Appendix A
HSPF Watershed Model

Draft
Lake Fort Gibson TMDL Report

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By

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Appendix A – HSPF Watershed Model

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A-1. INTRODUCTION

In the 2009 OWRB BUMP report on the lakes of Oklahoma, Fort Gibson Lake is identified as impaired for beneficial uses related to (a) Fish & Wildlife Propagation (FWP) because of low dissolved oxygen and (b) Aesthetic uses because of its status as a Nutrient Limited Watershed (NLW). Using monitoring data collected for the BUMP surveys, Fort Gibson Lake is one of 21 lakes in Oklahoma that have been designated as Nutrient Limited Watersheds in Oklahoma Water Quality Standards because of the Trophic Status Index (TSI).

Since Fort Gibson Lake is listed as a Nutrient Limited Watershed, a Nutrient Impairment Study is needed to definitively determine the presence or absence of nutrient impairment in the lake. In addition to its status as a NLW by ODEQ, Fort Gibson Lake was also identified in the 2008 EPA report as impaired for Fish and Wildlife Propagation in a warm water aquatic community because of low dissolved oxygen. A TMDL assessment for Fort Gibson Lake is required by EPA to determine appropriate load reductions that could be implemented to achieve compliance with water quality standards for the lake.

The Nutrient Impairment Study and the TMDL assessment of Fort Gibson Lake both require the development of modeling tools to specify cause-effect relationships between external flows and loading to the lake and the in-lake water quality response of nutrients, algae and dissolved oxygen. The objective of this modeling effort is to develop a hydrodynamic and water quality model using Environmental Fluids Dynamic Code (EFDC) for Fort Gibson Lake. The calibrated Fort Gibson Lake EFDC model will provide the cause-effect model framework that is needed for these water quality management investigations by Oklahoma DEQ (ODEQ) and EPA Region 6. Watershed hydrology and water quality model is developed and calibrated using Hydrological Simulation Program FORTRAN (HSPF) to characterize the flow and nutrient loadings from the tributaries and nonpoint sources of the Fort Gibson Lake.

Model development and calibration results for both HSPF and EFDC are discussed in this report. Simulation results for the model simulation time period are also presented and discussed in this report.

A-2. STUDY AREA DESCRIPTION

Fort Gibson Lake, located at the downstream end of the Lower Neosho watershed (HUC 11070209) about 5 miles northwest of Fort Gibson, OK, was formed as a 14,900 acre reservoir in 1953 by impounding the Lower Neosho River for hydropower and flood control. The reservoir, owned and operated by the U.S. Army Corps of Engineers Tulsa District, is located about 7.7 miles upstream of the confluence of the Neosho River with the Arkansas River. In addition to the Lower Neosho River, tributary inflows to the reservoir are contributed by Snake Creek, Clear Creek and Fourteen Mile Creek on the eastern shore of the lake. Lake Hudson, Spavinaw Lake and Lake Eucha are other impoundments in the Lower Neosho watershed that are upstream of Fort Gibson Lake. Grand Lake, a large reservoir in the Lake of the Cherokees Catalog Unit (11070206), is located upstream of Fort Gibson Lake. Figure A-1 shows the location of Fort Gibson Lake at the downstream end of the Lower Neosho watershed.

Sources of nutrient loading to Fort Gibson Lake that are related to nutrient enrichment and eutrophication in the lake include loading from the Headwaters-Upper-Middle Neosho basins, Elk and Spring basins and Lake of the Cherokees watersheds via outflows from Grand Lake and loading from the Lower Neosho basin via outflows from Lake Hudson, Lake Eucha, Spavinaw Lake and local loading downstream of Lake Hudson to Fort Gibson Lake from tributaries and nonpoint sources (Figure A-1). The flow and nutrient loadings from the Lower Neosho basin were estimated based on the United States Geological Survey (USGS) and OWRB BUMP monitoring data. The flow and nutrient loadings from the local tributaries and non-point sources were estimated using the watershed model of HSPF.

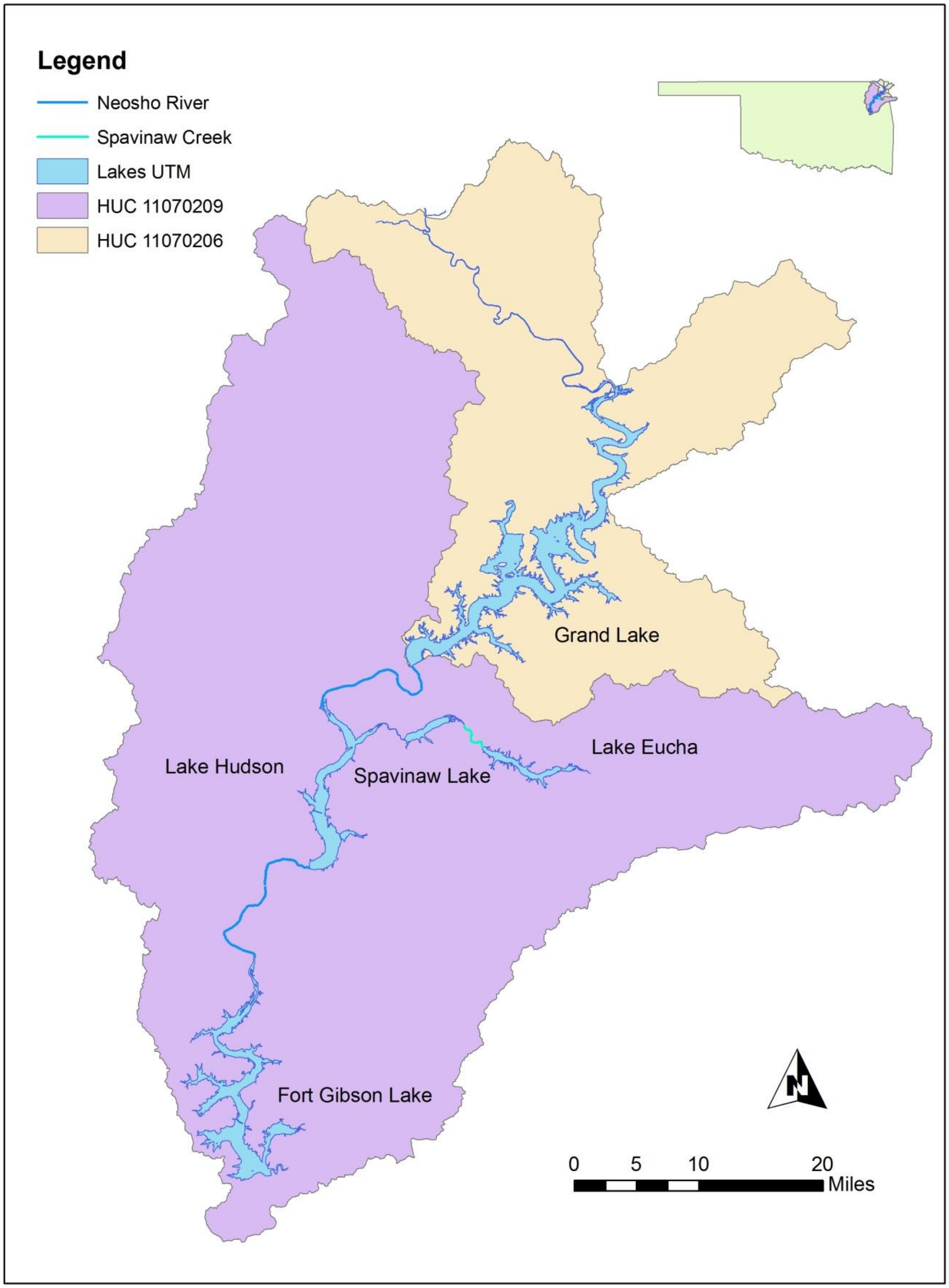

Figure A-1 Location of the Fort Gibson Lake

A-3. DEVELOPMENT AND CALIBRATION OF HSPF MODEL

This section describes the Hydrologic Simulation Program FORTRAN (HSPF) model setup and calibration results for Fort Gibson Lake. Detailed description of HPSF can be found in the literature (Donigian et al., 1999; Bicknell et al., 2001; Duda et al., 2002). The For Gibson Lake watershed was divided into 10 sub-watersheds that included major tributaries and point source discharges. The watershed model was progressively calibrated for flow, temperature, nutrients, and DO based on the available observed data. HSPF generates non-point source runoff and loads from land sources and drains them to adjacent stream segments. Flow in the stream segments is routed downstream along with water quality constituents. Appropriate land based and in-stream processes were selected and parameterized through model calibration. Modeled streamflow and pollutant concentrations are compared with observed data collected at flow gages and water quality monitoring stations for model calibration. Finally, time series of flow, temperature, and water quality constituent concentrations computed at different boundary locations of the Fort Gibson Lake serve as input to the Ft. Gibson Lake EFDC model.

A-3.1 Model Simulation Period

After a comprehensive revision of data availability for model setup and calibration of the watershed HSPF model and the lake EFDC model, the simulation period of the watershed model was selected from January 1, 2004 to December 31, 2008. The watershed hydrology was calibrated using the Army Corp of Engineer monitoring data from 1 January 2008 through 31 December 2008 in Pryor Creek as shown in Figure A-2. The water quality model was calibrated using OWRB BUMP monitoring data from 1 January 2005 to 31 December 2008 in Spring Creek (Figure A-2). A one-year spin up time (2004) was used to diminish the impact of the initial conditions.

A-3.2 Model Constituents

The modeled constituents for the Ft. Gibson Lake watershed model are given below.

- Flow
- Water temperature
- Total suspended solids
- ultimate BOD (UBOD)
- Nitrogen (TN, -NO_2+NO_3, organic N, NH_3/NH_4)
- Phosphorus (TP, organic P, Ortho-Phosphate)
- Total organic carbon (TOC)
- Phytoplankton (as Chl-a)
- Dissolved oxygen (DO)

A-3.3 Model Discretization

The model requires the acreage of various land uses in each sub-watershed and the stream reach to which the land segment discharges. The United States Environmental Protection Agency (USEPA) software BASINS was used to delineate the Fort Gibson Lake watershed and obtain the physical characteristics of each sub-watershed such as major changes in slope, channel cross-section, and depth. The Fort Gibson Lake watershed was delineated into 10 sub-watersheds shown in Figure A-2 based on the United States Geological Survey (USGS) National Elevation Dataset. Table A-1 provides the reach characteristics developed by BASINS used in the HSPF model.

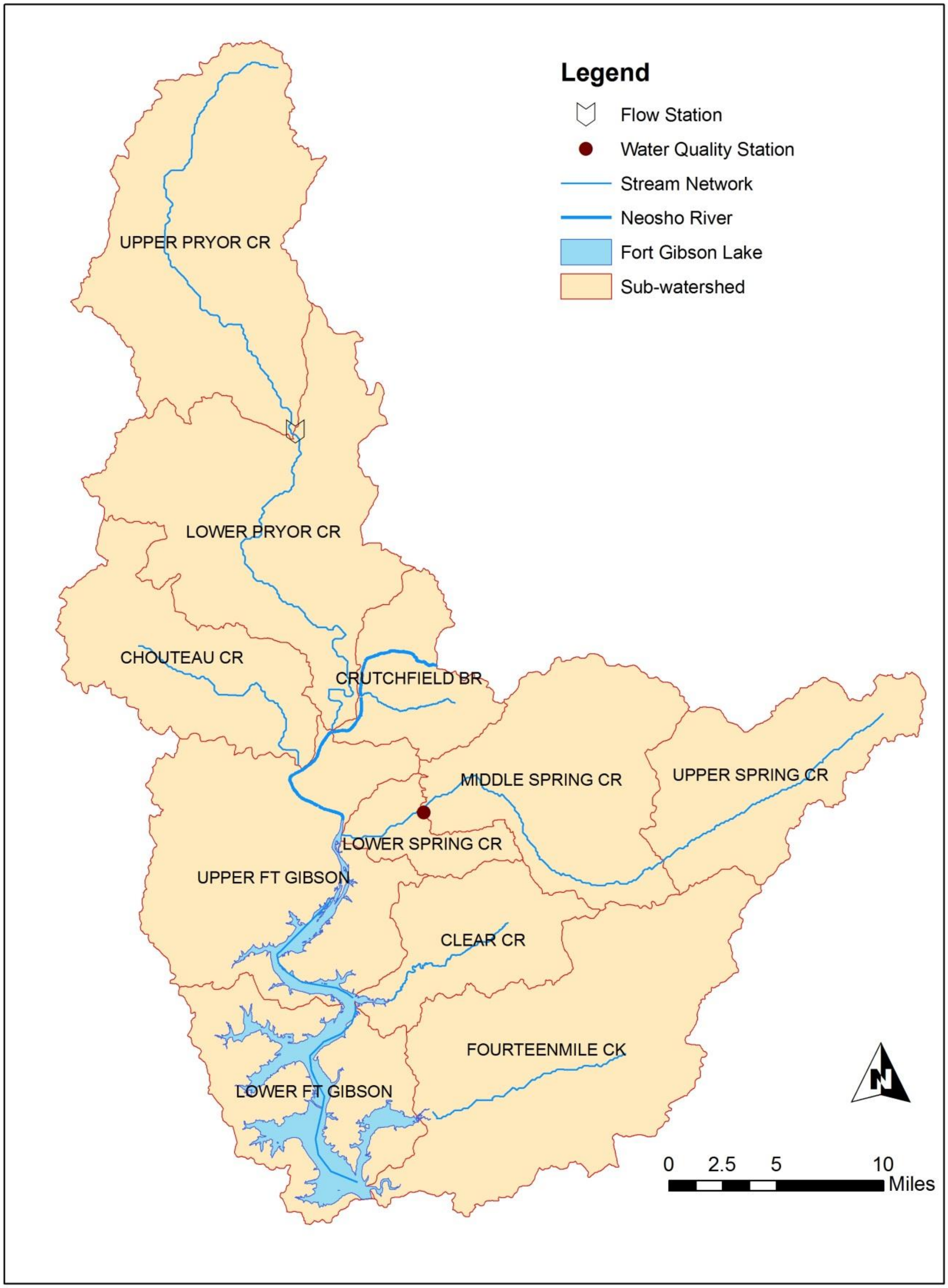

Figure A-2 Model Discretization of the Fort Gibson Lake Watershed

Table A-1 REACH Characteristics Developed by BASINS

Reach ID	REACH Name	Length (mile)	DELTH (feet)	Longitudinal Slope
1	CHOUTEAU CR	12.42	49	0.00075
2	CLEAR CR	8.7	213	0.00464
3	FOURTEENMILE CK	10.68	266	0.00472
5	LOWER PRYOR CR	22.67	75	0.00063
6	LOWER SPRING CR	4.37	164	0.00711
7	MIDDLE SPRING CR	15.78	167	0.00200
9	UPPER PRYOR CR	25.16	279	0.00210
10	UPPER SPRING CR	13.36	223	0.00316
11	CRTUCHFIELD BR	8.03	79	0.00186

A-3.4 Land Use

The 2006 NLCD land use data were used for the development of the watershed model. The land uses were grouped into eight different classes to capture the variation of watershed characteristics affecting the flow and pollutant loads. Figure A-3 shows the land use distribution by the 2006 National Land Cover Database (NLCD). The major land uses are pasture and forest. The area and percentage of each landuse is given in Table A-2.

Table A-2 Land Use Distribution in the Ft. Gibson Lake Watershed Model

Landuse	Area (acre)	Percentage
Agriculture - Cropland	11911.2	2.01%
Agriculture - Pasture	278308	46.85%
Barren or Mining	612.9	0.10%
Forest	202130.3	34.03%
Grass Land	58708.7	9.88%
Upland Shrub Land	785.4	0.13%
Urban	39319.2	6.62%
Water/Wetlands	2246.2	0.38%
Total	594021.9	100.00%

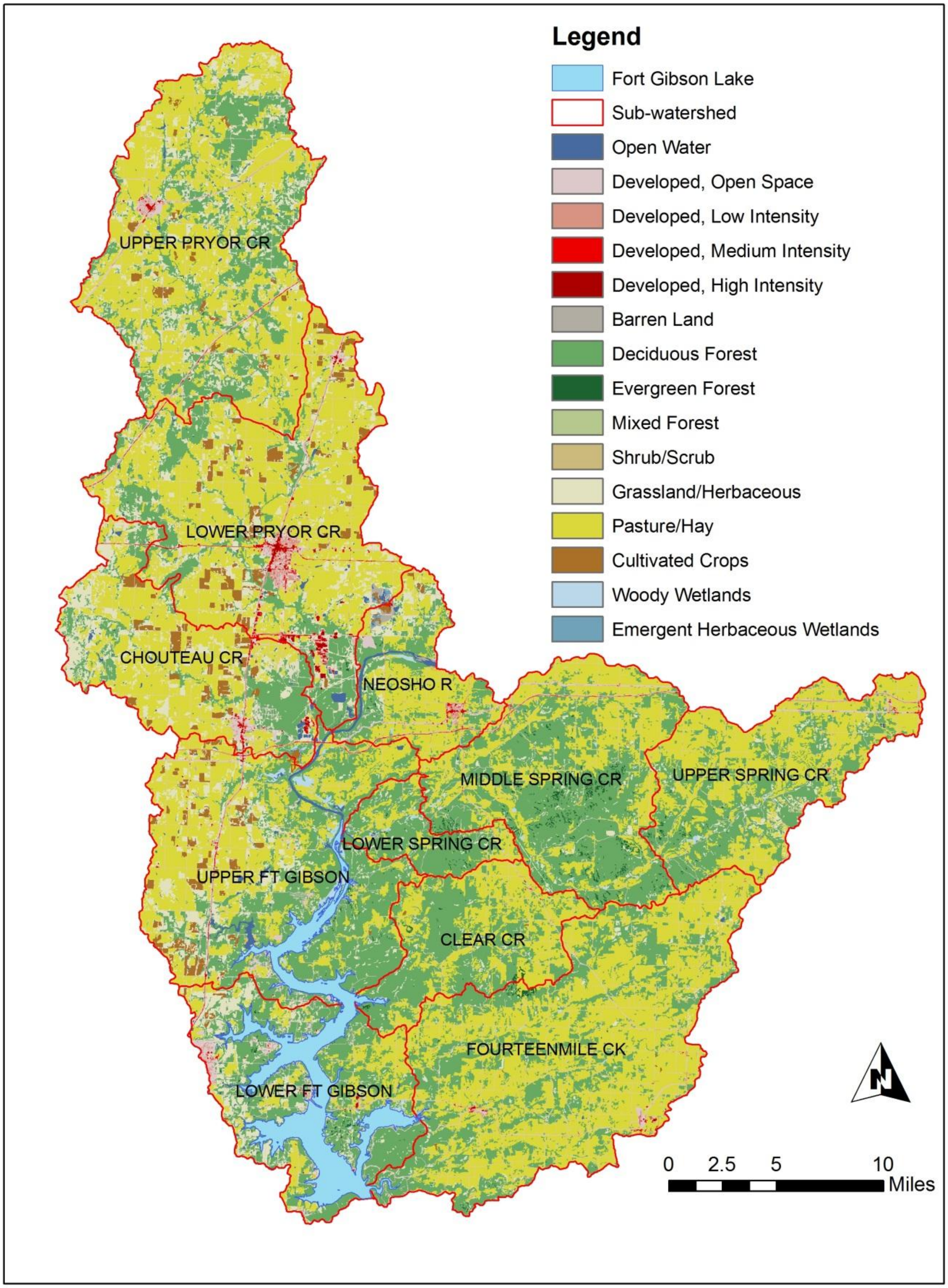

Figure A-3 Landuse Distribution in the Fort Gibson Lake Watershed

A-3.5 Meteorological Data

Seven meteorological variables are required for hydrological and water quality simulation using HSPF. These variables are precipitation, evapotranspiration, air temperature, dew point temperature, wind speed, solar radiation, and cloud cover. HSPF uses meteorological data to generate runoff and pollutant loads. Modeled runoff and pollutant loads from point and nonpoint sources were routed through stream reaches. Representative rainfall and potential evapotranspiration (PET) are the key meteorological inputs to HSPF.

Five-minute meteorological data from three MESONET stations as shown in Figure A-4 are used in the watershed model to represent the spatial variations. However, cloud cover data are not available at the MESONET stations. The cloud cover data from the NOAA NCDC stations of Tahlequah Municipal Airport and Claremore Regional Airport are used for the modeling domain. Detailed information of these stations is given in Table A-3. Daily PET data was computed in WDMUtil of BASINS using Hamon's method (Hamon, 1961). Daily PET was then desegregated to hourly values using WDMUtil.

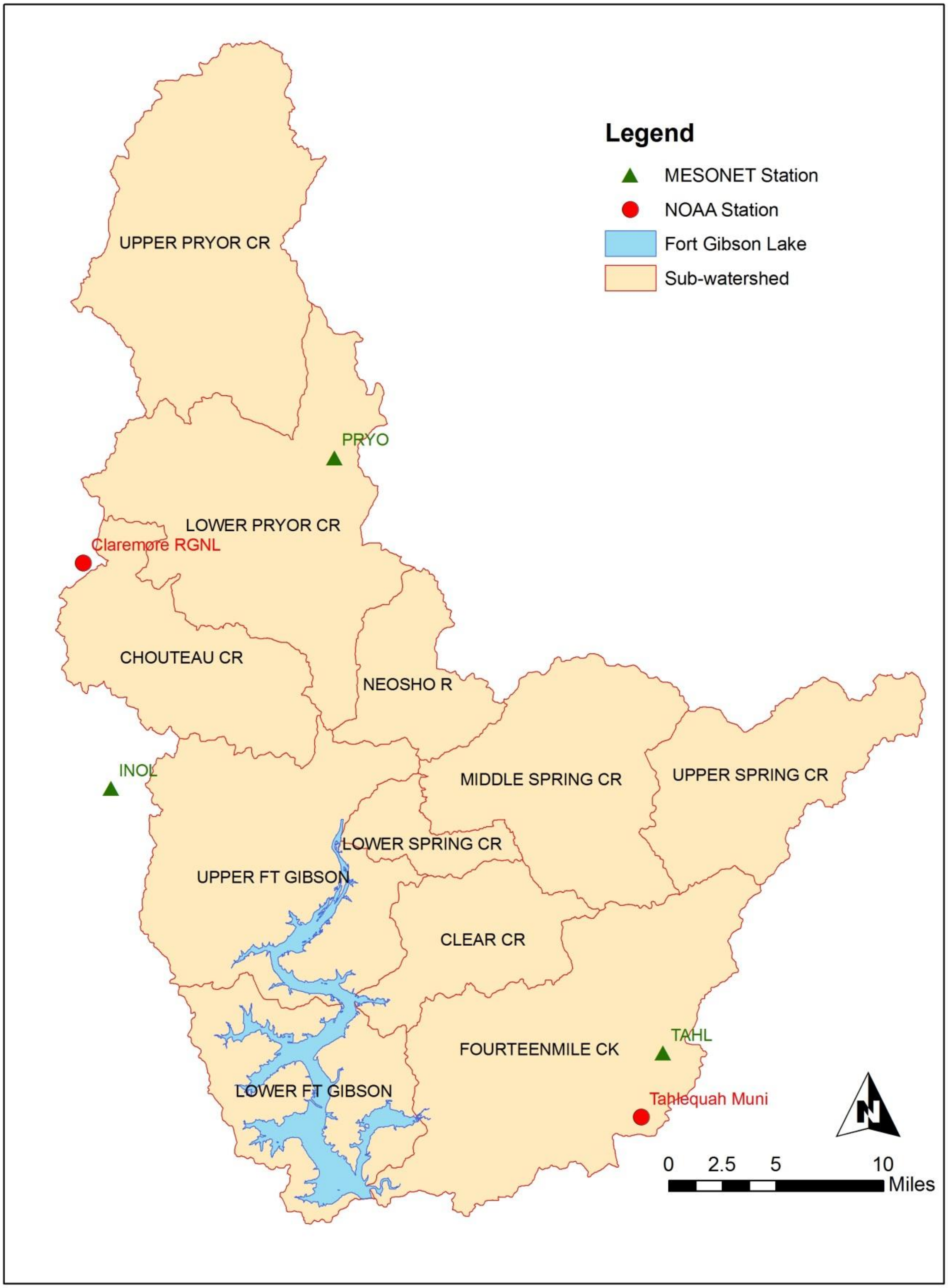

Figure A-4 Locations of MESONET and NOAA Meteorological Stations

Table A-3 Meteorological Stations Used in the HSPF Model

Station ID	Data Frequency	Station Name	Latitude	Longitude
PYRO	5-minute	Pryor	36.36914	-95.27138
INOL	5-minute	Inola	36.14246	-95.45067
TAHL	5-minute	Tahlequah	35.97235	-94.98671
Tahlequah	Hourly	Tahlequah Municipal Airport	35.92900	-95.00400
Claremore	Hourly	Claremore Regional Airport	36.29400	-95.47900

A-3.6 Point Source Discharge

The EPA National Pollutant Discharge Elimination System (NPDES) shows 10 wastewater facilities (point sources) discharge into the Neosho River. Five facilities, as shown in Figure A-5 and Table A-4, with a monthly average discharge higher than 0.1 MGD (0.15 cfs) were considered in this study. The waterbody (HSPF reach) receiving the effluent from each point source was identified using either the EPA's Permit Compliance System (PCS) data or their geographic locations using GIS.

Table A-4 Information of the Wastewater Treatment Facilities

NPDES_ID	Name	Facility	Latitude	Longitude	Design flow (MGD)
OK0022781	CHELSEA ECONOMIC DEV ATHRTY WWTP	MUNICIPAL or WATER DISTRICT	36.519322	-95.422621	0.5
OK0022764	CHOUTEAU WWTP	MUNICIPAL or WATER DISTRICT	36.188785	-95.317584	0.32
OK0040258	CALPINE PRYOR	PRIVATELY OWNED	36.238940	-95.275241	Inactive, permit closed in 2013
OK0040479	PRYOR CREEK WWTP	MUNICIPAL or WATER DISTRICT	36.271443	-95.340967	1.67
OK0022772	LOCUST GROVE WWTP	MUNICIPAL or WATER DISTRICT	36.207583	-95.171417	0.75

Effluent data for these NPDES facilities are required for model inputs of flow, water temperature, Total Suspended Solids (TSS), Total Organic Carbon (TOC), Nitrogen (TN,TKN,TON,NH3,NO3), Phosphorus (TP,TOP,PO4), Ultimate BOD (BODU) and Inorganic Suspended Solids (InorgSS). Discharge Monitoring Report (DMR) data were obtained from the EPA website (Table A-4). Monthly data were available for these five NPDES facilities during January 2004 to December 2008.

If a required water quality parameter is not available then stoichiometric ratios of typical effluent concentrations were used to estimate the missing parameter from available observations according to the facility type and literature values (Metcalf & Eddy, Inc., 1991; Rozzi et al., 1999; Stoddard et al., 2002; Hyder and Bari, 2011). Based on the BOD5 and TSS effluent data available from the DMR files, the Locust Grove WWTP (OK0022772) and Pryor Creek WWTP are categorized as tertiary or advanced waste treatment (AWT). Chelsea Economic Dev Athrty WWTP (OK0022781), Chouteau WWTP (OK0022764), and Calpine Pryor (OK0022772) are described as secondary treatment (SEC). Daily time series of flow and all effluent parameters were assigned from either observed data or estimated data based on linear interpolation of effluent data from 1 January 2004 through 31 December 2008.

Table A-5 Monitored DMR Data at the NPDES Facilities

Facility	Flow	TSS	CBOD5	DO	NH4
CHELSEA ECONOMIC DEV ATHRTY WWTP	√	√	√		
CHOUTEAU WWTP	√	√	√		
CALPINE PRYOR	√	√			
PRYOR CREEK WWTP	√	√	√	√	√
LOCUST GROVE WWTP	√	√	√	√	√

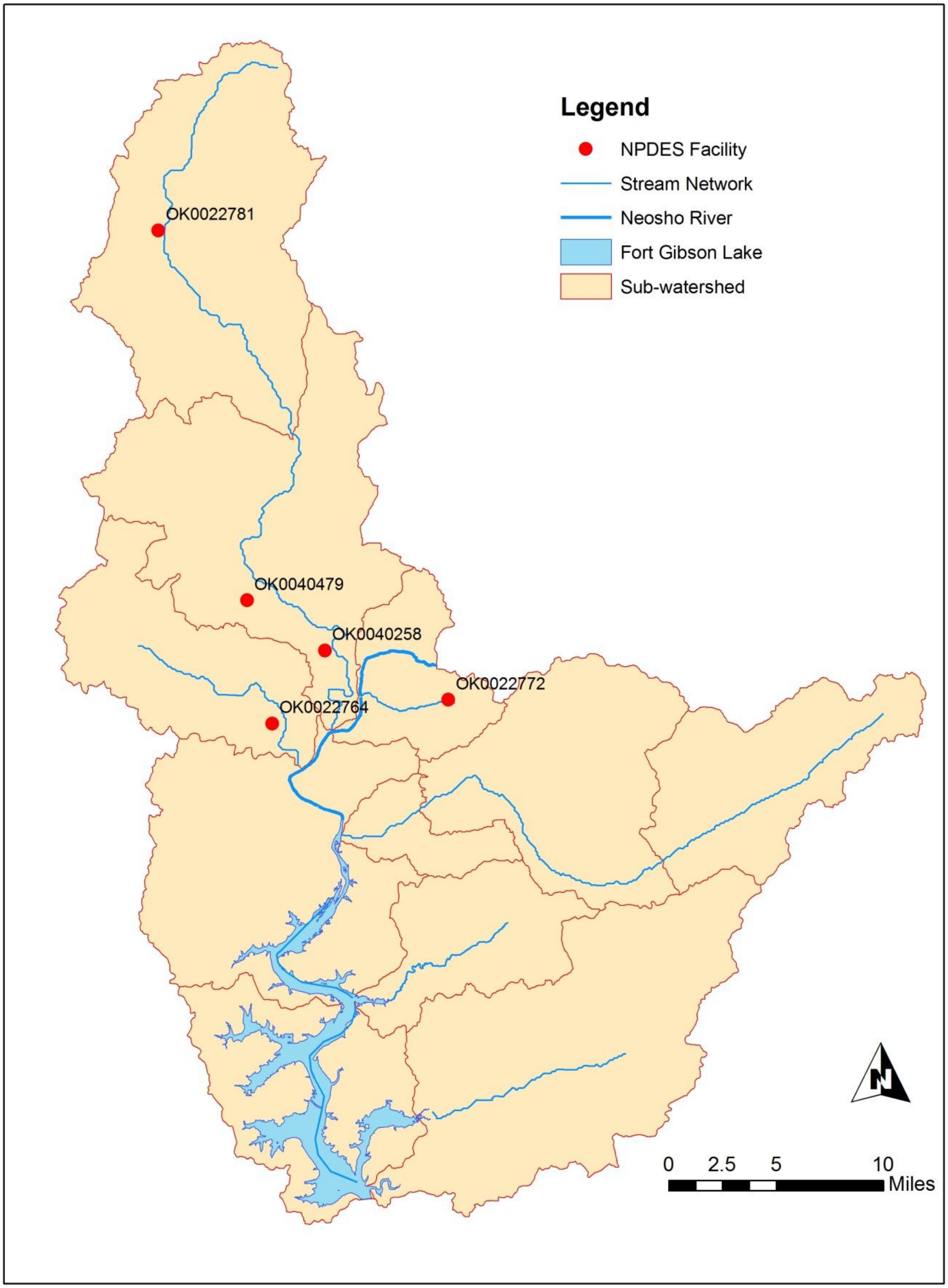

Figure A-5 Locations of the Major NPDES Facilities

A-3.7 Initial Conditions

In a continuous simulation model it is necessary to specify the state of the system at the start of the simulation. In HSPF, initial conditions are specified by assigning values to a number of state variables. HSPF input for initial hydrologic conditions are not directly measurable quantities. Generally, the variables that determine the initial hydrologic condition of the watershed were estimated by adjusting their values to match modeled flow with observed data. In this modeling project, a one-year spin up period was run to diminish the impact of initial conditions.

A-3.8 Model Comparison Statistics

Daily flow data are available at Pryor Creek. The model performance, or model-data comparison, statistical parameters selected for the calibration of the Fort Gibson Lake watershed model are the mean percent error (MPE), determination coefficient (R^2), and Nash-Sutcliffe Efficiency Coefficient (NS).

The MPE, R^2, and NS are calculated by

$$MPE = \frac{\sum_{i=1}^{N} \frac{(O_i - X_i)}{O_i}}{N}$$

$$R = \frac{N * \sum O_i X_i - \sum O_i * \sum X_i}{\sqrt{(N * \sum X_i^2 - \sum X_i * \sum X_i)(N * \sum O_i^2 - \sum O_i * \sum O_i)}}$$

$$NS = 1 - \frac{\sum_{i=1}^{N} (O_i - X_i)^2}{\sum_{i=1}^{N} (O_i - O_m)^2}$$

respectively.

Where:

O – the observed value;
X – the corresponding model value in space or time;
N – the number of valid data/model pairs; and
O_m – the mean of the observed data.

A-3.9 Hydrological Calibration Results

For the Fort Gibson Lake watershed model, flow was calibrated at upper Pryor Creek as shown in Figure A-2. The watershed model flow was calibrated for the period of January 1, 2008 through December 31, 2008.

The observed flow data at Pryor Creek and station location information were obtained by request from USACE. The USACE started to collect flow data on January 1, 2007 as shown in Figure A-6. There was an unusually high peak of observed flow of 23,200 cfs on May 8, 2007. Considering the total contributing area of 87,656.7 acres, it would require a daily rainfall of 6.3 inches for the entire contributing watershed to generate this high peak flow with an assumption that the entire contributing watershed is impervious and there are no evaporation and interception. There are three MESONET stations close to the upper Pryor Creek: PYRO, VINI, and NOWA as shown in Figure A-7. The observed rainfall data during May 5-13, 2007 for these three stations are given in Table A-5. Among these three stations, PRYO has the largest rainfall of 2.6 inches on May 7, 2007, which is still much lower than 6.3 inches. It is deemed that there could be errors in the observed flow data in 2007; hence, the 2007 flow data were not used in model-data comparison during flow calibration. Only the 2008 flow data at Pryor Creek were used for flow calibration.

Table A-6 Observed Daily Rainfall at MESONET Stations around Upper Pryor Creek (inch)

Date	PYRO	VINI	NOWA
5/5/2007	0	0	0
5/6/2007	0.08	0.03	0.29
5/7/2007	2.6	1.53	1.54
5/8/2007	0.14	0.07	0.18
5/9/2007	0.52	0.06	0.06
5/10/2007	0.35	0.5	0.11
5/11/2007	0	0.01	0
5/12/2007	0	0	0.01
5/13/2007	0	0	0

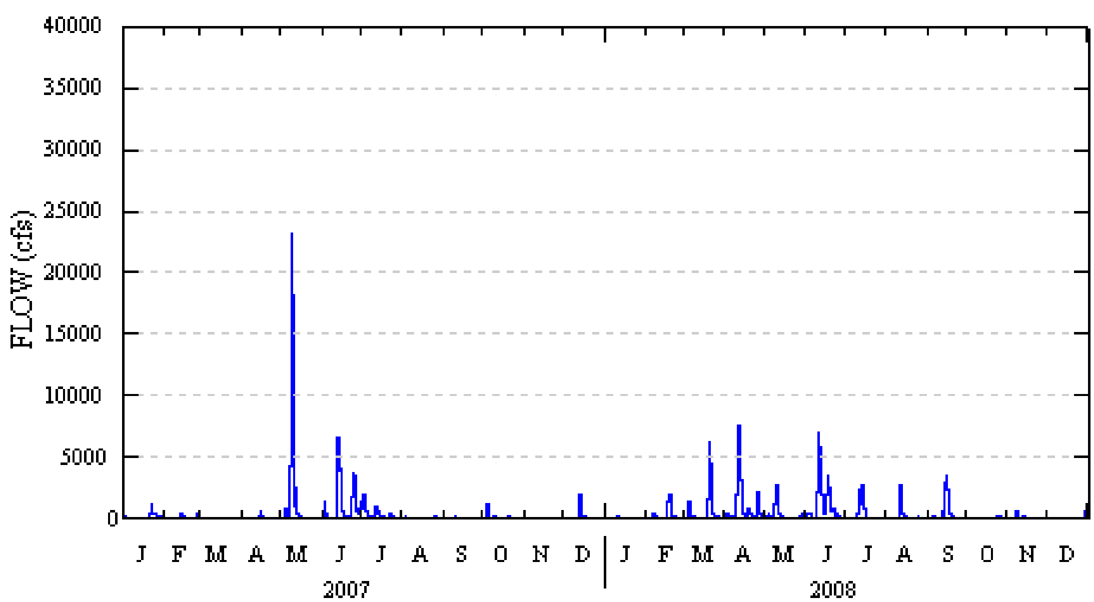

Figure A-6 Observed Flow Plot at the Pryor Creek

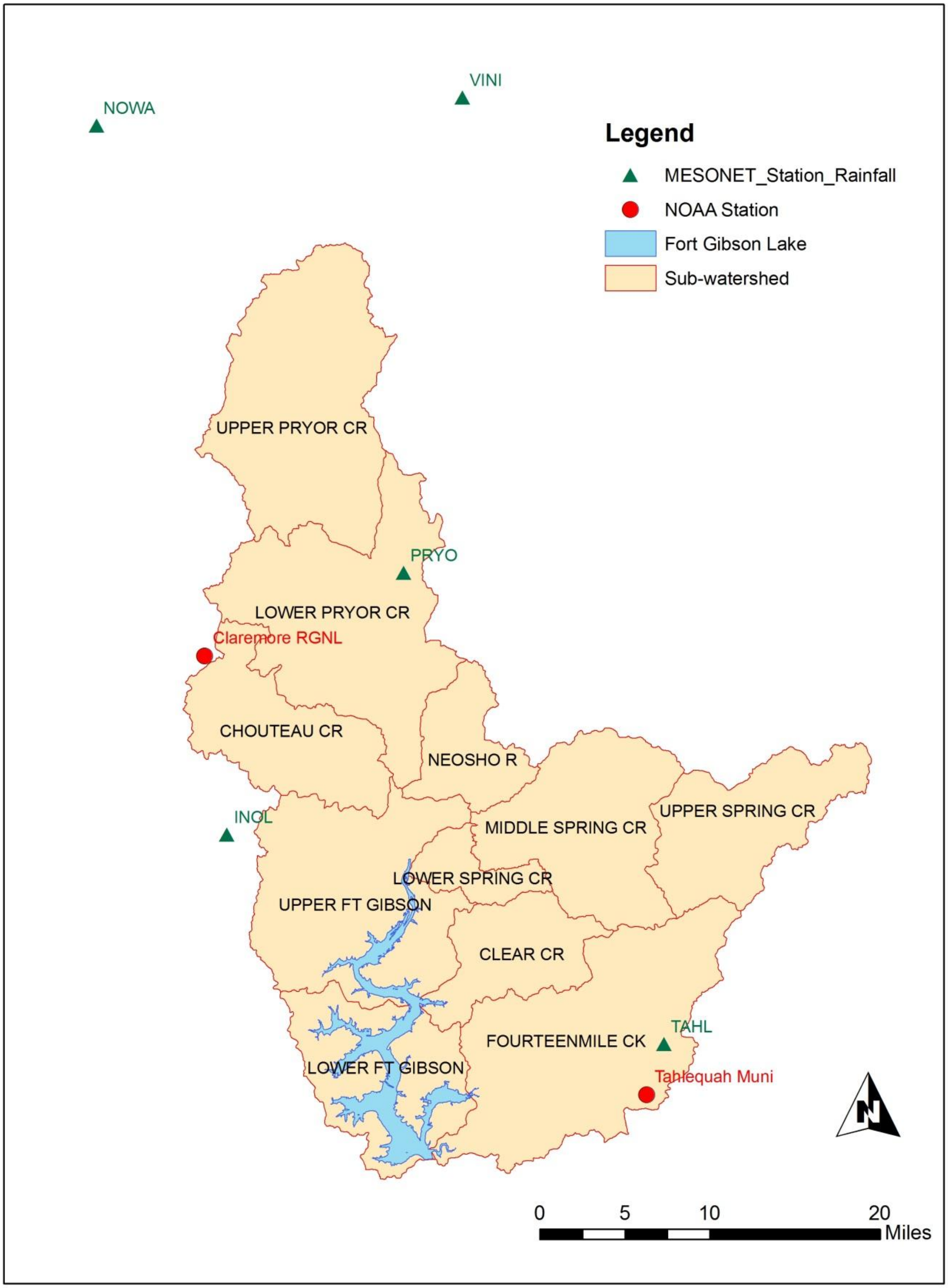

Figure A-7 MESONET Stations Close to the Upper Pryor Creek

The calibration plot for year 2008 is shown in Figure A-8. Generally, the hydrological calibration results are good with the mean percent error (MPE) of 7.6%. The watershed model slightly under-estimates the observed flow with average simulated flow of 328.7 cfs versus average monitored flow of 351.6 cfs. The calculated correlation coefficient between the observed and modeled flow is 0.79 and the Nash-Sutcliffe Efficiency Coefficient (NS) value is 0.44.

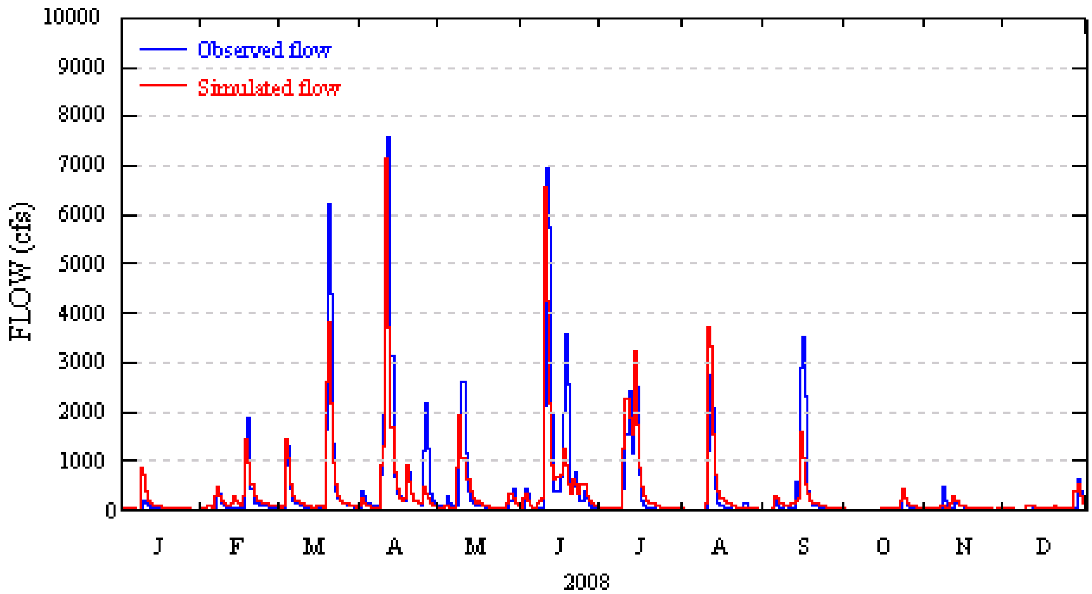

Figure A-8 Year 2008 Flow Calibration Plot at the Pryor Creek

A-3.10 Water Quality Calibration Results

Observed water temperature, DO, NO3, NH3, TN, PO4, and TP data are only available data at Spring Creek on a monthly basis. The calculated statistics between simulated and modeled data are given in Table A-6.

The model performance for water temperature simulation is good as indicated by the calculated correlation coefficient of 0.92 and the Nash-Sutcliffe Efficiency Coefficient (NS) of 0.70 in Table A-6. The simulated water temperature generally reflects the seasonal trend of the observed temperature as shown in Figure A-9. The mean observed water temperature is 61.9 F degree, while the paired HSPF simulated water temperature is 60.8 F degree.

Generally speaking, the HSPF modeled DO concentrations reflect the trend of observed data as shown in Figure A-10. The simulated DO values are within the range of observed data. The HSPF model slightly over-estimates the DO concentrations with the mean observed DO concentration of 9.29 mg/L versus the mean simulated DO concentration of 9.58 mg/L. The calculated mean percent error (MPE) is -3.2%. The calculated correlation coefficient between the observed and modeled DO is 0.49 and the Nash-Sutcliffe Efficiency Coefficient (NS) is 0.08.

The HSPF simulated nitrogen results agree fairly well with the observed data as shown in Figures A-11 to A-13. All the observed NH4 concentrations are labeled less than 0.05 mg/L and the paired simulated NH4 concentrations are all lower than 0.05 mg/L as shown in Figure A-12. The calculated statistics for NO4 and TN are given in Table A-6. The HSPF model under-estimates the NO3 and TN concentrations with the mean percent error (MPE) 41.4% for NO3 and 37.8% for TN (Table A-6). The calculated correlation coefficient and the Nash-Sutcliffe Efficiency Coefficient (NS) for TN are 0.21 and -0.35, respectively.

The calibrated results of PO4 and TP are given in Figure A-14 and Figure A-15. The calculated statistics are given in Table A-6. The HSPF model slightly under-estimates both PO4 and TP. The mean observed PO4 and TP are 0.008 and 0.015 mg/L whereas the mean simulated PO4 and TP concentrations are 0.006 and 0.013 mg/L as shown in Figures A-14 and A-15, respectively.

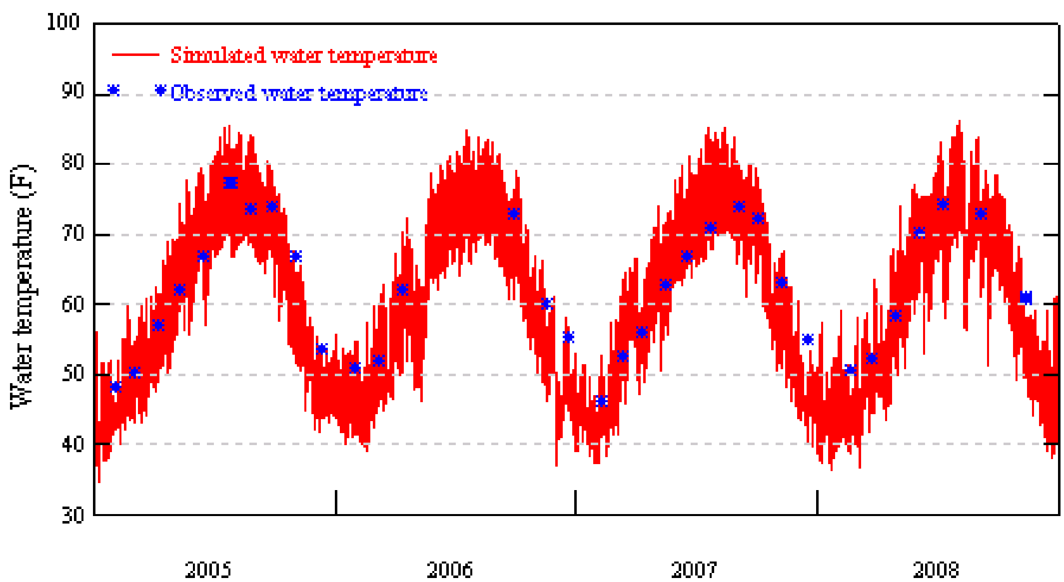

Figure A-9 Water Temperature Calibration Plot at the Spring Creek

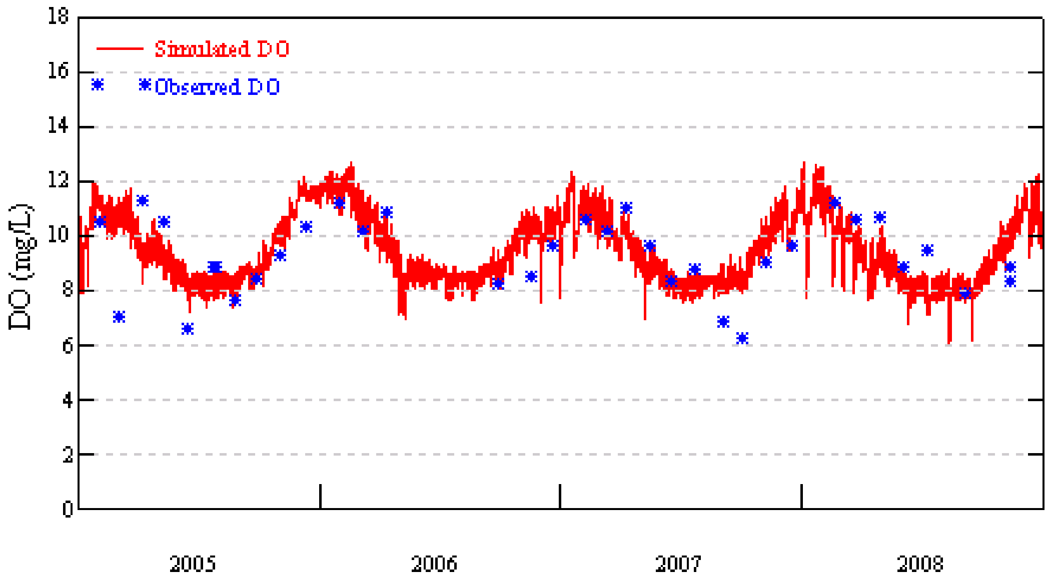

Figure A-10 DO Calibration Plot at the Spring Creek

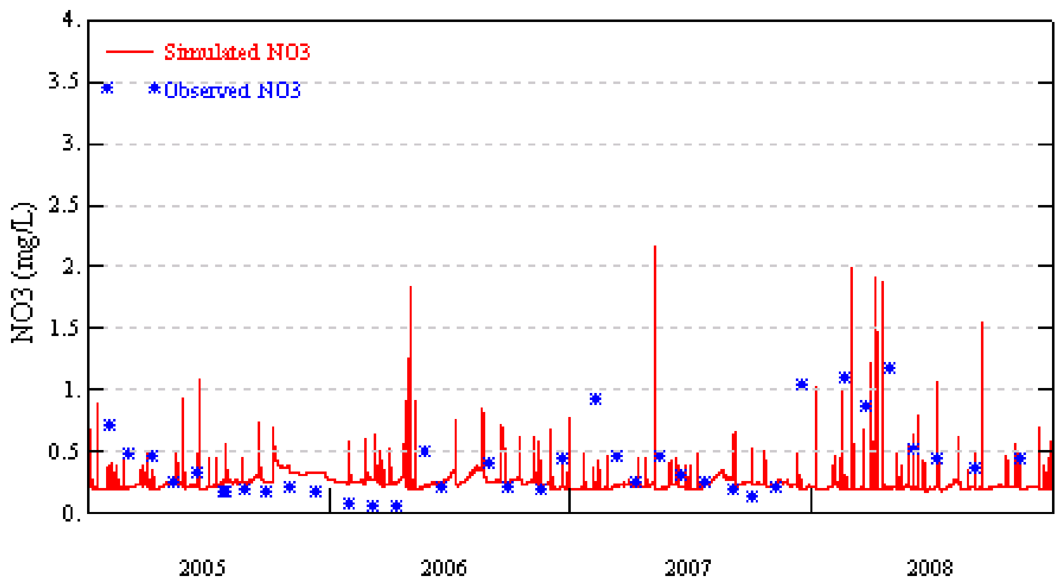

Figure A-11 NO3 Calibration Plot at the Spring Creek

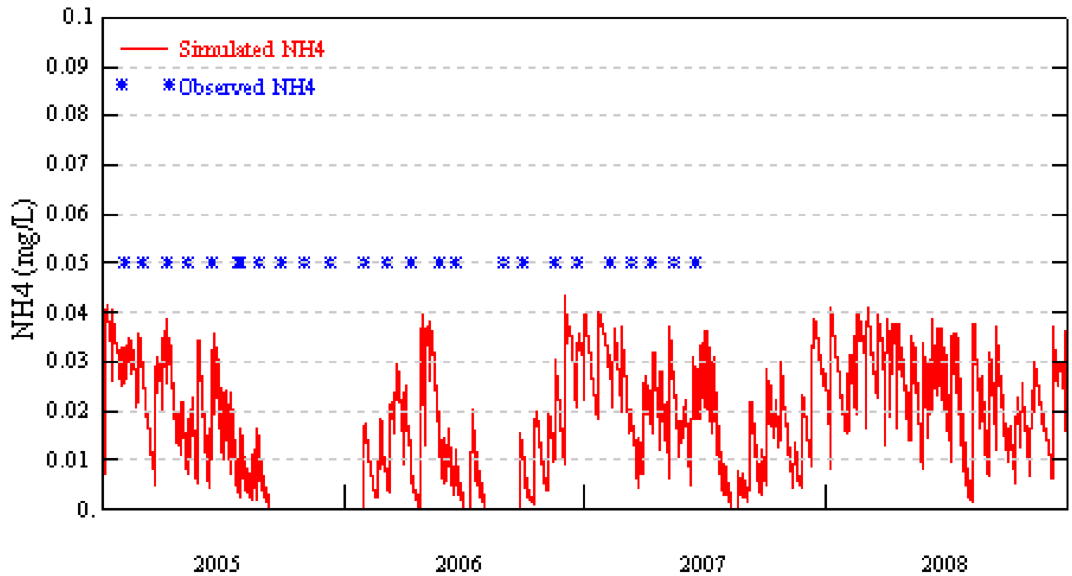

Figure A-12 **NH4 Calibration Plot at the Spring Creek**

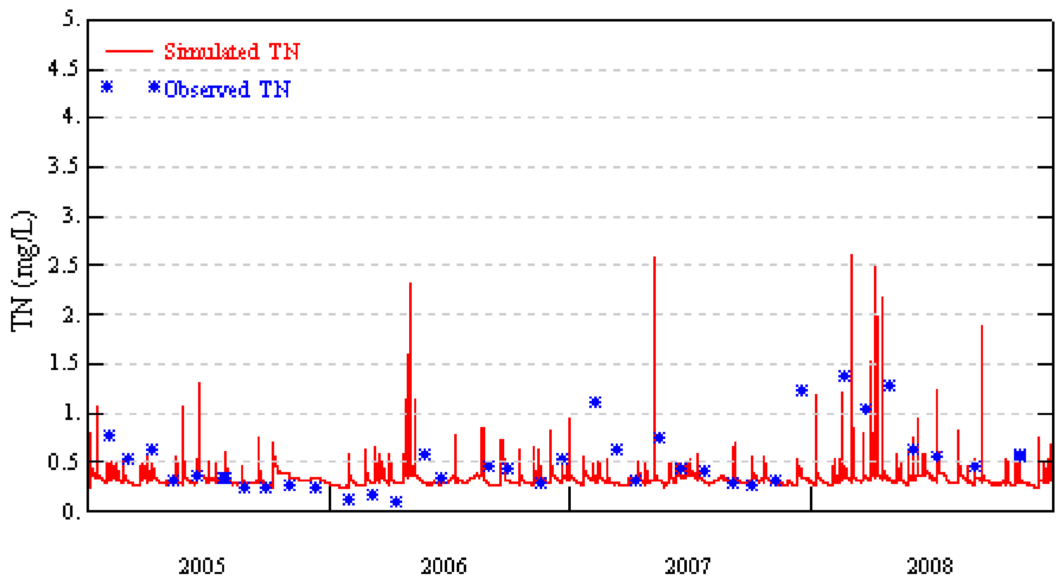

Figure A-13 **TN Calibration Plot at the Spring Creek**

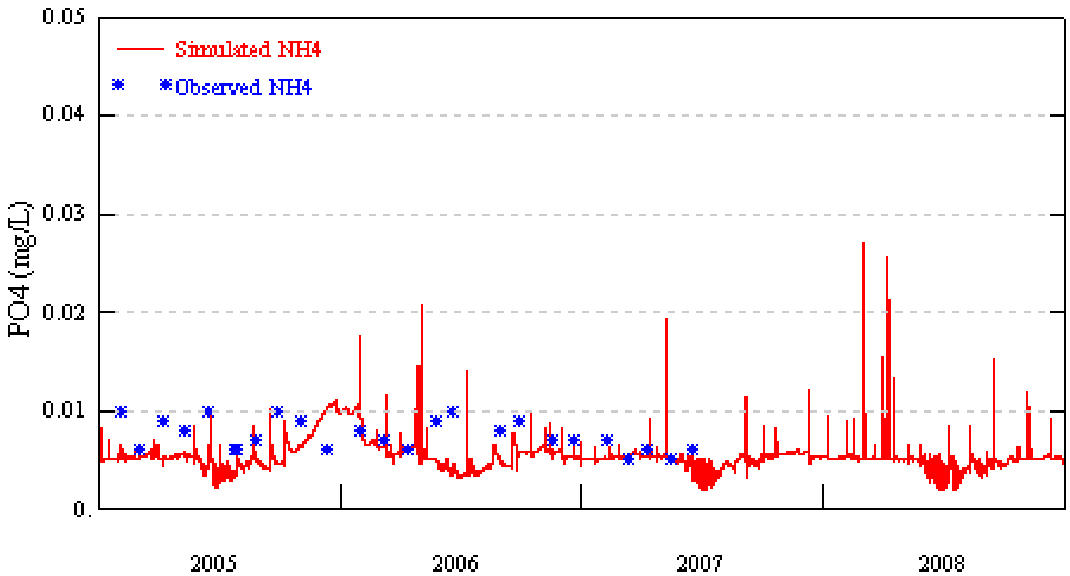

Figure A-14 PO4 Calibration Plot at the Spring Creek

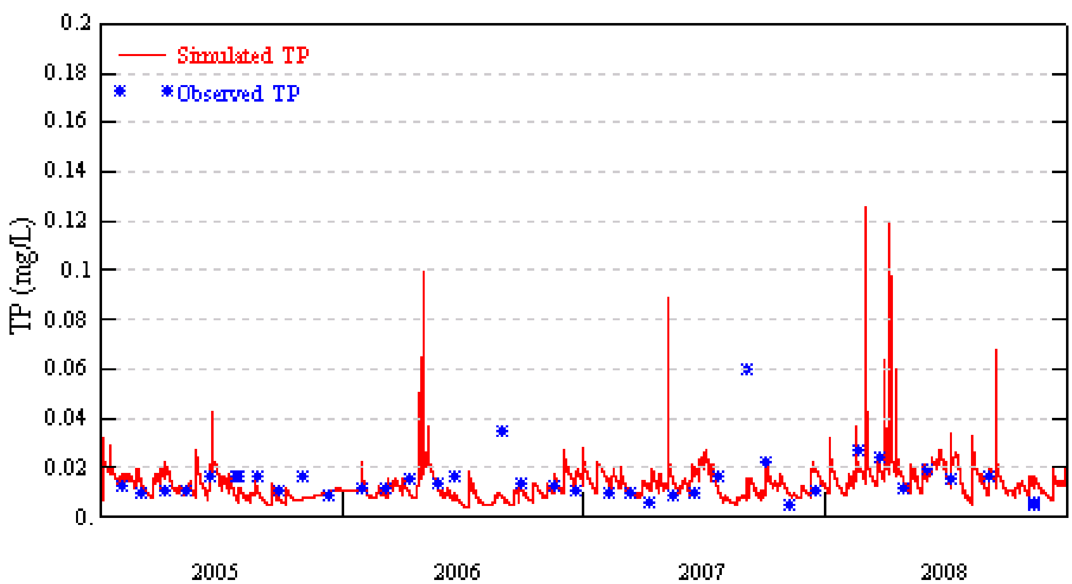

Figure A-15 TP Calibration Plot at the Spring Creek

Table A-7 Calculated Statistics for the Calibrated Water Quality Parameters

Parameter	Mean observed	Mean simulated	MPE	R	NS
Water temperature (F)	61.89	60.82	1.7	0.92	0.70
DO (mg/L)	9.29	9.58	-3.2	0.49	0.08
NO3 (mg/L)	0.406	0.239	41.2	-0.61	-0.52
TN (mg/L)	0.519	0.322	37.8	0.21	-0.35
PO4 (mg/L)	0.008	0.006	26.0	-0.09	-2.52
TP (mg/L)	0.015	0.013	-13.9	-0.19	-0.36

A-4. REFERENCES

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