot of simulated versus observed mean monthly streamflows (Figure 38) shows a very good fit, but flows below 10 cfs tend to be overestimated. Volume error between observed and simulated mean monthly streamflows was within ±10% in 12 months and within ±25% in 27 months of the 48-month validation period. The plot of monthly S/O ratios versus month of the year (Figure 39a) shows the model generally overestimated mean monthly streamflows in February, June, July, and September. This is consistent with the calibration results. The plot of monthly S/O ratios versus observed mean monthly streamflows (Figure 39b) shows datapoint scatter evenly around the S=O line except for very low flows (< 5 cfs). These low flows generally occur during the summer months, which the model consistently overestimated.

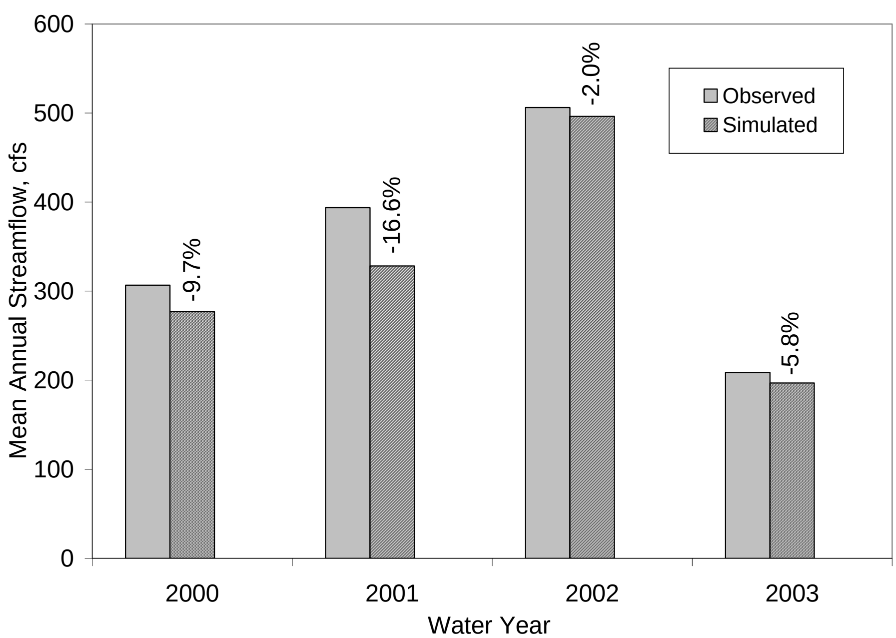


Figure 37. Comparison of mean annual streamflows during validation, Elgin gage (WY 2000-2003). Values along the bars are the absolute percent difference between the observed and simulated values.

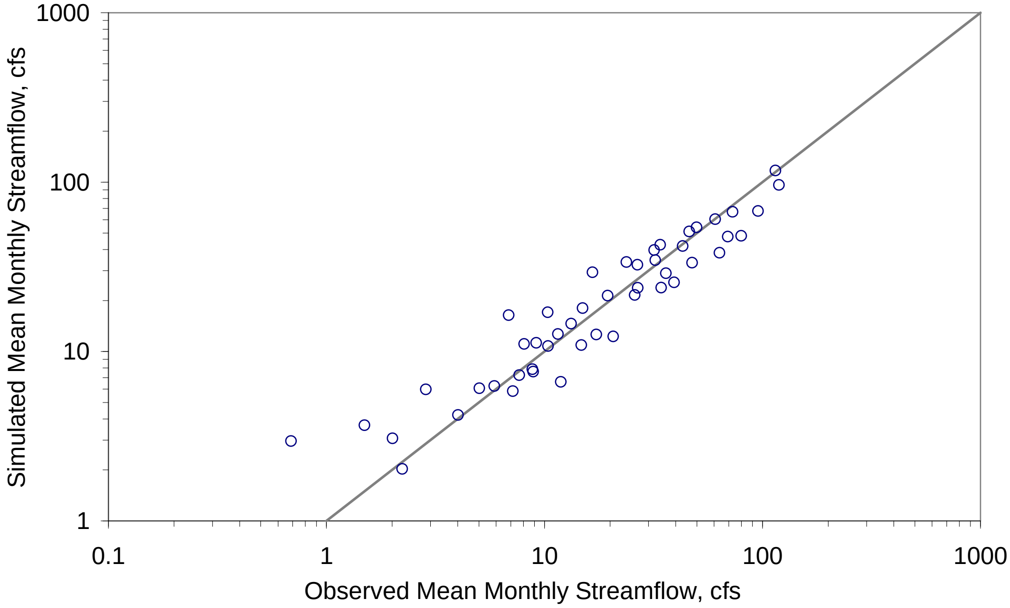


Figure 38. Observed and simulated mean monthly streamflows during validation, Elgin gage (WY 2000-2003).

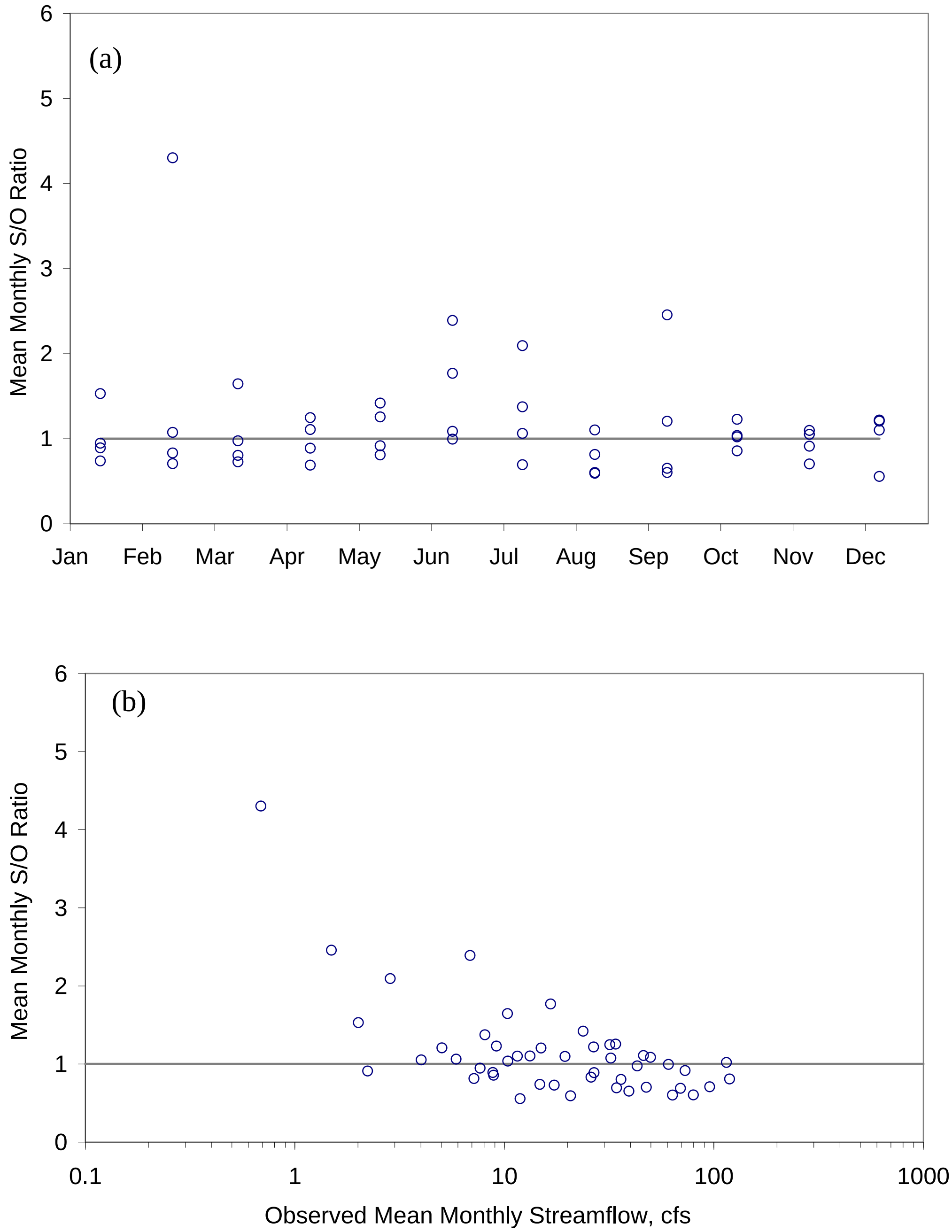


Figure 39. Comparison of simulated (S) and observed (O) mean monthly streamflow during validation, Elgin gage (WY 2000-2003): a) changes in monthly S/O ratios with month, and b) changes in monthly S/O ratios with observed monthly streamflow.

The scatter plot and flow duration curves of the observed and simulated daily streamflows (Figure 40 and Figure 41) show that the calibrated model simulated the range of daily streamflows well. The highest 10% flows were underestimated by -18.9%, whereas the lowest 50% flows were underestimated by -4.0%.

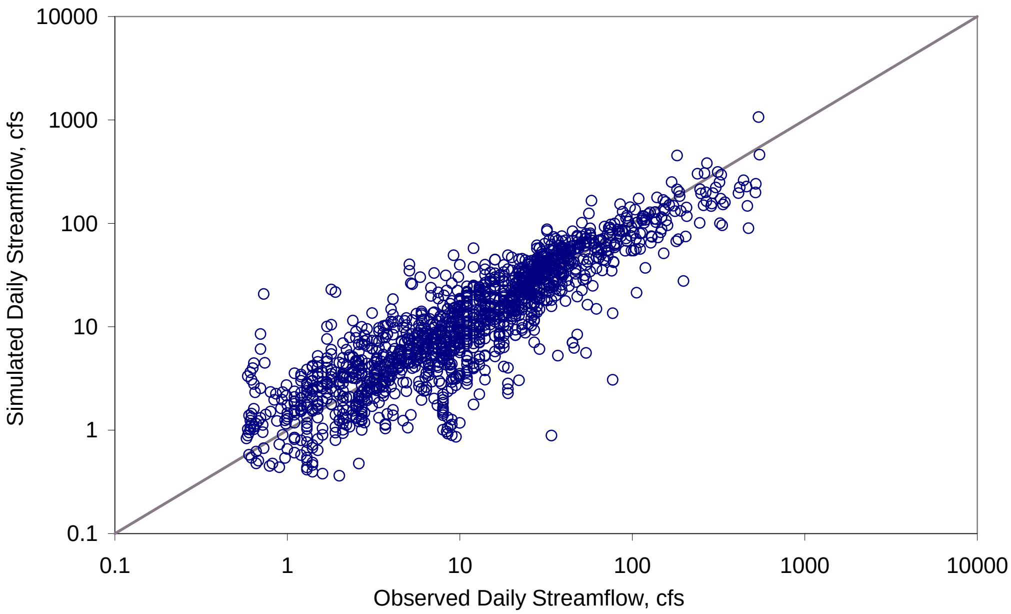


Figure 40. Observed and simulated daily streamflows during validation, Elgin gage (WY 1991-1999).

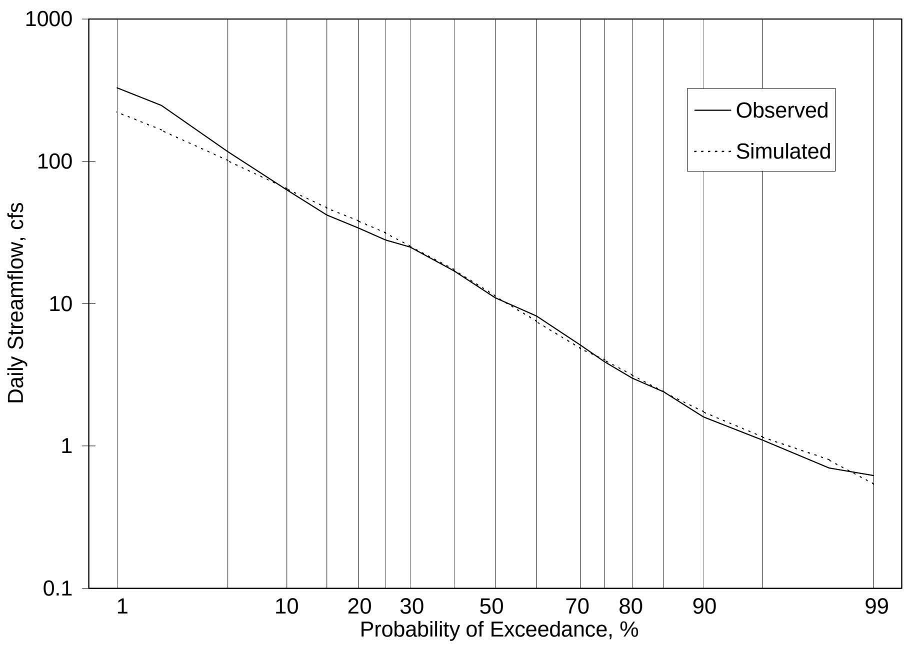


Figure 41. Flow duration curve for observed and simulated daily streamflows during validation, Elgin gage (WY 2000-2003).

Sensitivity Analysis of Model Parameters

The sensitivity analysis of selected HSPF parameters was performed to determine the relative effect of those parameters on simulated streamflow. Sensitivity analyses were conducted for both the Blackberry Creek and Poplar Creek watershed models after calibration. Model output for the calibration periods was used for these analyses: WY 1993-2000 for the Blackberry Creek watershed model and WY 1991-1999 for the Poplar Creek watershed model. Only one model parameter was evaluated per sensitivity run. Four model runs were conducted corresponding to specified percentages of changes in parameter values: -50%, -20%, +20%, and +50% change for the Blackberry Creek watershed model and -60%, -20%, +20%, and +60% change for parameters in the Poplar Creek watershed model. For those parameters with varying monthly values, values for all 12 months were changed by the fixed percentage. The average of the simulated daily streamflow for the respective calibration period was computed after each model run. That average was compared with streamflow simulated from the calibrated model to determine the percentage change the parameter had on modeled streamflow. After the four runs, the parameter is reset to its former (or calibrated) value, and the sensitivity analysis continues with the next parameter. Table 11 and Table 12 show results of model parameter sensitivity analysis for the Blackberry Creek and Poplar Creek watershed models, respectively.

Table 11. Percent Change in Simulated Daily Streamflow Compared to Calibrated Streamflow, Blackberry Creek Watershed

Parameter	*Change in parameter value from calibrated value*			
	-50%	*-20%*	*+20%*	*+50%*
LZSN	+10.4	+3.0	-2.1	-4.0
INFILT	-0.1	-0.17	+0.2	+0.7
AGWRC	+0.2	0.0	-1.6**	-1.6**
IRC	0.0	0.0	0.0	-0.3
UZSN	+8.1	+2.6	-2.1	-4.6
DEEPFR	+1.3	+0.6	-0.6	-1.9
LZETP	+36.2	+14.7	-14.8	-27.9
AGWETP	+0.3	+0.1	-0.1	-0.3
INTFW	-1.3	-0.7	-0.3	-0.2
CEPSC	+2.5	+1.1	-1.0	-1.6
NSUR	+0.03	+0.10	+0.05	+0.04

Notes: + = positive percent change.
- = negative percent change.
*Due to boundary conditions defined in the model, parameter values could not be changed to desired level so the model run used the maximum value allowed.

Table 12. Percent Change in Simulated Daily Streamflow Compared to Calibrated Streamflow, Poplar Creek Watershed

Parameter	*Change in parameter value from calibrated value*			
	-60%	*-20%*	*+20%*	*+60%*
LZSN	+12.0	+2.8	-2.8	-5.6
INFILT	-4.6	-1.9	+0.9	+2.8
AGWRC	+0.9	+0.9	-2.8*	-2.8*
IRC	0.0	0.0	0.0	0.0
UZSN	+4.6	+0.9	-0.9	-1.9
DEEPFR	+4.6	+1.9	-1.9	-4.6
LZETP	+32.4	+10.2	-8.7	-18.0
AGWETP	0.0	0.0	0.0	0.0
INTFW	0.0	0.0	0.0	0.0
CEPSC	+3.7	+0.9	-0.9	-2.8
NSUR	0.0	0.0	0.0	0.0

Notes: + = positive percent change.
- = negative percent change.
*Due to boundary conditions defined in the model, parameter values could not be changed to desired level so the model run used the maximum value allowed.

Comparing values in Table 11 and Table 12 shows both models have similar sensitivity. Parameter LZETP characterizing lower zone evapotranspiration is the most sensitive parameter. Increase in the LZETP value by 20% compared to the calibrated values results in approximately 10-15% change of simulated streamflow. Parameters LZSN and UZSN characterizing lower and upper zone storages, respectively, are the next most sensitive parameters.

Overall Assessment of Hydrologic Model Performance

Hydrologic models simulate annual and monthly flows very well but tend to overestimate streamflow during some low-flow summer months. The models generally did not show any seasonal bias or bias in over- or underestimating daily streamflows, except at the very low range of flows. In addition to the statistical and graphical comparisons discussed in previous sections, simulated and observed hydrographs were compared for the calibration and validation periods. Although the simulated hydrographs generally followed the trend of observed hydrographs reasonably well, the model under- or overestimated some peak values, particularly during large snowmelt events. Medium to low flow events are typically the most critical for water quality conditions, and the closeness of fit for this range of flows is excellent for the purposes of the model. Model performance during the validation and calibration periods was generally comparable.

In the Blackberry Creek watershed, validation periods selected were at the beginning and the end of the calibration period to investigate the effects of land use change. The hypothesis was that because the model represents land use conditions in 1999-2000, better agreement with observed flows would be expected with the later validation period than with the earlier validation period. Model performance for the later validation period was somewhat better than for the earlier validation period. During the course of model development, however, it became apparent that the spatial representation of precipitation has a more significant impact on simulation results. Because precipitation is the most important component of hydrologic modeling, its effects on streamflow simulations can be more pronounced than changes in land use in the watershed.

Discrepancies between observed and simulated streamflow values are partly due to lack of spatially representative precipitation data. Spatial variation of precipitation can be significant, but only one precipitation station was available for the Blackberry Creek watershed and two for the Poplar Creek watershed. In addition, the HSPF model has a very simplistic channel routing scheme, which does not match natural reach routing and flow attenuation exactly. Thus, it is not surprising that modeled streamflows compared to observed streamflows (which reflect routing and attenuation in the stream system) have a poorer fit on daily basis. These differences, however, balance out and become less significant on a long-term basis, thus, resulting in better fit between observed and simulated streamflows on a monthly or annual basis. Uncertainty also is introduced due to the accuracy limits of streamflow measurements. The USGS gage streamflow data are rated as "good," which means that about 95% of the observed daily values are within ±10% of the true value. Thus, on a daily basis, observed streamflow values can be expected to be in error by ±10%.

In this study, the hydrologic simulation model was calibrated to simulate an entire range of streamflows over a long period and was not focused on specific storm events. Discrepancies in simulated and observed streamflow values could be due to inherent errors or inaccuracies in climate and streamflow data, limited spatial representation of precipitation data, and limitations in the HSPF model, such as a very simplistic channel routing scheme that affects simulated daily flows. Overall modeling results, however, indicate that these simulated hydrologic data are useful for assessing hydrologic impacts of land use changes or climate change in the watershed.

Water Quality Model

Calibration Considerations

After the hydrologic component of the model is calibrated, other components can be added to the simulation. The following water quality constituents were chosen for detailed simulations (McConkey et al., 2004): suspended sediment, nitrogen, phosphorus, dissolved oxygen (DO), suspended algae (chlorophyll *a*), and fecal coliform bacteria. Additional constituents also must be included in the model due to their effects on selected constituents. For example, not only is water temperature an essential component of the DO cycle; it also influences many reaction rates.

Singh et al. (2007) describes the calibration process, goals, and criteria in detail. Observed data from one water quality station in the Blackberry Creek watershed (FoxDB Station 28), and three stations in the Poplar Creek watershed (FoxDB Stations 25, 615, and 895) were used to calibrate the HSPF models. Because the extent of calibration is limited by the available water quality data, the focus of this study is on reproducing apparent trends (e.g., changes of concentration with streamflow or seasonal changes during a year).

Only a limited number of observations are available during the study period (WY 1991-2003), so all data were used to calibrate the HSPF models. An iterative procedure was used to perform the calibration. The set of parameters was developed for the Poplar Creek watershed and then tested on the Blackberry Creek watershed until satisfactory results were obtained for both watersheds. Model performance was considered acceptable during the calibration process if simulated values fell within the same range as observations during the calibration period, and simulated and observed values generally indicated similar long-term and monthly trends. Results presented in the following sections reflect the set of calibration parameters determined in this way. Values for all calibration parameters and HRUs can be found in the HSPF input files (UCI files). At this stage of the project, model parameters vary with land use category only, not with hydrologic soil type or slope category. All land uses except wetlands and surface water are represented in significant percentage in at least one of the pilot watersheds, thus the agreement in model parameters was more easily achieved.

The model runs in hourly steps with hourly or daily outputs specified at water quality stations. Observed values for all constituents were plotted against a distribution of 24 hourly simulated values for the day of observation. This is necessary because streamflow is calibrated only to daily values. Calibration to hourly values would be possible for both streamflow and water quality constituents, but it was not attempted due to time constraints and data required. Ideally, the observation would fall within a range of values simulated the same day the sample was taken.

Observed water quality data also are compared directly to simulated daily averages. Only temperature and DO observations are compared to simulated hourly averages to account for changes caused by natural fluctuation, following a diurnal cycle of sunlight and air temperature. Although this enables simple comparison and illustration of trends, uncertainty associated with comparing observations to daily or hourly averages must be understood.

A water quality sample is collected at a single point in time, typically one sample on the day of sampling representing an instantaneous value. This instantaneous value is not directly comparable to the simulated hourly or daily averages. Actual values of concentrations measured in streams can vary significantly even from hour to hour during a storm event (e.g., sediment loading) or if the constituent is affected by diurnal cycle (e.g., temperature). At other times, a value may remain practically constant during a longer period, even a day. As streamflow is calibrated to daily values, uncertainty in predicting hourly results for water quality constituents increases.

Calibration of water quality components of the HSPF model is limited by frequency of ambient water quality data. In contrast to streamflow data measured by the USGS continuously (stage is recorded at least every hour), water quality is sampled much less frequently. Figure 42 illustrates this point. Given the frequency of recording precipitation and streamflow data, these data may be shown as a continuous line (Figure 42a). Continuous streamflow data can be summarized as average daily, monthly, or annual values. In contrast, TSS data available are shown as distinct points (Figure 42b). The HSPF model simulates continuous (hourly) TSS values that may be present in streamflow, but simulation accuracy cannot be demonstrated or improved without additional data.

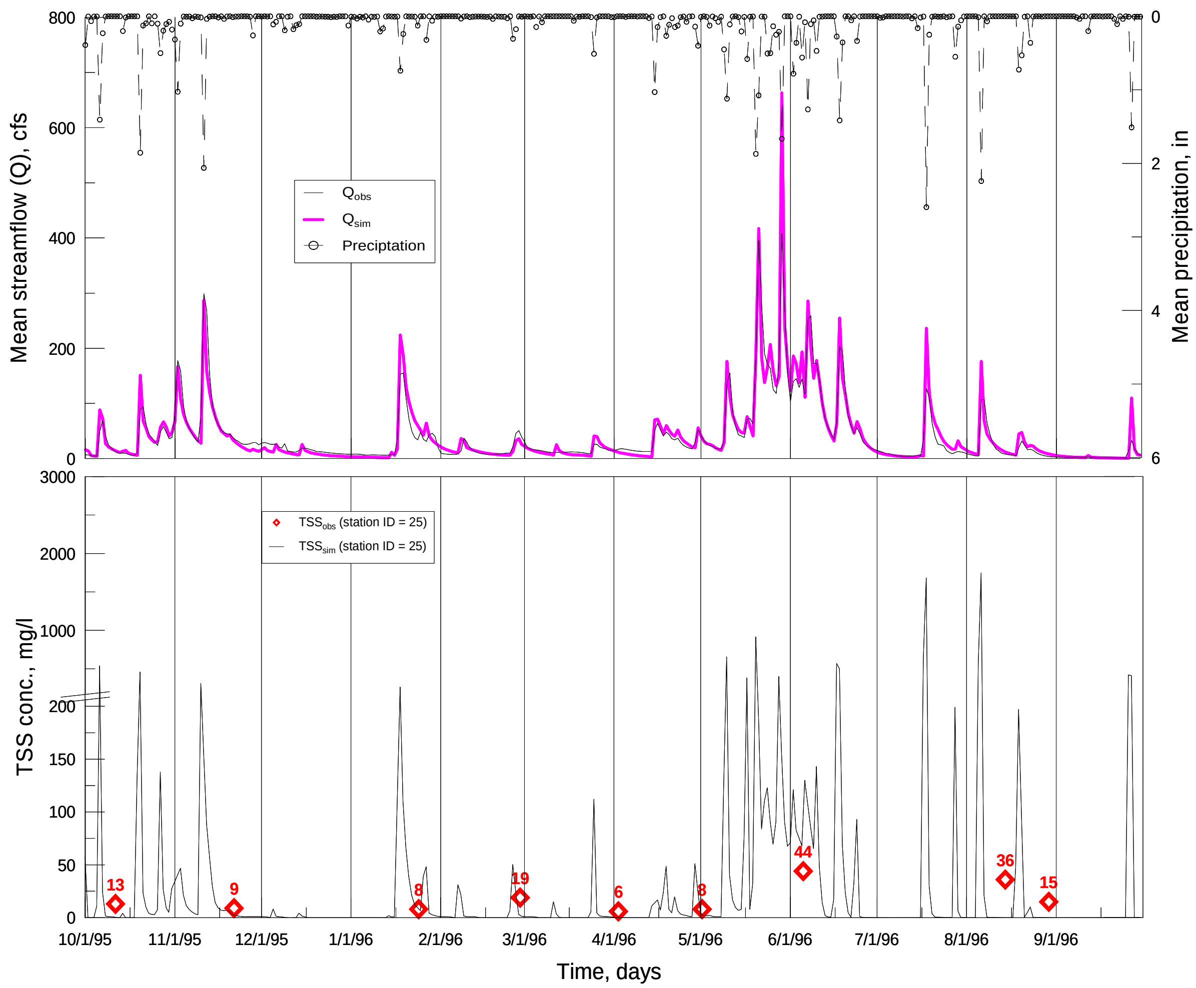


Figure 42. Comparison of precipitation, streamflow, and TSS data with model simulations.

Table 13 summarizes average daily streamflow characteristics during the calibration period and on days when water quality samples were collected and analyzed for TSS. It shows that observations were taken during a limited range of streamflows that occurred in the watershed during the calibration period. This is particularly important in the case of TSS because most surface sediment moves during high-flow events. Less frequent higher flows often are associated with a significant load of suspended sediment carried by runoff. Calibration cannot be considered reliable beyond the range of flows observed on days of sampling water quality even when a perfect match between observed and simulated values is achieved.

A long-term water quality monitoring program typically involves taking a sample once every month or 6 weeks, often missing peaks during storm events (Figure 42b), and such data may not provide sufficient information on constituent loadings. Water quality data collected at such intervals can, over a long period, provide insight to average conditions and seasonal changes in constituent concentrations although changes in land use, land management practices, or point source operations can affect data applicability to current conditions. Higher frequency sampling even during short durations can provide critical data for evaluating model performance during storm events.

Table 13. Comparison of Daily Streamflows on Days of Sampling for TSS and during Calibration Period

	Yorkville USGS gage (FoxDB Station 28)		*Elgin USGS gage (FoxDB Station 25)*	
	WY 1991-2003	*Days TSS samples taken*	*WY 1991-2003*	*Days TSS samples taken*
Mean daily flow, cfs				
Minimum	1.3	7.7	0.5	0.6
75% exceedance flow	14	21	3.3	4.0
50% exceedance flow	28	38	10	16
10% exceedance flow	118	131	64	73
Maximum	3460	501	861	270
Number of days				
Total	3288	99	3288	95
With flow less than observed 75% flow	822	17	822	10
With flow greater than observed 50% flow	1644	63	1644	64
With flow greater than observed 10% flow	329	10	329	15

Water Temperature

Because water temperature has a significant effect on many transformation and reaction processes in streams, it was the first water quality constituent modeled. Table 14 gives model calibration values for parameters influencing the stream water temperature.

Due to significant variation of temperature caused by a natural cycle during the day, the observations were compared directly to the simulated hourly values. Observed and simulated hourly values are compared graphically in scatter plots (Figure 43 and Figure 44) for FoxDB Station 28 on Blackberry Creek and FoxDB Station 25 on Poplar Creek, respectively. Simulated water temperature follows the same seasonal pattern exhibited by observed data (Figure 45). Observed values also are plotted against the distribution of hourly values simulated on the day of observation for FoxDB Stations 25 and 28 (Figure 46 and Figure 47). These figures show a very good fit on most days for all stations and both watersheds. Typical precision of temperature measurement is 0.5°C.

The calculation algorithm in the HSPF temperature module tends to produce erroneous results under certain conditions. A sudden increase in flow after a low flow sometimes is associated with an unrealistic spike in temperature for that particular computational interval. The accuracy of FTABLES in the low flow range influences the occurrence of these spikes. Unfortunately, Flood Insurance Study models that provide the most available detail on cross sections are not available for all streams modeled as separate reaches. Spikes were identified only in a limited number of mostly headwater reaches and do not have a significant effect on daily values or long-term simulation.

Table 14. Heat Transfer Parameters for Computing Water Temperature

Parameter	*Description*	*Units*	*Values used*
CFSAEX	Ratio of radiation incident to water surface to radiation incident to gage where data were collected, also accounts for shading		0.99 (November-March) 0.80 (April-May) 0.50 (June-October)
KATRAD	Atmospheric longwave radiation coefficient	K^{-2}	9.37
KCOND	Conductive-convective heat transport coefficient	Complex	6.1
KEVAP	Evaporation coefficient	Complex	2.3

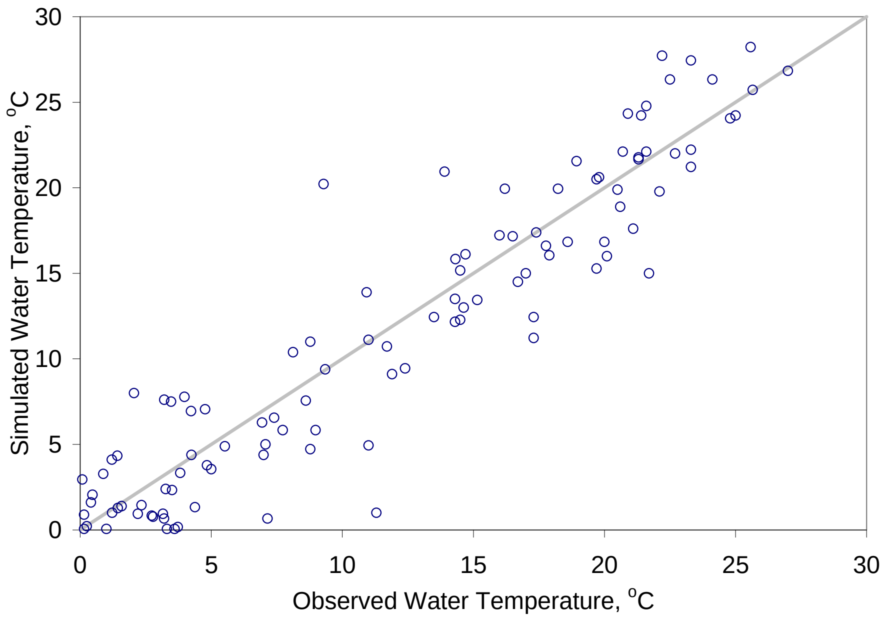


Figure 43. Comparison of observed instantaneous and simulated hourly water temperature, Blackberry Creek, FoxDB Station 28.

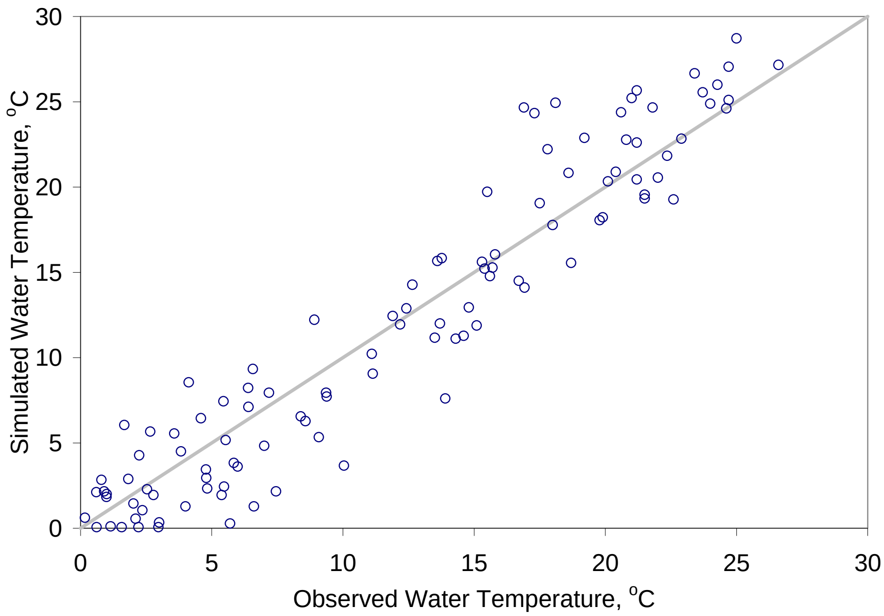


Figure 44. Comparison of observed instantaneous and simulated hourly water temperature, Poplar Creek, FoxDB Station 25.

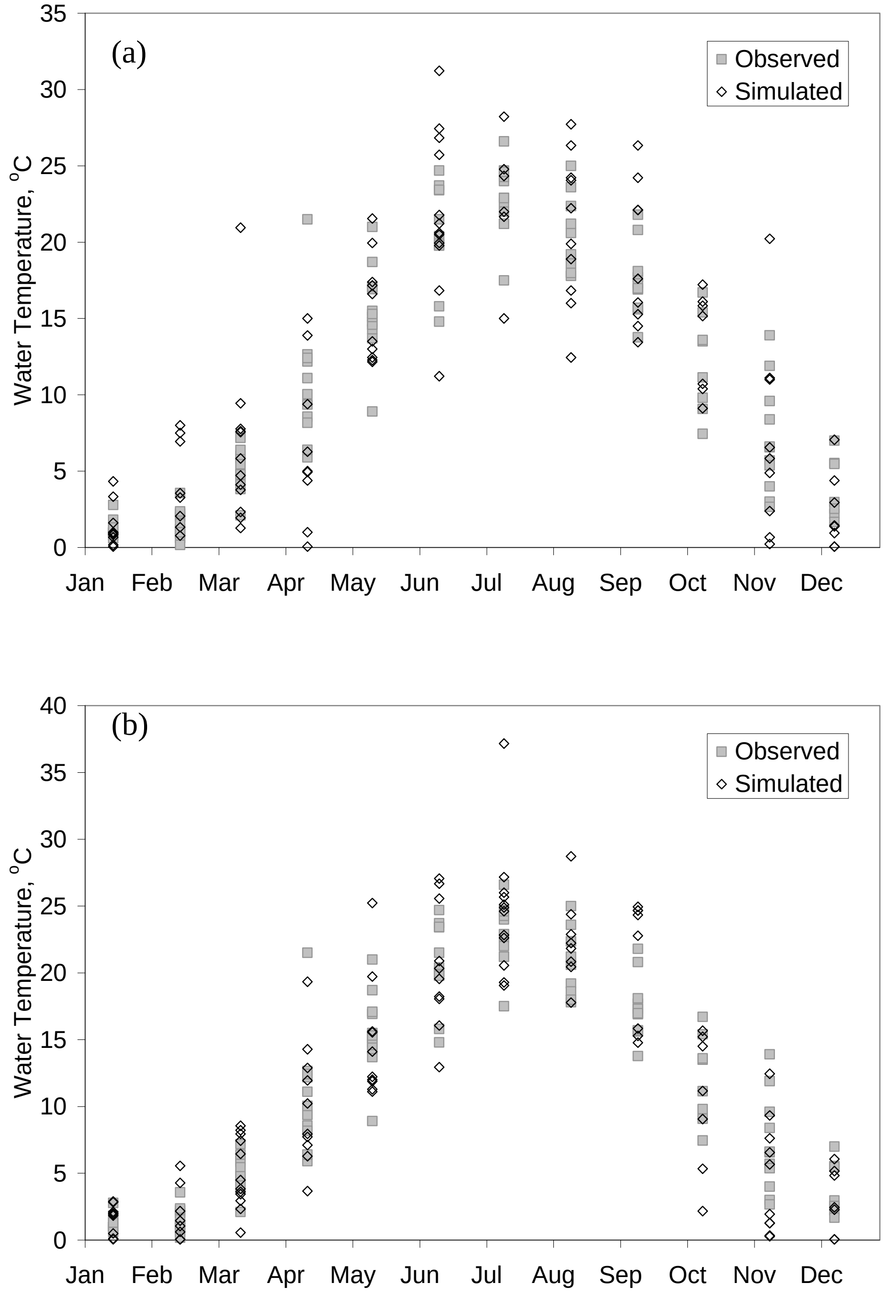
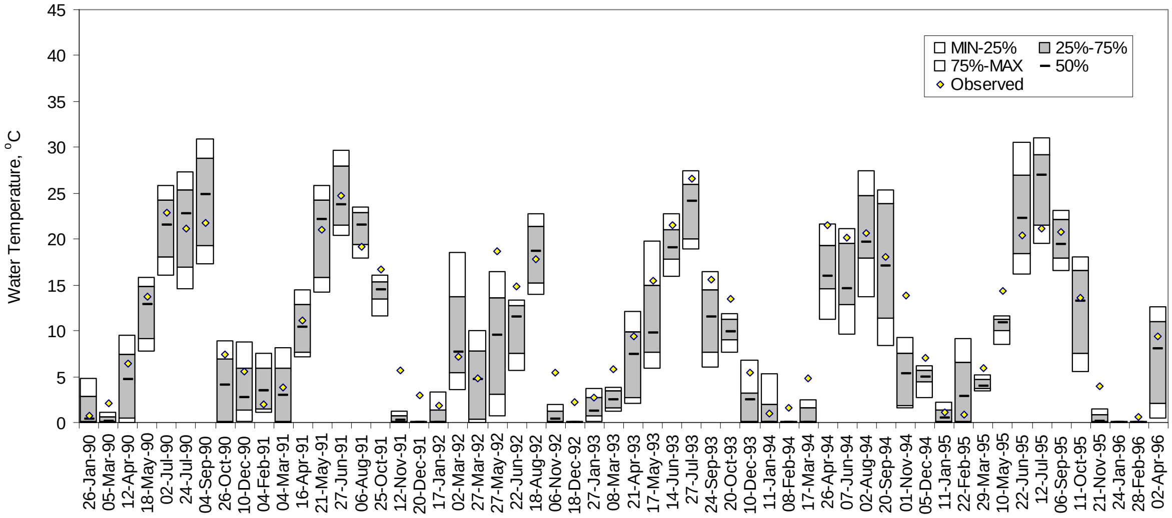


Figure 45. Changes in observed instantaneous and simulated hourly water temperature with month of a year, (a) Blackberry Creek, FoxDB Station 28, and (b) Poplar Creek, FoxDB Station 25.



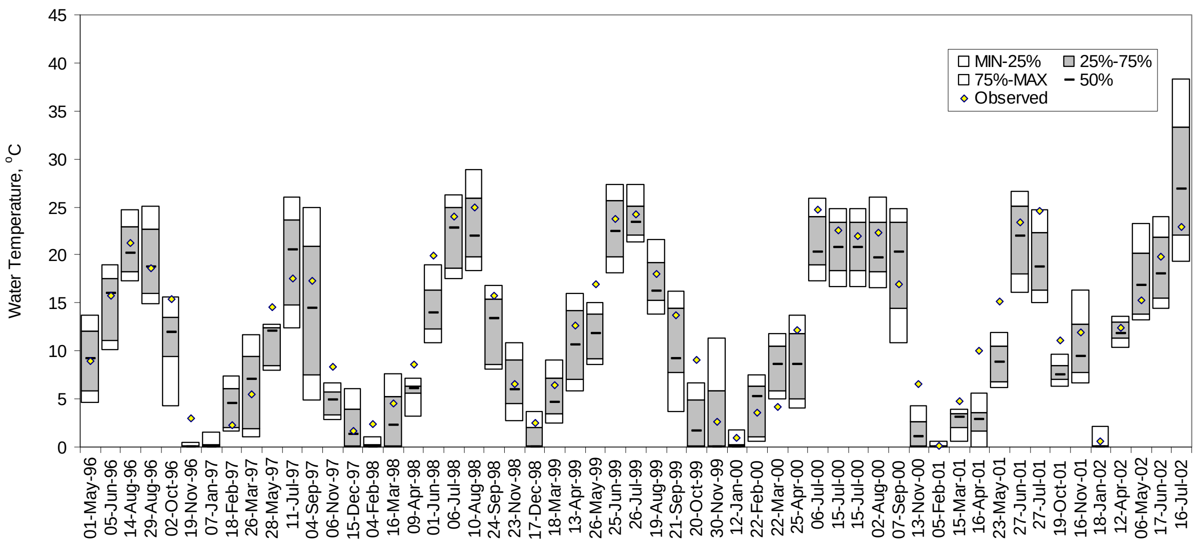


Figure 46. Comparison of observed instantaneous temperature and a distribution of temperature simulated on the same day, Poplar Creek watershed, FoxDB Station 25.

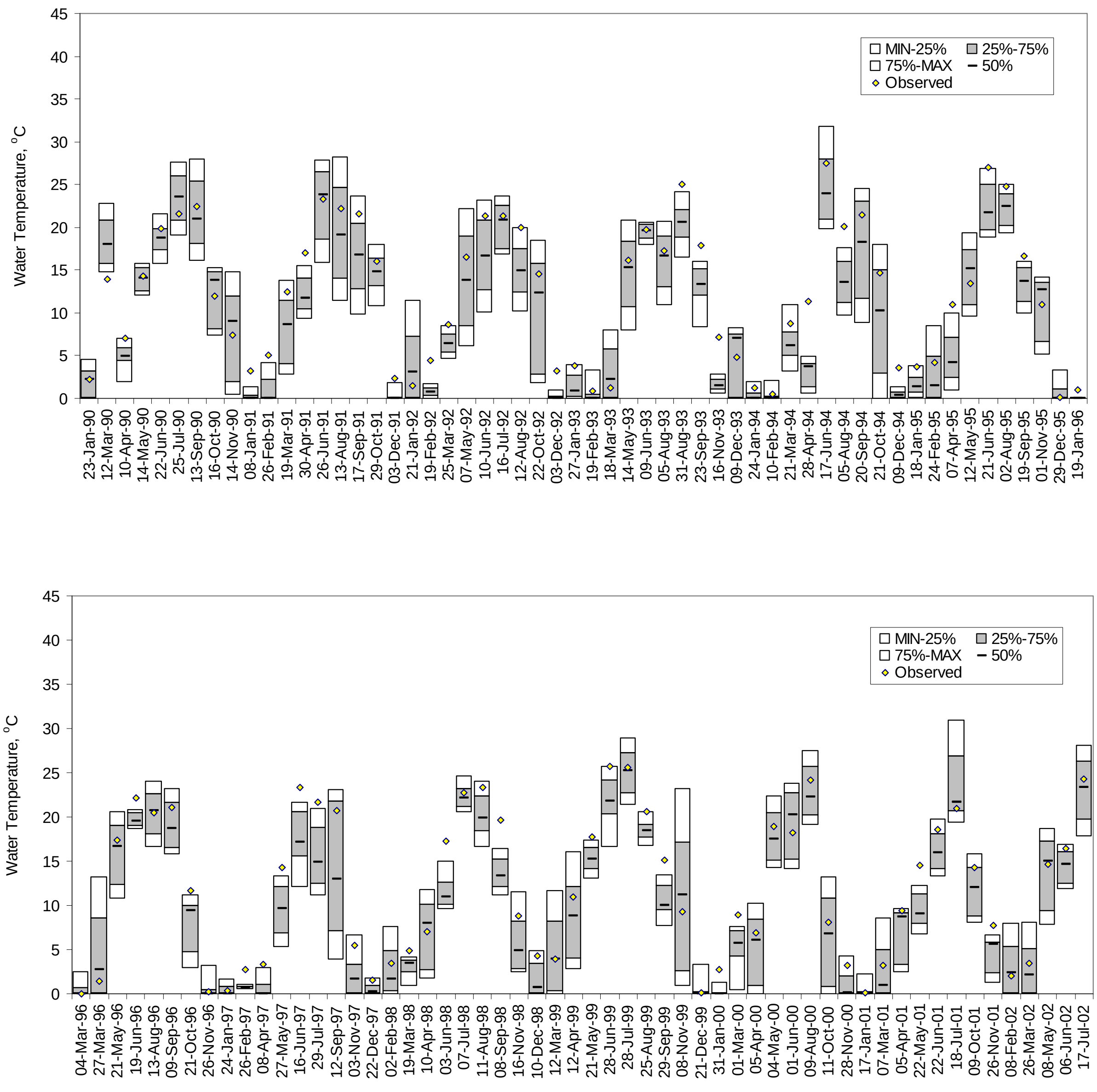


Figure 47. Comparison of observed instantaneous temperature and a distribution of temperature simulated on the same day, Blackberry Creek watershed, FoxDB Station 28.

Suspended Sediment (SS)

Simulation of SS is important not only to address issues of sedimentation and high SS content but also because of its ties to nutrients, especially phosphorus. Phosphorus and other constituents on the land surface attach to soil particles that may be carried to streams and rivers by erosion. Sediment concentration in the stream is, in part, a function of the rate of flow and highly correlated with runoff events. Input of SS from soil surfaces is simulated through detachment of soil particles from pervious lands and the accumulation/washoff process on impervious lands. Table 15 shows calibrated parameters. Discharge of SS reported by the permitted NPDES facilities (Table 5) was modeled as fine particles (clay).

Observed instantaneous and simulated average daily SS values were compared. Observed data exhibit an apparent method detection limit (MDL) of 1 milligram per liter (mg/l). All simulated values below the MDL were replaced with this value for comparison purposes. The State of Illinois does not specify a numerical water quality standard for SS concentration in rivers and streams. The only guidance provided in Section 302.203 of Title 35 (IAC, 2002) states: “Waters of the State shall be free from sludge or bottom deposits, floating debris, visible oil, odor, plant or algal growth, color or turbidity of other than natural origin.”

Table 15. The HSPF Parameters for Suspended Sediment Simulation

Parameter	*Description*	*Units*	*Values used*	*Comment*
SMPF	Support management practice factor	*	1	
AFFIX	Fraction by which detached sediment storage decreases each day due to soil compaction	day^{-1}	0.02-0.03	Varies with land use
COVER	Fraction of land area shielded from erosion by direct rainfall impact		0.29-1.0	Varies with land use and month
KRER	Coefficient in soil detachment equation	**	0.055-0.085	Varies with land use
JRER	Exponent in soil detachment equation	**	2.0-2.9	Varies with land use
KSER	Coefficient in detached sediment washoff equation	**	0.36-0.61	Varies with land use
JSER	Exponent in detached sediment washoff equation	**	1.5-2.6	Varies with land use
KGER	Coefficient in matrix soil scour equation	**	0.012-0.019	Varies with land use
JGER	Exponent in matrix soil scour equation	**	2.2-3.4	Varies with land use
ACCSDP	Solids accumulation rate on land surface	lb/ac/d	0.001	
REMSDP	Fraction of solids removed per day	day^{-1}	0.001	
JEIM	Exponent in the solids washoff equation	*	2.5-3.3	Varies with land use
KEIM	Coefficient in solids washoff equation	**	1.0-1.3	Varies with land use
KSAND	Coefficient in sandload power function	**	0.05	
EXPSND	Exponent in sandload power function	**	3.2	
W	Fall velocity in still water	in/s	0.5	
M	Erodibility coefficient of sediment	lb/ft^2-day	0.2-0.4	
TAUCD	Critical bed shear stress for deposition	lb/ft^2	0.106-0.466	Varies with reach
TAUCS	Critical bed shear stress for scour	lb/ft^2	0.103-0.655	Varies with reach

Notes: *Dimensionless.
**Units are complex.

Observed instantaneous (FoxDB Stations 28, 25, 615, and 895) and simulated daily SS concentrations are plotted versus the simulated daily streamflow (Figure 48, Figure 49, Figure 50, and Figure 51, respectively). Simulated SS concentrations generally are within the same range as observed values except during streamflows less than 20 cfs and 10 cfs for Blackberry and Poplar Creek, respectively. Simulated SS generally follows the same seasonal pattern exhibited by observed data (Figure 52).

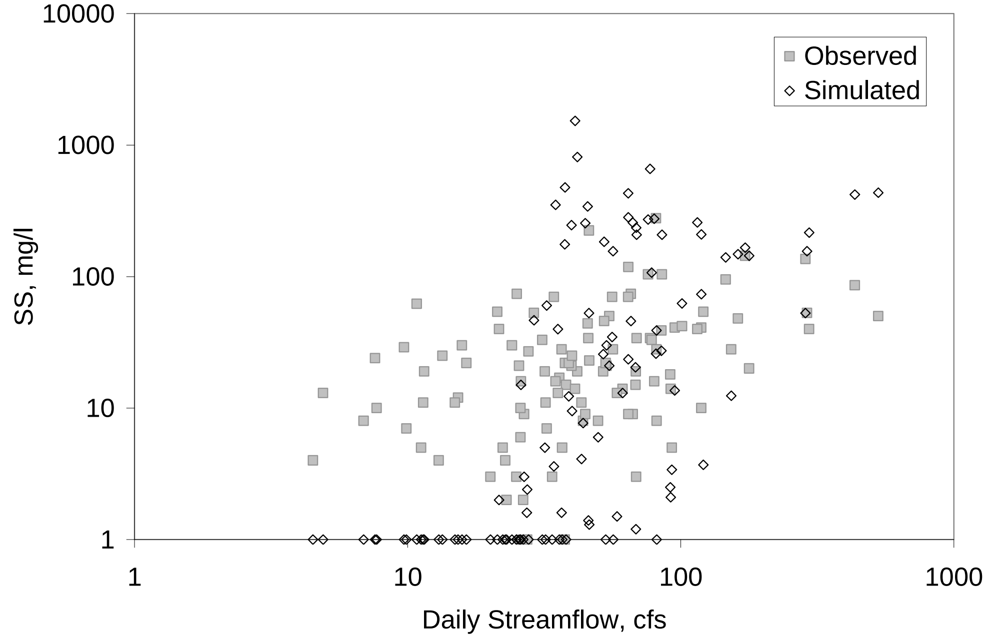


Figure 48. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with simulated daily flow, Blackberry Creek watershed, FoxDB Station 28.

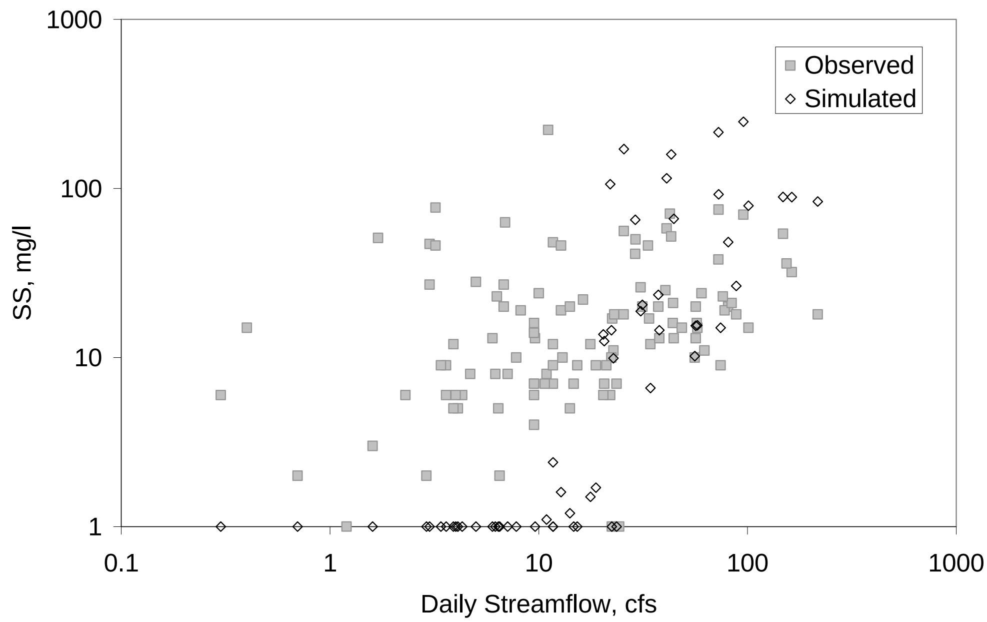


Figure 49. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with simulated daily flow, Poplar Creek, FoxDB Station 25.

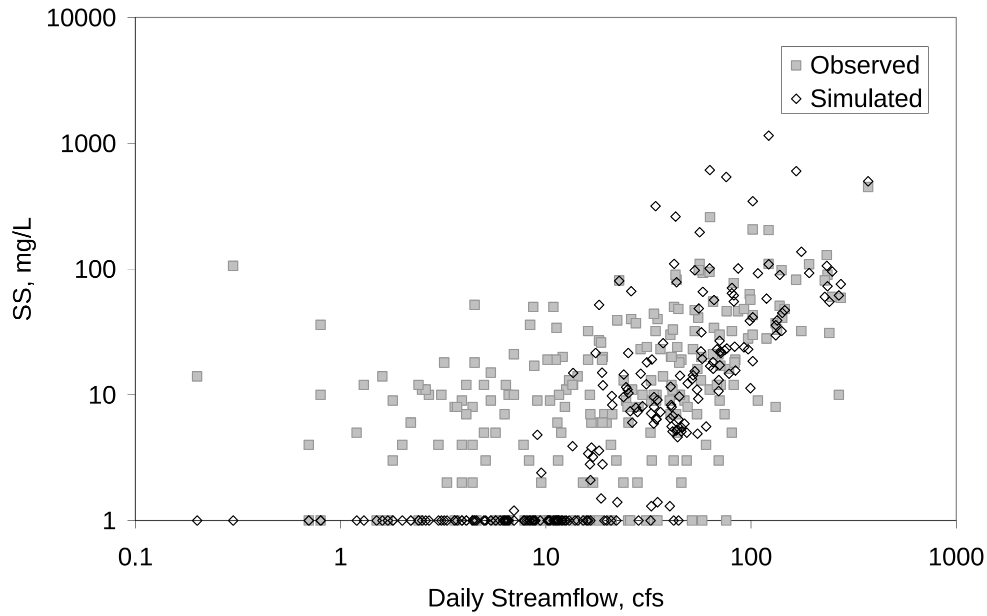


Figure 50. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with simulated daily flow, Poplar Creek, FoxDB Station 615.

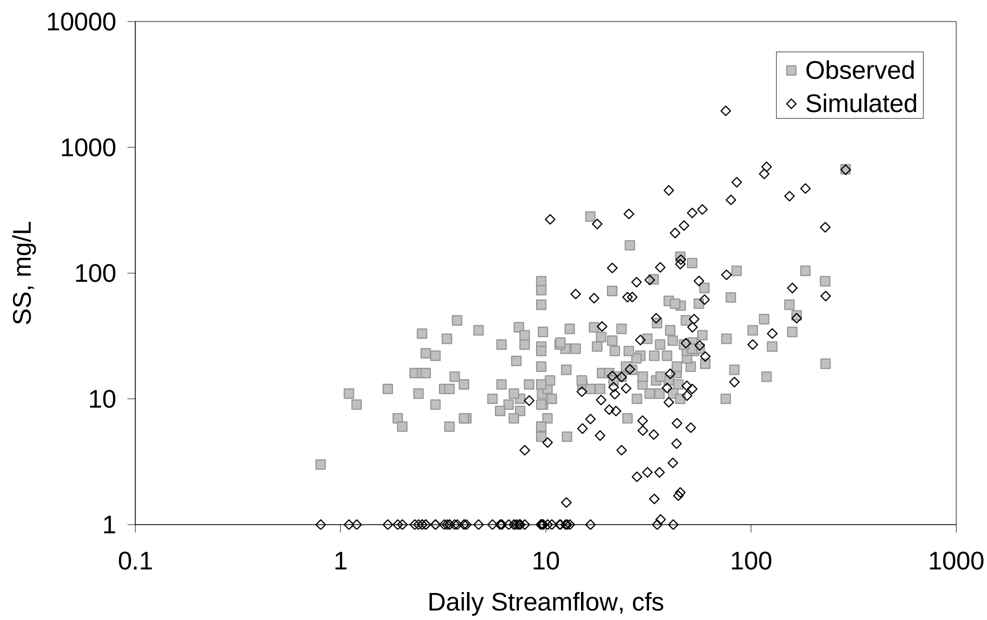


Figure 51. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with simulated daily flow, Poplar Creek, FoxDB Station 895.

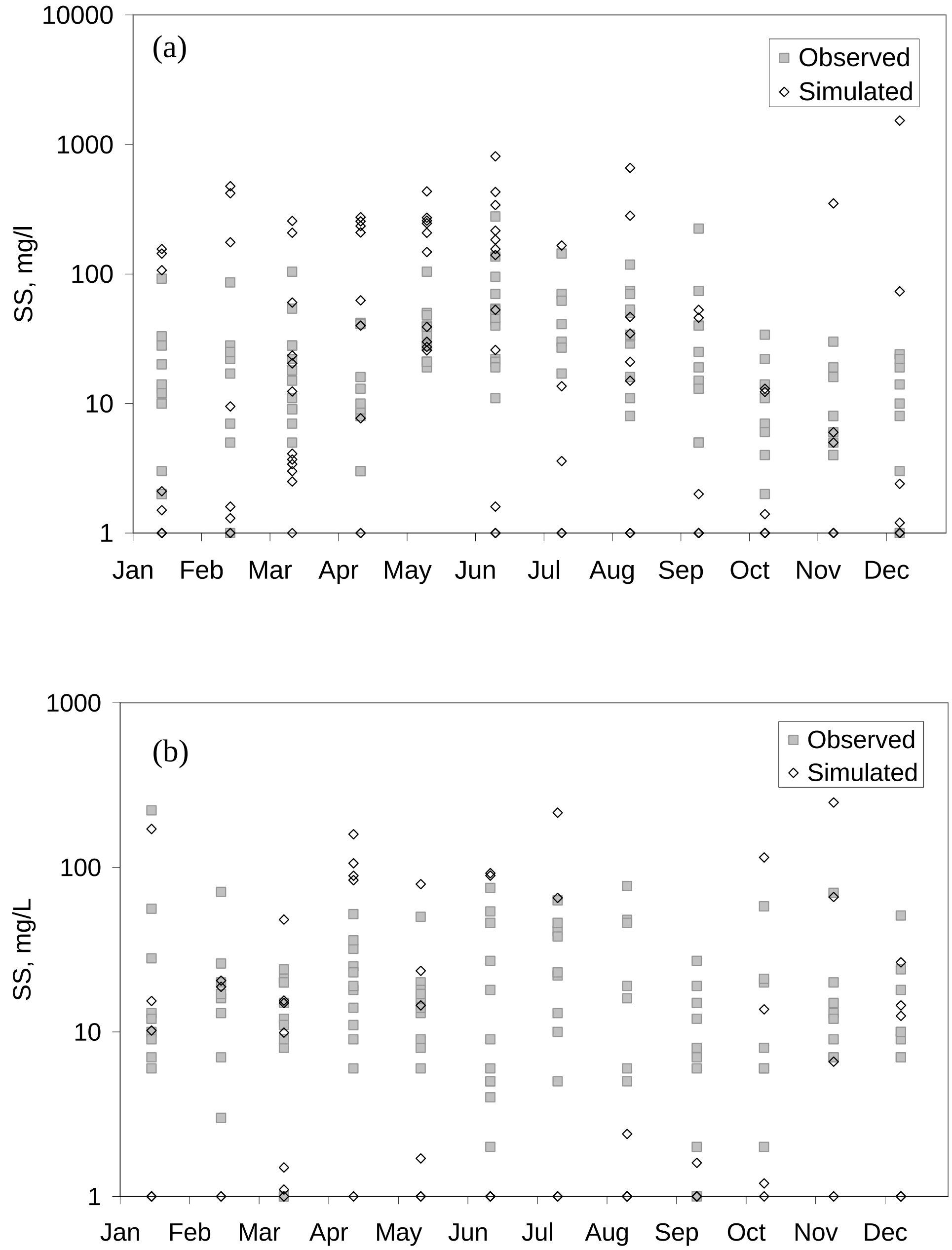


Figure 52. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with month of the year, a) Blackberry Creek, FoxDB Station 28, and b) Poplar Creek, FoxDB Station 25.

Figure 53 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily SS concentration over time. The model shows a fast response to any storm event (recognizable by an increase in flow) but also a sharp decline in concentration after the peak flow. Observations from Poplar Creek, FoxDB Station 25, and Blackberry Creek, FoxDB Station 28 are plotted with the distribution of 24 hourly values simulated for the same days that observation were taken (Figure 54 and Figure 55). Ideally, points representing observations fall within the range of simulated values symbolized by the column. This figure also shows that simulated values are generally within the same range as observations, but the models underestimated SS concentrations during some days, mostly when observed concentrations fell below 10 mg/l.

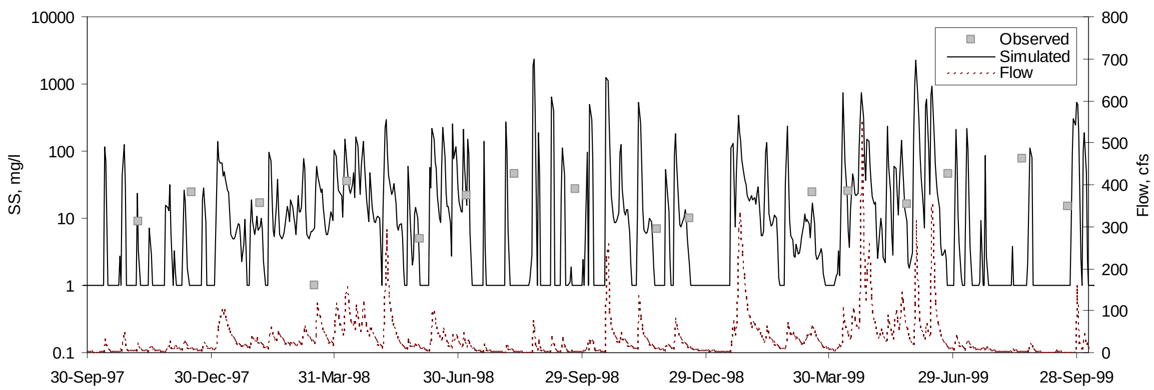


Figure 53. Time series of observed instantaneous and simulated mean daily suspended sediment concentrations, Poplar Creek, FoxDB Station 25, WY 1998-1999.

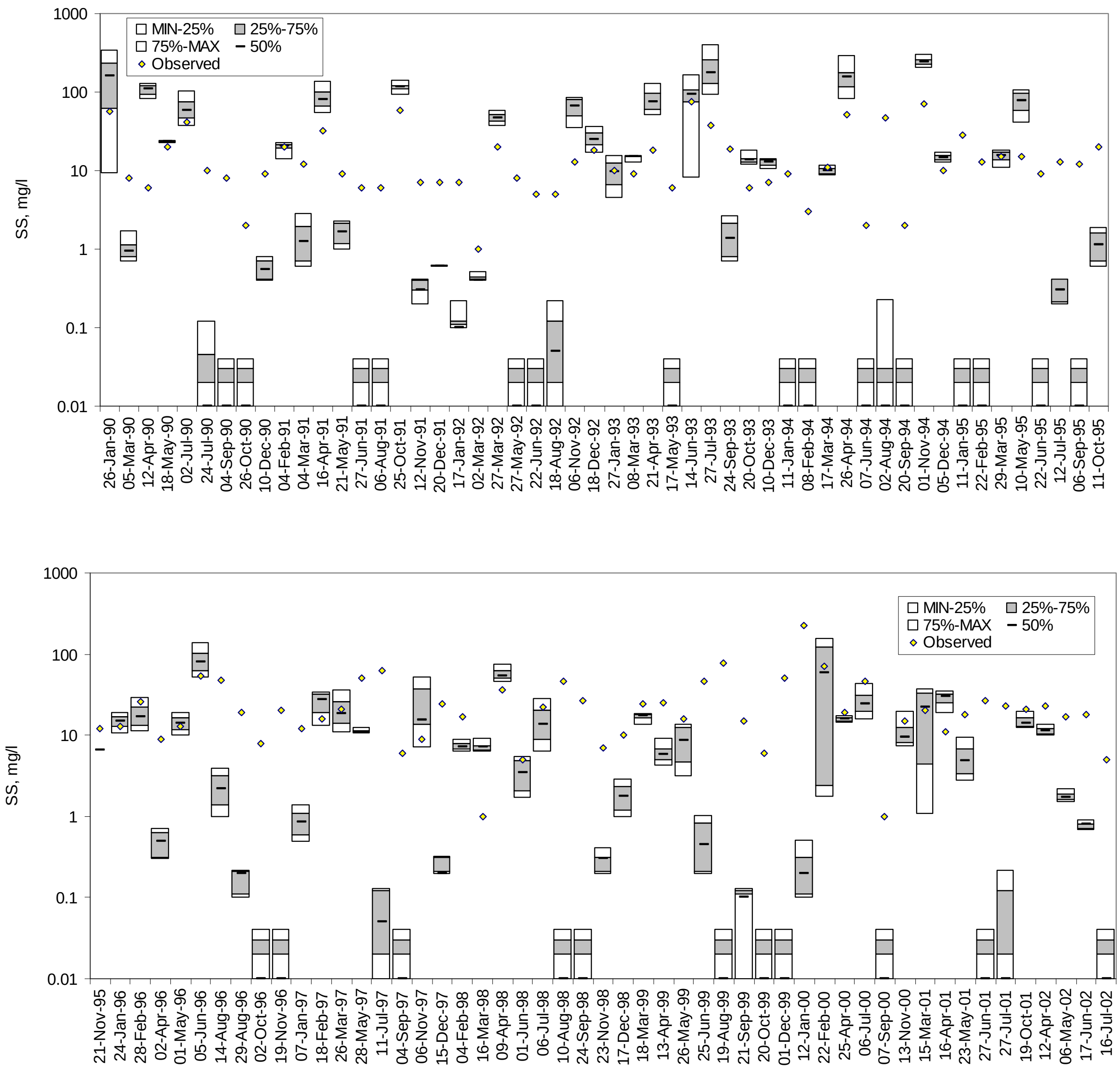


Figure 54. Comparison of observed instantaneous and a distribution of suspended sediment concentrations simulated on the same day, Poplar Creek watershed, FoxDB Station 25.

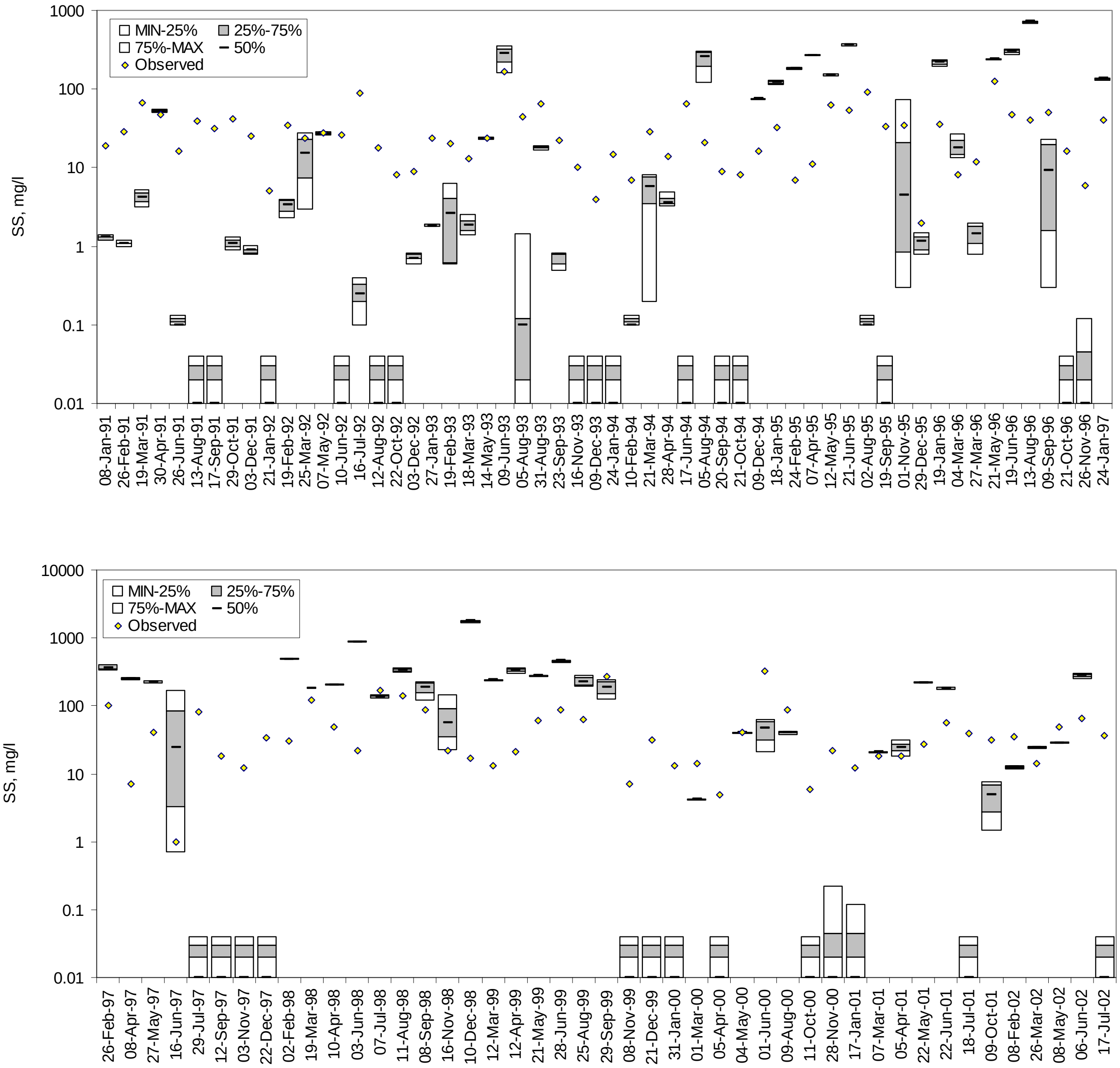


Figure 55. Comparison of observed instantaneous and a distribution of suspended sediment concentrations simulated on the same day, Blackberry Creek watershed, FoxDB Station 28.

Fecal Coliform Bacteria

Fecal coliform bacteria are an indicator of fecal pollution and pathogens that may be present in a stream. Calibration of fecal coliforms within the HSPF model involves estimating input loads and reaction coefficients. Surface loading is simulated using a simple accumulation/washoff algorithm. Table 16 summarizes calibration parameters. The model inputs included the discharge of fecal coliforms reported by the permitted NPDES facilities (Table 5).

Table 16. The HSPF Parameters for Fecal Coliform Bacteria Simulation

Parameter	*Description*	*Units*	*Values used*	*Comment*
Pervious land segment				
ACQOP	Daily accumulation rate of bacteria	cfu/ac-d	$8x10^8$-$1x10^{10}$	Varies with land use and month
SQOLIM	Maximum amount of bacteria in storage	cfu/ac	5 x ACQOP	
WSQOP	Runoff depth required to remove 90% bacteria in one hour	in/h	0.625-1.875	Varies with land use
IOQC	Interflow concentration	cfu/100 ml	7-60	Varies with land use
AOQC	Groundwater concentration	cfu/100 ml	3-35	Varies with land use
Impervious land segment				
ACQOP	Daily accumulation rate of bacteria	cfu/ac-d	$1.1 x10^7$	Varies with land use and month
SQOLIM	Maximum amount of bacteria in storage	cfu/ac	5 x ACQOP	
WSQOP	Runoff depth required to remove 90% bacteria in one hour	in/h	0.4	Varies with land use
Reach				
FSTDEC	Bacteria decay rate	d^{-1}	1.2	

Observed instantaneous and simulated average daily values were compared. Observed data exhibit an apparent MDL of 10 colony forming units (cfu)/100 ml. All simulated values below the MDL were replaced with this value. High reported values typically are accompanied by a remark code signifying counts too numerous to determine exact number of colony forming units. Thus, a perfect fit of the higher numbers cannot be expected from the model at or beyond this range. The actual value above which results are not considered reliable varies depending on laboratory procedures (e.g., dilution used). The State of Illinois specifies a numerical water quality standard for fecal coliforms in rivers and streams. Section 302.209 of Title 35 (IAC, 2002) states: “During the months May through October, based on a minimum of five samples taken over not more than a 30 day period, fecal coliform (STORET number 31616) shall not exceed a geometric mean of 200 per 100 ml, nor shall more than 10% of the samples during any 30 day period exceed 400 per 100 ml in protected waters.”

Figure 56, Figure 57, Figure 58, and Figure 59 show changes in observed instantaneous and simulated daily fecal coliform counts with daily flow for FoxDB Stations 28, 25, 615, and 895, respectively. The model matches the pattern quite well. Blackberry Creek observations are distributed randomly over the range of flows, while Poplar Creek observations show high values associated with low flows, a gradual decrease for middle range of flows, and another increase with high flows. Observed data exhibit a greater variation than simulated data as shown by a larger scatter of points. Simulated fecal coliform counts generally follow the same seasonal pattern exhibited by observed data (Figure 60).

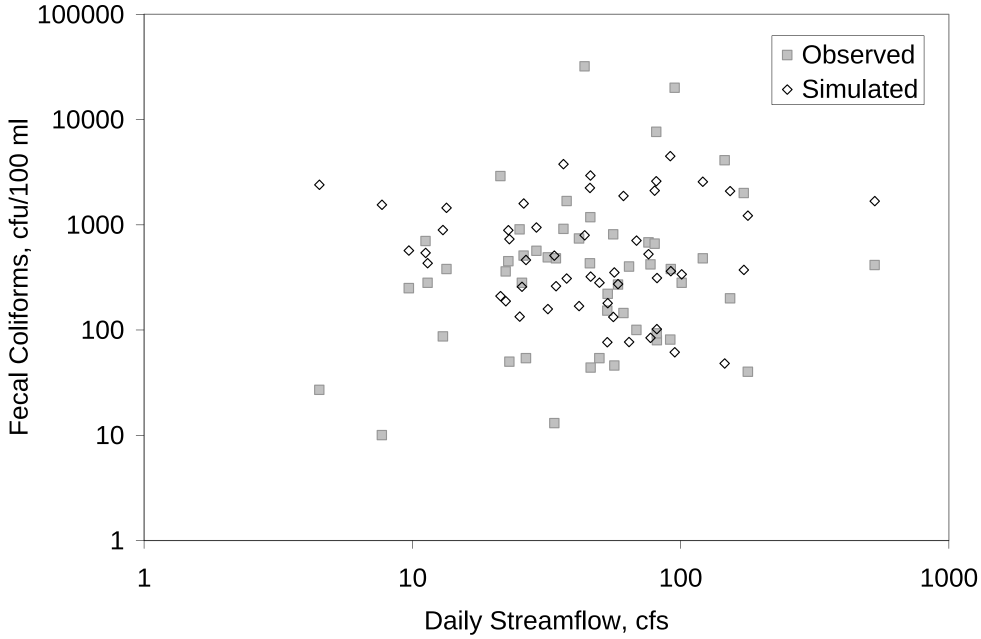


Figure 56. Changes in observed instantaneous and simulated mean daily fecal coliform counts with simulated daily flow, Blackberry Creek, FoxDB Station 28.

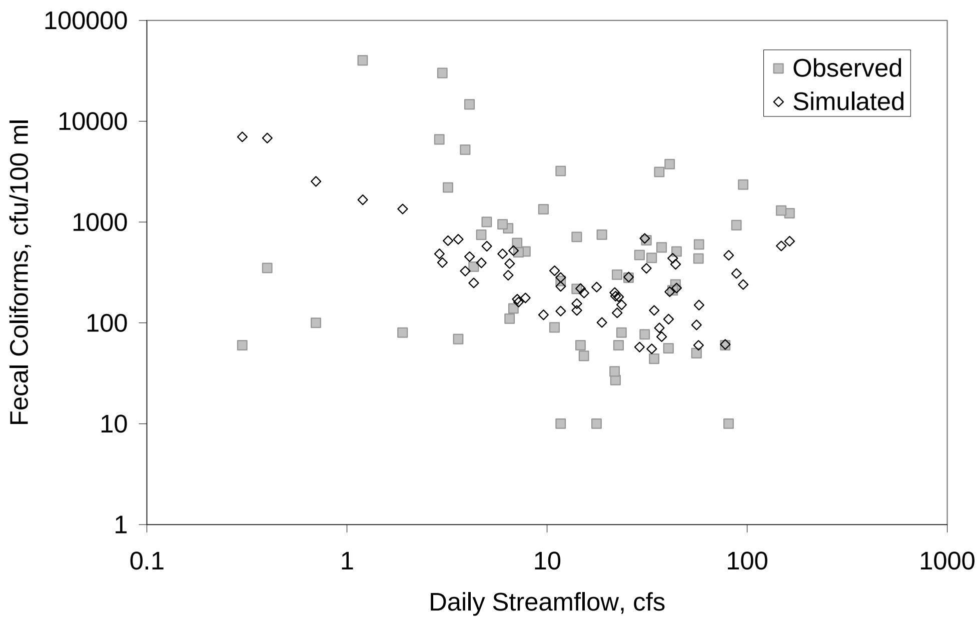


Figure 57. Changes in observed instantaneous and simulated mean daily fecal coliform counts with simulated daily flow, Poplar Creek, FoxDB Station 25.

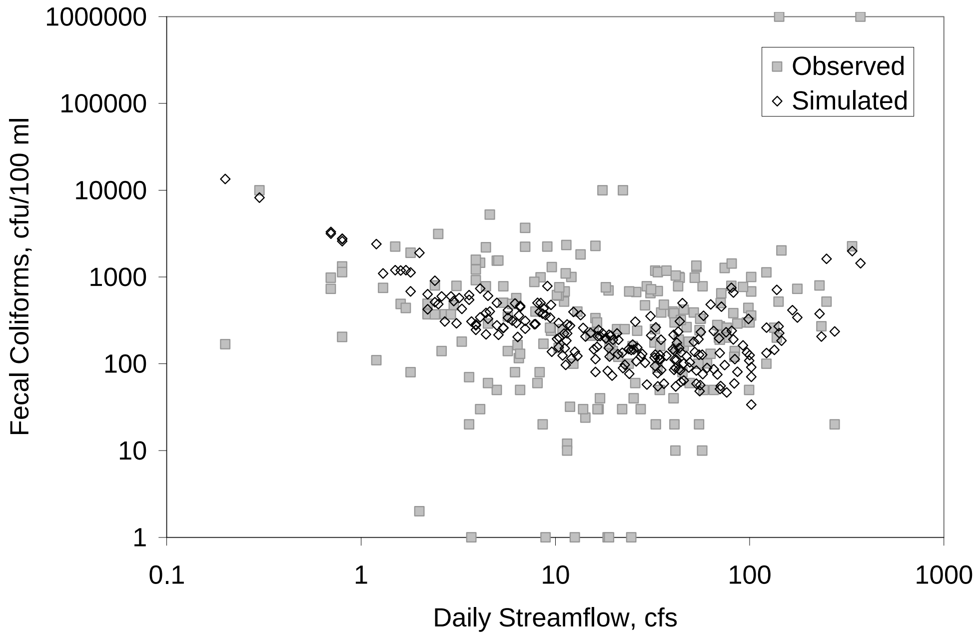


Figure 58. Changes in observed instantaneous and simulated mean daily fecal coliform counts with simulated daily flow, Poplar Creek, FoxDB Station 615.

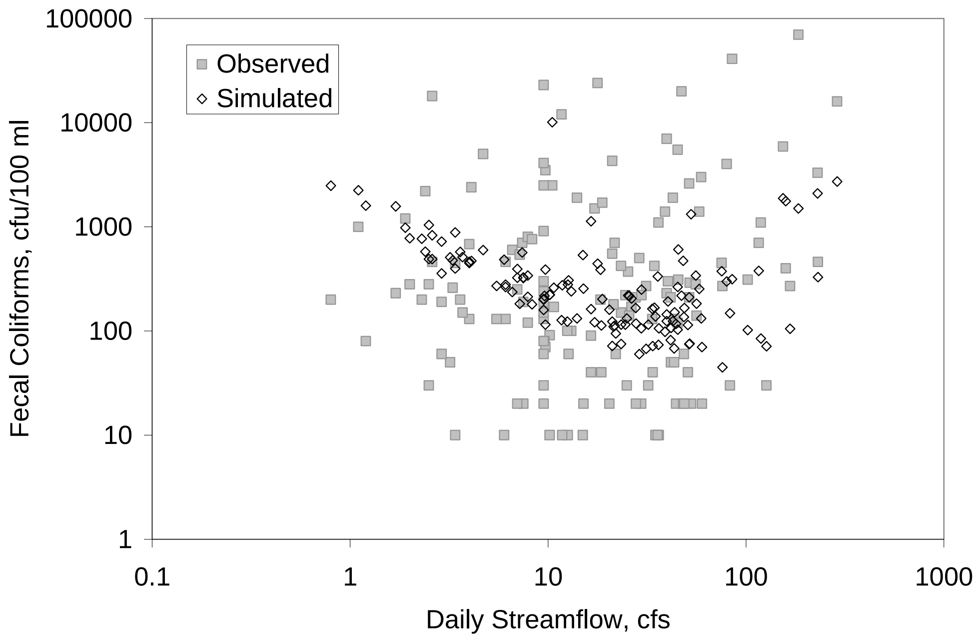


Figure 59. Changes in observed instantaneous and simulated mean daily fecal coliform counts with simulated daily flow, Poplar Creek, FoxDB Station 895.

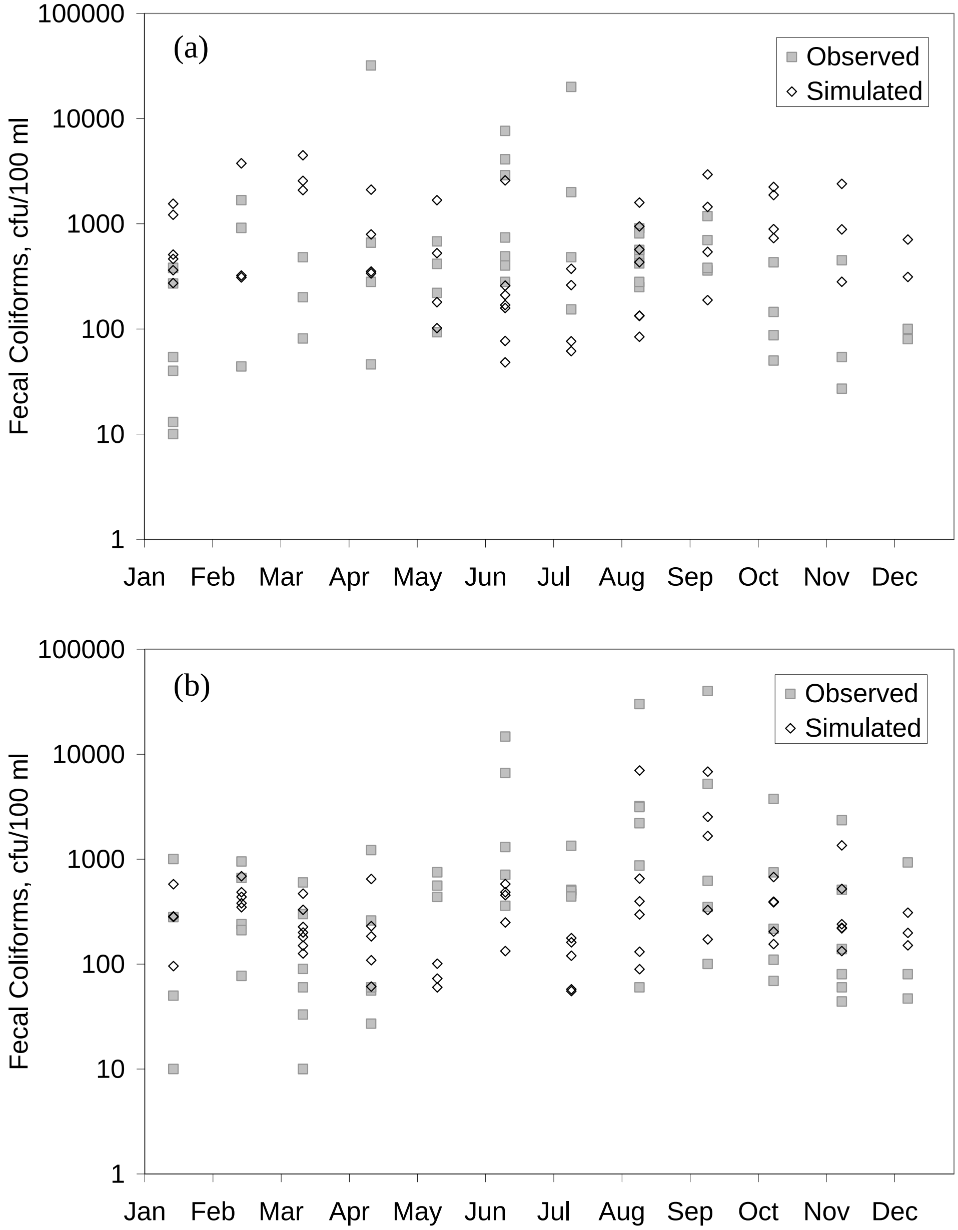


Figure 60. Changes in observed instantaneous and simulated mean daily fecal coliform counts with month of the year, a) Blackberry Creek, FoxDB Station 28, and b) Poplar Creek, FoxDB Station 25.

Figure 61 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily fecal coliform counts over time. Observations from FoxDB Station 25 are plotted with the distribution of 24 hourly values simulated for the same days that observations were taken (Figure 62). Ideally, the points representing observations fall within the range of simulated values symbolized in the figure by a column for each day. This figure shows that simulated values are generally within the same range as observations, but model does not simulate observed values precisely. The observed range has a wider scatter, partly due to precision of the laboratory analysis.

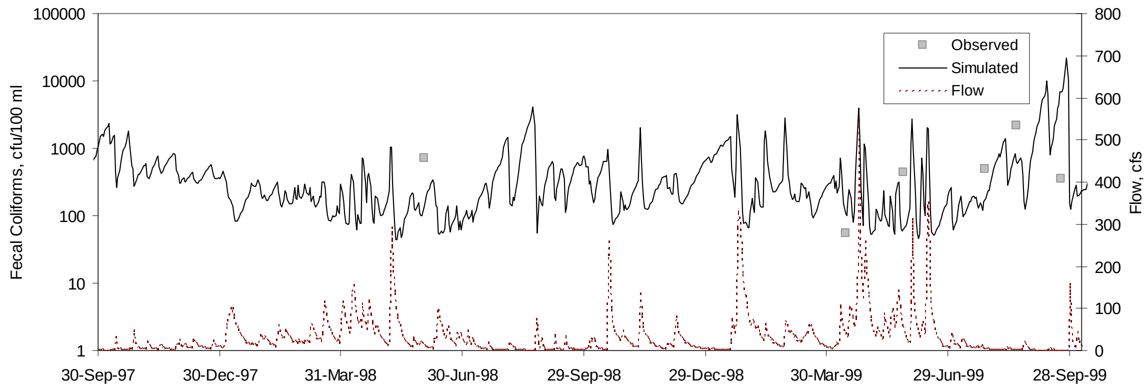


Figure 61. Time series of observed instantaneous and simulated mean daily fecal coliform counts, Poplar Creek, FoxDB Station 25, WY 1998-1999.

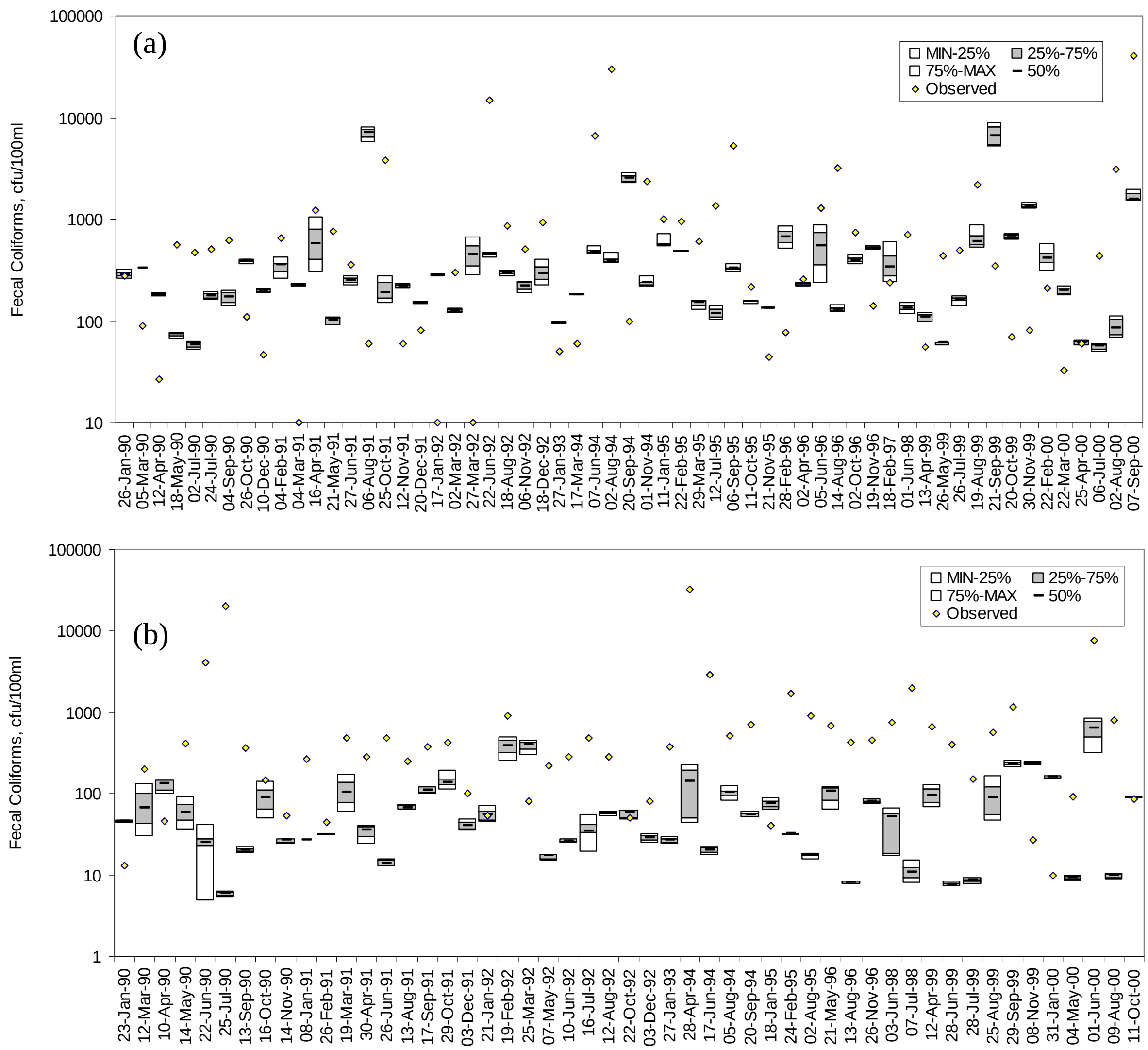


Figure 62. Comparison of observed instantaneous and a distribution of fecal coliforms simulated on the same day, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

Nitrogen

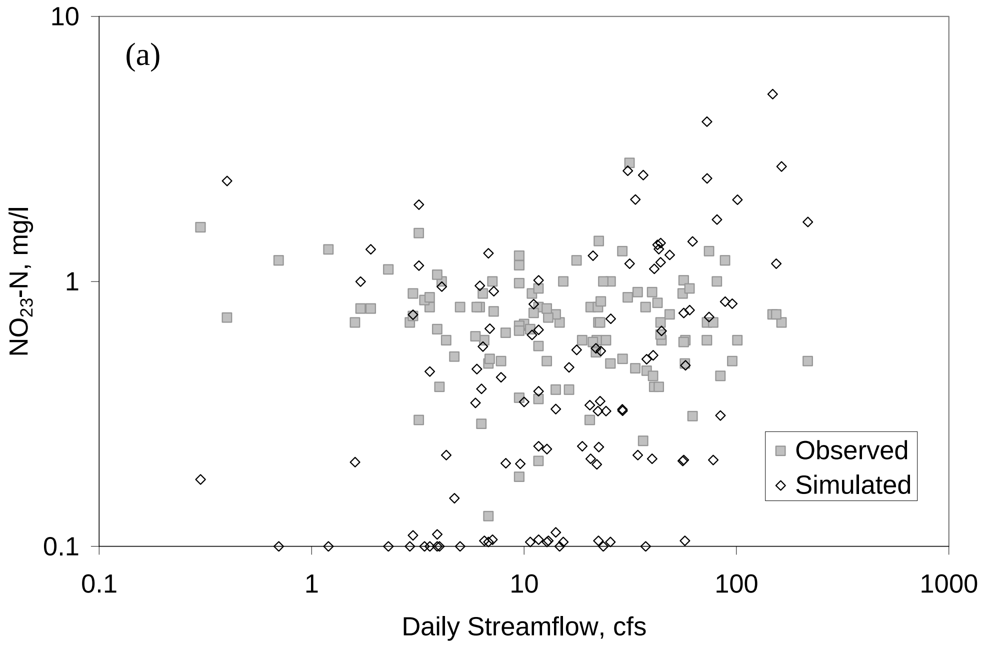
Calibration of the nitrogen cycle within the HSPF model is a complex process. The HSPF model simulates nitrogen in the following forms: nitrate (NO_3-N), nitrite (NO_2-N), dissolved and particulate ammonium (NH_4-N), and dead refractory organic nitrogen (N_{ORG}). The model simulates surface loadings of NO_3-N and NH_4-N directly but specifies surface loading of N_{ORG} as a percentage of organic loading. Organic matter is divided into N_{ORG}, organic phosphorus (P_{ORG}), organic carbon, and Biochemical Oxygen Demand (BOD). Several reaction parameters control transformation of inorganic nitrogen among individual forms in reaches. Dead refractory N_{ORG} is subject to settling and is increased by simulated dead algae. Surface loadings are simulated through the simple routine of buildup and washoff, similar to the simulation of loadings for fecal coliform bacteria. Table 17 summarizes calibration parameters for the nitrogen cycle.

Observed instantaneous and simulated average daily values were compared. Observed data exhibit an apparent method detection limit (MDL) of 0.01 mg/l for NH_4-N, and 0.1 mg/l for NO_{2+3}-N. All simulated values below the MDL were replaced with this value. The State of Illinois specifies the numerical water quality standard for NH_4-N concentration in rivers and streams. Section 302.212 of Title 35 (IAC, 2002) states: “Total ammonia nitrogen (as N: STORET Number 00610) must in no case exceed 15 mg/l.” In addition, acute, chronic, and sub-chronic standards are calculated using a set of equations and values of pH and temperature at the time of sampling. Examples of values for different combinations of pH and temperature are shown (Appendix E).

Table 17. The HSPF Parameters for Nitrogen Simulation (Values for NH_4/Values for NO_3)

Parameter	*Description*	*Units*	*Values used*	*Comment*
Pervious land segment				
ACQOP	Daily accumulation rate on the surface	lb/ac-d	0.006-0.04/ 0.005-0.167	Varies with land use and month
SQOLIM	Maximum amount of nitrogen in storage	lb/ac	15x ACQOP/ 30 x ACQOP	Varies with land use and month
WSQOP	Runoff depth required to remove 90% of storage in one hour	in/h	0.01-0.8/ 0.01-0.8	Varies with land use
IOQC	Interflow concentration	mg/l	0.01-0.06/ 0.1-1.6	Varies with land use
AOQC	Groundwater concentration	mg/l	0.05/0.16	
Impervious land segment				
ACQOP	Daily accumulation rate of nitrogen	lb/ac-d	0.07/ 0.01-0.025	Varies with land use
SQOLIM	Maximum amount of nitrogen in storage	lb/ac	15x ACQOP/ 30x ACQOP	Varies with land use
WSQOP	Runoff depth required to remove 90% of storage in one hour	in/h	0.5/0.5	Varies with land use
Reaches				
KTAM20	Oxidation rate of total ammonia	hr^{-1}	0.005	
KNO220	Oxidation rate of nitrite	hr^{-1}	0.02	
KNO320	Oxidation rate of nitrate	hr^{-1}	0.001	

Results in this section are presented only for FoxDB Stations 25 and 28 as other stations in the Poplar Creek watershed exhibit a similar trend to that for FoxDB Station 25. Figure 63 and Figure 64 show changes in observed instantaneous and simulated daily NO_{2+3}-N concentration with daily flow and month of year, respectively. Figure 65 and Figure 66 show changes in observed instantaneous and simulated daily NH_4-N concentration with daily flow and month of year, respectively. Figure 67 and Figure 68 show changes in observed instantaneous and simulated daily total nitrogen (TN) concentration with daily flow and month of year, respectively. The Poplar Creek watershed model matches patterns adequately. Simulated values generally follow the same seasonal pattern exhibited by observed data, except for slight underestimation in some months. The Blackberry Creek watershed model underestimates NO_{2+3}-N, and, consequently, TN. Observations from FoxDB Station 28 in Blackberry Creek show a very strong relationship of NO_{2+3}-N with flow (Figure 63b). The almost linear increase (on log-log scale) contrasts with a weak relationship at Poplar Creek FoxDB Station 25 (Figure 63a). The Blackberry Creek watershed is predominantly rural with 54% agricultural land use. This strong relationship may indicate a significant influence of tile drainage. Nitrate is very soluble and is flushed out of soils with rainfall through tile drainage. HSPF does not simulate tile drainage explicitly, however, this would affect mostly low flows. Figure 69 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily concentrations over time.



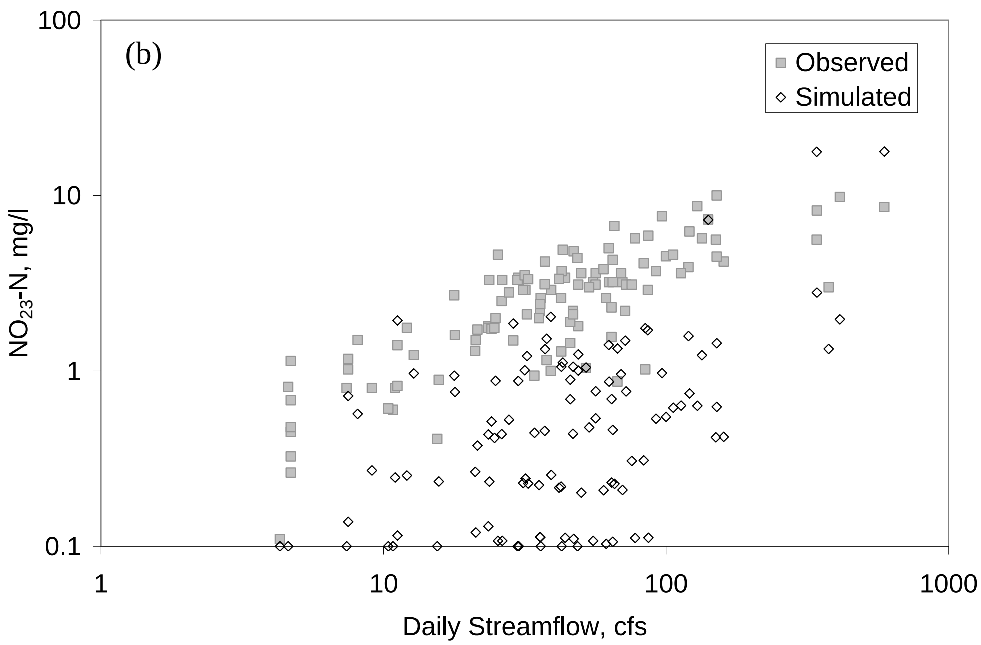
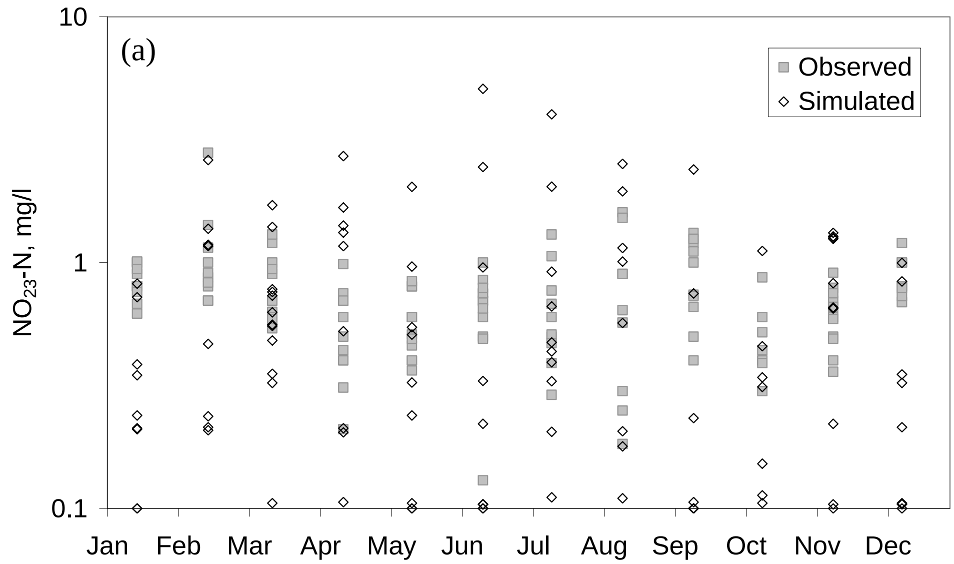


Figure 63. Changes in observed instantaneous and simulated mean daily nitrate nitrogen with simulated daily flow, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.



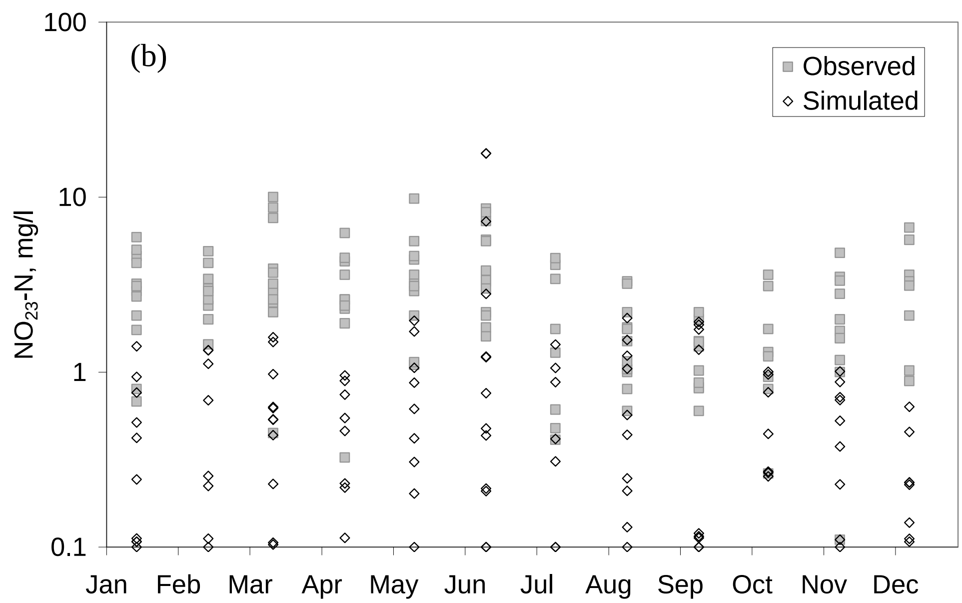


Figure 64. Changes in observed instantaneous and simulated mean daily nitrate nitrogen with month of a year, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

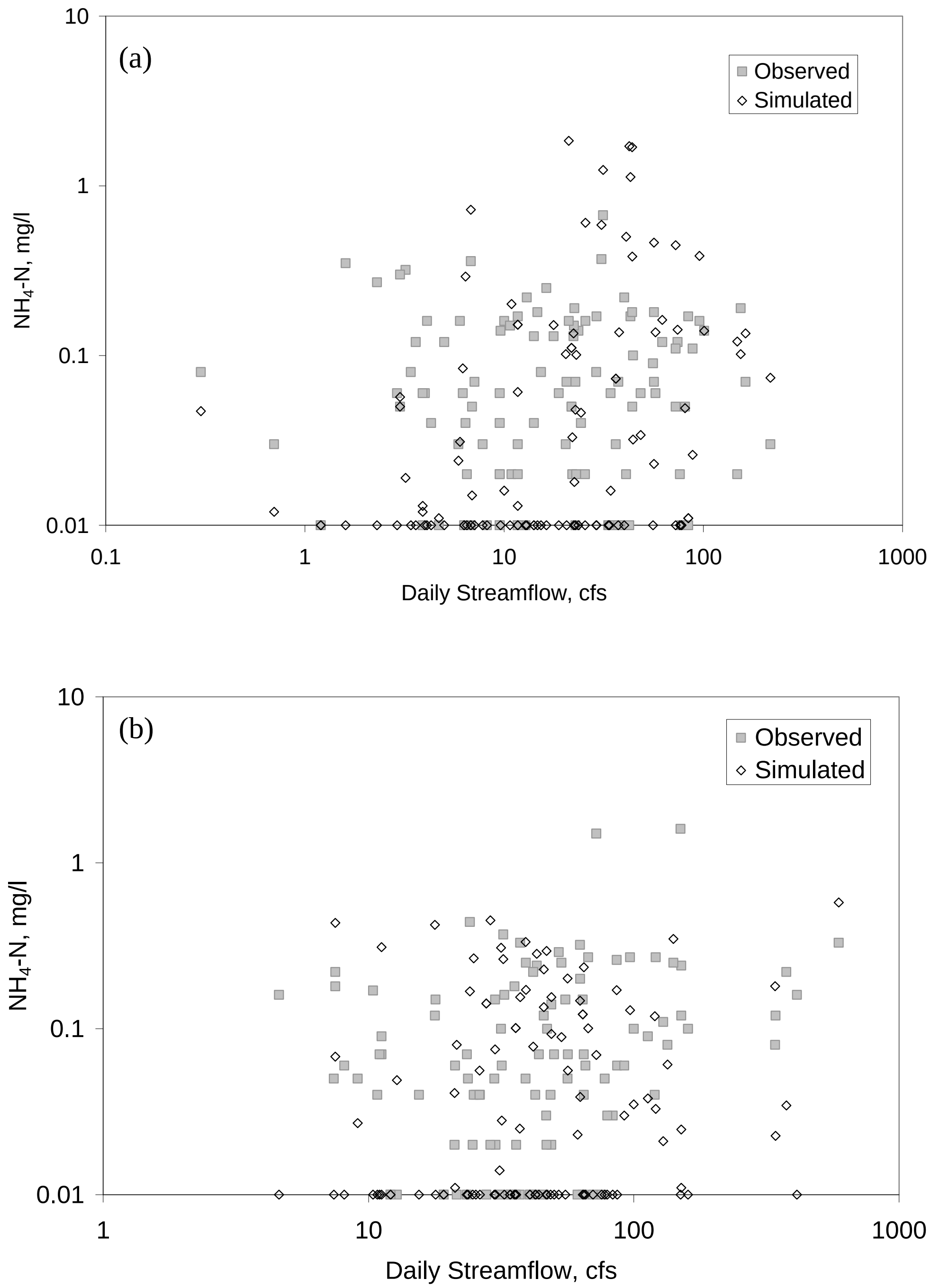


Figure 65. Changes in observed instantaneous and simulated mean daily ammonia nitrogen with simulated daily flow, Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

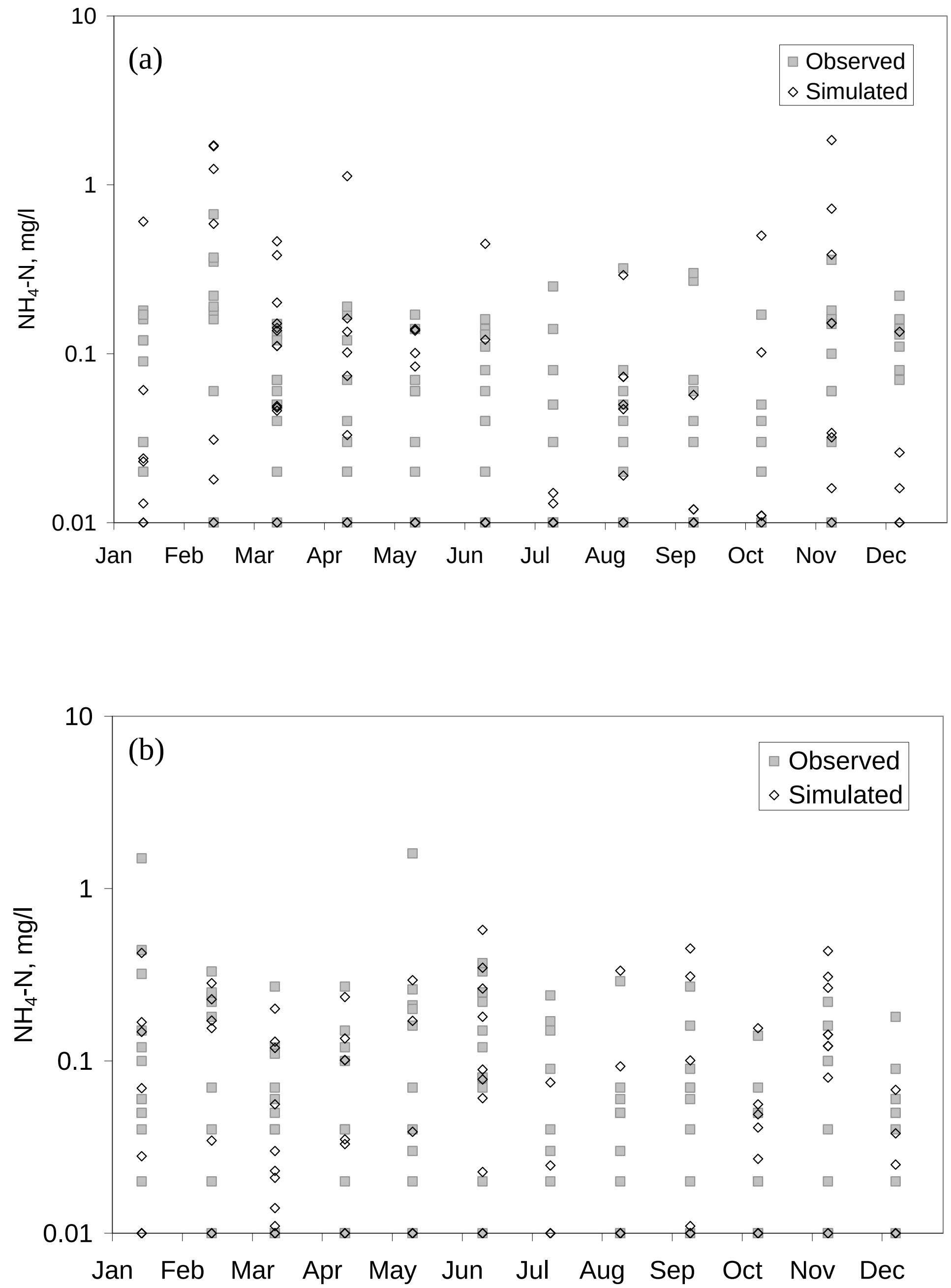


Figure 66. Changes in observed instantaneous and simulated mean daily ammonia nitrogen with month of a year, Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

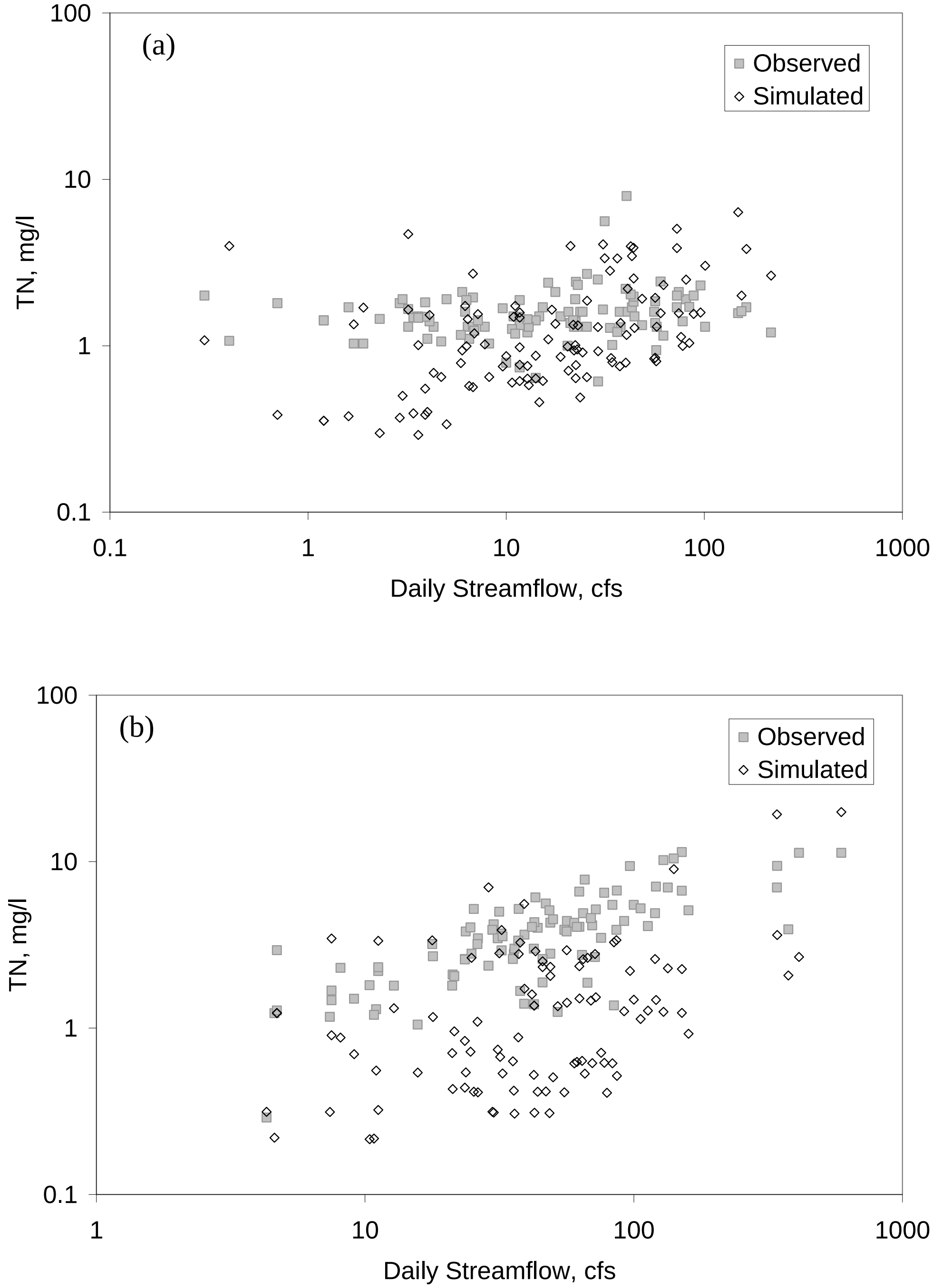


Figure 67. Changes in observed instantaneous and simulated mean daily total nitrogen with simulated daily flow, Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

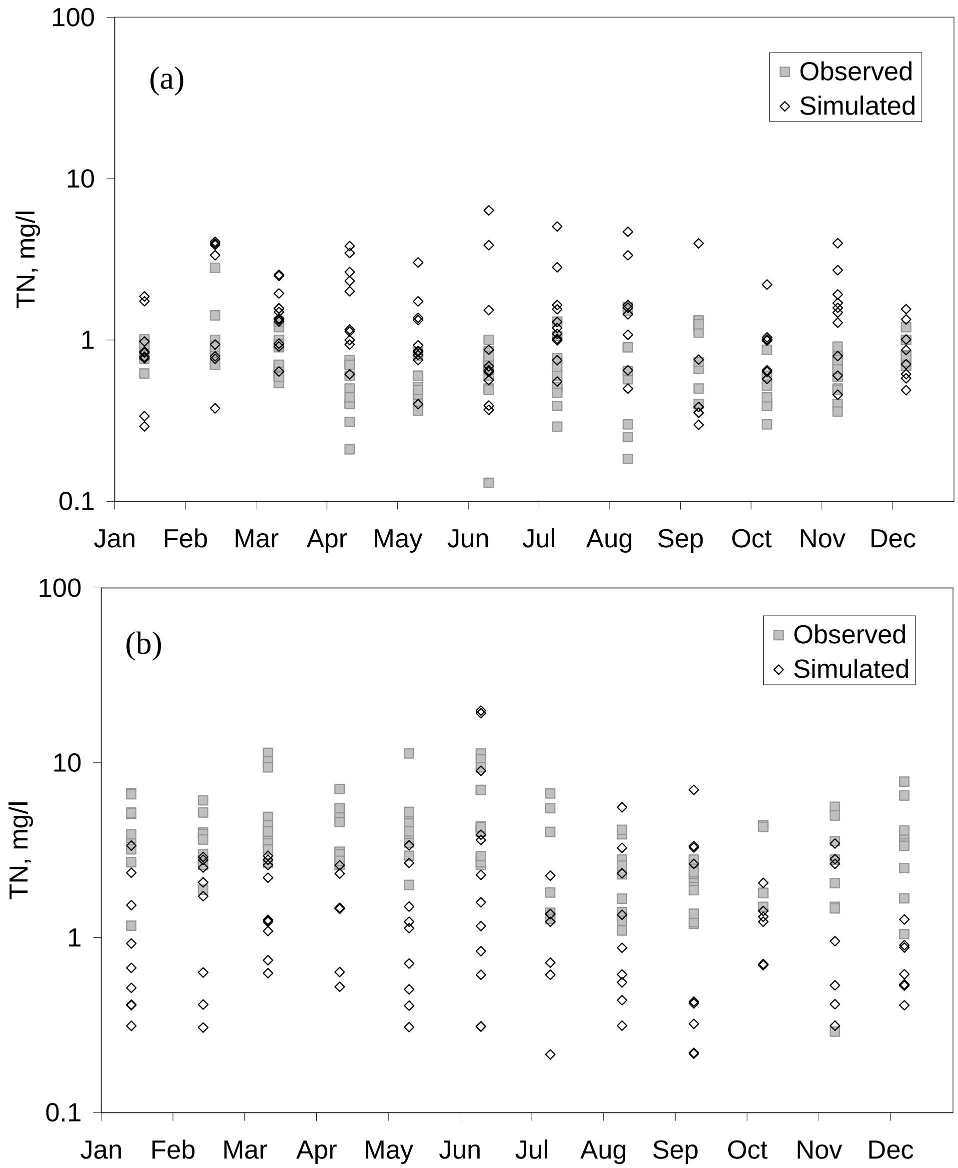


Figure 68. Changes in observed instantaneous and simulated mean daily total nitrogen with month of a year, Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

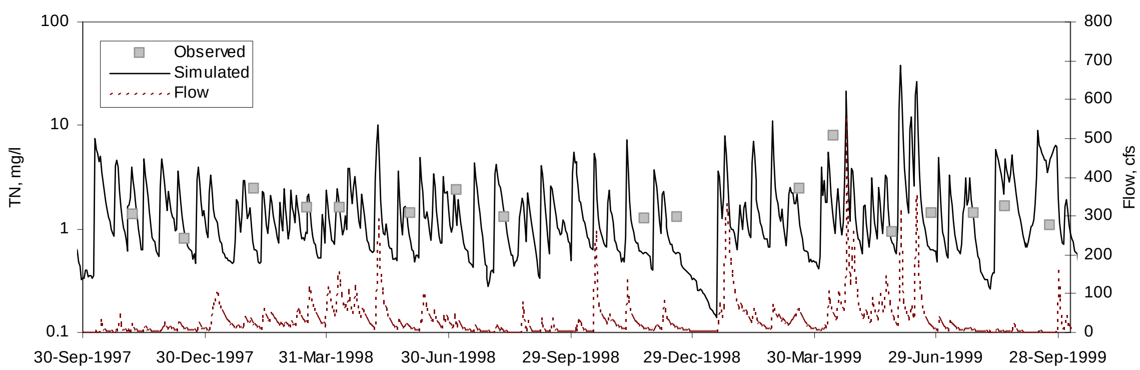


Figure 69. Time series of observed instantaneous and simulated mean daily total nitrogen concentration, Poplar Creek, FoxDB Station 25, WY 1998-1999.

Phosphorus

Phosphorus has a high affinity to fine soil particles, which means it often is associated with sediment. Thus, the inputs from the land surface are simulated as being associated with both sediment and overland flow. Phosphorus in stream reaches is simulated as dissolved orthophosphate (PO_4), particulate PO_4, and P_{ORG}. The adsorption/desorption and scour/deposition processes govern the fate of phosphorus in a reach, with additional effects from algae activity and BOD decay. Table 18 summarizes calibration parameters for the phosphorus cycle.

Observed instantaneous and simulated average daily values were compared. The observed data exhibit an apparent MDL of 0.03 mg/l. All simulated values below the MDL were replaced with this value. The State of Illinois does not specify a numerical water quality standard for phosphorus concentration in rivers and streams, but nutrient criteria currently are under development.

The results in this section are presented only for FoxDB Stations 25 and 28 as other stations in Poplar Creek exhibit a similar trend as that for FoxDB Station 25. Figure 70 shows changes in observed instantaneous and simulated daily total phosphorus (TP) concentration with daily flow. The Poplar Creek model matches the pattern adequately. The Blackberry Creek model underestimates TP concentration. Simulated TP for Poplar Creek generally follows the same seasonal pattern exhibited by observed data (Figure 71); the Blackberry Creek model underestimates TP. Figure 72 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily concentrations over time.

Table 18. The HSPF Parameters for Phosphorus Simulation

Parameter	*Description*	*Units*	*Values used*	*Comment*
Pervious land segment				
ACQOP	Daily accumulation rate on the surface	lb/ac-d	0.0006-0.005	Varies with land use
SQOLIM	Maximum amount of phosphorus in storage	lb/ac	0.01-0.05	Varies with land use
WSQOP	Runoff depth required to remove 90% of storage in one hour	in/h	0.01-0.8	Varies with land use
IOQC	Interflow concentration	mg/l	0.03	
AOQC	Groundwater concentration	mg/l	0.03	
POTFW	Washoff potency factor	lb/ton	0.02-2.0	Varies with land use
POTFS	Scour potency factor	lb/ton	0.01-0.2	Varies with land use
Impervious land segment				
ACQOP	Daily accumulation rate of phosphorus	lb/ac-d	0.003-0.004	Varies with land use
SQOLIM	Maximum amount of phosphorus in storage	lb/ac	0.03	
WSQOP	Runoff depth required to remove 90% of storage in one hour	in/h	0.5	Varies with land use
POTFW	Washoff potency factor	lb/ton	0.55-0.65	Varies with land use
Reaches				
ADPOPM(1)	Partition coefficient for PO4-P adsorbed to sand	ml/g	100	
ADPOPM(2)	Partition coefficient for PO4-P adsorbed to silt	ml/g	1000	
ADPOPM(3)	Partition coefficient for PO4-P adsorbed to clay	ml/g	1000	

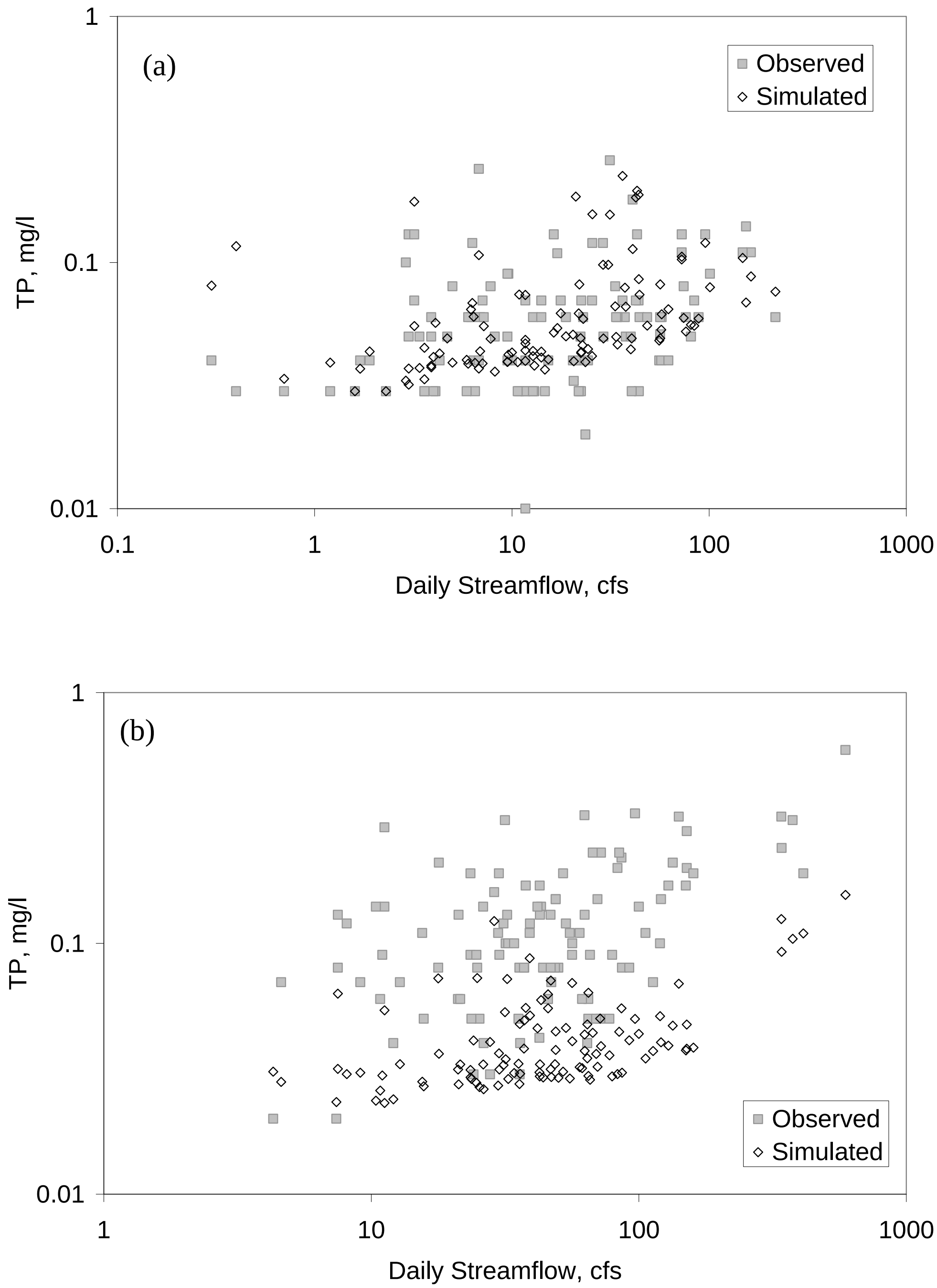
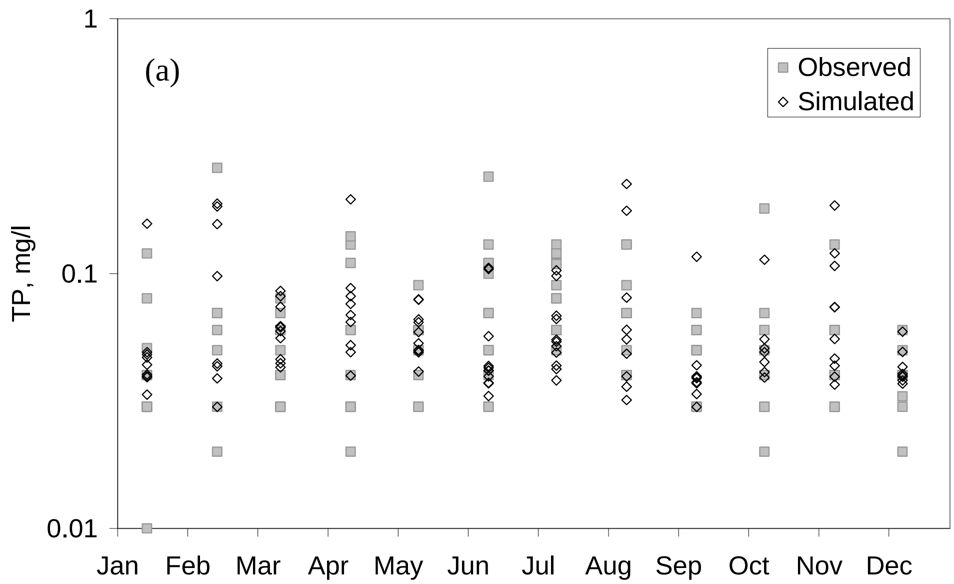


Figure 70. Changes in observed instantaneous and simulated mean daily total phosphorus with simulated daily flow, Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.



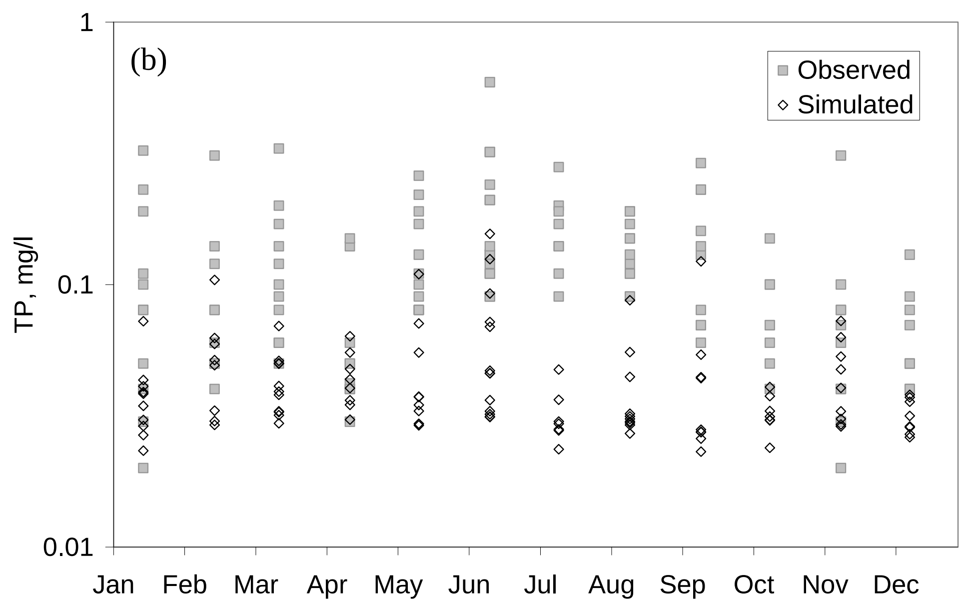


Figure 71. Changes in observed instantaneous and simulated mean daily total phosphorus with month of a year, Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

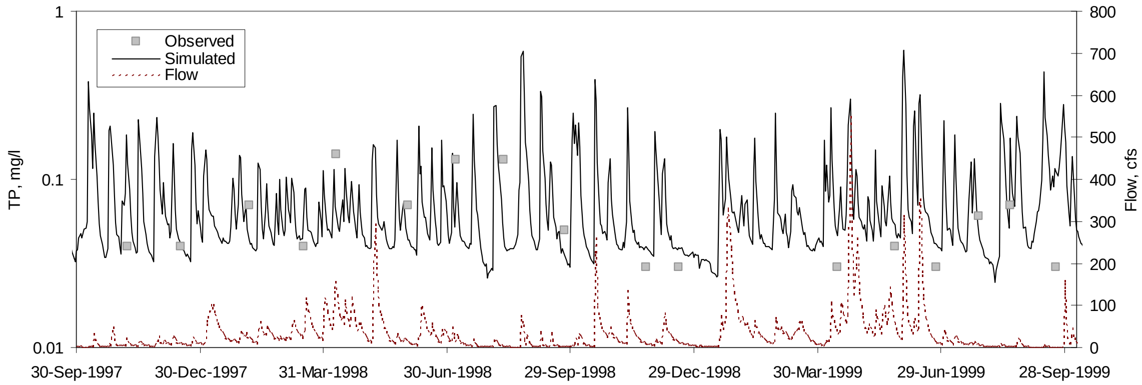


Figure 72. Time series of observed instantaneous and simulated mean daily total phosphorus concentration, Poplar Creek, FoxDB Station 25, WY 1998-1999.

Dissolved Oxygen Regime

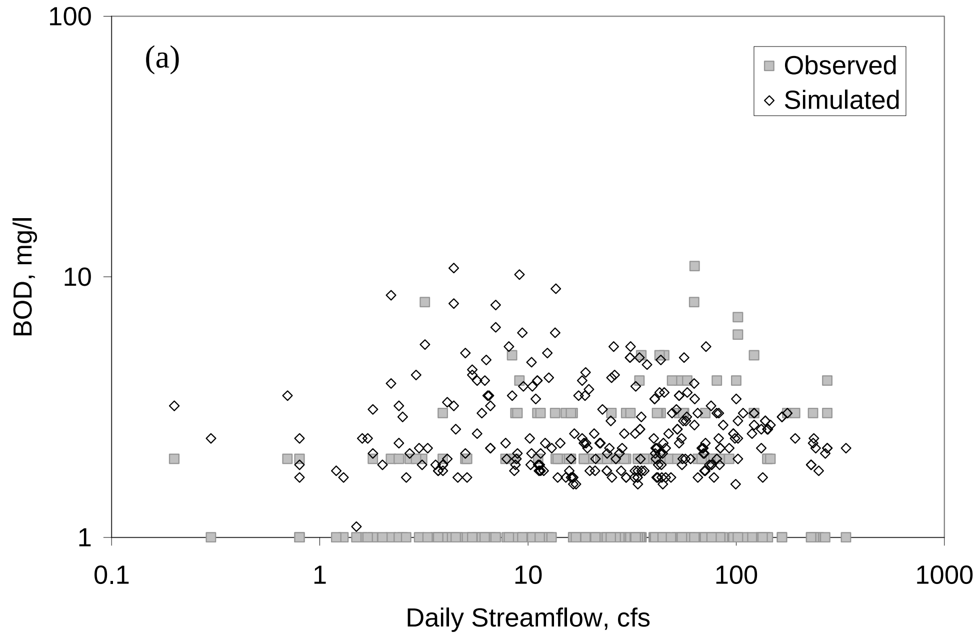
Dissolved oxygen (DO) concentration is a result of complex processes, including degradation of organic matter, physical reaeration, algae growth and respiration, effects of temperature. and nutrient cycling. Accumulation and removal of organic matter on the surface is simulated as BOD. Table 19 summarizes calibration parameters for the DO regime.

Observed instantaneous and simulated average daily values of BOD were compared. Observed data exhibit an apparent MDL of 1 mg/l. All simulated values below the MDL were replaced with this value. The State of Illinois does not specify a numerical water quality standard for BOD in rivers and streams. Section 302.203 of Title 35 (IAC, 2002) states: “Waters of the State shall be free from sludge or bottom deposits, floating debris, visible oil, odor, plant or algal growth, color or turbidity of other than natural origin.”

The BOD measurements are available only for Poplar Creek, FoxDB Stations 615 and 895. Figure 73 shows changes in observed instantaneous and simulated daily BOD concentration with daily flow for these two stations. The values do not show any clear pattern for the flow, but the range of values was reproduced successfully. Simulated BOD for Poplar Creek generally follows the same seasonal pattern exhibited by observed data (Figure 74). Figure 75 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily concentrations over time.

Table 19. The HSPF Parameters for Simulation of DO Regime

Parameter	*Description*	*Units*	*Values used*	*Comment*
Pervious land segment				
ACQOP	Daily accumulation rate on surface	lb/ac-d	0.15-0.6	Varies with land use
SQOLIM	Maximum amount of BOD in storage	lb/ac	10 x ACQOP	Varies with land use
WSQOP	Runoff depth required to remove 90% of storage in one hour	in/h	0.01-0.8	Varies with land use
IOQC	Interflow concentration	mg/l	1-2	Varies with land use
AOQC	Groundwater concentration	mg/l	1-2	Varies with land use
Impervious land segment				
ACQOP	Daily accumulation rate of bacteria	lb/ac-d	0.2-0.4	Varies with land use
SQOLIM	Maximum amount of BOD in storage	lb/ac	5	Varies with land use
WSQOP	Runoff depth required to remove 90% of storage in one hour	in/h	0.5	
Reaches				
KBOD20	Unit BOD decay rate at 20°C	hr^{-1}	0.1	
KODSET	Rate of BOD settling	ft/hr	0.005	
BENOD	Benthal oxygen demand at 20°C	mg/m^2-hr	40	
REAK	Empirical constant for equation used to calculate reaeration coefficient	hr^{-1}	0.2	



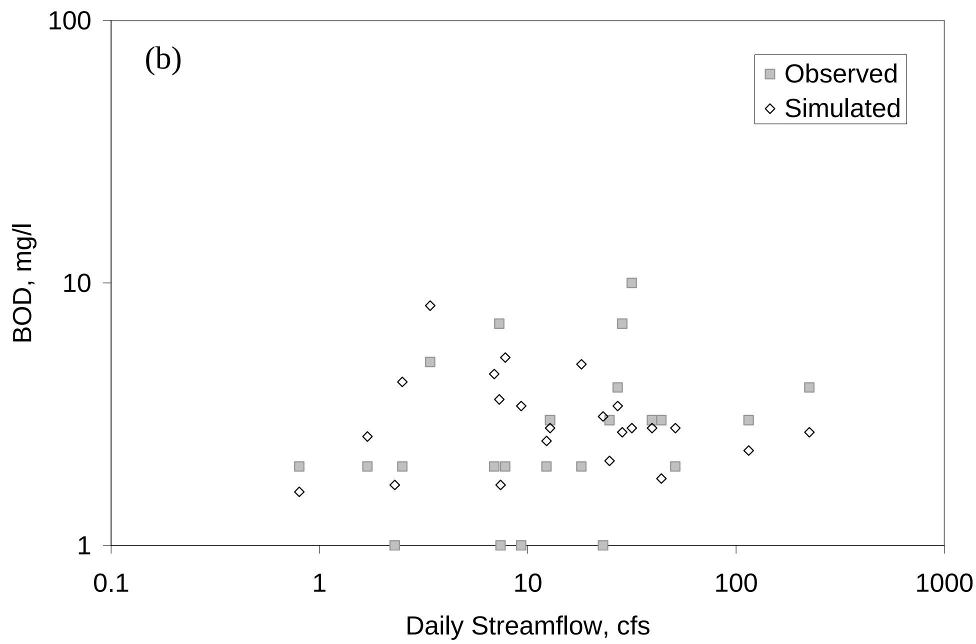


Figure 73. Changes in observed instantaneous and simulated mean daily BOD with simulated daily flow, Poplar Creek, a) FoxDB Station 615, and b) FoxDB Station 895.

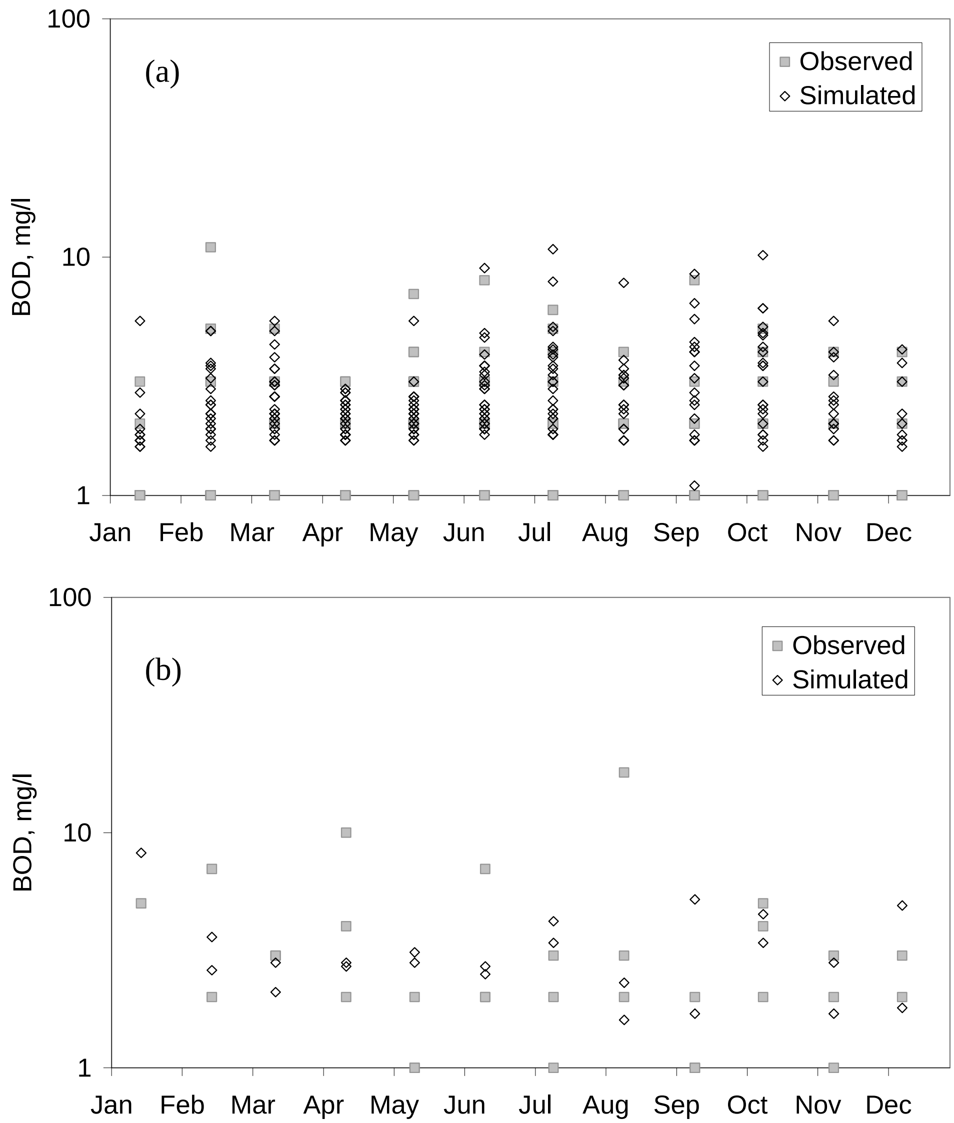


Figure 74. Changes in observed instantaneous and simulated mean daily BOD with month of a year, Poplar Creek, a) FoxDB Station 615, and b) FoxDB Station 895.

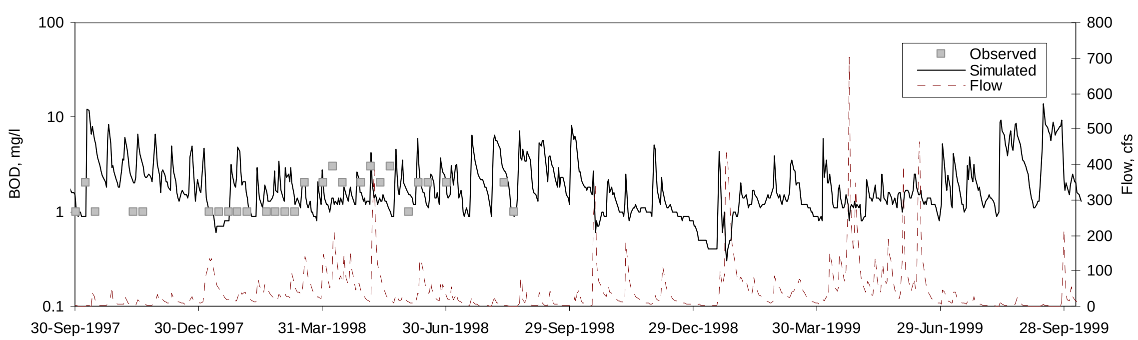
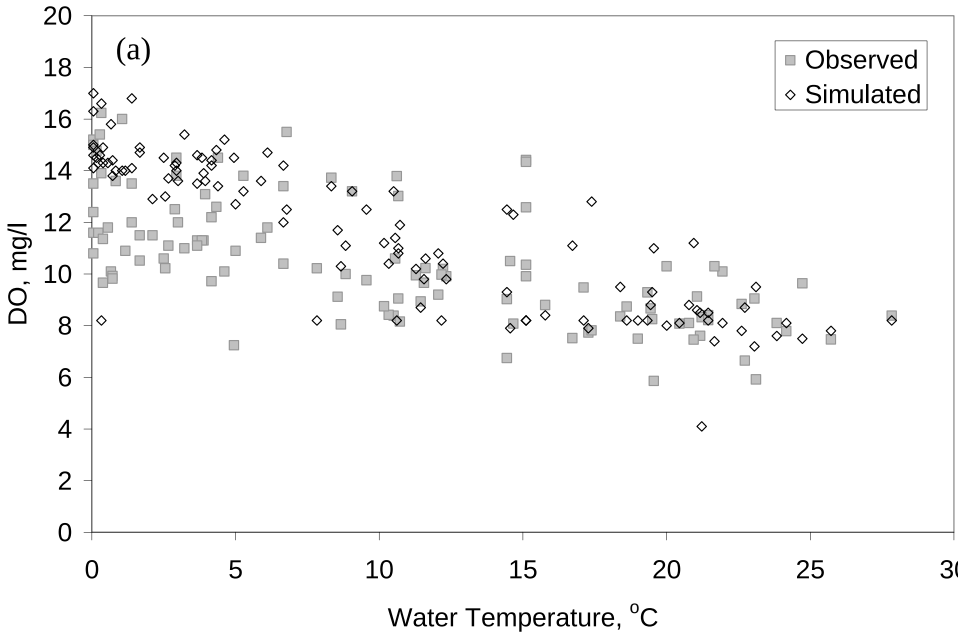


Figure 75. Time series of observed instantaneous and simulated mean daily BOD concentration, Poplar Creek, FoxDB Station 615, WY 1998-1999.

Observed instantaneous and simulated hourly values of DO were compared. Observed data are all above the MDL. The State of Illinois specifies the numerical water quality standard for DO in rivers and streams. Section 302.206 of Title 35 (IAC, 2002) states: "Dissolved oxygen (STORET number 00300) shall not be less than 6.0 mg/l during at least 16 hours of any 24 hour period, nor less than 5.0 mg/l at any time."

Figure 76 shows changes in observed instantaneous and simulated hourly DO concentration with average daily temperature for these two stations. The model overestimates DO during days with low temperature (below 10°C). Figure 77 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily concentrations over time. Observations from FoxDB Station 25 are plotted with the distribution of 24 hourly values of DO simulated for the same days observations were taken (Figure 78). Ideally, points representing observations fall within the range of simulated values symbolized in the figure by a column for each day. This figure shows simulated values generally within the same range as observations, but the model does not simulate observed values precisely.



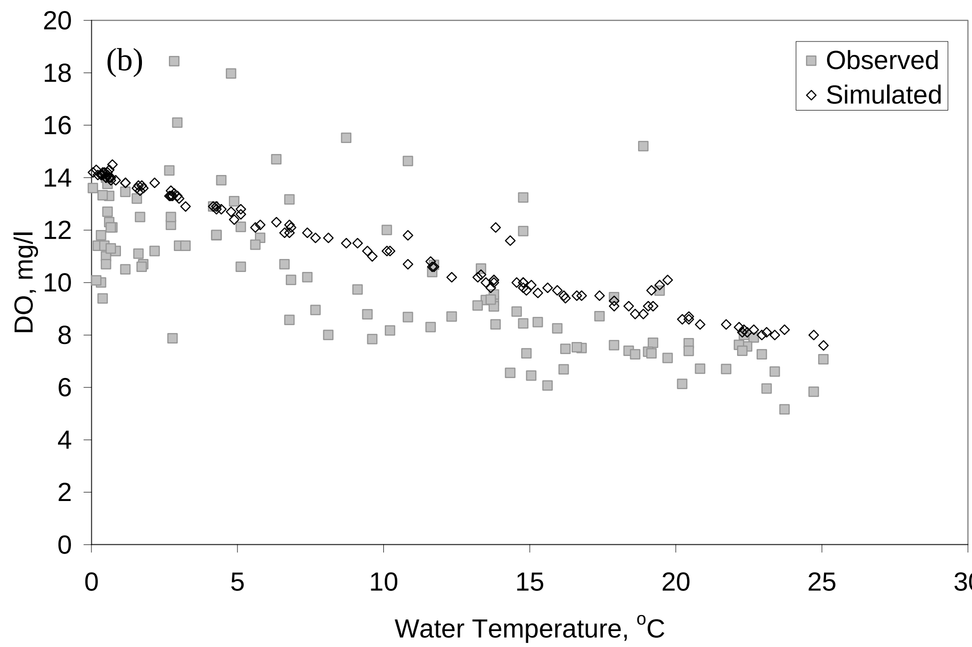


Figure 76. Changes in observed instantaneous and simulated hourly DO with simulated daily temperature, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

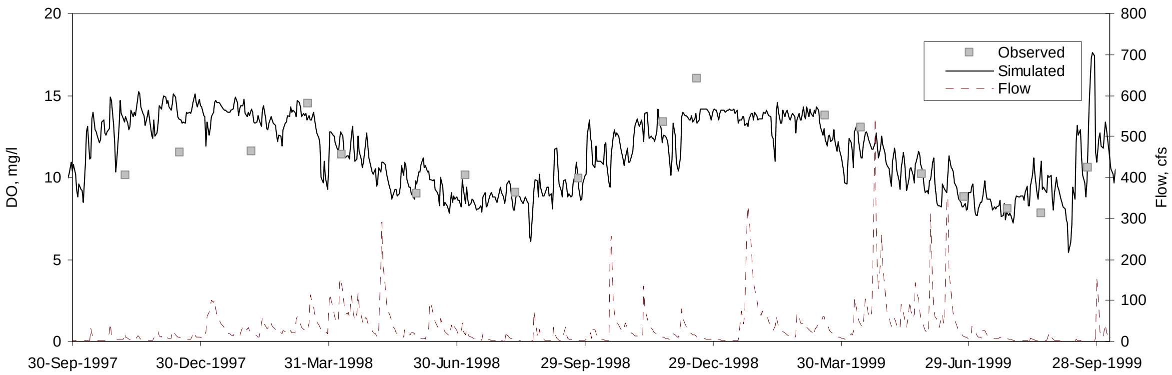


Figure 77. Time series of observed instantaneous and simulated mean daily DO concentration, Poplar Creek, FoxDB Station 25, WY 1998-1999.

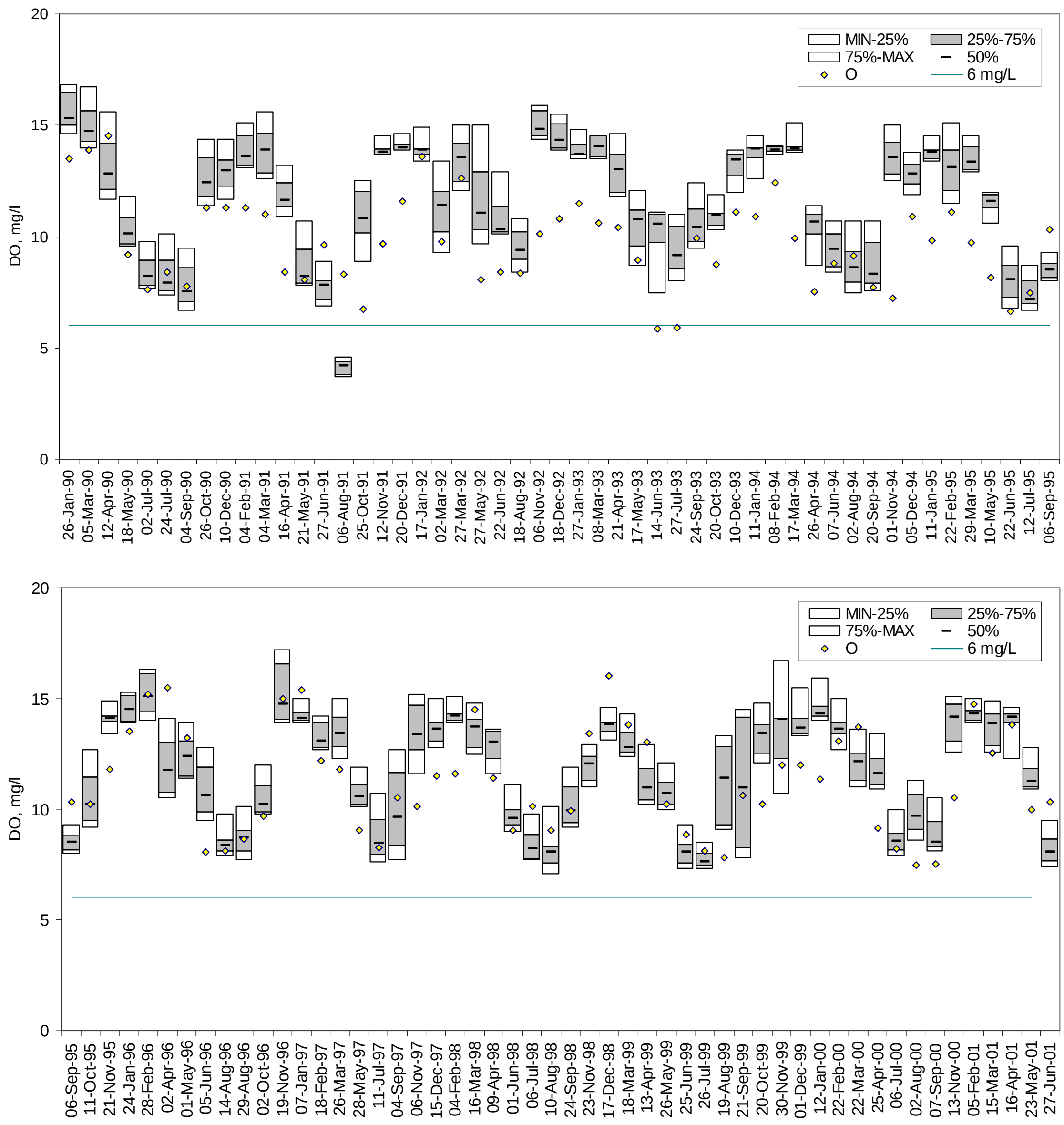


Figure 78. Comparison of observed instantaneous and a distribution of dissolved oxygen simulated on the same day, Poplar Creek watershed, FoxDB Station 25.

Overall Assessment of Water Quality Model Performance

Water quality models simulate daily concentration of selected constituents adequately based on the selected performance criteria (simulation of trends). Monitoring programs with data available for calibration were not designed to determine loads or concentrations during runoff events or to evaluate peak concentrations. The models show no significant seasonal bias or bias over the range of streamflows for most constituents. Suspended sediment concentrations are underestimated at very low flows. NO_{2+3}-N and TP in Blackberry Creek. Additional adjustment of loading parameters for NO_{2+3}-N and TP is necessary to increase simulated concentrations. Redistribution of the loading over the year may be necessary, as nutrient parameters are now kept constant in the model.

Water quality simulation highly depends on hydrologic simulation. Hydrologic parameters developed for Poplar and Blackberry Creek watersheds will be refined during calibration of the Fox River mainstem model. Changes in hydrology parameters likely will necessitate adjustments in water quality parameters. The models currently perform very well. Parameters can be adjusted to improve the model performance; however, the preliminary calibration was concluded due to time constraints. Necessary adjustments will be made during the planned calibration of the Fox River mainstem and the remaining tributary watersheds.

Illustrations of Model Use

Comparison of Poplar Creek and Blackberry Creek Watershed Models

Models of the Poplar and Blackberry Creek watersheds were calibrated to the extent possible with existing data under constraints of time and resources available and then used to determine volume of water and loads (SS, TN, and TP) generated by these watersheds. Because of limited calibration at this phase of the study, generated loads are displayed only to illustrate how the results can be presented and to compare relative contributions of urban and rural watersheds without specifically quantifying the load.

Loads were calculated at the USGS gages for both watersheds (FoxDB Stations 25 and 28). The Blackberry Creek watershed drains twice as much area as the Poplar Creek watershed so total load from the Blackberry Creek watershed is expected to be higher. Presentation of unit area loads helps compare relative contribution from these watersheds. This is true for the total volume of water flowing through the selected sites (Figure 79a). Unit area flow varies from year to year: the pattern does not indicate one watershed as contributing more per unit area (Figure 79b). Watersheds also are located in different parts of the Fox River watershed. Thus, models used different climate stations, which also affects the pattern.

Total SS load is driven by precipitation. The year 1996 brought some rainfall extremes recorded at the Aurora climate station and reflected in high total load of all constituents from the Blackberry Creek watershed discussed here (Figure 80a). Total SS loads are much closer for both watersheds, but in some years, the smaller, urban Poplar Creek watershed generates higher total load than the larger agricultural Blackberry Creek watershed. Unit area SS loads are higher for the Poplar Creek watershed than for the Blackberry Creek watershed (Figure 80b) in all years except WY 1996-1998.

Total load of TN displays larger differences between the two watersheds (Figure 81a). The Blackberry Creek watershed generates higher loads than the Poplar Creek watershed in all years except WY 2001. The unit area loads do not show a consistent trend, the overall averages are comparable (Figure 81b). However, the Blackberry Creek watershed model underestimated TN concentrations and consequently, the relative comparison of the two watersheds is affected by the underestimation.

Total and unit area loads of TP also are presented (Figure 82). The Poplar Creek watershed generates higher loads than the Blackberry Creek watershed in six years and lower in five years. The Poplar Creek watershed contributes a larger amount in terms of unit area load (with the exception of WY 1996). However, the TP concentrations simulated for Blackberry Creek watershed are underestimated significantly, affecting the comparison. The final calibration is scheduled for the next phase of this study to improve results presented here.

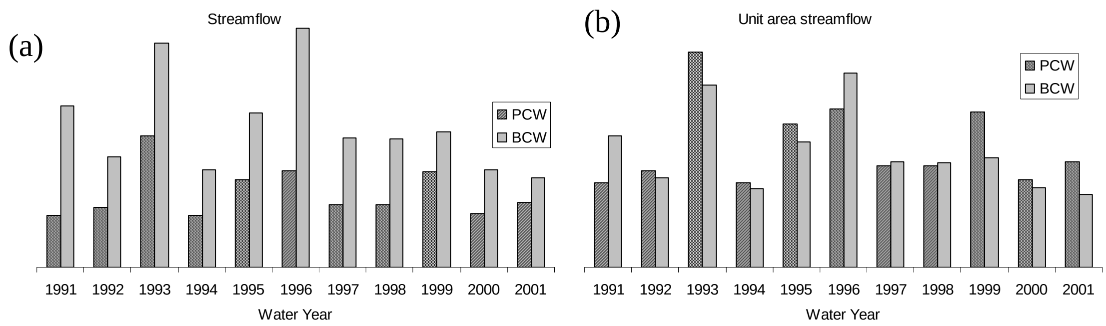


Figure 79. Comparison of streamflow originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total flow, and b) unit area flow.

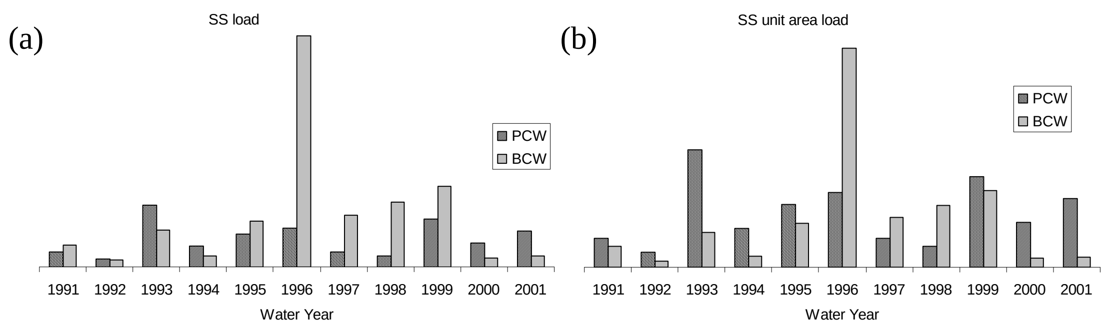


Figure 80. Comparison of SS loads originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total load, and b) unit area load.

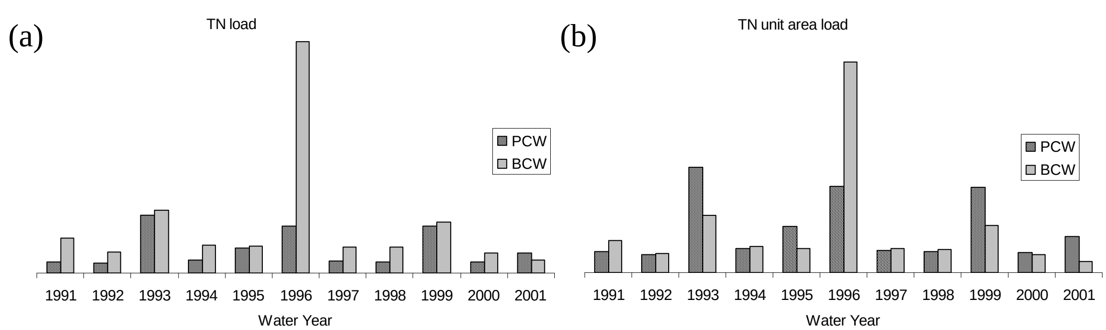


Figure 81. Comparison of TN loads originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total load, and b) unit area load.

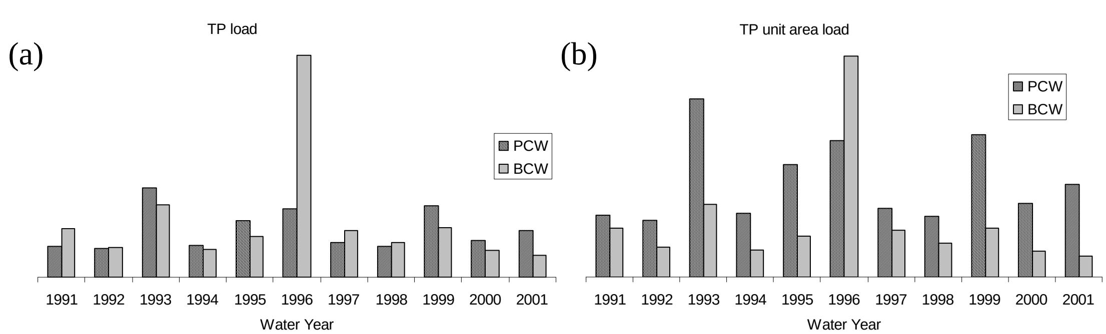


Figure 82. Comparison of TP loads originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total load, and b) unit area load.

Comparison to Water Quality Standards

Dissolved oxygen was selected to demonstrate the use of the model for evaluating compliance with water quality standards. The reader is advised to keep in mind the purpose of this section is to illustrate model use for watershed assessments. Further calibration as planned for the next phase of the study would be necessary to evaluate the actual compliance with standards based on simulated values.

Water quality standards for DO are specified as follows (IAC, 2002): "Dissolved oxygen (STORET number 00300) shall not be less than 6.0 mg/l during at least 16 hours of any 24 hour period, nor less than 5.0 mg/l at any time."

Simulated values were analyzed for compliance with the water quality standards. Table 20 summarizes the findings for FoxDB Stations 25 and 28 on Poplar Creek and Blackberry Creek, respectively. Water quality simulated at FoxDB Station 25 shows 38 instances over the 9-year period when simulated DO concentration fell below 5 mg/l and 5 days when DO concentration fell below 6 mg/l for 8 hours or more. The DO concentration did not fall below the 5 mg/l standard at FoxDB Station 28 during this period, and there were only 4 days when DO concentration fell below 6 mg/l for 8 hours or more there. The low DO occurs exclusively during summer months as might be expected.

Table 20. Comparison of Simulated Values with Water Quality Standards

WY	*Number of simulated values below 5 mg/l*		*Number of periods below 6 mg/l that lasted at least 8 hours*		*Critical month*
	Station 25	*Station 28*	*Station 25*	*Station 28*	
1992	0	0	0	4	May
1993	2	0	0	0	July
1994	0	0	0	0	
1995	3	0	0	0	July, August
1996	1	0	0	0	July
1997	0	0	0	0	
1998	20	0	2	0	August
1999	12	0	3	0	September
2000	0	0	0	0	

Summary and Conclusions

In this study, hydrologic models to simulate streamflow and other components of the water budget were developed using available data for the Blackberry Creek and Poplar Creek watersheds located in the Fox River watershed, using the HSPF model in the BASINS 3.1 modeling environment. Once fully developed, the models will provide the watershed planners and managers with simulated hydrologic data for assessing hydrologic impacts of land use changes in the watersheds.

The Blackberry Creek watershed model was calibrated for WY 1993-2000. Values of several model parameters were adjusted within reasonable limits to improve fit between the observed and simulated data on a long-term, annual, monthly, and daily basis. The calibrated model was validated for two different periods (WY 1991-1992 and WY 2001-2003) at the Yorkville gage and a 3-year period (WY 2000-2003) at the Montgomery gage. Sensitivity analysis of the calibrated model parameters also was conducted.

The Poplar Creek watershed model was calibrated for April 1991-WY 1999. Values of several model parameters were adjusted within reasonable limits to improve fit between the observed and simulated data on a long-term, annual, monthly, and daily basis. The calibrated model was validated for a 4-year period (WY 2000-2003). Streamflow data from the USGS gage at Elgin (USGS ID 05550500) were used for model calibration and validation. Sensitivity analysis of the calibrated model parameters also was conducted.

The models then were expanded to simulate water quality. Existing water quality data were used to calibrate the model for SS, fecal coliform, various forms of nitrogen and phosphorus, DO, and other supporting constituents, such as temperature and BOD. Due to the limited number of observations, models were calibrated to simulate trends apparent in the data rather than matching individual observations. This goal was achieved for SS, fecal coliforms, DO, and some forms of nitrogen, although the Blackberry Creek watershed model currently underestimates NO_{2+3}-N and TP. Model coefficients will be improved in subsequent parts of this study as these watershed loading models are created for additional tributary watersheds in the Fox River watershed as well as the Fox River mainstem, and as observations describe a wider range of conditions.

The models were used to evaluate relative contribution of flow, SS, TN, and TP, as well as to assess the compliance of simulated DO with water quality standards. These calculations are presented as examples to illustrate model use in watershed management and planning. The models are not yet fully calibrated so these examples should not be used to make decisions or to assess conditions in these two watersheds.

The models simulate complex processes on the surface as well as in stream reaches. The Poplar Creek and the Blackberry Creek watersheds served as pilot watersheds that were used to create models for remaining tributary watersheds in the Fox River watershed as well as the Fox River mainstem. Model parameters may need to be refined in this process, but they represent a good starting point and give results consistent with observations.

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Appendix A1. Water Quality Station Description and Location in Blackberry Creek Watershed

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach)* 28 (25)
Water Temperature	Date range	10/1961-10/2003
(°C)	# of samples	130
00010	Min	-0.01
	Max	27.5
	Mean	11.6
	Median	11.1
	StdDev	8.34
pH	Date range	12/1977-10/2003
(SU)	# of samples	112
00400, 00406	Min	6.76
	Max	9.16
	Mean	7.99
	Median	7.99
	StdDev	0.41
TSS	Date range	3/1979-10/2003
(mg/l)	# of samples	109
00530	Min	1.00
	Max	328
	Mean	46.7
	Median	32.0
	StdDev	53.15
Residue, Volatile	Date range	3/1979-10/2003
Nonfilterable	# of samples	109
(mg/l)	Min	1.00 (BDL)
00535	Max	50.0
	Mean	12.5*
	Median	10
	StdDev	10.4*
Nitrogen Ammonia,	Date range	12/1977-10/2003
Total	# of samples	109
(mg/l as N)	Min	0.01 (BDL)
00610	Max	1.60
	Mean	0.20*
	Median	0.11
	StdDev	0.32*
Nitrogen, Kjeldahl,	Date range	12/1977-10/2003
Total	# of samples	94
(mg/l as N)	Min	0.10 (BDL)
00625	Max	3.14
	Mean	0.88*
	Median	0.72
	StdDev	0.66*

Appendix A1 (continued)

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach) 28 (25)*
Nitrite plus Nitrate, Total (mg/l as N) 00630	Date range	12/1977-10/2003
	# of samples	108
	Min	0.11
	Max	8.70
	Mean	2.76
	Median	2.25
	StdDev	2.02
Phosphorus, Total (mg/l as P) 00665	Date range	12/1977-10/2003
	# of samples	105
	Min	0.020
	Max	0.590
	Mean	0.158
	Median	0.130
	StdDev	0.114
Phosphorus, Dissolved (mg/l as P) 00666	Date range	10/1979-10/2003
	# of samples	113
	Min	0.008
	Max	0.219
	Mean	0.070
	Median	0.060
	StdDev	0.053
DO (mg/l) 00299, 00300	Date range	12/1977-10/2003
	# of samples	165
	Min	5.16
	Max	18.4
	Mean	9.99
	Median	9.54
	StdDev	2.63
DO (% saturation) 00301	Date range	12/1977-12/1998
	# of samples	75
	Min	64.3
	Max	118
	Mean	87.6
	Median	87.5
	StdDev	10.6
Fecal Coliforms (cfu/100 ml) 31616	Date range	12/1977-10/2000
	# of samples	40
	Min	10 (BDL)
	Max	32000 (TNTC)
	Mean	1510**
	Median	420**
	StdDev	5171**

Appendix A1 (concluded)

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach) 28 (25)*
Chlorophyll-A,	Date range	7/2002
Trichromatic	# of samples	1
Uncorrected	Min	5.34
(µg/l)	Max	5.34
32210	Mean	5.34
	Median	5.34
	StdDev	
Chlorophyll-A	Date range	7/2002
Spectrophotometric	# of samples	1
Corrected	Min	5.83
(µg/l)	Max	5.83
32211	Mean	5.83
	Median	5.83
	StdDev	
Chlorophyll-B	Date range	7/2002
Trichromatic	# of samples	1
Uncorrected	Min	1.00 (BDL)
(µg/l)	Max	1.00
32212	Mean	1.00*
	Median	1.00*
	StdDev	
Chlorophyll-C	Date range	7/2002
Trichromatic	# of samples	1
Uncorrected	Min	1.00 (BDL)
(µg/l)	Max	1.00
32214	Mean	1.00*
	Median	1.00*
	StdDev	

Notes: SU = standard units.
BDL = below detection limit.
TNTC = too numerous to count.
*Calculated values may be affected due to presence of BDL values.
**Calculated values may be affected due to presence of TNTC values.

Appendix A2. Water Quality Station Description and Location in Poplar Creek Watershed

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach)* 25 (26)	615 (31)	895 (35)
Water Temperature	Date range	10/1974-09/2003	9/1994-8/1995	3/1989-12/2003
(^{o}C)	# of samples	126	40	128
00010	Min	-0.20	0.08	0.00
	Max	26.6	24.9	31.5
	Mean	12.1	12.0	14.7
	Median	12.3	11.0	15.1
	StdDev	7.86	7.61	8.40
pH	Date range	10/1976-9/2003	2/1991-8/1998	3/1989-12/2003
(SU)	# of samples	111	260	128
00400, 00406	Min	7.07	7.23	5.90
	Max	8.38	8.70	9.23
	Mean	7.83	8.01	7.88
	Median	7.88	8.00	7.89
	StdDev	0.29	0.22	0.54
TSS	Date range	10/1976-9/2003	2/1991-8/1998	3/1989-12/2003
(mg/l)	# of samples	103	235	135
00530	Min	1.00	BDL	3.00
	Max	222	448	668
	Mean	21.8	24.8*	34.6
	Median	15.0	10.0	20.0
	StdDev	26.6	43.9*	64.8
Residue, Volatile	Date range	10/1977-9/2003		3/1989-12/2003
Nonfilterable	# of samples	104		114
(mg/l)	Min	1.00		(BDL)
00535	Max	26.0		68.0
	Mean	5.97		6.72*
	Median	5.00		5.00
	StdDev	4.31		7.79*
Nitrogen, Ammonia,	Date range	10/1976-7/2000		
Dissolved	# of samples	1		
(mg/l as N)	Min	0.02 (BDL)		
00608	Max	0.02 (BDL)		
	Mean	0.02*		
	Median	0.02*		
	StdDev			
Nitrogen, Ammonia,	Date range	10/1977-9/2003	2/1991-8/1998	3/1989-12/2003
Total	# of samples	109	235	135
(mg/l as N)	Min	0.01 (BDL)	0.01 (BDL)	0.01 (BDL)
00610	Max	0.67	0.57	0.33
	Mean	0.09*	0.08*	0.08*
	Median	0.06	0.06	0.05
	StdDev	0.10*	0.06*	0.07*

Appendix A2 (continued)

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach)* 25 (26)	615 (31)	895 (35)
Ammonia, Unionized	Date range	10/1976-12/1998		3/1989-12/2003
(mg/l as N)	# of samples	72		127
00612	Min	0.0010		BDL
	Max	0.0204		0.0313
	Mean	0.0020		0.0024*
	Median	0.0010		0.0007
	StdDev	0.0030		0.0045*
Nitrogen, Kjeldahl,	Date range	12/1977-9/2003		3/1989-12/2003
Total	# of samples	108		135
(mg/l as N)	Min	0.1 (BDL)		0.07
00625	Max	7.50		5.46
	Mean	0.88*		1.09
	Median	0.80		0.97
	StdDev	0.77*		0.63*
Nitrogen, Kjeldahl,	Date range	7/1988-7/2000		
Dissolved	# of samples	1		
(mg/l as N)	Min	0.602		
00623	Max	0.602		
	Mean	0.602		
	Median	0.602		
	StdDev			
Nitrogen, Organic Total	Date range			3/1989-12/2003
(mg/l as N)	# of samples			125
00605	Min			0.07
	Max			5.46
	Mean			1.01
	Median			0.91
	StdDev			0.64
Nitrite, Nitrogen	Date range	10/1977-7/2000		
Dissolved	# of samples	1		
(mg/l as N)	Min	(0.01)BDL		
00613	Max	(0.01)BDL		
	Mean	0.01*		
	Median	0.01*		
	StdDev			
Nitrite plus Nitrate	Date range	10/1980-9/2003		3/1989-12/2003
Total	# of samples	108		135
(mg/l as N)	Min	0.13		0.01 (BDL)
00630	Max	2.80		10.7
	Mean	0.74		0.54*
	Median	0.70		0.40
	StdDev	0.35		0.95*

Appendix A2 (continued)

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach)* 25 (26)	615 (31)	895 (35)
Nitrite plus Nitrate Dissolved	Date range	7/1988-7/2000		
(mg/l as N)	# of samples	1		
00631	Min	0.501		
	Max	0.501		
	Mean	0.501		
	Median	0.501		
	StdDev			
Total Phosphorus	Date range	12/1977-9/2003	3/1991-6/1998	3/1989-12/2003
(mg/l as P)	# of samples	105	63	135
00665	Min	0.001 (BDL)	BDL	0.010 (BDL)
	Max	0.260	0.380	2.510
	Mean	0.062*	0.147*	0.157*
	Median	0.050	0.130	0.090
	StdDev	0.041*	0.087*	0.281*
Dissolved Phosphorus	Date range	5/1978-9/2003		3/1989-6/2001
(mg/l as P)	# of samples	112		110
00666	Min	0.001 (BDL)		0.010 (BDL)
	Max	0.220		2.300
	Mean	0.022*		0.084*
	Median	0.020		0.050
	StdDev	0.022*		0.218*
Ortho-P	Date range	10/1976-7/2000		
(mg/l)	# of samples	1		
00671	Min	0.017		
	Max	0.017		
	Mean	0.017		
	Median	0.017		
	StdDev			
DO	Date range	6/1977-9/2003	9/1994-8/1995	3/1989-12/2003
(mg/l)	# of samples	165	30	135
00299, 00300	Min	5.86	6.50	3.90
	Max	16.2	14.5	15.0
	Mean	10.3	10.1	9.25
	Median	9.98	9.20	9.10
	StdDev	2.37	2.64	2.45
DO	Date range	6/1977-12/1998		
(% saturation)	# of samples	72		
00301	Min	65.2		
	Max	134		
	Mean	90.8		
	Median	88.9		
	StdDev	13.7		

Appendix A2 (concluded)

Water quality constituent (units) and STORET code	*Statistics*	*FoxDB Station (HSPF Reach)* 25 (26)	615 (31)	895 (35)
BOD	Date range		2/1991-8/1998	3/1989-12/1991
(mg/l)	# of samples		257	14
00310	Min		BDL	1 (BDL)
	Max		11.0	7
	Mean		1.33*	2.71*
	Median		1.00	2.00
	StdDev		1.56*	1.54*
Fecal Coliforms	Date range	11/1980-9/2000	2/1991-8/1998	3/1989-12/2003
(cfu/100 ml)	# of samples	54	216	135
31616	Min	10 (BDL)	BDL	10
	Max	TNTC	TNTC	70000
	Mean	2300**	9911**	2337
	Median	398**	290**	210
	StdDev	6923**	95946**	7895
Chlorophyll-A	Date range			2/2002-12/2003
Spectrophotometric	# of samples			18
Corrected	Min			2.30
(µg/l)	Max			32.1
32211	Mean			15.2
	Median			15.6
	StdDev			8.84
Chlorophyll-A,	Date range	7/1988-7/2000		
Phytoplankton,	# of samples	1		
Chromo-Fluoro	Min	12.1		
(µg/l)	Max	12.1		
70953	Mean	12.1		
	Median	12.1		
	StdDev			
Chlorophyll-A,	Date range	7/2000		
Periphyton,	# of samples	1		
Chromo-Fluoro	Min	25.3		
(µg/l)	Max	25.3		
70957	Mean	25.3		
	Median	25.3		
	StdDev			

Notes: SU = standard units.
BDL = below detection limit.
TNTC = too numerous to count.
* Calculated values may be affected due to presence of BDL values.
** Calculated values may be affected due to presence of TNTC values.

Appendix B. Subwatershed Characteristics

Table B-1. Blackberry Creek Watershed Model

Subwatershed ID	*Total area, acre*	*Pervious area, acre*	*Impervious area, acre*	*Impervious fraction of total area, %*
1	1486	1478	8	0.5
2	2002	1909	93	4.6
3	2937	2891	46	1.6
4	1430	1417	13	0.9
5	1168	1140	28	2.4
6	524	498	26	5.0
7	1605	1587	18	1.1
8	608	605	3	0.5
9	1657	1641	16	1.0
10	255	253	2	0.8
11	564	561	3	0.5
12	1023	999	24	2.3
13	4147	4118	29	0.7
14	688	617	71	10.3
15	2078	1790	288	13.9
16	432	416	16	3.7
17	2201	2129	72	3.3
18	1153	1060	93	8.1
19	1318	1268	50	3.8
20	1450	1394	56	3.9
21	3383	3324	59	1.7
22	853	809	44	5.2
23	569	560	9	1.6
24	2139	1961	178	8.3
25	3330	3275	55	1.7
26	4589	4131	458	10.0
27	1431	1420	11	0.8
28	2747	2720	27	1.0
Total	47767	45971	1796	3.8

Table B-2. Poplar Creek Watershed Model

Subwater-shed ID	*Total area, acre*	*Pervious area, acre*	*Impervious area, acre*	*Impervious fraction of total area, %*
1	492	466	26	5.3
2	967	967	0	0.0
3	656	628	28	4.2
4	318	299	19	5.8
5	480	407	73	15.2
6	1502	1394	108	7.2
7	928	870	58	6.2
8	900	773	127	14.1
9	211	211	0	0.0
10	712	476	236	33.1
11	938	790	148	15.8
12	750	699	51	6.8
13	101	101	0	0.0
14	2005	1388	617	30.8
15	783	783	0	0.0
16	359	306	53	14.7
17	1761	1523	238	13.5
18	857	826	31	3.6
19	573	529	44	7.7
20	1300	907	393	30.2
21	482	482	0	0.0
22	760	710	50	6.6
23	431	329	102	23.6
24	2606	1810	796	30.6
25	1236	870	366	29.6
26	335	243	92	27.5
27	128	98	30	23.4
28	940	828	112	11.9
29	188	179	9	4.7
30	677	658	19	2.8
31	363	325	38	10.6
32	357	337	20	5.7
33	462	411	51	11.0
34	537	410	127	23.7
35	611	503	108	17.6
36	1087	1049	38	3.5
Total	27793	23586	4207	15.1

Appendix C. Types of Hydrologic Response Units (HRUs) in the Poplar Creek and the Blackberry Creek Watersheds

		Blackberry Creek watershed		*Poplar Creek watershed*	
No.	*HRU Type*[1]	*Total area, acre*	*Fraction of area, %*	*Total area, acre*	*Fraction of area, %*
1	COR21	9968	20.9	128	0.5
2	COR22	2459	5.1	252	0.9
3	COR31	1243	2.6	0	0.0
4	COR32	0	0.0	573	2.1
5	FOR21	2179	4.6	0	0.0
6	FOR22	1090	2.3	852	3.1
7	FOR23	0	0.0	191	0.7
8	FOR31	414	0.9	0	0.0
9	FOR32	0	0.0	1912	6.9
10	FOR33	0	0.0	289	1.0
11	FOR42	0	0.0	789	2.8
12	FOR43	0	0.0	164	0.6
13	SOY21	8466	17.7	225	0.8
14	SOY22	2754	5.8	165	0.6
15	SOY31	904	1.9	0	0.0
16	SOY32	0	0.0	174	0.6
17	SWA21	125	0.3	0	0.0
18	SWA22	99	0.2	151	0.5
19	SWA23	0	0.0	14	0.1
20	SWA31	54	0.1	0	0.0
21	SWA32	0	0.0	138	0.5
22	SWA42	0	0.0	202	0.7
23	SWM21	324	0.7	0	0.0
24	SWM22	93	0.2	67	0.2
25	SWM23	0.0	0.0	27	0.1
26	SWM31	75	0.2	0	0.0
27	SWM41	108	0.2	0	0.0
28	SWM42	0	0.0	141	0.5
29	UHD21	0	0.0	17	0.1
30	UHD22	0	0.0	71	0.3
31	UHD23	0	0.0	14	0.1
32	UHD31	0	0.0	25	0.1
33	UHD32	0	0.0	310	1.1
34	UHDIe1	328*	0.7*	94	0.3
35	UHDIe2	93*	0.2*	857	3.1
36	UHDIe3	108*	0.2*	37	0.1

Appendix C (concluded)

No.	HRU Type[1]	Blackberry Creek watershed Total area, acre	Blackberry Creek watershed Fraction of area, %	Poplar Creek watershed Total area, acre	Poplar Creek watershed Fraction of area, %
37	UHDIn1	0	0.0	31	0.1
38	UHDIn2	0	0.0	286	1.0
39	UHDIn3	0	0.0	13	0.1
40	ULM21	0	0.0	179	0.6
41	ULM22	0	0.0	925	3.3
42	ULM23	0	0.0	173	0.6
43	ULM31	0	0.0	593	2.1
44	ULM32	0	0.0	3455	12.4
45	ULM33	0	0.0	94	0.3
46	ULM42	0	0.0	202	0.7
47	ULM43	0	0.0	29	0.1
48	ULMIe1	856*	1.8*	208	0.8
49	ULMIe2	215*	0.5*	1163	4.2
50	ULMIe3	196*	0.4*	75	0.3
51	ULMIn1	0	0.0	208	0.8
52	ULMIn2	0	0.0	1163	4.2
53	ULMIn3	0	0.0	72	0.3
54	UOS21	4312	9.0	241	0.9
55	UOS22	1311	2.7	1341	4.8
56	UOS23	0	0.0	323	1.2
57	UOS31	1062	2.2	183	0.7
58	UOS32	0	0.0	6129	22.1
59	UOS33	0	0.0	373	1.3
60	UOS41	0	0.0	107	0.4
61	UOS42	0	0.0	2067	7.4
62	UOS43	0	0.0	281	1.0
63	RGR21	5216	10.9	0	0.0
64	RGR22	2616	5.5	0	0.0
65	RGR31	1099	2.3	0	0.0

Notes: [1]COR=Corn, SOY=Soybean, FOR=Forest, SWA=Surface water, SWM=Wetland, UHD=Urban high density, ULM=Urban low-medium density, UOS=Urban open space, RGR=Rural grassland, I=Impervious, e=effective, and n=noneffective.
*effective and noneffective areas combined in the Blackberry Creek watershed.

Appendix D1. Hydrologic Response Units (HRUs) in the Subwatersheds of the Blackberry Creek Watershed Model

HRU type[1]	*Subwatershed ID*	*HRU area, acre*	*HRU type*[1]	*Subwatershed ID*	*HRU area, acre*	*HRU type*[1]	*Subwatershed ID*	*HRU area, acre*
COR22	1	530	ULM22*	5	14	RGR21	11	146
SOY22	1	434	COR22	6	93	FOR21	11	26
RGR22	1	359	SOY22	6	92	UOS21	11	6
FOR22	1	131	RGR22	6	159	SWM21	11	4
UOS22	1	16	FOR22	6	11	SWA21	11	2
SWM22	1	8	UOS22	6	129	ULM22*	11	3
ULM22*	1	8	SWA22	6	14	COR22	12	289
COR22	2	628	ULM22*	6	8	SOY22	12	249
SOY22	2	527	ULM22*	6	18	RGR22	12	267
RGR22	2	223	COR22	7	137	FOR22	12	133
FOR22	2	93	SOY22	7	259	UOS22	12	49
UOS22	2	427	RGR22	7	647	SWM22	12	8
SWM22	2	5	FOR22	7	391	SWA22	12	4
SWA22	2	6	UOS22	7	108	ULM22*	12	3
ULM22*	2	33	SWM22	7	27	ULM22*	12	21
ULM22*	2	60	SWA22	7	18	COR21	13	1857
COR22	3	656	ULM22*	7	3	SOY21	13	1446
SOY22	3	1073	ULM22*	7	15	RGR21	13	487
RGR22	3	672	COR21	8	328	FOR21	13	258
FOR22	3	237	SOY21	8	163	UOS21	13	50
UOS22	3	242	RGR21	8	95	SWM21	13	20
SWM22	3	8	FOR21	8	10	ULM22*	13	4
SWA22	3	3	UOS21	8	5	ULM22*	13	25
ULM22*	3	23	SWM21	8	4	COR21	14	95
ULM22*	3	23	ULM22*	8	1	SOY21	14	207
COR21	4	311	ULM22*	8	2	RGR21	14	67
SOY21	4	754	COR31	9	273	FOR21	14	5
RGR21	4	276	SOY31	9	175	UOS21	14	220
FOR21	4	45	RGR31	9	671	SWM21	14	23
UOS21	4	19	FOR31	9	302	ULM22*	14	42
SWM21	4	9	UOS31	9	68	ULM22*	14	29
SWA21	4	3	SWM41	9	108	COR31	15	292
ULM22*	4	4	SWA31	9	44	SOY31	15	238
ULM22*	4	9	ULM22*	9	6	RGR31	15	174
COR21	5	87	ULM22*	9	10	FOR31	15	24
SOY21	5	288	COR21	10	70	UOS31	15	994
RGR21	5	675	SOY21	10	131	SWM31	15	58
FOR21	5	39	RGR21	10	47	SWA31	15	10
UOS21	5	31	UOS21	10	5	ULM22*	15	102
SWM21	5	11	ULM22*	10	2	ULM22*	15	186
SWA21	5	9	COR21	11	123	COR21	16	236
ULM22*	5	14	SOY21	11	254	SOY21	16	101

Appendix D1 (concluded)

HRU type[1]	*Subwatershed ID*	*HRU area, acre*	*HRU type*[1]	*Subwatershed ID*	*HRU area, acre*	*HRU type*[1]	*Subwatershed ID*	*HRU area, acre*
RGR21	16	33	ULM22*	20	7	COR21	25	1248
UOS21	16	44	ULM22*	20	49	SOY21	25	518
SWA21	16	2	COR21	21	700	RGR21	25	883
ULM22*	16	9	COR31	21	678	FOR21	25	198
ULM22*	16	7	SOY21	21	500	UOS21	25	366
COR21	17	653	SOY31	21	491	SWM21	25	46
SOY21	17	361	RGR21	21	400	SWA21	25	16
RGR21	17	593	RGR31	21	254	ULM22*	25	8
FOR21	17	301	FOR21	21	100	ULM22*	25	47
UOS21	17	178	FOR31	21	88	COR21	26	1114
SWM21	17	24	UOS21	21	96	SOY21	26	1137
SWA21	17	19	SWM31	21	17	RGR21	26	284
ULM22*	17	21	ULM22*	21	23	FOR21	26	163
ULM22*	17	51	ULM22*	21	36	UOS21	26	1354
COR22	18	126	COR21	22	149	SWM21	26	71
SOY22	18	120	SOY21	22	166	SWA21	26	8
RGR22	18	289	RGR21	22	125	ULM22*	26	108
FOR22	18	94	FOR21	22	51	ULM22*	26	350
UOS22	18	340	UOS21	22	274	COR21	27	430
SWM22	18	37	SWM21	22	12	SOY21	27	496
SWA22	18	54	SWA21	22	32	RGR21	27	380
ULM22*	18	23	ULM22*	22	8	FOR21	27	82
ULM22*	18	70	ULM22*	22	36	UOS21	27	22
COR21	19	278	COR21	23	110	SWM21	27	10
SOY21	19	159	SOY21	23	70	ULM22*	27	11
RGR21	19	188	RGR21	23	115	COR21	28	1239
FOR21	19	274	FOR21	23	176	SOY21	28	922
UOS21	19	356	UOS21	23	76	RGR21	28	107
SWM21	19	7	SWM21	23	13	FOR21	28	90
SWA21	19	6	ULM22*	23	9	UOS21	28	317
ULM22*	19	8	COR21	24	499	SWM21	28	31
ULM22*	19	42	SOY21	24	361	SWA21	28	14
COR21	20	441	RGR21	24	183	ULM22*	28	27
SOY21	20	432	FOR21	24	283			
RGR21	20	132	UOS21	24	588			
FOR21	20	78	SWM21	24	36			
UOS21	20	305	SWA21	24	11			
SWM21	20	3	ULM22*	24	71			
SWA21	20	3	ULM22*	24	107			

Notes: [1]COR=Corn, SOY=Soybean, FOR=Forest, SWA=Surface water, SWM=Wetland, UHD=Urban high density, ULM=Urban low-medium density, UOS=Urban open space, RGR=Rural grassland, I=Impervious, e=effective, and n=noneffective.
* effective and noneffective combined in the Blackberry Creek watershed.

Appendix D2. Hydrologic Response Units (HRUs) in the Subwatersheds of the Poplar Creek Watershed Model

HRU type[1]	*Subwater-shed ID*	*HRU area, acre*	*HRU type*[1]	*Subwater-shed ID*	*HRU area, acre*	*HRU type*[1]	*Subwater-shed ID*	*HRU area, acre*
SOY32	1	27	ULM32	6	201	UHDIn1	11	13
FOR32	1	57	UOS32	6	597	ULMIe1	11	48
FOR42	1	26	UOS42	6	246	ULMIn1	11	48
ULM32	1	48	ULMIe2	6	54	SOY22	12	101
ULM42	1	19	ULMIn2	6	54	FOR22	12	205
UOS32	1	134	SOY32	7	88	ULM22	12	94
UOS42	1	62	FOR32	7	90	UOS22	12	220
SWM42	1	28	ULM32	7	107	UOS42	12	79
SWA42	1	65	UOS32	7	441	ULMIe2	12	25
ULMIe2	1	13	UOS42	7	144	ULMIn2	12	25
ULMIn2	1	13	ULMIe2	7	29	COR32	13	29
FOR32	2	189	ULMIn2	7	29	COR22	13	16
FOR42	2	143	COR32	8	115	FOR32	13	7
UOS32	2	297	UHD32	8	25	FOR42	13	13
UOS42	2	180	ULM32	8	99	UOS32	13	15
SWM42	2	56	ULM42	8	31	UOS42	13	21
SWA42	2	102	UOS32	8	504	UHD32	14	54
FOR32	3	64	UHDIe2	8	55	ULM32	14	844
ULM32	3	51	UHDIn2	8	18	UOS32	14	334
UOS32	3	297	ULMIe2	8	27	UOS42	14	156
UOS42	3	95	ULMIn2	8	27	UHDIe2	14	122
SWA32	3	121	COR32	9	84	UHDIn2	14	41
ULMIe2	3	14	COR22	9	32	ULMIe2	14	227
ULMIn2	3	14	FOR32	9	19	ULMIn2	14	227
FOR32	4	36	FOR42	9	17	COR32	15	120
ULM32	4	34	UOS32	9	25	COR22	15	43
UOS32	4	159	UOS42	9	34	FOR42	15	85
UOS42	4	53	UHD32	10	50	UOS32	15	367
SWA32	4	17	ULM32	10	158	UOS42	15	168
ULMIe2	4	9	ULM42	10	52	FOR42	16	22
ULMIn2	4	9	UOS32	10	159	ULM32	16	98
COR32	5	35	UOS42	10	57	ULM42	16	27
UHD32	5	13	UHDIe2	10	113	UOS32	16	93
ULM32	5	62	UHDIn2	10	38	UOS42	16	66
UOS32	5	262	ULMIe2	10	43	ULMIe2	16	26
SWA42	5	35	ULMIn2	10	43	ULMIn2	16	26
UHDIe2	5	30	COR21	11	128	FOR32	17	277
UHDIn2	5	10	SOY21	11	225	UHD32	17	45
ULMIe2	5	17	UHD21	11	17	ULM32	17	192
ULMIn2	5	17	ULM21	11	179	ULM22	17	59
FOR32	6	235	UOS21	11	241	ULM42	17	56
FOR42	6	115	UHDIe1	11	39	UOS32	17	639

Appendix D2 (continued)

HRU type[1]	*Subwater-shed ID*	*HRU area, acre*	*HRU type*[1]	*Subwater-shed ID*	*HRU area, acre*	*HRU type*[1]	*Subwater-shed ID*	*HRU area, acre*
UOS22	17	255	ULMIe3	22	25	UOS23	27	18
UHDIe2	17	101	ULMIn3	22	25	UHDIe3	27	5
UHDIn2	17	34	FOR32	23	43	UHDIn3	27	2
ULMIe2	17	52	UHD32	23	8	ULMIe3	27	13
ULMIn2	17	52	ULM32	23	143	ULMIn3	27	10
FOR32	18	274	UOS32	23	102	FOR22	28	150
FOR42	18	116	UOS42	23	33	UHD22	28	21
ULM32	18	57	UHDIe2	23	19	ULM22	28	93
UOS32	18	379	UHDIn2	23	6	UOS22	28	346
ULMIe2	18	15	ULMIe2	23	39	SWM22	28	67
ULMIn2	18	15	ULMIn2	23	39	SWA22	28	151
COR32	19	120	FOR32	24	176	UHDIe2	28	47
COR22	19	50	UHD32	24	91	UHDIn2	28	16
FOR32	19	127	ULM32	24	973	ULMIe2	28	25
FOR42	19	56	UOS32	24	422	ULMIn2	28	25
UHD32	19	8	UOS42	24	148	FOR23	29	84
ULM32	19	38	UHDIe2	24	204	ULM23	29	16
UOS32	19	68	UHDIn2	24	68	UOS23	29	38
UOS42	19	62	ULMIe2	24	262	SWM23	29	27
UHDIe2	19	18	ULMIn2	24	262	SWA23	29	14
UHDIn2	19	6	FOR22	25	77	ULMIe3	29	4
ULMIe2	19	10	FOR42	25	29	ULMIn3	29	4
ULMIn2	19	10	UHD22	25	35	COR22	30	65
UHD31	20	25	ULM22	25	484	FOR22	30	378
ULM31	20	593	UOS22	25	179	ULM22	30	35
UOS31	20	183	UOS42	25	66	UOS22	30	180
UOS41	20	107	UHDIe2	25	79	ULMIe2	30	9
UHDIe1	20	55	UHDIn2	25	26	ULMIn2	30	9
UHDIn1	20	18	ULMIe2	25	130	COR22	31	46
ULMIe1	20	160	ULMIn2	25	130	SOY22	31	64
ULMIn1	20	160	FOR42	26	35	FOR22	31	42
FOR33	21	127	UHD22	26	10	UHD22	31	5
FOR43	21	80	ULM22	26	117	ULM22	31	44
UOS33	21	127	UOS22	26	59	UOS22	31	102
UOS23	21	61	UOS42	26	22	SWM42	31	22
UOS43	21	87	UHDIe2	26	22	UHDIe2	31	11
FOR33	22	162	UHDIn2	26	7	UHDIn2	31	4
FOR43	22	58	ULMIe2	26	32	ULMIe2	31	12
ULM33	22	94	ULMIn2	26	32	ULMIn2	31	12
ULM43	22	29	FOR23	27	19	SOY32	32	59
UOS33	22	246	FOR43	27	26	FOR42	32	27
UOS43	22	121	ULM23	27	35	ULM32	32	38

Appendix D2 (concluded)

HRU type[1]	*Subwatershed ID*	*HRU area, acre*	*HRU type[1]*	*Subwatershed ID*	*HRU area, acre*	*HRU type[1]*	*Subwatershed ID*	*HRU area, acre*
ULM42	32	17	ULMIn2	33	15	UOS43	35	73
UOS32	32	116	FOR32	34	38	UHDIe3	35	32
UOS42	32	80	UHD32	34	9	UHDIn3	35	11
ULMIe2	32	10	ULM32	34	187	ULMIe3	35	33
ULMIn2	32	10	UOS32	34	109	ULMIn3	35	33
FOR32	33	77	UOS42	34	67	COR32	36	70
UHD32	33	7	UHDIe2	34	20	FOR32	36	203
ULM32	33	54	UHDIn2	34	7	FOR42	36	105
UOS32	33	168	ULMIe2	34	50	ULM32	36	71
UOS42	33	70	ULMIn2	34	50	UOS32	36	442
SWM42	33	35	FOR23	35	88	UOS42	36	158
UHDIe2	33	16	UHD23	35	14	ULMIe2	36	19
UHDIn2	33	5	ULM23	35	122	ULMIn2	36	19
ULMIe2	33	15	UOS23	35	206			

Note: [1]COR=Corn, SOY=Soybean, FOR=Forest, SWA=Surface water, SWM=Wetland, UHD=Urban high density, ULM=Urban low-medium density, UOS=Urban open space, RGR=Rural grassland, I=Impervious, e=effective, and n=noneffective.

Appendix E. Illinois Toxicity-Based Water Quality Standard for NH_4-N (after IAC, 2002)

Table E-1. pH-Dependent Values of the AS (Acute Standard)

pH	*Acute Standard (mg/l)*
≤7.6	15.0
7.7	14.4
7.8	12.1
7.9	10.1
8.0	8.41
8.1	6.95
8.2	5.73
8.3	4.71
8.4	3.88
8.5	3.20
8.6	2.65
8.7	2.20
8.8	1.84
8.9	1.56
9.0	1.32

Table E-2. Temperature and pH-Dependent Values of the CS (Chronic Standard) for Fish Early Life Stages Absent

pH	*Temperature, °C*									
	0-7	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
6.0	11.3	10.6	9.92	9.30	8.72	8.17	7.66	7.19	6.74	6.32
6.1	11.2	10.5	9.87	9.25	8.67	8.13	7.62	7.15	6.70	6.28
6.2	11.2	10.5	9.81	9.19	8.62	8.08	7.58	7.10	6.66	6.24
6.3	11.1	10.4	9.73	9.12	8.55	8.02	7.52	7.05	6.61	6.19
6.4	11.0	10.3	9.63	9.03	8.47	7.94	7.44	6.98	6.54	6.13
6.5	10.8	10.1	9.51	8.92	8.36	7.84	7.35	6.89	6.46	6.06
6.6	10.7	9.99	9.37	8.79	8.24	7.72	7.24	6.79	6.36	5.97
6.7	10.5	9.81	9.20	8.62	8.08	7.58	7.11	6.66	6.25	5.86
6.8	10.2	9.58	8.98	8.42	7.90	7.40	6.94	6.51	6.10	5.72
6.9	9.93	9.31	8.73	8.19	7.68	7.2	6.75	6.33	5.93	5.56
7.0	9.60	9.00	8.43	7.91	7.41	6.95	6.52	6.11	5.73	5.37
7.1	9.20	8.63	8.09	7.58	7.11	6.67	6.25	5.86	5.49	5.15
7.2	8.75	8.20	7.69	7.21	6.76	6.34	5.94	5.57	5.22	4.90
7.3	8.24	7.73	7.25	6.79	6.37	5.97	5.6	5.25	4.92	4.61
7.4	7.69	7.21	6.76	6.33	5.94	5.57	5.22	4.89	4.59	4.30
7.5	7.09	6.64	6.23	5.84	5.48	5.13	4.81	4.51	4.23	3.97
7.6	6.46	6.05	5.67	5.32	4.99	4.68	4.38	4.11	3.85	3.61
7.7	5.81	5.45	5.11	4.79	4.49	4.21	3.95	3.70	3.47	3.25
7.8	5.17	4.84	4.54	4.26	3.99	3.74	3.51	3.29	3.09	2.89
7.9	4.54	4.26	3.99	3.74	3.51	3.29	3.09	2.89	2.71	2.54
8.0	3.95	3.70	3.47	3.26	3.05	2.86	2.68	2.52	2.36	2.21
8.1	3.41	3.19	2.99	2.81	2.63	2.47	2.31	2.17	2.03	1.91
8.2	2.91	2.73	2.56	2.40	2.25	2.11	1.98	1.85	1.74	1.63
8.3	2.47	2.32	2.18	2.04	1.91	1.79	1.68	1.58	1.48	1.39
8.4	2.09	1.96	1.84	1.73	1.62	1.52	1.42	1.33	1.25	1.17
8.5	1.77	1.66	1.55	1.46	1.37	1.28	1.2	1.13	1.06	0.99
8.6	1.49	1.40	1.31	1.23	1.15	1.08	1.01	0.95	0.89	0.84
8.7	1.26	1.18	1.11	1.04	0.98	0.92	0.86	0.80	0.75	0.71
8.8	1.07	1.01	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60
8.9	0.92	0.86	0.81	0.76	0.71	0.66	0.62	0.58	0.55	0.51
9.0	0.79	0.74	0.69	0.65	0.61	0.57	0.54	0.50	0.47	0.44

Note: At 15°C and above, the criterion for fish ELS Absent is the same as the criterion for fish ELS Present.

Table E-3. Temperature and pH-Dependent Values of the CS (Chronic Standard) for Fish Early Life Stages Present

pH	Temperature, °Celsius									
	0	*14*	*16*	*18*	*20*	*22*	*24*	*26*	*28*	*30*
6.0	6.95	6.95	6.32	5.55	4.88	4.29	3.77	3.31	2.91	2.56
6.1	6.91	6.91	6.28	5.52	4.86	4.27	3.75	3.30	2.90	2.55
6.2	6.87	6.87	6.24	5.49	4.82	4.24	3.73	3.28	2.88	2.53
6.3	6.82	6.82	6.19	5.45	4.79	4.21	3.70	3.25	2.86	2.51
6.4	6.75	6.75	6.13	5.39	4.74	4.17	3.66	3.22	2.83	2.49
6.5	6.67	6.67	6.06	5.33	4.68	4.12	3.62	3.18	2.80	2.46
6.6	6.57	6.57	5.97	5.25	4.61	4.05	3.56	3.13	2.75	2.42
6.7	6.44	6.44	5.86	5.15	4.52	3.98	3.50	3.07	2.70	2.37
6.8	6.29	6.29	5.72	5.03	4.42	3.89	3.42	3.00	2.64	2.32
6.9	6.12	6.12	5.56	4.89	4.30	3.78	3.32	2.92	2.57	2.25
7.0	5.91	5.91	5.37	4.72	4.15	3.65	3.21	2.82	2.48	2.18
7.1	5.67	5.67	5.15	4.53	3.98	3.50	3.08	2.70	2.38	2.09
7.2	5.39	5.39	4.90	4.31	3.78	3.33	2.92	2.57	2.26	1.99
7.3	5.08	5.08	4.61	4.06	3.57	3.13	2.76	2.42	2.13	1.87
7.4	4.73	4.73	4.30	3.78	3.32	2.92	2.57	2.26	1.98	1.74
7.5	4.36	4.36	3.97	3.49	3.06	2.69	2.37	2.08	1.83	1.61
7.6	3.98	3.98	3.61	3.18	2.79	2.45	2.16	1.90	1.67	1.47
7.7	3.58	3.58	3.25	2.86	2.51	2.21	1.94	1.71	1.50	1.32
7.8	3.18	3.18	2.89	2.54	2.23	1.96	1.73	1.52	1.33	1.17
7.9	2.80	2.80	2.54	2.24	1.96	1.73	1.52	1.33	1.17	1.03
8.0	2.43	2.43	2.21	1.94	1.71	1.50	1.32	1.16	1.02	0.90
8.1	2.10	2.10	1.91	1.68	1.47	1.29	1.14	1.00	0.88	0.77
8.2	1.79	1.79	1.63	1.43	1.26	1.11	0.97	0.86	0.75	0.66
8.3	1.52	1.52	1.39	1.22	1.07	0.94	0.83	0.73	0.64	0.56
8.4	1.29	1.29	1.17	1.03	0.91	0.80	0.70	0.62	0.54	0.48
8.5	1.09	1.09	0.99	0.87	0.76	0.67	0.59	0.52	0.46	0.40
8.6	0.92	0.92	0.84	0.73	0.65	0.57	0.50	0.44	0.39	0.34
8.7	0.78	0.78	0.71	0.62	0.55	0.48	0.42	0.37	0.33	0.29
8.8	0.66	0.66	0.60	0.53	0.46	0.41	0.36	0.32	0.28	0.24
8.9	0.56	0.56	0.51	0.45	0.40	0.35	0.31	0.27	0.24	0.21
9.0	0.49	0.49	0.44	0.39	0.34	0.30	0.26	0.23	0.20	0.18

Note: At 15°C and above, the criterion for fish ELS Absent is the same as the criterion for fish ELS Present.

Illinois State WATER Survey (1895)

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