Appendix A
HSPF Watershed Model

Preliminary Draft
Lake Thunderbird TMDL Report

Prepared for
Oklahoma Department of Environmental Quality
Water Quality Division

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By
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PLEASE NOTE !

THIS IS A PRELIMINARY DRAFT DOCUMENT THAT HAS BEEN SUBMITTED TO EPA FOR TECHNICAL REVIEW ONLY. IT IS NOT THE DRAFT TMDL THAT WILL BE PROPOSED FOR ADOPTION. CHANGES WILL BE MADE AFTER THE EPA REVIEW. IN THE INTEREST OF FULL TRANSPARENCY, IT IS BEING RELEASED FOR INTERESTED PARTIES TO READ. DEQ IS NOT ACCEPTING COMMENTS ON THIS DOCUMENT AND WILL NOT RESPOND TO QUESTIONS REGARDING ITS CONTENTS. FOLLOWING EPA CONCURRENCE, DEQ WILL RELEASE A REVISED DRAFT TMDL FOR A FULL PUBLIC REVIEW AND COMMENT PROCESS.

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Appendix A - HSPF Watershed Model

A.1 Overview of HSPF model

The Hydrological Simulation Program FORTRAN (HSPF), supported by EPA and the USGS as a public domain model (Bicknell et al., 2001), is a lumped parameter watershed runoff model that simulates watershed hydrology and non-point source pollutant loadings for organic matter, nutrients, sediments, bacteria and toxic chemicals within a watershed network of delineated sub-basins. The internal stream model routes flow and water quality constituents through a network of river reaches for each sub-basin of the watershed. The HSPF hydrologic sub-model provides for simulation of water balances in each sub-basin based on precipitation, evaporation, water withdrawals, irrigation, diversions, wastewater discharges, infiltration, and active and deep groundwater reservoirs. Empirical model parameters are assigned for each sub-basin land use through model calibration to simulate the water balance and pollutant loading from a sub-basin. HSPF is designed as a time variable model with results generated on an hourly or daily basis. Hundreds of applications of HSPF over the past two decades have included short-term storm events and/or continuous simulations over annual and decadal cycles. BMP alternatives designed to reduce pollutant loads to receiving waters can be represented in HSPF by adjustments of land use-based yield coefficients for a pollutant. Windows-based user-friendly GUI software tools such as WinHSPF (Duda et al., 2001), GenScn (Kittle et al., 1998) and HSPFParm (Donigian et al., 1999) have been developed to facilitate pre- and post-processing tasks for HSPF. Time series results for streamflow and pollutant loads generated by HSPF have been linked for input to hydrodynamic (e.g., EFDC) and water quality models (e.g., EFDC, WASP7) in numerous applications over the past decade. HSPF is considered a Level 3 Complex or Advanced Model. The URL for HSPF is http://www.epa.gov/ceampubl/swater/hspf/index.htm.

A.2 Model Setup and Data Sources

A.2.1 Model domain for watershed representation

Lake Thunderbird watershed model domain was developed based on the stream network in the watershed as described by USGS's NHD database and flow path calculations based on the USGS's 10-m Digital Elevation Model (DEM) dataset. The total watershed drainage area to the lake is 256 square miles.

A.2.2 Model discretization sub-watersheds

For a better representation of spatial variations of land use/cover, precipitation, soil type and topography, the lake watershed model was disaggregated into 66 subwatersheds/stream reaches, as shown in Figure A-1, based on the stream network in the watershed as described by USGS's NHD database and flow path calculations based on the DEM dataset. These subwatersheds were further grouped into six (6) groups and each group was assigned to one (1) weather station or rainfall gage. All other meteorological data (e.g., air temperature and solar radiation) as reported by the Oklahoma MESONET station at the Westheimer Airport just outside the watershed in Norman were shared by all the subwatersheds.

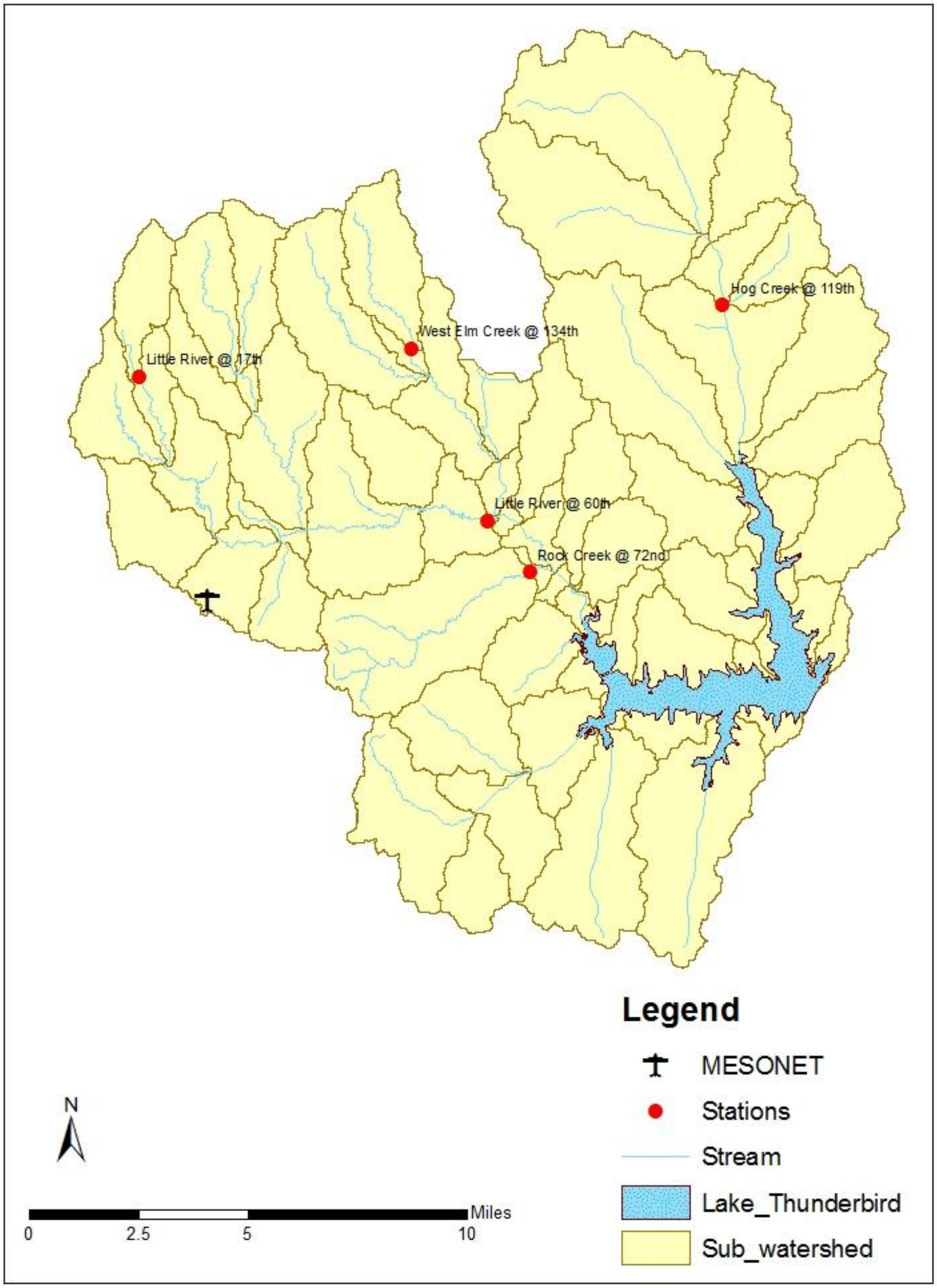

Figure A-1 Subwatershed and Stream Network

A.2.3 Land use data

During the watershed model setup, the NLCD 2006 land use/cover for the lake watershed was not available. Therefore, the NLCD 2001 land use/cover was used. However, more recent land use/cover was desirable because years 2008 and 2009 were selected for the watershed model calibration years. A comparison of the land use/cover change between 2006 and 2001 was made when the NLCD 2006 land use/cover data (Fry et al., 2011) became available later, as summarized in Table A.1. It was found that very minor land use/cover was changed between 2006 and 2001. Less than 1.4% of the total land use/cover was changed to the Developed Land Use (Open Space, Low Intensity, Medium Intensity, and High Intensity) from other types of land use/cover from 2001 to 2006. Therefore, using 2001 land use/cover data for the watershed model was considered to be appropriate.

Table A-1 Comparison of the land use/cover change between 2006 and 2001

Land Use Category	2001 Land Use	2006 Land Use	Difference (2006 - 2001)
Open Water	4.37%	3.48%	-0.89%
Developed, Open Space	9.17%	10.18%	1.01%
Developed, Low Intensity	4.34%	4.56%	0.23%
Developed, Medium Intensity	2.01%	2.15%	0.14%
Developed, High Intensity	0.43%	0.44%	0.01%
Barren Land, Rock, Sand, Clay	0.02%	0.06%	0.05%
Deciduous Forest	35.28%	35.08%	-0.21%
Evergreen Forest	0.23%	0.23%	-0.01%
Grassland, Herbaceous	38.52%	38.06%	-0.46%
Pasture, Hay	3.48%	3.43%	-0.05%
Cultivated Crops	2.15%	2.29%	0.14%
Emergent Herbaceous Wetlands	0.01%	0.05%	0.04%
Total	100.00%	100.00%	0.00%

In the Lake Thunderbird watershed model, the land use/cover was regrouped into twelve (12) land use categories, that is, Water, Bermuda grass/roadways, Deciduous Forest, Range Land, Urban Medium Density, Pasture, Agriculture, Wetland, Urban High Density, Evergreen Forest, Urban Commercial, and Urban Low Density

A.2.4 Meteorological forcing data

Precipitation data were obtained from five (5) OCC (the Oklahoma Conservation Commission) rain gages and one (1) MESONET station at the Westheimer Airport just outside the watershed in Norman. All other meteorological data (e.g., air temperature and solar radiation) were obtained from the MESONET station at the Westheimer Airport.

Meteorological data were either aggregated/averaged or disintegrated into hourly values if the raw station data were with a time step smaller or larger than one hour, respectively. Data gaps in the raw station data were filled by using data from the nearby station or by linear interpretation. All time marks for timed model input data and monitoring data were converted to Central Daylight Saving Time (CDT). The HSPF timer was also set based on the CDT.

A.3 HSPF Model Calibration

Computer water quality models are simplified representation of the physical world. In addition, observed data from monitoring have inherent errors from the sample collection process, equipment used, and lab analysis procedures. As a result, models, even after calibration, do not produce results that match exactly with observed data. To judge if a model performs as designed and simulates pollutant loads with a reasonable accuracy, graphic comparison and statistical analysis are conducted to evaluate model performance. In this study, observed stream discharge and water quality parameters were plotted on the same graphs with model simulated time series of these same parameters. Visual inspections were made to compare the observed and simulated data. Three statistics, percent difference of average values (% error), correlation coefficient (r2), and Nash-Sutcliffe coefficient (N-S), were calculated to evaluate how well model simulation matched observed data. The targets for all parameters except TSS for the three statistics are ±20%, 0.5, and 0.5, respectively. For TSS, the targets for the three statistics are ±50%, 0.5, and 0.5, respectively. Among the three statistics, % error was targeted as a necessary condition for a calibrated model for all parameters and monitoring sites. The other two statistics were targeted but not used as rigid criteria for rejection or acceptance of model calibration and results.

As Figure A-2 shows, among the five monitoring sites the Little River at 60th Ave site (the L60 site) has the largest drainage area (21% of the entire watershed) and most diverse landuse types. Therefore, during the calibration process, the L60 site carried the most weight in determining the end point of calibration for all water quality parameters.

A.3.1 Model simulation period

Development and calibration of the HSPF watershed model requires a host of site specific data. In addition to obtaining available data from various national data sources, an intensive one-year stream monitoring was conducted by the Oklahoma Conservation Commission (OCC) with support from DEQ from April 2008 to April 2009. Five monitoring stations were set up in the lake watershed on major tributaries with programmable automatic samplers (autosamplers) and rain gages (Figure A.2). Data obtained from these stations provided the basis for the model calibration.

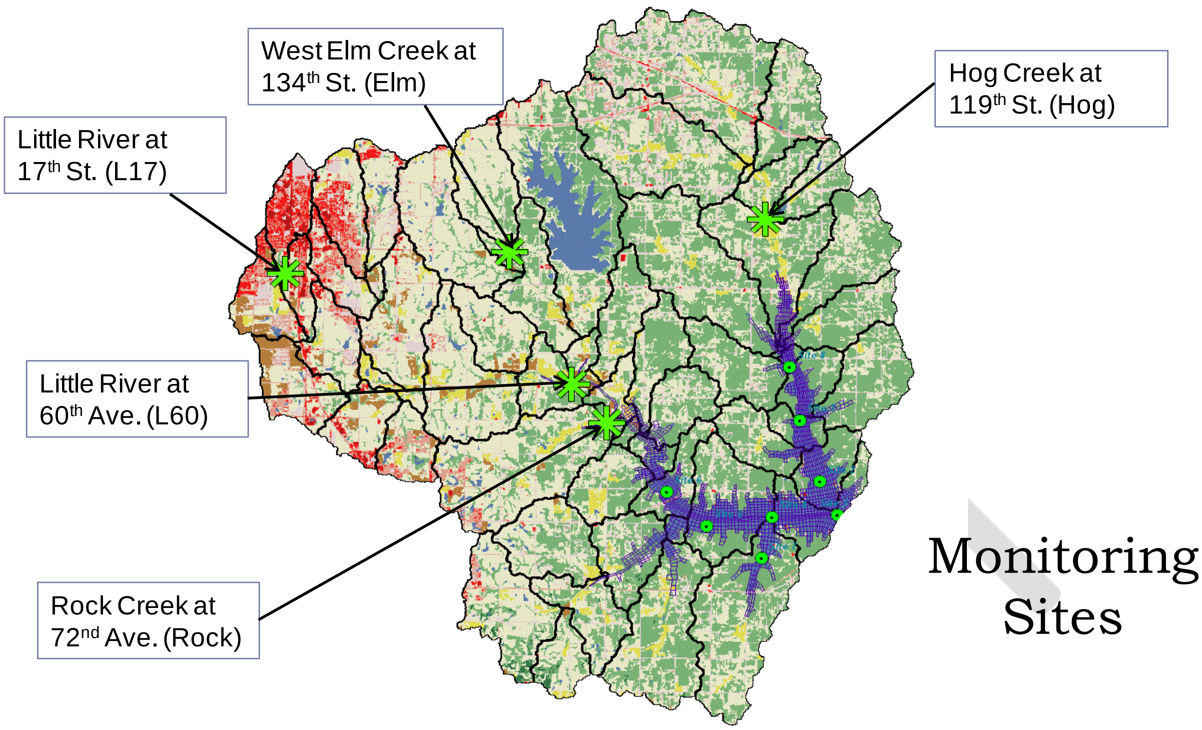

Figure A-2. Stream monitoring sites for the HSPF calibration (green dots are the monitoring sites for lake water quality by OWRB)

Ideally, multiple year flow and water quality datasets collected at several key locations throughout a watershed are needed to calibrate and validate a watershed loading model such as HSPF model such that the calibrated watershed model is robust enough to be able to reproduce different wet, dry and average weather conditions reasonably well. However, for this study, because of data limitation, April 17, 2008 – April 26, 2009 where necessary data for model building and calibration is available was selected for the watershed model calibration period and no validation was conducted.

According to the annual precipitation analysis based on data from the MESONET Norman stations, 2008 and 2009, where the calibration period lies, the watershed area had annual precipitation of 36.0 and 35.7 inches, respectively. These annual amounts are very close to the 30-year normal of 37.4 inches for the area. This suggests that in the calibration period the pollutant loadings from the watershed can be considered "average". Therefore, loadings simulated by the HSPF model in the same period were used in this study for the lake model to calculate average load reduction needs for the watershed.

A.3.2 Streamflow

Five monitoring stations, as shown in Figure A.2, were set up in the lake watershed on major tributaries with programmable automatic samplers (autosamplers) by OCC. Due to various reasons, such as vandalism, equipment breakdowns and malfunctions, and extreme flows, autosamplers and the attached depth loggers at all five stations were not functioning for at one time or another during the one-year monitoring period. In addition, some of the stations did not start operation until several months into the monitoring period. As a result, data gaps exist to various degrees at all five stations.

Stream discharge rating curves based on water depth were initially developed for the monitoring stations using stream survey data, limited number of discharge measurements, and Manning's equation. As more stream discharge measurements with a wider range of discharge rates became available well into the monitoring period, the rating curves were refined and updated. They were finalized after the monitoring work was completed and the discharge record was revised retrospectively. This affected the flow-weighted sampling for total phosphorus (TP) and total Kjeldahl nitrogen (TKN) as they required accurate discharge rate for correct flow weighting. The model calibration process accounted for this inconsistency by simulating water depth at the monitoring sites and using the initial rating curves to simulate the concentrations of TP and TKN of the flow-weighted composite samples.

Discharge by the stream, or flow volume in the stream, resulting from the hydrologic processes in the watershed, is the foundation of a watershed water quality model. Much effort was devoted to this part of the model calibration in this study. Figures A.3 to A.6 show the hourly stream discharge simulated by the HSPF model at the five monitoring stations in the watershed. Discharge rates derived from water depth measurements taken by the autosamplers are also shown on the plots (blue asterisks). Different from traditional stream gages, depth measurements by the autosamplers were not made on a pre-set equal time step. Instead, they were made based on equal passing-through discharge at the gage in the stream channel to accommodate the flow weighted sampling of TP and TKN. As a result, direct comparison between measured and simulate stream discharges were not possible. Instead, daily average discharges calculated from the hourly model simulation were compared to daily average discharges calculated from the autosampler measurements for model calibration. Statistics for comparing the observed data and the model simulation were calculated as shown in Table A.2.

Data gaps exist in all 5 monitoring sites for depth measurements due to the occasional failures of the autosamplers. Therefore, a direct calculation of the measured total discharge at each of the five monitoring sites and the entire watershed during the calibration period was not possible.

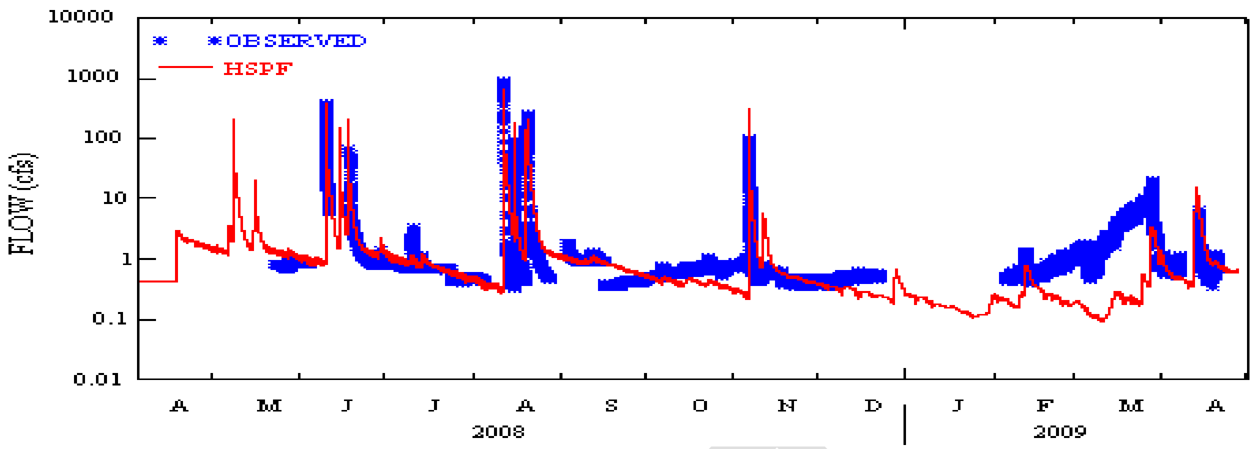

Figure A-3 West Elm Creek (Elm) site stream discharge plot

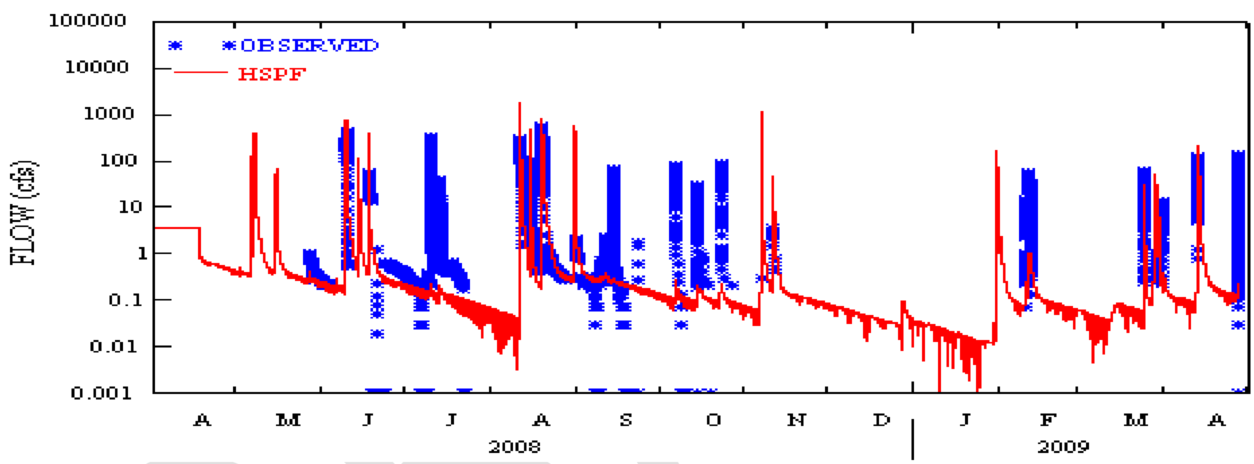

Figure A-4 Little River at 17th St. (L17) site stream discharge plot

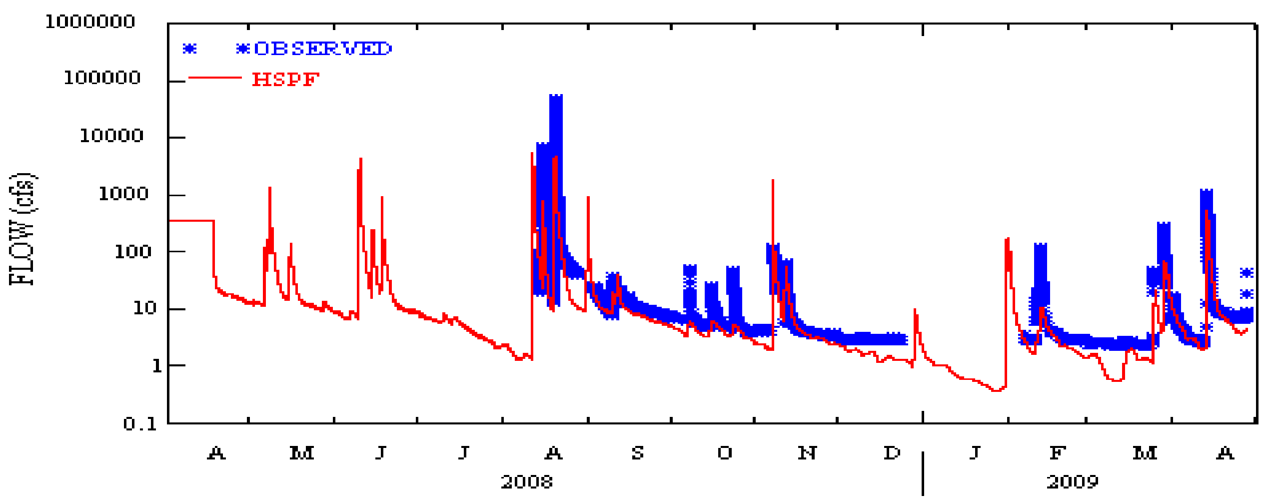

Figure A-5 Little River at 60th Ave. (L60) site stream discharge (Log scale)

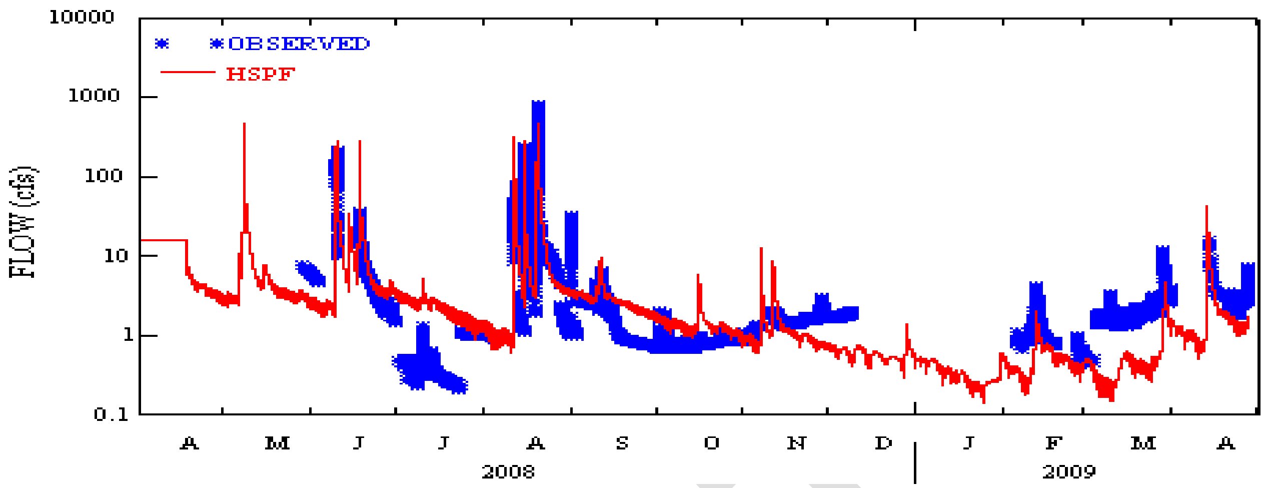

Figure A-6 Rock Creek at 72th Ave. (Rock) site stream discharge (Log scale) plot

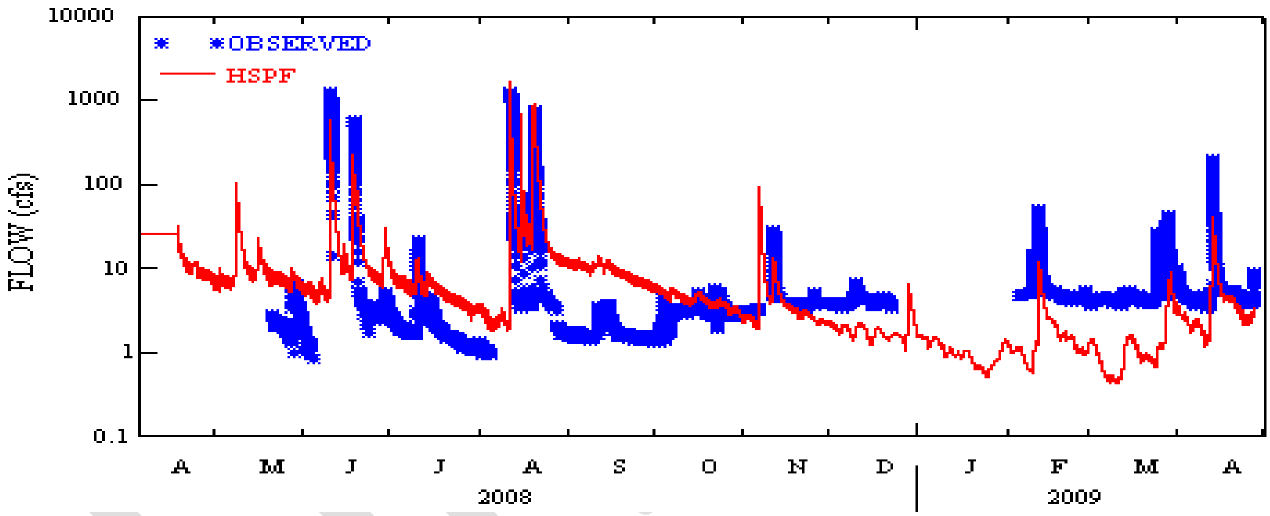

Figure A-7 Hog Creek at 119th St. (Hog) site stream discharge plot (Log scale) plot

Table A-2 Daily flow statistics of the HSPF model simulation

Sites	Daily Average (observed, cfs) *	Daily Average (HSPF, cfs) #	% difference	r^2	Nash-Sutcliffe coefficient
L17	7.6	6.2	-18%	0.92	0.66
Elm	2.3	2.4	+4%	0.90	0.89
L60	9.6	11.0	+15%	0.66	0.63
Rock	3.6	3.5	-3%	0.78	0.78
Hog	13.2	15.3	+16%	0.60	0.56

* Obs. data not available all the time; #simulated data corresponding to obs.

Finally, as an overall check of the model, the total discharge (in million cubic feet) from the watershed into the lake (lake inflow) simulated by the model for the entire calibration period was compared to those calculated by the Army Corps of Engineers (ACOE) and COMCD. The ACOE and COMCD's calculations are based on a mass balance of the lake storage:

Lake inflow = lake volume change + outflow + evaporation + withdrawal

The methods of the ACOE and COMCD differ in their treatment of evaporation estimation and the accounting of the water withdrawal for municipal uses. The total inflow simulated by the HSPF model was 77,200 million cubic feet over the period, comparing to 80,100 and 70,400 million cubic feet from ACOE and COMCD, respectively.

The key HSPF parameters in stream discharge calibration were: MFACT, LZSN, LZETP, INFILT, AGWRC, UZSN, INTFW, IRC, and RETSC.

A.3.3 Water temperature

Water temperature in the stream is influenced by air temperature, available solar radiation, shading by riparian vegetation, the temperature of runoff and groundwater input to the stream, and the heat exchange between the flowing water and stream bed. It is an important indication of the model's ability in correctly accounting for all the watershed conditions mentioned above. In addition, water temperature of the flow into the lake from the lake tributaries direct affect the lake thermal regime, especially during high flow events, leading to changes of the nutrient balances in the lake and in turn, algal growth.

Water temperature calibration was based on the instantaneous field measurements of the stream water temperature at the monitoring stations during the weekly sample collection trip. HSPF simulated water temperature values at the hour nearest to the sampling time were extracted for the statistical calculations. As shown in Table A.3 and Figure A.8, the model did an excellent job in simulating water temperature, including the diurnal fluctuation. This is the result of the well calibrated stream discharge and the fact that heat exchange between water and the environment is determined mostly by physically based processes where parameters such as water heat capacity have mostly been well documented or measured in the literature.

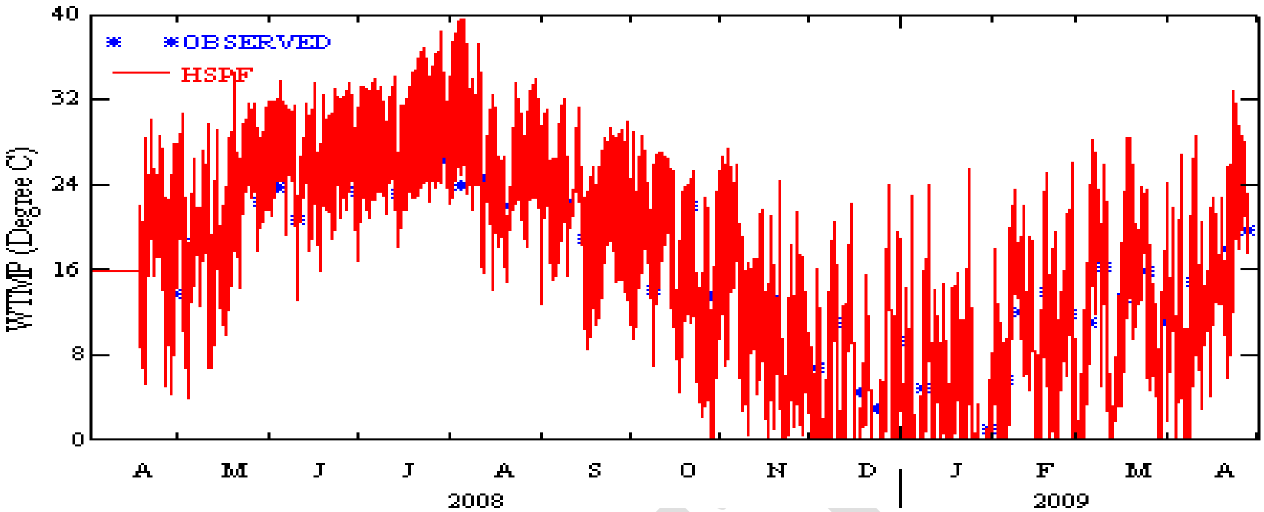

Figure A-8 Little River at 17th St. (L17) site water temperature plot.

Table A-3 Instantaneous sample statistics of the HSPF model simulation for water temperature

Sites	Sample average (°C)	HSPF average (°C)	% difference	r^2	Nash-Sutcliffe coefficient
L17	16.3	16.3	0%	0.72	0.71
Elm	13.7	13.6	-1%	0.94	0.93
L60	13.8	13.6	-1%	0.95	0.92
Rock	17.0	16.2	-11%	0.90	0.88
Hog	14.4	14.5	+1%	0.94	0.94

The key HSPF parameters in water temperature calibration were CFSAEX and LGPT1.

A.3.4 Total suspended sediment (TSS)

TSS calibration was based on the lab measurements of the grab samples taken at the monitoring stations during the weekly sample collection trip. HSPF simulated TSS at the hour nearest to the sampling time were extracted for the statistical calculations. Because the weekly trips were made on a schedule that did not take into account flow conditions, most TSS samples were taken under low flow conditions with a few under medium flow conditions. As TSS is highly dependent on flow conditions, high TSS levels were not captured by the grab samples. This data limitation also applies to monitoring data of other water quality parameters based on grab samples, namely, dissolved phosphate (PO4), total organic carbon (TOC), Nitrate (NO3), and ammonium (NH4).

Figures A.9 to A.11 show the observed TSS plotted along with simulated hourly levels at three monitoring sites. It should be noted that the detection limit for TSS is 10 mg/L and many of the observed TSS were below this detection limit. Overall, the model very well captured the rise and fall of the TSS in the streams. Table A.4 indicates that the TSS calibration at all five sites met the % error criterion while deviating from the r2 criterion at four sites and did not meet the N-S target in any of these sites.

Historical data and regular field observations indicate that streambank erosion is a major source of sediment in the streams of the watershed. Although HSPF simulates stream bed erosion with a simple sheer stress based algorithm, the model does not fully account for factors such as localized differences in water and sediment supply to stream and bank stability as influenced by soil property and riparian vegetation.

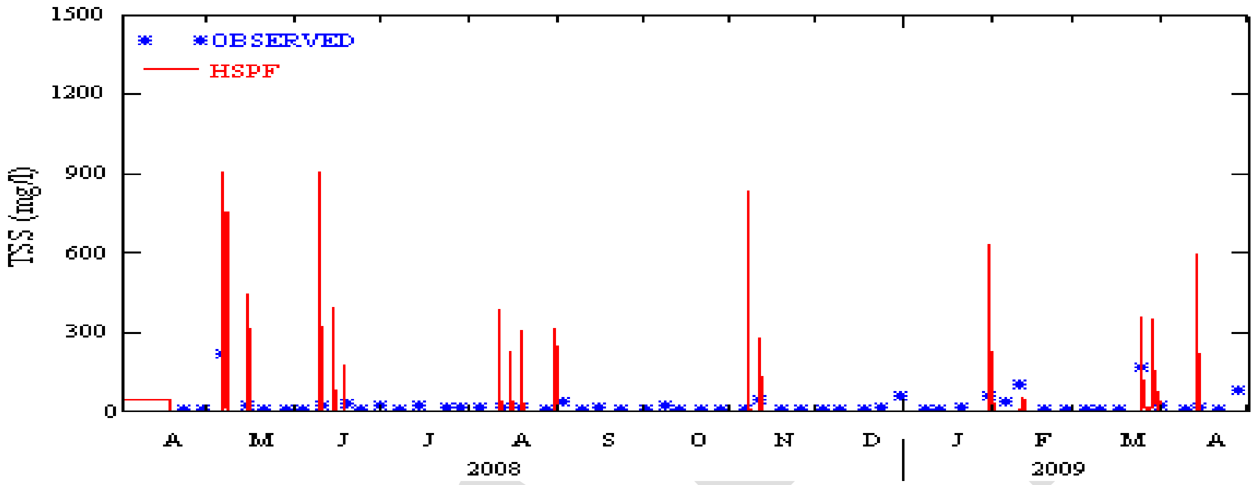

Figure A-9 Little River at 17th St. (L17) site total suspended sediment plot.

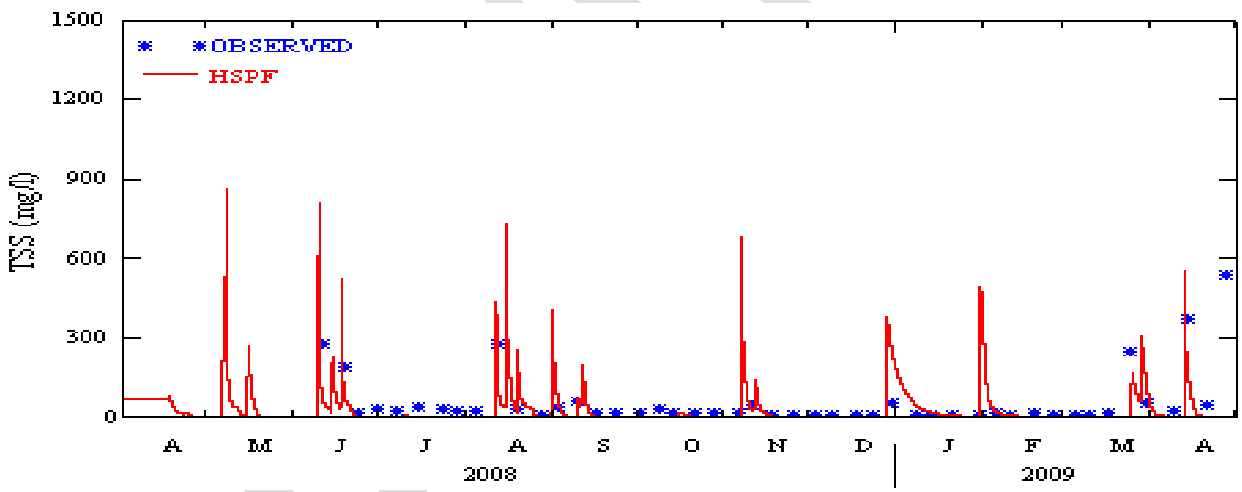

Figure A-10 Little River at 60th Ave. (L60) site total suspended sediment plot.

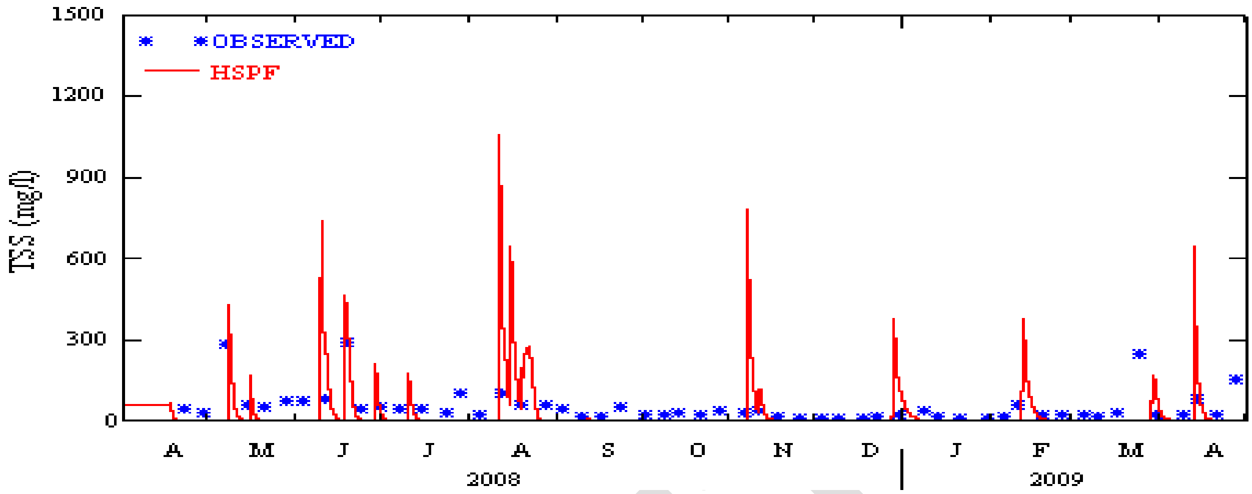

Figure A-11 Hog Creek at 119th St. (Hog) site total suspended sediment plot.

Table A-4 Grab sample statistics of the HSPF model simulation for TSS

Sites	Grabs ample average* (mg/L)	HSPF average (mg/L)	% difference	r^2	Nash-Sutcliffe coefficient
L17	19.0	20.7	8.9%	0.63	-0.56
Elm	7.2	9.8	29.3%	0.47	-0.65
L60	45.6	25.2	-44.7%	0.46	0.4
Rock	20.7	26.9	28.7%	0.40	-0.48
Hog	47.8	32.2	-32.6%	0.21	-0.98

* Samples below the 10 mg/L detection limit were assigned a value of 5 mg/L.

The key HSPF parameters in TSS calibration were COVER, AFFIX, KRER, KSER, KGER, KEIM, ACCSDP and REMSDP for sediment production; and TAUCD and TAUCS for sediment in-stream transport.

A.3.5 Dissolved Oxygen

Similar to water temperature, DO calibration was based on the instantaneous field measurements of the stream DO at the monitoring stations during the weekly sample collection trip. Dissolved oxygen level in streams is a function of flow rate, air and water temperatures, oxygen demand material (BOD) and algal activities in the water. While HSPF simulated all these factors in this study, it should be noted that no field measurements were available to calibrate BOD and algae abundance levels in streams in the lake watershed. Only default or assumed model parameter values were used. Nevertheless, model simulation of DO at all five sites met all three the statistical targets except N-S at the in Rock Creek site (Table A.5). Figure A.12, as a representative to all sites, shows that the simulation mirrored well the field measurements except during the winter months of December and January. The DO supersaturation in those month indicated by the field measurements suggests algal growth that was not captured by the model.

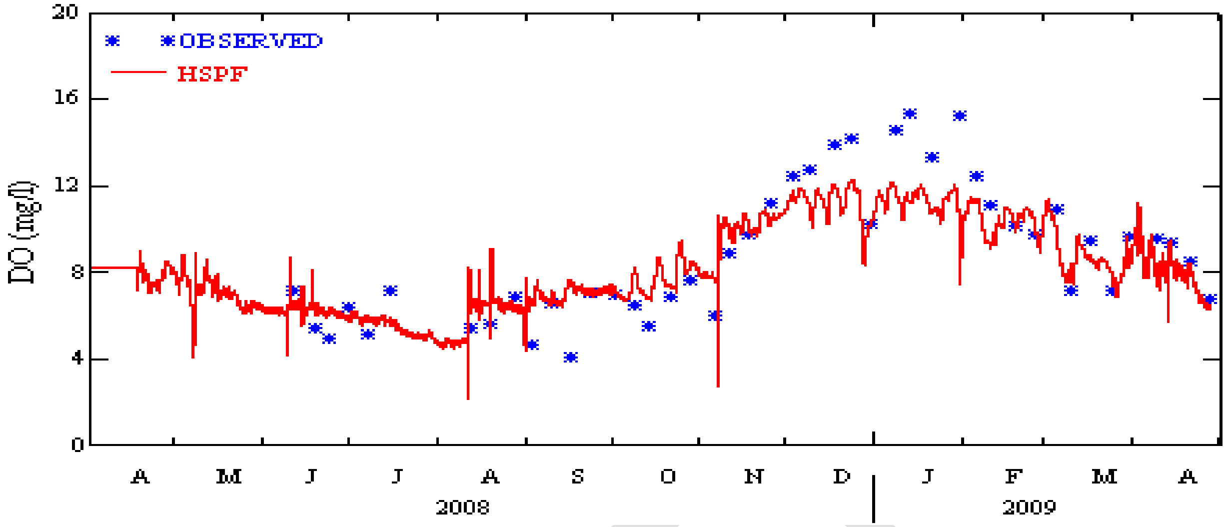

Figure A-12 Little River at 60th Ave. (L60) site DO plot.

Table A-5 Instantaneous sample statistics of the HSPF model simulation for DO

Sites	Sample average (mg/L)	HSPF average (mg/L)	% difference	r^2	Nash-Sutcliffe coefficient
L17	8.5	8.0	-6.2%	0.71	0.71
Elm	8.6	8.4	-3.1%	0.79	0.77
L60	8.6	8.5	-0.1%	0.86	0.77
Rock	7.3	8.5	+16.5%	0.55	0.25
Hog	8.9	8.7	-2.6%	0.84	0.80

The key HSPF parameters in DO calibration were POTFW, IFLW-CONC, GRND-CONC, ACQOP, and SQOLIM for BOD; and IFWDOX, GRNDDOX, KBOD20, and BENOD for in-stream DO processes.

A.3.6 Organic Carbon

Similar to TSS, calibration for total organic carbon (TOC) was based on grab sample data that represented mostly low and medium flow conditions. Figure A.13 shows that the model gave close simulation of the measured data in the stream for the L60 site. Calibration statistics for TOC were not used as targets for calibration.

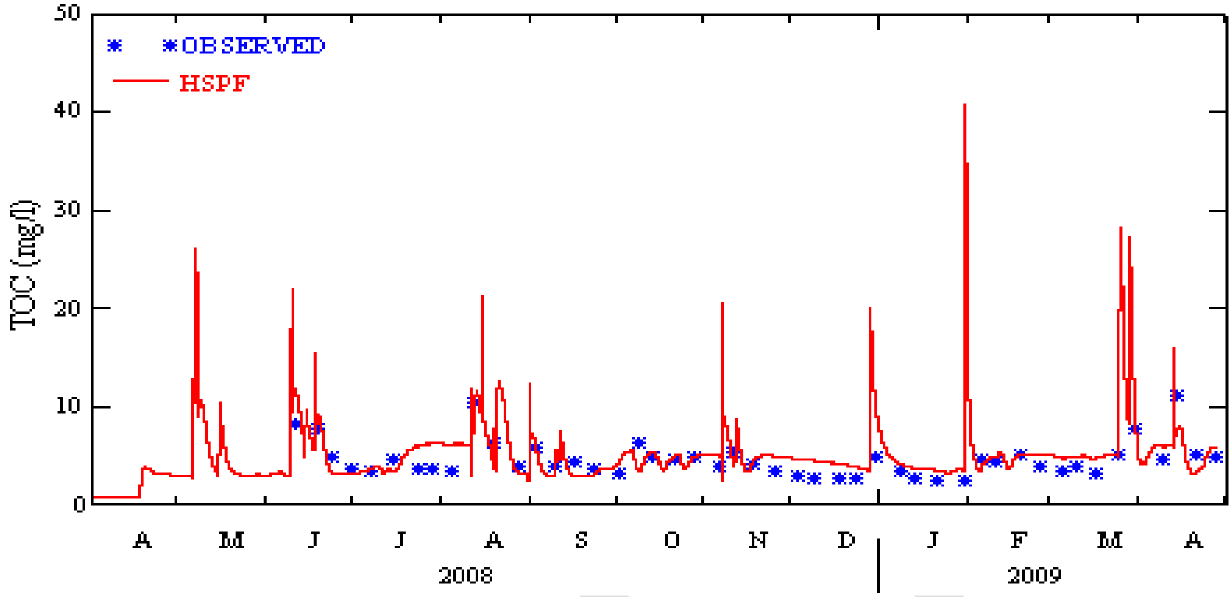

Figure A-13 Little River at 60th Ave. (L60) site TOC plot

A.3.7 Phosphorus

Total phosphorus (TP) and Total Kjeldahl nitrogen (TKN) monitoring was conducted using the autosamplers programmed to take equal amount (15 mL) of water samples each time a preset amount of discharge passing through the stream. These aliquots of water samples were composited and preserved with sulfuric acid for about one week before sent to the lab for analysis. These essentially discharge-weighted measurements of TP and TKN concentration gave a better indication of TP and TKN loadings from the watershed than grab samples that often miss high discharge events. However, the success of discharge-weighted water sampling is highly dependent on the accuracy of stream discharge measurements and hence the discharge rating curve used to translate stream depth measurements to discharge rates.

It should be noted here that the rating curves used to calculate stream discharges from depth measurements were not fully established until the data collection phase was completed. Flow conditions in the streams at the initial stage of the project limited the discharge measurements to low and medium levels. Consequently rating curves based on these discharge measurements and used in the first several sampling events were not suitable for high discharge conditions. The rating curves were updated later when higher discharge measurements became available. Nevertheless, equipment limitation and field conditions prevented the measurement of peak discharges. Eventually rating curves that accounted for high to extremely high discharges were developed using both discharge measurements and the Manning's equation with assumed roughness coefficients. The result of the continuous revision of the rating curves was that the discharge-weighted sampling of TP and TKN was not executed as designed.

Nevertheless, data collected from the TP and TKN sampling still served their purpose of capturing the fluctuation of TP and TKN levels in the streams under all discharge conditions and providing this information for model calibration of TP and TKN loadings from the watershed. To accomplish this, water depth as simulated by HSPF at each monitoring site was extracted from model runs and the rating curves used at the time corresponding to each simulated depth were used to calculate the discharge. Next, simulated TP or TKN concentrations were extracted from the model runs. Then a discharge weighted TP or TKN concentration was calculated using those modeled discharge and concentrations. In essence, model data in conjunction with the rating curves used at the time of sampling were used to simulate the TP or TKN levels in the samples collected.

Table A.6 shows the results of the TP calibration as described above. All three statistical criteria were met for the West Elm Creek (Elm) site. The Elm site drainage is dominated by the landuse type of rangeland (74%), which also the most common landuse type (38%) for the entire lake watershed. The L60 site drains the most area among the five sites and has the most diverse landuse types. The % error criterion was met at four sites but failed at L60 site. The Little River at 17th Ave (L17) and the Rock Creek (Rock) sites did not meet the r2 or the N-S criteria.

Table A-6 Composite (discharge weighted) sample statistics of the HSPF model simulation for TP

Sites	Sample average (mg/L)	HSPF average (mg/L)	% difference	r^2	Nash-Sutcliffe coefficient
L17	0.215	0.25	5.5%	0.0	-1.54
Elm	0.074	0.074	0.3%	0.85	0.84
L60	0.247	0.151	-38.7%	0.52	0.37
Rock	0.235	0.195	-17.1%	0.10	-0.25
Hog	0.170	0.156	-8.3%	0.52	0.34

PO4 data was also available for calibration. Similar to TSS, calibration for PO4 was based on grab sample data that represented mostly low and medium flow conditions. In addition, observed PO4 concentrations were often below its detection limit, which made point to point comparison of model-data difficult.

Figure A.14 shows that the model gave close simulation of the measured data in the stream for the L60 site. Calibration statistics of PO4 were not used as targets for calibration.

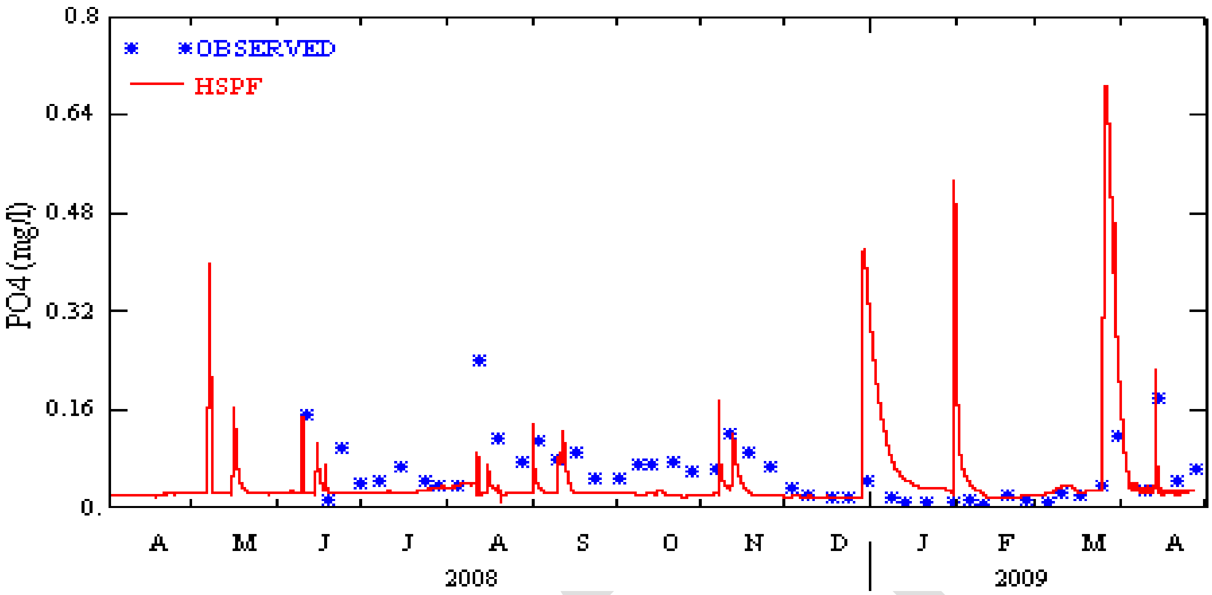

Figure A-14 Little River at 60th Ave. (L60) site PO_4 plot

A.3.8 Nitrogen

Total Kjeldahl nitrogen (TKN) data were available for calibration. The TKN was calibrated the same way as TP and had very similar calibration results at the monitoring sites (Table A.7). The Elm and L60 sites had excellent statistics for all three criteria while the L17 and Rock sites did not meet the r2 or the N-S criteria.

Table A-7 Composite (discharge weighted) sample statistics of the HSPF model simulation for TKN

Sites	Sample average (mg/L)	HSPF average (mg/L)	% difference	r^2	Nash-Sutcliffe coefficient
L17	1.35	1.56	9.1%	0.09	-1.56
Elm	0.51	0.52	1.6%	0.79	0.78
L60	1.33	1.11	-16.6%	0.67	0.59
Rock	1.14	1.03	-10.1%	0.19	-0.08
Hog	1.11	0.91	-17.7%	0.65	0.47

NO3 data was also available for calibration. Similar to TSS, calibration for NO3 was based on grab sample data that represented mostly low and medium flow conditions. In addition, observed NO3 concentrations were often below its detection limit, which made point to point comparison of model-data difficult.

Figure A.15 shows that the model gave close simulation of the measured data in the stream for the L60 site for NO3. Calibration statistics of NO3 were not used as targets for calibration.

Sample data for NH4 were mostly below detection limit of 0.1 mg/L. Out of the over 250 samples collected, only 4 were above detection limit. As a result NH4 calibration was attempted only for the general trend that showed very low levels (< 0.1 mg/L) in low and medium flow conditions.

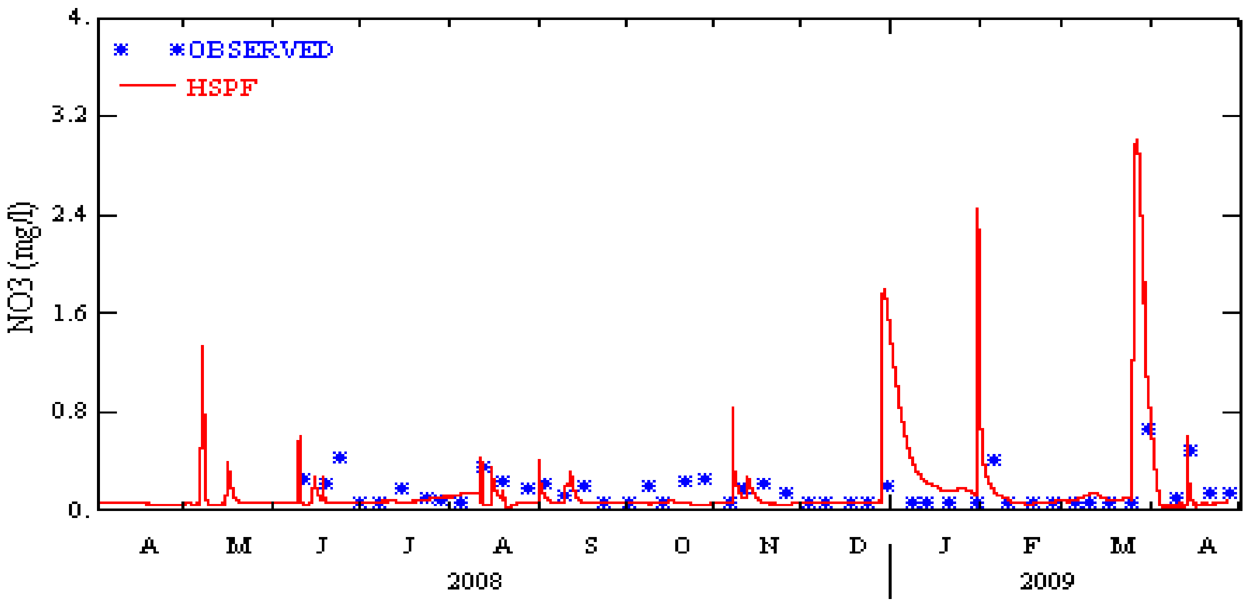

Figure A-15 Little River at 60th Ave. (L60) site NO3 plot

The key HSPF parameters in the calibration of these parameters were POTFW, IFLW-CONC, GRND-CONC, ACQOP, and SQOLIM.

A.3.9 Load budget for TSS, TN, TP and CBOD/TOC loads from HSPF watershed for existing calibration conditions

The HSPF model framework consists of a network of sub-watersheds that generate flow and pollutant loading from runoff over the land uses of sub-watersheds defined within a larger watershed domain for a project. Sub-watersheds are defined by an in-stream reach where flow and pollutant loads simulated as land use dependent runoff are input and routed through a reach that is defined by length, volume, surface area, depth and hydraulic residence time. In this study, sub-watersheds that drain into Lake Thunderbird via a tributary generate flow and water quality concentrations at specific downstream outlet locations at the lake. Sub-watersheds that are adjacent to and drain directly into Lake Thunderbird generate water volume and loads from distributed runoff over the entire sub-watershed. By aggregating the pollutant loading from all the tributaries and NPS overland area, the pollutant annual budget estimated by HSPF model is given by Table A.8. The pollutant loadings for each sub-watershed loadings on a per acre per year basis are given by Figure A.16 through Figure A.20.

Table A-8 HSPF load budget

Total HSPF watershed Loads: 4/27/2008-4/26/2009					
Watershed	TN	TP	BOD	Sediment	TOC
Load	1000 lb/yr	1000 lb/yr	1000 lb/yr	1000 lb/yr	1000 lb/yr
Tributary	268.943	57.001	818.460	28,503.2	1,369.796
Distributed	17.045	0.593	49.656	1,544.4	88.209
Total	285.988	57.595	868.116	30,047.6	1,458.005

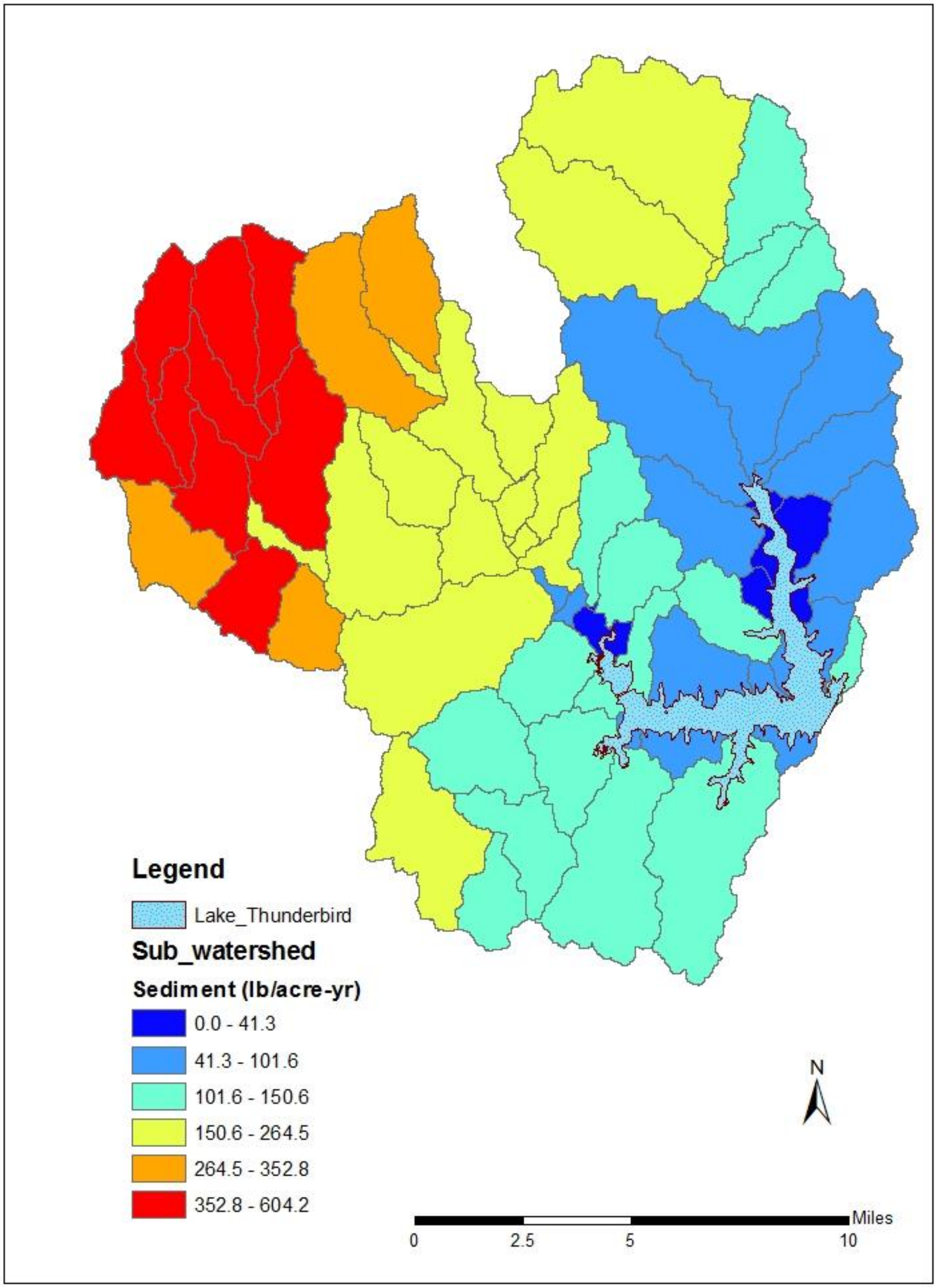

Figure A-16 Calculated sub-watershed sediment loadings by HSPF model

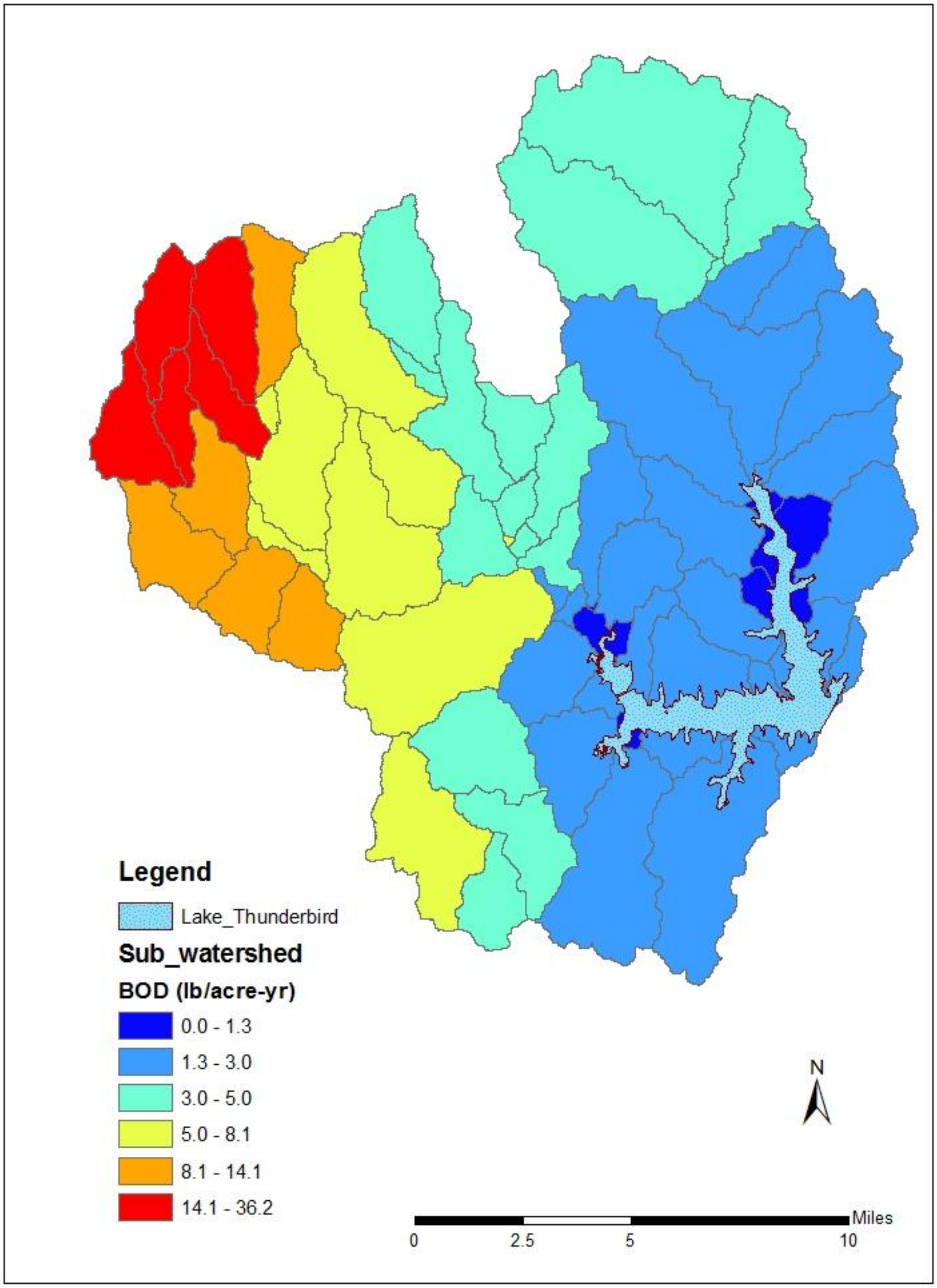

Figure A-17 Calculated sub-watershed BOD loadings by HSPF model

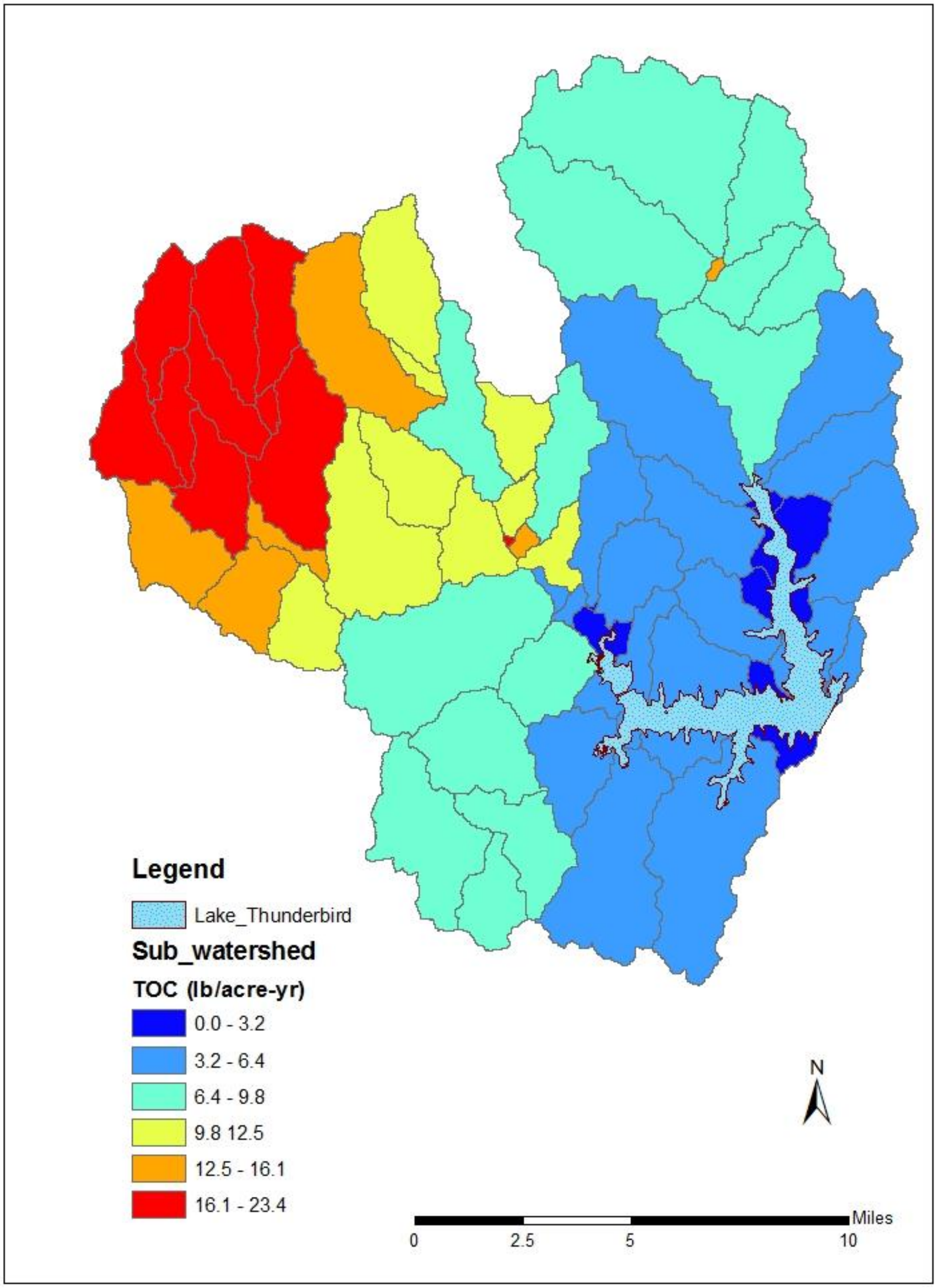

Figure A-18 Calculated sub-watershed TOC loadings by HSPF model

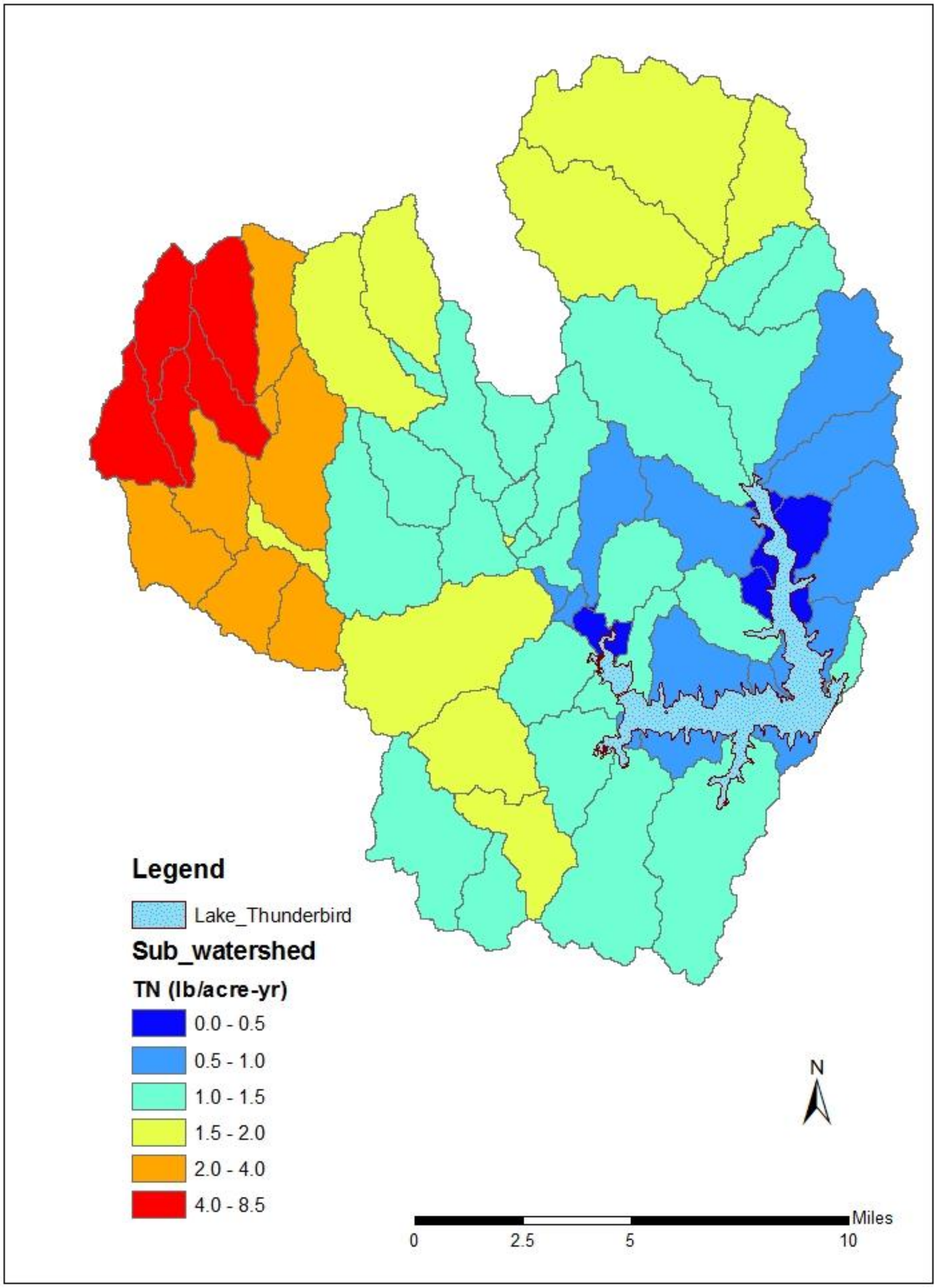

Figure A-19 Calculated sub-watershed TN loadings by HSPF model

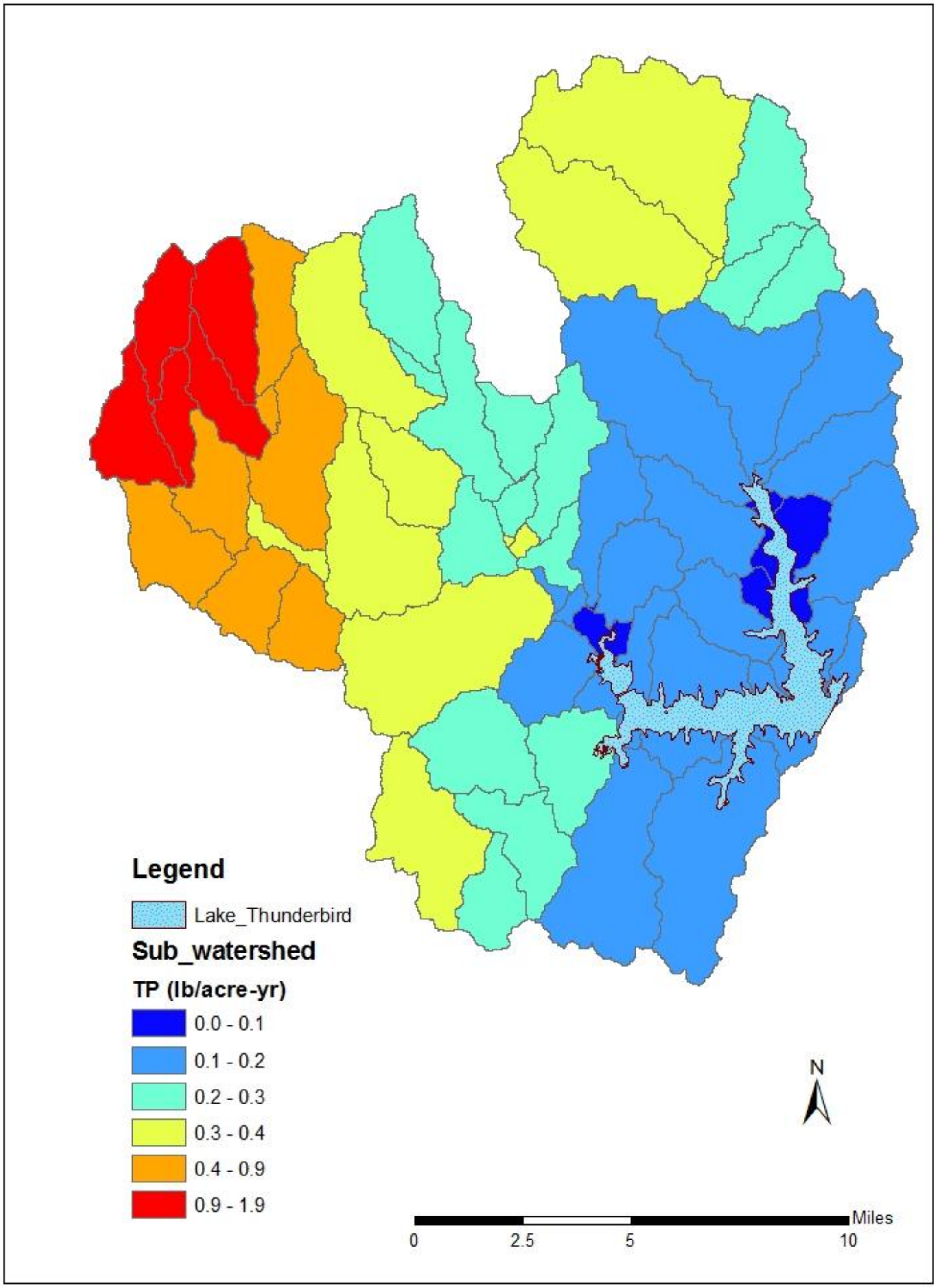

Figure A-20 Calculated sub-watershed TP loadings by HSPF model

A.4 Time series plots of all HSPF Flow, WTEMP, TSS and WQ results

For easy reference, all the model-data comparisons of flow, water temperature, TSS, and water quality at all the sites are presented below.

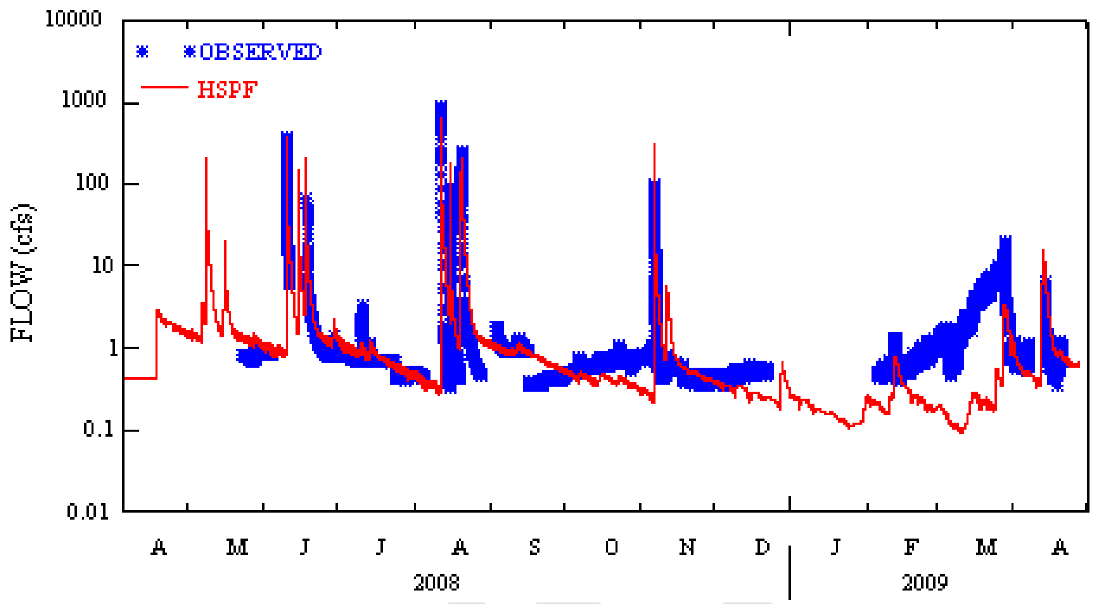

Figure A-21 Comparison of observed and simulated stream flows at Elm station

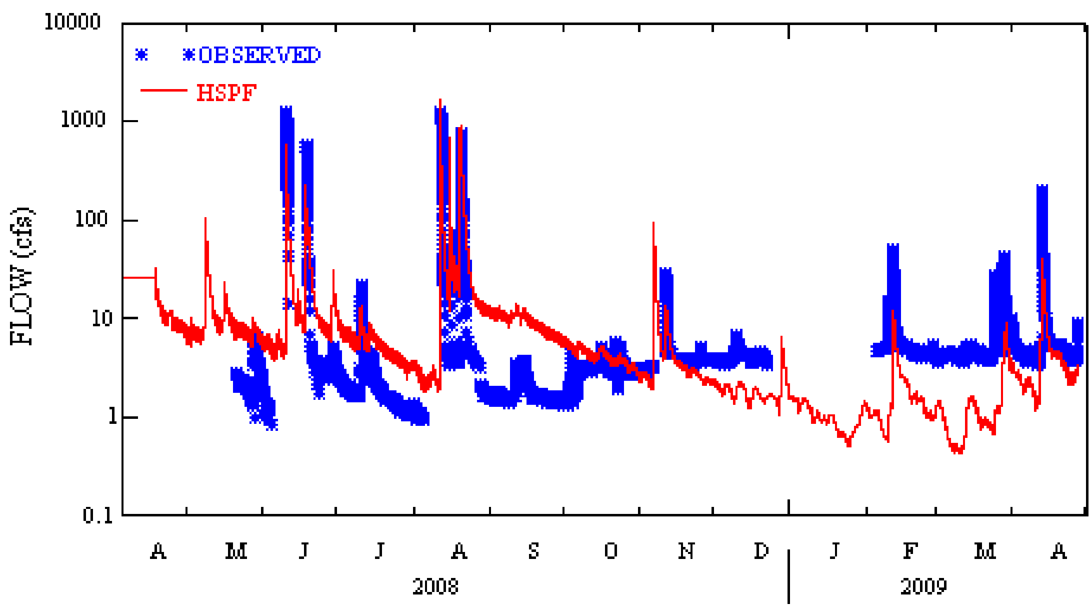

Figure A-22 Comparison of observed and simulated stream flows at Hog station

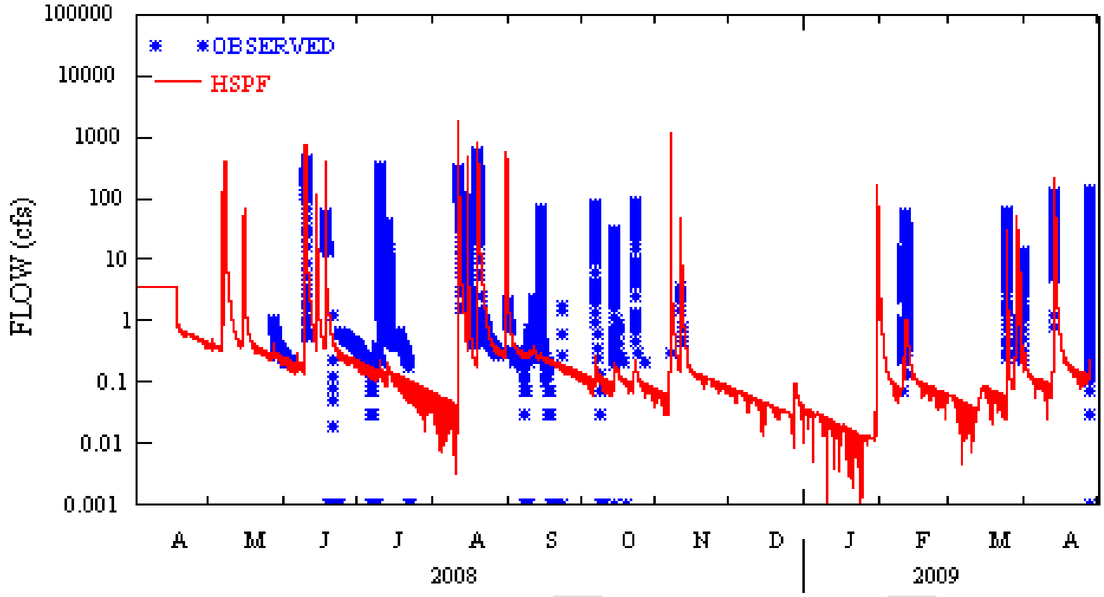

Figure A-23 Comparison of observed and simulated stream flows at L17 station

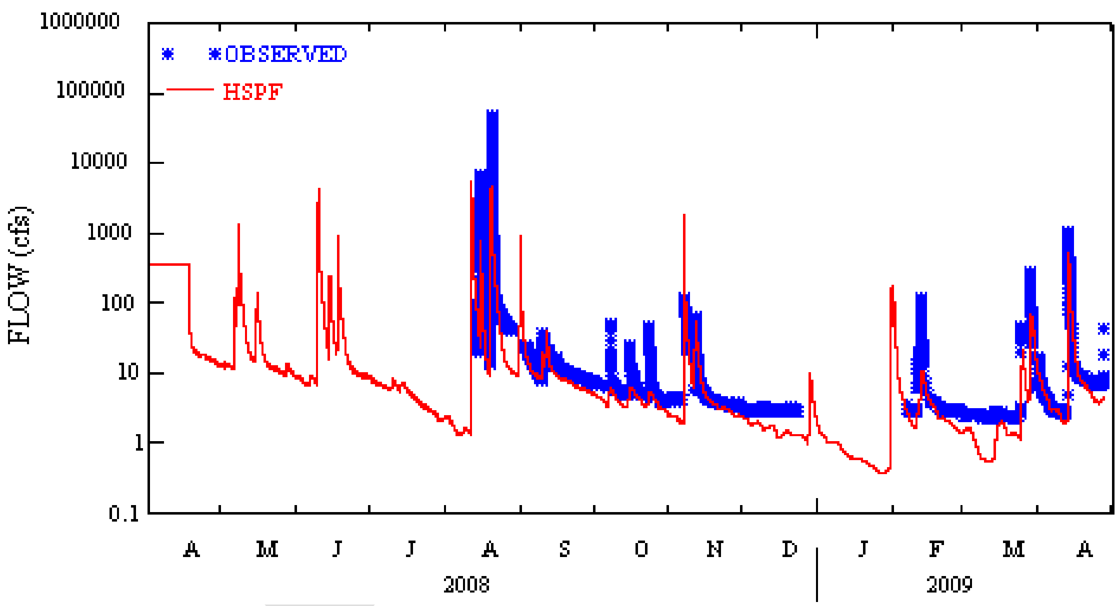

Figure A-24 Comparison of observed and simulated stream flows at L60 station

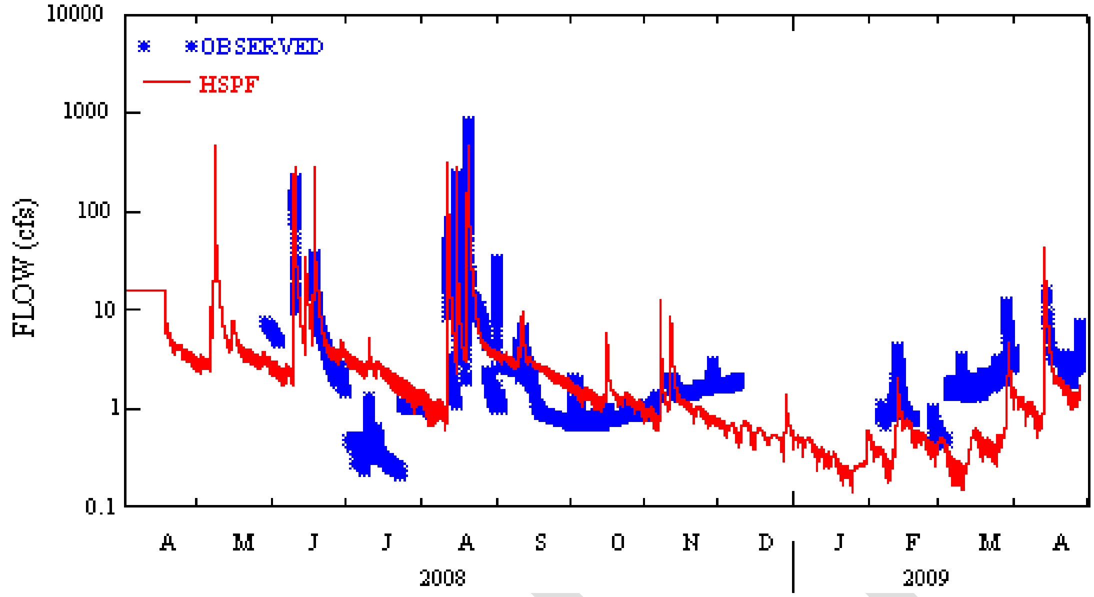

Figure A-25 Comparison of observed and simulated stream flows at Rock station

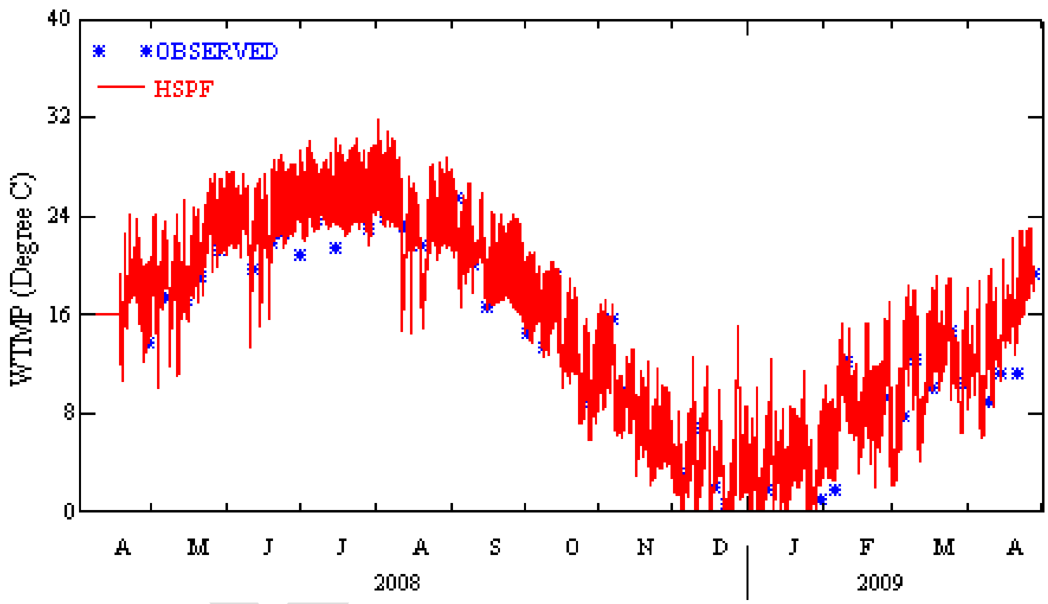

Figure A-26 Comparison of observed and simulated stream temperatures at ELM station

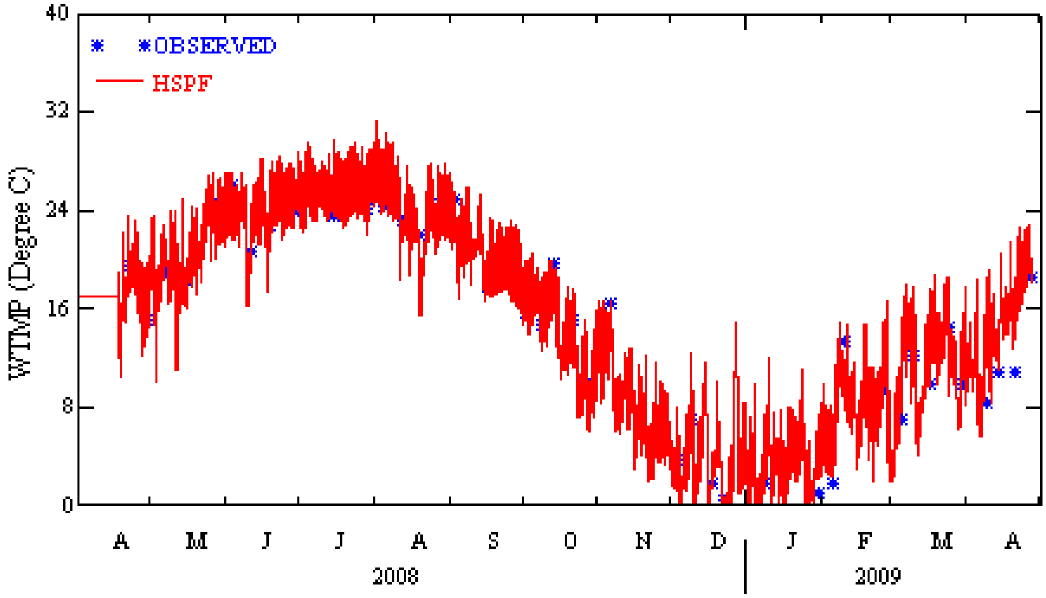

Figure A-27 Comparison of observed and simulated stream temperatures at Hog station

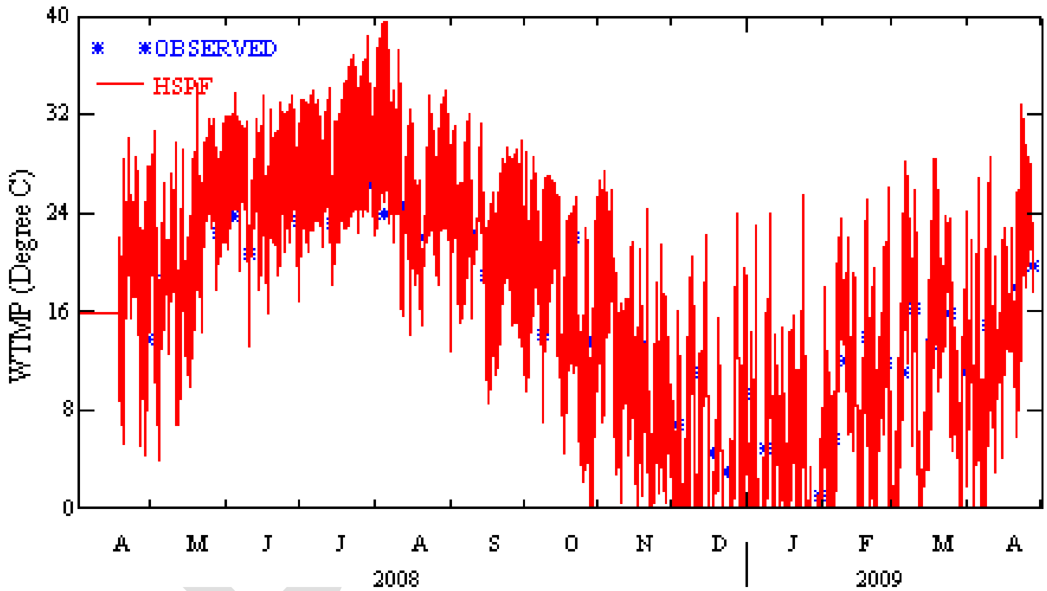

Figure A-28 Comparison of observed and simulated stream temperatures at L17 station

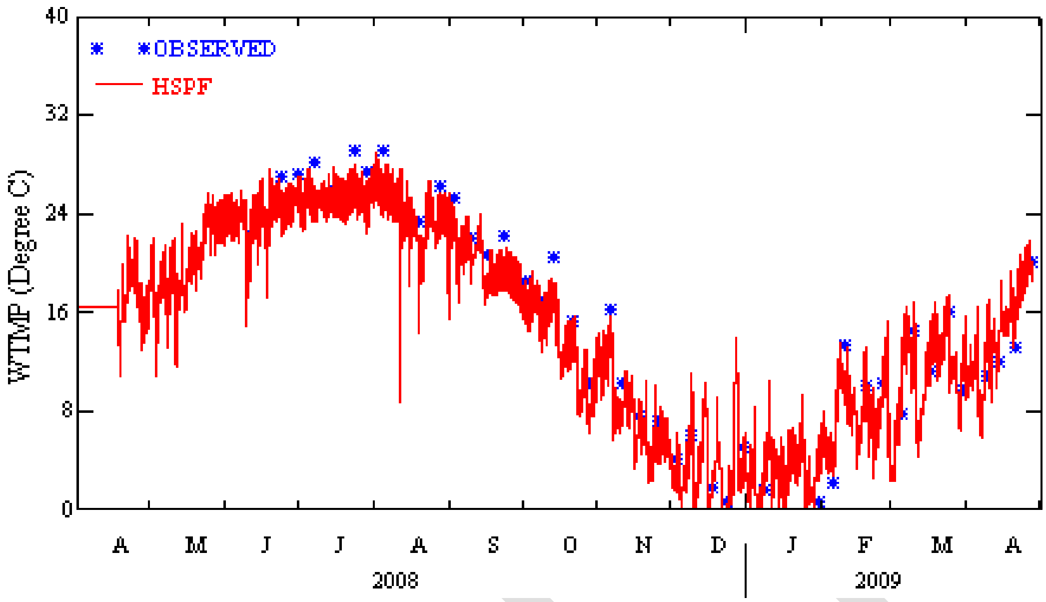

Figure A-29 Comparison of observed and simulated stream temperatures at L60 station

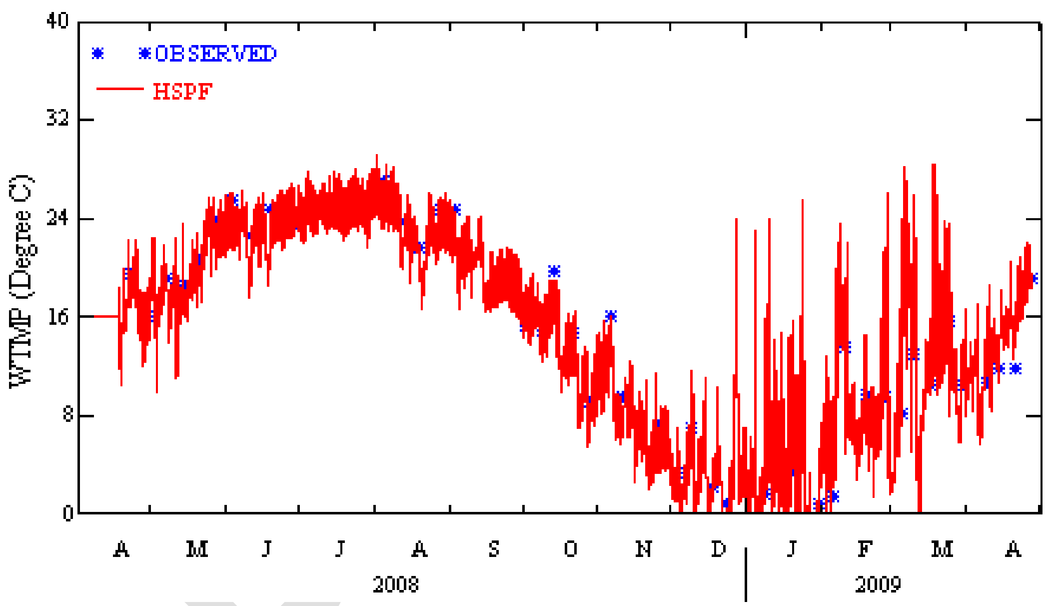

Figure A-30 Comparison of observed and simulated stream temperatures at Rock station

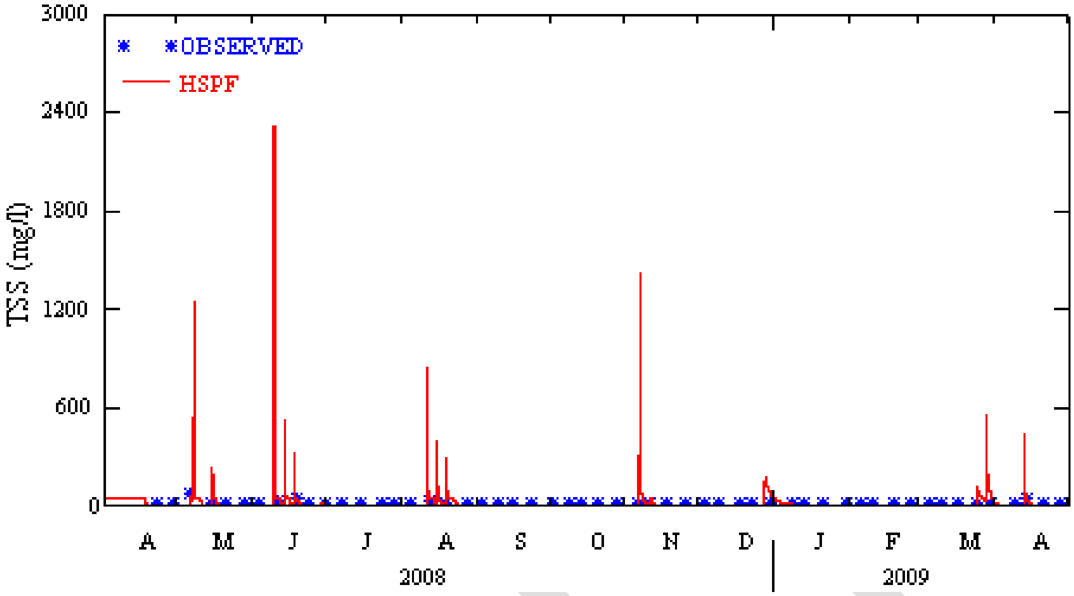

Figure A-31 Comparison of observed and simulated stream TSS concentrations at Elm station

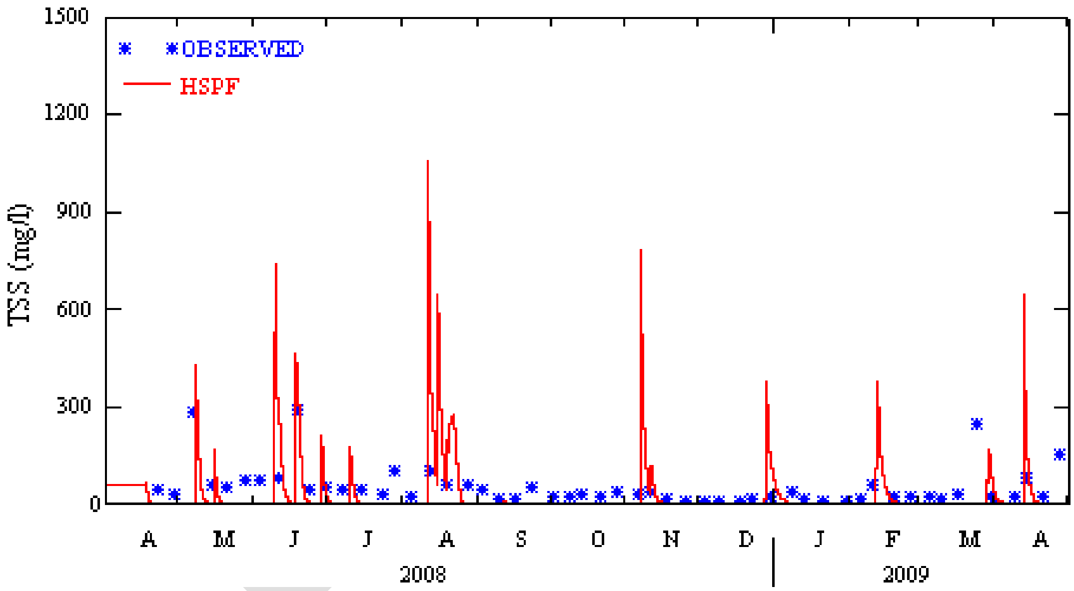

Figure A-32 Comparison of observed and simulated stream TSS concentrations at Hog station

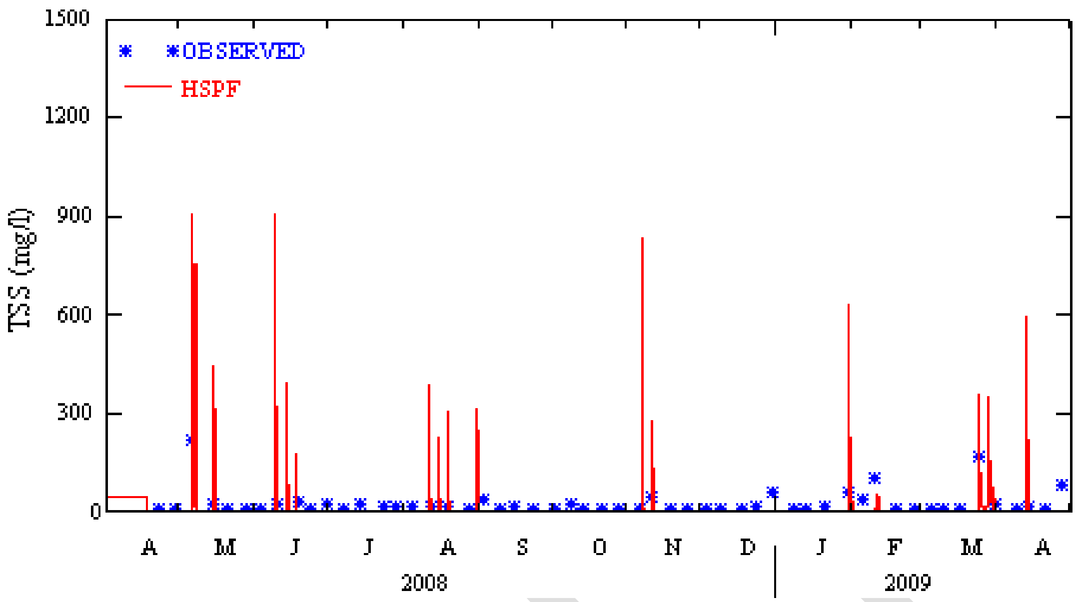

Figure A-33 Comparison of observed and simulated stream TSS concentrations at L17station

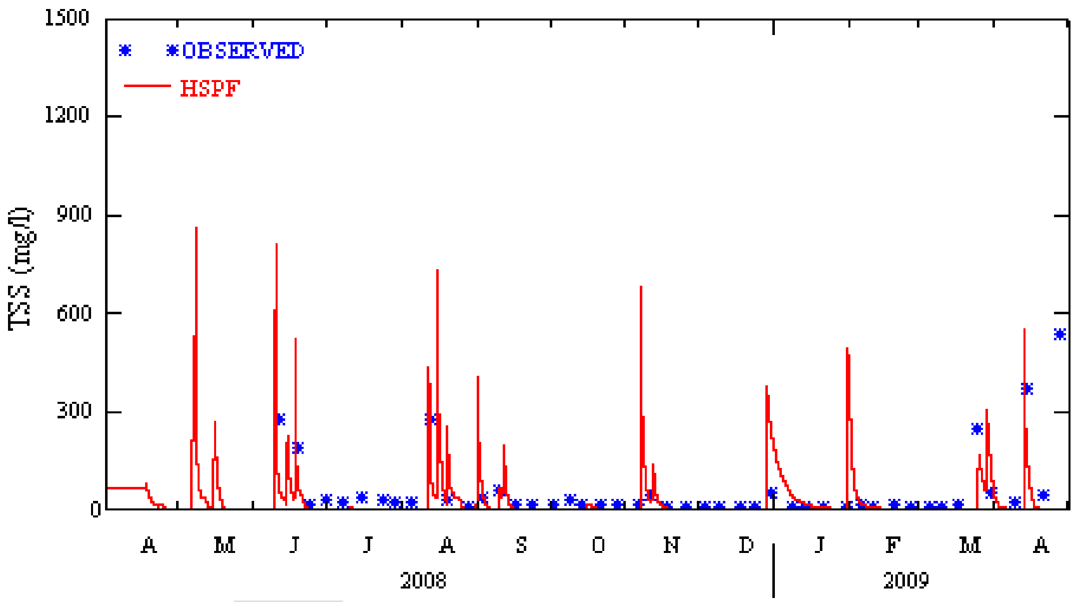

Figure A-34 Comparison of observed and simulated stream TSS concentrations at L60 station

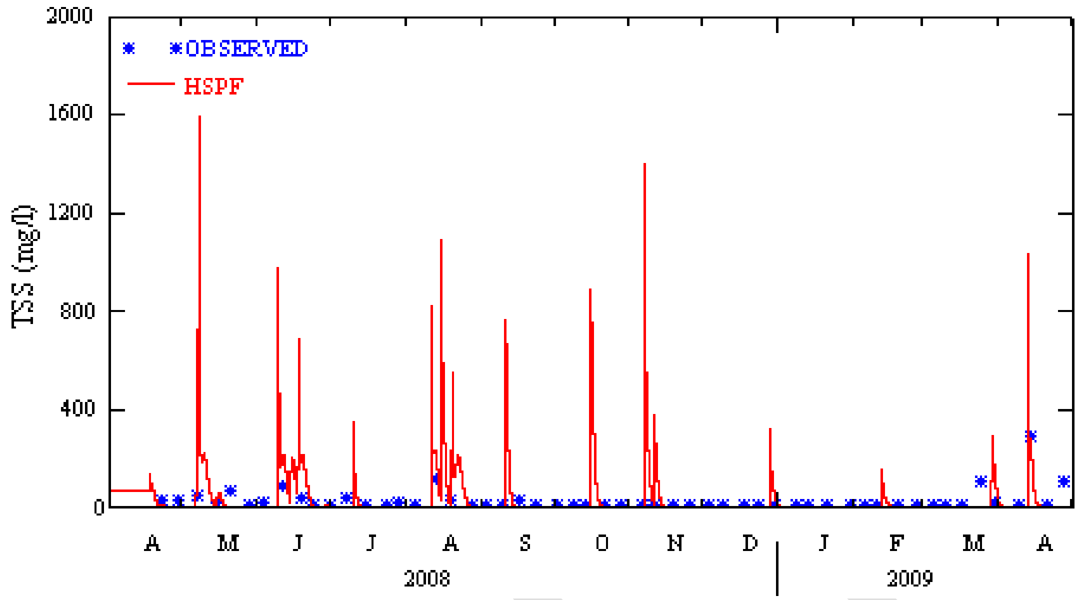

Figure A-35 Comparison of observed and simulated stream TSS concentrations at Rock station

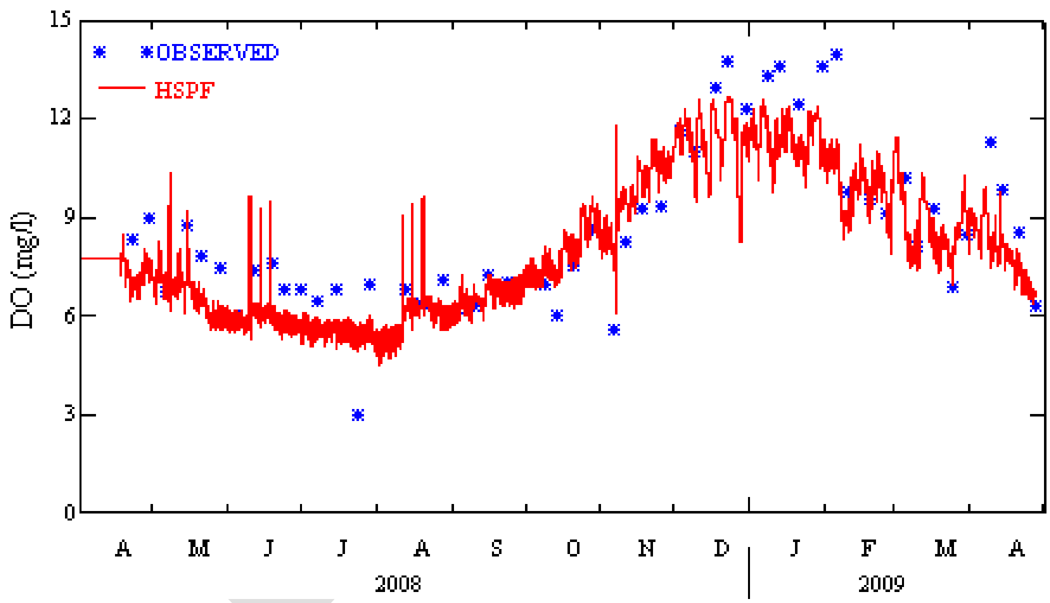

Figure A-36 Comparison of observed and simulated stream DO concentrations at Elm station

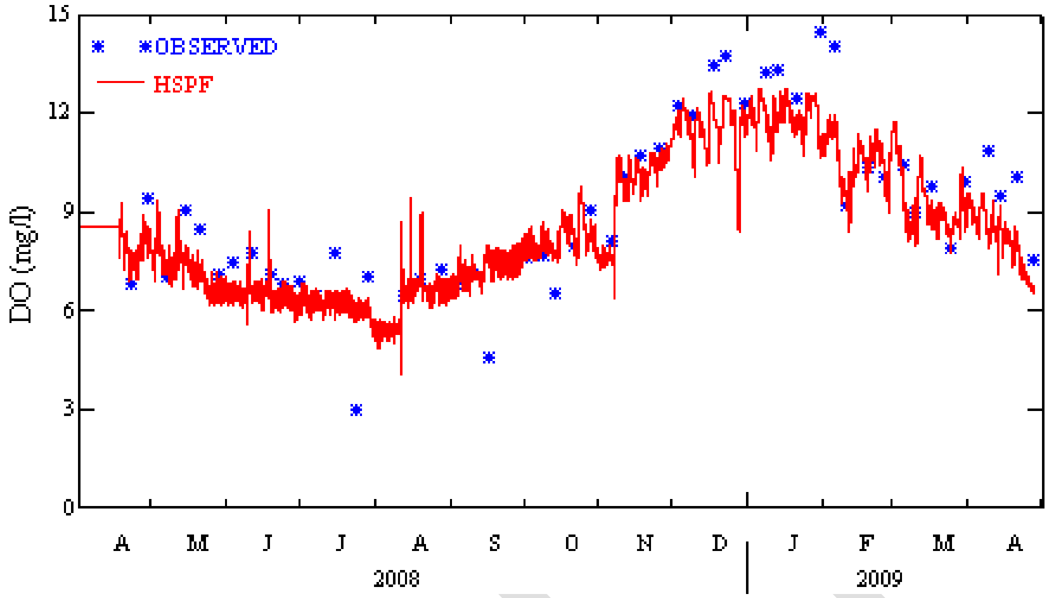

Figure A-37 Comparison of observed and simulated stream DO concentrations at Hog station

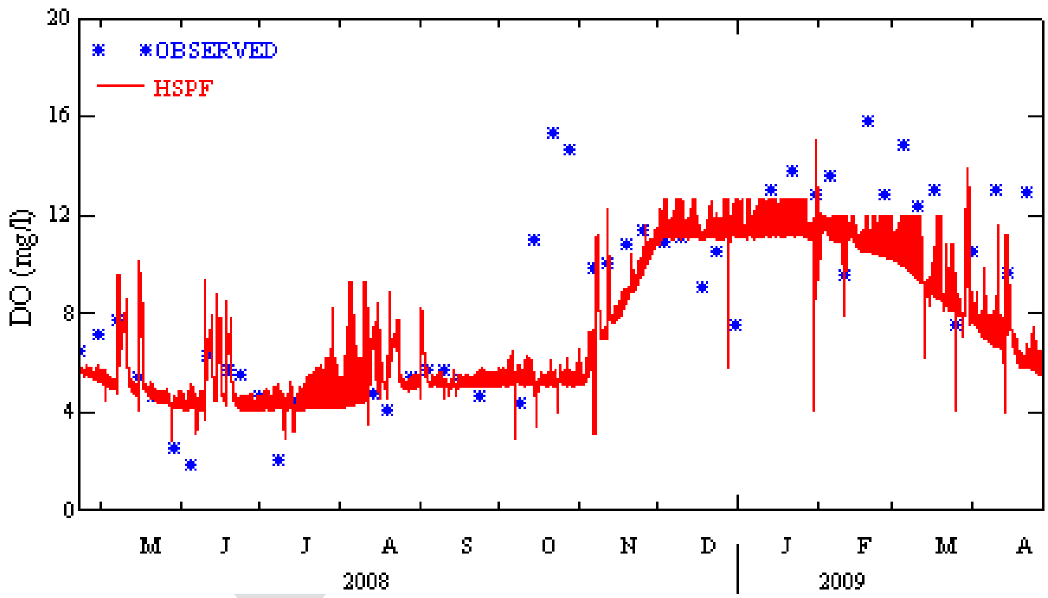

Figure A-38 Comparison of observed and simulated stream DO concentrations at L17 station

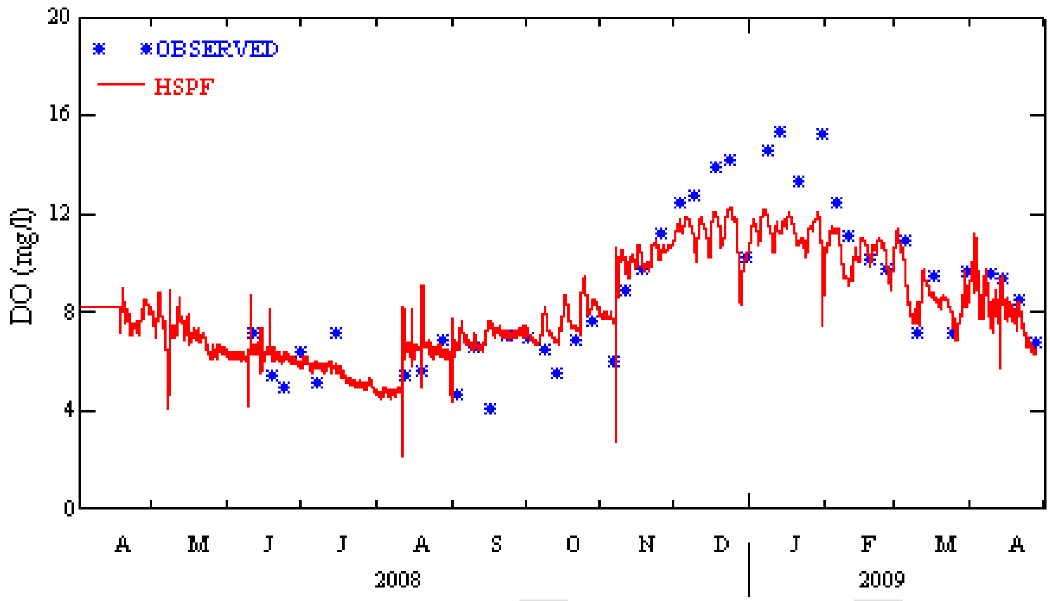

Figure A-39 Comparison of observed and simulated stream DO concentrations at L60 station

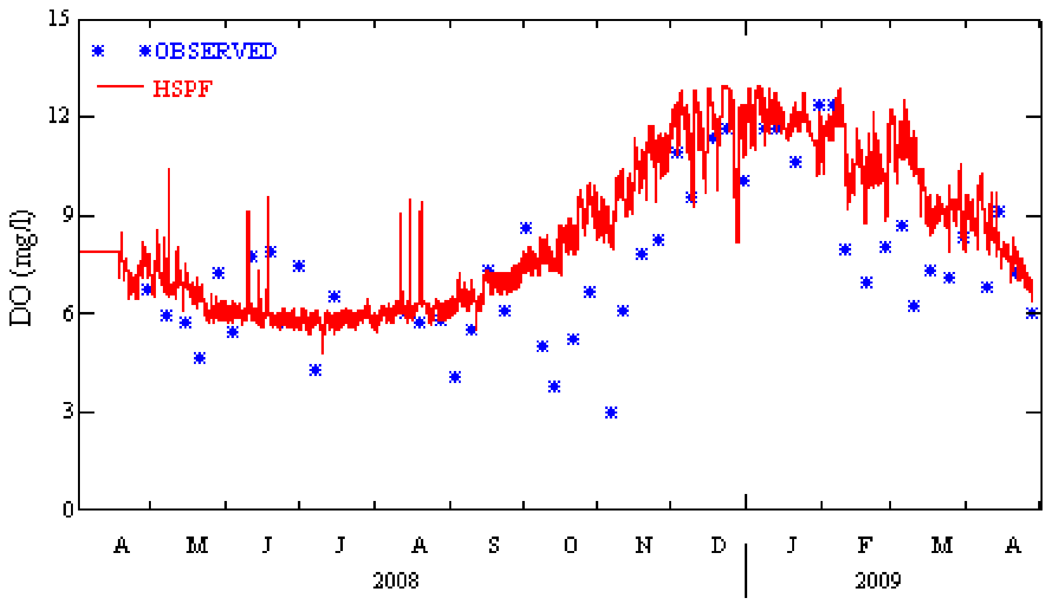

Figure A-40 Comparison of observed and simulated stream DO concentrations at Rock station

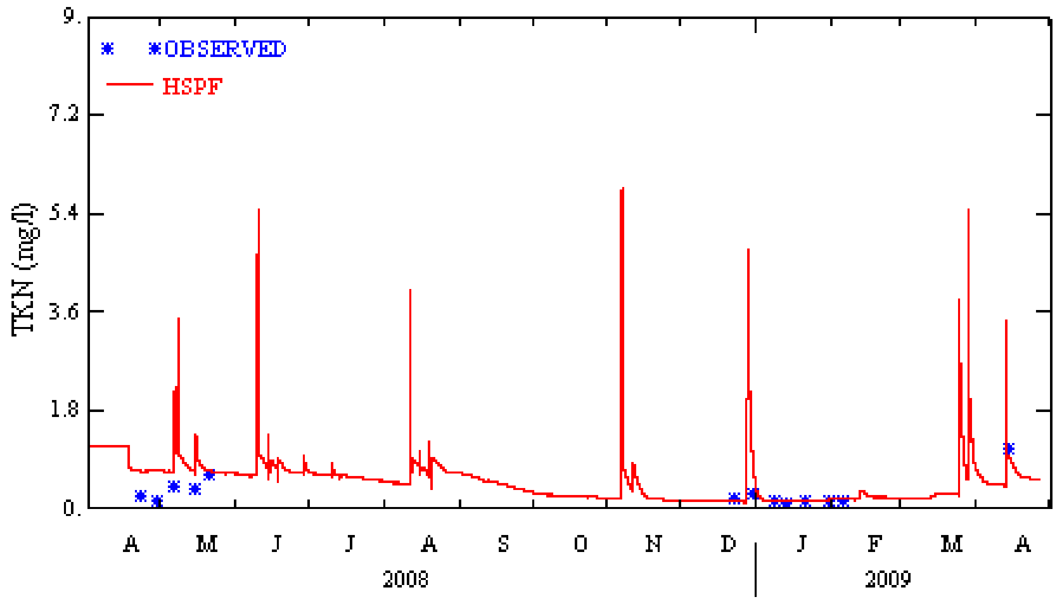

Figure A-41 Comparison of observed and simulated stream TKN concentrations at Elm station

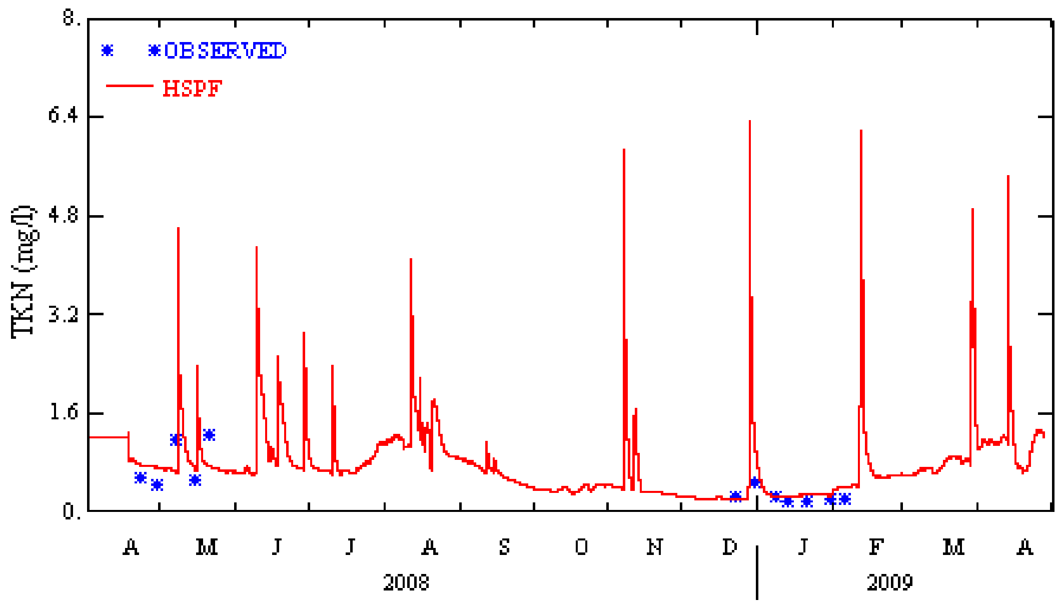

Figure A-42 Comparison of observed and simulated stream TKN concentrations at Hog station

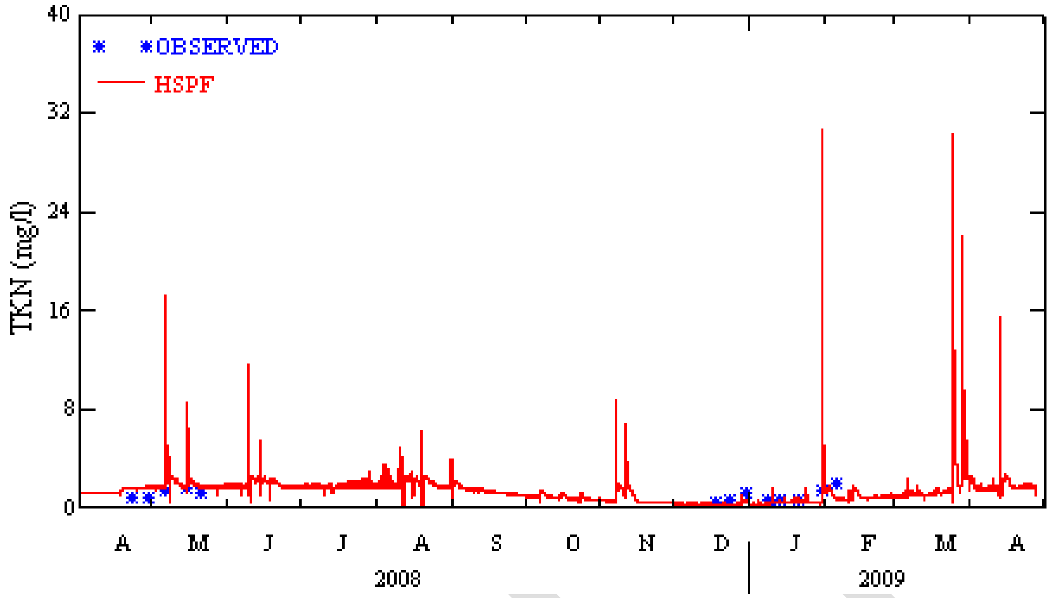

Figure A-43 Comparison of observed and simulated stream TKN concentrations at L17 station

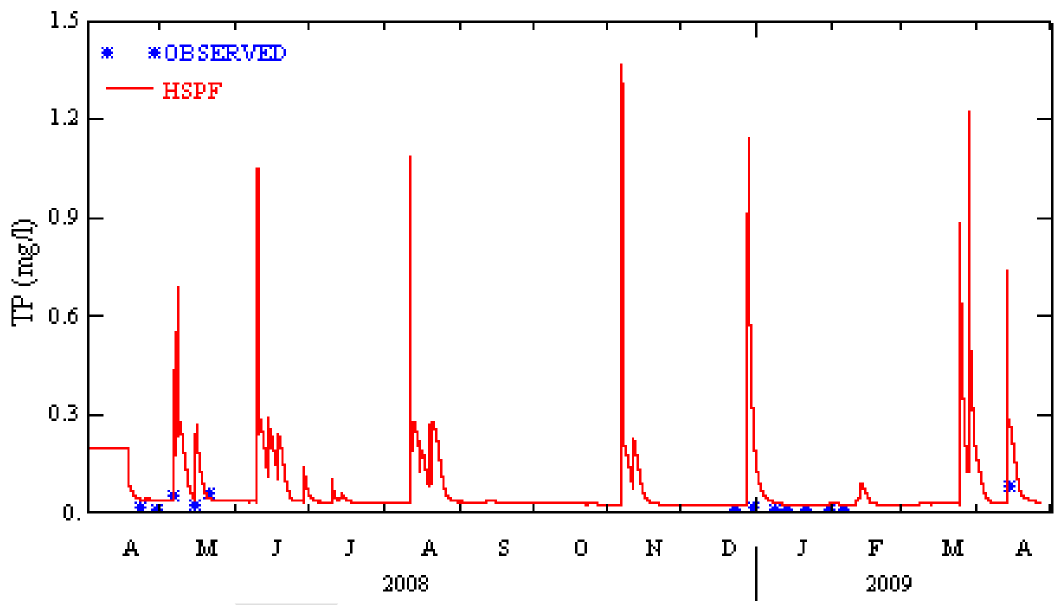

Figure A-44 Comparison of observed and simulated stream TP concentrations at Elm station

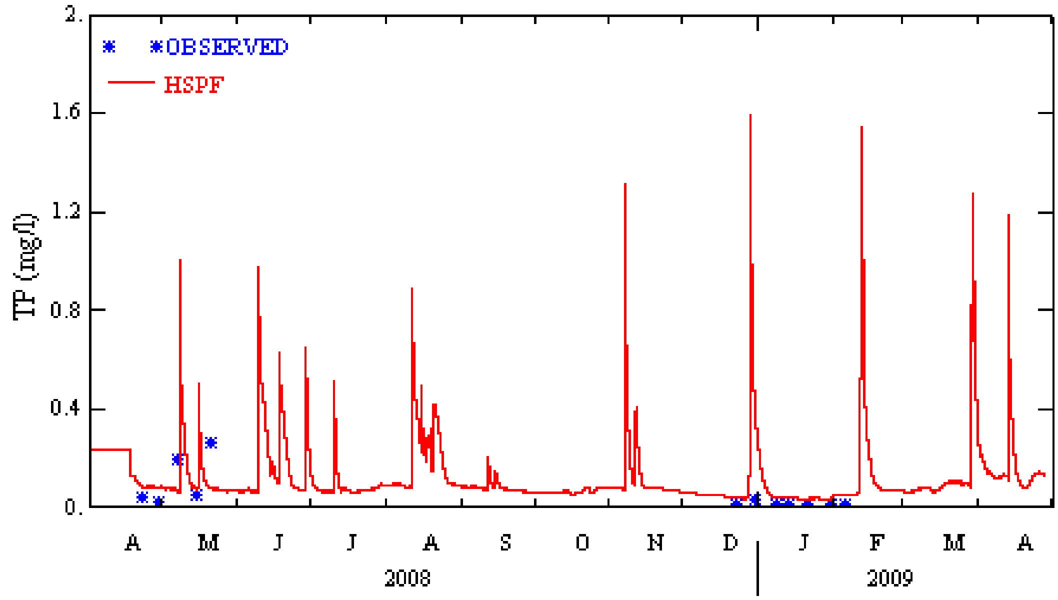

Figure A-45 Comparison of observed and simulated stream TP concentrations at Hog station

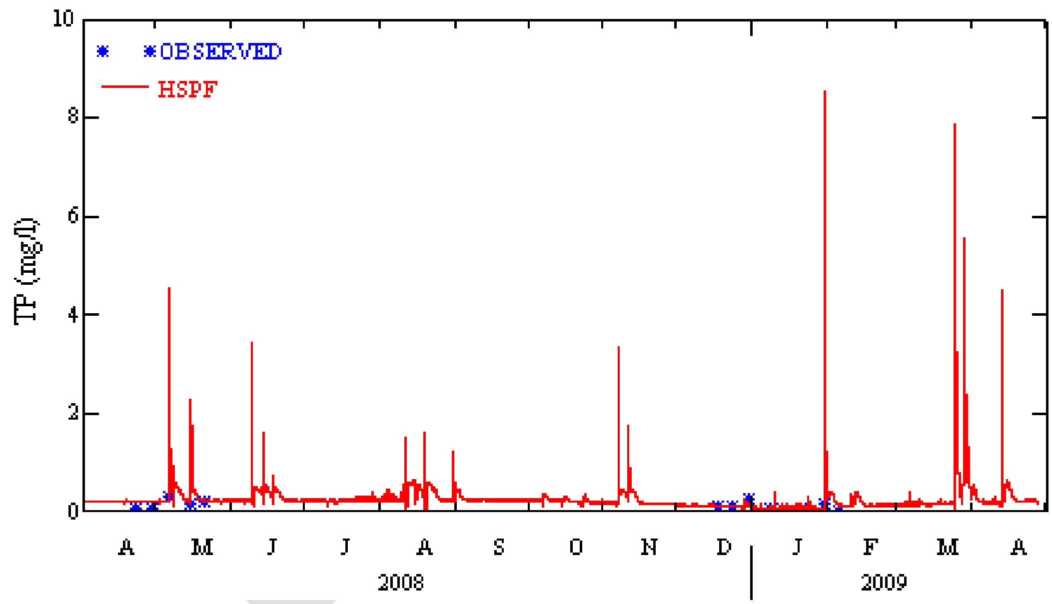

Figure A-46 Comparison of observed and simulated stream TP concentrations at L17 station

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