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HYDROLOGIC AND WATER QUALITY MODELING OF THE LAKE JESUP WATERSHED USING HYDROLOGICAL SIMULATION PROGRAM – FORTRAN (HSPF)

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

Hydrologic and Water Quality Modeling of the Lake Jesup Watershed Using Hydrological Simulation Program – Fortran (HSPF)

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Executive Summary

The Lake Jesup watershed is a subbasin of the Middle St. Johns River Basin located in Seminole County, Florida, including a small portion of Orange County. The total drainage area of the Lake Jesup watershed is approximately 152 square miles, of which about 17 square miles are the water surface of Lake Jesup. This study applies a Hydrological Simulation Program – Fortran (HSPF) model to the drainage basin of Lake Jesup, which includes four major subbasins: Howell Creek watershed, Gee Creek watershed, Soldier Creek watershed, and Ungauged watershed.

The primary purpose of developing the HSPF watershed model is to support the development of Pollutant Load Reduction Goals of total nitrogen (TN) and total phosphorus (TP) for Lake Jesup. The HSPF watershed model estimates the loadings of flow and nutrients (TN and TP) from the watershed to Lake Jesup under existing and future conditions and evaluates the effects of watershed management scenarios on the watershed loadings.

Modeling Process

Hydrologic calibration of HSPF is performed for Howell Creek, Gee Creek, and Soldier Creek over the simulation period from 10/1997 to 09/2003. The accuracy of HSPF flow predictions is evaluated using several statistical measures recommended by HSPEXP, an expert system for calibration of HSPF. These statistical measures are also suggested in the Technical Memorandum No. 47 of the St. Johns River Water Management District for HSPF hydrologic calibration. The results show a good agreement between the simulated flows and the observed flows in terms of water mass balance, high and low flow distributions, seasonal flow distribution, and low flow recession. Water quality calibration of HSPF is performed at several water quality sampling sites across the watershed. The results of water quality calibration show that the simulated land use loadings are generally within their expected ranges reported in the literature and HSPF adequately reproduces the observed water quality data, including water temperature, dissolved oxygen, total suspended solids, TN, and TP. Overall, the calibration results indicate that the HSPF model adequately represents the hydrologic and water quality processes in the Lake Jesup watershed. Therefore, the calibrated HSPF model can be used to evaluate the hydrologic and water quality responses to potential management scenarios, and the loads generated by the HSPF model can be used as inputs for the future Lake Jesup eutrophication model.

Current Conditions

The watershed loadings of flow, TN, and TP are summarized in Tables ES.1 – ES.3. On average, the annual flow contributions from the watershed to Lake Jesup is 95,482.0 acre-ft/yr, of which 50% is contributed from the Howell Creek watershed, 12% from the Gee Creek watershed, 12% from the Soldier Creek watershed, and 26% from the Ungauged watershed. The average annual watershed loadings of TN and TP are 140.7 metric ton N/yr and 18.7 metric ton P/yr. The Howell Creek watershed contributes 42% of the nutrient loads, the Gee Creek watershed 12%, the Soldier Creek watershed 12%, and the Ungauged watershed 34%. There is significant variation between the watershed loadings in the three dry years (10/1998 – 09/2001) and those in the three wet years (10/1997 – 09/1998 and 10/2001 – 09/2003). The average dry year watershed loadings of flow, TN, and TP are 63,286.2 acre-ft water/yr, 95.5 metric ton N/yr, and 12.9 metric ton P/yr, respectively. The average wet year watershed loadings are 127,677.7 acre-ft water/yr, 185.8 metric ton N/yr, and 24.6 metric ton P/yr, which are approximately 2 times of the dry year watershed loadings.

Table ES.1. Contributions of flow from the watershed (acre-ft/yr).

Water Year	Howell	Gee	Soldier	Ungauged	Total
1998	61720.2	15880.7	15202.3	32574.2	125377.4
1999	30345.7	7371.7	6723.2	9616.3	54056.9
2000	29310.1	6813.2	6299.4	16804.3	59227.0
2001	38027.4	9037.9	8156.1	21353.2	76574.6
2002	47325.3	11750.9	11088.4	33807.0	103971.6
2003	78452.8	20382.0	19953.4	34896.0	153684.2
Average	47530.3	11872.7	11237.1	24841.8	95482.0

Table ES.2. Contributions of TN from the watershed (metric ton N/yr).

Water Year	Howell	Gee	Soldier	Ungauged	Total
1998	74.5	21.4	22.7	58.7	177.3
1999	38.1	10.1	11.1	21.4	80.6
2000	34.3	9.0	9.4	33.2	86.0
2001	47.4	12.8	13.5	46.3	120.0
2002	57.7	16.8	18.1	67.3	159.9
2003	94.8	29.1	31.7	64.7	220.3
Average	57.8	16.5	17.7	48.6	140.7

Table ES.3. Contributions of TP from the watershed (metric ton P/yr).

Water Year	Howell	Gee	Soldier	Ungauged	Total
1998	10.5	2.6	2.6	7.1	22.8
1999	5.5	1.4	1.4	2.4	10.7
2000	5.1	1.2	1.1	3.9	11.3
2001	7.2	1.8	1.8	5.9	16.6
2002	8.7	2.2	2.2	8.5	21.7
2003	14.0	3.7	3.9	7.6	29.2
Average	8.5	2.2	2.2	5.9	18.7

Scenario Analysis

The calibrated HSPF model is used to assess the impact of various management scenarios on the nutrient loadings to Lake Jesup. A general description of the simulated scenarios is given as follows:

1. Current – current (1997 – 2003) conditions;
2. Future – future land use with 100% Best Management Practice (BMP) implementation for future development (newly increased residential, industrial, and commercial areas);
3. Future + 25% BMP – future conditions + 25% BMP implementation for current land uses without BMPs (excluding forest, water, and wetland);
4. Future + 50% BMP – future conditions + 50% BMP implementation for current land uses without BMPs (excluding forest, water, and wetland);
5. Future + 75% BMP – future conditions + 75% BMP implementation for current land uses without BMPs (excluding forest, water, and wetland);
6. Pristine – all forested (except water and wetland) watershed.

The simulation of these scenarios is performed over the entire simulation period from 10/1997 to 09/2003. It is assumed that all the newly implemented BMPs in scenarios 2 – 5 are wet detention ponds. Figure ES.1 compares the estimated TN and TP loadings to Lake Jesup under these six scenarios. The estimated TP loading under the future scenario is close to the current TP loading level, suggesting that the implementation of BMPs for all the future development and the decrease of the agriculture and pasture areas (as indicated in the future land use map) would effectively control the increase of TP loads. Because the removal efficiencies of BMPs for nitrogen are relatively low compared with those for phosphorus, the implementation of BMPs is less successful in controlling the increase of TN loading from the watershed. The projected future conditions have an 11% increase of TN loading from the current level. Additional reductions of watershed nutrient contributions can be achieved by implementing BMPs to the areas currently without receiving treatment. Implementing BMPs to 25%, 50%, and 75% of the current land uses without BMPs and 100% of future development could reduce nutrient loadings from the projected future levels by 3%, 6%, and 9% for TN and by 6%, 11%, and 17% for TP. Despite implementing BMPs to an extreme level (Future + 75% BMP), the resulting nutrient loadings will still be well above the estimated background loadings under the pristine scenario, which account for only 31% and 32% of the projected future TN and TP levels. To achieve greater nutrient reductions than those in the simulated BMP implementation scenarios, watershed management should focus on implementing nonstructural BMPs (such as better source control and stormwater reuse) to reduce nutrient loading rates from developed areas and using BMP treatment trains to improve nutrient removal efficiencies.

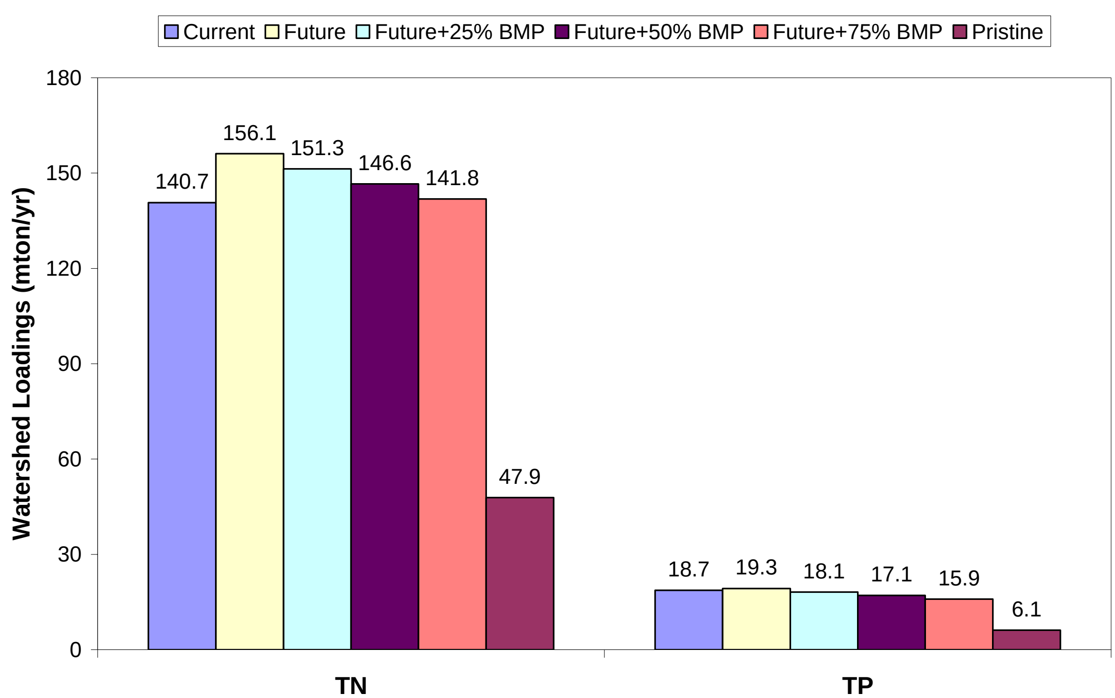

Figure ES.1. Comparison of average annual TN and TP loads to Lake Jesup for the six simulated scenarios.

Future Investigations

This work shows that the HSPF model can adequately predict the flow and water quality concentrations across the Lake Jesup watershed. The accuracy of HSPF predictions could be further improved by collecting additional field data for model calibration and validation. Specific suggestions for future investigations are listed as follows:

- Investigate the interaction between groundwater and surface water in the Lake Jesup watershed. This information is helpful to assess whether the current formulation of HSPF can adequately represent the groundwater processes in the study area.
- Collect additional information on BMPs at the drainage area of Navy Canal (subwatershed 27) and assess the effectiveness of these BMPs on the removal of TN and TP. This will help to explain the observed low TN and TP concentrations in Navy Canal.
- Identify the sources contributing to the observed high TP levels at Sweetwater Creek and Solary Canal.
- Study which nonstructural BMPs could effectively reduce TN and TP loads to Lake Jesup and incorporate their effects in the scenario analysis.
- Conduct field studies to calculate the pollutant removal efficiencies of the existing BMPs in the Lake Jesup watershed. The results of these field studies could help to refine the removal efficiencies used in this study.

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1. Introduction

The Florida Legislature requires the Water Management Districts to develop Pollutant Load Reduction Goals (PLRGs) for the impaired water bodies within their boundaries (Florida Administrative Code 62-40). In 2002, the St. Johns River Water Management District (SJRWMD) adopted the Surface Water Improvement and Management (SWIM) plan and began the PLRG process for the Middle St. Johns River Basin (MSJRB). In 2004, the SJRWMD contracted with BCI Engineers and Scientists, Inc. to provide the engineering services for the development of watershed models for the MSJRB.

Lake Jesup, Florida, is a hyper-eutrophic lake in the MSJRB. To support the development of PLRGs for total nitrogen (TN) and total phosphorus (TP) at Lake Jesup, this study applies a mechanistic watershed simulation model to estimate the loadings of flow and nutrients (TN and TP) from the watershed to Lake Jesup under existing and future conditions and to evaluate the effects of various watershed management scenarios on the watershed loadings. This chapter describes the study area, introduces the modeling approach, and overviews the organization of this report.

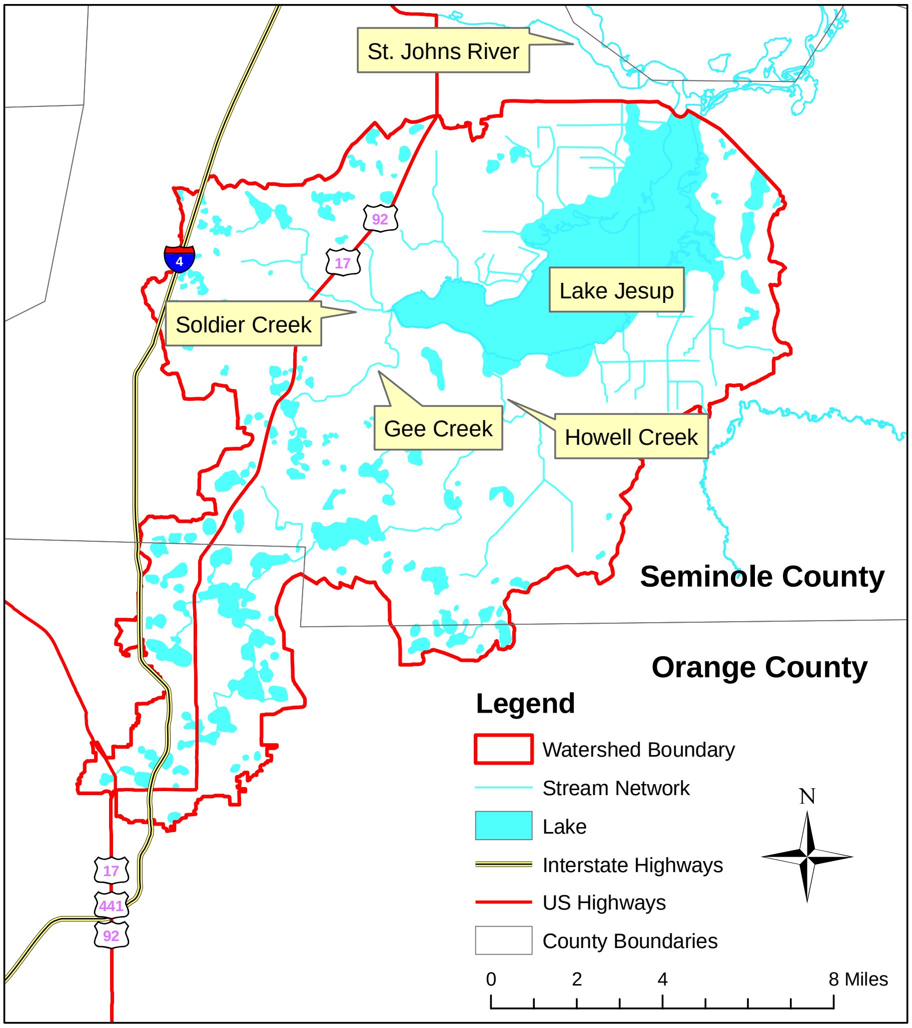
1.1 Study Area

The Lake Jesup watershed is a subbasin of the MSJRB located in Seminole County, Florida, including a small portion of Orange County (Figure 1.1). The total drainage area of the Lake Jesup watershed is approximately 152 square miles, of which about 17 square miles are the water surface of Lake Jesup. Lake Jesup is connected to St. Johns River through a narrow channel at the northern end of the lake. The watershed is drained to Lake Jesup through three large tributaries (Howell Creek, Gee Creek, and Soldier Creek) and a number of smaller tributaries and canals (e.g. Six Mile Creek, Salt Creek, Sweetwater Creek, Navy Canal, Kentucky Canal, and Cameron Canal). In addition, many lakes, including Lake Virginia, Lake Maitland, and Lake Howell, and detention ponds exist within the watershed. They serve as storage facilities for stormwater runoff and provide significant benefits for the improvement of water quality.

The Lake Jesup watershed is a highly urbanized watershed. Urban areas, including residential areas, industrial areas, and commercial areas, make up 46% of the watershed. Numerous lakes and wetlands cover 33% of the watershed. Open areas, pasture, rangeland, forest, and agriculture areas make up the other major land uses in the watershed.

The climate of the study area is humid subtropical. Based on the climatologic data compiled from the National Oceanic and Atmospheric Administration over the period 10/1997 – 09/2003, the temperature ranges from an average of 61 Degrees Fahrenheit (degF) in January to an average of 81 degF in July. The average annual rainfall over this period is about 54 inches. Approximately 60% of the annual rainfall occurs in the summer season from June to September. Average monthly rainfall ranges from 2 inches to 8 inches, and annual rainfall ranges from 41 inches to 66 inches.

Lake Jesup and its adjacent surrounding drainage areas overlie the Eastern Plain physiographic area, and the remaining areas of the watershed overlie the Osceola Plain physiographic area (Schellentrager and Hurt 1990). The Eastern Plain and the Osceola Plain are both broad and flat areas. Elevations of the study area range from 5 feet to 125 feet above sea level, with an average elevation of 46 feet. Soils of the watershed are generally sandy and well-drained, with the exception of some large marsh areas adjacent to Lake Jesup (Schellentrager and Hurt 1990; Keesecker 1992).



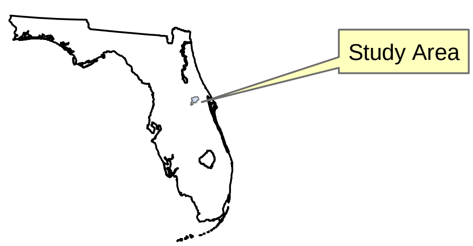


Figure 1.1. The Lake Jesup watershed, Florida.

1.2 Modeling Approach

The Hydrological Simulation Program – Fortran (HSPF) model version 12.0 (Bicknell et al. 2001) is used in this study to simulate the hydrology and water quality in the Lake Jesup watershed. The HSPF model is a lumped-parameter, continuous simulation model that simulates both point and nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates instream water quality processes (Bicknell et al. 2001). This model framework is selected because of its capability to handle a variety of water quality constituents and to represent complex land uses and pollutant sources in the watershed. In addition, HSPF has been incorporated into BASINS (U.S. Environmental Protection Agency (USEPA) 2001b), supported by the USEPA as a standard watershed modeling framework for Total Maximum Daily Load (TMDL) development. Many recent applications of HSPF (e.g. Bergman et al. 2002; Wicklein and Schiffer 2002) have demonstrated that HSPF can accurately predict stream flow and concentrations of various water quality constituents in Florida.

The watershed is conceptually represented in HSPF by a series of storage compartments (e.g. surface depression, soil zone, ground water zone, river segment). Based on the principal of mass conservation, HSPF performs continuous budget analysis of water quantity and quality for these storage compartments. Given the inputs of meteorological time series and the parameter values related to watershed characteristics, HSPF generates time series of runoff, stream flow, loading rates, and concentrations of various instream water quality constituents.

While most parameters of HSPF can be specified by watershed spatial and physical data (e.g. land use, topography, stream characteristics, and soil property), a few parameters, such as those related to infiltration, evaporation, and instream kinetics, need to be determined in the calibration and validation process. Model calibration is the process of adjusting values of model parameters to accurately reproduce the observed flow and water quality data. Validation is the testing of the selected parameter values. In general, the observed flow and water quality data from one time period are used for calibration, and the data from another time period are used for validation. Once calibrated and validated, the HSPF model is considered to be able to accurately represent the hydrologic and water quality processes in the watershed and can be utilized for scenario analysis.

1.3 Organization of the Report

To describe the procedures and to present the results for the application of HSPF to the Lake Jesup watershed, this report is organized as follows. Chapter 2 summarizes the data used for HSPF modeling at the Lake Jesup watershed and their sources. Chapter 3 describes the formulation, calibration, and validation of the HSPF model. In addition, a summary of watershed modeling results for existing conditions is presented in Chapter 3. Analysis of management scenarios is described and discussed in Chapter 4. Finally, Chapter 5 summarizes the results of this study and discusses the future effort needed to improve the Lake Jesup watershed HSPF model.

2. Data Collection

The development of HSPF model requires various types of data, including watershed physical and spatial data (subwatershed delineation, land use, etc.), meteorological data, stream flow data, and water quality data. These data and their sources are described bellow.

2.1 Subwatershed Delineation

A Geographic Information System (GIS) layer of subwatershed boundaries for the Lake Jesup watershed was obtained from the SJRWMD. The Lake Jesup watershed is divided into 39 subwatersheds (Figure 2.1) based on the stream network and topography of the watershed. These subwatersheds are grouped into five major subbasins: Howell Creek watershed (subwatersheds 1 - 9), Gee Creek watershed (subwatersheds 10 - 15), Soldier Creek watershed (subwatersheds 16 - 23), Ungauged watershed (subwatersheds 24 - 38), Lake Jesup and its adjacent drainage areas (subwatershed 39), as shown in Figure 2.1. Howell Creek, Gee Creek, and Soldier Creek are major tributaries to Lake Jesup. U.S. Geological Survey (USGS) flow gauges are installed along the main stems of these tributaries. The Ungauged watershed includes the drainage areas of several smaller streams and canals where stream flows are not continuously monitored.

Subwatersheds 3, 11, and 16 are closed drainage areas and do not contribute surface runoff to downstream. No simulation is performed for these subwatersheds. Subwatershed 39 includes Lake Jesup and its adjacent drainage areas. The total acreage of these adjacent drainage areas varies constantly with the change of the surface area of Lake Jesup. To model the loads contributed from these adjacent drainage areas to Lake Jesup, a 10,720-acre area (the average surface area of Lake Jesup in the period from

10/1997 to 09/2003) of water and wetland in subwatershed 39 is counted as Lake Jesup, and the remaining area in subwatershed 39 is counted as the drainage area to Lake Jesup. For simplicity, the adjacent drainage area in subwatershed 39 is not referred as a separate subwatershed and is considered as a part of the Ungauged watershed. This study focuses on the simulation of hydrology and water quality in the Howell Creek watershed, the Gee Creek watershed, the Soldier Creek watershed, and the Ungauged watershed (including the drainage area adjacent to Lake Jesup in subwatershed 39). Analysis of hydrology and water quality processes in Lake Jesup will be conducted as a separate study and will not be described in this report.

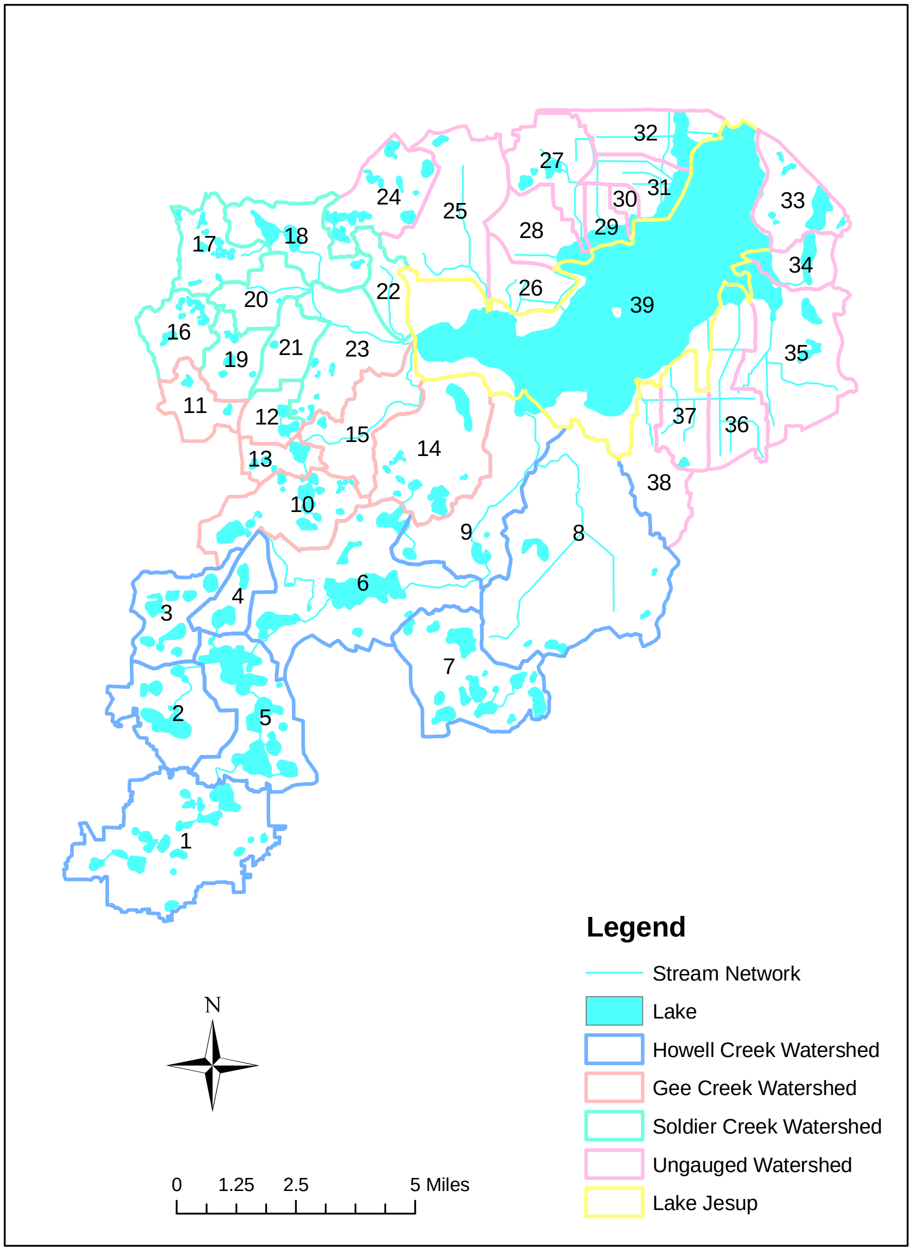


Figure 2.1. Subwatersheds, stream network, major subbasins in the Lake Jesup watershed.

2.2 Land Uses

A GIS land use map for the Lake Jesup watershed was obtained from the SJRWMD. The land use information is primarily based on aerial photographs taken in 1999 and 2000. The SJRWMD identified over 100 different land use classes within the watershed based on the Florida Land Use Classification Code System (FLUCCS). For modeling purposes, these land use classes are grouped into 13 major land uses following the Land Use Classification Table developed by the engineering division of SJRWMD (Bergman 2004). Consolidation of the original land use classes is mainly based on similarities in hydrologic properties and nutrient loads. Table 2.1 and Figure 2.2 show the distribution of these aggregated land uses in the Lake Jesup watershed.

Table 2.1. Distribution of consolidated land uses in the Lake Jesup watershed.

Land Use	Acreage	Percent of the Lake Jesup watershed
Low Density Residential (LDR)	5742	5.9
Medium Density Residential (MDR)	22494	23.1
High Density Residential (HDR)	5024	5.1
Industrial and Commercial (IND)	12060	12.4
Mining (MIN)	117	0.1
Open Land (OPE)	2332	2.4
Pasture (PAS)	4521	4.6
Agriculture General (AGG)	3129	3.2
Agriculture Tree Crop (AGT)	1947	2.0
Rangeland (RAN)	2285	2.3
Forest (FOR)	5482	5.6
Water (WAT)	13974	14.3
Wetland (WET)	18455	18.9

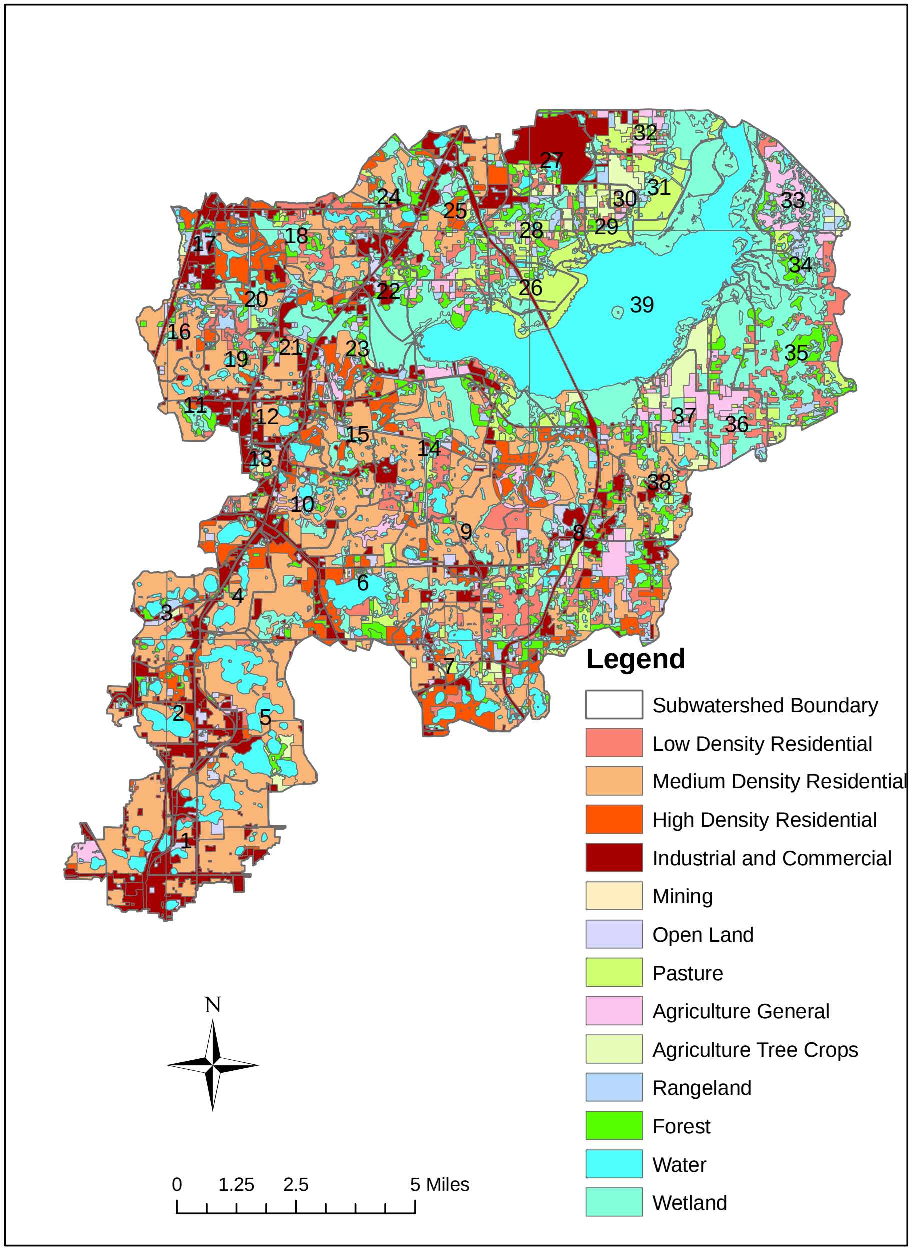


Figure 2.2. Land uses in the Lake Jesup watershed.

2.3 Best Management Practices

Information on Best Management Practices (BMPs) in the Lake Jesup watershed was obtained from Florida Department of Environmental Protection (FDEP). This information was developed by PBS&J, Inc. and was used by FDEP for the development of TMDLs for Lake Jesup. Seven types of BMPs were identified, including swale, dry detention pond, swale/dry detention pond, wet detention pond, Orlando 100% on-site retention, Orlando private BMPs, and lake drainage well. Table 2.2 lists the acreage and percentage of watershed area served by each of these BMPs. Figure 2.3 shows the spatial distribution of BMP treatment areas in the Lake Jesup watershed.

Table 2.2. Treatment areas served by BMPs in the Lake Jesup watershed.

BMP Type	Acreage Served	Percent of the Lake Jesup watershed
Swale	1194	1.2
Dry Detention Pond	10991	11.3
Swale/Dry Detention Pond	289	0.3
Wet Detention Pond	12086	12.4
Orlando 100% On-site Retention	33	0.03
Orlando Private BMPs	6	0.01
Lake Drainage Well	3043	3.1
No BMPs	69923	71.7

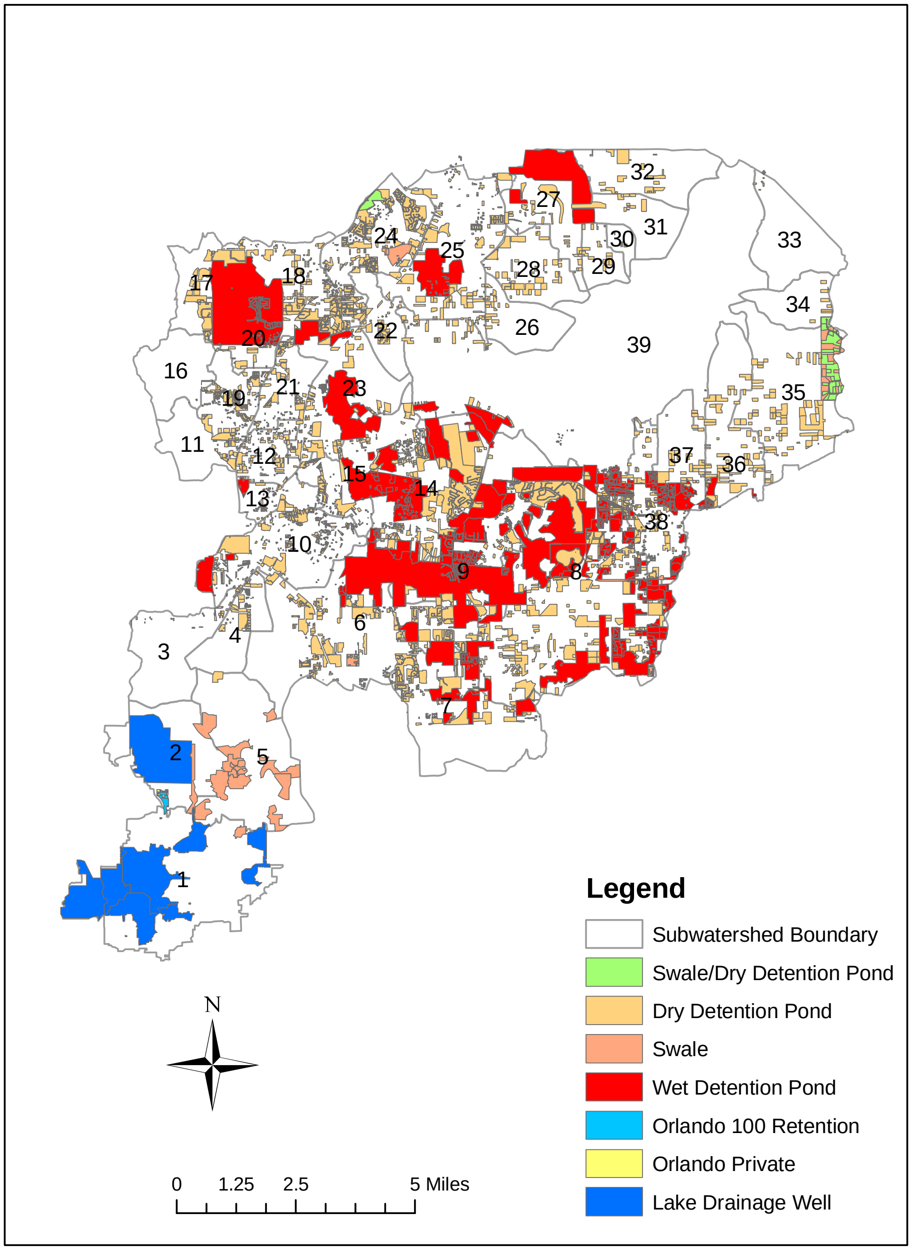


Figure 2.3. Spatial distribution of BMP treatment areas in the Lake Jesup watershed.

2.4 Meteorological Data

HSPF requires 8 hourly meteorological time series as input data, including precipitation, evaporation, air temperature, wind speed, solar radiation, potential evapotranspiration, dew point temperature, and cloud cover. To collect the required data, weather stations within and around the Lake Jesup watershed were analyzed for their types of data collected, length of record, and missing data. Table 2.3 lists the weather stations used in this study. The weather data from these stations were obtained from the SJRWMD. The weather data from other nearby stations were also collected for this study, but they were not used for watershed modeling because they do not cover the entire simulation period from 10/1997 to 09/2003 in this study.

Table 2.3. Major weather stations within or near the Lake Jesup watershed.

Station Name	Location	Date Type	Period of Record	Time Interval
CHARST	Charlotte Street near Altamonte Springs	Precipitation	8/1/1994 – 12/31/2003	Daily Hourly
SANFORD	Sanford Airport	Precipitation	1/1/1995 – 12/31/2003	Daily
LISBON	Lisbon	Pan Evaporation	1/1/1960 – 12/31/2003	Daily
ORLANDO	Orlando International Airport	Wind Speed Air Temperature Dew Point Temperature Cloud Cover	5/7/1952 – 6/30/1996 for Cloud Cover; 5/7/1952 – 12/31/2002 for others	Hourly
S61W	Lake Tohopekeliga	Solar Radiation	10/20/1992 – Present	Daily

The wind speed data, the air temperature data, and the dew point temperature data from ORLANDO are only available up to the end of 2002, and the cloud cover data from ORLANDO are not available for the simulation period. The air temperature data and the dew point temperature data are extended to 09/2003 using their daily average values calculated over the period 01/1993 – 09/2002. The wind speed data and the cloud cover data are extended to cover the whole simulation period using their monthly average values calculated over the period 01/1993 – 09/2002 and the period 07/1987 – 06/1996, respectively.

The meteorological data are imported into a Weather Data Management (WMD) database using WDMUtil (USEPA 2001a), a utility program for managing meteorological data for HSPF. WDMUtil is also used to disaggregate the daily precipitation data from SANFORD into an hourly time step based on the observed hourly precipitation time series from CHARST. In addition, WDMUtil is used to disaggregate the daily pan evaporation data from LISBON and the daily solar radiation data from S61W into hourly data. The algorithms used for disaggregating the above data can be found in the user's manual of WDMUtil (USEPA 2001a).

To get accurate rainfall time series for model input, rainfall data from the two weather stations are assigned to their adjacent major subbasins in the Lake Jesup watershed (Figure 2.4). The precipitation data from CHARST are used as the input for the Howell Creek watershed, the Gee Creek watershed, and the Soldier Creek watershed in the HSPF model. The precipitation data from SANFORD are assigned to the Ungauged watershed.

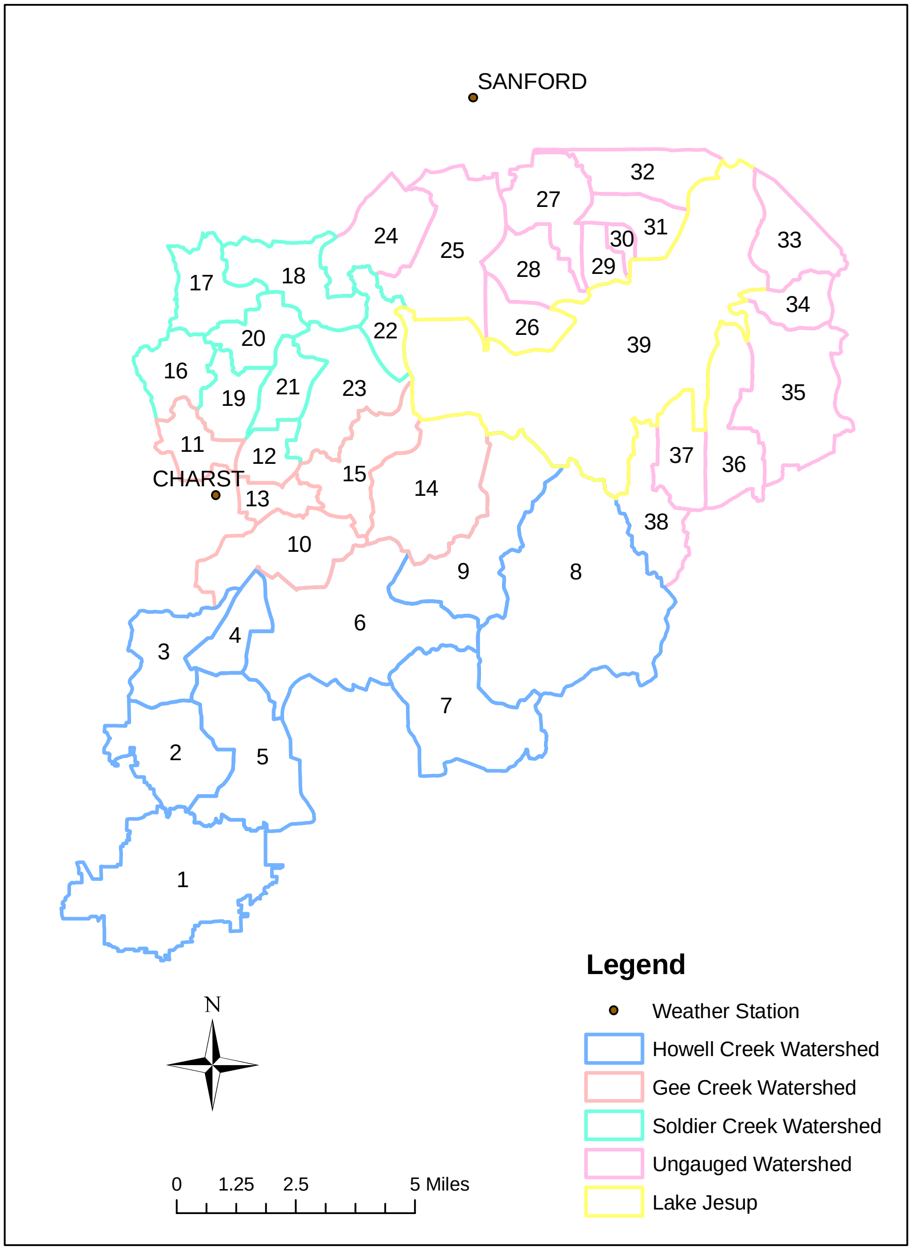


Figure 2.4. Major subbasins and precipitation stations used in the Lake Jesup watershed HSPF model.

This study assumes that the potential evaporation from water surface equals the potential evapotranspiration in the watershed. The potential evapotranspiration is estimated by applying a pan coefficient to the pan evaporation data from LISBON. Different pan coefficients were used in the previous studies. Keesecker (1992) used the monthly pan coefficients to estimate the evaporation from Lake Jesup over the period 1980 – 1990. These monthly pan coefficients vary from 0.775 in March to 0.929 in July with a mean value of 0.86. Phelps and German (1996) selected a pan coefficient of 0.8 for evaporation estimation at the Winter Park Chain of Lakes in subwatersheds 1 – 5 over the period 1989 – 1992. In this study, an annual pan coefficient of 0.9 is used. Although this coefficient is slightly higher than the values in Keesecker (1992) and Phelps and German (1996), it is considered to be appropriate because the recent pan evaporation data at LISBON, especially those after the year of 2000, seem to be lower than their historical values (D. Clapp of SJRWMD, personal communication, 2004). The estimated average potential evapotranspiration using the pan coefficient of 0.9 is 47.5 in/yr over the period from 10/1997 to 09/2003. This estimate is close to the estimated average evapotranspiration rate of 46 – 47 in/yr for the study area by Tibbals (1990).

The hydrologists of the SJRWMD are currently working on the adjustment of the LISBON pan evaporation data to correct the low readings in recent years (D. Clapp of SJRWMD, personal communication, 2006). Once the adjustment is completed, the adjusted LISBON pan evaporation data will be used for the Lake Jesup watershed HSPF model. A pan coefficient similar to those in Keesecker (1992) and Phelps and German (1996) is likely to be used for the adjusted LISBON data in order to generate reasonable estimates of the potential evapotranspiration in the Lake Jesup watershed.

2.5 Observed Flow Data

Continuous daily flow data have been monitored by the USGS at five sites along the main stems of Howell Creek, Gee Creek, and Soldier Creek (Table 2.4). The flow data from these sites were directly downloaded from USGS's web site. Figure 2.5 shows the locations of the USGS gauges.

Table 2.4. USGS flow stations in the Lake Jesup watershed.

Station Name	Station Number	Period of Record
Howell Creek near Altamonte Springs	02234308	10/1996 – 09/2003
Howell Creek near Slavia	02234324	02/1972 – 09/2003
Howell Creek at SR434 near Oviedo	02234344	06/1999 – 09/2003
Gee Creek near Longwood	02234400	01/1972 – 09/2003
Soldier Creek near Longwood	02234384	02/1972 – 09/2003

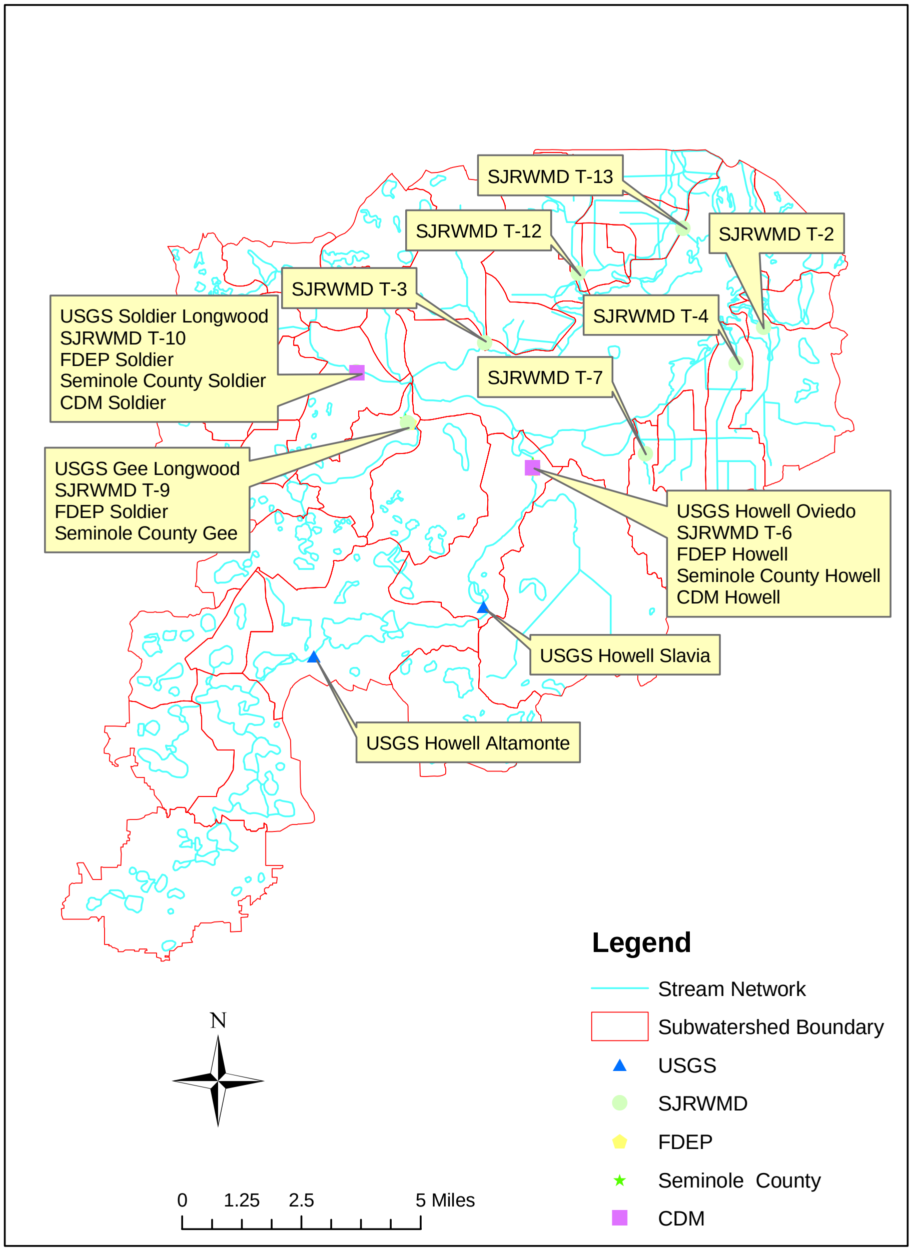


Figure 2.5. USGS flow stations and water quality sampling stations in the Lake Jesup watershed.

2.6 Water Quality Sampling Data

Water quality data have been collected by various organizations at over 200 sites across the watershed. For water quality calibration, seventeen stations near the outlets of Gee Creek, Soldier Creek, Howell Creek, Six Mile Creek, Navy Canal, Chub Creek, Salt Creek, Sweetwater Creek, and Solary Canal are chosen (Table 2.5). The locations of these water quality sampling stations are shown in Figure 2.5.

Table 2.5. Sampling organization, station description, and data source of the water quality stations used for water quality calibration.

Sampling Organization	Station Description	Source
FDEP	Howell Creek, Gee Creek, Soldier Creek near State Road 419	SJRWMD
Seminole County	Howell Creek, Gee Creek, Soldier Creek	SJRWMD
SJRWMD	T-2 at Salt Creek T-3 at Six Mile Creek T-4 at Sweetwater Creek T-6 at Howell Creek T-7 at Solary Canal T-9 at Gee Creek T-10 at Soldier Creek T-12 at Navy Canal T-13 at Chub Canal	SJRWMD
CDM	Near the outlets of Howell Creek and Soldier Creek	CDM (2001; 2003)

2.7 Point Sources

FDEP identified 21 permitted point source dischargers in the Lake Jesup watershed (FDEP 2003). Of these point sources, 11 are domestic wastewater facilities, 7 are industrial wastewater facilities, 2 are concrete batch plants, and 1 is a ground water treatment system at a petroleum contamination site (FDEP 2003). There are four major domestic wastewater treatment plants with a design capacity over 1.0 million gallons per day (MGD): Seminole County Environmental Services/Greenwood Lakes domestic wastewater facility (3.50 MGD), Winter Springs East wastewater treatment plant (WWTP) (2.01 MGD), Winter Springs West WWTP (1.55 MGD), and Casselberry WWTP (1.4 MGD). They do not directly discharge to surface water, and all the treated wastewater is reclaimed for irrigation, car wash, or other purposes (R. Hazard of Seminole County Government, personal communication, 2004; FDEP 2003). Four industrial wastewater treatment facilities directly discharge to surface water. The largest industrial discharger has a daily effluent of 0.028 MGD. No water quality monitoring data are available for these industrial dischargers. These point sources are not expected to have a major impact on the flow and pollutant loadings to the Lake Jesup. Therefore, they are not explicitly simulated in the HSPF model.

2.8 Nonpoint Sources

Nonpoint sources in the watershed are evaluated based on their contributions from watershed land uses, failing septic tanks, and atmospheric deposition. Nonpoint source loadings from a specific land use are determined in the process of water quality calibration based on the expected loadings reported in the literature and the observed water quality data. The calibration of water quality parameters for the estimation of nonpoint source loadings from watershed land uses is discussed in the next chapter. This section describes the characterization of the failing septic tanks and atmospheric deposition in the Lake Jesup watershed.

The number of failing septic tanks within the study area is estimated based on the reported septic tank repairs in Seminole County. The number of annual repairs ranges from 339 to 570 in the period 1997 – 2002 (Florida Department of Health 2004). To account for the possibility that not all failing septic tanks in the county are reported and repaired, the high end of the reported range, 570, is used in this study as the average number of failing septic tanks in Seminole County. It is assumed that these failing septic tanks are distributed evenly in the residential areas (including low, medium, and high density residential areas). The total residential area in Seminole County is 60,511 acres based on the 2000 land use coverage obtained from the SJRWMD. The average number of failing septic tanks per acre residential area is calculated as 570 / 60,511 = 0.00942 per acre. Total residential area in the Lake Jesup watershed is 33,260 acres. Thus, the number of failing septic tanks in the watershed is estimated as 0.00942 × 33,260 = 313 septic tanks.

Pollutant contributions from these failing septic tanks are modeled in two ways depending on their proximity to the stream network in the Lake Jesup watershed. For the septic tanks more than 50-ft away from streams and lakes, pollutant loadings are handled inexplicitly and are lumped to the pollutant loadings from residential areas. The septic tanks within 50-ft of streams and lakes are considered as direct pipes discharging untreated wastewater to the stream network. These direct pipes are modeled as point sources in HSPF. There are 699 acres of residential areas within 50-ft of the stream network in the Lake Jesup watershed. The number of estimated direct pipes in the watershed is 0.00942 × 699 = 7. The direct pipes are assigned to 7 subwatersheds (subwatersheds 1, 5, 6, 7, 14, 18, 24) with the highest acreage of residential area within 50-ft of the stream network.

According to USEPA (1980), per capita flow rate from a failing septic tank is about 7.18×10^{-5} cfs. The average number of persons per household in Seminole County is 2.59 (US Census 2000). The estimated flow rate from a failing septic tank is 7.18×10^{-5} ×

2.59 = 1.86×10^{-4} cfs. Pollutant concentrations of failing septic tank effluent are assumed to equal the average concentration measurements in Florida complied by Parsons (2000). Table 2.6 shows the average pollutant concentrations used in this study. It is assumed that the effluent flow rate and pollutant concentrations are constant over the simulation period.

Table 2.6. Pollutant concentrations of failing septic tank effluent.

Parameters	Concentration (mg/l)
Biological Oxygen Demand[1] (BOD)	352.5
Total Suspended Solids[2] (TSS)	161
Total Nitrogen[3] (TN)	39
Total Phosphorus[4] (TP)	11

Note:
1 – According to Parsons (2000), average measured BOD_5 = 141 mg/l. This study assumes that BOD = 2.5 BOD_5;
2 – This study assumes that TSS loads from failing septic tanks contain 50% silt and 50% clay;
3 – This study treats TN loads from septic tanks as nitrate (NO3) loads;
4 – This study treats TP loads from septic tanks as orthophosphate (PO4) loads.

Simulation of atmospheric deposition is also handled in two ways in HSPF. While atmospheric deposition to the land surface is lumped into nonpoint source loadings from land uses, atmospheric deposition to the surface of streams and lakes is modeled explicitly. This study assumes that only inorganic forms of nitrogen and phosphorus are contributed from atmospheric deposition. Inorganic N (ammonia (NH4) and NO3) and inorganic P (PO4) concentrations of wet deposition are assumed to be 0.43 mg/l and 0.009 mg/l, which are the same concentrations of wet deposition for TN and TP estimated by Brezonik et al. (1983). Inorganic N and P dry deposition rates are assumed to be 150 mg N/m^2/yr and 20 mg P/ m^2/yr, respectively. These values are equal to the TN and TP dry deposition rates for the Lake Apopka area estimated by X. Gao of FDEP (personal communication 2004). It is also assumed that inorganic N deposition contains 75% NO3 and 25% NH_4 (Brandt-Williams of SJRWMD, personal communication, 2006). The above annual loadings are evenly allocated as the monthly input to the HSPF model.

3. HSPF Model Development

The HSPF version 12.0 (Bicknell et al. 2001) is used to simulate the hydrologic and water quality processes in the Lake Jesup watershed. The simulation period is from 10/1997 to 09/2003, which includes both wet and dry years and covers a variety of hydrologic conditions. This chapter will first present the formulation of HSPF for hydrologic and water quality simulation of the Lake Jesup watershed, followed by a description of hydrologic and water quality calibration of the HSPF model for Howell Creek, Gee Creek, and Soldier Creek. Next, the application of the calibrated HSPF parameters to the Ungauged watershed is discussed. Finally, a summary of modeling results for current conditions (10/1997 – 09/2003) of the Lake Jesup watershed is provided.

3.1 HSPF Formulation

To set up the HSPF model, the first step is to obtain an accurate conceptual representation of the watershed. Then various submodules of HSPF are specified for the simulation of different hydrologic and water quality processes.

3.1.1 Watershed Segmentation

A watershed and its stream network are characterized in HSPF by various pervious land segments (PERLND), impervious land segments (IMPLND), and reach segments (RCHRES) based on subwatershed delineation, land uses, and the ratio of perviousness and imperviousness for each land use. As described in section 2.2, the land uses in the Lake Jesup watershed are grouped into 13 categories. These consolidated land uses are further divided into pervious and impervious factions. The pervious portion of a land use in a subwatershed is represented as a PERLND, and the impervious portion of a land use in a subwatershed is represented as an IMPLND. The assignment of pervious/impervious factions for land uses is discussed in section 3.1.2.

For modeling purposes, the stream network in a subwatershed is grouped together and represented as a RCHRES. The geometric and hydraulic properties of a RCHRES are represented in HSPF by a FTABLE, which describes the relationships between stage, surface area, volume, and discharge for the reach segment. Development of FTABLEs for the stream network in the Lake Jesup watershed is described in section 3.1.3.

The reach segment draining a subwatershed receives the runoff and water quality constituents from the land segments in that subwatershed. For the area without BMP treatment, the runoff and water quality constituents are delivered to the reach segment directly. However, for the area with BMP treatment, the runoff and water quality constituents are first delivered to BMPs, and then the outputs from BMPs are delivered to the reach segment. Characterization of various BMPs and their impacts on peak flow attenuation and pollutant reduction is described in section 3.1.4.

3.1.2 Effective Impervious Area

Impervious areas include all surface areas that prevent water from infiltrating into the ground. Typical impervious areas are roofs, roads, and parking lots. These impervious areas can be classified into two categories: effective impervious area (EIA) and noneffective impervious area (NEIA). EIAs, or directly connected impervious areas, are the impervious areas that directly connect to the drainage network with no opportunity for infiltration. NEIAs are the impervious areas that drain to pervious areas. In this study, only EIAs are modeled as IMPLND, and NEIAs are lumped to PERLND.

Among 13 consolidated land uses, 4 land uses (LDR, MDR, HDR, and IND) are assumed to have EIAs. The remaining land uses are assumed to be 100% pervious. Percentages of EIA for LDR, MDR, HDR, and IND are determined during hydrologic calibration by varying the percentages within their typical ranges reported in the literature. Calibration of these percentage values focuses on matching the observed flows during small storm events because most runoff during small storms is generated from EIAs. Impacts of changing imperviousness percentages on total mass balance and seasonal flow distribution are also considered. Table 3.1 lists the percentages of EIA used in this study. In many subwatersheds, the stream network is partially or completely surrounded by wetlands, which receive the runoff originated from impervious areas. To account for the storage effects of these wetland areas, no EIAs are modeled in subwatersheds 14, 19, 20, 21, and 23.

Table 3.1. Percentages of effective impervious area by land use.

Land Uses	% Imperviousness
Low Density Residential (LDR)	5
Medium Density Residential (MDR)	10
High Density Residential (HDR)	40
Industrial and Commercial (IND)	60

3.1.3 Development of FTABLE for Stream Network

In HSPF, the stream network in a subwatershed is grouped together and represented as a reach segment, which could be either a free-flowing stream or a mixed lake. The FTABLEs for stream reaches are developed based on the Manning’s equation. The stream reaches in the Lake Jesup watershed are modeled as streams with uniform trapezoidal cross-sections. Channel cross-section characteristics are based on the survey data of the drainage inventory studies at the Lake Jesup watershed (Dyer, Riddle, Mills &

Precourt 1994; Singhofen & Associates 1996a and 1996b; CDM 2000). Stream length, slope, and elevation are estimated based on the stream network and digital elevation map obtained from the SJRWMD. Manning's n coefficients for these streams are estimated by comparing the calculated stage-discharge relationships with the measured relationships at several USGS flow gauge sites. Table 3.2 shows physical characteristics of stream segments in the subwatersheds with stream reaches.

Table 3.2. Characteristics of stream segments.

Sub-watershed	Length (ft)	Bottom Width (ft)	Top Width (ft)	Depth (ft)	Slope	Manning's Coefficient
8	31058	15	140	8	0.00138	0.094
9	26600	10	150	8.5	0.00132	0.096
14	9840	3	200	5	0.00051	0.099
15	19057	5	40	8	0.00208	0.093
18	12310	5	200	5	0.00081	0.099
20	7657	5	120	4	0.00157	0.098
21	6560	5	100	3	0.00229	0.097
22	9856	3	100	3	0.00345	0.098
23	14500	5	40	5	0.00172	0.093
25	21691	5	50	8	0.00138	0.095
27	14894	5	50	8	0.00295	0.095
28	7957	5	50	8	0.00063	0.095
29	5150	5	30	6	0.00350	0.092
30	3000	5	40	5	0.00300	0.093
31	10578	6	50	6	0.00189	0.094
32	13730	8	60	6	0.00182	0.093
34	10188	5	40	6	0.00147	0.093
35	21133	10	60	6	0.00095	0.092
36	7987	6	70	7	0.00063	0.095
37	4228	5	50	8	0.00142	0.095
38	7728	5	40	8	0.00259	0.093

Development of FTABLEs for lake reaches is based on the storage-discharge relationship tables of the Storm Water Management Model (SWMM) for the Lake Jesup watershed developed by Karama (1998). Only the lakes with a large surface area and a high volume are modeled as reach segments. When several large lakes exist in a subwatershed, they are combined to form a single fully mixed lake.

In total, 21 stream reaches and 12 lake reaches are represented in the HSPF model. No reach segments are modeled for the closed subwatersheds 3, 11, and 16. The runoff and water quality constituents from subwatersheds 26 and 33 are assumed to enter Lake Jesup directly because these two watersheds are adjacent to Lake Jesup and there are no clear major drainage channels. In addition, this study assumes that the runoff and water quality constituents from the adjacent drainage area of Lake Jesup in subwatershed 39 directly enter Lake Jesup.

3.1.4 BMP Characterization

Among the seven types of BMPs identified in the Lake Jesup watershed (see section 2.3), five types of BMPs are explicitly simulated: dry detention pond, wet detention pond, swale, lake drainage well, and swale/dry detention pond. Orlando 100% on-site retention and Orlando private BMPs are not explicitly modeled because they only serve approximately 37 acres or 0.04% of the Lake Jesup watershed.

The available BMP data do not support detailed modeling of BMPs in the Lake Jesup watershed. The BMPs in the watershed are mostly on-site BMPs and serve relatively small areas. The efforts involved in compiling related information and performing detailed simulations for each individual BMP in the watershed would be time-consuming. Therefore, the focus of this study is to simulate the effects of various BMPs on peak flow attenuation and pollutant load reduction at subwatershed levels.

A RCHRES is used in the HSPF model to represent all the dry detention ponds or all the wet detention ponds in a subwatershed. HSPF routes surface runoff, interflow, and their associated water quality constituents generated from the contributing areas through the dry pond RCHRES and routes surface runoff, interflow, baseflow, and their associated water quality constituents generated from the contributing areas through the wet pond RCHRES. Table 3.3 lists the assumptions used for the FTABLE development. These assumptions are generally based on SJRWMD's permitting rules and typical design procedures for detention ponds in the study area. To make the HSPF model relatively simple and efficient, complex water quality processes in detention ponds are not simulated in the HSPF model. Instead, water quality constituents are routed through the pond RCHRES as conservative constituents, and a set of removal efficiencies are applied to various water quality constituent outflows from the RCHRES.

Table 3.3. Summary of the assumptions used to develop FTABLEs for dry and wet detention pond RCHRES in the HSPF model.

	Assumptions
Dry Detention Pond RCHRES	1. The surface area of dry pond RCHRES in a subwatershed is 5% of its total contributing area; 2. Dry detention pond side slope is 3H: 1V; 3. Dry detention pond depth is 5 feet, including 2 feet for water quality treatment, 2 feet for peak flow attenuation, and 1 foot for free board; 4. The recovery time for a half of water quality treatment volume is 24 hours and the recovery time for a half of peak flow attenuation volume is 12 hours.
Wet Detention Pond RCHRES	1. The surface area of wet pond RCHRES in a subwatershed is 5% of its total contributing area; 2. Wet detention pond side slope is 3H: 1V; 3. Wet detention pond depth is 13 feet, including 8 feet for permanent pool, 2 feet for water quality treatment, 2 feet for peak flow attenuation, and 1 foot for free board; 4. The recovery time for a half of water quality treatment volume is 48 hours and the recovery time for a half of peak flow attenuation volume is 12 hours.

The effects of swales and lake drainage wells are simulated by directly applying a set of removal efficiencies to the runoff and water quality constituents from their contributing areas. While the removal efficiencies for swales are only specified for the water quality constituents associated with surface runoff, the removal efficiencies for lake drainage wells are applied to all runoff types (surface flow, interflow, and baseflow) and their associated water quality constituents. The swale/dry detention pond is conceptualized as a treatment train, in which the runoff and water quality constituents from contributing areas pass sequentially through a swale and a dry detention pond. Since the swale is assumed to not affect stormwater runoff, the surface runoff and interflow from contributing areas are routed through a dry pond RCHRES directly. To simulate the effects of swale/dry detention pond on water quality, the removal efficiencies of swale are first applied to the water quality constituents associated with surface runoff and then the resulting water quality constituents associated with surface runoff, in combination with the water quality constituents associated with interflow, is routed through a dry pond RCHRES.

The pollutant removal efficiencies used in the HSPF model are presented in Table 3.4. The removal efficiencies for dry detention pond, wet detention pond, and swale are mainly based on the median values of the reported ranges in *Preliminary Data Summary of Urban Storm Water Best Management Practices* (USEPA 1999), *National Pollutant Removal Database for Stormwater Treatment Practice, 2nd Edition* (Center for Watershed Protection 2000), and *Literature Review of Stormwater Best Management Practices* (CDM 2002). These median values are considered reasonable to represent the average performance of individual BMPs at subwatershed levels. Following Gao (2006), the pollutant removal efficiency of lake drainage wells is assumed to be 64%. The 64% removal efficiency is also applied to the runoff contributed to lake drainage wells.

Table 3.4. Pollutant removal efficiencies used in the HSPF model (%).

	Dry detention pond	Wet detention pond	Swale	Lake drainage well
TSS	50	80	80	64
Total Ammonia	5	25	15	64
Nitrate + Nitrite	5	25	15	64
PO4	20	55	30	64
BOD[1]	20	35	30	64

Note:
1 – BOD is used as a surrogate for organic N and organic P. See the next section for further discussion on the simulated water quality constituents.

3.1.5 Specification of HSPF Submodules

HSPF has a modular structure, in which the simulation of PERLND, IMPLND and RCHRES is handled by the PERLND module, the IMPLND module, and the RCHRES module, respectively. Each of these modules includes a variety of submodules performing different tasks. This section briefly describes the HSPF submodules and the hydrologic and water quality processes modeled by these submodules. Detailed description of these submodules can be found in Bicknell et al. (2001).

Hydrologic simulation for PERLND and IMPLND is carried out in the PWATER submodule and the IWATER submodule. The simulated hydrologic processes for a PERLND include interception, infiltration, evapotranspiration, runoff, and deep percolation. The simulated processes for an IMPLND are similar to those for a PERLND, except there are no infiltration and subsequent subsurface processes. Hydraulic behaviors in a RCHRES are simulated in the HYDR submodule.

Water quality simulation in this study considers the following water quality constituents: total suspended solids (TSS), water temperature, dissolved oxygen (DO), biological oxygen demand (BOD), total ammonia (TAM), nitrite (NO2), nitrate (NO3), organic nitrogen (OrgN), total nitrogen (TN), orthophosphate (PO4), organic phosphorus (OrgP), total phosphorus (TP), phytoplankton, and benthic algae.

To simulate TSS loadings from the watershed, the SEDMNT submodule (for PERLND) and the SOLIDS submodule (for IMPLND) are used. SEDMNT and SOLIDS simulate many sediment processes, including detachment/attachment of sediment particles from/to the soil matrix, attachment of sediment particles, and washoff of detached sediment. Instream sediment transport is handled by SEDTRN, which considers scour, deposition and advection processes. Because transport characteristics of sediment vary significantly with different particle sizes, HSPF simulates three fractions of TSS: sand, silt, and clay. This study assumes that the sediment loads from the watershed contain 20% sand, 40% silt, and 40% clay. Each fraction of sediment is simulated separately in SEDTRN. Sediment-nutrient interactions are not simulated in this study because there are few stormwater sediment samples for calibration of sediment simulation.

Water temperature and DO concentration of runoff are simulated in PWTGAS (for PERLND) and IWTGAS (for IMPLND). Water temperature of each runoff type (surface runoff, interflow, or baseflow) is equal to soil temperature in the layer where the runoff originates. That is, water temperature of surface runoff equals the surface layer soil temperature, water temperature of interflow equals the upper layer soil temperature, and the temperature of baseflow equals the lower layer and groundwater layer soil temperature. Soil temperature in HSPF is simulated based on a linear regression relationship with air temperature. DO concentration in surface runoff is assumed to be saturated. DO concentrations in interflow and baseflow vary monthly and are specified by the modeler.

Instream water temperature is simulated in HTRCH, which calculates the heat budget in a reach segment. The major processes considered in HSPF include advection, absorption of solar radiation, absorption of longwave radiation, conduction-convection, emission of longwave radiation, conduction-convection, and evaporation. Instream DO processes are simulated in the RQUAL submodule, which will be discussed shortly.

PQUAL (for PERLND) and IQUAL (for IMPLND) are used to estimate loads of TAM, NO3, PO4, and BOD from watershed land uses. Surface pollutant loads associate with surface runoff and are modeled using a first-order washoff approach. The pollutants stored on land surface are calculated based on monthly-varied accumulation and removal rates; and subsequent washoff of pollutants is calculated as a first order function of surface runoff. Subsurface pollutant contributions to the stream associate with interflow and baseflow. The pollutant concentrations in interflow and baseflow are assumed to be constant throughout the year.

To model various species of nitrogen and phosphorus and their interactions with other water quality constituents, the RQUAL submodule of HSPF is used. RQUAL simulates the fate and transport of various water quality constituents in the water column and quantifies the impacts on instream water quality by the following processes:

- Processes affecting BOD and DO: reaeration, BOD decay, benthic oxygen demand, nitrification/denitrification, benthic release of BOD, sinking of BOD material, photosynthesis, respiration, and depth of phytoplankton and benthic algae.

- Processes affecting nitrogen and phosphorus: nitrification/denitrification, BOD decay, benthic release of ammonia (NH4) and PO4, sinking of organic nitrogen and phosphorus, sinking of phytoplankton, growth/respiration/depth of phytoplankton and benthic algae.
- Processes affecting phytoplankton and benthic algae: sinking, growth, respiration, and depth.

It should be noted that the BOD loads from the watershed serve as a surrogate for the loads of organic N and organic P, and that BOD in the water column is only the non-refractory (degradable) fraction of the BOD from the watershed. This study assumes that 40% of BOD loads from watershed is non-refractory. The refractory fraction of BOD is represented as refractory organic N and refractory organic P in the water column. Non-refractory organic N and P are not modeled explicitly in RQUAL. They are included as a portion of BOD, and the decay of BOD in the water column results in the release of NH4 and PO4. TN and TP are also not modeled directly in RQUAL. TN and TP concentrations are calculated based on the concentrations of inorganic nitrogen, inorganic phosphorus, refractory organic N, refractory organic P, BOD, and phytoplankton.

3.2 Hydrologic Calibration and Validation

A variety of HSPF hydrologic parameters relating to watershed storage, infiltration, evaporation, and deep percolation are adjusted in the hydrologic calibration processes to match the observed flows at four USGS flow stations: Howell Creek near Oviedo (USGS 02234344), Howell Creek near Slavia (USGS 02234324), Gee Creek near Longwood (USGS 0223400), and Soldier Creek near Longwood (USGS 02234384). The extents of adjustment for these hydrologic parameters are generally within their reasonable ranges reported in USEPA (2000). One exception is the parameter controlling the fraction of water in the groundwater zone entering the deep groundwater (DEEPFR). High DEEPFR values, above the reported "maximum possible" values in USEPA (2000), are used for the PERLND segments in the upstream subwatersheds of the Howell Creek watershed, the Gee Creek watershed, and the Soldier Creek watershed. The high deep groundwater loss is considered to be reasonable because the upstream subwatersheds are located in the recharge region and have relatively high elevations where significant recharge loss to regional surficial aquifer and the low-lying upper Floridian aquifer is expected. In addition, this study assumes that there is significant leakage loss from the lakes in the upstream region of the Howell Creek watershed (subwatersheds 1 – 5) to groundwater. The leakage rate is estimated as 33 inches per year according to a water budget analysis for the Winter Park Chain of Lake in subwatersheds 1 – 5 (Phelps and German 1996). The annual leakage loss is estimated by multiplying the leakage rate by the average surface areas of the lakes. Furthermore, a constant groundwater discharge to the downstream region of the Howell Creek watershed (subwatersheds 8 – 9) is simulated in the HSPF model. This groundwater discharge may come from the regional surficial aquifer or the upper Floridian aquifer. The above assumptions on groundwater processes in the study area are necessary to balance the water budget at the four USGS flow stations. A groundwater study is suggested for the Lake Jesup watershed to further confirm the adequacy of these assumptions.

Figures 3.1 – 3.4 compare the simulated flows and the observed flows at the four calibration sites over the calibration period 10/1999 – 09/2003. It can be seen that good agreement is achieved between the simulated flows and the observed flows. In addition, the performance of hydrologic simulation is evaluated using several statistical measures recommended by HSPEXP (Lumb et al. 1994), an expert system for calibration of HSPF. These statistical measures are also suggested in a technical memorandum of the SJRWMD for HSPF calibration (Bergman 2003). The statistical measures evaluate the fitness between simulated and observed flows in terms of mass balance, low flow recession, high-flow/low-flow distribution, and seasonal distribution. As shown in Table 3.5, the hydrologic calibration performs well except a few violations of the errors in winter flow volume for the two Howell Creek sites and the error in low flow recession for Howell Creek near Slavia.

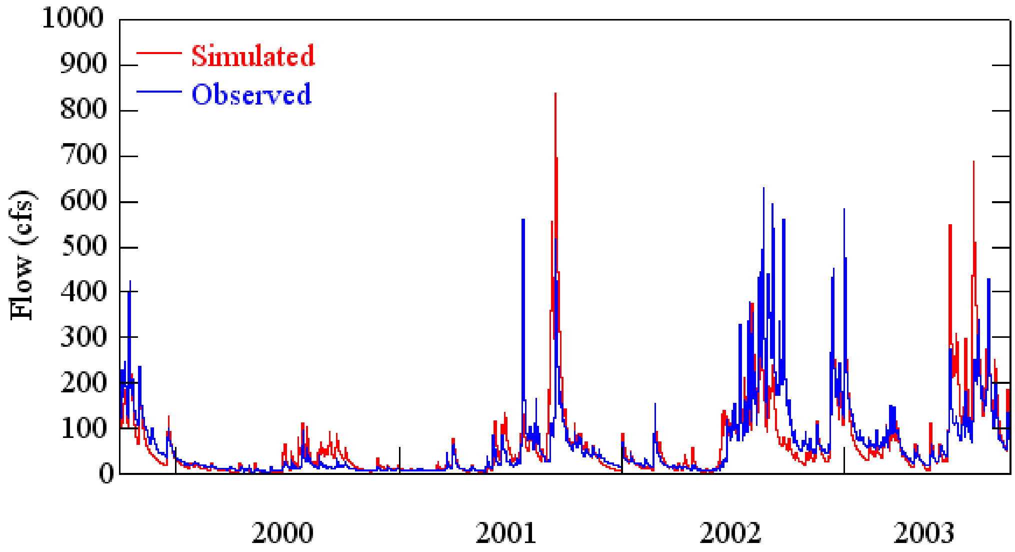


Figure 3.1. Observed and simulated daily flows for Howell Creek near Oviedo (10/1999 – 09/2003).

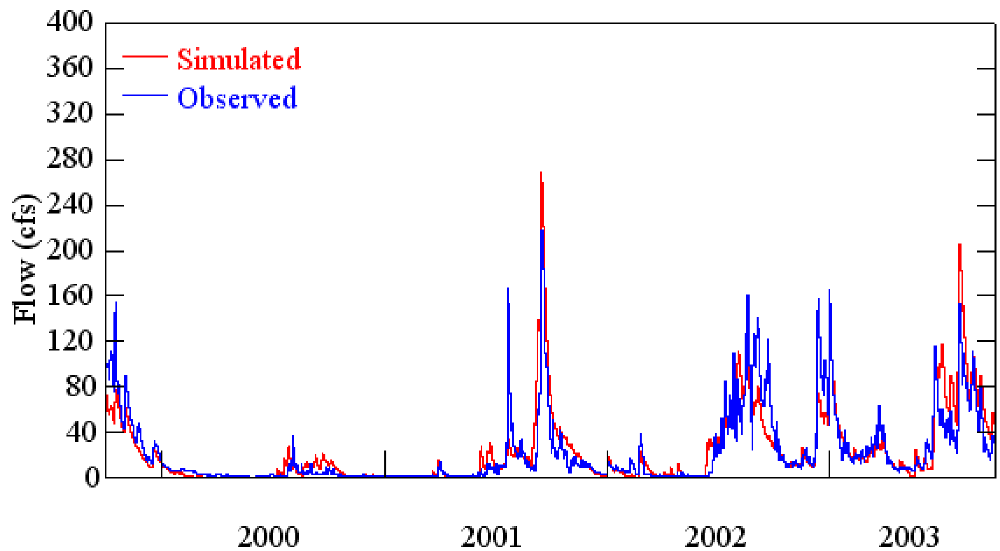


Figure 3.2. Observed and simulated daily flows for Howell Creek near Slavia (10/1999 – 09/2003).

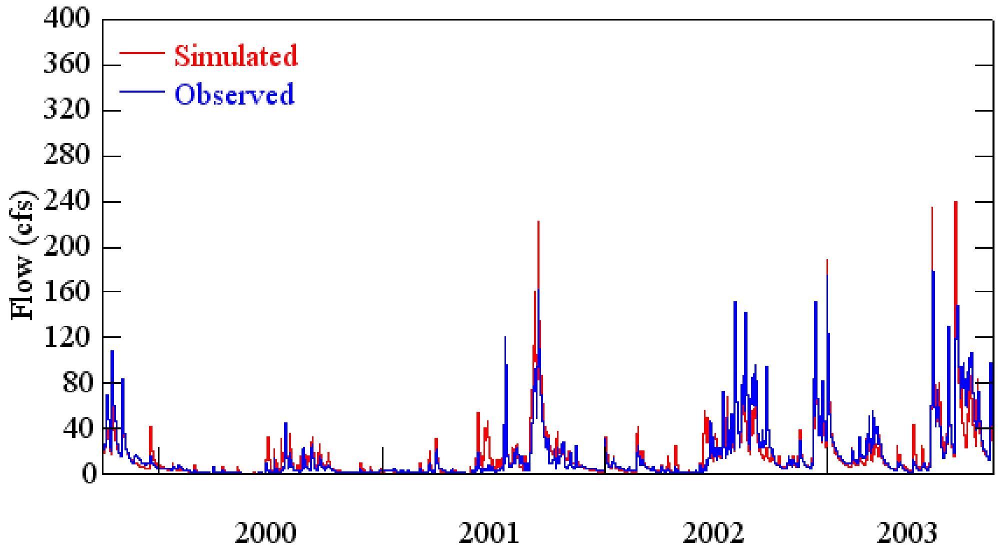


Figure 3.3. Observed and simulated daily flows for Gee Creek near Longwood (10/1999 – 09/2003).

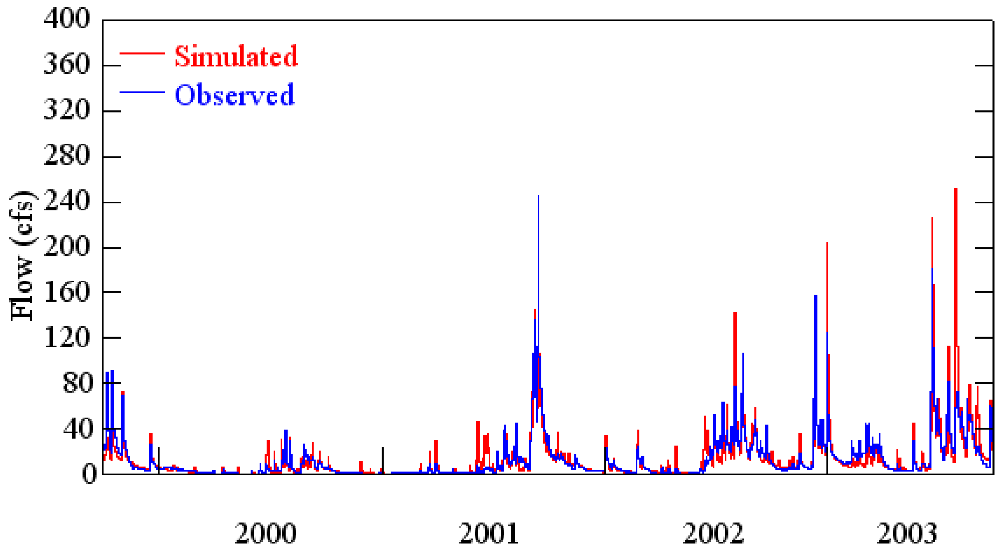


Figure 3.4. Observed and simulated daily flows for Soldier Creek near Longwood (10/1999 – 09/2003).

Table 3.5. Percent errors of hydrologic calibration measures over the period from 10/1999 to 09/2003 and the hydrologic calibration criteria suggested by HSPEXP.

	Howell Creek near Oviedo	Howell Creek near Slavia	Gee Creek near Longwood	Soldier Creek near Longwood	Recommended Calibration Criteria
Error in total volume (%)	-0.4	1.4	0.3	1.5	+/- 10
Error in low-flow recession	0.00	0.02	0.00	0.00	+/- 0.01
Error in 50% lowest flow volume (%)	4.1	-1.6	7.2	6.1	+/- 10
Error in 10% highest flow volume (%)	0.6	-0.7	-8.2	8.5	+/- 15
Error in summer flow volume (%)	11.3	14.8	3.4	4.6	+/- 15
Error in winter flow volume (%)	-16.2	-21.4	-7.7	0.8	+/- 15[1]

Note:
1 – HSPEXP does not have the recommended calibration criterion for the error in winter flow volume. It is assumed that this criterion is the same as the criterion for the error in summer flow volume.

To validate hydrologic calibration, HSPF is run with the calibrated parameters over the validation period 10/1997 – 09/1999. Due to the lack of continuous flow data at the USGS Oviedo station in the validation period, the validation test is not performed for Howell Creek near Oviedo. The percent errors of validation measures are shown in Table 3.6. It can be seen that most errors are within the ranges of recommended calibration criteria of HSPEXP, indicating a good agreement between simulated and observed flows. Some high validation errors, especially the high errors in summer flow volume, are likely caused by a few observed rainfall values at CHARST, which are affected by localized storm events and are not representative to the average rainfall across the whole watershed. Figures 3.5 – 3.7 show that HSPF reasonably reproduces observed flow records in the validation period.

Table 3.6. Percent errors of hydrologic validation measures over the period from 10/1997 to 09/1999.

	Howell Creek near Slavia	Gee Creek near Longwood	Soldier Creek near Longwood
Error in total volume (%)	-3.4	14.4	-0.2
Error in low-flow recession	0.01	-0.02	-0.01
Error in 50% lowest flow volume (%)	-7.3	-3.6	-16.2
Error in 10% highest flow volume (%)	-1.6	11.3	9.9
Error in summer flow volume (%)	-27.4	30.7	-2.4
Error in winter flow volume (%)	2.2	8.5	8.2

During the process of hydrologic calibration and validation, the daily flow-frequency duration curves and the correlation of simulated and observed daily flows are also evaluated. In addition, simulated and observed stages are compared at the calibration sites. Furthermore, the comparison of simulated and observed flows is performed for monthly values. The plots for these comparisons are provided in Appendix B. Based on the results of hydrologic calibration and validation, it is concluded that the HSPF model reasonably represents the hydrologic processes of the watershed. Values of calibrated HSPF hydrologic parameters are shown in Table A.1 in Appendix A.

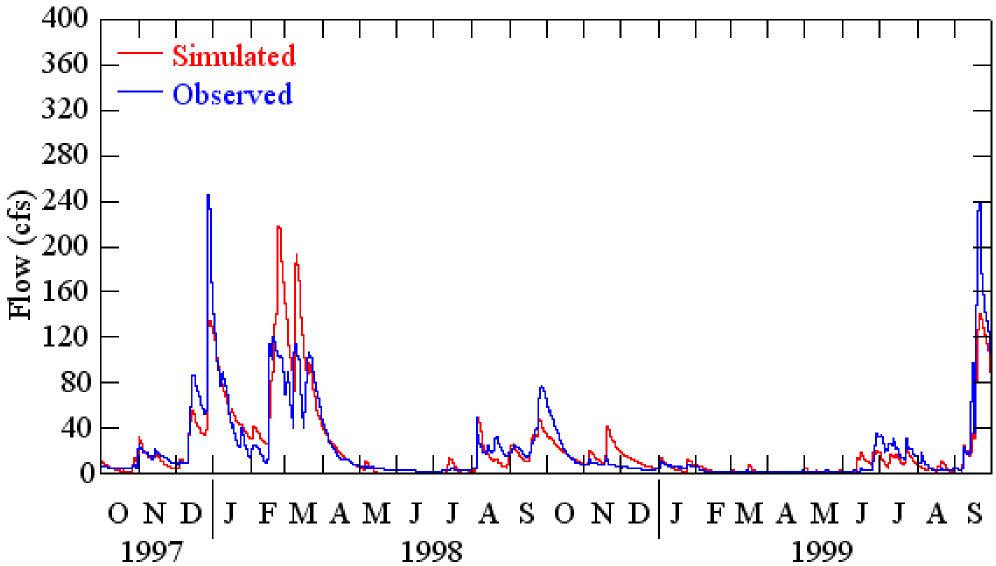


Figure 3.5. Observed and simulated daily flows for Howell Creek near Slavia (10/1997 – 09/1999).

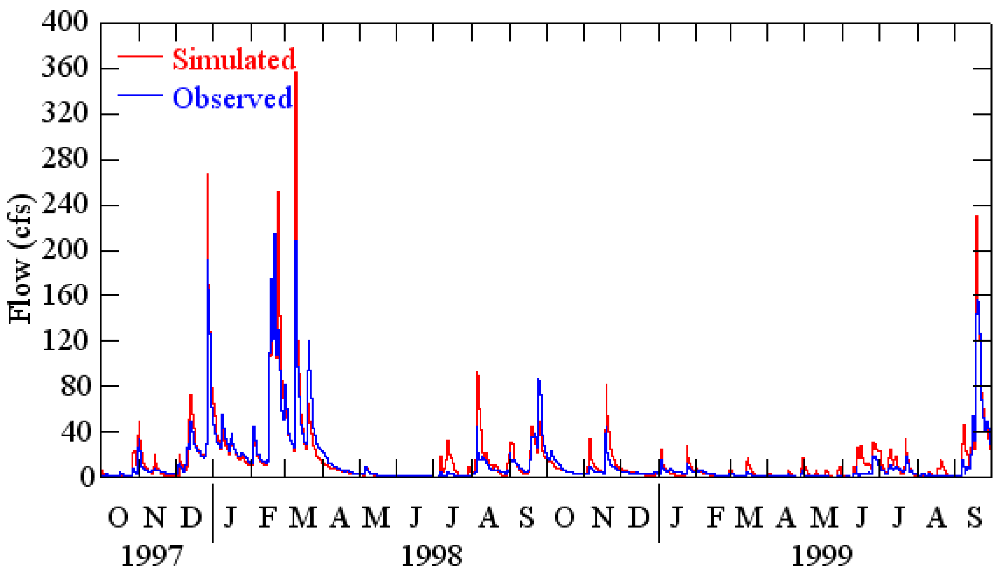


Figure 3.6. Observed and simulated daily flows for Gee Creek near Longwood (10/1997 – 09/1999).

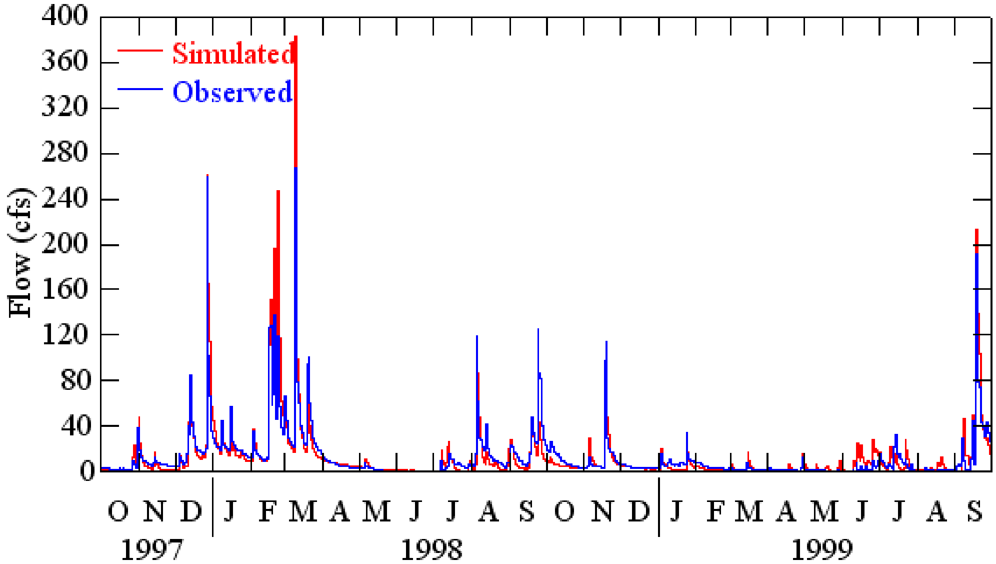


Figure 3.7. Observed and simulated daily flows for Soldier Creek near Longwood (10/1997 – 09/1999).

3.3 Water Quality Calibration

There is limited water quality data available in the Lake Jesup watershed. Using only a subset of available water quality data for calibration may reduce the ability of the calibrated HSPF model to accurately represent the water quality processes of different hydrologic conditions in the watershed. Therefore, all water quality data in the 6-year simulation period from 10/1997 to 09/2003 are selected for water quality calibration. Validation test of the calibrated water quality parameters could be conducted when additional data become available.

Water quality calibration involves two major steps: (1) adjusting the land use-specific parameters (e.g. accumulation rates, depletion/removal rates, wash-off rates, sub-surface concentrations) to match land use loadings with the expected loadings reported in the literature; (2) selecting the instream water quality parameters (e.g. reaeration rate, nitrification rate, phytoplankton growth rate) to reproduce the observed water quality concentrations at calibration sites. These two steps are performed adaptively in the calibration process. If good agreement between the simulated and observed instream water quality data cannot be achieved in the second step while maintaining the instream water quality parameters within the realistic ranges, the land use-specific parameters determined in the first step will be re-adjusted.

Table 3.7 compares HSPF simulated loadings of TSS, TN, and TP for 13 land uses with their expected loadings complied by Harper (1994) and Bergman (2004). Note that the HSPF parameters controlling the pollutant loading rates are kept homogeneous for the areas with the same land use. Variation of the land use loading rates is caused by the differences in precipitation inputs and in a few hydrologic parameters among subwatersheds. It can be seen that the simulated land use loadings are generally within the expected ranges.

Table 3.7. Simulated and expected loading rates by land use (lb/acre/yr).

Land Use	TSS		TN		TP	
	Expected	Simulated	Expected	Simulated	Expected	Simulated
LDR	12 – 44	29 – 34	1.9 – 8.0	3.0 – 10.2	0.21 – 0.84	0.33 – 1.16
MDR	35 – 163	79 – 88	2.9 – 14.2	4.3 – 11.2	0.40 – 1.90	0.50 – 1.29
HDR	281 – 738	390 – 429	6.0 – 23.5	10.6 – 15.4	1.44 – 4.74	1.23 – 1.79
IND	275 – 983	510 – 554	5.4 – 22.3	14.1 – 17.3	1.34 – 4.84	1.58 – 1.95
MIN	41 – 160	114 – 157	0.8 – 3.8	1.3 – 5.0	0.12 – 0.49	0.15 – 0.63
OPE	19 – 42	23 – 31	2.1 – 5.3	1.1 – 4.8	0.16 – 0.53	0.10 – 0.57
PAS	33 – 114	57 – 79	3.7 – 16.0	2.4 – 12.4	0.59 – 1.83	0.40 – 1.66
AGG	38 – 275	87 – 122	3.0 – 22.5	3.4 – 13.2	0.66 – 4.99	0.53 – 1.77
AGT	32 – 127	53 – 73	2.1 – 8.5	1.9 – 8.3	0.53 – 2.11	0.34 – 1.37
RAN	5 – 19	19 – 26	1.7 – 7.5	1.4 – 5.1	0.09 – 0.40	0.24 – 0.65
FOR	4 - 19	14 – 19	0.8 – 4.5	0.9 – 3.8	0.11 – 0.57	0.10 – 0.47
WAT	2 – 19	10 – 17	0.7 – 7.2	0.3 – 2.2	0.08 – 1.00	0.03 – 0.18
WET	0 – 25	10 – 17	0.0 – 4.0	0.3 – 2.2	0.00 – 0.74	0.03 – 0.18

Table 3.8 compares the average simulated and observed concentrations for nine water quality constituents at the calibration sites of Howell Creek, Gee Creek, and

Soldier Creek. Figures 3.8 – 3.13 compare the observed TN and TP concentrations with the simulated concentrations at the three calibration sites. Graphical comparison for other water quality constituents is provided in Appendix C. In general, simulated water quality concentrations closely match the observed values, which indicates that the HSPF water quality model is well calibrated. Values of calibrated HSPF water quality parameters are shown in Table A.2 in Appendix A.

Table 3.8. Average observed and simulated water quality constituents (degF for Water Temperature and mg/l for other constituents).

Water Quality Constituents	Howell Creek near Oviedo		Gee Creek near Longwood		Soldier Creek near Longwood	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Water Temperature	71.3	67.6	70.6	67.6	70.1	67.3
DO	7.39	7.68	6.81	7.72	7.47	7.84
TAM	0.05	0.05	0.06	0.06	0.04	0.07
NO2+NO3	0.27	0.28	0.20	0.29	0.22	0.38
Org-N	0.74	0.72	0.80	0.72	0.97	0.72
TN	1.06	1.04	1.06	1.18	1.23	1.40
PO4	0.08	0.09	0.08	0.08	0.10	0.09
Org-P	0.06	0.04	0.06	0.04	0.09	0.04
TP	0.14	0.15	0.14	0.15	0.19	0.17

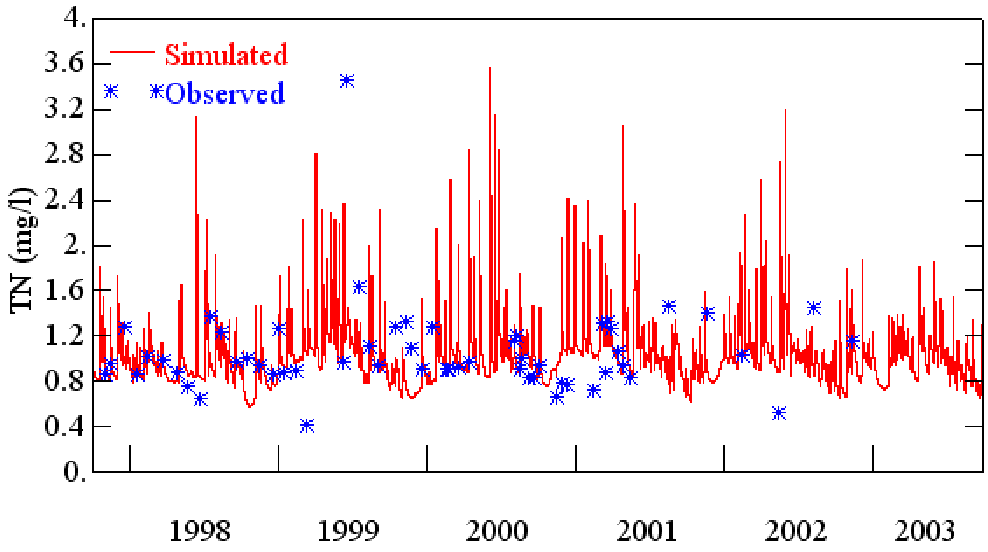


Figure 3.8. Observed and simulated TN concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

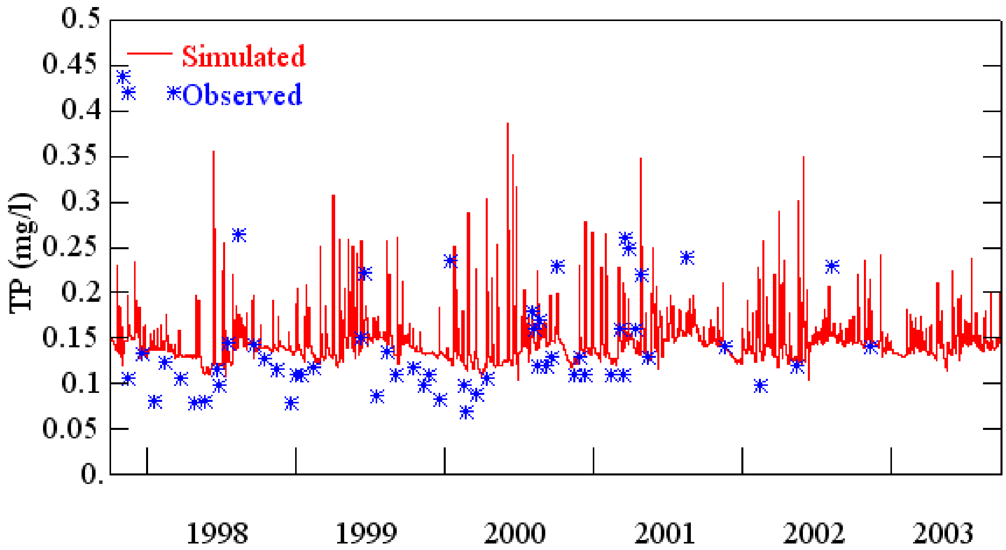


Figure 3.9. Observed and simulated TP concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

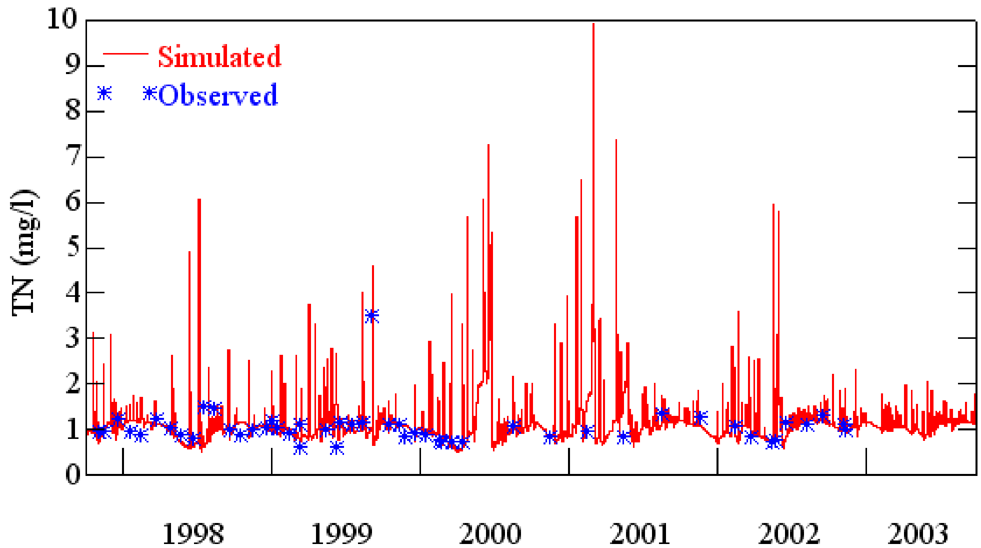


Figure 3.10. Observed and simulated TN concentrations for Gee Creek near Londwood (10/1997 – 09/2003).

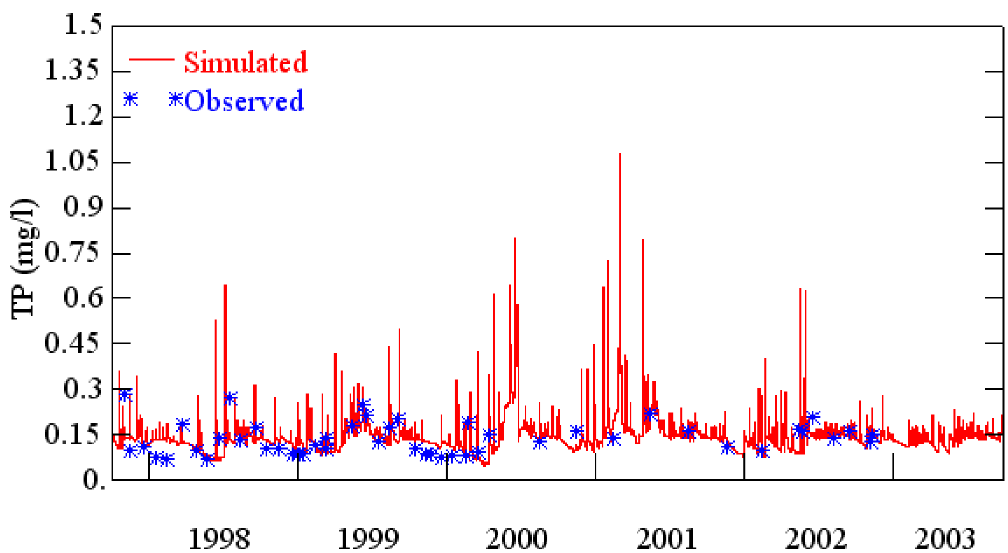


Figure 3.11. Observed and simulated TP concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

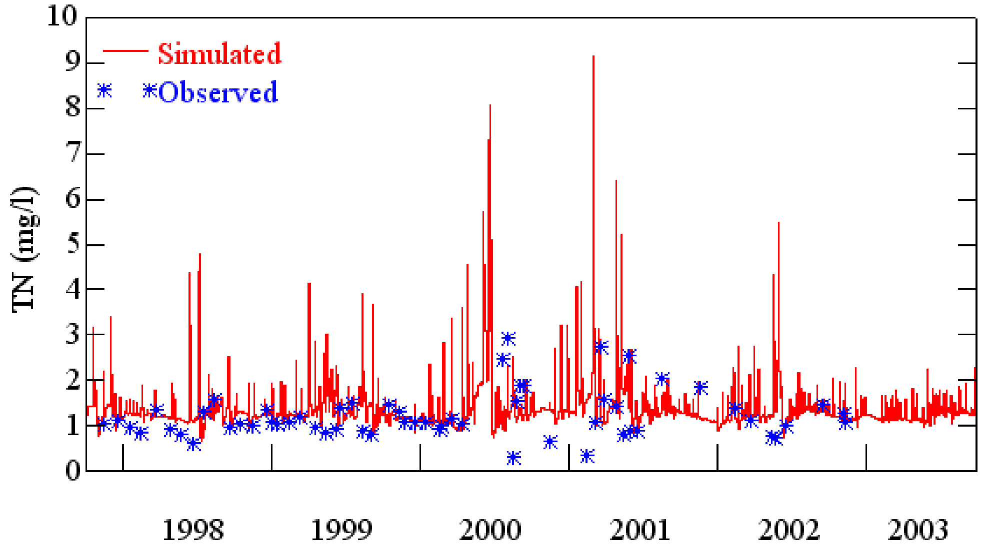


Figure 3.12. Observed and simulated TN concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

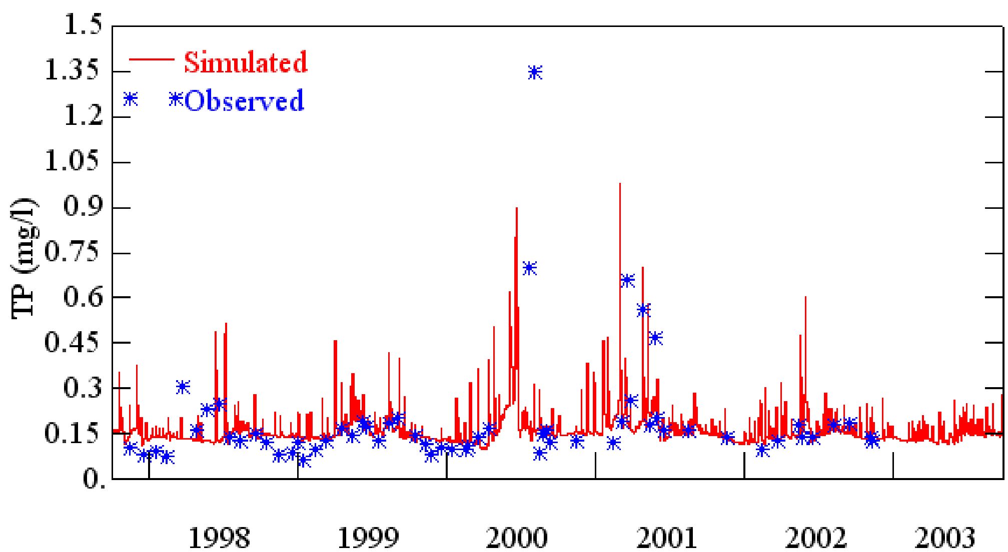


Figure 3.13. Observed and simulated TP concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

3.4 Application of HSPF to the Ungauged Watershed

After the HSPF model is calibrated for the Howell Creek watershed, the Gee Creek watershed, and the Soldier Creek watershed, the calibrated parameter values are used to model the Ungauged watershed. Some parameters are modified to better represent the hydrologic and water quality processes in the Ungauged watershed (see Appendix A for details). The performance of HSPF simulation at the Ungauged watershed is evaluated by comparing the simulated and observed TN and TP concentrations at Six Mile Creek, Navy Canal, Chub Creek, Salt Creek, Sweetwater Creek, and Solary Canal (Figures 3.14 – 3.25). Key observations and conclusions for HSPF simulation of the Ungauged watershed are discussed as follows:

- There is very good agreement between the observed and simulated TN and TP concentrations for Six Mile Creek, Chub Creek, and Salt Creek.
- The simulated TN and TP concentrations are higher than the observed concentrations at Navy Canal. The TN and TP loads to Navy Canal mainly come from LDR and IND, which account for about 65% of the drainage area of Navy Canal (subwatershed 27). The over-prediction is likely caused by the following two reasons: (1) the pollutant removal efficiencies of BMPs used in the HSPF model are lower than the actual removal efficiencies in this subwatershed; (2) the BMP treatment areas in this subwatershed are not fully counted in the BMP treatment area map (Figure 2.3). It is suggested to collect more information about BMPs in subwatershed 27, which could justify the adjustment of removal efficiencies or BMP treatment areas to better reflect local conditions in this subwatershed.

- HSPF accurately reproduces the observed TN concentrations for Sweetwater Creek and Solary Canal, but it under-predicts the observed TP concentrations. The observed TP concentrations at Sweetwater Creek and Solary Canal are significantly higher than those in other tributaries and canals. Further investigation is needed to explain the high TP concentrations at Sweetwater Creek and Solary Canal.
- Under-prediction of TP at Sweetwater Creek and Solary Canal could cancel out the over-prediction of TP at Navy Canal, resulting in a reasonable averaged TP prediction.

Although there is room for improving TN and TP predictions at Navy Canal and TP predictions at Sweetwater Creek and Solary Canal, current HSPF calibration for the Ungauged watershed is considered acceptable for watershed-wide predictions of TN and TP loadings.

Overall, HSPF adequately reproduces the observed water quantity and quality data across the Lake Jesup watershed, indicating the HSPF model accurately represents the hydrologic and water quality processes in the watershed. Therefore, the calibrated HSPF model can be used to evaluate the hydrologic and water quality responses of the Lake Jesup watershed to potential management scenarios.

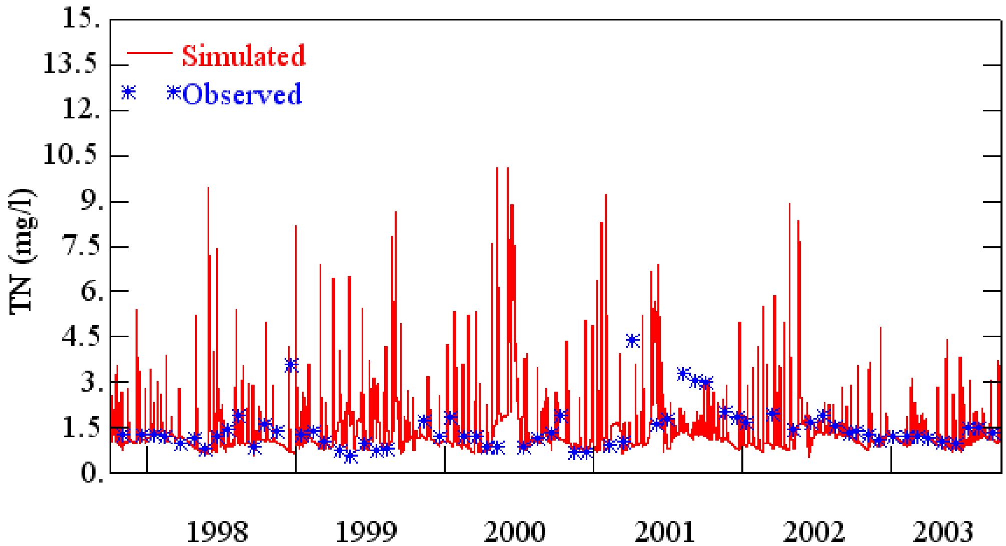


Figure 3.14. Observed and simulated TN concentrations for Six Mile Creek (10/1997 – 09/2003).

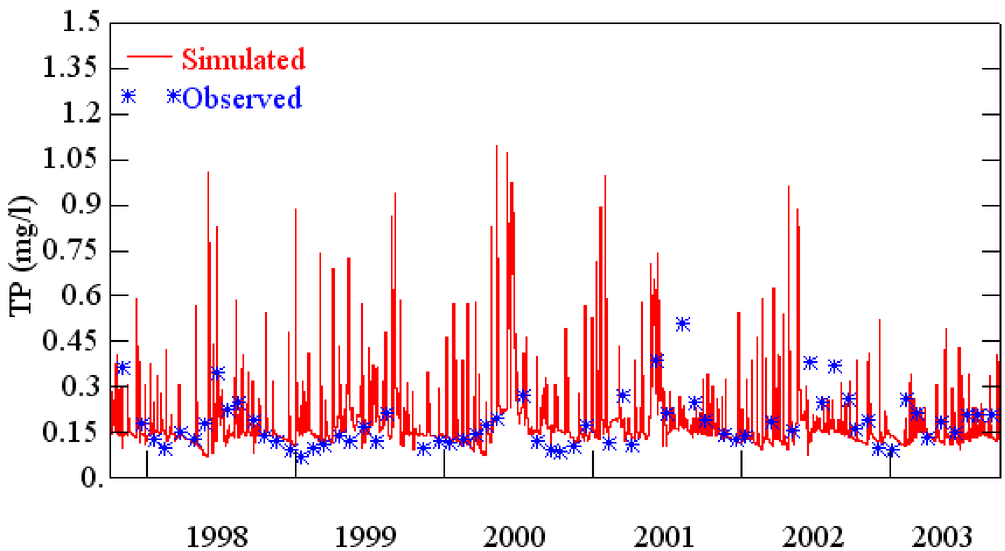


Figure 3.15. Observed and simulated TP concentrations for Six Mile Creek (10/1997 – 09/2003).

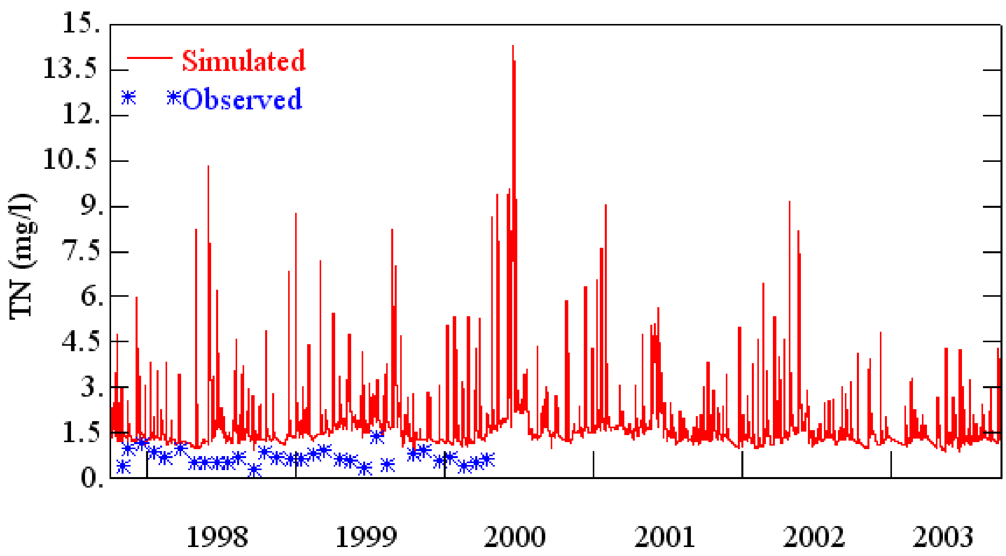


Figure 3.16. Observed and simulated TN concentrations for Navy Canal (10/1997 – 09/2003).

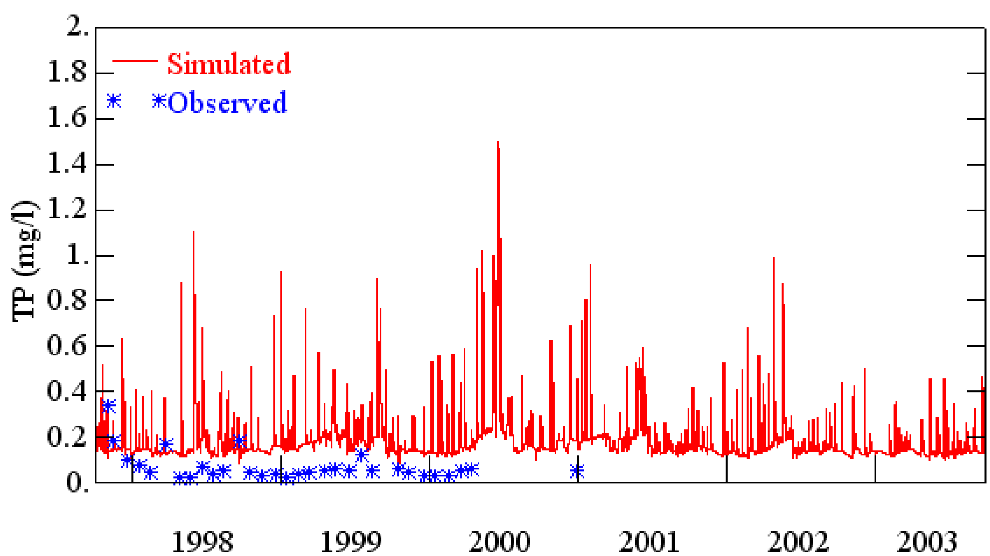


Figure 3.17. Observed and simulated TP concentrations for Navy Canal (10/1997 – 09/2003).

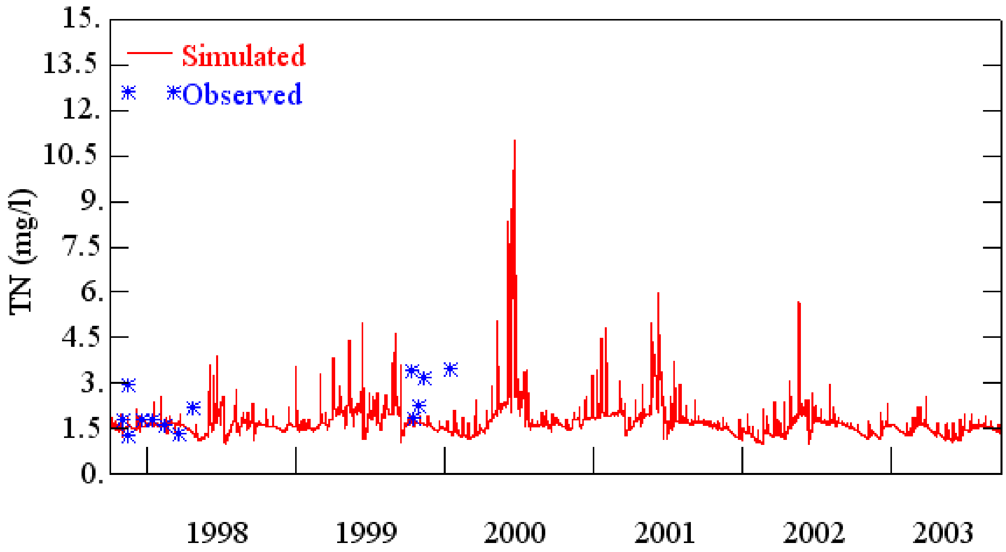


Figure 3.18. Observed and simulated TN concentrations for Chub Creek (10/1997 – 09/2003).

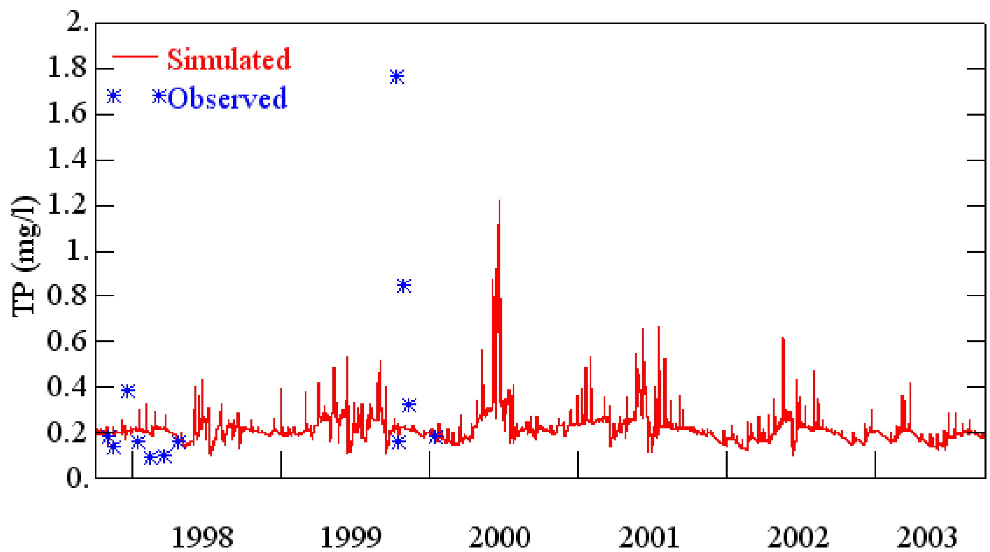


Figure 3.19. Observed and simulated TP concentrations for Chub Creek (10/1997 – 09/2003).

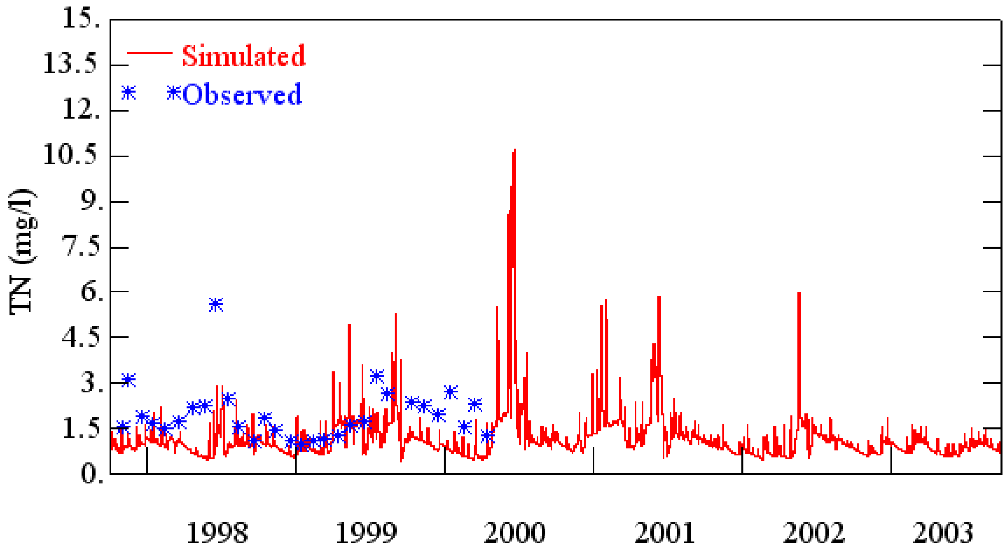


Figure 3.20. Observed and simulated TN concentrations for Salt Creek (10/1997 – 09/2003).

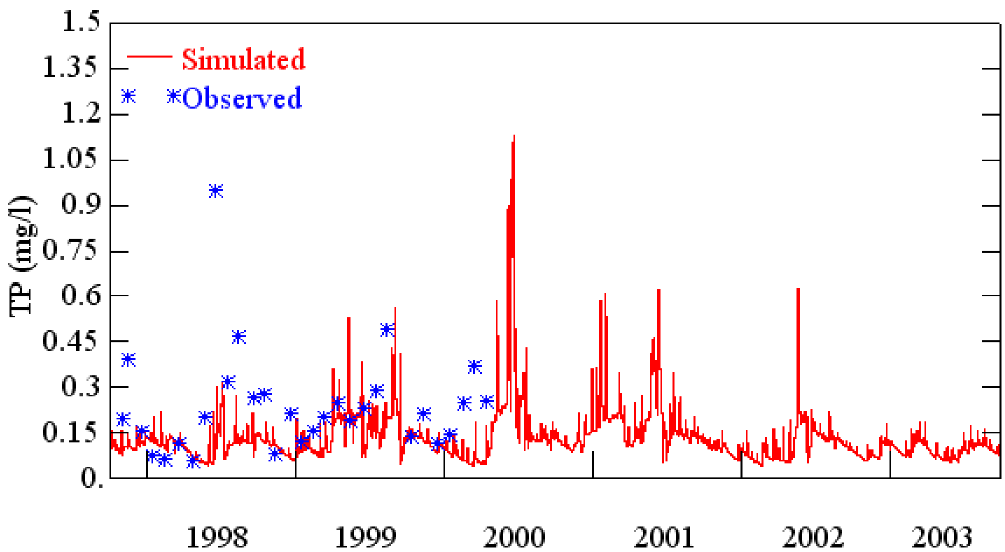


Figure 3.21. Observed and simulated TP concentrations for Salt Creek (10/1997 – 09/2003).

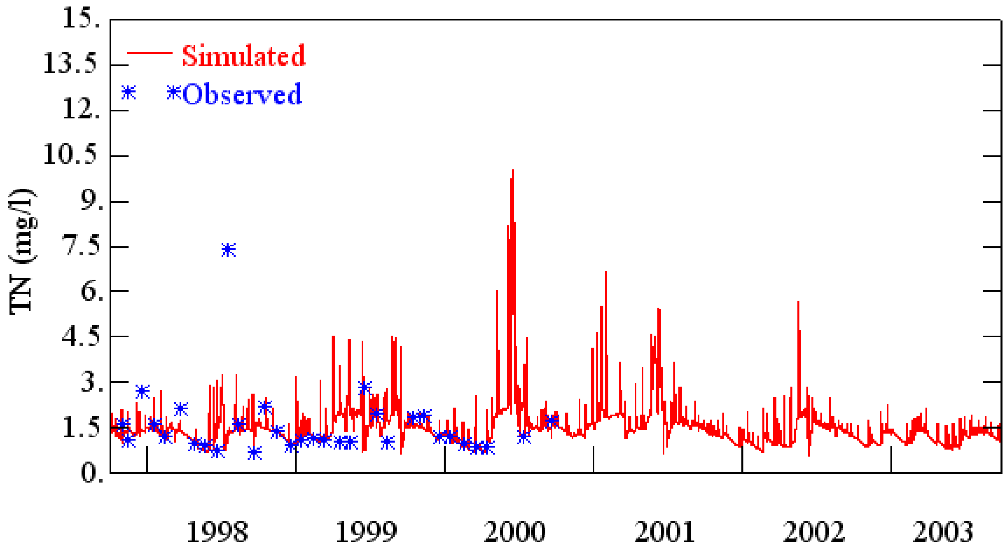


Figure 3.22. Observed and simulated TN concentrations for Sweetwater Creek (10/1997 – 09/2003).

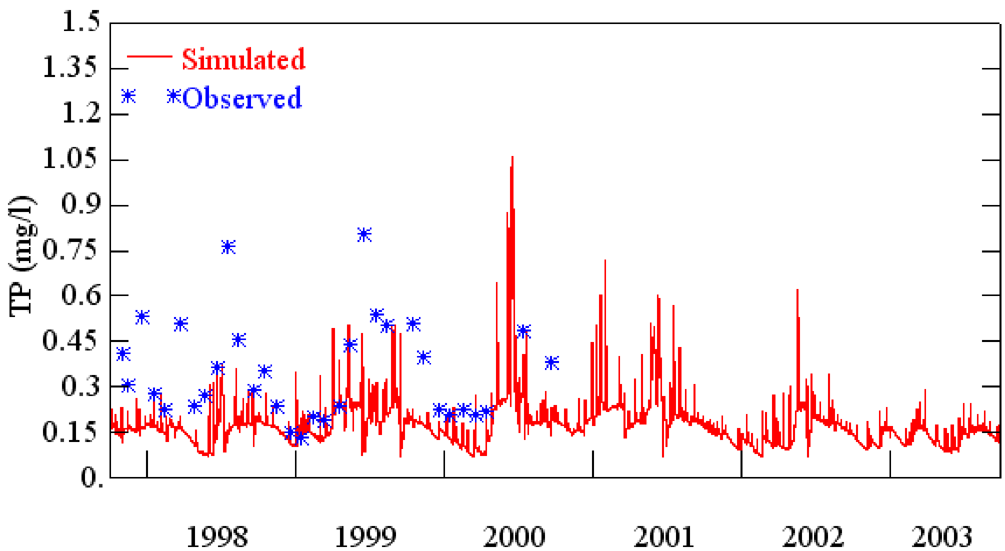


Figure 3.23. Observed and simulated TP concentrations for Sweetwater Creek (10/1997 – 09/2003).

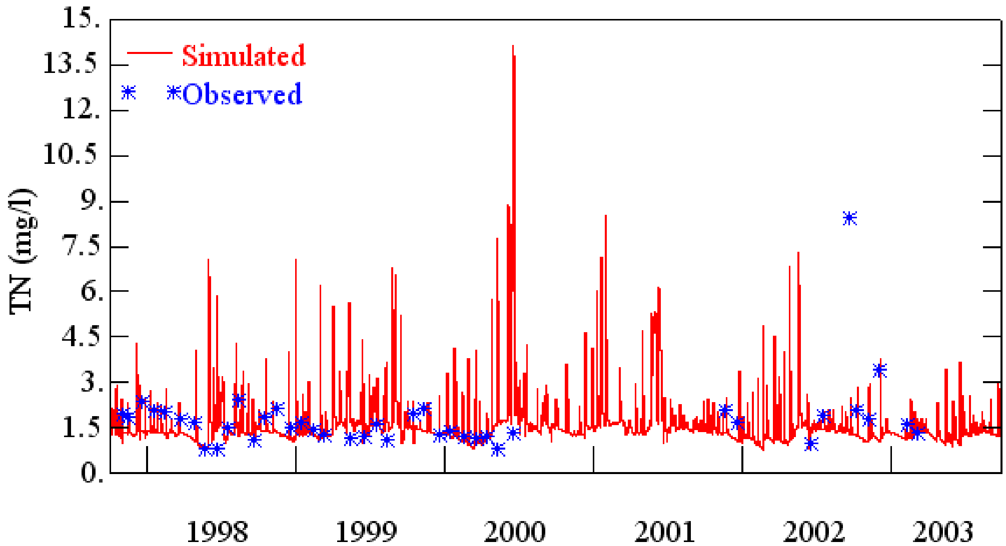


Figure 3.24. Observed and simulated TN concentrations for Solary Canal (10/1997 – 09/2003).

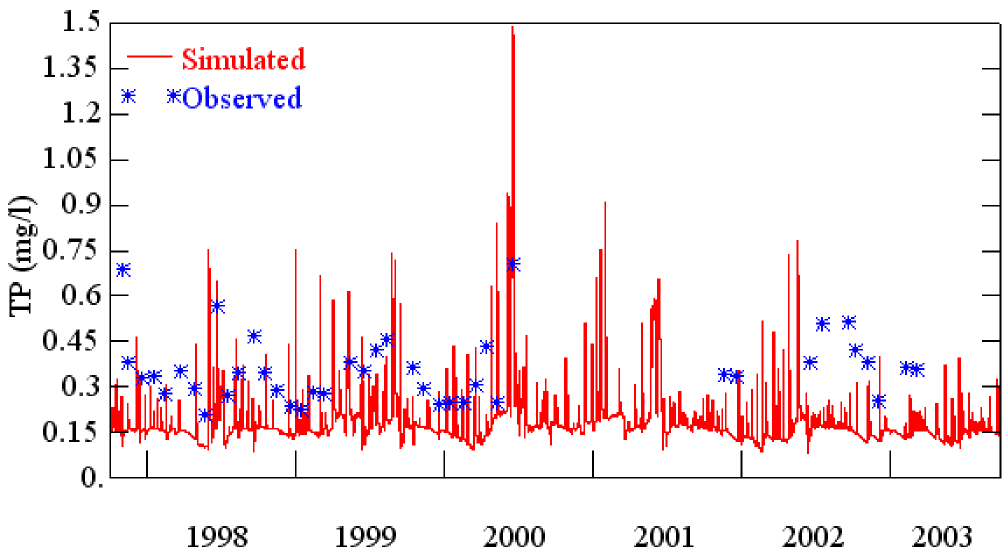


Figure 3.25. Observed and simulated TP concentrations for Solary Canal (10/1997 – 09/2003).

3.5 Summary of Modeling Results for Current Conditions

The HSPF modeling results for current conditions (10/1997 – 09/2003) are summarized for the Howell Creek watershed, the Gee Creek watershed, the Soldier Creek watershed, and the Ungauged watershed. The summarized results are divided into three parts: watershed-wide water budget, nonpoint source loadings of land uses, and watershed loadings of flow, TN, and TP.

The watershed-wide annual water budgets for the four major subbasins are presented in Tables 3.9 – 3.12. Over the period from 10/1997 to 09/2003, the Lake Jesup watershed receives about 54.3 in/yr rainfall. 66% of rainfall becomes evapotranspiration, 27% runoff, and 5% deep percolation. The watershed-wide total runoff varies from 10.5 in/yr at the Ungauged watershed to 19.4 in/yr at the Howell Creek watershed. On average, about 48% of total runoff is surface runoff, 8% interflow, and 44% baseflow.

Table 3.9. Watershed-wide precipitation, runoff, deep percolation, evapotranspiration, and storage change at the Howell Creek watershed (inches).

Water year	Precip-itation	Surface runoff	Interflow	Baseflow	Deep Percolation	Evapotran-spiration	Storage change
1997	63.5	13.1	2.3	9.7	1.6	33.2	3.6
1998	45.2	7.4	0.7	5.6	-0.7	31.1	1.1
1999	40.7	5.7	0.2	6.3	-0.5	30.5	-1.5
2000	53.1	8.6	1.2	6.8	0.1	32.7	3.6
2001	57.2	8.7	1.1	9.0	1.0	39.4	-2.0
2002	72.6	14.0	3.1	13.2	3.2	36.6	2.5
Average	55.4	9.6	1.4	8.4	0.8	33.9	1.2

Table 3.10. Watershed-wide precipitation, runoff, deep percolation, evapotranspiration, and storage change at the Gee Creek watershed (inches).

Water year	Precip-itation	Surface runoff	Interflow	Baseflow	Deep Percolation	Evapotran-spiration	Storage change
1997	63.5	10.6	2.2	6.6	4.9	35.2	3.9
1998	45.2	5.5	0.7	2.9	2.4	32.6	1.0
1999	40.7	4.1	0.2	4.4	2.6	31.9	-2.5
2000	53.1	6.5	1.2	3.4	3.3	33.9	4.7
2001	57.2	6.5	1.1	6.9	4.2	41.4	-2.9
2002	72.6	11.4	3.0	10.3	6.7	38.3	2.8
Average	55.4	7.4	1.4	5.8	4.0	35.5	1.2

Table 3.11. Watershed-wide precipitation, runoff, deep percolation, evapotranspiration, and storage change at the Soldier Creek watershed (inches).

Water year	Precip-itation	Surface runoff	Interflow	Baseflow	Deep Percolation	Evapotran-spiration	Storage change
1997	63.5	9.0	2.1	6.1	5.5	36.5	4.2
1998	45.2	4.3	0.7	2.7	2.7	33.7	1.0
1999	40.7	3.0	0.2	4.2	3.0	33.0	-2.7
2000	53.1	5.2	1.2	2.9	3.7	34.8	5.3
2001	57.2	5.1	1.0	6.6	4.8	42.6	-2.9
2002	72.6	9.7	2.9	10.0	7.5	39.3	3.2
Average	55.4	6.1	1.3	5.4	4.5	36.7	1.3

Table 3.12. Watershed-wide precipitation, runoff, deep percolation, evapotranspiration, and storage change at the Ungauged Creek watershed (inches).

Water year	Precip-itation	Surface runoff	Interflow	Baseflow	Deep Percolation	Evapotran-spiration	Storage change
1997	60.5	6.6	1.4	5.6	4.9	39.4	2.5
1998	37.2	2.3	0.1	1.7	1.6	32.4	-1.0
1999	43.1	2.8	0.3	3.9	3.1	32.2	0.7
2000	53.3	4.5	1.1	3.3	3.7	36.7	3.9
2001	61.2	5.3	1.5	7.3	5.2	43.6	-1.7
2002	58.4	5.3	1.3	8.0	5.5	39.9	-1.6
Average	52.3	4.5	1.0	5.0	4.0	37.4	0.5

Annual nonpoint source loading rates by land use for the four major subbasins in the study area are shown in Tables 3.13 – 3.16. The developed areas (LDR, MDR, HDR, and IND) have the highest nonpoint source loading rates. A major portion of these loadings comes from EIAs. Although agriculture (AGG and AGT) and pasture (PAS) only account for 5.2% and 4.6% of the total study area, they contribute a significant portion of TN and TP because of their high loading rates. The undeveloped areas (FOR, WAT, and WET) have the lowest loading rates.

Table 3.13. Average annual land use loading rates for the Howell Creek watershed (lb/acre/yr).

LU	TSS	TAM	NO3	ORGN	TN	PO4	ORGP	TP	BOD
LDR	31.0	0.4	3.0	5.7	9.1	0.61	0.43	1.04	81.7
MDR	82.9	0.4	2.0	4.7	7.1	0.47	0.35	0.82	67.3
HDR	409.0	0.8	2.8	10.1	13.7	0.82	0.76	1.58	145.3
IND	526.1	0.9	2.5	11.8	15.2	0.81	0.89	1.70	170.2
MIN	136.4	0.4	1.2	2.8	4.3	0.33	0.21	0.54	39.8
OPE	26.5	0.3	1.0	2.0	3.3	0.23	0.15	0.38	28.9
PAS	68.8	0.7	3.8	6.3	10.8	0.99	0.47	1.46	90.6
AGG	105.2	0.7	3.6	6.2	10.5	0.95	0.47	1.42	89.8
AGT	62.0	0.4	1.8	2.6	4.8	0.61	0.19	0.81	36.9
RAN	22.8	0.3	2.1	2.3	4.7	0.43	0.17	0.61	33.2
FOR	16.6	0.2	1.3	1.6	3.2	0.27	0.12	0.39	23.8
WAT	12.2	0.1	0.3	0.4	0.7	0.03	0.03	0.06	6.0
WET	15.9	0.1	0.6	0.9	1.7	0.07	0.07	0.14	13.3

Table 3.14. Average annual land use loading rates for the Gee Creek watershed (lb/acre/yr).

LU	TSS	TAM	NO3	ORGN	TN	PO4	ORGP	TP	BOD
LDR	21.8	0.3	2.0	3.4	5.7	0.39	0.26	0.64	49.1
MDR	66.0	0.4	1.9	4.0	6.3	0.43	0.30	0.73	57.9
HDR	396.0	0.7	2.4	8.9	12.0	0.73	0.67	1.40	128.4
IND	514.3	0.8	2.4	10.6	13.7	0.77	0.80	1.56	152.6
MIN	133.9	0.3	1.0	2.2	3.5	0.27	0.17	0.43	32.0
OPE	26.5	0.2	0.8	1.4	2.4	0.16	0.11	0.27	20.8
PAS	68.2	0.5	2.7	4.5	7.7	0.73	0.34	1.08	65.4
AGG	101.7	0.2	1.4	2.8	4.4	0.44	0.21	0.65	39.8
AGT	59.2	0.2	1.0	1.6	2.8	0.37	0.12	0.49	23.3
RAN	22.6	0.2	1.5	1.7	3.4	0.34	0.13	0.47	25.2
FOR	16.3	0.1	0.9	1.1	2.1	0.17	0.08	0.25	15.7
WAT	13.3	0.05	0.2	0.3	0.6	0.03	0.03	0.05	4.9
WET	14.8	0.1	0.3	0.5	0.9	0.04	0.04	0.07	7.0

Table 3.15. Average annual land use loading rates for the Soldier Creek watershed (lb/acre/yr).

LU	TSS	TAM	NO3	ORGN	TN	PO4	ORGP	TP	BOD
LDR	25.7	0.2	1.4	2.5	4.0	0.27	0.17	0.45	35.8
MDR	53.9	0.3	1.7	3.2	5.2	0.37	0.24	0.62	46.9
HDR	363.0	0.5	2.2	7.0	9.7	0.65	0.52	1.18	100.4
IND	501.9	0.6	2.4	8.4	11.5	0.73	0.64	1.36	121.9
MIN	138.2	0.3	1.0	2.3	3.6	0.28	0.17	0.45	33.0
OPE	28.8	0.2	0.8	1.5	2.5	0.17	0.11	0.28	21.6
PAS	68.5	0.4	2.1	3.6	6.2	0.61	0.27	0.88	52.6
AGG	107.8	0.5	3.0	5.3	8.8	0.82	0.40	1.22	76.6
AGT	69.5	0.2	1.1	1.8	3.1	0.41	0.13	0.54	25.5
RAN	24.5	0.2	1.0	1.4	2.6	0.28	0.10	0.38	20.1
FOR	17.1	0.1	0.8	1.0	1.9	0.16	0.08	0.23	14.6
WAT	13.7	0.1	0.2	0.4	0.7	0.03	0.03	0.06	5.6
WET	14.7	0.1	0.3	0.5	0.9	0.04	0.04	0.07	7.0

Table 3.16. Average annual land use loading rates for the Ungauged Creek watershed (lb/acre/yr).

LU	TSS	TAM	NO3	ORGN	TN	PO4	ORGP	TP	BOD
LDR	25.4	0.2	1.6	3.3	5.1	0.33	0.25	0.58	47.0
MDR	79.4	0.4	1.8	4.2	6.3	0.41	0.32	0.73	60.8
HDR	372.2	0.7	2.3	9.1	12.0	0.70	0.68	1.38	130.9
IND	522.3	0.9	2.5	11.6	14.9	0.79	0.88	1.67	168.0
MIN	91.7	0.2	0.7	1.5	2.4	0.18	0.11	0.30	22.0
OPE	18.6	0.2	0.7	1.3	2.2	0.15	0.10	0.25	19.3
PAS	38.9	0.3	1.8	3.1	5.2	0.50	0.23	0.73	44.4
AGG	63.2	0.4	2.0	3.5	5.8	0.53	0.26	0.80	50.7
AGT	39.2	0.3	1.4	1.9	3.6	0.46	0.14	0.60	27.2
RAN	14.3	0.1	1.0	1.2	2.4	0.24	0.09	0.33	17.7
FOR	11.0	0.1	0.7	0.8	1.6	0.13	0.06	0.19	12.0
WAT	10.2	0.1	0.3	0.4	0.7	0.03	0.03	0.06	5.6
WET	10.2	0.1	0.3	0.4	0.7	0.03	0.03	0.06	5.6

Tables 3.17 – 3.19 summarize the estimated watershed loadings of flow, TN, and TP. On average, the annual flow contributions from the watershed to Lake Jesup is 95,482.0 acre-ft/yr, of which 50% is contributed from the Howell Creek watershed, 12% from the Gee Creek watershed, 12% from the Soldier Creek watershed, and 26% from the Ungauged watershed. The average annual watershed loadings of TN and TP are 140.7 metric ton N/yr and 18.7 metric ton P/yr. The Howell Creek watershed contributes 42% of the nutrient loads, the Gee Creek watershed 12%, the Soldier Creek watershed 12%, and the Ungauged watershed 34%. There is significant variation between the watershed loadings in the three dry years (10/1998 – 09/2001) and those in the three wet years (10/1997 – 09/1998 and 10/2001 – 09/2003). The dry year watershed loadings of flow, TN, and TP are 63,286.2 acre-ft water/yr, 95.5 metric ton N/yr, and 12.9 metric ton P/yr, respectively. The wet year watershed loadings are 127,677.7 acre-ft water/yr, 185.8 metric ton N/yr, and 24.6 metric ton P/yr, which are approximately 2 times of the dry year watershed loadings.

Table 3.17. Contributions of flow from the watershed (acre-ft/yr).

Water Year	Howell	Gee	Solider	Ungauged	Total
1998	61720.2	15880.7	15202.3	32574.2	125377.4
1999	30345.7	7371.7	6723.2	9616.3	54056.9
2000	29310.1	6813.2	6299.4	16804.3	59227.0
2001	38027.4	9037.9	8156.1	21353.2	76574.6
2002	47325.3	11750.9	11088.4	33807.0	103971.6
2003	78452.8	20382.0	19953.4	34896.0	153684.2
Average	47530.3	11872.7	11237.1	24841.8	95482.0

Table 3.18. Contributions of TN from the watershed (metric ton N/yr).

Water Year	Howell	Gee	Solider	Ungauged	Total
1998	74.5	21.4	22.7	58.7	177.3
1999	38.1	10.1	11.1	21.4	80.6
2000	34.3	9.0	9.4	33.2	86.0
2001	47.4	12.8	13.5	46.3	120.0
2002	57.7	16.8	18.1	67.3	159.9
2003	94.8	29.1	31.7	64.7	220.3
Average	57.8	16.5	17.7	48.6	140.7

Table 3.19. Contributions of TP from the watershed (metric ton P/yr).

Water Year	Howell	Gee	Solider	Ungauged	Total
1998	10.5	2.6	2.6	7.1	22.8
1999	5.5	1.4	1.4	2.4	10.7
2000	5.1	1.2	1.1	3.9	11.3
2001	7.2	1.8	1.8	5.9	16.6
2002	8.7	2.2	2.2	8.5	21.7
2003	14.0	3.7	3.9	7.6	29.2
Average	8.5	2.2	2.2	5.9	18.7

4. Analysis of Management Scenario

After the calibration of the HSPF model, the model is used to assess the impact of various management scenarios on the nutrient loadings to Lake Jesup. In this study, six watershed management scenarios are analyzed, including current conditions, future conditions, future conditions with three difference implementation levels of BMPs, and pristine conditions. This section will first describe the projected future land uses. Then, six watershed scenarios simulated in the HSPF model are discussed. Finally, the estimated nutrient loadings under the six simulated scenarios are presented and discussed.

4.1 Future Land Uses

The future land use GIS map was obtained from the SJRWMD. The future land use information is based on the 2020 comprehensive plans of Seminole County and Orange County. There are 16 major land use categories for the future land uses: Agriculture (AG), Commercial (COM), Conservation (CONS), Industrial (IND), Institutional (INST), Mixed Use (MU), Office (OFF), Planned Development (PD), Recreational (REC), High Density Residential (RH), Low Density Residential (RL), Medium Density Residential (RM), Rural Residential (RR), Very Low Density Residential (RVL), Unknown (UNK), Water (WAT). The definition for these future land uses is inconsistent with the definition for the current land uses. For example, future low density residential is defined as residential development up to 5 dwelling units per acre, while current low density residential is defined as less than 2 dwelling units per acre, and 2 to 5 units per acre is defined as medium density residential for current land uses.

Consistent land use classes must be used so that the calibrated model parameters under the current conditions can be applied to the future conditions. To estimate the future distributions of HSPF land uses in the study area, the following procedures are used. First, current and future land uses are grouped into seven general land use classes (Table 4.1). It is assumed that the definition of current and future land uses is consistent within these general land use categories. There are no mining land uses identified in the future land use. Therefore, it is also assumed that the mining area no longer exists in the study area for the future conditions. Then, the acreage of the general land uses for each subwatershed is calculated based on the future land use map. Finally, assuming the proportions of HSPF land uses in each general land use are unchanged from current to future conditions, the acreage of each general future land use in each subwatershed is distributed to its corresponding HSPF land uses according to the proportions of the HSPF land uses in each subwatershed under current conditions.

The changes of 13 HSPF land uses in the Lake Jesup watershed from the current conditions to the future conditions are summarized in Table 4.2. It can be seen that LDR will have a 15% decrease in the future, but the overall residential area will increase slightly. IND will increase significantly, up 61% from current conditions. These increases of future development come from the loss of non-urban areas, especially agriculture and pasture areas. It is a little unexpected to see a 27% decrease of the water surface in the future. A visual comparison of current and future land use map indicates that many current water surfaces within the residential, industrial, and commercial areas are not identified as water surfaces in the future land use map. This may result from the coarse resolution of the future land use map. In addition, many current water land use is identified as wetland for the future conditions, which may explain the 11% increase of the wetland area in the future.

Table 4.1. Grouping of HSPF land uses and future land uses into general land uses.

General Land Use	HSPF Land Use Class	Future Land Use Class
Residential	LDR MDR HDR	RL RM RH PD
Industrial and Commercial	IND	COM IND INST MU OFF
Open	OPN	REC
Agriculture	AGG AGT	AG
Rural	PAS RAN FOR	RR RVL UNK
Water	WAT	WAT
Wetland	WET	CONS

Table 4.2. Comparison of current and future HSPF land uses in the Lake Jesup watershed.

HSPF Land Use	Current acreage[1]	Future acreage[1]	% Change
LDR	5607	4781	-15
MDR	20406	23197	14
HDR	4895	5506	12
IND	11408	18419	61
MIN	117	0	-100
OPE	2154	1771	-18
PAS	4521	2546	-44
AGG	3126	759	-76
AGT	1915	279	-85
RAN	2224	1577	-29
FOR	5261	4561	-13
WAT	13500	9791	-27
WET	18192	20139	11

Note:
1 – the closed watersheds 3, 11, and 16 are not excluded.

4.2 Watershed Management Scenarios

A total of six watershed scenarios are analyzed in this study. General descriptions of these simulated scenarios are given as follows:

1. Current – current (1997 – 2003) conditions;
2. Future – future land use with 100% BMP implementation for future development (newly increased LDR, MDR, HDR, and IND);
3. Future + 25% BMP – future conditions + 25% BMP implementation for current land uses without BMPs (excluding FOR, WAT, and WET);
4. Future + 50% BMP – future conditions + 50% BMP implementation for current land uses without BMPs (excluding FOR, WAT, and WET);
5. Future + 75% BMP – future conditions + 75% BMP implementation for current land uses without BMPs (excluding FOR, WAT, and WET);
6. Pristine conditions – all forested (except WAT and WET) watershed.

The current scenario is used as a baseline scenario for comparison. The future scenario is designed to estimate how much increase in the nutrient loads to Lake Jesup resulting from the projected future growth. As required by Florida Statute Chapter 403, all the future development (LDR, MDR, HDR, and IND) will receive stormwater treatment through BMPs. To evaluate to what extent the nutrient loadings can be controlled by further implementing BMPs, three different levels (25%, 50%, and 75%) of BMP implementation are simulated for current land uses without BMP treatment. These three BMP implementation levels are uniformly assigned to the land uses segments currently without BMPs in each subwatershed. A 75% level of BMP implementation for current land uses without BMPs, plus 100% BMP implementation for future development, could be considered as an extreme case of BMP implementation, which results in the maximum achievable nutrient removal based on the assumed BMP nutrient removal efficiency. This study assumes that all the newly implemented BMPs in scenarios 2 – 5 are wet detention ponds. The approach of BMP characterization described in section 3.1.4 is used to simulate the effects of BMPs in scenarios 2 – 5. Finally, the pristine scenario is design to represent the natural background conditions in the Lake Jesup watershed.

4.3 Scenarios Analysis Results

The simulation of these scenarios is performed over the entire simulation period from 10/1997 to 09/2003. Figure 4.1 compares the estimated TN and TP loadings to Lake Jesup under these six scenarios. The estimated TP loading under the future scenario is close to the current TP loading level, suggesting that the implementation of BMPs for all the future development and the decrease of the agriculture and pasture areas (as indicated in the future land use map) would effectively control the increase of TP loads. Because the removal efficiencies of BMPs for nitrogen are relatively low compared with those for phosphorus, the implementation of BMPs is less successful in controlling the increase of TN loading from the watershed. The projected future conditions have an 11% increase of TN loading from the current level. Additional reductions of watershed nutrient contributions can be achieved by implementing BMPs to the areas currently without receiving treatment. Implementing BMPs to 25%, 50%, and 75% of the current land uses without BMPs and 100% of future development could reduce nutrient loadings from the projected future levels by 3%, 6%, and 9% for TN and by 6%, 11%, and 17% for TP. Despite implementing BMPs to an extreme level (Future + 75% BMP), the resulting nutrient loadings will still be well above the estimated background loadings under the pristine scenario, which account for only 31% and 32% of the projected future TN and TP levels. To achieve greater nutrient reductions than those in the simulated BMP implementation scenarios, watershed management should focus on implementing nonstructural BMPs (such as better source control and stormwater reuse) to reduce nutrient loading rates from developed areas and using BMP treatment trains to improve nutrient removal efficiencies.

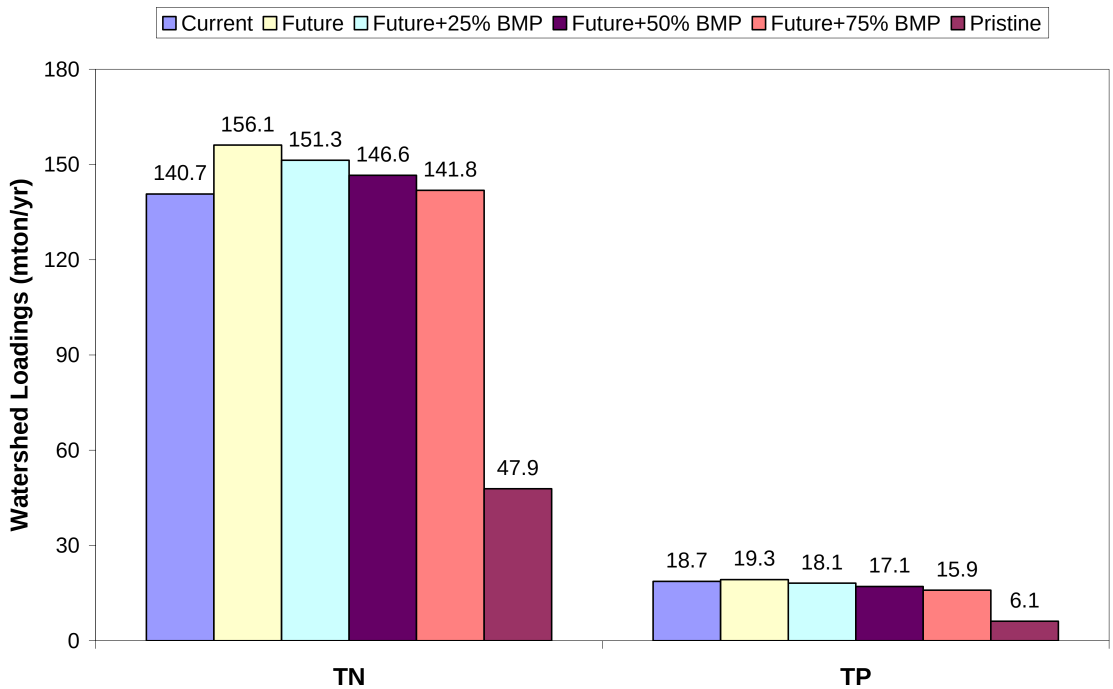


Figure 4.1. Comparison of average annual TN and TP loads to Lake Jesup for the six simulated scenarios.

5. Summary and Conclusion

This study applies a HSPF model to the drainage basin of Lake Jesup, which includes four major subbasins: Howell Creek watershed, Gee Creek watershed, Soldier Creek watershed, and Ungauged watershed. The model development involves three major steps: data collection, hydrologic calibration, and water quality calibration. Various types of data are collected and compiled for the development of the watershed model. These data include watershed physical and spatial data, meteorological data, stream flow data, and water quality data. Hydrologic calibration of HSPF is performed for Howell Creek, Gee Creek, and Soldier Creek. The results show a good agreement between the simulated flows and the observed flows in terms of water mass balance, high and low flow distributions, seasonal flow distribution, and low flow recession. Water quality calibration of HSPF is performed at several water quality sampling sites across the watershed. The results of water quality calibration show that the simulated land use loadings are generally within their expected ranges reported in the literature and HSPF accurately reproduces the observed water quality data. Overall, the calibration results indicate that the HSPF model adequately represents the hydrologic and water quality processes in the Lake Jesup watershed. Therefore, the calibrated HSPF model can be used to evaluate the hydrologic and water quality responses of the Lake Jesup watershed to potential watershed management scenarios, and the loads generated by the HSPF model can be used as inputs for the future Lake Jesup eutrophication model.

Current conditions of watershed loadings of flow and nutrients (TN and TP) are summarized over a 6-year period from 10/1997 to 09/2003. On average, the annual flow contribution from the watershed to Lake Jesup is 95,482.0 acre-ft/yr. The average annual watershed loadings of TN and TP are 140.7 metric ton N/yr and 18.7 metric ton P/yr. There is significant variation between the watershed loadings in the three dry years (10/1998 – 09/2001) and those in the three wet years (10/1997 – 09/1998 and 10/2001 – 09/2003). The dry year watershed loadings of flow, TN, and TP are 63,286.2 acre-ft water/yr, 95.5 metric ton N/yr, and 12.9 metric ton P/yr, respectively. The wet year watershed loadings are 127,677.7 acre-ft water/yr, 185.8 metric ton N/yr, and 24.6 metric ton P/yr, which are approximately 2 times of the dry year watershed loadings.

In addition to the current conditions, five other watershed scenarios are analyzed: future conditions, future conditions with three different implementation levels (25%, 50%, and 75%) of BMPs, and pristine conditions. This study assumes that all the future development (LDR, MDR, HDR, and IND) receives stormwater treatment through wet detention ponds. The projected future TN and TP loadings are 11% and 3% above the current TN and TP loadings. Additional nutrient removal can be achieved by implementing wet detention ponds to the areas currently without BMP treatment, but the resulting nutrient loadings are still well above the estimated background loadings under the pristine scenario. To achieve greater nutrient reductions than those in the simulated BMP implementation scenarios, watershed management should focus on implementing nonstructural BMPs (such as better source control and stormwater reuse) to reduce nutrient loading rates from developed areas and using BMP treatment trains to improve nutrient removal efficiencies.

This work shows that the HSPF model can adequately predict the flow and water quality concentrations across the Lake Jesup watershed. The accuracy of HSPF predictions could be further improved by collecting additional field data for model calibration and validation. Specific suggestions for future investigation are listed as follows:

- Investigate the interaction between groundwater and surface water in the Lake Jesup watershed. This information is helpful to assess whether the current formulation of HSPF can adequately represent the groundwater processes in the study area.
- Collect additional information on BMPs at the drainage area, especially the LDR and IND area, of Navy Canal (subwatershed 27) and assess the effectiveness of these BMPs on the removal of TN and TP. This will help to explain the observed low TN and TP concentrations in Navy Canal.
- Identify the sources contributing to the observed high TP concentrations at Sweetwater Creek and Solary Canal.
- Study which nonstructural BMPs could effectively reduce TN and TP loads to Lake Jesup and incorporate their effects in the scenario analysis.
- Conduct field studies to calculate the pollutant removal efficiencies of the existing BMPs in the Lake Jesup watershed. The results of these field studies could help to refine the removal efficiencies used in this study.

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Appendix A. Calibrated HSPF Parameters

Table A.1. Calibrated key hydrologic parameters in the Lake Jesup watershed HSPF model.

Parameter	Units	Typical[1]	Possible[1]	Calibrated
PERLND Parameters				
LZSN	inches	3 – 8	2 – 15	7.0 for LDR, MDR, HDR, IND, MIN, OPE, PAS, RAN 8.0 for AGG, AGT 10.0 for FOR 5.0 for WAT, WET
INFILT	In/hr	0.01 – 0.25	0.001 – 0.5	0.25 for LDR, MDR, HDR, IND 0.30 for MIN, OPE, PAS, AGG, AGT, RAN, FOR 0.50 for WAT, WET
LSUR	ft	200 – 500	100 – 700	500
SLSUR	none	0.01 – 0.15	0.001 – 0.3	0.001 for WAT, WET 0.007 – 0.064 for other land uses
KVARY	1/inch	0 – 3	0 – 5	1.5 for subwatersheds 7 – 9 0.0 for other land uses
AGWRC	none	0.92 – 0.99	0.85 – 0.999	0.995 for WAT, WET 0.95 – 0.97 for other land uses
DEEPFR	none	0.0 – 0.2	0.0 – 0.5	0.70 – 0.95 for subwatersheds 1 – 5, 10 – 13, 17 – 19 0.35 for subwatersheds 24 – 38 0.05 – 0.20 for subwatershed 6, 14 – 15, 20 – 21 0.00 for subwatershed 15, 22 – 23 Discharge for subwatersheds 8 – 9[2]
BASETP	none	0 – 0.05	0 – 0.2	0.03
AGWETP	none	0 – 0.05	0 – 0.2	0.3 for Water and Wetland 0.0 for other land uses
CEPSC	inches	0.03 – 0.2	0.01 – 0.4	0.15 for LDR, MDR, AGG, AGT 0.10 for HDR, IND, MIN, OPE, PAS, RAN, WAT, WET 0.20 for FOR
UZSN	inches	0.1 – 1	0.05 – 2	1.0 for LDR, MDR, HDR, IND 1.1 for MIN, OPE, PAS, AGG, AGT, RAN 1.2 for FOR 2.0 for WAT, WET
NSUR	none	0.15 – 0.35	0.05 – 0.50	0.20 for LDR, MDR, HDR 0.15 for IND 0.25 for MIN, OPE, PAS, AGG,

				AGT, RAN, FOR 0.40 for WAT, WET
INFTW	none	1 – 3	1 – 10	0.0 for WAT, WET 1.0 for other land uses
IRC	none	0.5 – 0.7	0.3 – 0.85	0.8 for WAT, WET 0.7 for other land uses
LZETP	none	0.2 – 0.7	0.1 – 0.9	0.3 – 0.9 varied by land use and by month
IMPLND Parameters				
LSUR	ft	50 – 150	50 – 250	200
SLSUR	none	0.01 – 0.05	0.001 – 0.15	0.007 – 0.064
RETSC	inches	0.03 – 0.1	0.01 – 0.3	0.1
RCHRES Parameters				
KS	none	0 – 0.5	0 – 0.99	0.5

Note:
1 – Typical and possible values of HSPF hydrologic parameters come from USEPA 2000;
2 – Calibrated discharge rate for subwatersheds 8 – 9 is 8 inches per acre.

Table A.2. Calibrated key instream water quality parameters in the Lake Jesup watershed HSPF model.

Parameter	Unit	Calibrated
KBOD20	/hr	0.004
KODSET	ft/hr	0.01
BENOD	mg/m2-hr	25.0
TCBEN	none	1.074
EXPOD(1)	none	1.2
BRBOD(2)	mg/m2-hr	0.0001
BRBOD	mg/m2-hr	0.0001
EXPREL	none	2.82
REAK	/hr	0.1
EXPRED	none	-1.673
EXPREV	none	0.969
BRTAM(1)	mg/m2-hr	0.0
BRTAM(2)	mg/m2-hr	0.0
BRPO4(1)	mg/m2-hr	0.0
BRPO4(2)	mg/m2-hr	0.0
ANAER	mg/L	0.005
KTAM20	/hr	0.015
KNO220	/hr	0.002
TCNIT	none	1.07
KNO320	/hr	0.002
TCDEN	none	1.04
DENOXT	mg/L	5.0

RATCLP	none	0.63
NONREF	none	0.5
LITSED	L/mg-ft	0.0
ALNPR	none	0.8
EXTB	/ft	1.0
MALGR	/hr	0.075
CMMLT	ly/min	0.033
CMMN	mg/L	0.025
CMMNP	mg/L	0.0001
CMMP	mg/L	0.005
TALGRH	degF	95
TALGRL	degF	38
TALGRM	degF	75
ALR20	/hr	0.005
ALDH	/hr	0.01
ALDL	/hr	0.001
OXALD	/hr	0.03
NALDH	mg/L	0.01
PALDH	mg/L	0.002
PHYSET	ft/hr	0.005
REFSET	ft/hr	0.005

Note: A summary of the literature values for these parameters can be found in Tetra Tech (1985).

Appendix B. Additional Plots of Hydrologic Calibration

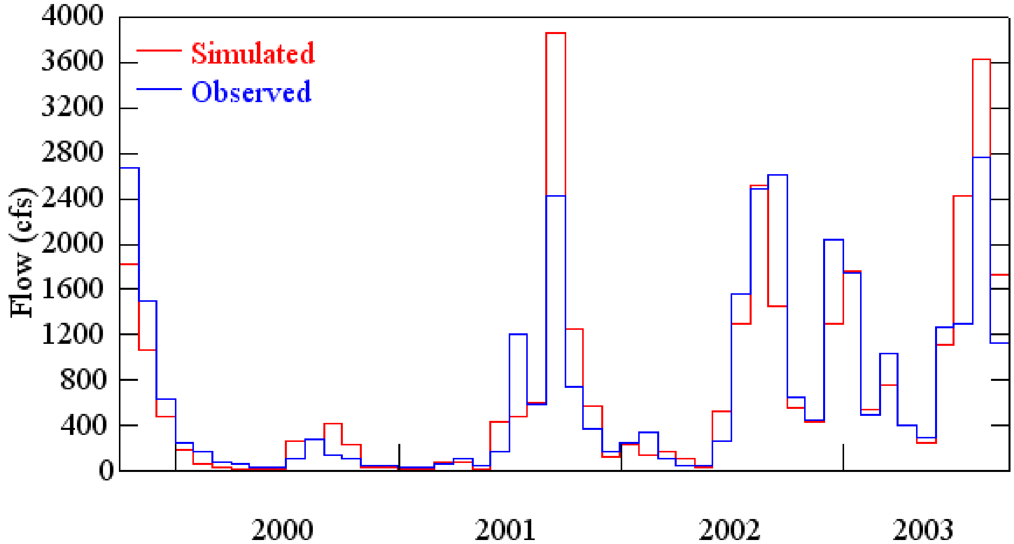

Figure B.1. Observed and simulated monthly flows for Howell Creek near Slavia (10/1999 – 09/2003).

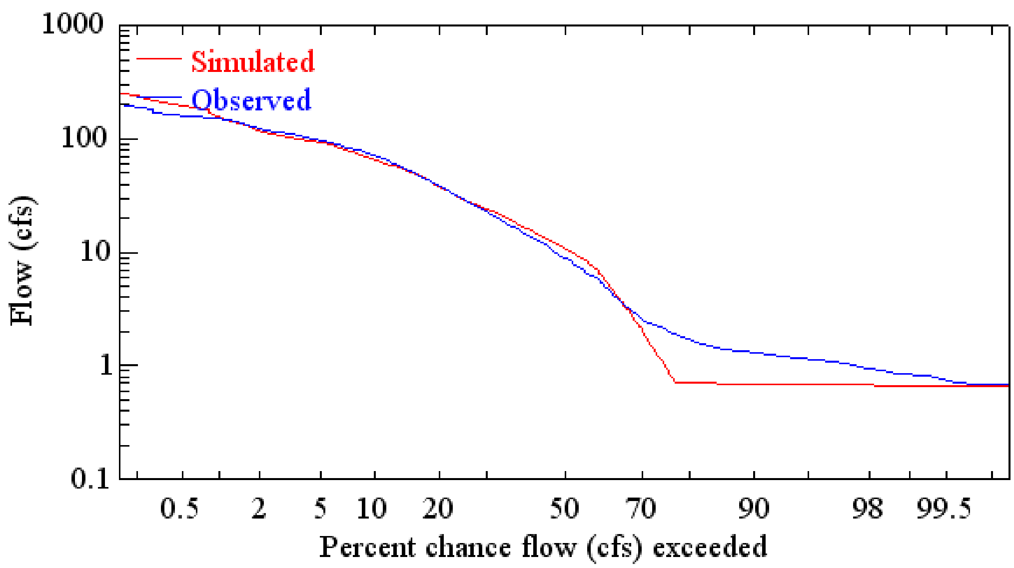

Figure B.2. Observed and simulated daily flows frequency curves for Howell Creek near Slavia (10/1999 – 09/2003).

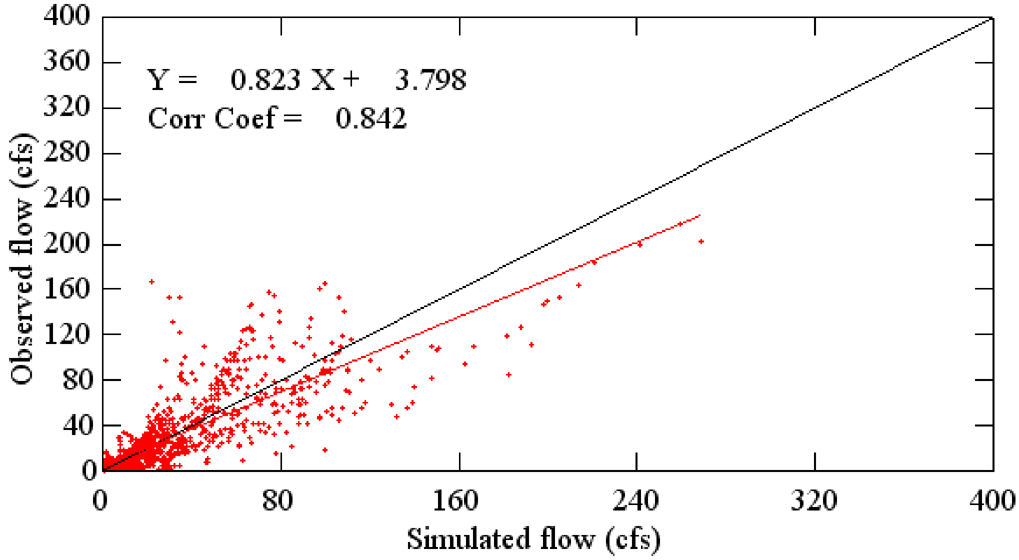

Figure B.3. Scatter plots of observed and simulated daily flows for Howell Creek near Slavia (10/1999 – 09/2003).

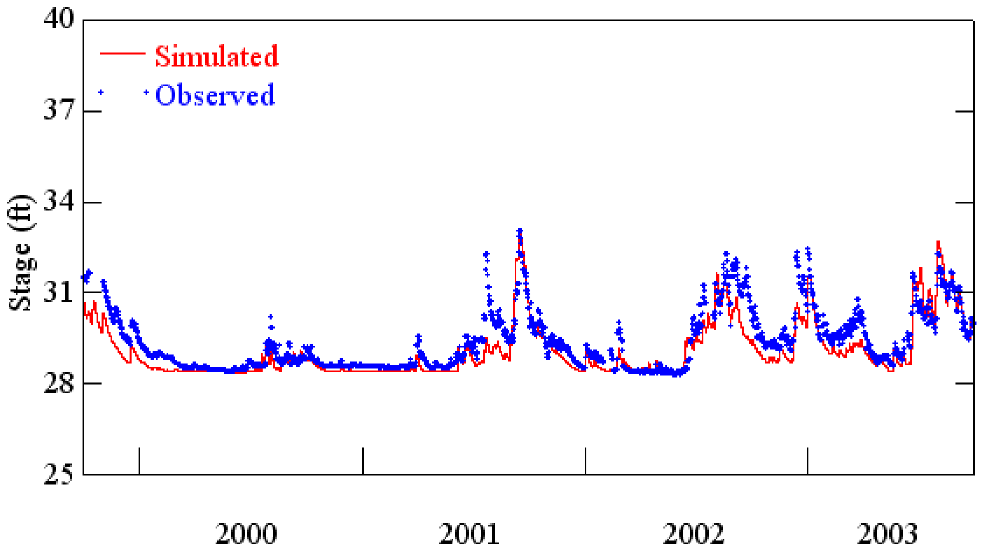

Figure B.4. Observed and simulated daily stages for Howell Creek near Slavia (10/1999 – 09/2003).

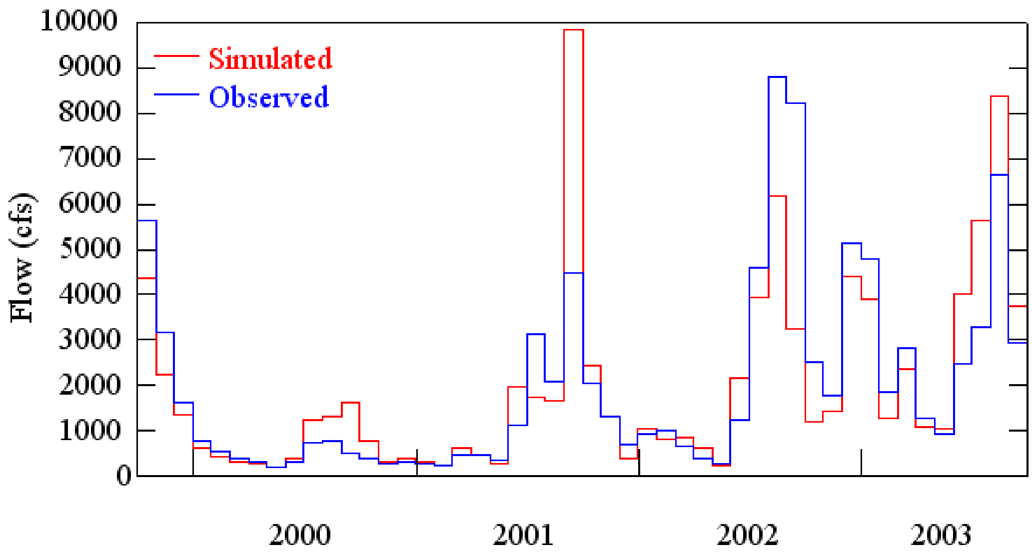

Figure B.5. Observed and simulated monthly flows for Howell Creek near Oviedo (10/1999 – 09/2003).

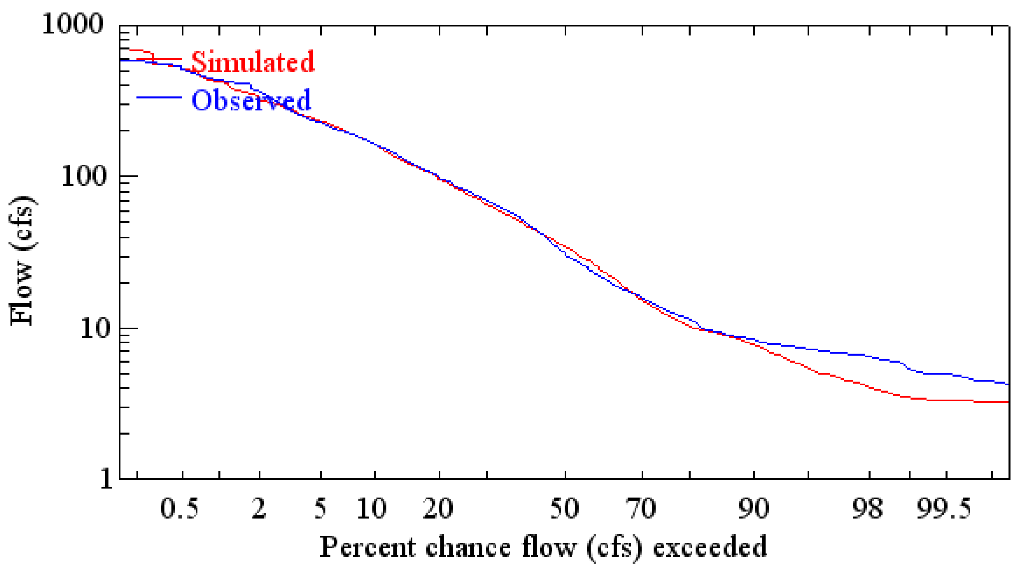

Figure B.6. Observed and simulated daily flow frequency curves for Howell Creek near Oviedo (10/1999 – 09/2003).

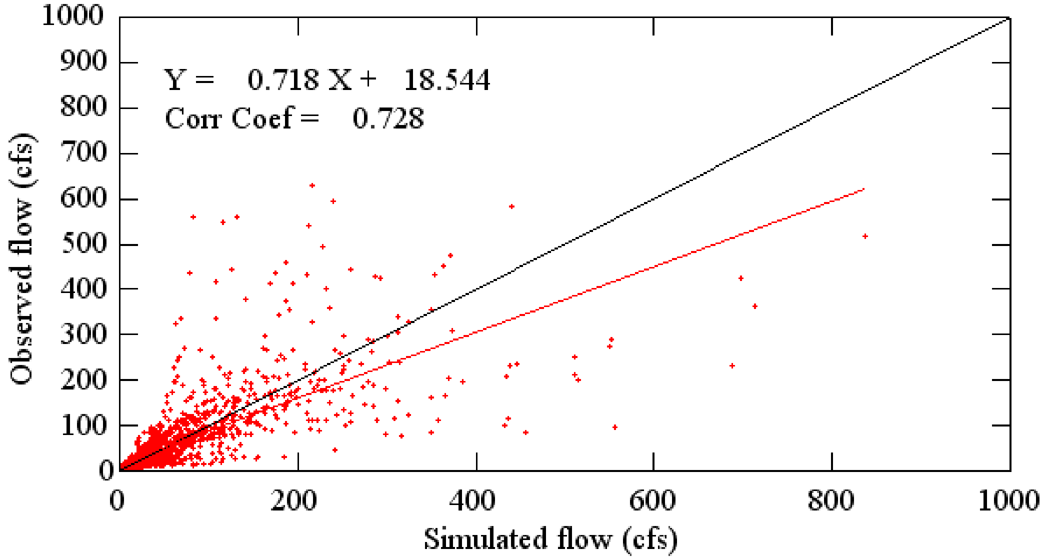

Figure B.7. Scatter plots of observed and simulated daily flows for Howell Creek near Oviedo (10/1999 – 09/2003).

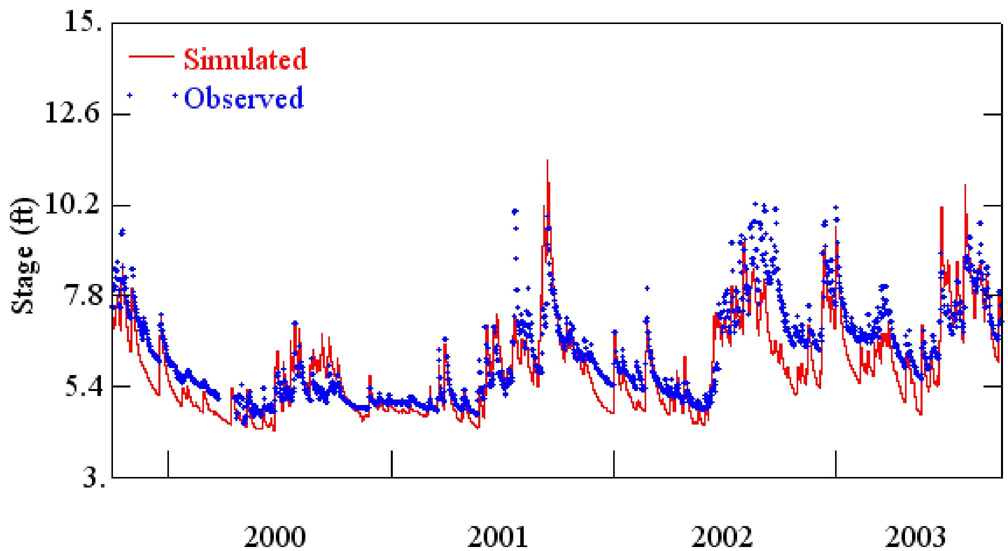

Figure B.8. Observed and simulated daily stages for Howell Creek near Oviedo (10/1999 – 09/2003).

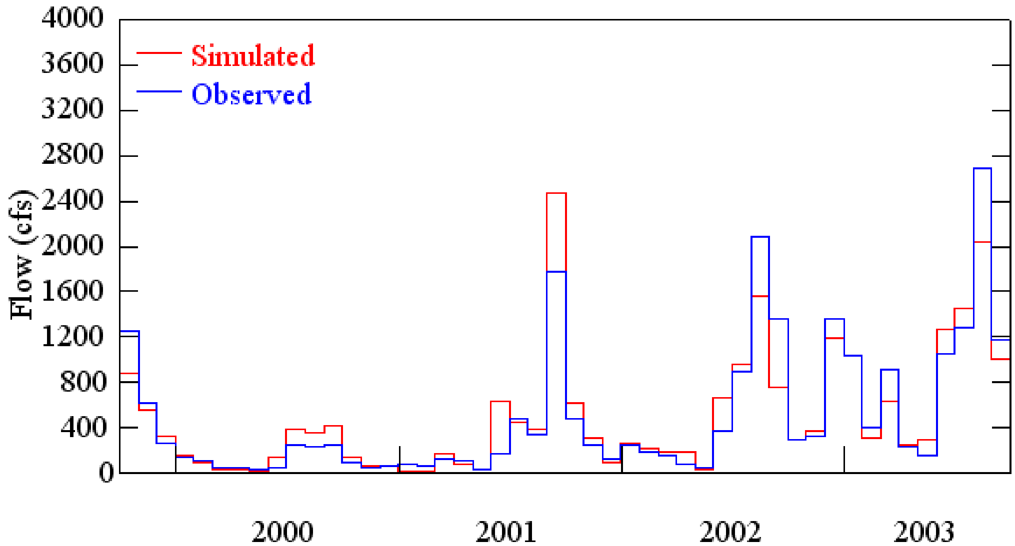

Figure B.9. Observed and simulated monthly flows for Gee Creek near Longwood (10/1999 – 09/2003).

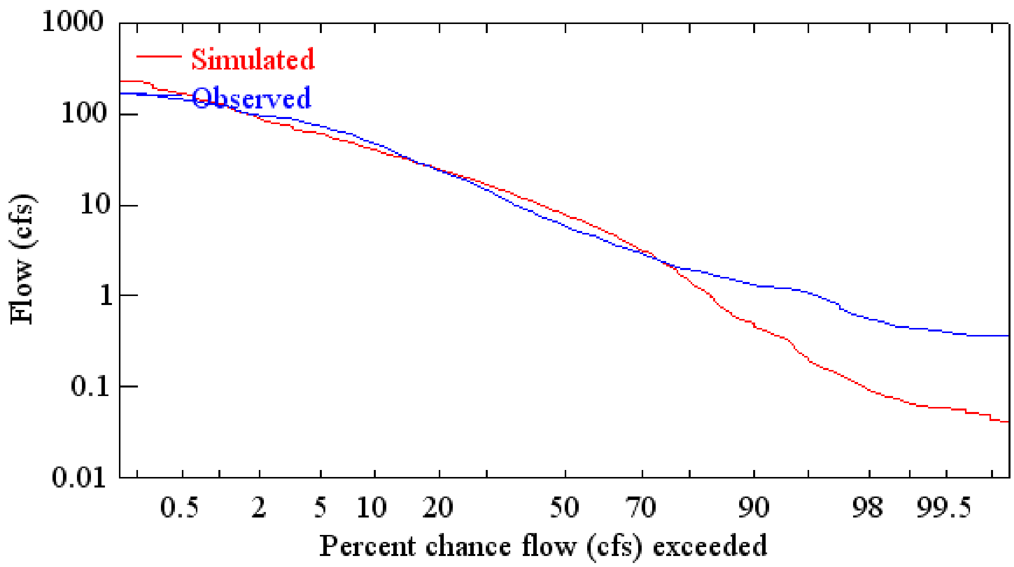

Figure B.10. Observed and simulated daily flow frequency curves for Gee Creek near Longwood (10/1999 – 09/2003).

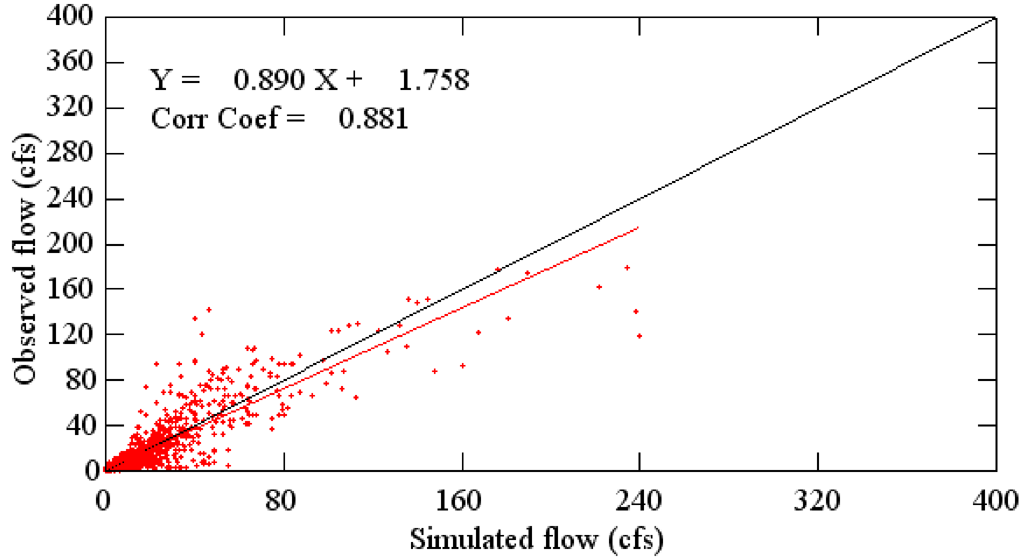

Figure B.11. Scatter plots of observed and simulated daily flows for Gee Creek near Longwood (10/1999 – 09/2003).

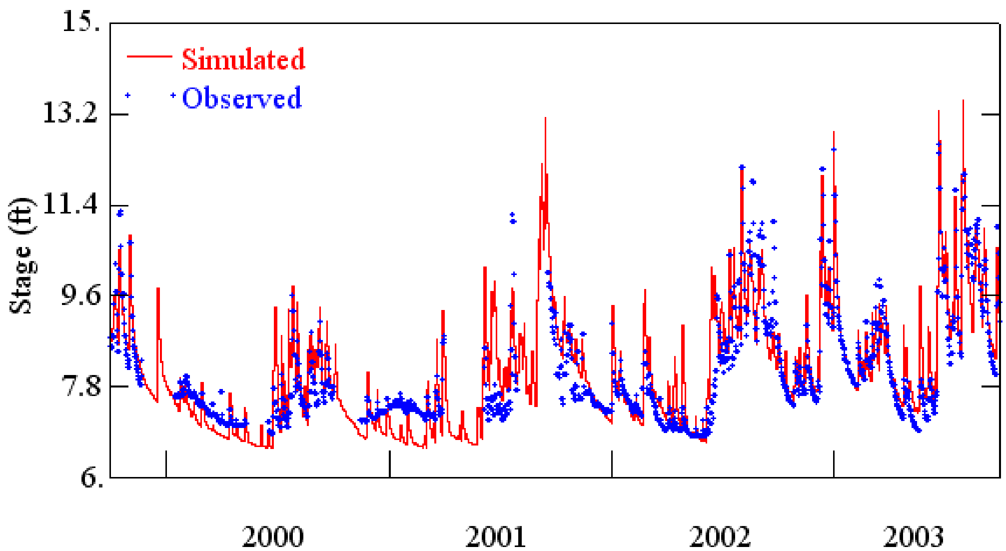

Figure B.12. Observed and simulated daily stages for Gee Creek near Longwood (10/1999 – 09/2003).

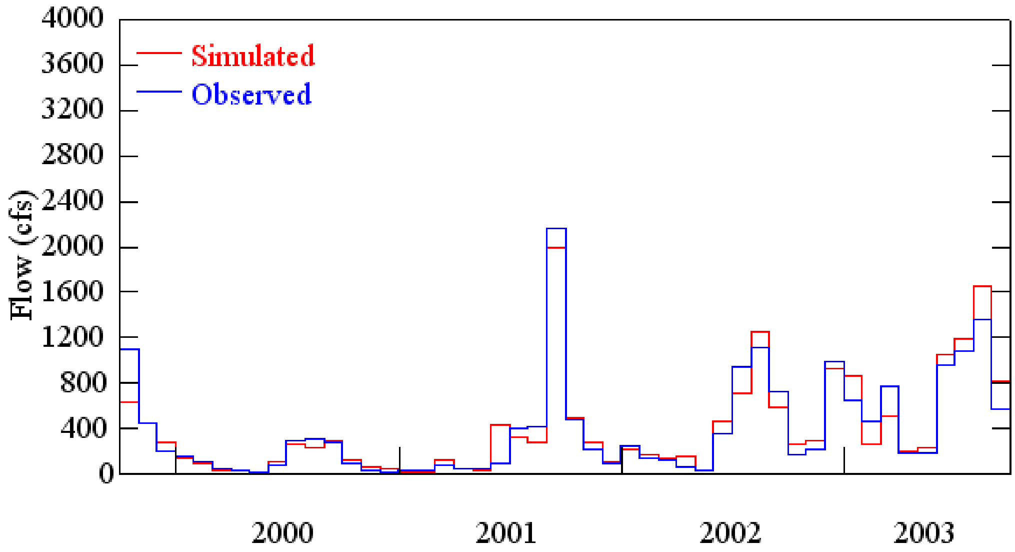

Figure B.13. Observed and simulated monthly flows for Soldier Creek near Longwood (10/1999 – 09/2003).

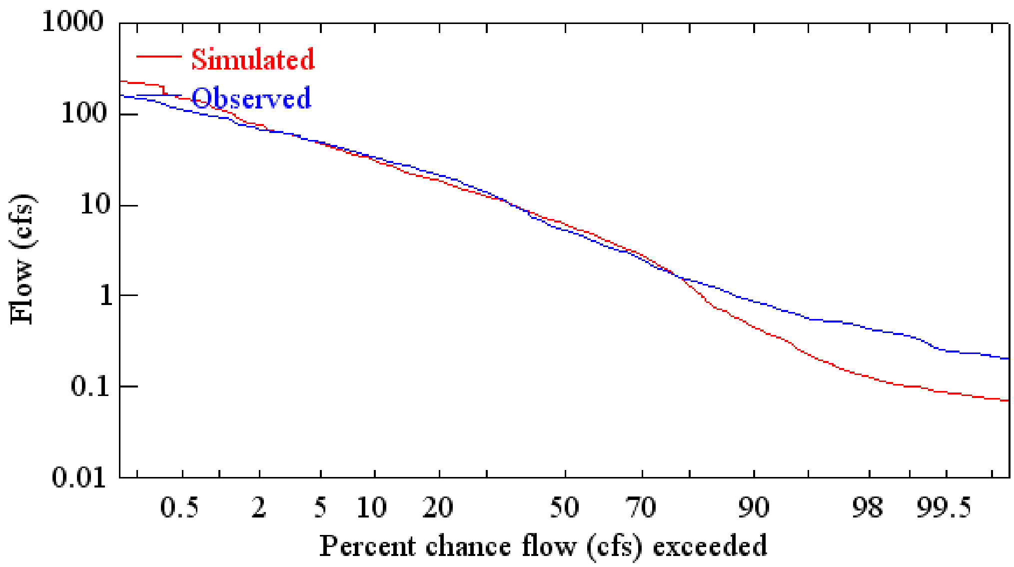

Figure B.14. Observed and simulated daily flow frequency curves for Soldier Creek near Longwood (10/1999 – 09/2003).

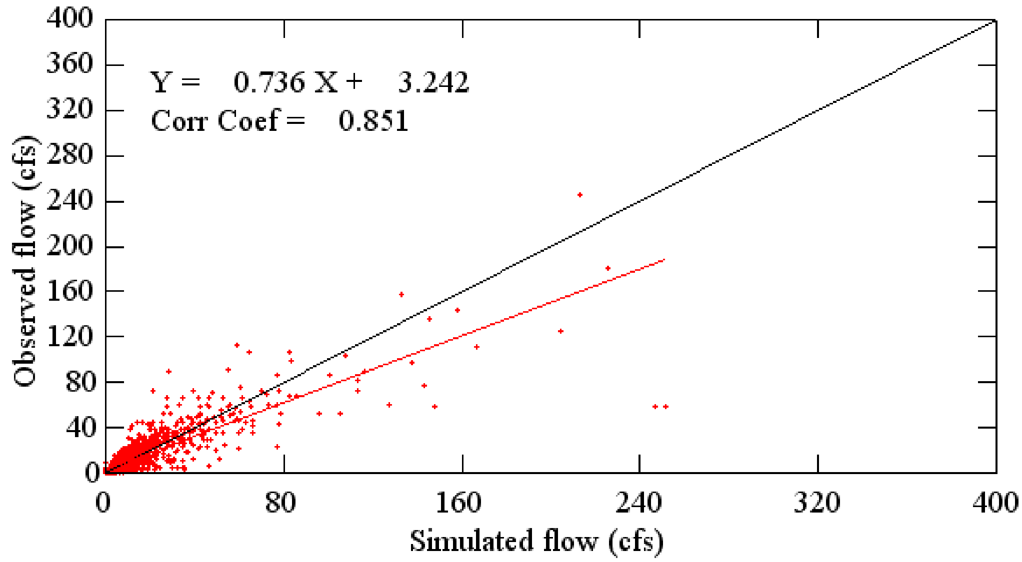

Figure B.15. Scatter plots of observed and simulated daily flows for Soldier Creek near Longwood (10/1999 – 09/2003).

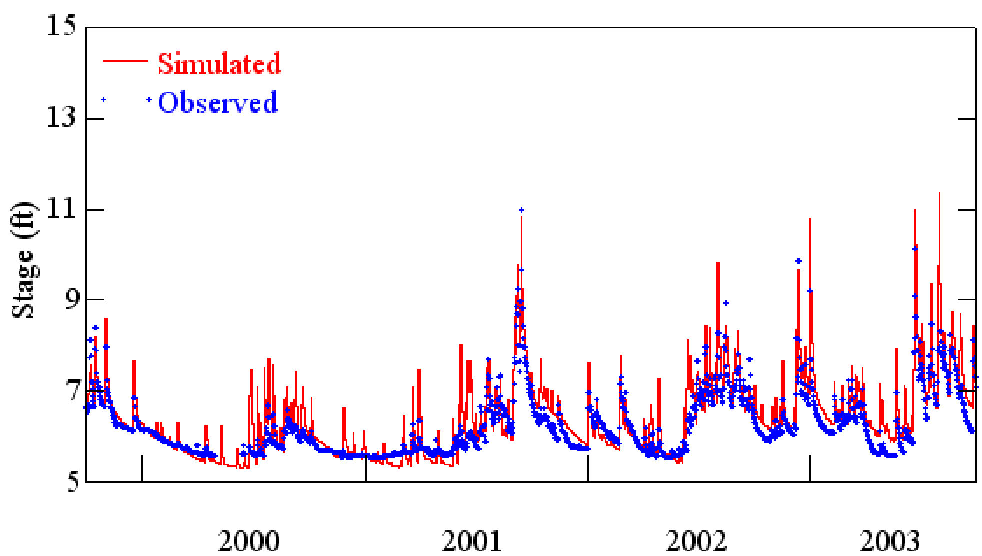

Figure B.16. Observed and simulated daily stages for Soldier Creek near Longwood (10/1999 – 09/2003).

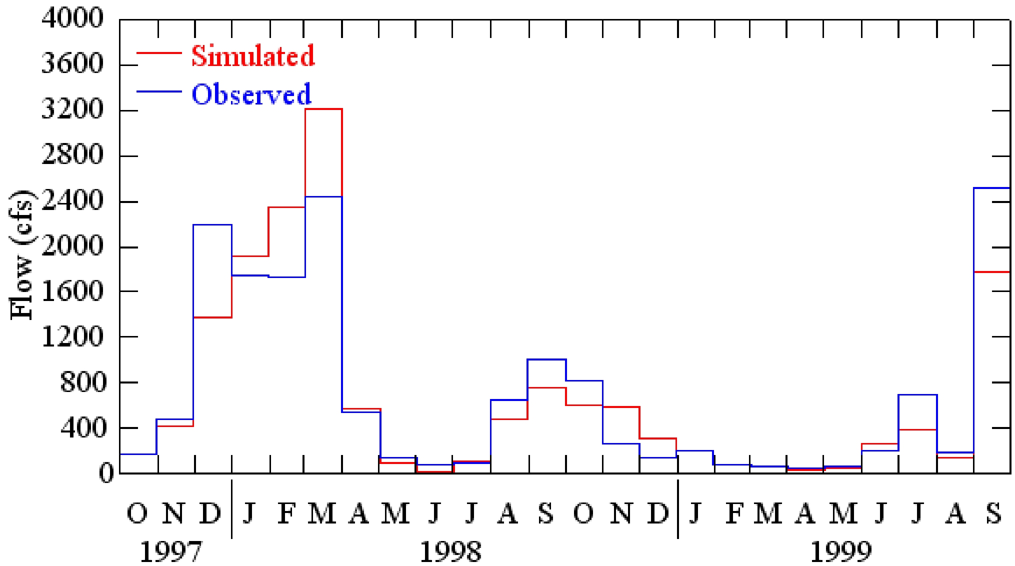

Figure B.17. Observed and simulated monthly flows for Howell Creek near Slavia (10/1997 – 09/1999).

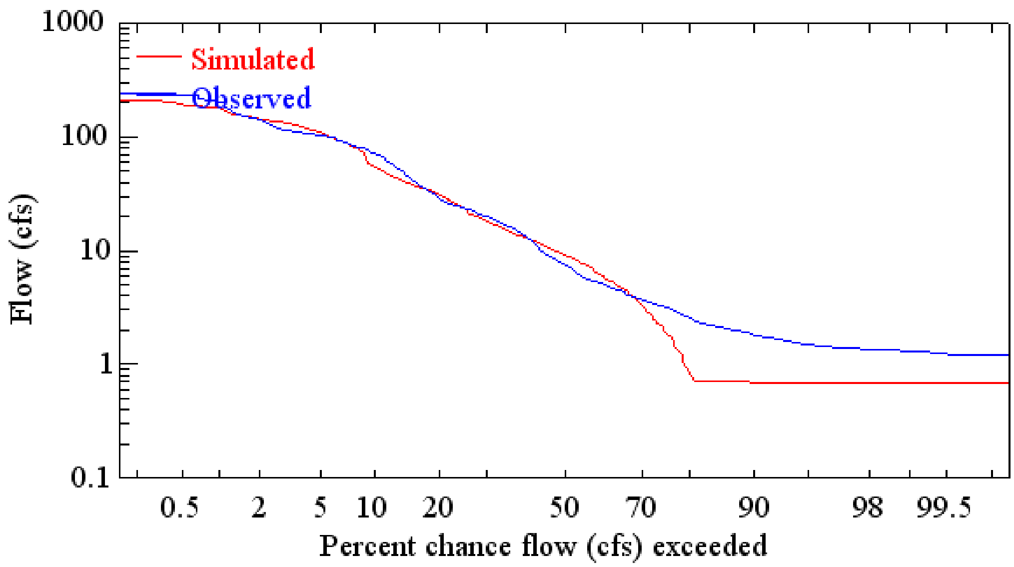

Figure B.18. Observed and simulated daily flow frequency curves for Howell Creek near Slavia (10/1997 – 09/1999).

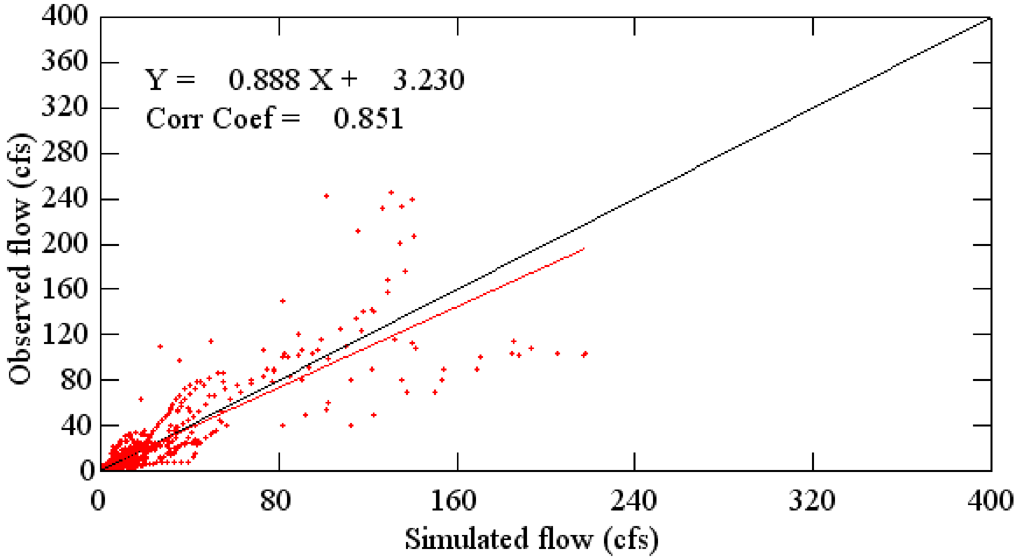

Figure B.19. Scatter plots of observed and simulated daily flows for Howell Creek near Slavia (10/1997 – 09/1999).

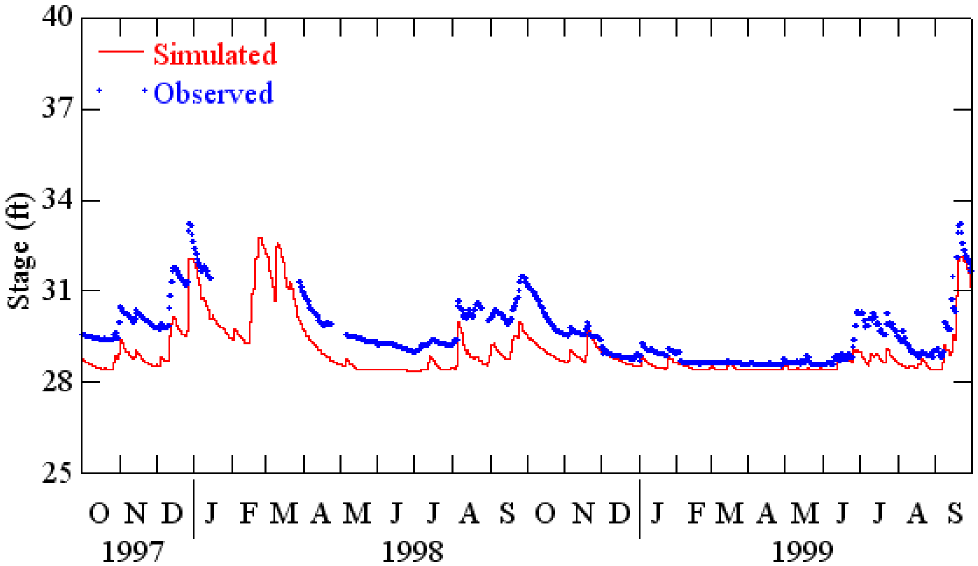

Figure B.20. Observed and simulated daily stages for Howell Creek near Slavia (10/1997 – 09/1999).

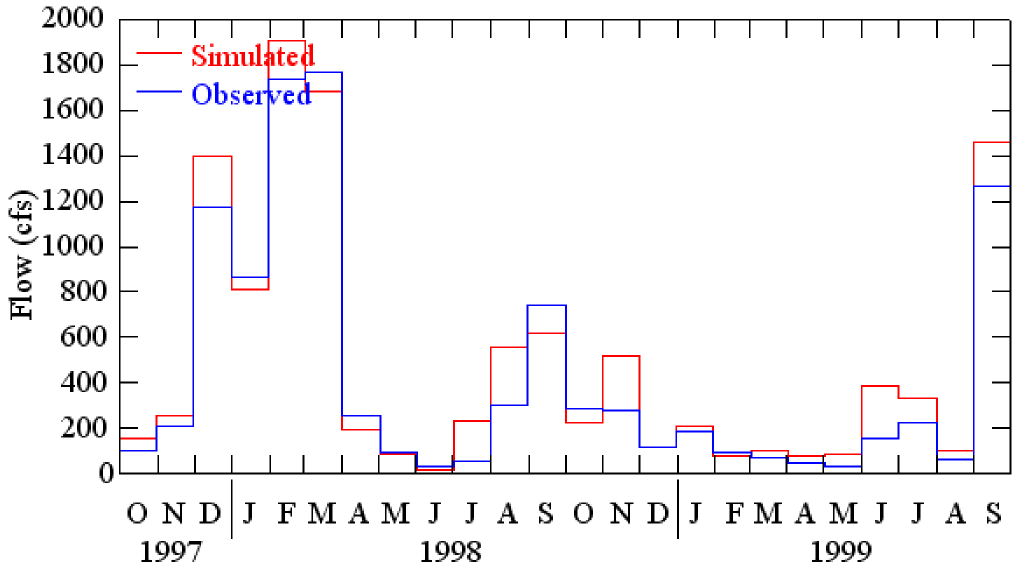

Figure B.21. Observed and simulated monthly flows for Gee Creek near Longwood (10/1997 – 09/1999).

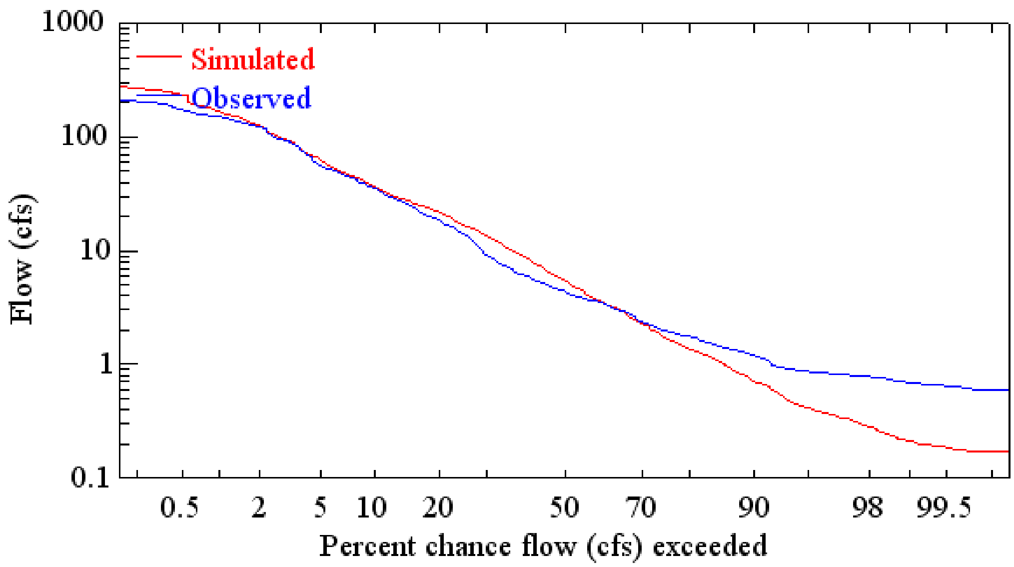

Figure B.22. Observed and simulated daily flow frequency curves for Gee Creek near Longwood (10/1997 – 09/1999).

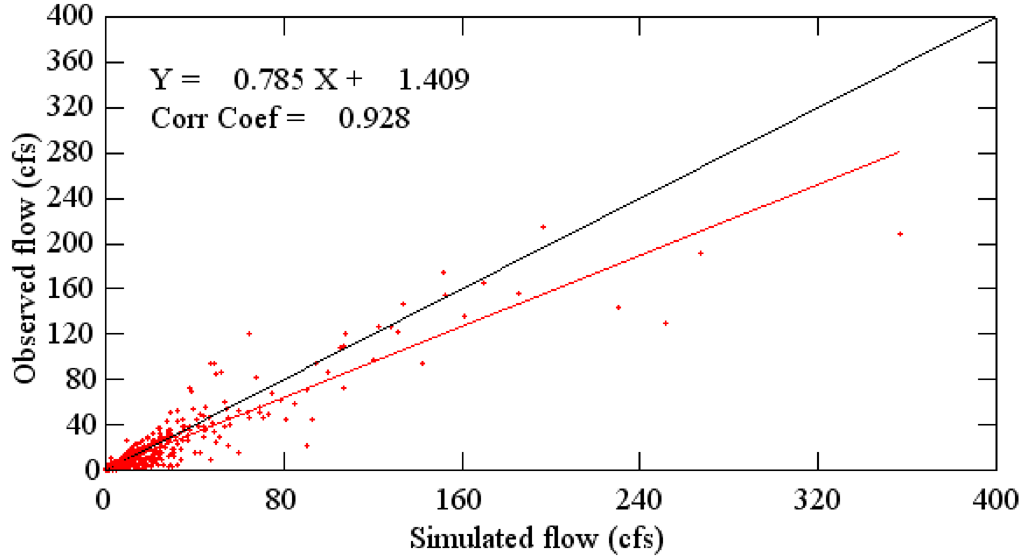

Figure B.23. Scatter plots of observed and simulated daily flows for Gee Creek near Longwood (10/1997 – 09/1999).

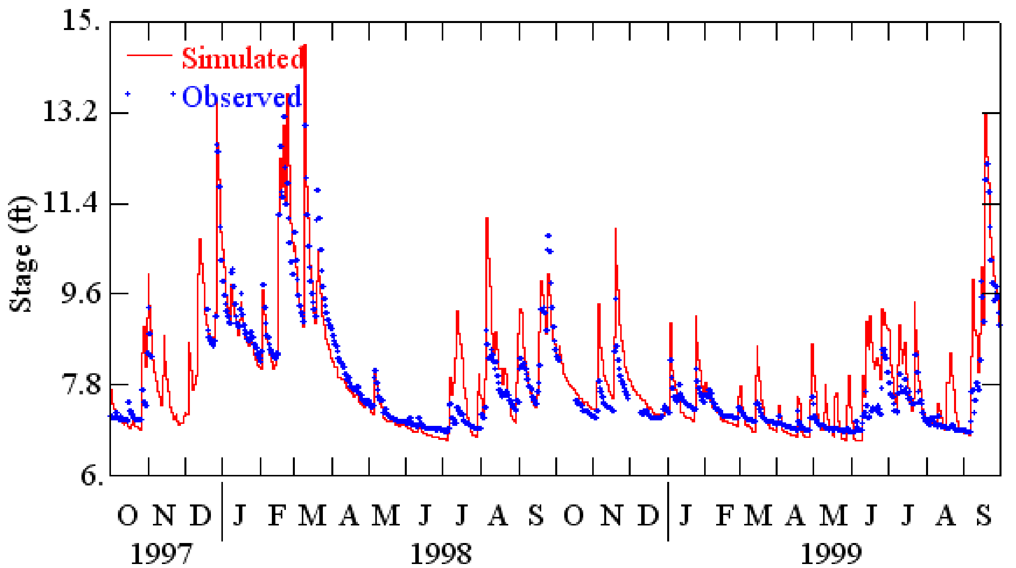

Figure B.24. Observed and simulated daily stages for Gee Creek near Longwood (10/1997 – 09/1999).

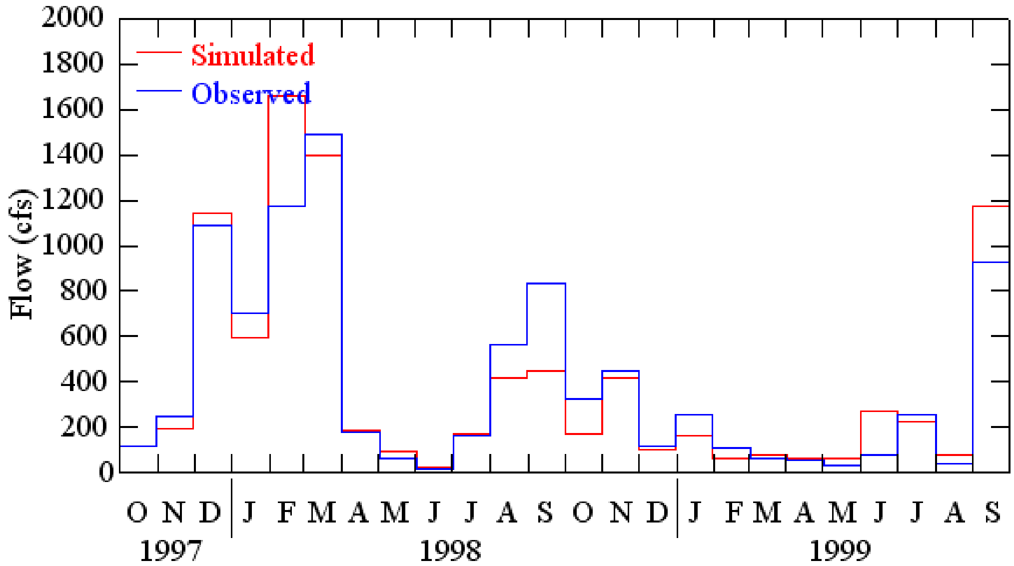

Figure B.25. Observed and simulated monthly flows for Soldier Creek near Longwood (10/1997 – 09/1999).

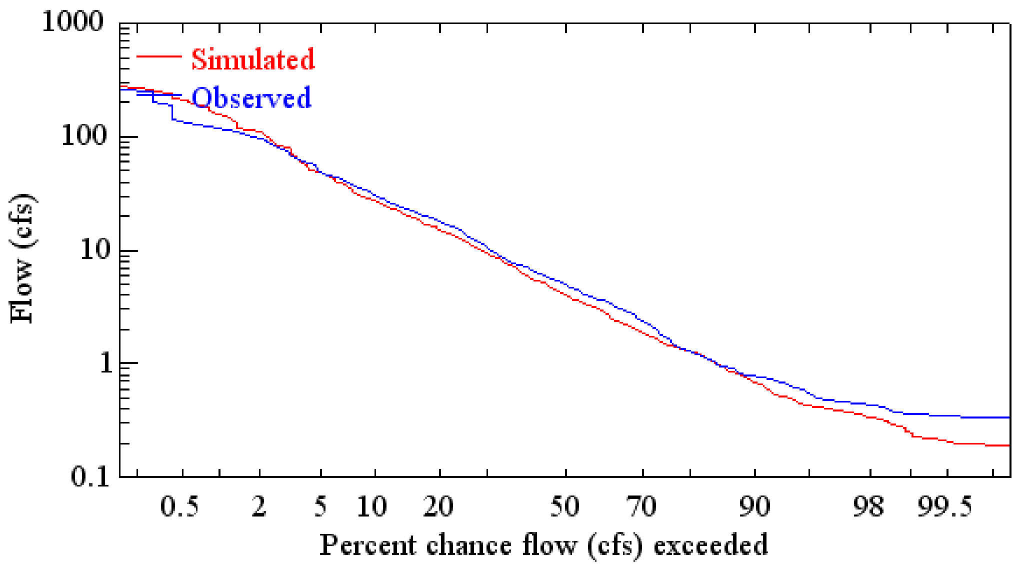

Figure B.26. Observed and simulated daily flow frequency curves for Soldier Creek near Longwood (10/1997 – 09/1999).

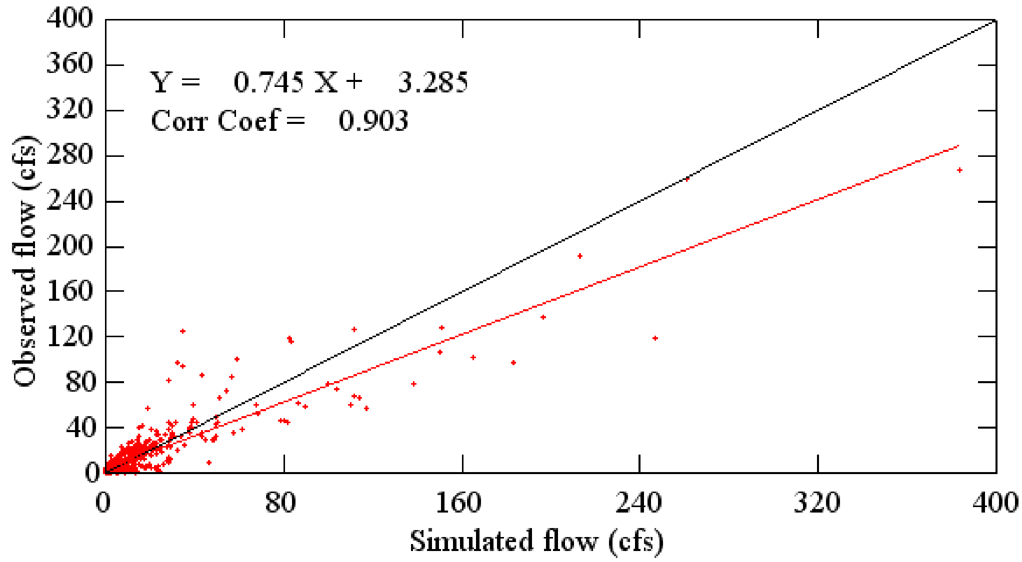

Figure B.27. Scatter plots of observed and simulated daily flows for Soldier Creek near Longwood (10/1997 – 09/1999).

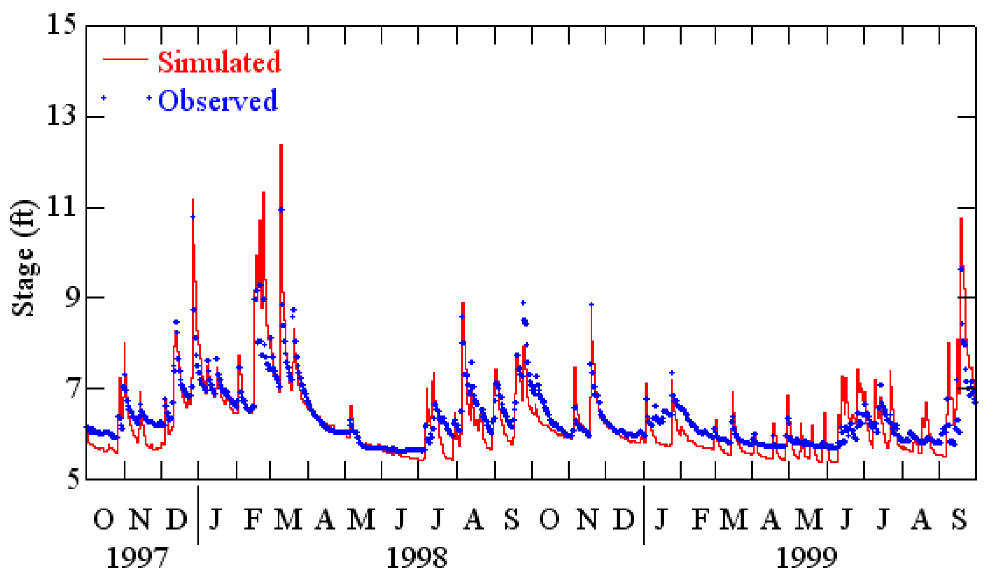

Figure B.28. Observed and simulated daily stages for Gee Creek near Longwood (10/1997 – 09/1999).

Appendix C. Additional Plots of Water Quality Calibration

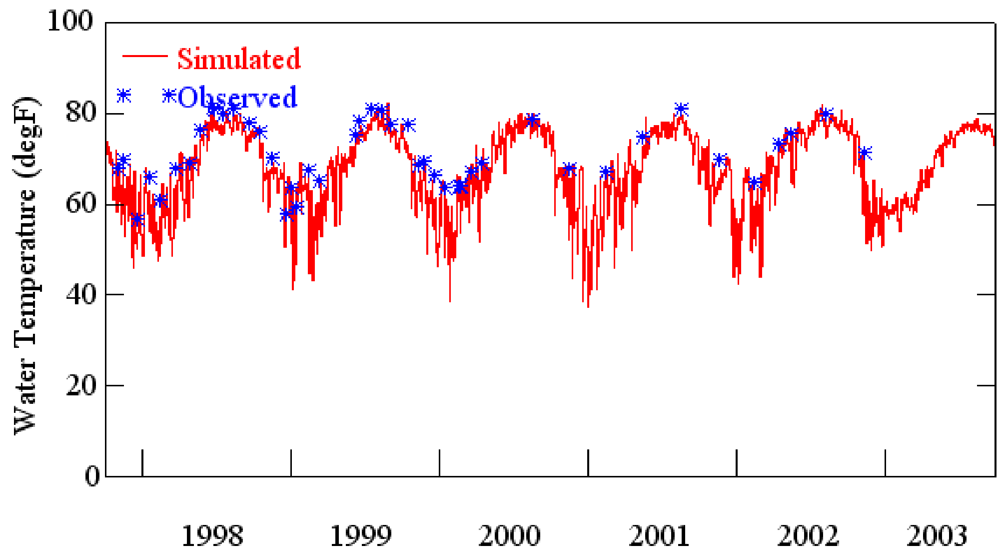

Figure C.1. Observed and simulated water temperature for Howell Creek near Oviedo (10/1997 – 09/2003).

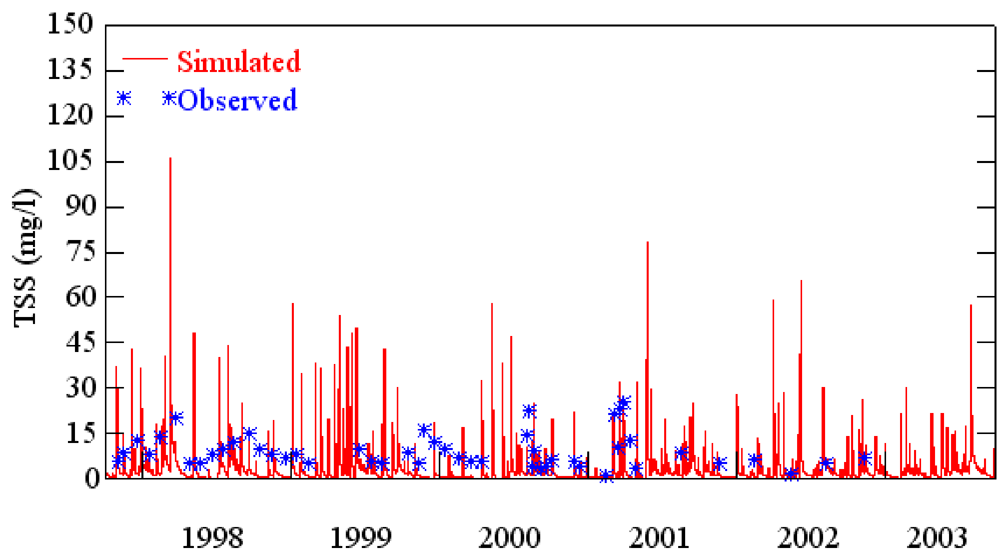

Figure C.2. Observed and simulated TSS concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

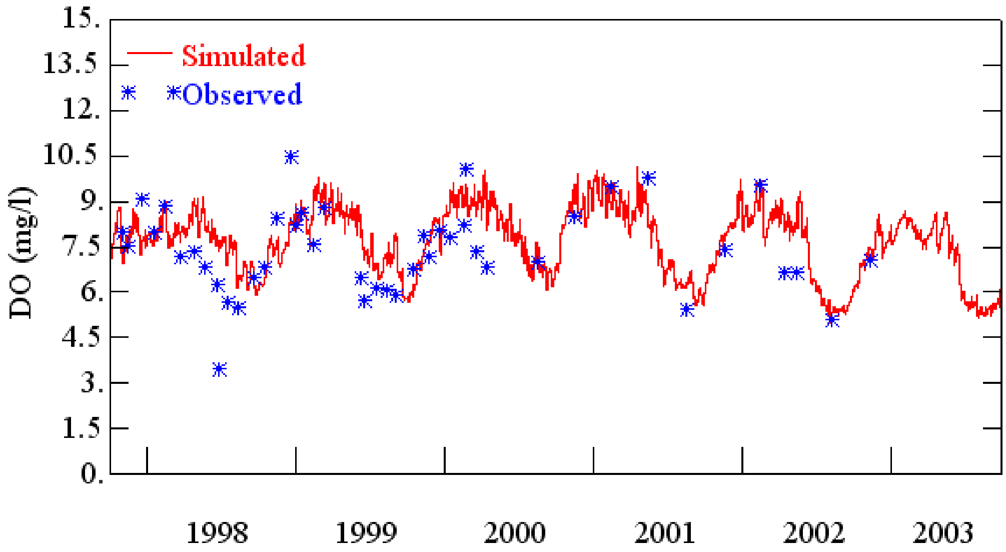

Figure C.3. Observed and simulated DO concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

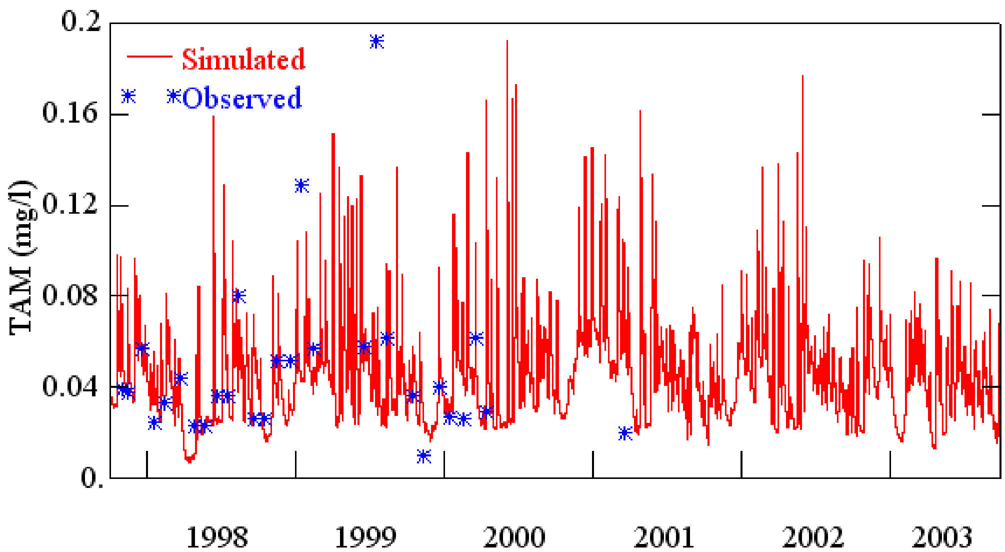

Figure C.4. Observed and simulated TAM concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

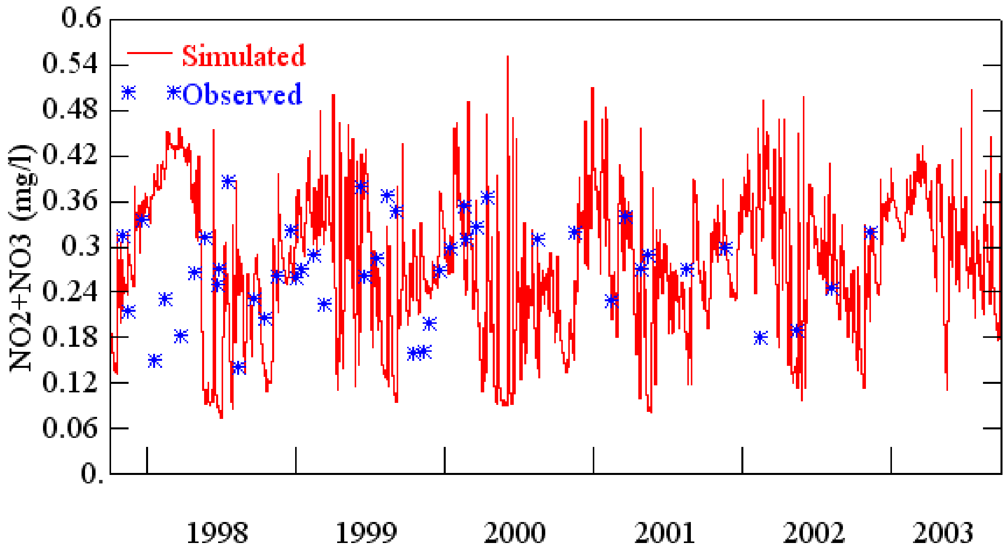

Figure C.5. Observed and simulated NO2+NO3 concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

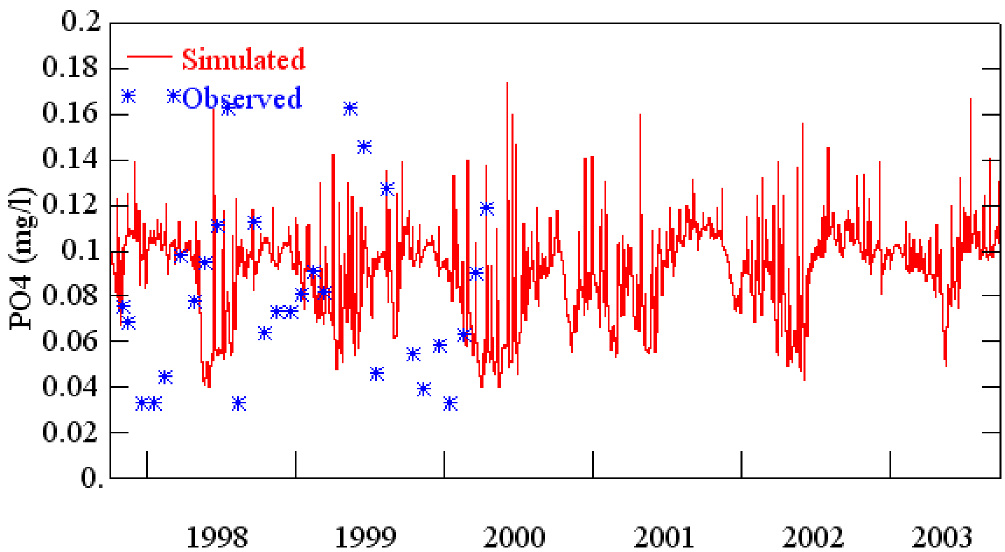

Figure C.6. Observed and simulated PO4 concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

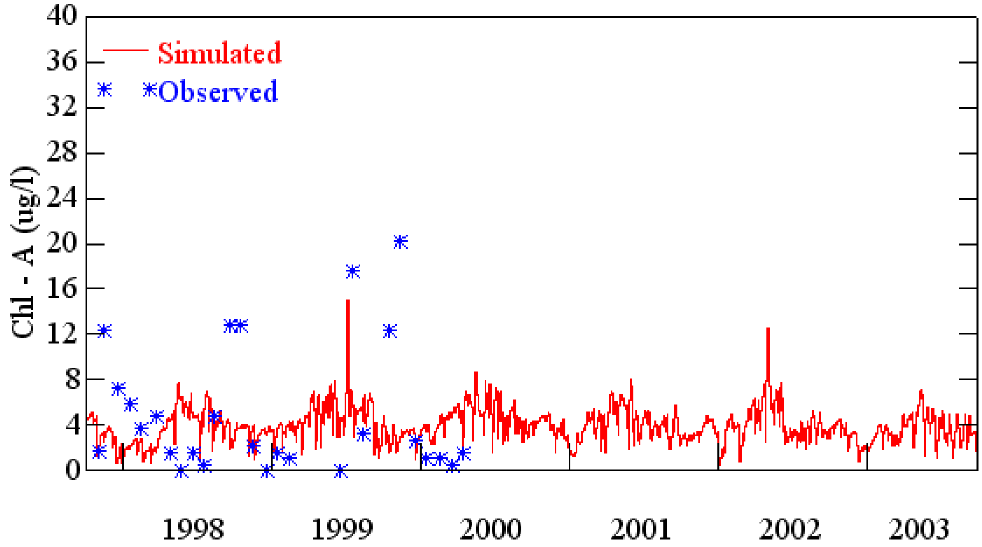

Figure C.7. Observed and simulated Chl – A concentrations for Howell Creek near Oviedo (10/1997 – 09/2003).

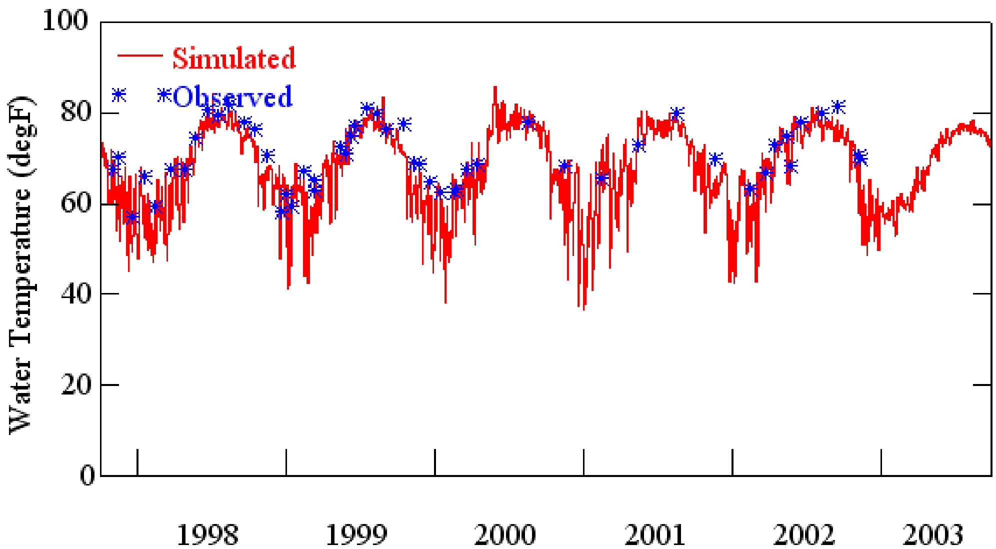

Figure C.8. Observed and simulated water temperature for Gee Creek near Longwood (10/1997 – 09/2003).

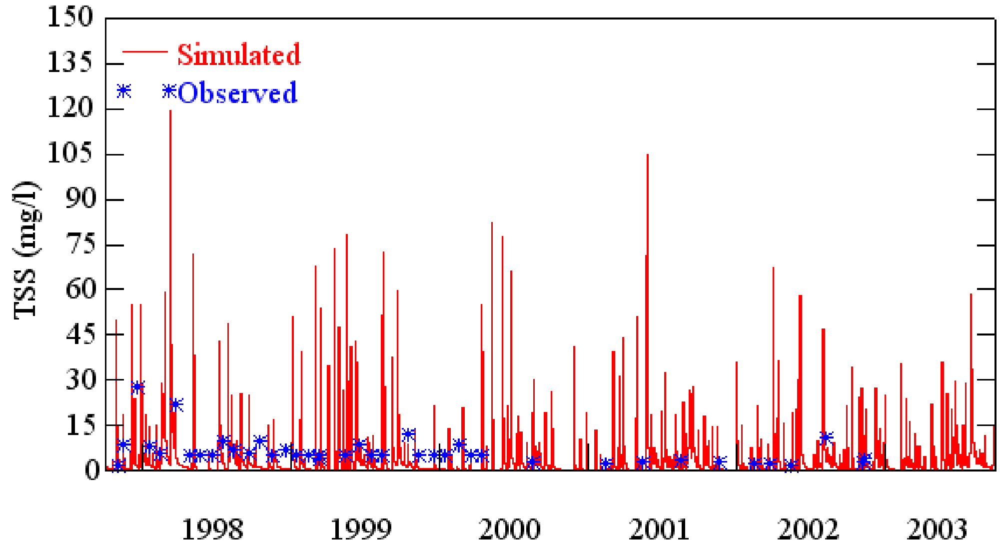

Figure C.9. Observed and simulated TSS concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

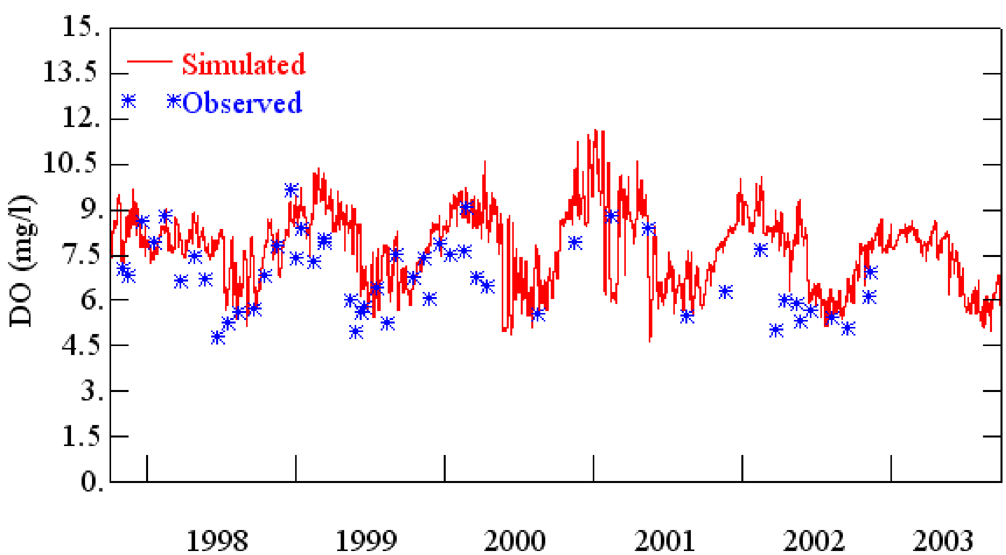

Figure C.10. Observed and simulated DO concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

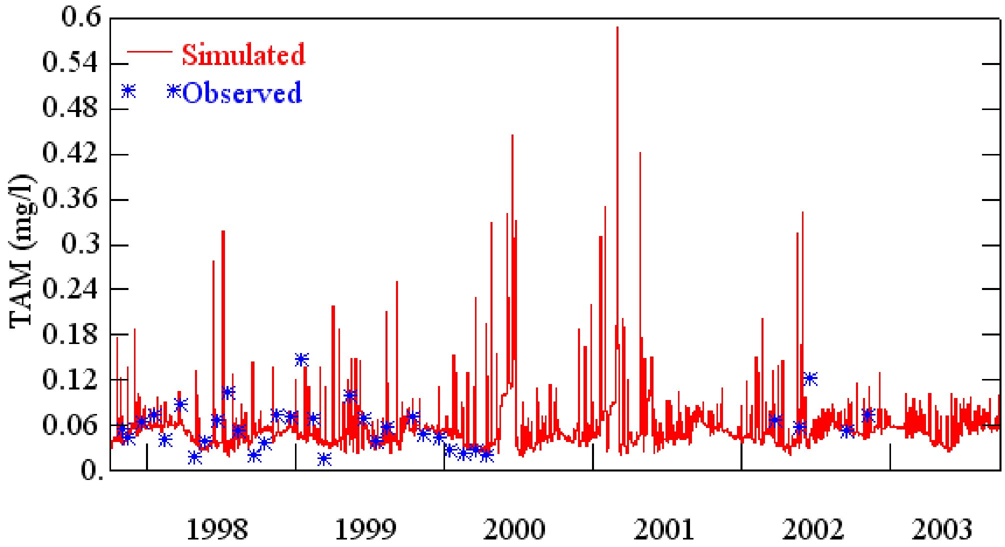

Figure C.11. Observed and simulated TAM concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

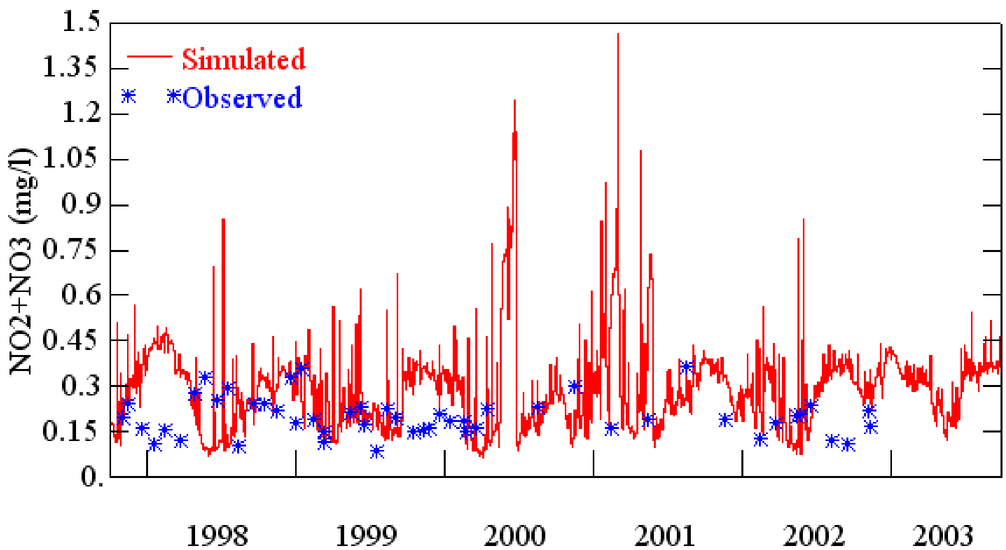

Figure C.12. Observed and simulated NO2+NO3 concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

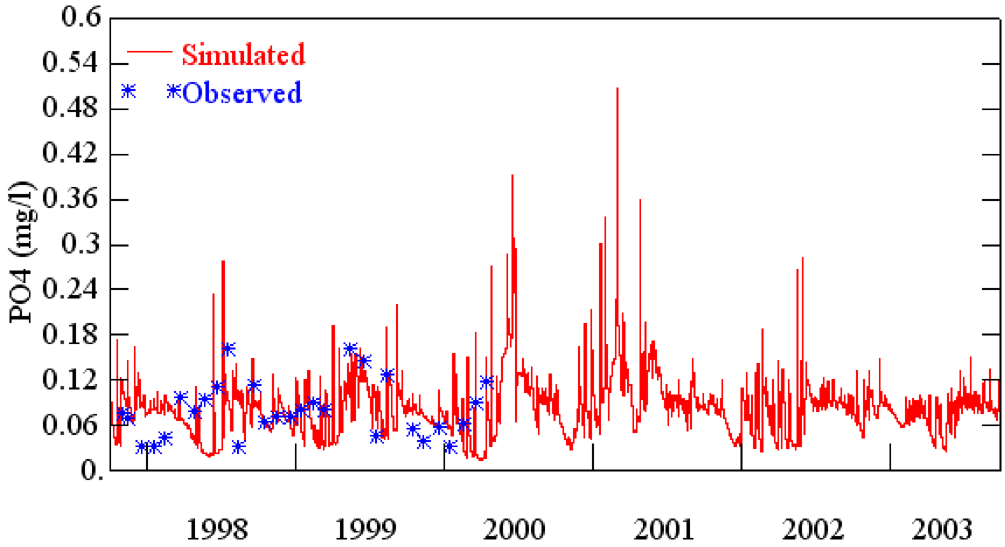

Figure C.13. Observed and simulated PO4 concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

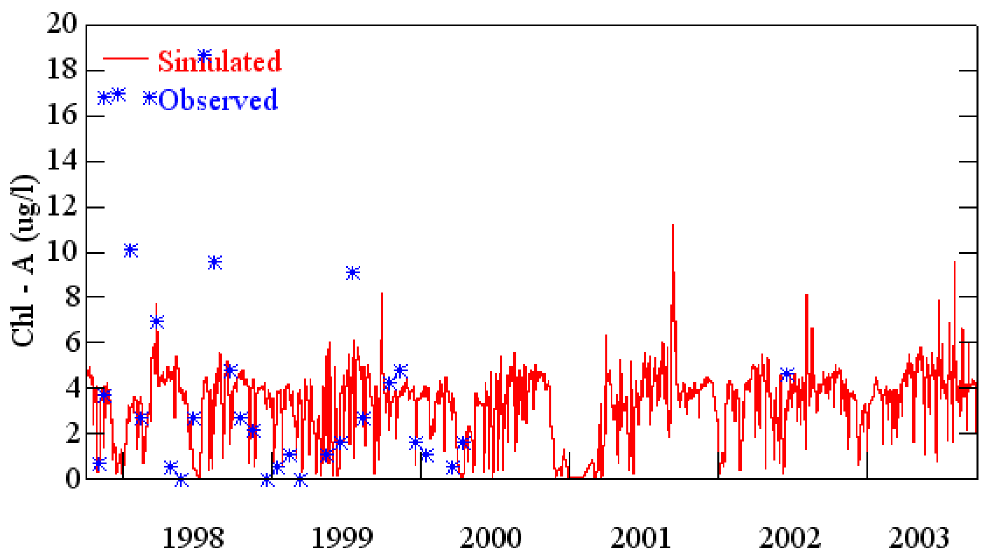

Figure C.14. Observed and simulated Chl – A concentrations for Gee Creek near Longwood (10/1997 – 09/2003).

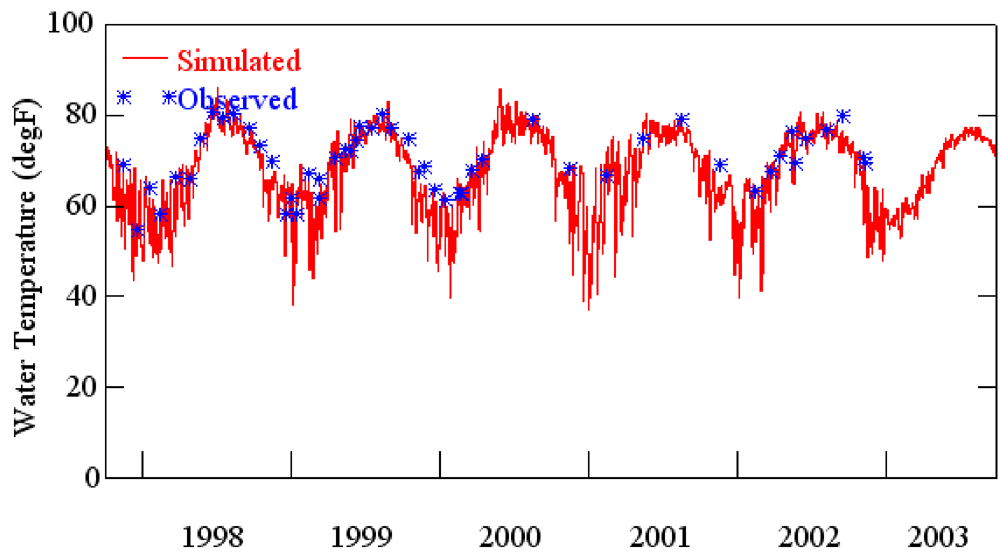

Figure C.15. Observed and simulated water temperature for Soldier Creek near Longwood (10/1997 – 09/2003).

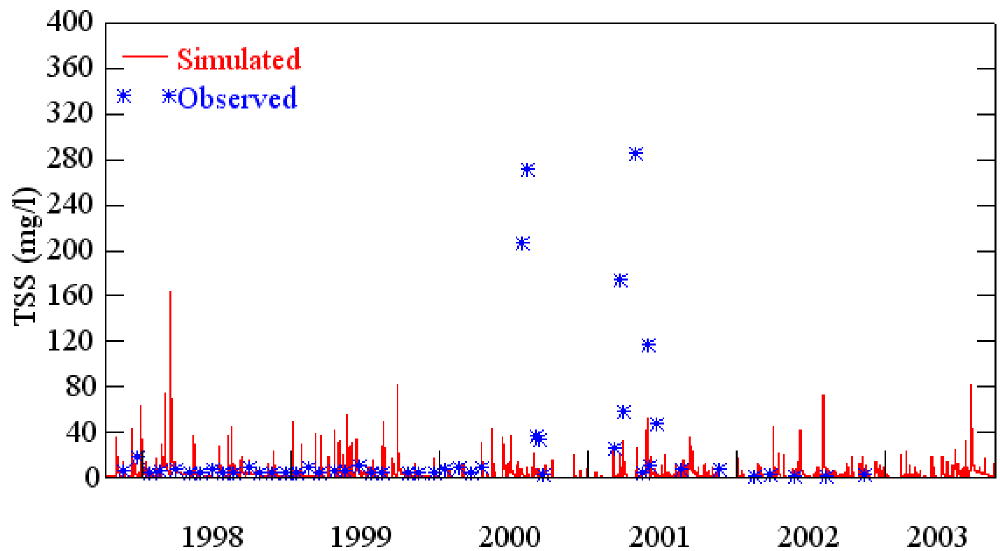

Figure C.16. Observed and simulated TSS concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

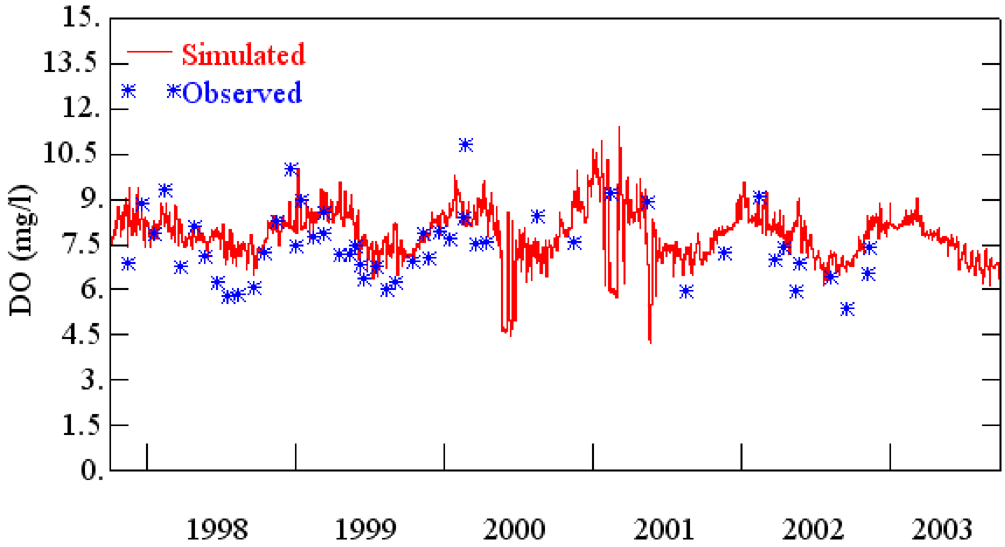

Figure C.17. Observed and simulated DO concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

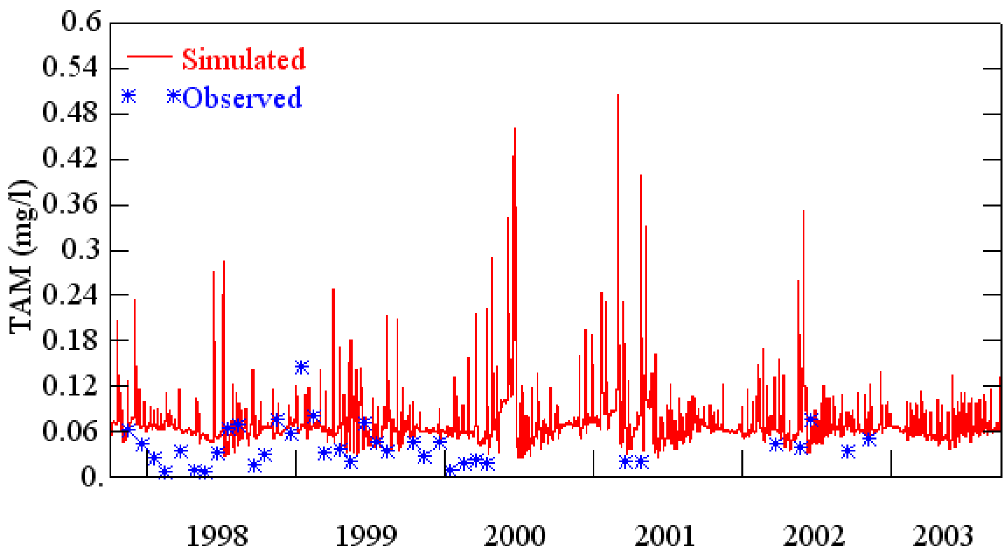

Figure C.18. Observed and simulated TAM concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

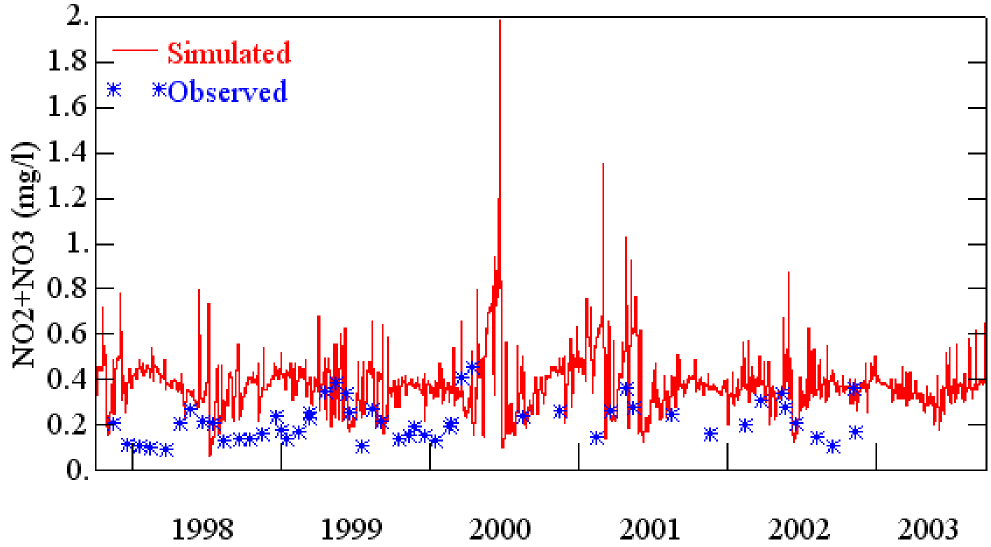

Figure C.19. Observed and simulated NO2+NO3 concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

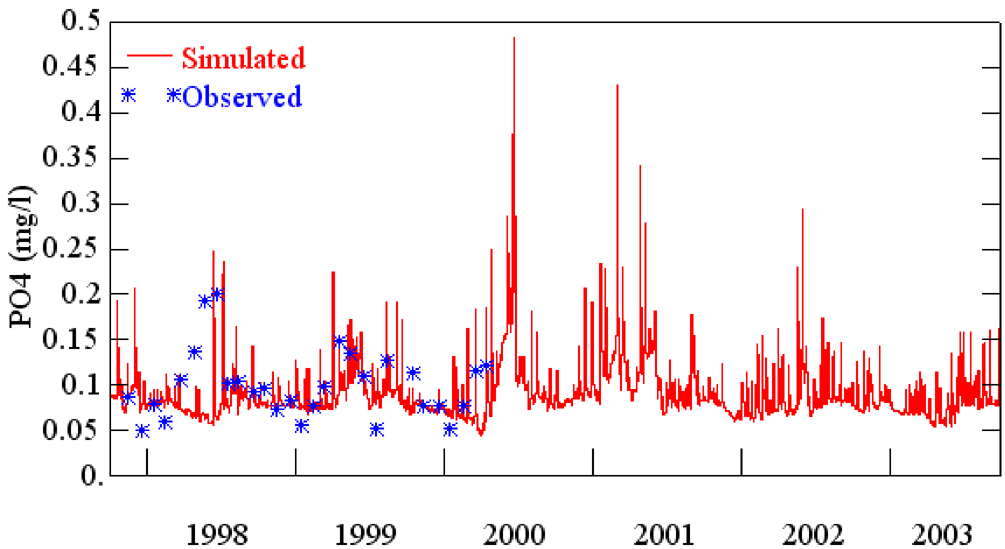

Figure C.20. Observed and simulated PO4 concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

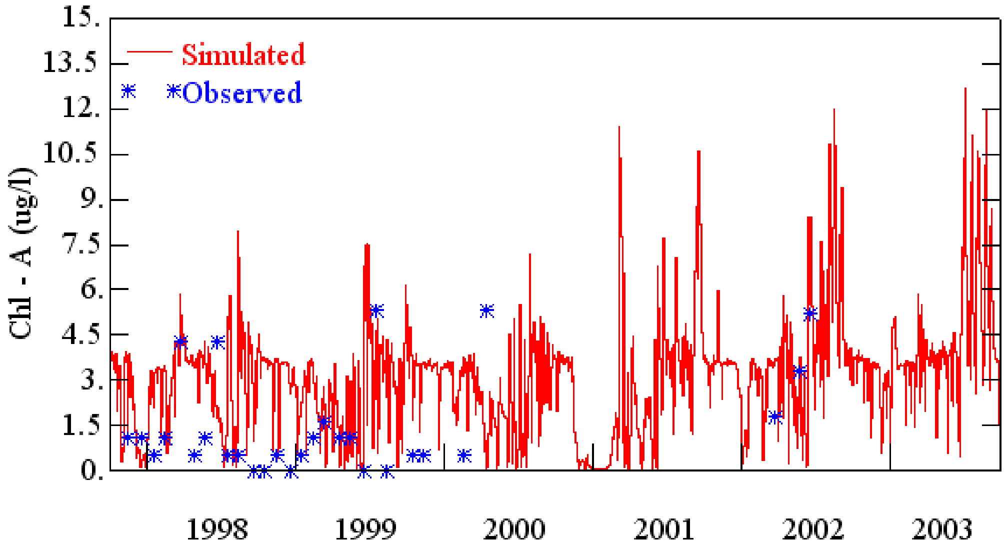

Figure C.21. Observed and simulated Chl – A concentrations for Soldier Creek near Longwood (10/1997 – 09/2003).

Appendix D. Responses to the Reviewer's Recommendations

A peer-review for this work has been done by Patrick Tara and Harshal Parikh of INTERA, Inc. (Tara and Parikh 2006). Detailed responses to the reviewer's recommendations follow. Unless noted otherwise, report locations refer to the final report.

Recommendation no. 1. Replace rainfall time series to improve spatial representation.

The rainfall data for the Lake Jesup watershed HSPF model were from two weather stations: CHARST and SANFORD. The rainfall data from other stations within or near the Lake Jesup watershed, including those suggested by the reviewer (see figure 3 in the reviewer's report), were also collected for this study. These data were not used for watershed modeling because they do not cover the entire 6-year simulation period from 10/1997 to 09/2003. To clarify this point, the following sentence has been added to the first paragraph of section 2.4:

"The weather data from other nearby stations were also collected, but they were not used for watershed modeling because they do not cover the entire simulation period from 10/1997 to 09/2003 in this study."

Recommendation no. 2. Replace ET time series to improve data filling.

The data filling issue pointed out by the reviewer refers to the one-month gap in the LISBON pan evaporation data where the averaged pan evaporation estimates were used (see figure 6 in the reviewer's report). The filling period is relatively short compared to the 6-year simulation period in this study; therefore, the data filling is not expected to have a large impact on the long-term simulation results. The hydrologists of the SJRWMD are currently working on the adjustment of the LISBON pan evaporation data (D. Clapp of SJRWMD, personal communication, 2006). Once the adjustment is completed, the adjusted LISBON pan evaporation data will be used for the Lake Jesup watershed HSPF model.

Recommendation no. 3. Defend the pan coefficient.

An annual pan coefficient of 0.9 was used in this study. Although this coefficient is higher than the values in Keesecker (1992) and Phelps and German (1996), it is considered to be appropriate because the recent pan evaporation data at LISBON, especially those after the year of 2000, seem to be lower than their historical values (D. Clapp of SJRWMD, personal communication, 2004). The estimated average potential evapotranspiration using the pan coefficient of 0.9 is 47.5 in/yr over the period from 10/1997 to 09/2003. This estimate is close to the estimated average evapotranspiration rate of 46 – 47 in/yr for the study area by Tibbals (1990).

The hydrologists of the SJRWMD are currently working on the adjustment of the LISBON pan evaporation data to correct the low readings in recent years (D. Clapp of SJRWMD, personal communication, 2006). Once the adjustment is completed, the adjusted LISBON pan evaporation data will be used for the Lake Jesup watershed HSPF model. A pan coefficient similar to those in Keesecker (1992) and Phelps and German

(1996) is likely to be used for the adjusted LISBON data in order to generate reasonable estimates of the potential evapotranspiration in the Lake Jesup watershed.

The above discussion about the pan coefficient is now added to section 2.4 (page 16, the second paragraph).

Recommendation no. 4. Perform thorough review of the basin boundaries, ground truth if necessary.

The subwatershed boundaries used in this study were obtained from the SJRWMD. During this study, district staff had conducted several ground truth visits to the study area to confirm the accuracy of the delineated subwatershed boundaries.

Recommendation no. 5. Correct deficiencies in the lake and wetland TAET using the PERLND.

The issue for the reviewer is the simulated total evaporation/evapotranspiration (ET) from water and wetland PERLND segments in the dry season (see page 13 in the reviewer's report). The total ET loss from lakes and wetlands during the dry season is likely greater than their total rainfall input. This high ET loss rate is sustained by groundwater outflows from aquifer systems to lakes and wetlands. The HSPF model simulates hydrologic processes in each PERLND segment independently, without interactions with other land segments and aquifer systems. Therefore, by not simulating the groundwater input to water and wetland PERLND segments, the HSPF model tends to under-predict the ET loss from wetland and water segments in the dry season. So I agree with the reviewer on the difficulties for water and wetland PERLND segments to maintain high ET rates through the dry season.

However, HSPF simulates the baseflow ET loss from PERLND segments. The baseflow ET loss typically accounts for the ET from riparian vegetation as baseflow enters the stream network. In this study, the baseflow ET loss could be generalized to include the ET loss from wetland vegetation and lake surface as baseflow from upland land segments passes through wetlands and lakes to the stream network. A BASET (parameter controlling the baseflow ET loss) value of 0.3 was used for all PERLND segments in the HSPF model to generate significant baseflow ET loss. The underestimation of ET loss from wetland and water PERLND segments during the dry season is compensated by the simulated baseflow ET loss from other land segments. This implicit approach provides a reasonable simplification for the complex hydrologic processes at wetlands and lakes and gives an adequate estimation for the water and wetland ET loss at subwatershed scales.

Recommendation no. 6. Utilize the PERLND reaches for storage attenuation by routing basin runoff to those reaches.

The Lake Jesup watershed is characterized in HSPF by various land segments (PERLND and IMPLND) and reach segments (RCHRES). The reach segments represent the stream network in the study area, including major streams and lakes. The land segments represent various drainage areas of the stream network, including urban areas, agriculture areas, forest areas, wetlands (wetland PERLND) and small lakes (water PERLND). The hydrologic processes in each land segment are simulated independently, without interactions with other land segments. The flow pathways from one land segment to other land segments are not explicitly simulated, and the runoff from a land segment drains directly to a reach segment.

I think the above formulation of the land and reach segments is appropriate for this study. This formulation provides a conceptual simplification of the complex hydrologic processes and captures major physical and hydrologic characteristics in the watershed. The simulation results show the HSPF model can adequately reproduce the observed water quantity and quality data across the Lake Jesup watershed, indicating the implicit simulation of the storage effects of wetlands and small lakes does not significantly affect the simulation of major hydrologic and water quality processes at watershed and subwatershed scales. The suggested approach would significantly complicate the modeling process and may not add to the accuracy of the model simulation. Suitable information for implementing the suggested approach, such as hydraulic characteristics and geometry data for the wetlands and small lakes in the study area, may not be readily available.

Recommendation no. 7. Minimize the area fluctuations present in the reach F-Tables.

The water areas were represented as various reach segments (stream RCHRES, lake RCHRES, dry pond RCHRES, wet pond RCHRES) and land segments (water PERLND) in the Lake Jesup watershed HSPF model. Stream RCHRES segments and lake RCHRES segments represent major streams and lakes in the watershed. Dry pond RCHRES segments and wet pond RCHRES segments provide generalized representations of various dry detention ponds and wet detention ponds at subwatershed levels. The remaining water areas, typically small lakes, in the watershed were represented as water PERLND segments in the HSPF model.

The drainage area to a RCHRES segment varies constantly with the change of RCHRES surface area. The HSPF model, however, does not explicitly simulate the variation of the drainage area. The acreages of various land segments, except for water PERLND, draining to a reach segment were determined based on the land use map and were treated as fixed values in the HSPF model. The acreage of water PERLND was determined by subtracting the simulated mean surface areas of reach segments from the total water area determined from the land use map. This ensures the averaged water surface area in the HSPF model equals to the water area calculated from the land use map. Because the water body in the watershed represented by a RCHRES segment is generally well defined, the variation of its drainage area resulting from the variation of its surface area is generally vary small compared to the total drainage area. Therefore, the above approach to specify land segment areas in the HSPF model should adequately represent the drainage area to a reach segment.

Recommendation no. 8. Add regional groundwater discharge to the appropriate ungaged basins. A groundwater study would be necessary to better estimate the discharge quantities and temporal variation.

Because groundwater basin boundaries may not coincide with boundaries for surface water basins, there could be substantial regional groundwater flow across surface water basin boundaries. However, the regional groundwater discharge does not appear to be of great significance in this watershed because the HSPF model adequately reproduces the observed water quantity and quality data across the Lake Jesup watershed despite neglecting to simulate the regional groundwater discharge. The regional groundwater issue could be further investigated. As I suggested for the future investigations (section 5, page 70), further investigations on the interaction between groundwater and surface water in the Lake Jesup watershed would be helpful to assess whether the current formulation of HSPF can adequately represent the groundwater processes in the study area.

Recommendation no. 9. Perform baseflow separation and plot the baseflow contributions from the reaches. The baseflow contribution should be smooth and defensible. The fluxes should be supported by baseflow separation of the observed streamflow.

Many large lakes exist upstream of the streamflow gauging sites in the Lake Jesup watershed. These lakes slowly release surface runoff after storm events, affecting the baseflow estimates from a baseflow separation analysis. The average baseflow at Howell Creek Slavia site estimated by the reviewer using a baseflow separation technique is 2.92 inches, which is higher than the HSPF simulated baseflow of 2.28 inches (see page 23 in reviewer's report). This overestimation of baseflow likely results from the storage effects of upstream lakes.

A variety of techniques have been used in this study to evaluate the simulated baseflow components. They include the evaluation of low-flow recession rates, graphic comparison of flows and stages, and flow duration analysis. The modeling results show that the HSPF model provides reasonable simulations during the baseflow conditions.