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Fox River Watershed Investigation: Stratton Dam to the Illinois River

Phase II

Blackberry Creek and Poplar Creek Hydrologic and Water Quality Simulation Models

Executive Summary

by

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A Division of the Illinois Department of Natural Resources
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Abstract

This report summarizes model preparation and results from hydrologic and water quality simulation models for two major tributaries to the Fox River, Blackberry Creek and Poplar Creek. These models were prepared under contract with the Fox River Study Group, Inc. as part of a multiphase project for the Fox River watershed below Stratton Dam. Blackberry Creek and Poplar Creek watersheds were selected for study as they represent a variety of land uses in the Fox River watershed in the study area below Stratton Dam and also have long-term flow records and some water quality data. Blackberry Creek watershed represents primarily agricultural land use. Poplar Creek watershed represents primarily urban land use. Hydrologic and water quality components of the Hydrological Simulation Program FORTRAN (HSPF) model version 12 were calibrated to the extent possible with available data under time and resource constraints. Results of the hydrologic simulation models for each tributary are very good for the range of flow conditions of interest. Sufficient water quality data are not available to allow a full evaluation of the performance of the water quality simulations; however, simulated water quality components do follow trends indicated by observed data available. The models may be used to simulate watershed hydrology and provide qualitative comparisons of water quality constituent loading from the two watersheds. Model parameters developed through this process will be applied during preparation of HSPF models for other tributary watersheds to the Fox River.

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Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect those of the Fox River Study Group or the Illinois State Water Survey.

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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. It summarizes model preparation and results from hydrologic and water quality simulation models for two tributaries of the Fox River, Blackberry Creek and Poplar Creek. 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. The suite of water quality models envisioned will characterize the various sources and causes of impairment.

Reporting Structure

The Phase I report (McConkey et al., 2004) reviews 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 (HSPF) model version 12 (Bicknell et al., 2001) was selected to simulate watershed loading, delivery, and routing of point and nonpoint 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 watershed hydrology. 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). The Part 2 report (Bartosova et al., 2007a) 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. Hydrologic model parameters were validated using climate and streamflow data from a period other than the calibration period. Sensitivity analyses were performed.

The Part 3 report (Bartosova et al., 2007b) 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 report also discusses confidence in model simulations.

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.

This report provides a summary of model preparation and initial results from the HSPF models for the Blackberry Creek and Poplar Creek watersheds, major tributaries to the Fox River in northeastern Illinois, discussed more thoroughly in the Part 1 and 2 reports.

Modeling Approach

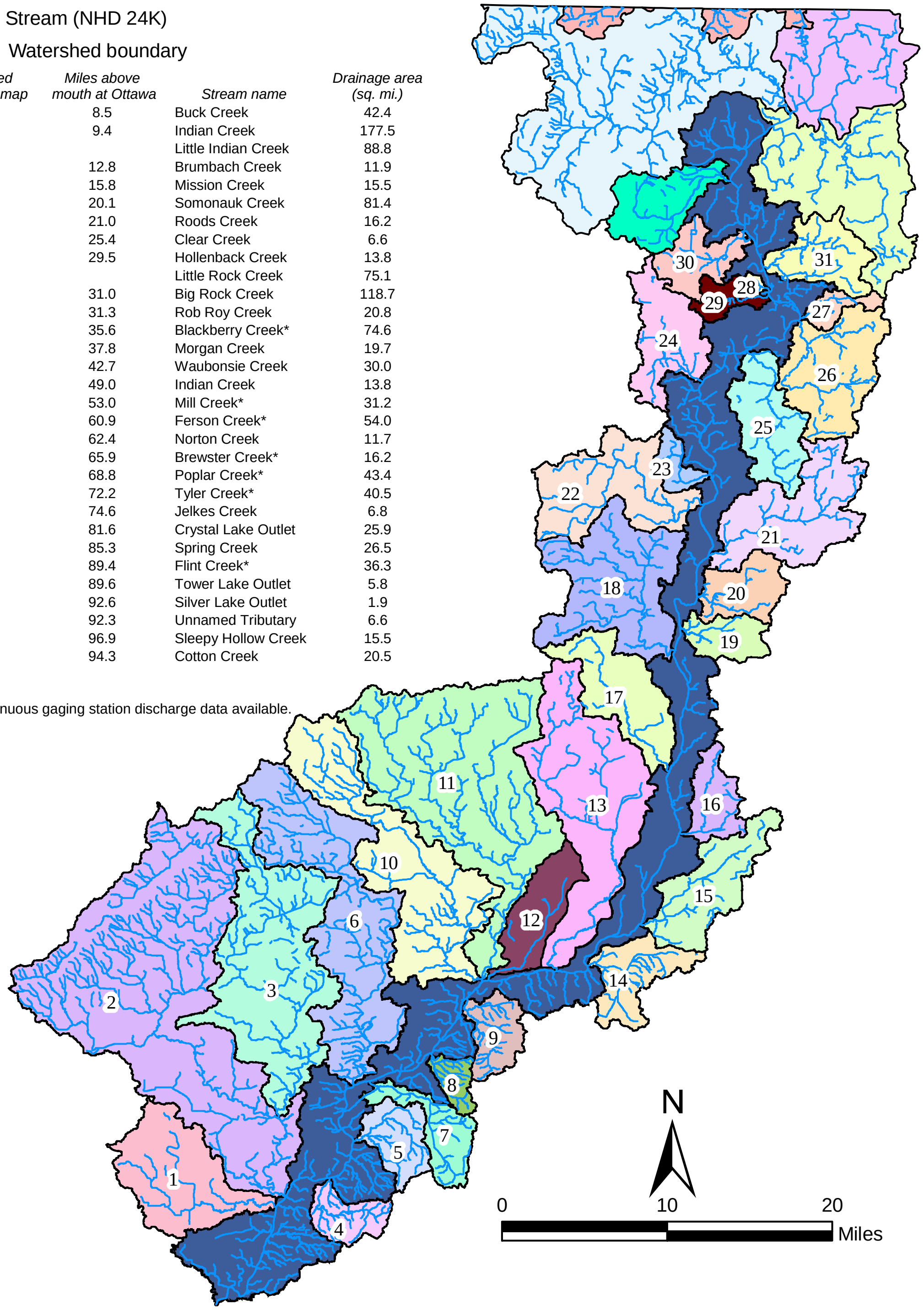
The modeling plan was designed to meet several objectives:

- Use standard, public domain models that are widely accepted and used.
- Disseminate modeling results so that other investigators readily can use and build on the knowledge base.
- Use models that adequately mimic physical, chemical, and biological processes to allow transfer of results and to provide tools for investigating future conditions and alternate scenarios.
- Enable easy updates and improvements as more information becomes available through the model structure. McConkey et al. (2004) provide modeling recommendations.

A suite of water quality models is being prepared to simulate various sources of pollutants and their impact on water quality. Watershed loading models will provide insights on the impacts of land use change, delivery of pollutants from nonpoint sources, and watershed hydrology.

- The HSPF model version 12 (Bicknell et al., 2001) was selected as the watershed loading model. This widely accepted model includes detailed hydrologic processes and options to simulate pollutant generation and transport for a variety of flow conditions.
- The United States Environmental Protection Agency (USEPA) QUAL2 model (Brown and Barnwell, 1987; Chapra and Pelletier, 2003) will be used to assess complex interactions and chemistry of various constituents in the Fox River during steady-state low-flow conditions.
- The ISWS is preparing individual HSPF watershed loading models for 31 major tributaries to the Fox River as well as components to simulate runoff from areas draining directly to the Fox River mainstem and processes in the mainstem. Figure 1 shows the Fox River watershed in Illinois and its tributary watersheds in the study area.

Watershed loading models will provide information on delivery of pollutants from the land surface. These models will be used primarily to simulate variable flow conditions more typical of medium to high flows. The initial modeling focuses on the Fox River mainstem; thus, the initial goal of preparing the tributary models is to simulate loading from the composite tributary watersheds to the Fox River. The overall model framework, however, allows incorporation of results in the Fox River mainstem model as individual watershed models are improved, possibly by individual watershed groups.



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 considered as separate HSPF models.

Standard models are based on functional relationships that must be tailored to the physical conditions and climate of individual watersheds. These specifications are accomplished through calibration, when the values of various model parameters are adjusted to achieve simulated values comparable to observed values. Limited precipitation, streamflow, and water quality data are available at present to calibrate and test each tributary watershed model, however. Given this limitation, two tributary watersheds were selected for calibration of model parameters. Values of model parameters then will be transferred to other watershed models.

The Blackberry Creek and Poplar Creek watersheds were chosen as the pilot watersheds as they represent contrasting land uses, agricultural and urban, respectively, and also have long-term flow records and some water quality data spanning the calibration and validation period. Long-term simulation is needed (at least 10 years) to calibrate the HSPF model hydrology components. Water years (WY) 1991-2003 represent the most current time period available at study initiation and were selected as the study period. The study period then was divided into respective calibration and validation periods.

Initial calibration of the two tributary watersheds is constrained by data availability, notably climate data for the hydrologic model and water quality data for the water quality model. Initial calibration of water quality reported herein is a starting point for a qualitative comparison of pollution sources, and the calibration process provides insight to high-priority data needs. The long-term plan includes further calibration of models using data collected as described in the monitoring plan (Bartosova et al., 2005). Results from calibration and validation model runs establish confidence in model application and also typical variation between model outputs and measured values.

Using various conditions in model calibration is crucial for evaluating different management options or land use scenarios. The stepwise calibration process used in this project was designed to develop and test calibration parameters under different conditions. The pilot watersheds represent contrasting land uses and different soil conditions. Five additional watersheds with discharge data available were used to evaluate performance of calibration parameters outside the pilot watersheds (Bartosova et al., 2007b). Parameters will be fine-tuned on the Fox River mainstem during the next part of the study.

Numerous chemical, physical, and biological constituents must be considered in assessing the health of a river. This study focuses on chemical and biological constituents identified by the IEPA as contributing to the impairment of the Fox River and its tributaries. The following water quality constituents were chosen for detailed simulation (McConkey et al., 2004): suspended sediment (SS), nitrogen, phosphorus, dissolved oxygen (DO), algae (chlorophyll *a*), and fecal coliforms. The model also must include additional constituents 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.

Watershed Descriptions

The 73-square-mile (sq. mi.) Blackberry Creek watershed is located in south-central Kane County and north-central Kendall County, Illinois. Blackberry Creek is a 32-mile-long stream originating north of Elburn in central Kane County and draining to the Fox River near Yorkville in Kendall County. Nearly 54% of the Blackberry Creek watershed is covered with row crops such as corn and soybeans. Urban high density or urban low/medium density areas and urban open space cover nearly 18% of the watershed area. About 9% 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. 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 sq. mi. Poplar Creek watershed is located in eastern Kane County and western Cook County, Illinois. Poplar Creek is an 18-mile-long stream originating northwest of South Barrington in Cook County and draining to the Fox River near Elgin in Kane County. Nearly 75% of the Poplar Creek watershed is covered with urban high density and urban low/medium density areas, and urban open space. Nearly 15% 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 and Table 2 compare the distribution of land use and hydrologic soil groups, respectively, in the Fox River watershed and the 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 more closely mimics that of the entire Fox River watershed while the Poplar Creek watershed represents encroaching development from the Chicago metropolitan area.

The hydrologic soil group classification used is from the U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey Manual* (Soil Survey Division Staff, 1993). The description of each soil group is provided in Table 3, a reproduction of Table 3-9 of the manual. Soils were classified based on hydrologic soil groups (A, B, C, or D) as specified in available digital soil coverages with the most detail. Soils A are highly permeable (e.g., sand) while soils D have a very low infiltration rate (e.g., clay). The most detailed soils data available were used in the analysis. Singh et al. (2007) and Bartosova et al. (2007a) provide complete details on the soil databases.

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

Model classification	*Percent watershed area*		
	*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
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.

Table 2. Representation of Hydrologic Soil Groups in the Study Area

Hydrologic soil group	*Percent watershed area*		
	*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

Notes: *Illinois portion of watershed only.
STATSGO = State Soil Geographic dataset.
SSURGO = Soil Survey Geographic dataset.

Table 3. Criteria for Placement in Hydrologic Soil Groups

Hydrologic soil group	*Criteria**
A	Saturated hydraulic conductivity is very high or in the upper half of high and internal free water occurrence is very deep.
B	Saturated hydraulic conductivity is in the lower half of high or in the upper half of moderately high and free water occurrence is deep or very deep.
C	Saturated hydraulic conductivity is in the lower half of moderately high or in the upper half of moderately low and internal free water occurrence is deeper than shallow.
D	Saturated hydraulic conductivity is below the upper half of moderately low and/or internal free water occurrence is shallow or very shallow and transitory though permanent.

Source: Soil Survey Division Staff (1993)

Note:
*The criteria are guidelines only. They are based on the assumption that the minimum saturated hydraulic conductivity occurs within the upper most 0.5 meter. If the minimum occurs between 0.5 and 1.0 meter, then saturated hydraulic conductivity for the purpose of placement is increased one class. If the minimum occurs below 1 meter, then the value for the soil is based on values above 1 meter using the rules previously given.

Data for Model Preparation

Precipitation is the driving force in the model simulations. Only climate stations with data collected during WY 1990-2003, the period of interest, can be considered. While there are two stations with precipitation data collected near the Blackberry Creek watershed, during the course of the project it was determined that only the Aurora station has a precipitation record consistent with the streamflow record near the watershed outlet. Hourly precipitation data for the St. Charles station also were being revised by the network operator and thus were not available. In addition to precipitation data, model simulations require other climate data such as temperature and evaporation. Climate data collected near St. Charles were used for the Blackberry Creek watershed model. Simulations for the Poplar Creek watershed benefit from input from three stations recording daily precipitation at Barrington, Streamwood, and Elgin. Climate data are available from stations at St Charles, O'Hare International Airport, and Rockford, Illinois. Climate data are available at hourly intervals, but most of the precipitation data recorded near the watersheds are daily totals. Resolution of the observed data limits model accuracy of streamflow simulations to daily averages at best, but the model can calculate values at hourly time steps.

Figure 2 shows the Blackberry Creek watershed and locations of precipitation and streamflow stations. There are two U.S. Geological Survey (USGS) streamflow gages in the Blackberry Creek watershed. The USGS streamflow gage at Yorkville (USGS ID 05551700) in Kendall County is near the mouth of Blackberry Creek. Station records start in 1961 and continue through the present. The drainage area is 70 sq. mi. The USGS gage at Montgomery (USGS ID 05551675) in Kane County is farther upstream. The gage became operational in 1998, and is active through the present. The drainage area is 55 sq. mi.

Figure 3 shows the Poplar Creek watershed and the locations of the precipitation and streamflow stations. There is one USGS streamflow gage in the Poplar Creek watershed at Elgin (USGS ID 05550500), which has a drainage area of 32.5 sq. mi.

Digital, spatial datasets were used to develop model input parameters that define physical characteristics of the watershed, including land use (land cover), soil types, and slope. Land cover for Illinois from the IILCP (IDOA, 2003) is 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. Soils data were gleaned from several different sources for the most detailed information. Watershed slope was derived from National Elevation Dataset (NED) raster data distributed by the USGS. Singh et al. (2007) and Bartosova et al. (2007a) describe these data in detail.

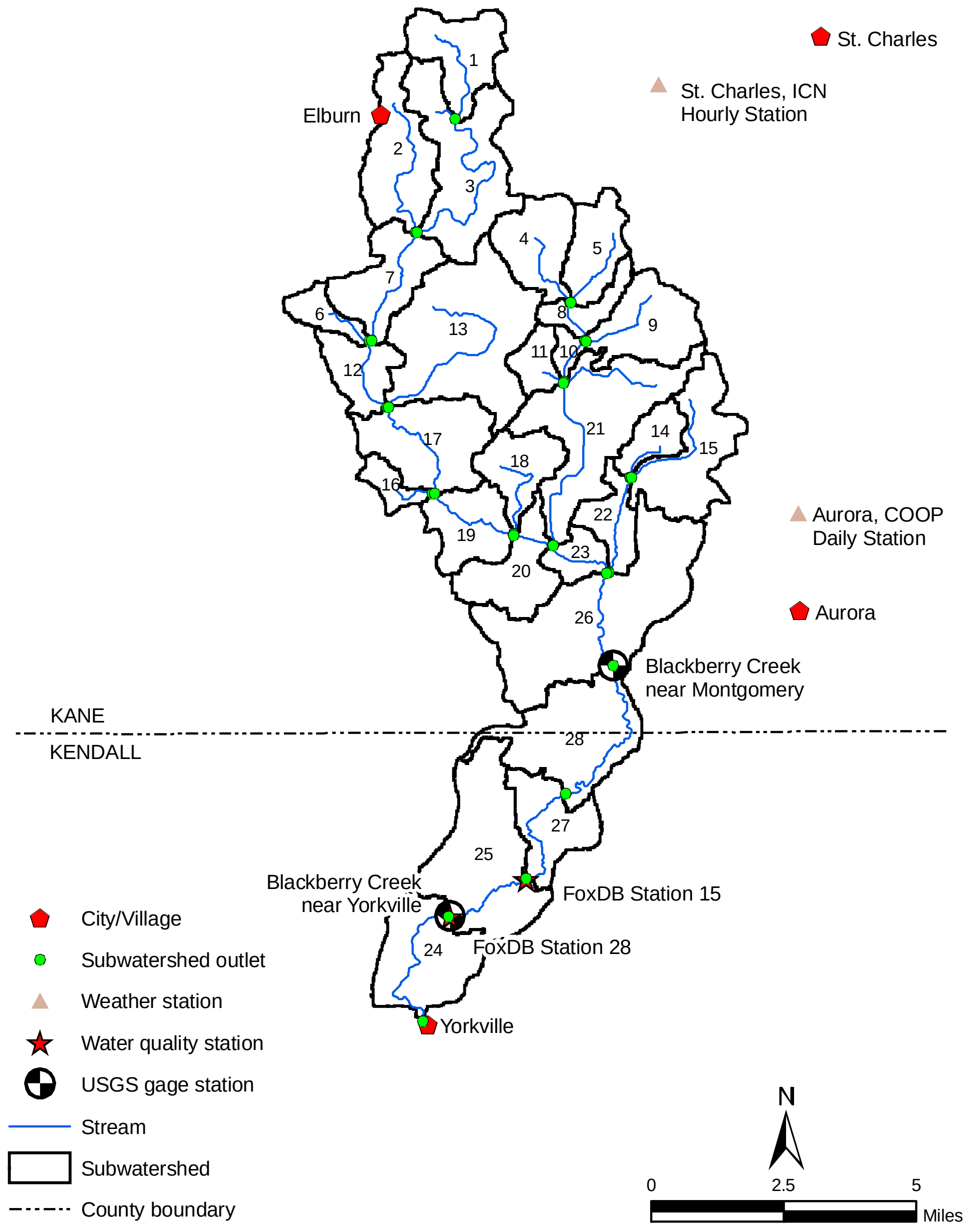


Figure 2. Delineation of Blackberry Creek watershed and location of precipitation and streamflow gages.

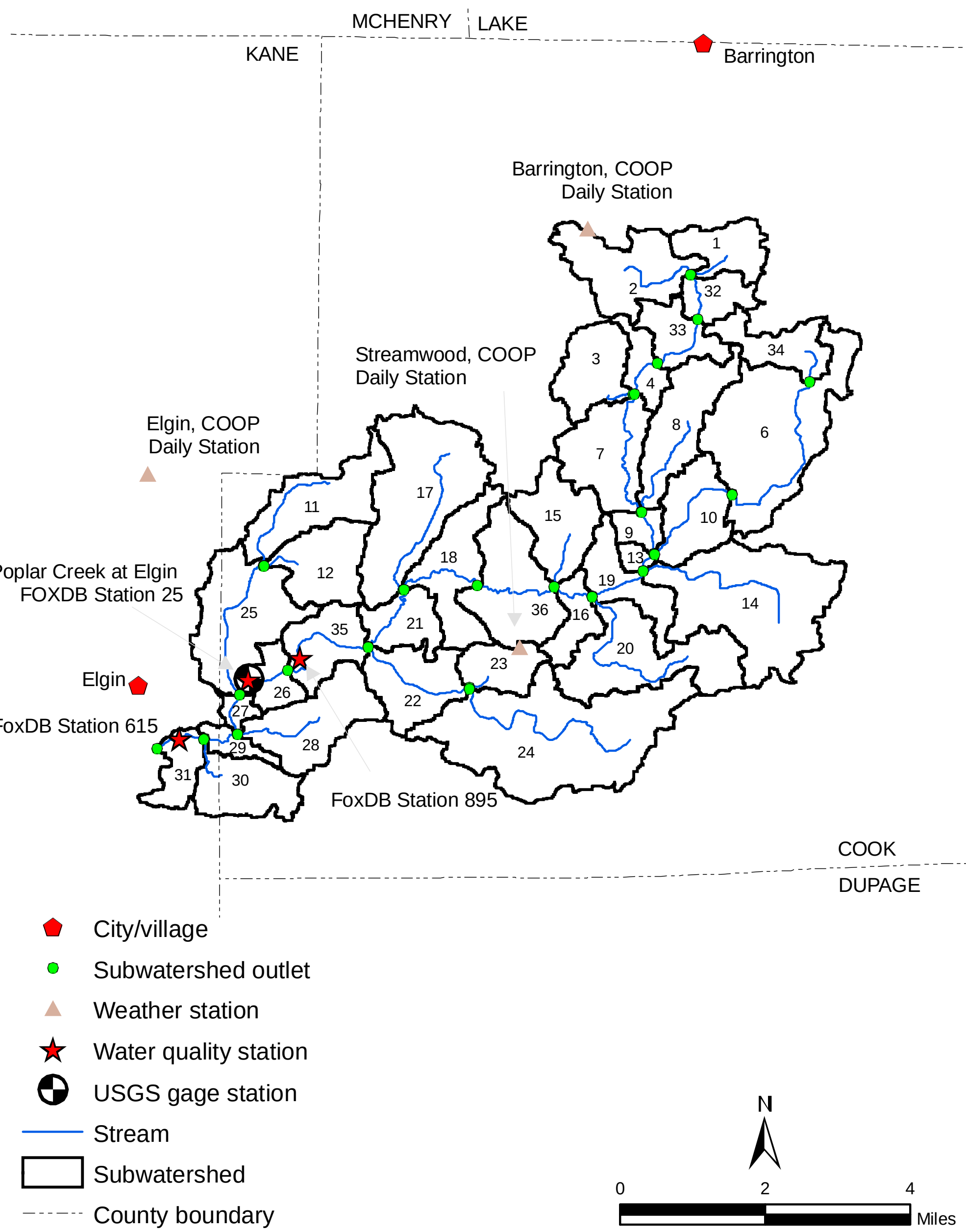


Figure 3. Delineation of the Poplar Creek watershed and location of precipitation and streamflow gages.

Water Quality Data

The FoxDB is a relational database of water quality data available for the Fox River watershed (McConkey et al., 2004). Water quality data are available for one station on Blackberry Creek (Figure 2) and three stations on Poplar Creek (Figure 3). The IEPA samples Blackberry Creek near Yorkville (Station 28 in the FoxDB) and Poplar Creek at Elgin (Station 25 in the FoxDB). Water quality data also are available for other locations (Station 615 and 895 in the FoxDB) sampled by the Fox River Water Reclamation District and the Metropolitan Water Reclamation District of Greater Chicago, respectively. Bartosova et al. (2007a) provide statistical analyses of various water quality constituents collected at the water quality stations.

Point Sources

Discharge of water from municipal, industrial, or private wastewater treatment plants and combined sewer overflows requires a permit from the IEPA through the National Pollution Discharge Elimination System (NPDES). A phased plan to include storm sewer outflows is also in place. Table 4 lists the NPDES facilities identified in the Blackberry Creek and Poplar Creek pilot watersheds. Information on discharges reported by permitted facilities to the USEPA and the IEPA are stored in the Permit Compliance System (PCS) database with recent data available online through the USEPA EnviroFacts data warehouse (USEPA, 2003). The PCS database includes required monthly average discharges and concentrations reported by individual permit owners. Some discharge reports include total suspended solids (TSS), pH, biochemical oxygen demand (BOD), and ammonium (NH_4-N), 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 the NPDES facilities located in the study watersheds were downloaded during the data compilation phase of the study reported in McConkey et al. (2004) and reformatted into HSPF model input time series. The IEPA also was contacted for any archived data.

Most facilities listed in Table 4 currently are not discharging into receiving streams. Blackberry Aquatic Center typically discharges only during summer months (May-August). Waubonsee Community College, the only facility reporting discharge regularly every month when data were acquired, stopped discharging in September 2006. Although some facilities may be inactive at present, model calibration requires historical discharges during the study period.

Table 4. 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.

Model Calibration Results

Simulating movement of water through the watershed, from precipitation to streamflow, is the foundation of water quality modeling. Hydrologic processes must be calibrated before attempting to model generation, transport, and transformation of any water quality constituents. The Blackberry Creek watershed model (i.e., rural hydrologic response units or HRUs) was calibrated first. Relevant model parameters were transferred directly to the Poplar Creek watershed model for HRUs with the same properties 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 (calculation point).

Model components are calibrated to achieve the closest match possible between simulated values and observations under time and resource constraints. Once this is achieved, models can be used to fill in data gaps and simulate possible future events. Given the limited knowledge of natural processes, the ability to create formulas expressing physical conditions, and data accuracy, perfect agreement is not expected. Comparison of simulated values and observations provides insights on model strengths and weaknesses, however. Calibration adjustments are made to improve accuracy of simulations for periods of interest, which in this project are times when water quality conditions are most critical. Singh et al. (2007) provide a full discussion of sources of uncertainty in the models.

Hydrologic Model Components

Calibration Results

Calibration of the hydrologic model components was a significant focus of this phase of the project. The objective of model calibration is to simulate daily streamflows (and later the concentration of constituents) from each tributary watershed. While there are many processes in the hydrologic cycle, only observed streamflow data were available for calibration. Precipitation data serve as model input. Singh et al. (2007) and Bartosova et al. (2007a) describe methodology and provide a detailed report of hydrologic calibration, respectively.

The hydrologic model simulates annual and monthly flows well but tends to overestimate streamflow during some low-flow summer months. The model shows no significant seasonal bias or bias over the range of streamflows. Simulated hydrographs generally follow the trend of observed hydrographs reasonably well, but the model underestimates or overestimates some peak values. Medium to low-flow events are typically the most critical for water quality conditions, and, fortunately, closeness of fit for this range of flows of greatest interest is excellent. Figure 4 compares simulated and observed annual flows in Blackberry Creek at Yorkville. Figure 5 shows flow duration curves generated from simulated and observed daily flows. Figure 6 and Figure 7 show a similar comparison of annual and daily flows in Poplar Creek at Elgin during the calibration period. Model performance during the validation and calibration periods is generally comparable. During the calibration period, simulated and observed hydrographs are generally similar, but the model underestimates or overestimates some peak flows during large snowmelt events. Bartosova et al. (2007a) provide a full discussion of model statistics and sensitivity analyses.

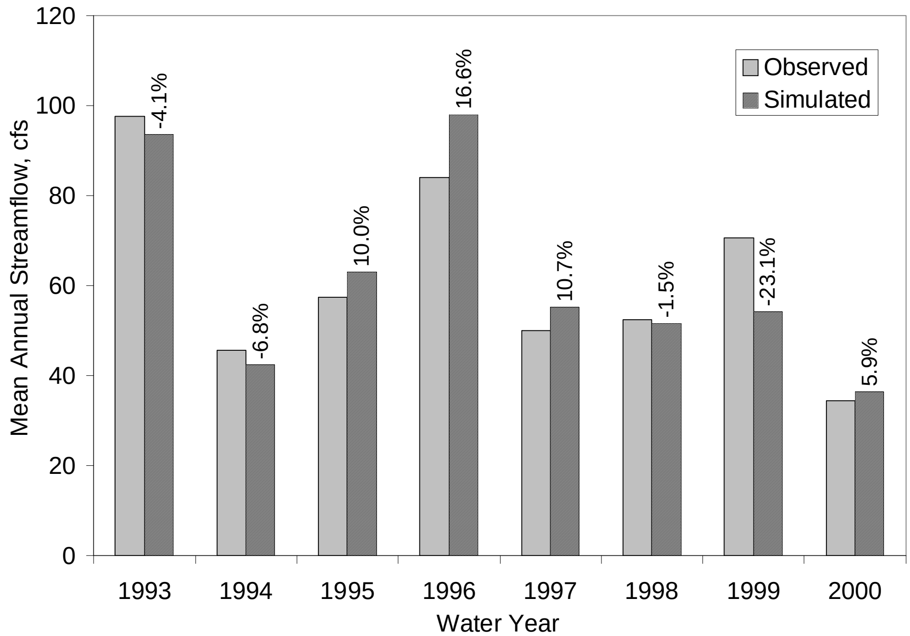


Figure 4. Observed and simulated mean annual streamflows during calibration, Yorkville gage (WY 1993-2000).

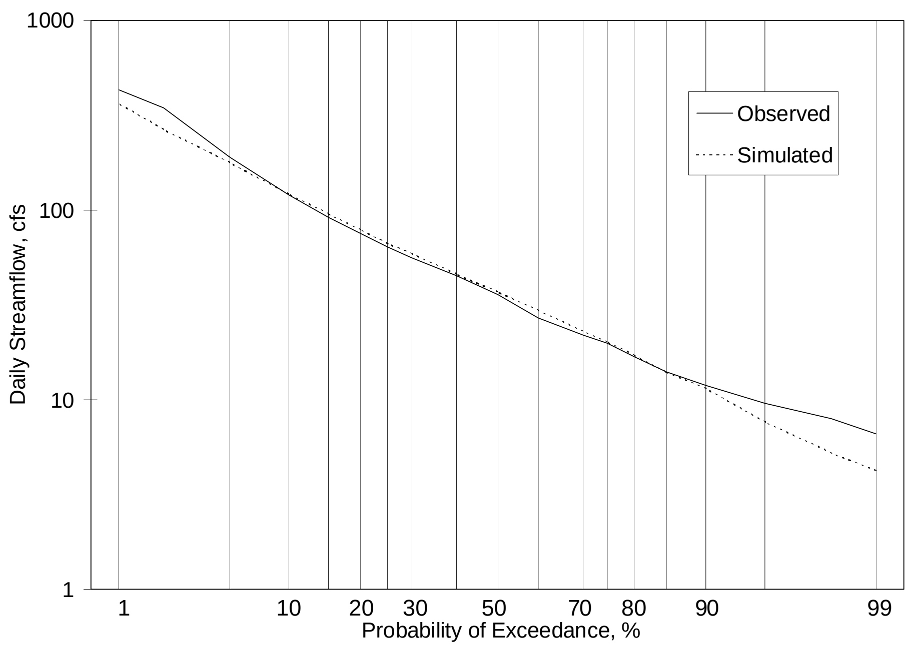


Figure 5. Flow duration curve for observed and simulated daily streamflow during calibration, Yorkville gage (WY 1993-2000).

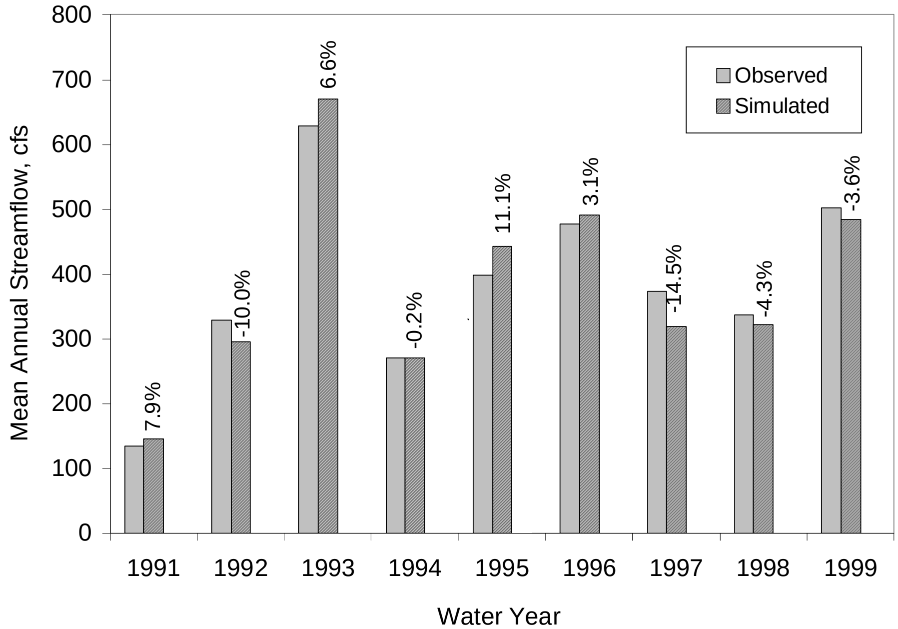


Figure 6. Observed and simulated mean annual streamflows during calibration, Elgin gage (WY 1991-1999).

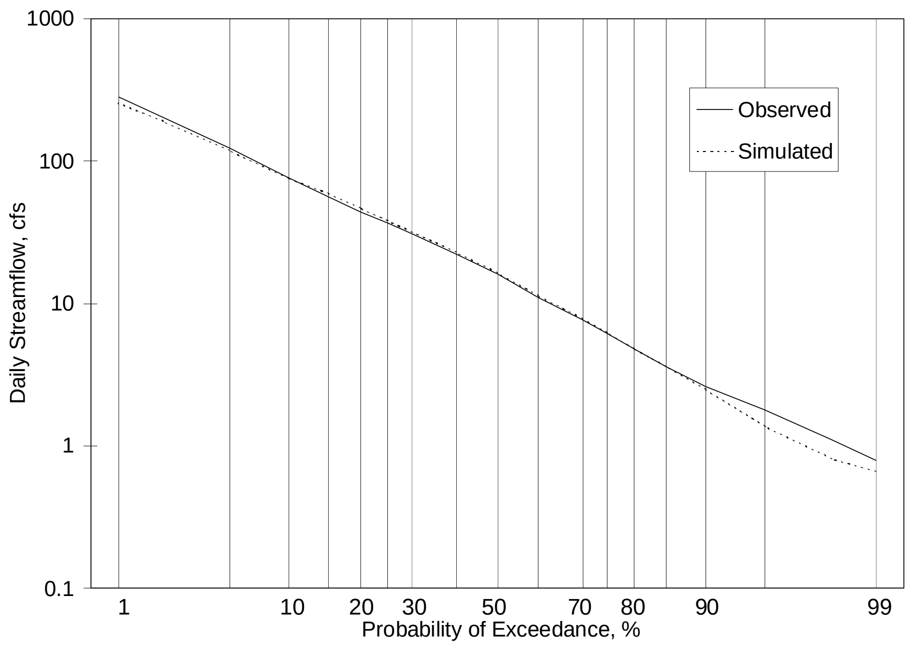


Figure 7. Flow duration curve for observed and simulated daily streamflows during calibration, Elgin gage (WY 1991-1999).

Limitations to Model Simulations Matching Observed Flows

During the course of model development, it became apparent that the spatial representation of precipitation significantly affects 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. Differences between simulated and observed streamflows for the Blackberry Creek watershed model to a great extent can be attributed to lack of spatially representative precipitation data. Spatial variation of precipitation can be significant, but a precipitation gage network of sufficient density to provide spatially representative data is rare, e.g., only one precipitation station was available for the Blackberry Creek watershed and two stations for the Poplar Creek watershed.

Limitations in the HSPF model also influence results. For example, the HSPF model's very simplistic channel routing scheme does not match natural reach routing and flow attenuation exactly. Thus, it is not surprising that modeled streamflows have a poorer fit on a daily basis than observed streamflows that reflect routing and attenuation in the stream system. These differences become less significant on a long-term basis. Consequently, fit between observed and simulated streamflows is better on a monthly or annual basis. Uncertainty also is introduced due to the accuracy limits of streamflow measurements. The rating the USGS uses to describe the accuracy of streamflow data classifies data as "good" when 95% of the observed daily values are within 10% of the true value. Thus, on a daily basis, the error in observed streamflow values can be as much as 10%.

In this study, the hydrologic simulation model was calibrated to simulate an entire range of streamflows over a long period, not specific events. Differences between simulated and observed streamflow values could be due to variability in climate and streamflow data, limited spatial representation of precipitation data, and HSPF model limitations, such as the simplistic channel routing scheme that affects daily simulated flows. Overall modeling results, however, indicate the model may provide watershed planners and managers with useful simulated hydrologic data for assessing hydrologic impacts of land use changes in the watershed.

Water Quality Components

Calibration of water quality components of the HSPF model is limited primarily by availability of ambient water quality data. The USGS measures streamflow data almost continuously with stage recorded at least every hour, though the number of sites may be limited. Water quality is sampled much less frequently with a sample taken once in several weeks, but the number of sites is typically larger. Figure 8 illustrates this point. Given the frequency of recording precipitation and streamflow data, these data may be shown as continuous in contrast to the data available for TSS shown in Figure 8 as points only. The HSPF model simulates hourly TSS values, but accuracy of these finer scale simulations cannot be demonstrated or improved without additional data.

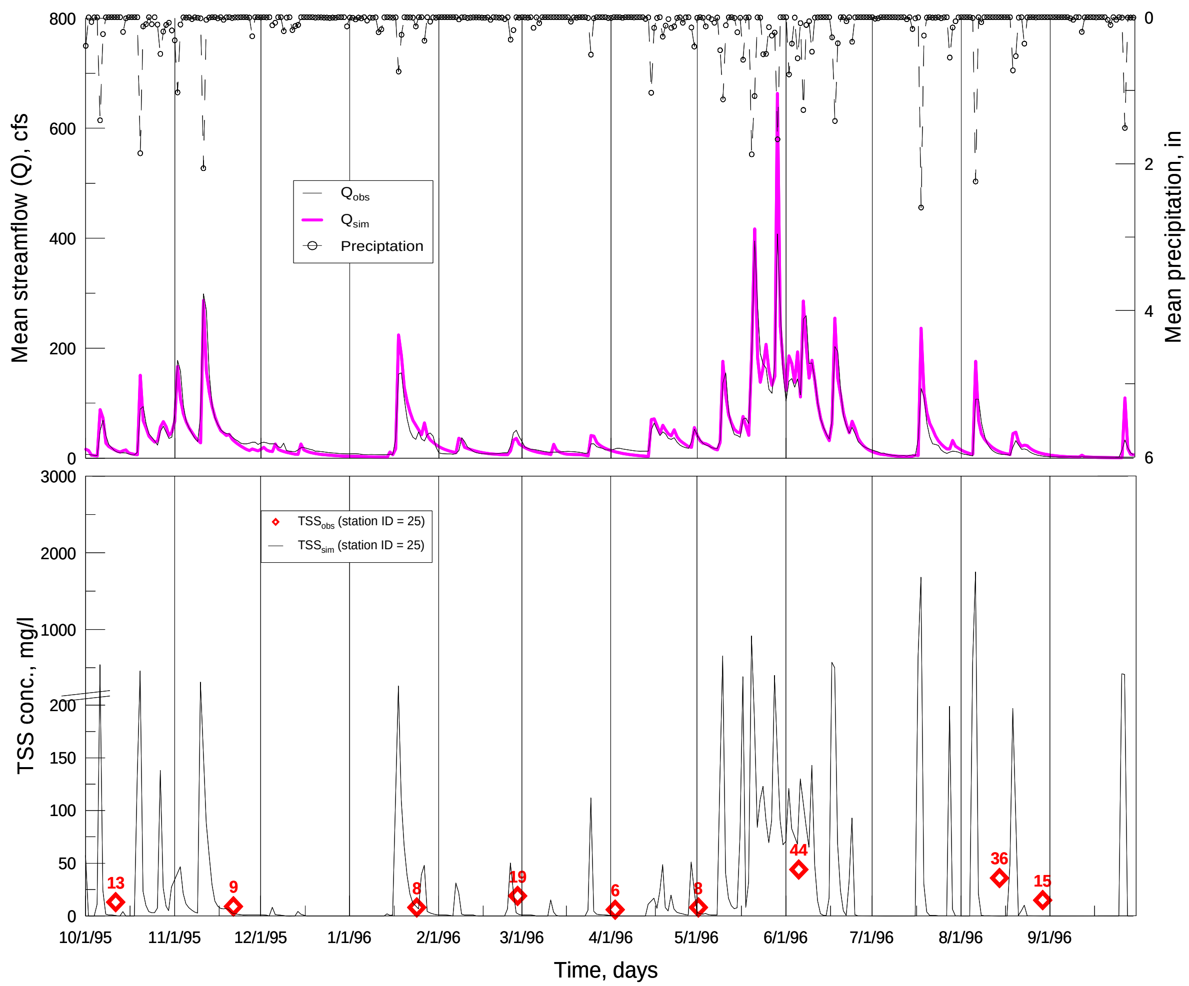


Figure 8. Comparison of precipitation, streamflow, and TSS data with model simulations.

Available water quality data are not observed with the same frequency as streamflow records, so methods of comparison and presentation of simulation results must be handled differently. Continuous streamflow data can be summarized as average daily, monthly, or annual values. 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 8), and such data may not provide accurate information about individual storm events. Most water quality data available describe a sample taken from the receiving water once during the sampling day. Such information represents a single point in time on the day of sampling. The observation at a single fixed point in time may or may not represent actual average constituent concentration for the entire day. Data averages, needless to say, may not represent monthly averages.

It is virtually impossible to simulate water quality values that match instantaneous sample data: water quality samples represent data at a point in time and are not adequate to compute average values, and sufficient precipitation data are not available to compute hourly or highly accurate daily streamflow. The expectation is to simulate values that match trends exhibited by sample data. Improvement of such simulations requires more data.

Reflecting on hydrologic modeling, streamflow is simulated in hourly steps with output as daily averages, and calibrated to the extent possible to best match observed (averaged) daily values available for every day during the calibration period. The same procedure cannot be applied directly to calibrating water quality constituents as explained above. Thus, simulated water quality data were output as both hourly and daily values. Three methods of comparing simulated values to observations were used:

- The instantaneous observed values and values simulated for the sampling time are compared directly for constituents exhibiting a strong diurnal cycle (e.g., temperature) if the sampling time is known.
- The instantaneous observed values and a distribution of 24 hourly values simulated for the sampling day are compared.
- The instantaneous observed values and simulated average daily values are compared to illustrate trends.

Singh et al. (2007) describe calibration and validation processes, goals, and criteria. 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 model. 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. An iterative procedure was used to perform the calibration. The set of parameters was tested on both Blackberry and Poplar Creek watersheds until satisfactory results were obtained. The results presented for the following constituents reflect the set of calibration parameters determined in this way.

Water Temperature (T)

Water temperature has a significant effect on many transformation and reaction processes. Due to significant temperature variation caused by a natural cycle during the day, the HSPF temperature simulation component was run on an hourly basis, and hourly model output was compared with corresponding observations. Observed and simulated hourly values are compared graphically in scatter plots (Figure 9 and Figure 10) for FoxDB Station 28 on Blackberry Creek and FoxDB Station 25 on Poplar Creek, respectively. All figures show a very good fit on most days for both stations and watersheds, with scatter randomly distributed about the ideal 1:1 line.

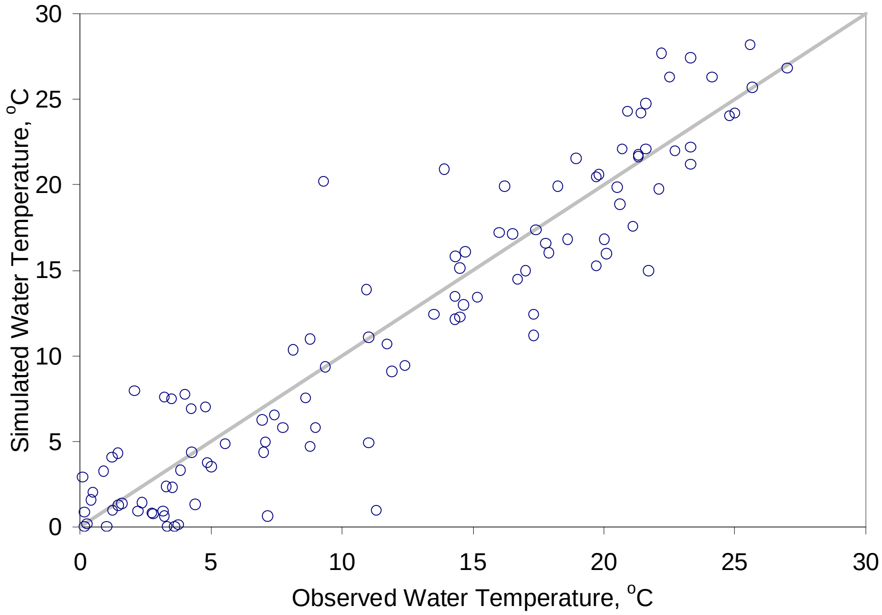


Figure 9. Comparison of observed instantaneous and simulated hourly water temperature, Blackberry Creek, FoxDB Station 28.

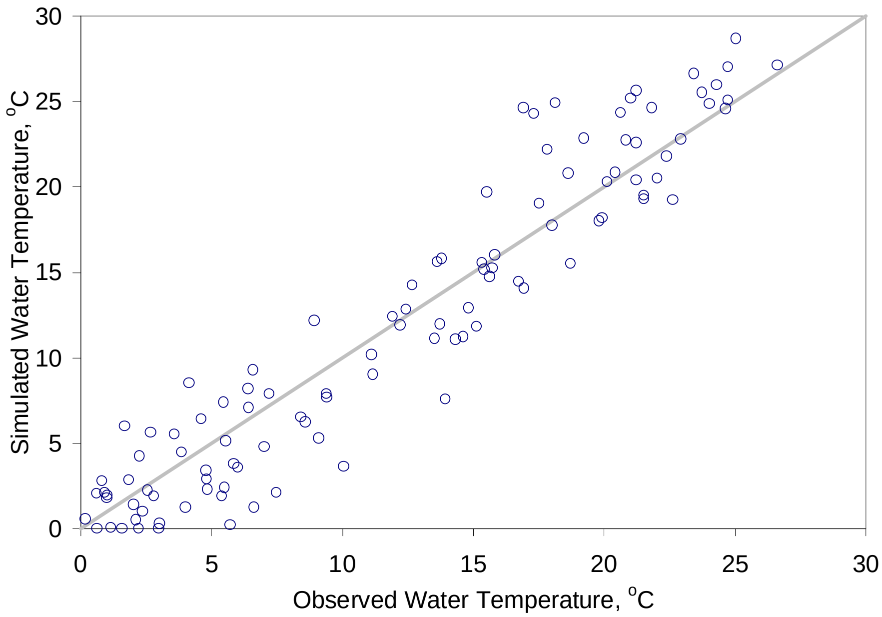


Figure 10. Comparison of observed instantaneous and simulated hourly water temperature, Poplar Creek, FoxDB Station 25.

Suspended Sediment (SS)

Input of SS from land surfaces is simulated through detachment of soil particles from pervious lands and accumulation and washoff processes on impervious lands. Simulation of SS is important as some constituents on the land surface, especially phosphorus, attach to soil particles and enter streams and rivers through erosion.

Figure 11 and Figure 12 plot observed instantaneous and simulated daily SS concentrations versus the simulated average daily streamflow for Blackberry Creek and Poplar Creek stations, respectively. Simulated SS concentrations are generally within the same range as observed values except during streamflows less than 20 cubic feet per second (cfs) and 10 cfs for Blackberry Creek and Poplar Creek, respectively. Daily flow exceeds 20 cfs about 80% of the time in Blackberry Creek and exceeds 10 cfs about 70% of the time in Poplar Creek.

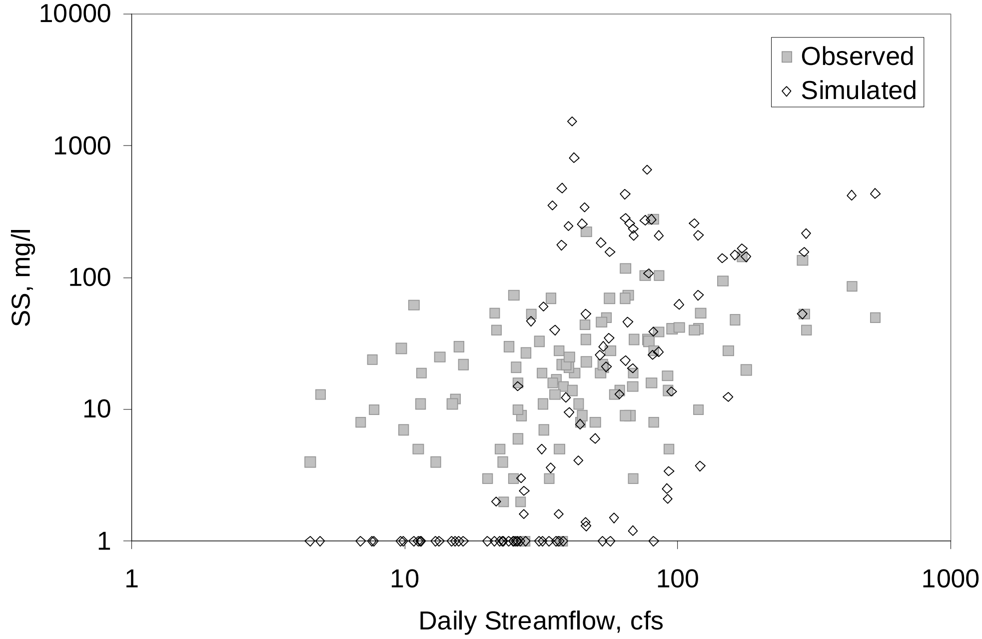


Figure 11. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with simulated daily flow, Blackberry Creek, FoxDB Station 28.

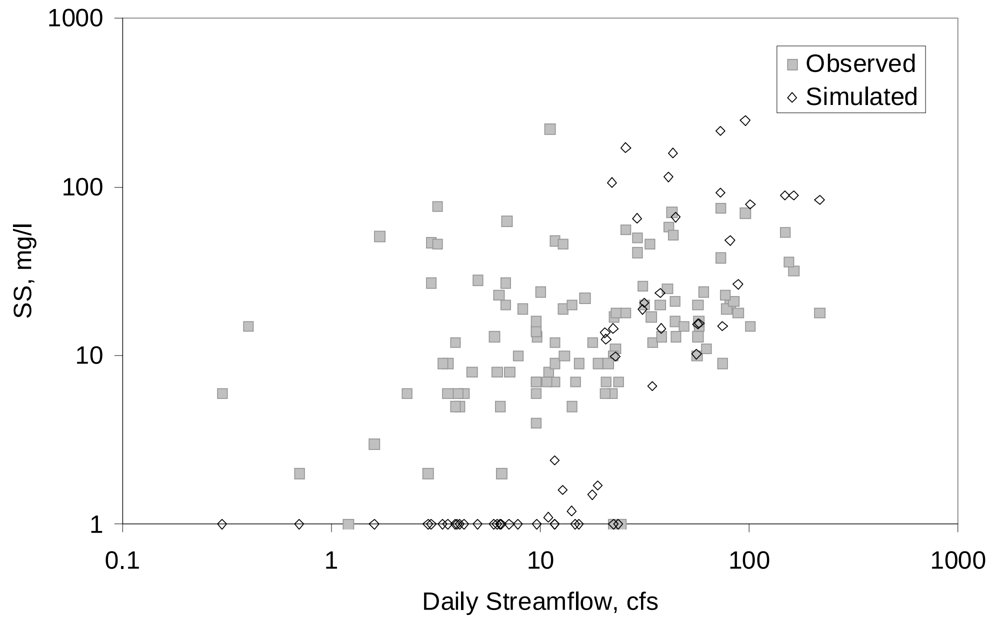


Figure 12. Changes in observed instantaneous and simulated mean daily suspended sediment concentrations with simulated daily flow, Poplar Creek, FoxDB Station 25.

Fecal Coliform Bacteria

Calibration of the fecal coliform component within the HSPF model involves estimating input loads and reaction coefficients. Surface loading is simulated using a simple accumulation and washoff algorithm. Observed fecal coliform data are used exactly as reported from the monitoring agency. A remark code typically accompanies high reported values signifying counts too numerous to determine the exact number of colony forming unit (cfu). Thus, perfect fit of higher numbers cannot be expected from the model, but only a correspondence with simulated high values.

Figure 13 and Figure 14 show changes in observed instantaneous and simulated daily fecal coliform counts with daily flow for Blackberry Creek (FoxDB Station 28) and Poplar Creek (FoxDB Station 25), respectively. The model matches the pattern quite well, though patterns vary. Poplar Creek FoxDB Station 25 shows high values associated with low flows, gradually decreasing values for middle flows, and increases again with high flows. Blackberry Creek FoxDB Station 28 shows an almost random scatter with flow. Figure 15 shows a sample time series for WY 1998-1999, plotting observed and simulated daily fecal coliforms over time for Poplar Creek FoxDB Station 25.

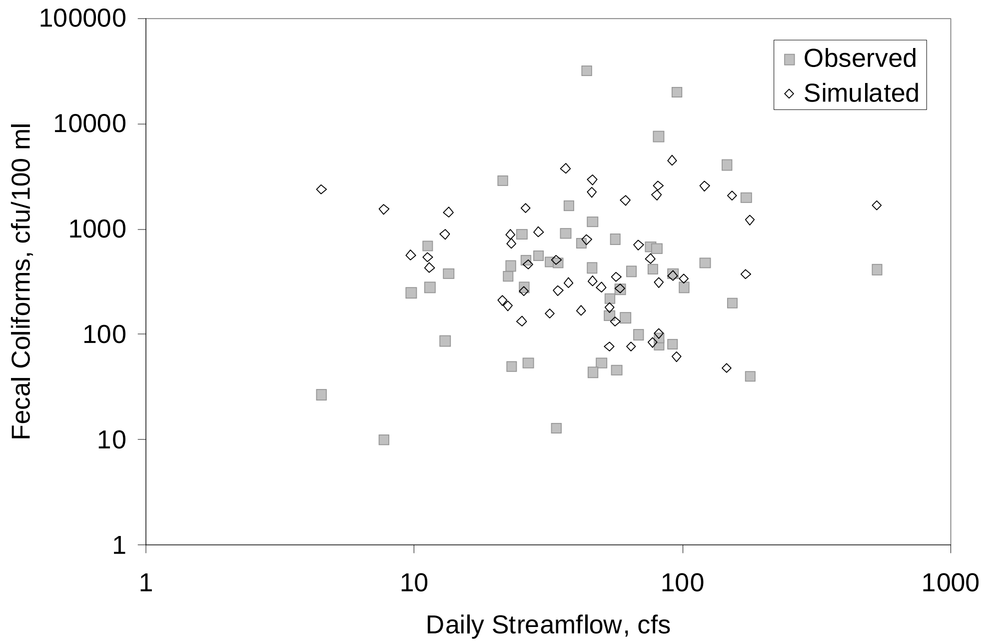


Figure 13. Changes in observed instantaneous and simulated mean daily fecal coliform counts with simulated daily flow, Blackberry Creek, FoxDB Station 28.

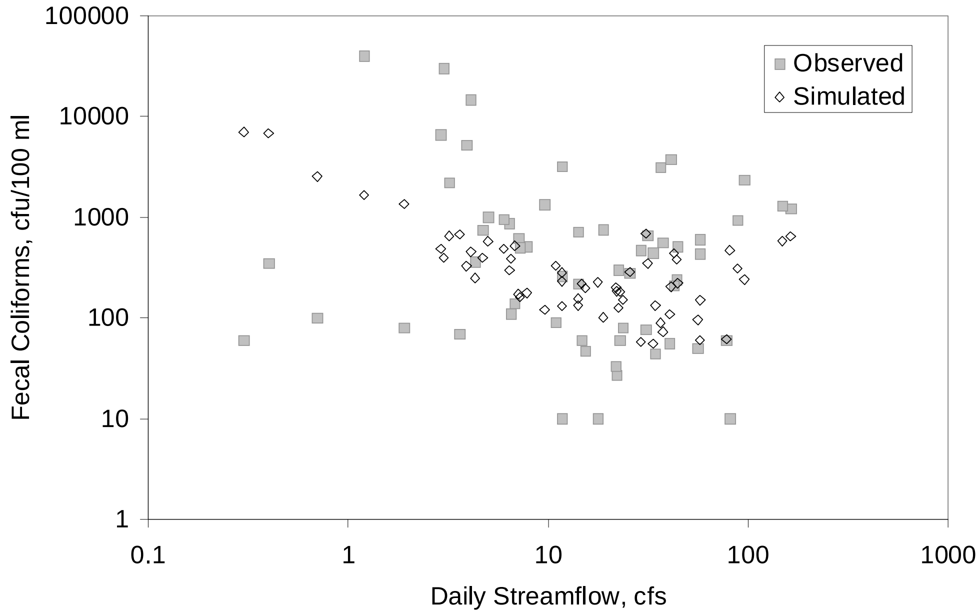


Figure 14. Changes in observed instantaneous and simulated mean daily fecal coliform counts with simulated daily flow, Poplar Creek, FoxDB Station 25.

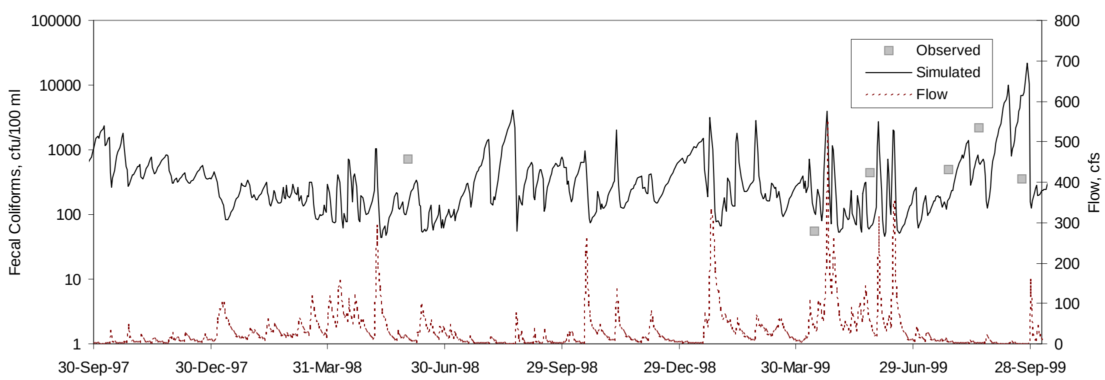


Figure 15. Time series of observed instantaneous and simulated mean daily fecal coliform counts, Poplar Creek, FoxDB Station 25, WY 1998-1999.

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 while surface loading of N_{ORG} is proportional to organic loading simulated as BOD. Reaction parameters control nitrogen transformation in individual forms. Surface loadings are simulated through the simple routine of buildup and washoff, similar to that for fecal coliforms.

Figure 16-Figure 18 show changes in observed instantaneous and simulated average daily concentration with daily flow for NO_3-N, NH_4-N, and total nitrogen (TN), respectively, for Blackberry Creek and Poplar Creek stations. The Poplar Creek watershed model adequately matches the patterns. 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. Underestimation of NO_3-N by the HSPF model possibly is related to how NO_3-N contributions from pervious land are incorporated in model calculations. Nitrate is transported with surface runoff, interflow (subsurface flow), and groundwater. While surface runoff loading is calculated using an accumulation and washoff algorithm, NO_3-N concentration in interflow and groundwater is input as a constant. The strong correlation of flow and NO_3-N in the Blackberry Creek watershed (Figure 16b) indicates an increase in concentration with flow, perhaps due to significant influence of tile drainage. This issue will be addressed during calibration of the Fox River mainstem with a wider range of conditions and more water quality data available. Figure 19 shows an sample of time series for WY 1998-1999, plotting observed instantaneous and simulated daily TN concentrations in Poplar Creek, FoxDB Station 25, over time.

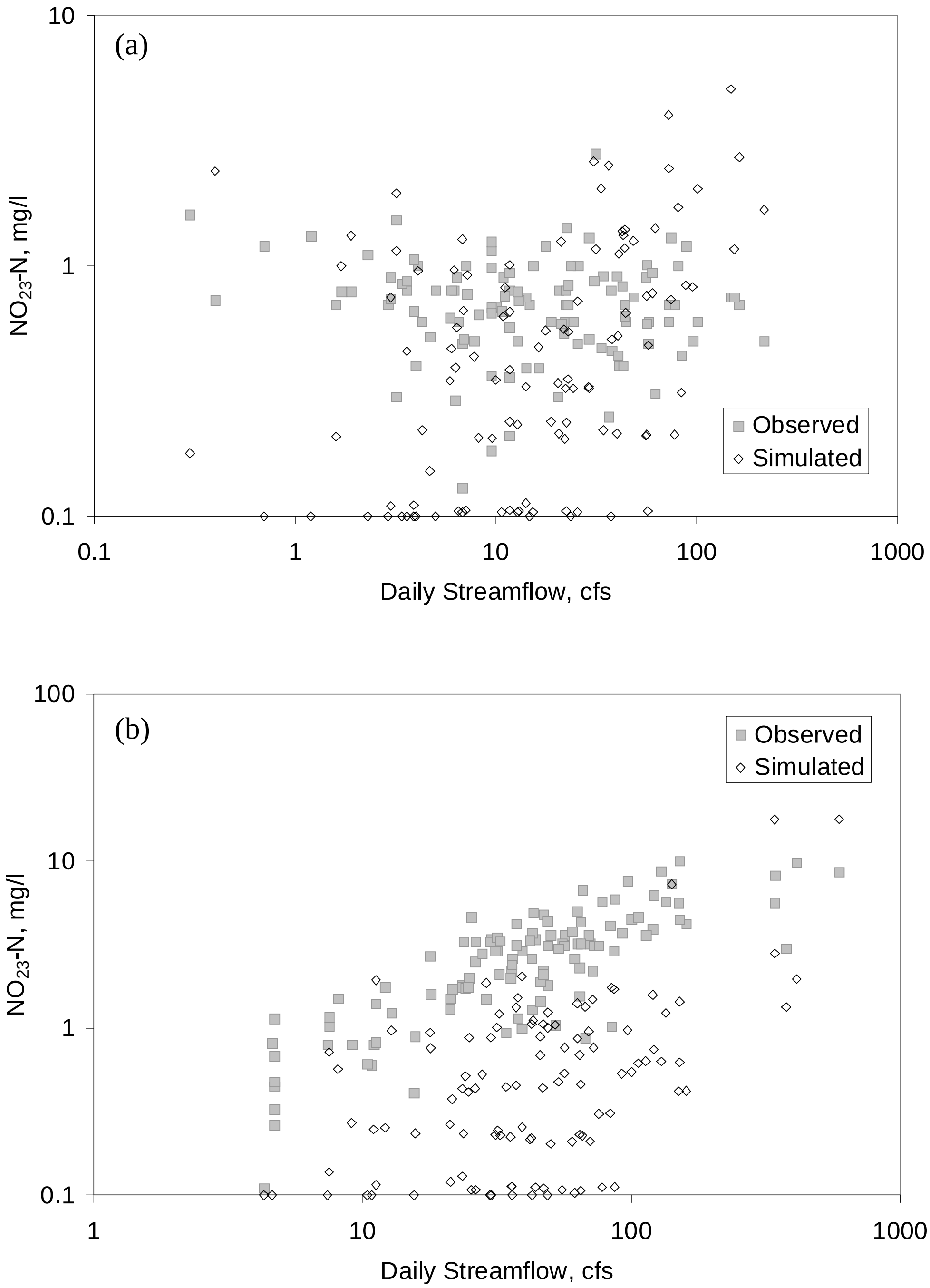
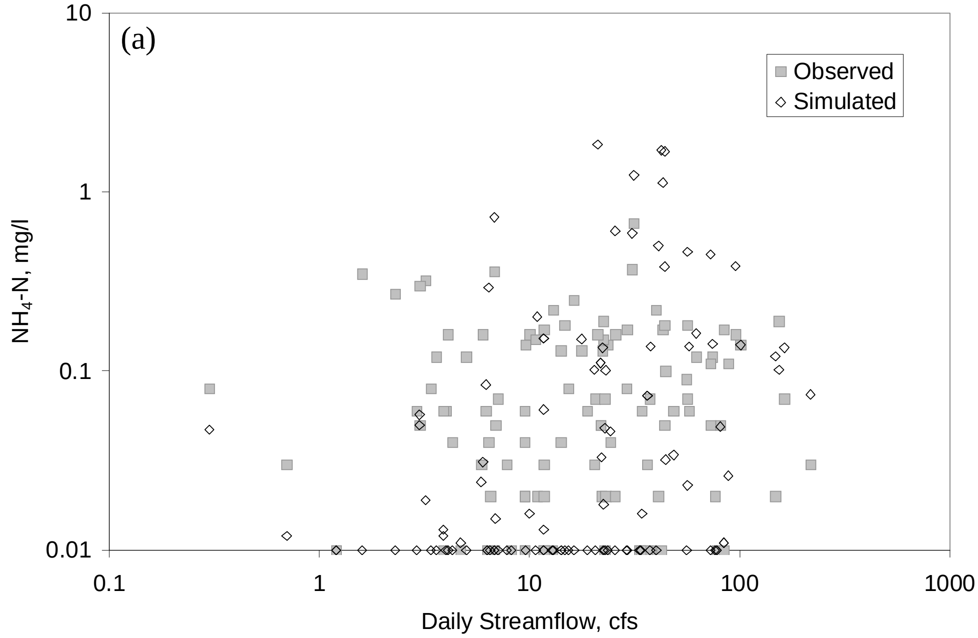


Figure 16. Changes in observed instantaneous and simulated mean daily nitrate nitrogen with simulated daily flow, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.



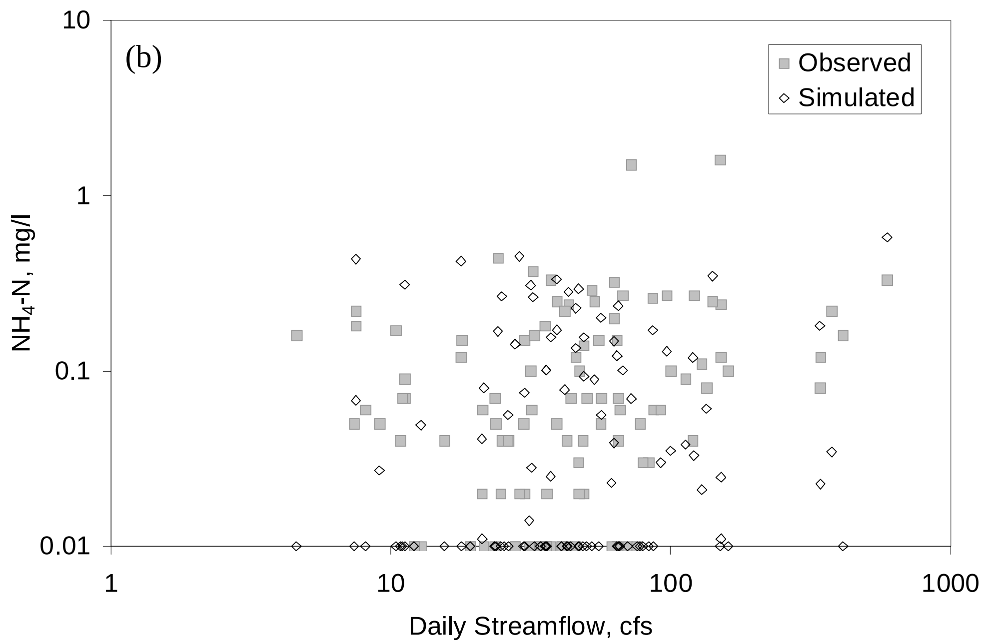
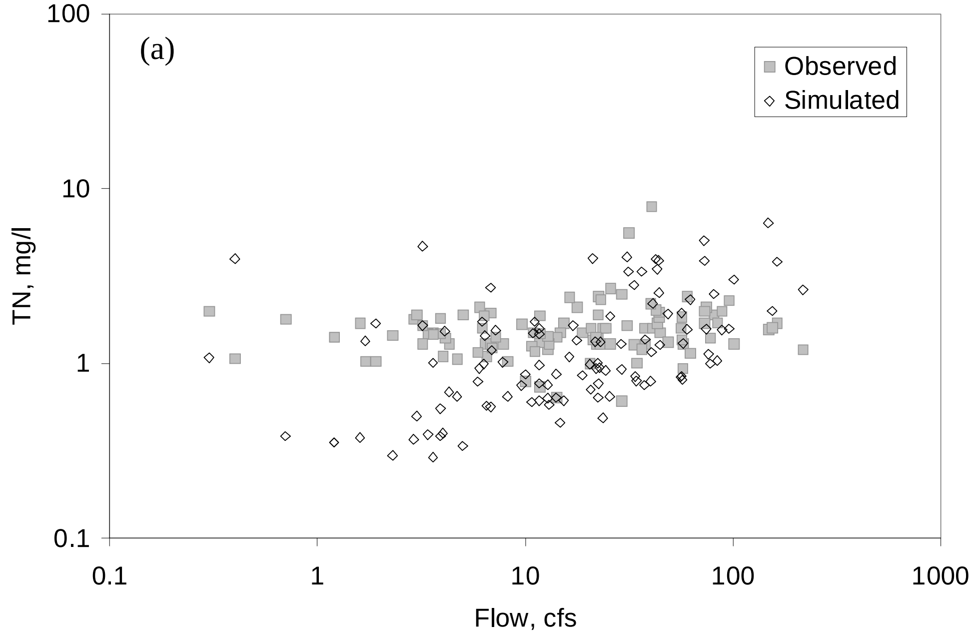


Figure 17. Changes in observed instantaneous and simulated mean daily ammonia nitrogen with simulated daily flow, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.



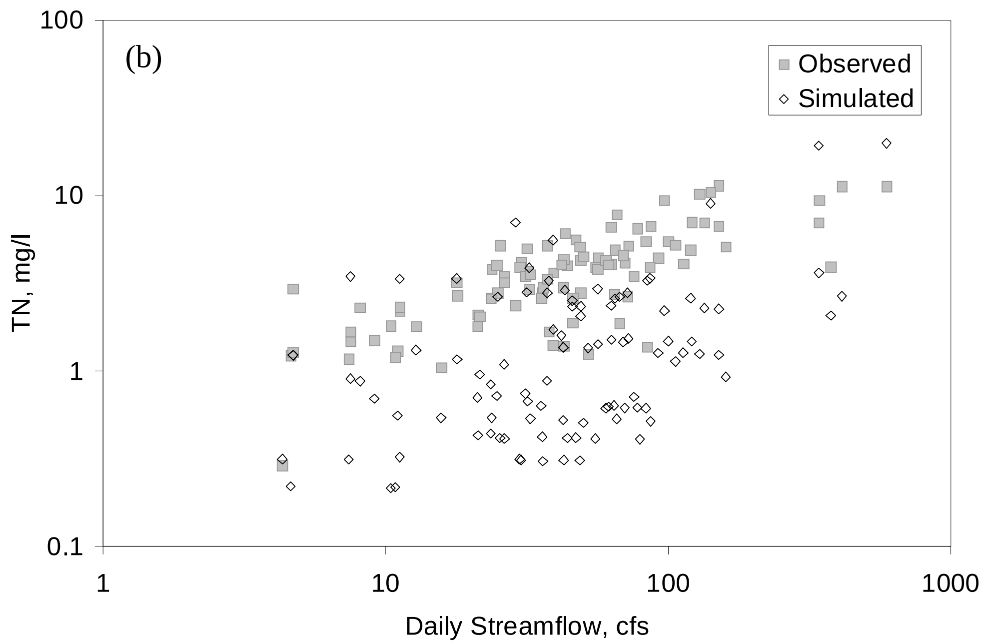


Figure 18. Changes in observed instantaneous and simulated mean daily total nitrogen with simulated daily flow, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

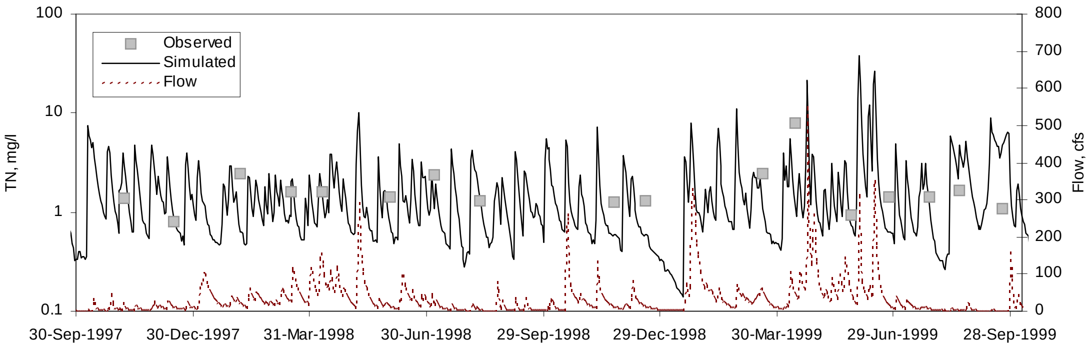
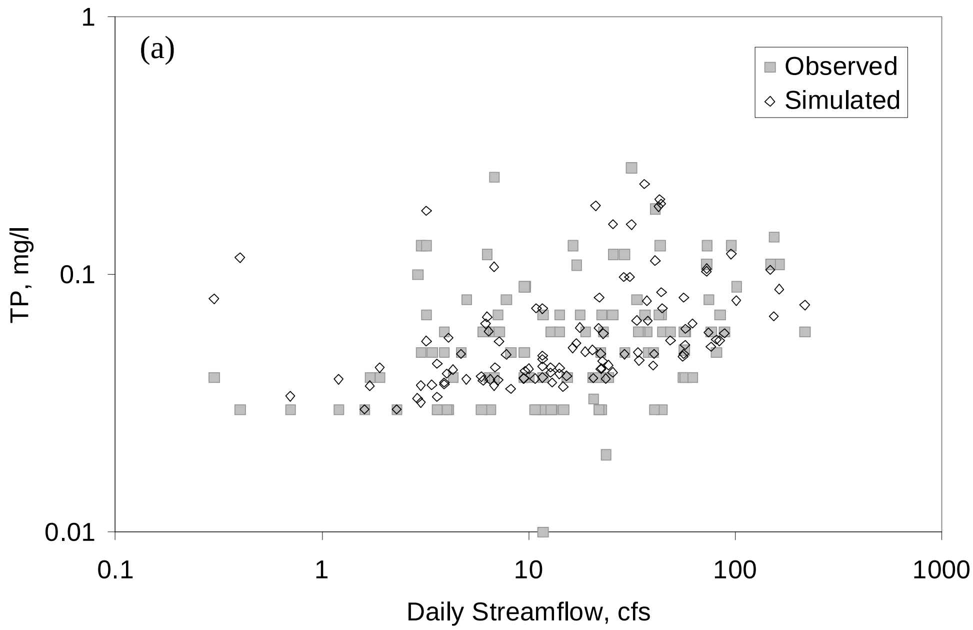


Figure 19. Time series of observed instantaneous and simulated mean daily total nitrogen, Poplar Creek, FoxDB Station 25, WY 1998-1999.

Phosphorus

Phosphorus has a high affinity for fine soil particles, which means it often is associated with sediment. Thus, inputs from the surface are simulated as associated with both sediment and overland flow. Phosphorus in stream reaches is simulated as dissolved orthophosphate (PO_4), particulate PO_4, and organic phosphorus. Adsorption/desorption and scour/deposition processes govern the fate of phosphorus in a reach, with additional effects from algae activity and BOD decay. Figure 20 shows changes in observed instantaneous and simulated daily total phosphorus (TP) concentration with daily flow. The Poplar Creek model adequately matches the pattern. The Blackberry Creek model underestimates TP concentration. Figure 21 shows a sample time series for WY 1998-1999, plotting observed instantaneous and simulated daily TP concentrations over time.



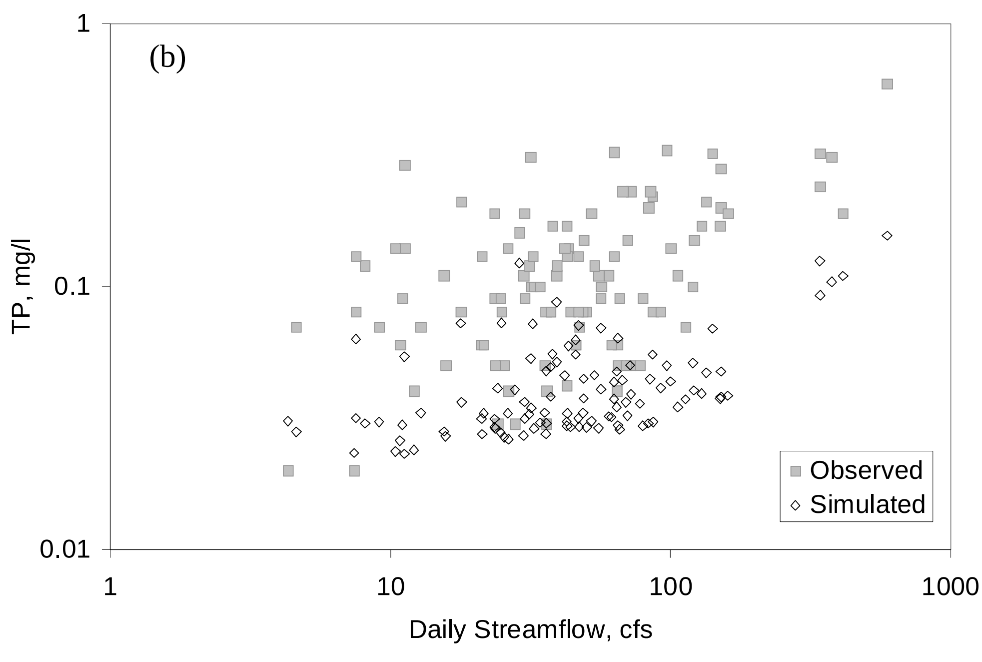


Figure 20. Changes in observed instantaneous and simulated mean daily total phosphorus with simulated daily flow, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.

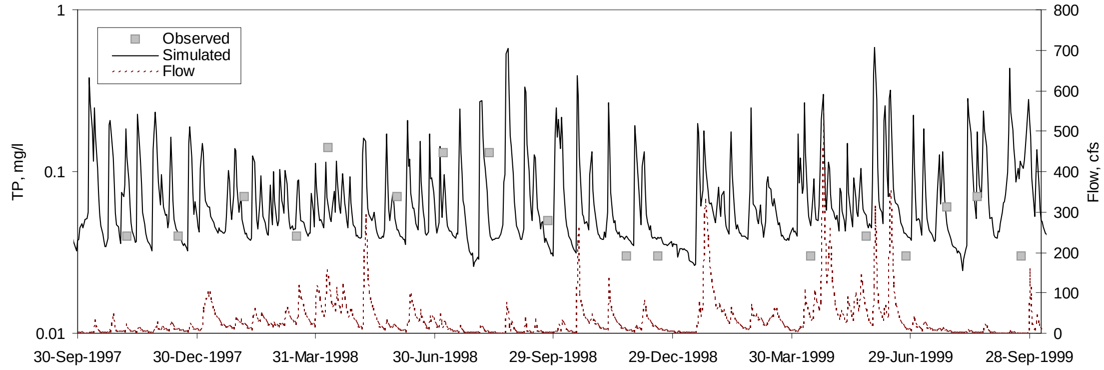


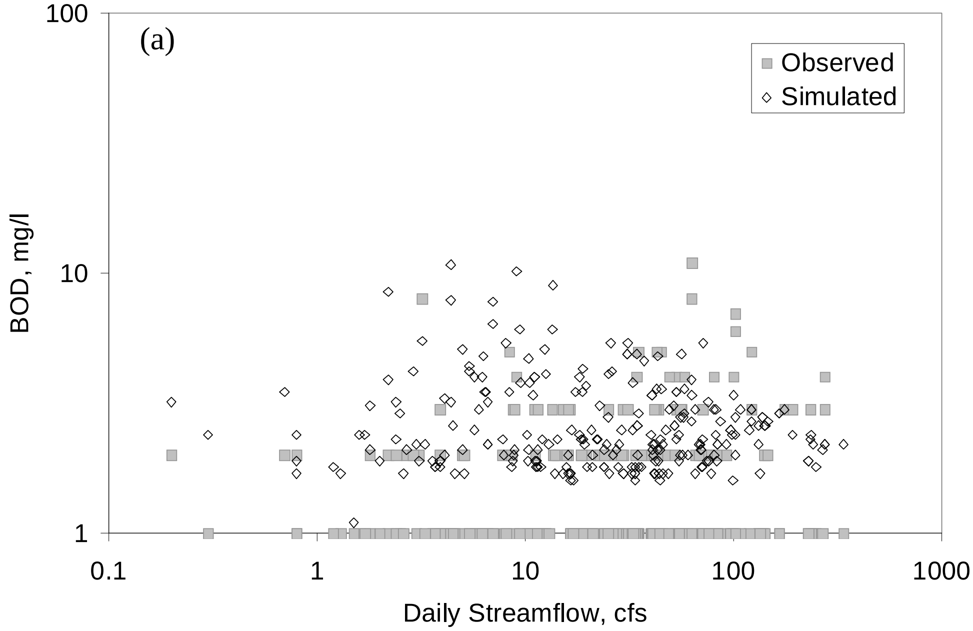
Figure 21. Time series of observed instantaneous and simulated mean daily total phosphorus concentration, Poplar Creek, FoxDB Station 25, WY 1998-1999.

Dissolved Oxygen Regime

Dissolved oxygen (DO) concentrations are a result of complex processes, including degradation of organic matter, physical reaeration, algae growth and respiration, and effects of temperature and nutrient cycling. For simulating the DO concentration, the HSPF model considers kinetic processes, such as decomposition of organic matter, sediment oxygen demand (SOD), benthic releases of settled decomposable materials, photosynthesis from algae and water plants, and reaeration. Chlorophyll *a* concentration affects DO concentration and nutrient cycling in the water. The HSPF model simulates the biomass of algae and converts it to an approximate chlorophyll *a* concentration internally. Phosphate, nitrate, and total ammonia serve as a source of nutrients for algae growth and are considered bioavailable in the HSPF model.

Accumulation and removal of organic matter on the land surface is simulated as BOD. The BOD measurements are available only for FoxDB Stations 615 and 895 on Poplar Creek, however. Figure 22 shows changes in observed and simulated daily BOD concentration with daily flow for these two stations. The values do not show any clear pattern with flow, but the range of values was reproduced successfully. Figure 23 shows a sample time series for WY 1998-1999, plotting observed and simulated daily concentrations over time.

Figure 24 shows changes in observed and simulated average daily DO concentration with average daily temperature for these two stations. The model overestimates DO during days with low temperature (below 10°C). Observations from FoxDB Station 25 are plotted with the distribution of 24 hourly values of DO simulated for the same days when observations were made (Figure 25). Ideally, points representing observations would lie within the range of simulated values symbolized by the column. This figure shows that simulated values are generally within the same range as observations, though the model does not simulate observed values precisely.



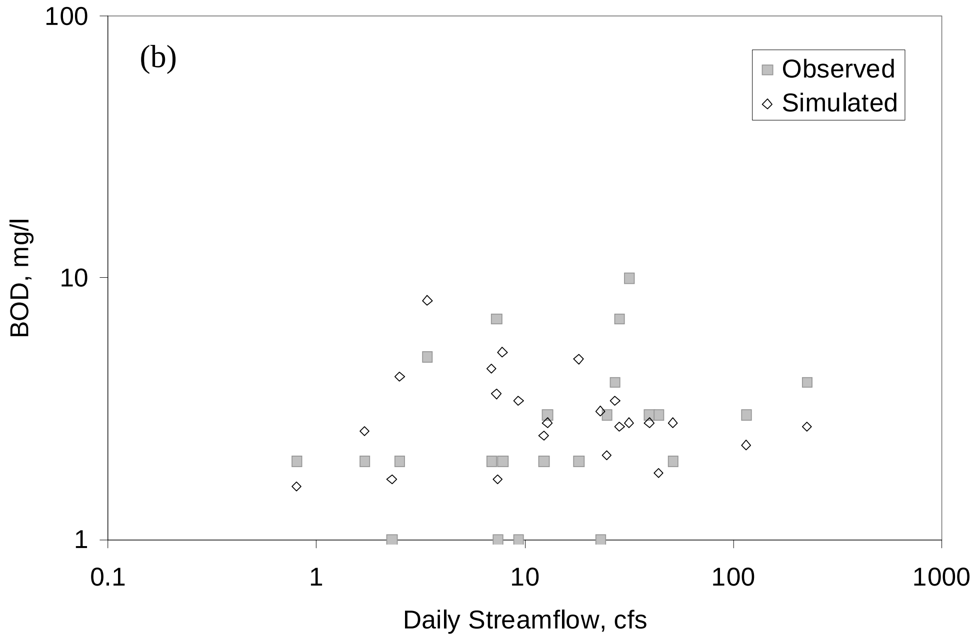


Figure 22. Changes in observed instantaneous and simulated mean daily BOD with simulated daily flow, Poplar Creek, a) FoxDB Station 615, and b) FoxDB Station 895.

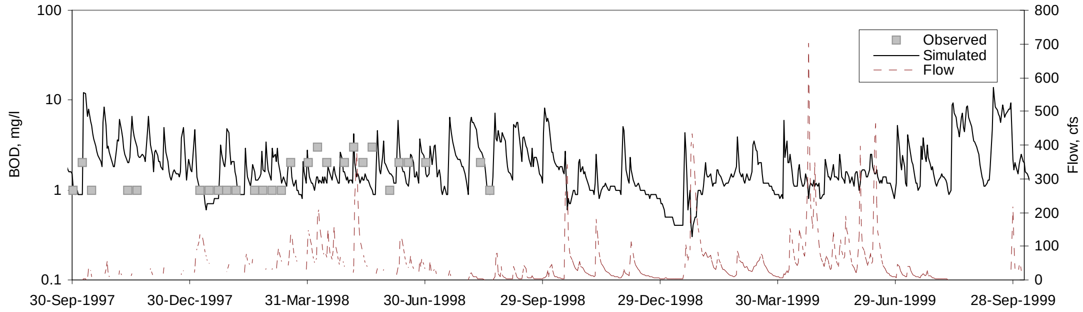
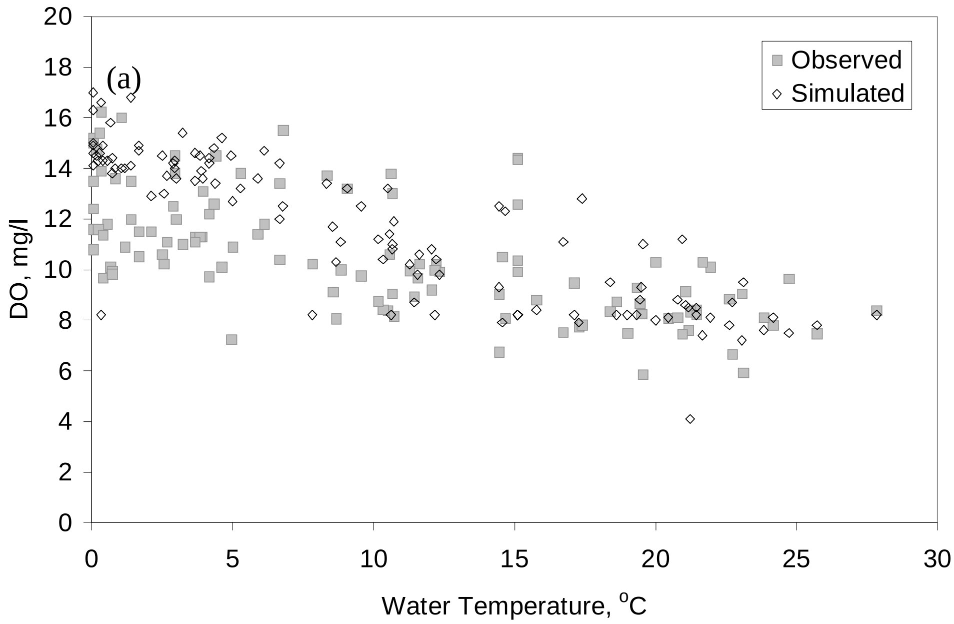


Figure 23. Time series of observed instantaneous and simulated mean daily BOD concentration, Poplar Creek, FoxDB Station 615, WY 1998-1999.



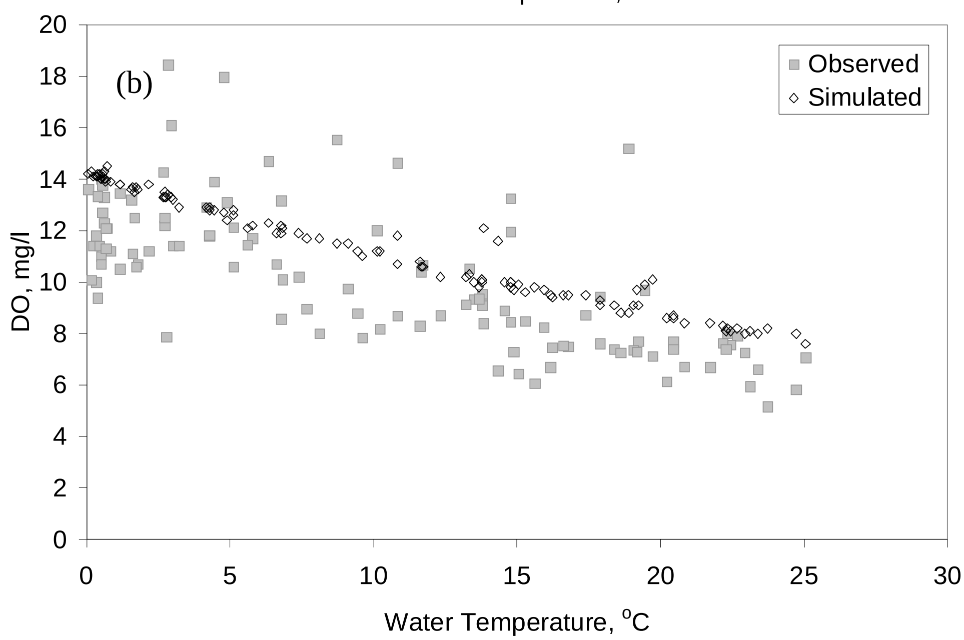
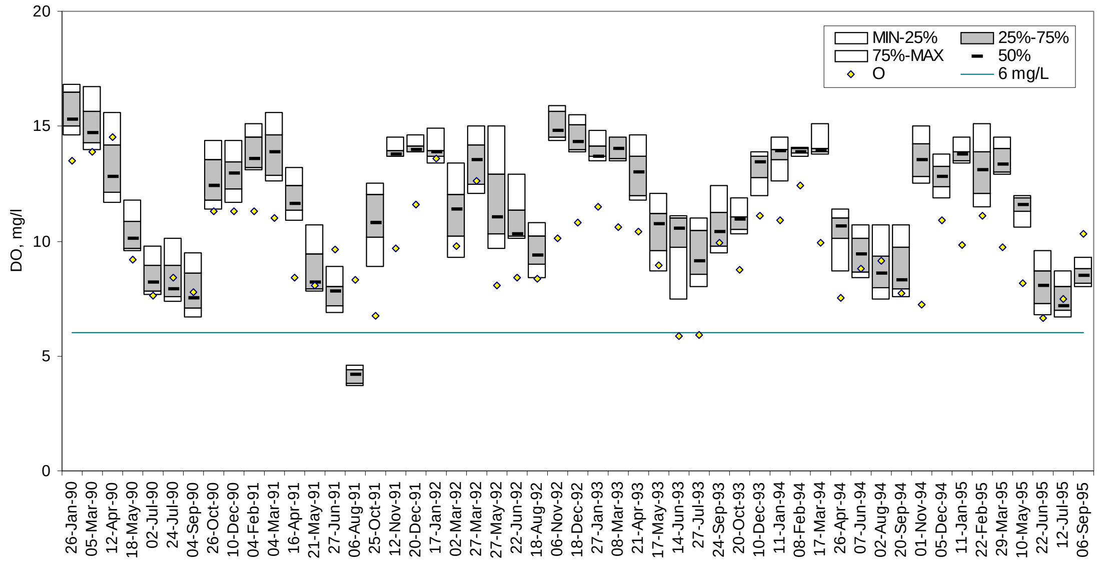


Figure 24. Changes in observed instantaneous and simulated hourly DO with simulated daily temperature, a) Poplar Creek, FoxDB Station 25, and b) Blackberry Creek, FoxDB Station 28.



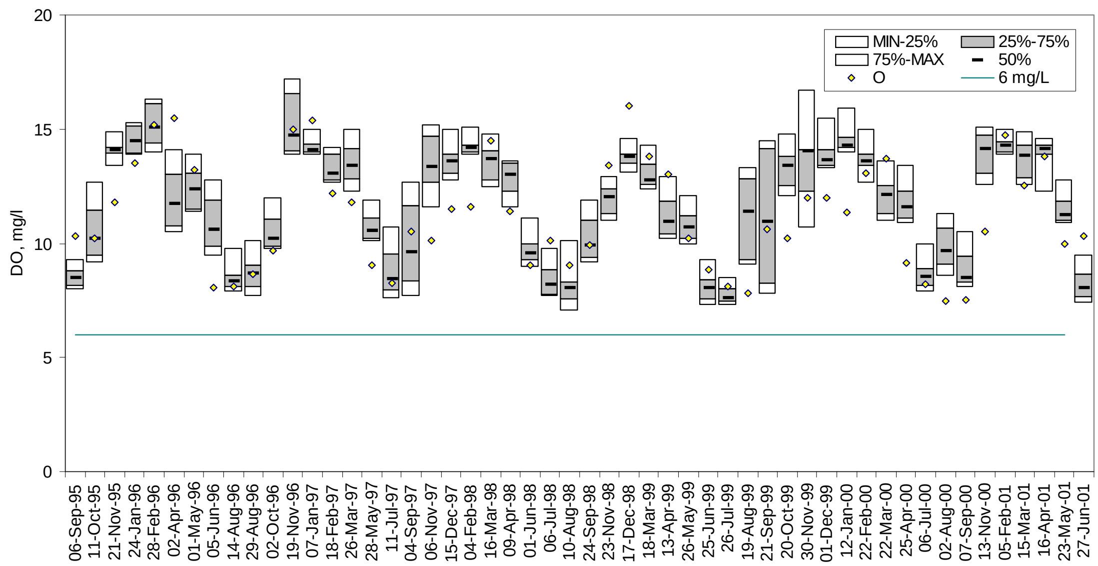


Figure 25. Comparison of observed instantaneous and a distribution of dissolved oxygen simulated on the same day, Poplar Creek, FoxDB Station 25.

Illustrations of Model Use

Comparison of Poplar Creek and Blackberry Creek Watershed Models

Models of the Poplar Creek and Blackberry Creek watersheds calibrated to the extent possible with existing data under time and resource constraints as described in the previous chapter were used to determine the quantity (load) generated from these watersheds for streamflow, SS, TN, and TP. Because of limited calibration at this phase of the study, generated loads are displayed only to illustrate how results can be presented and to compare the contribution of urban and rural watersheds without placing a precise value on these loads.

Loads were calculated at the location of USGS streamflow gages for both watersheds (same location as 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. Unit area loads were calculated to compare relative contributions from these watersheds. Unit area flow varies from year to year; the pattern does not clearly indicate one watershed as the larger contributor. The watersheds are also in different parts of the Fox River watershed. Thus, different climate stations were used in these models, which also may affect the pattern.

Total SS load is driven by precipitation. The year 1996 brought extreme rainfalls recorded at the Aurora climate station and reflected in high total load of all constituents from the Blackberry Creek watershed as discussed here (Figure 26a). Total SS loads are much closer for both watersheds, but the smaller, urban Poplar Creek watershed generates higher total load than the larger agricultural Blackberry Creek watershed in some years. Unit area SS loads are higher for the Poplar Creek watershed than for the Blackberry Creek watershed (Figure 26b) in all years except WY 1996-1998.

Total TN load displays larger differences between the two watersheds (Figure 27a). The Blackberry Creek watershed generates higher loads than the Poplar Creek watershed in all years except WY 2001. Unit area loads show no consistent trend, and overall averages are comparable (Figure 27b). The Blackberry Creek watershed model, however, underestimates TN concentrations, which affects the relative comparison of the two watersheds.

Total and unit area TP loads also are presented (Figure 28). The Poplar Creek watershed generates higher loads than the Blackberry Creek watershed in six years and lower loads in five years. The Poplar Creek watershed contributes a larger amount in terms of unit area load (with the exception of WY 1996). Significantly underestimated TP concentrations simulated for Blackberry Creek watershed, however, affect the comparison. Final calibration is scheduled for the next phase of the study to improve results presented here.

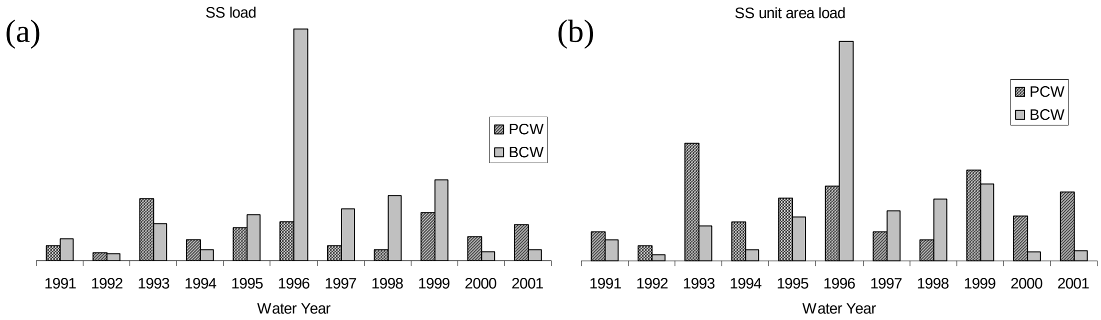


Figure 26. Comparison of SS loads originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total load, and b) unit area load.

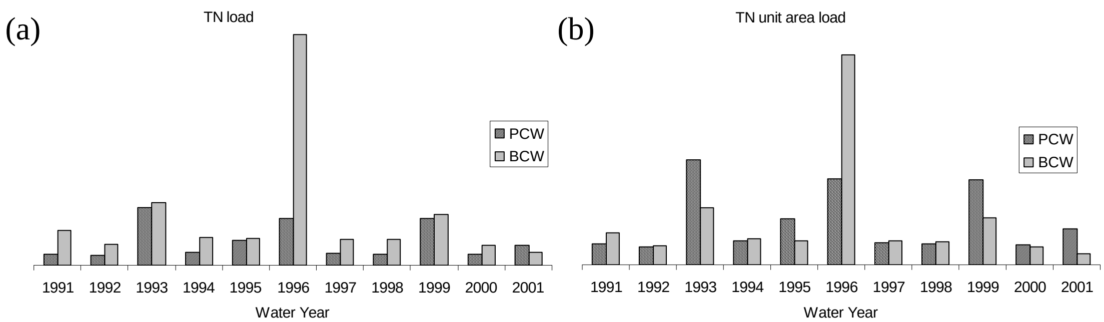


Figure 27. Comparison of TN loads originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total load, and b) unit area load.

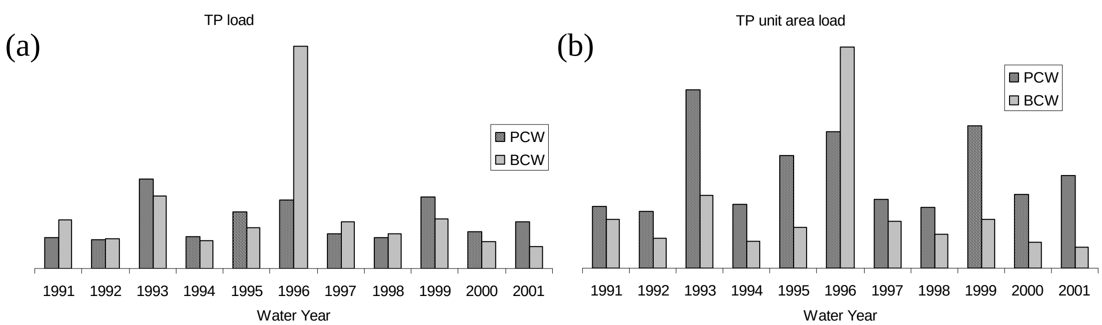


Figure 28. Comparison of TP loads originated from Poplar Creek (PCW) and Blackberry Creek (BCW) watersheds, a) total load, and b) unit area load.

Comparison to Water Quality Standards

Dissolved oxygen was selected to demonstrate model use for evaluating compliance with water quality standards. The reader is advised to remember the purpose of this section: to illustrate model use in watershed assessment. Further calibration as planned for the next phase of the study will be required in evaluating 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 5 summarizes the findings for FoxDB Stations 25 and 28 on Poplar Creek and Blackberry Creek, respectively. FoxDB Station 25 shows 38 instances over the 9-year period with simulated DO concentration below 5 mg/L and 5 days with DO concentration 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 at FoxDB Station 28. Low DO occurs exclusively during summer months, as can be expected.

Table 5. 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 25*
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, models to simulate streamflow and other components of the water budget as well as selected water quality constituents were developed using available data for the Poplar Creek and Blackberry Creek watersheds in the Fox River watershed using the HSPF model. Once fully developed, the models will provide watershed planners and managers with simulated data for assessing hydrologic and water quality impacts of land use changes in the watershed.

The Blackberry Creek watershed model was calibrated for WY 1993-2000. Values of model parameters were adjusted within reasonable limits to improve fit between observed and simulated streamflow 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 four-year period (WY 2000-2003) at the Montgomery gage. The Poplar Creek watershed model was calibrated for April 1991 through WY 1999 and validated for a four-year period (WY 2000-2003). Streamflow data from a USGS streamflow gage at Elgin (USGS 05550500) were used for model calibration and validation. Sensitivity analyses of calibrated model parameters were performed for both calibrated watersheds. Statistical and graphic analyses of simulated values show the models meet generally recognized accuracy standards.

Models were expanded to simulate water quality. Existing water quality data were used to calibrate models for SS, fecal coliforms, nitrogen, 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 most forms of nitrogen and phosphorus, although the Blackberry Creek watershed model currently underestimates NO_3-N and TP concentrations. Model parameters will be adjusted further in subsequent parts of this study, as watershed models are created for additional tributary watersheds in the Fox River watershed, the Fox River mainstem, and a wider range of conditions is described by observations.

Models were used to illustrate (i) relative contribution of flow, SS, TN, and TP, as well as (ii) an assessment of the compliance with water quality standards for DO. These calculations are presented as examples of model use for watershed management and planning. Considering that models are not fully calibrated yet, these examples should not be used to make decisions or to assess conditions in the Poplar Creek or Blackberry Creek watersheds.

The models are set to simulate complex processes on the land surface and in stream reaches. The Poplar Creek and the Blackberry Creek watersheds serve as pilot watersheds to create the models for remaining tributary watersheds in the Fox River watershed as well as the Fox River mainstem. Coefficients 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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