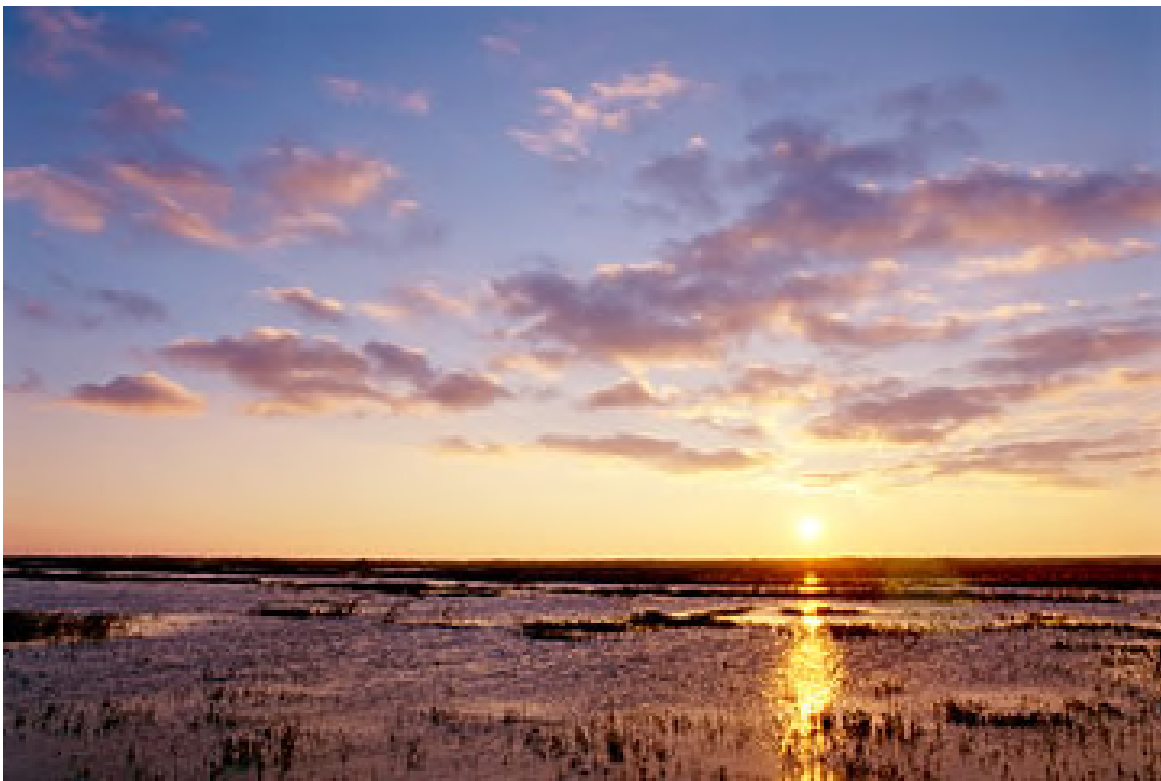


Final Hydrology and Water Quality Modeling Report

for the

Lake Jesup Watershed, Florida



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LIST OF ACRONYMS AND ABBREVIATIONS

BMAP	Basin Management Action Plan
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CDS	Continuous Deflective Separation (unit)
Department	Florida Department of Environmental Protection
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EFDC	Environmental Fluid Dynamics Code (model)
FDOH	Florida Department of Health
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellites
HSPF	Hydrologic Simulation Program – FORTRAN (model)
NASA	National Aeronautics and Space Administration
NEXRAD	Next-Generation Radar
NH ₄	Ammonia
NO ₃	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NO _x	Nitrogen Oxide
OrgN	Organic Nitrogen
OrgP	Organic Phosphorus
PDF	Portable Document Format
PLRG	Pollutant Load Reduction Goal
PO ₄	Orthophosphate
PSU	Practical Salinity Unit
SDR	Sediment Delivery Ratio
SJRWMD	St. Johns River Water Management District
SOD	Sediment Oxygen Demand
SSURGO	Soil Survey Geographic Database
TAM	Total Ammonia
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WASP	Water Quality Analysis Simulation Program

Section 1.0 INTRODUCTION

Lake Jesup is one of the largest lakes in Central Florida and is part of the St. Johns River system. Lake Jesup has a surface area of about 8,000 acres and drains a watershed of about 85,000 acres, including a large portion of Seminole County, a small portion of Orange County, the entire City of Winter Springs, and portions of the City of Altamonte Springs, City of Casselberry, Town of Eatonville, City of Lake Mary, City of Longwood, City of Maitland, City of Orlando, City of Oviedo, City of Sanford, and City of Winter Park.

The Florida Department of Environmental Protection (department) identified Lake Jesup as impaired for nutrients and unionized ammonia. To address these impairments, the department adopted total maximum daily loads (TMDLs) in 2006, which set limits on the amount of total phosphorus (TP) and total nitrogen (TN) that the lake could receive and still meet water quality standards. The department worked with local stakeholders to develop a basin management action plan (BMAP) to implement projects needed to achieve the TMDLs. The BMAP was adopted in 2010.

During BMAP development, the stakeholders raised concerns about the Bathtub model used to develop the TMDLs. The main concerns were that the model did not account for attenuation of nutrients in the watershed and that in-lake processes, such as nitrogen fixation and sediment flux, were not included. To address these concerns, the department and St. Johns River Water Management District (SJRWMD) committed to developing a new model during the first BMAP iteration to better represent Lake Jesup and its watershed.

After BMAP adoption, SJRWMD developed three models for Lake Jesup in order to set their Pollutant Load Reduction Goal (PLRG) for the lake. These models included the watershed Hydrologic Simulation Program – FORTRAN (HSPF) model, in-lake hydrodynamics Environmental Fluid Dynamics Code (EFDC) model, and in-lake water quality dynamics Water Quality Analysis Simulation Program (WASP) model. These models provided more detailed watershed loading, updated land use coverage, updated urban best management practices (BMPs) coverage, and in-lake water quality dynamics, which were all improvements from the original Bathtub model that was used to develop the TMDLs. SJRWMD completed development of these models in 2015 and their model reports are attached in **Appendix D** for the HSPF model and **Appendix E** for the EFDC and WASP models.

To develop the PLRG, SJRWMD focused on calibrating the HSPF model to the total watershed loading to the lake and including a general representation of the in-lake processes in the EFDC and WASP models. However, for the TMDL and BMAP processes, the department needed more detailed models to better represent the distribution of nutrient loading throughout the watershed and to account for the in-lake nutrient loading. Therefore, the department contracted with Tetra Tech, Inc. and AMEC Foster Wheeler, Inc. to evaluate and revise SJRWMD's models to meet the needs of the TMDL and BMAP processes. The overall goals were to update the models so that the department had the necessary tools to revise the TMDLs, if needed, and to update BMAP allocations and project credit calculations in future BMAP iterations.

This report summarizes the data used in the model updates (**Section 2.0**), revisions made and calibration results for the HSPF watershed model (**Section 3.0**), and revisions made and calibration results for the EFDC and WASP in-lake models (**Section 4.0**). This report focuses on the modifications made to the

models to meet TMDL and BMAP needs. Additional details about the models and setup can be found in the SJRWMD model reports in **Appendix D** and **Appendix E**.

1.1 MODEL LINKAGES

The HSPF model simulates the hydrology and water quality conditions in the watershed. The EFDC model simulates hydrodynamics and the WASP model simulates water quality within Lake Jesup. The three models were used together to represent the watershed loading and the resulting conditions in Lake Jesup.

The HSPF model provided tributary flows and temperature to the EFDC model, as well as the tributary water quality concentrations to the WASP model. The EFDC and WASP models were linked through the hydrodynamic linkage file. The EFDC model hydrodynamic linkage file provided the inter-cell flow and velocities, as well as cell volume, temperature, and salinity at each simulation time step, representing the circulation and transport patterns in the lake. This file was subsequently used by the WASP model to evaluate the fate and transport of the different water quality variables under analysis.

Additional details about the results from each of the models are included in **Section 3.0** for the HSPF model and **Section 4.0** for the EFDC and WASP models.

Section 2.0 DATA COMPILATION AND EVALUATION

This section describes the data used in the HSPF, EFDC, and WASP models and the sources of those data.

2.1 METEOROLOGICAL DATA

2.1.1 HSPF Model

The updated model uses the same meteorological data as SJRWMD's model (Jia 2015), and SJRWMD provided the necessary data for the model extension period (2012-2014). The data for the HSPF model include precipitation, potential evaporation, air temperature, wind speed, solar radiation, dew point temperature, and cloud cover. Precipitation data were obtained from SJRWMD's Next-Generation Radar (NEXRAD) Doppler radar rainfall database, and these data are collected on a 2 x 2 kilometer grid. Potential evapotranspiration data and solar radiation data are from Geostationary Operational Environmental Satellites (GOES) datasets maintained by the U.S. Geological Survey (USGS). The GOES data are collected daily. Other meteorological data were obtained from the Orlando International Airport weather station and were downloaded from the Integrated Surface Database maintained by the National Oceanic and Atmospheric Administration (NOAA).

Table 1 summarizes the meteorological data used in the HSPF model, and **Appendix D** has additional details about how the meteorological data were processed for the model.

TABLE 1: METEOROLOGICAL DATA FOR THE HSPF MODEL

Data Type	Data Source	Description
Precipitation	SJRWMD	Doppler 2 x 2 km radar grid data
Potential Evaporation	USGS	GOES 2 x 2 km satellite grid data
Solar Radiation	USGS	GOES 2 x 2 km satellite grid data
Air Temperature	NOAA	Orlando International Airport gauge data
Wind Speed	NOAA	Orlando International Airport gauge data
Dew Point Temperature	NOAA	Orlando International Airport gauge data
Cloud Cover	NOAA	Orlando International Airport gauge data

2.1.2 EFDC and WASP Models

The updated EFDC and WASP models use the same meteorological data as SJRWMD's models (Sucsy and Brandt-Williams 2015). The EFDC model uses daily rainfall and evaporation data to maintain the mass budget and hourly winds to simulate wind-driven lake circulation and mixing. The WASP model uses daily solar radiation and fraction of daylight hours for simulating phytoplankton growth, as well as daily water temperature for modification of chemical reaction rates and growth and respiration of phytoplankton. Daily time series of solar radiation, evaporation, wind speed, air temperature, and relative humidity were obtained from USGS satellite-based evapotranspiration estimates that are available over Florida on a 2-kilometer grid (<http://fl.water.usgs.gov/et/>). Time series of hourly wind speed and direction were obtained from the National Aeronautics and Space Administration (NASA) Land Data Assimilation System. Additional details about the meteorological data in the EFDC and WASP models can be found in **Appendix E**.

2.2 FLOW AND WATER QUALITY DATA

2.2.1 HSPF Model

Flow data used in HSPF model calibration were from five long-term daily USGS gages, which are located at five sites along Howell Creek, Soldiers Creek, and Gee Creek (**Table 2**). The flow data from these gages were downloaded from USGS's website at <http://waterdata.usgs.gov/fl/nwis/rt>.

TABLE 2: FLOW GAGES USED FOR HSPF MODEL CALIBRATION

USGS Gage	Location
02234308	Howell Creek Above Lake Howell
02234324	Howell Creek Below Lake Howell
02234344	Howell Creek Outlet
02234384	Soldiers Creek
02234400	Gee Creek

There are more than 200 water quality stations within the Lake Jesup watershed. Since it is not feasible to setup and calibrate the model to that many stations, Tetra Tech selected a sub-set of these stations, as shown in **Table 3**, which were strategically located throughout the watershed. These stations also include the locations where stakeholders added monitoring as part of the first BMAP iteration. The data from these stations are collected as monthly grab samples. The locations of the water quality stations used for HSPF model calibration and validation are shown in **Figure 1**.

TABLE 3: WATER QUALITY STATIONS USED FOR HSPF MODEL CALIBRATION AND VALIDATION

Station ID	Station Location	Model Subwatershed
21FLKWATSEM-TRIPLETN-1	Seminole – Lake Triplet North	10
21FLSEM PRA	Prairie Lake	10
21FLSEM FAR	Fairy Lake	12
21FLSEM GEE-CASS	Gee Creek – Casselberry	15
21FLSEM ML01	Greenwood Lake	17
21FLSEM SOLDN-LM	Soldiers Creek Downstream – Lake Mary	18
21FLSEM SOLUP-LM	Soldiers Creek Upstream – Lake Mary	18
21FLSEM NAV	Navy Canal at Pineway	27
21FLCEN 20011158	Ditch at Cameron Avenue	30
21FLCEN 20010011	Sweetwater Creek just Upstream of Deleon Street – Oviedo	38
21FLSEM SOLARY	Solary Canal	38
21FLSEM BERC	Bear Gully Creek	41
21FLSEM BGU	Bear Gully Lake	42
21FLORANXBURKTCNL2	Lake Burkett Discharge South of Aloma Street	44
21FLSEM HCRB	Howell Creek	45
21FLSEM HOW	Lake Howell	46
21FLSEM HCCB	Howell Creek	47
Lake Waumpi	Lake Waumpi – Maitland	49
Weir at Howell Branch	Weir at Howell Branch – Winter Park	51
21FLORANHB26	Lake Minnehaha	52
21FLORANHB13	Lake Gem	53
21FLORANHB32	Park	53

Station ID	Station Location	Model Subwatershed
21FLORANHB36	Lake Sue	61
21FLORL SUE	Lake Sue in Orlando, Florida	61
21FLORL ROWENA	Lake Rowena in Orlando, Florida	63
21FLORL ADAIR	Lake Adair in Orlando, Florida	75
21FLSEM TUS	Tuskawilla Lake	91
21FLSEM ALM	Lake Alma	93
21FLKWATSEM-SEARCY-1	Seminole – Lake Searcy	94
21FLSEM SEA	Lake Searcy	94
21FLSEM CHUBB	Chub Creek at Lake Mary Boulevard	96
21FLCEN 20010763	Salt Creek at Packard Avenue	98

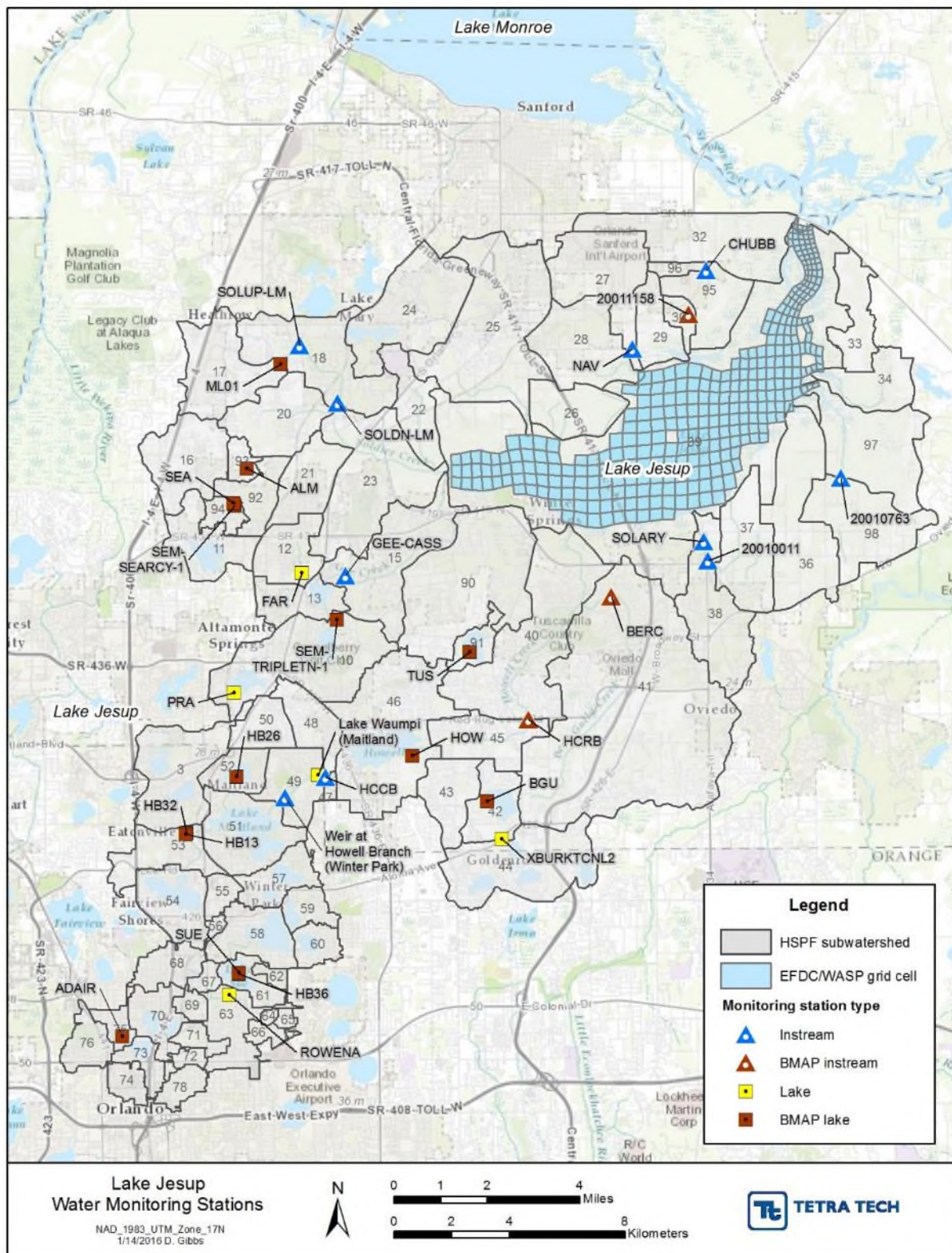


FIGURE 1: MAP OF WATER QUALITY STATIONS USED IN MODEL CALIBRATION/VERIFICATION

2.2.2 EFDC and WASP Models

Water level data from USGS station 02234435 were used to force the EFDC model downstream boundary condition. These data were obtained from the USGS website at <http://waterdata.usgs.gov/fl/nwis/rt>. In addition, water quality data from 11 in-lake stations were used to calibrate both the EFDC and WASP models. The water quality data were obtained from the department and Seminole County.

The locations of the flow and water quality stations are shown in **Figure 2**. Additional details about the water quality stations are summarized in **Table 4**.

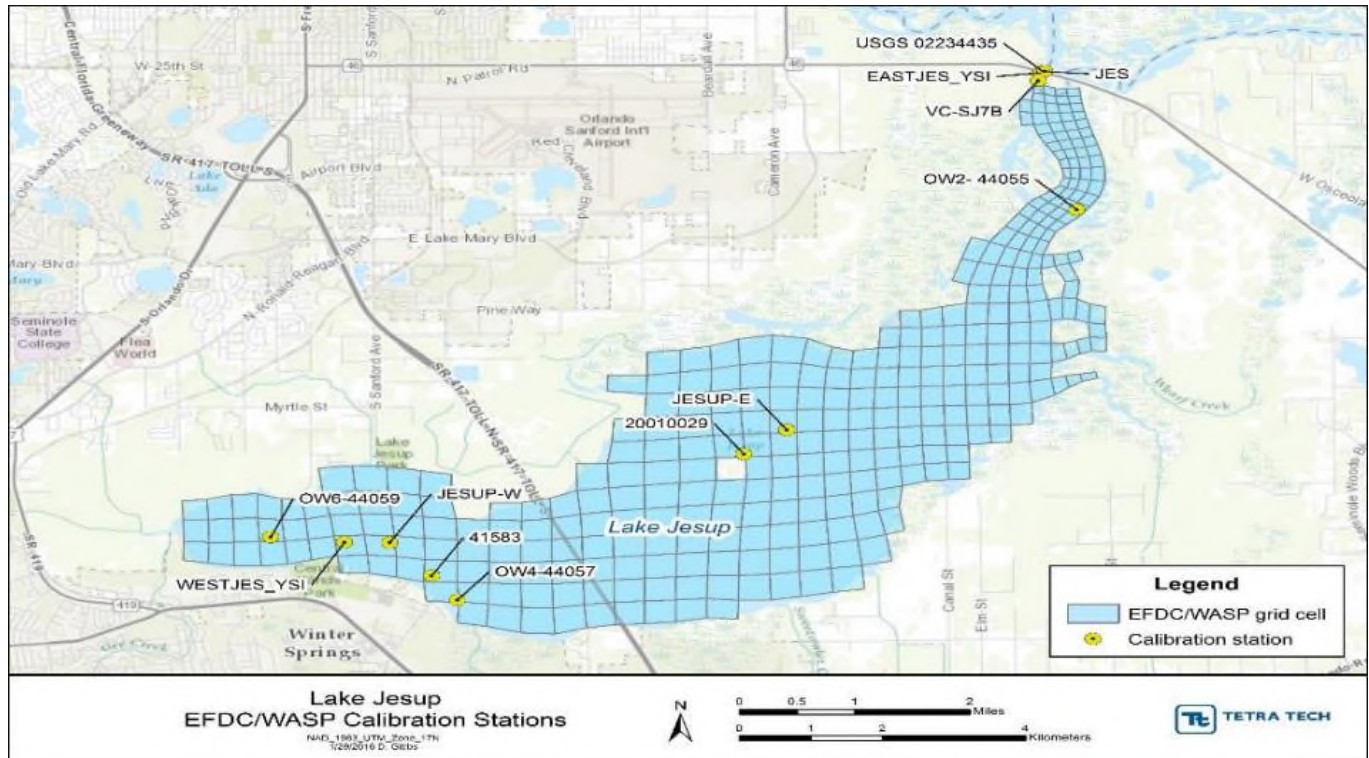


FIGURE 2: LOCATION OF EFDC AND WASP MODEL CALIBRATION STATIONS

TABLE 4: EFDC AND WASP MODEL CALIBRATION STATIONS

Sampling Entity	Station ID	Station Type	Sampling Frequency	Model
Seminole County	EASTJES_YSI	YSI*	Continuous	EFDC and WASP
Seminole County	JES	Water Quality	Quarterly	EFDC and WASP
Volusia County	VC-SJ78	Water Quality	Monthly	EFDC and WASP
SJRWMD	OW2	Water Quality	Monthly	EFDC and WASP
Seminole County	JESUP-E	YSI*	Continuous	EFDC and WASP
Department	21FLCEN 20010029	Water Quality	One time (2008)	WASP
SJRWMD	OW4	Water Quality	Monthly	EFDC and WASP
Department	21FLGW 41583	Water Quality	One time (2012)	EFDC and WASP
Seminole County	JESUP-W	YSI*	Continuous	EFDC and WASP
Seminole County	WESTJES_YSI	YSI*	Continuous	EFDC and WASP
SJRWMD	OW6	Water Quality	Monthly	EFDC and WASP

* YSI sondes/probes are suspended at approximately one meter depth.

2.3 LAND USES IN THE HSPF MODEL

The updated HSPF model and SJRWMD model (Jia 2015) both use SJRWMD's 2009 land use and land cover. The land use classes in this coverage were grouped into 13 major land uses, which were aggregated based on similarities in hydrologic properties and nutrient loads. **Table 5** and **Figure 3** show the aggregated land use categories and where these land uses are located within the Lake Jesup watershed.

Tetra Tech also maintained SJRWMD's representation of wetlands in the model. The wetland land use category is split into two subgroups to represent riparian (adjacent to streams or lakes) or non-riparian wetlands. The model also accounts for whether riparian wetlands are impacted or pristine. Additional details about how the wetlands are characterized in the model are included in **Appendix D**.

TABLE 5: SUMMARY OF LAND USES IN THE LAKE JESUP WATERSHED

Land Use	Area (Acres)	Percent of Area
Low Density Residential (LDR)	4,857.8	5.70%
Medium Density Residential (MDR)	21,577.1	25.32%
High Density Residential (HDR)	5,331.7	6.26%
Industrial and Commercial (IND)	13,476.4	15.82%
Mining (MIN)	29.2	0.03%
Open Land (OPE)	1,116.4	1.31%
Pasture (PAS)	2,647.8	3.11%
Agriculture General (AGR)	2,990.5	3.51%
Agriculture Tree Crop (AGT)	620.2	0.73%
Rangeland (RAN)	1,394.9	1.64%
Forest (FOR)	5,150.7	6.05%
Water (WAT)	5,827.5	6.84%
Wetland (WET)	20,182.2	23.69%
Total	85,202.4	100.0%

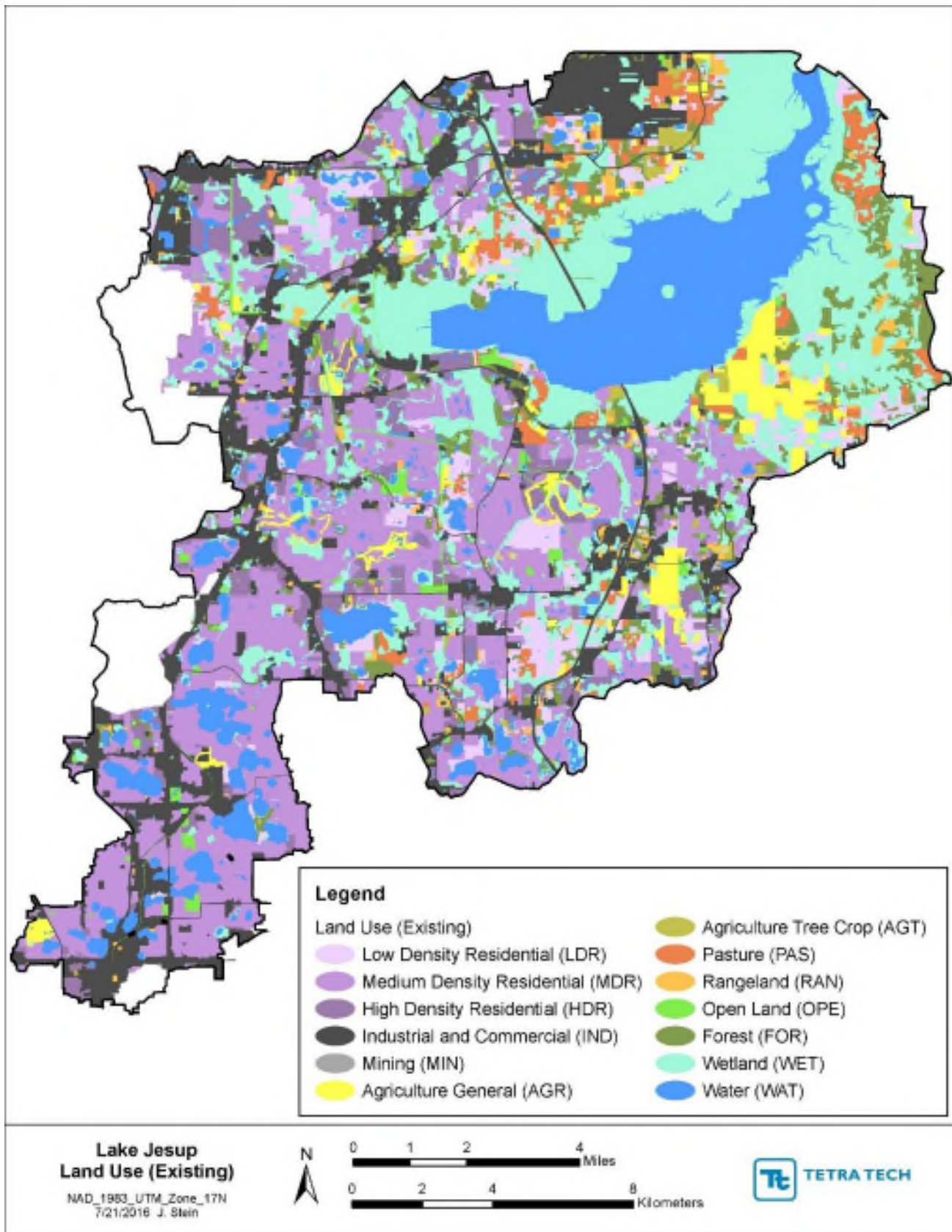


FIGURE 3: LAND USES IN THE LAKE JESUP WATERSHED

2.4 BMPs IN THE HSPF MODEL

The BMP coverage used in the updated HSPF model is the same coverage as was used in the SJRWMD model (Jia 2015). The model only includes urban BMPs; agricultural BMPs will be addressed through the BMAP process. The BMP coverage was based on information from the department, and includes structural BMPs that were part of the 2006 TMDL model, as well as completed structural BMPs that were included in the BMAP from 2006 through May 31, 2013. The BMPs in the model include baffle boxes, inlet baskets, continuous deflective separation (CDS) units, swales, dry detention ponds, wet detention ponds, City of Orlando 100% on-site retention, City of Orlando private BMPs, and lake drainage wells. For modeling purposes, these BMPs were grouped into eight categories based on their pollutant removal efficiencies. **Table 6** lists the acreage and percentage of watershed area served by each of these BMP categories.

TABLE 6: ACREAGE TREATED BY BMPs IN THE LAKE JESUP WATERSHED

BMP Type	Area Treated (Acres)	Percent of Watershed
Baffle Box, Inlet Basket, CDS Unit	2,417.3	2.8%
Alum	631.3	0.7%
Dry Pond	8,322.3	9.8%
Dry Pond Treatment Train	455.6	0.5%
Swale	443.9	0.5%
Wet Pond	13,106.2	15.4%
Wet Pond Treatment Train	544.1	0.6%
Drainage Well, Orlando 100% On-site Retention, Orlando Private BMPs	2,464.3	2.9%
Sum	28,385.0	33.2%

The BMP removal efficiencies used in the updated HSPF model are the same as those used in the SJRWMD model (Jia 2015). However, Tetra Tech revised the efficiencies of alum injection BMPs to better match the available literature. The BMP removal efficiencies for total suspended solids (TSS), ammonia (NH₄), nitrate (NO₃), orthophosphate (PO₄), organic nitrogen (OrgN), and organic phosphorus (OrgP) used in the HSPF model are presented in **Table 7**.

TABLE 7: BMP REMOVAL EFFICIENCIES IN THE HSPF MODEL

BMP Type	TSS Removal Efficiency (%)	NH ₄ Removal Efficiency (%)	NO ₃ Removal Efficiency (%)	PO ₄ Removal Efficiency (%)	OrgN and OrgP Removal Efficiency (%)
Baffle Box, Inlet Basket, CDS Unit ¹	30%	5%	5%	5%	5%
Alum ²	30%	50%	50%	90%	35%
Dry Pond ¹	40%	5%	5%	20%	20%
Dry Pond Treatment Train ¹	50%	10%	10%	25%	25%
Swale ¹	40%	15%	15%	15%	20%
Wet Pond ²	60%	25%	25%	55%	30%
Wet Pond Treatment Train ²	70%	30%	30%	60%	35%
Drainage Well ²	64%	64%	64%	64%	64%

¹ The removal efficiencies only apply to water quality constituents associated with surface runoff and interflow.

² The removal efficiencies apply to water quality constituents associated with surface runoff, interflow, and baseflow.

2.5 ATMOSPHERIC DEPOSITION IN THE HSPF MODEL

Simulation of atmospheric deposition in the updated HSPF model is the same as in the SJRWMD model (Jia 2015). Atmospheric deposition to the land surface is lumped into the nonpoint source loading from the land uses. Atmospheric deposition to the surface of streams and lakes in the watershed is modeled explicitly. The model assumes that atmospheric deposition only contributes inorganic forms of nitrogen and phosphorus. NH_4 , NO_3 , and PO_4 concentrations from wet deposition are set at 0.15 mg N/L, 0.74 mg N/L, and 0.04 mg P/L, which are the precipitation-weighted mean concentrations from site FL32 of the National Atmospheric Deposition Program (<http://nadp.sws.uiuc.edu>) located in Orange County. NH_4 , NO_3 , and PO_4 dry deposition rates are set at 37 mg N/m²/yr, 149 mg N/m²/yr, and 10 mg P/m²/yr, which are based on SJRWMD's dry deposition samples measured at Lake Lochloosa in Alachua County. The annual atmospheric deposition loadings are evenly allocated as monthly inputs in the HSPF model.

2.6 POINT SOURCES IN THE HSPF MODEL

As noted in the original TMDL document (DEP 2006), by 1983, direct discharges from wastewater treatment plants to Lake Jesup had been either routed outside the watershed or discharged to land application systems or percolation ponds. Therefore, there are no wastewater point sources that discharge directly to surface waters in the Lake Jesup watershed.

However, the City of Sanford North wastewater treatment facility, which is located in the Lake Monroe watershed, discharges to Lake Jesup through Site 10. Site 10 is a 1,800-acre wastewater reuse site located on the northeast shore of Lake Jesup. Site 10 provides additional treatment of the effluent from the wastewater treatment facility through a series of irrigation fields, wetlands, and stormwater treatment ponds. The representation of Site 10 in the updated model is the same as the SJRWMD model (Jia 2015). Site 10 is delineated into three parts: (1) the area outside of the Lake Jesup watershed, which is not included in the model; (2) the area with the reuse water irrigation fields drain to Lake Jesup, which is treated by the stormwater ponds before discharging to Lake Jesup; and (3) the area of Site 10 that is forested areas and wetlands, which does not receive the reuse water. Additional details about the representation of Site 10 in the HSPF model are included in **Appendix D**.

2.7 SEPTIC SYSTEMS IN THE HSPF MODEL

Septic system loads were input to the SJRWMD version of the HSPF model as point source time series ("direct pipes"), only for those parcels intercepting the 50 foot buffer around streams and lakes. Loads to streams and lakes from septic systems in parcels more than 50-feet away from streams and lakes are implicitly grouped into the overall pollutant loadings from residential land uses (Jia 2015). As part of the model update, Tetra Tech added representation of all septic systems within the watershed, both failing and properly functioning.

The total number of septic systems in each subwatershed was estimated using the septic system coverages provided by Orange County and Seminole County. Based on these coverages, there are 30,730 septic systems in Seminole County and 74,651 septic systems in Orange County. The septic system loading was estimated using 2.8 people per household, which is the average persons per household for the two counties based on U.S. Census Bureau data. Tetra Tech used an estimate of 70 gallons of water per day per person (U.S. Environmental Protection Agency [USEPA] 2002). It was assumed that 15% of the water used in the house never makes it to the septic tank, and that it takes an average of 60 days for the septic flow to reach a waterbody. A first order decay rate was applied to each constituent to determine the concentration

after 60 days. For phosphorus, it was assumed that 90% was sorbed to sediment; therefore, only 10% of the effluent concentration was used to calculate decay after 60 days. **Table 8** summarizes the effluent concentrations, decay rates, and concentration at stream after 60 days used in the HSPF model, which were taken from USEPA 2002.

TABLE 8: SEPTIC SYSTEM EFFLUENT CONCENTRATIONS USE IN THE HSPF MODEL

Parameter	Effluent Concentration (mg/L)	Decay Rate (1/day)	Concentration at Stream (mg/L)**
Biochemical oxygen demand (BOD)	105	0.16	0.003
TN	70.258	0.1	0.1263
OrgN	0.458	0.1	0.0008
Total ammonia (TAM)	10.5	0.1	0.0189
Nitrogen oxide (NO _x)	59.3	0.1	0.1066
TP*	0.3	0.014	0.1287
OrgP*	0.3	0.014	0.1287
PO ₄ *	0	0.014	0
TSS	10	0	10
Dissolved oxygen (DO)	N/A	N/A	4

N/A – Not applicable

*Assumes that 90% of phosphorus is sorbed to sediment.

**Assumes septic system flow takes an average of 60 days to reach stream.

Non-failing septic system loads were developed into a direct input time series for each subwatershed. For failing septic systems, the failure rates that SJRWMD calculated were used (Jia 2015). SJRWMD used Florida Department of Health (FDOH) data to determine that the number of annual system repairs ranges from 74 to 556 for Seminole County and 973 to 1,199 for Orange County in the period from 2003 to 2012 (FDOH 2013). To account for the possibility that not all failing septic systems are reported and repaired, the high end of the reported ranges were used. Therefore, the estimated septic system failure rates for Seminole County and Orange County are 1.8% (556 failures out of 30,730 septic tanks) and 1.6% (1,199 failures out of 74,651 septic tanks).

Both failing and functioning septic tanks were input in the model as point sources.

2.8 BATHYMETRY IN THE EFDC AND WASP MODELS

Lake Jesup bathymetry in the updated models was the same as SJRWMD's models (Sucsy and Brandt-Williams 2015). The bathymetry is from a digital elevation model (DEM) of the area developed by SJRWMD for the St. Johns River Water Supply Impact Study. The DEM contains a grid of 2,000 x 2,000 cells at 10-meter spacing. Additional details are included in **Appendix E**.

2.9 GROUND WATER SEEPAGE IN THE EFDC AND WASP MODELS

Ground water flows and nutrient loads from seepage were estimated by Harper (2013). The values in the Harper report were used as a starting point in the updated models.

Section 3.0 HSPF WATERSHED MODEL

In updating the HSPF model, Tetra Tech focused on addressing major stakeholder comments as well as on addressing limitations of the original model that affected the information needed for the TMDLs and BMAP. The model re-calibration focused on improving the model loading in comparison to available measured data in the watershed. The major modifications made to the HSPF model are as follows:

- Refined the model into additional subwatersheds, which allows for a comparison between the model results and the significant amount of stakeholder data collected as part of the first BMAP.
- Created site-specific model F-Tables for key lakes throughout the watershed using the available bathymetry and stage data. In combination with the additional subwatershed delineations, this allowed for a more refined water quantity and quality calibration.
- Confirmed that the hydrological results continue to track well with USGS gage data in the watershed after refining the subwatershed delineations and creating site-specific F-Tables.
- Revised land use loading rates for OrgP to better simulate instream water quality conditions.
- Added representation of all septic systems within the watershed, both failing and properly functioning.
- Revised the simulation of alum injection BMPs to better match the available literature.
- Revised the simulation of upland loading of PO₄ to be associated with sediment.
- Revised the simulation of instream PO₄ to be associated with sediment.
- Used local soils data to disaggregate TSS into representative instream sand, silt, and clay components.
- Used a sediment delivery ratio to account for upland trapping of sediment.
- Revised the water quality calibration to be a manual calibration that focused on the range of the observed data rather than just the medians.
- Improved significantly the model's ability to simulate observed water quality in many of the upstream monitoring stations. For example, the simulation of TP at several locations in the previous model was significantly overestimated but is now more consistent with the observed data (although a few places are still over predicted).

3.1 HSPF MODEL REVISIONS

3.1.1 Model Domain

The SJRWMD model included a separate gaged domain and an ungaged domain. Tetra Tech and the department determined that the best approach was to keep the two model domains separate to reduce model run time. Therefore, the original model structure with two domains was retained.

3.1.2 Simulation Period

The original model simulation period ended in 2012, and Tetra Tech extended the simulation period through 2014. Tetra Tech gathered the 2013-2014 meteorological data from SJRWMD, as well as the 2013-2014 water quality data for BMAP monitoring stations, and other key stakeholder stations in the watershed, from the department. These data were used to update the model simulation period. The current model simulation period is therefore January 1, 2002 through December 31, 2014, with the year 2002 as a one-year model spin up period.

3.1.3 Re-Delineation of Subwatersheds

Several stakeholders commented that the original HSPF model was not calibrated to the BMAP data in the upstream portion of the watershed. To address these comments, Tetra Tech updated the subwatershed delineations to add additional subwatersheds so that eight of the stakeholder stations in the Lake Jesup watershed could be used for model calibration. The remaining BMAP stations, as well as additional stakeholder stations, were used to assess the model results, although the data from these stations were not used for model calibration.

The department requested that Tetra Tech delineate subwatersheds for each of the six other impaired lakes in the watershed. These lakes are Lake Howell, Lake Tuskawilla, Lake Alma, Lake Adair, Lake Searcy, and Bear Gully Lake. The City of Longwood, City of Orlando, City of Winter Park, and Seminole County provided delineations for the impaired lakes, and the associated lakes in their chains, which Tetra Tech used to update the model delineations.

The original model subwatershed delineations and the revised subwatershed delineations are shown in **Figure 4**. Based on the boundaries provided by the stakeholders, several small areas from the original model domain were removed because they do not flow towards Lake Jesup (see **Figure 5**). The total number of modeling subwatersheds increased from 39 in the original model to 73 in the revised model.

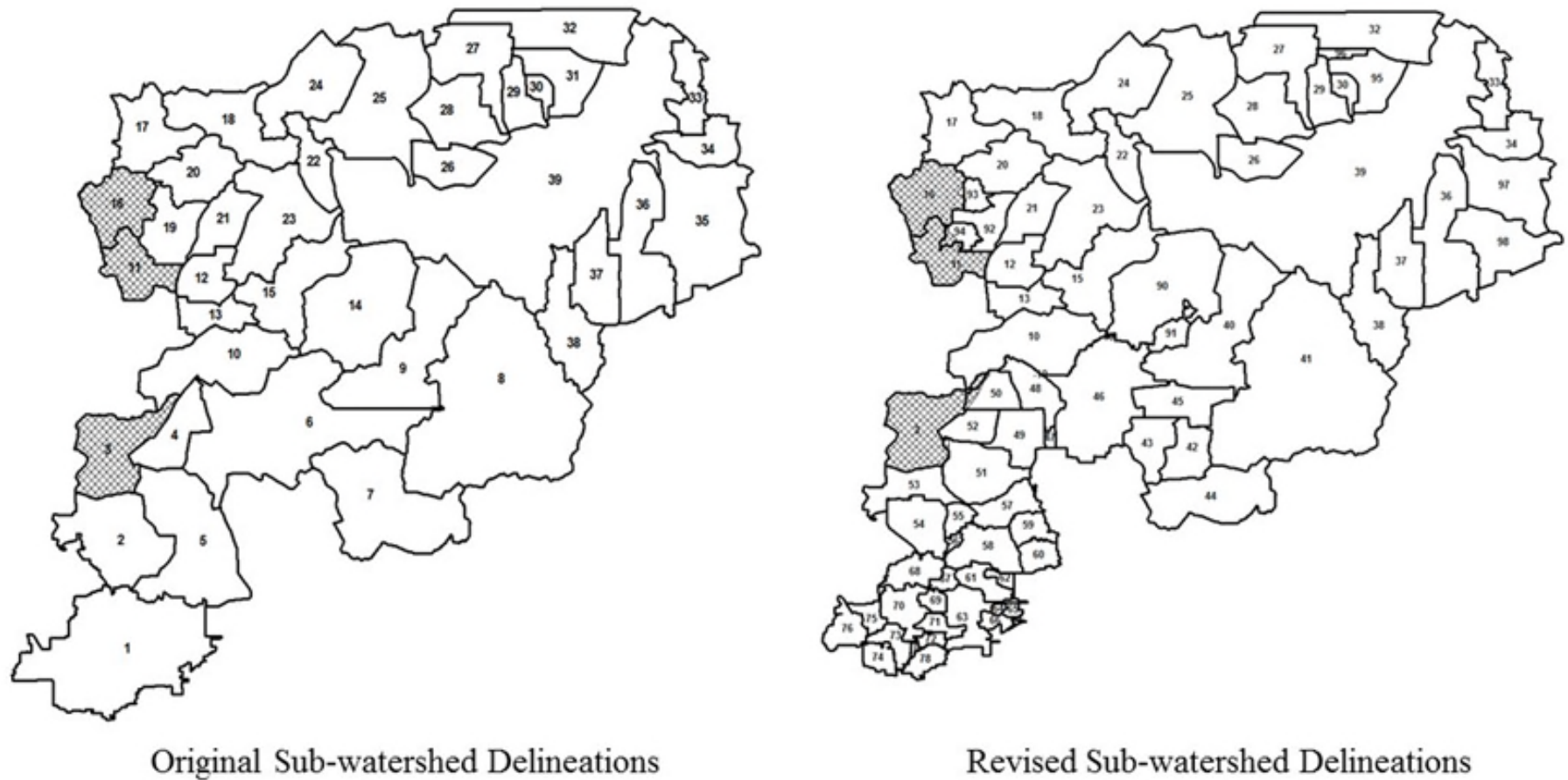


FIGURE 4: ORIGINAL AND REVISED SUBWATERSHED DELINEATIONS IN THE HSPF MODEL

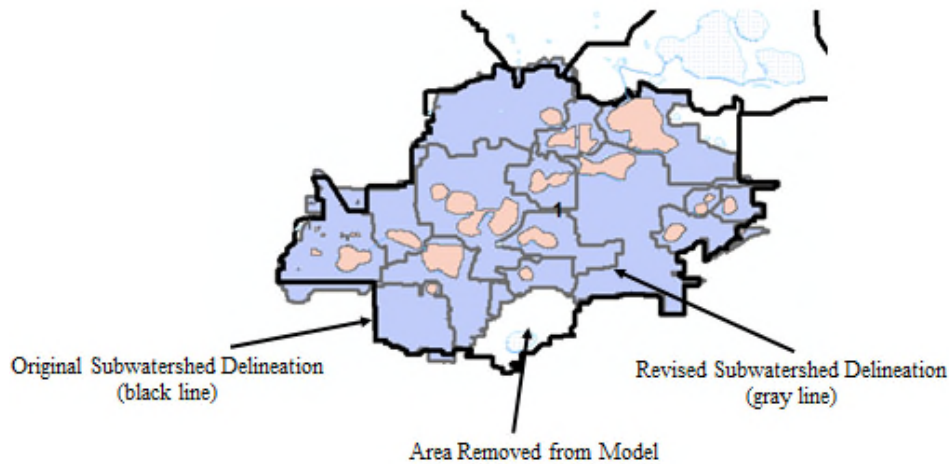


FIGURE 5: MODIFICATIONS MADE TO THE ORIGINAL SUBWATERSHED 1 DELINEATION

3.1.4 Sediment Sorption of Nutrients

Upland PO_4 is now simulated as associated with TSS for both pervious and impervious land uses, instead of simulated through its own buildup/washoff routines. Instream PO_4 is now modeled as sediment-associated in the reach simulation, using literature information (Stevenson et al 1999). Based on the current setup of the model, activating sediment-associated TAM causes numerical instabilities in TAM and DO concentrations throughout much of the modeling domain. Therefore, Tetra Tech did not activate sediment-associated TAM.

3.1.5 Septic Systems

Tetra Tech updated the model simulation for septic systems using an approach that accounts for both failing and functioning septic systems. **Section 2.7** provides the details for this approach.

3.1.6 Upland TSS Disaggregation into Instream Sand, Silt, and Clay

Tetra Tech used the available Soil Survey Geographic Database (SSURGO) county-level soils Geographic Information System (GIS) data to characterize surficial sand-silt-clay fractions of TSS. These data indicate that the composition of the soils in the watershed is approximately 95% sand, 3% silt, and 2% clay. These values were adjusted to 85% sand, 10% silt, and 5% clay in the model due to enrichment ratios favoring silt and clay, which are transported more easily than sand in runoff.

The simulated edge of the field loadings did not explicitly consider the sediment deposition processes on the land. Sediment deposition processes can occur anywhere between the point of erosion to the edge of the stream. Sediment deposition/trapping occurs due to reduced flow velocities in flatter areas, especially for larger sand and silt particles. To simulate the sediment removal processes from the upland loads to the edge of the stream loads, the following Sediment Delivery Ratio (SDR) was applied to the upland loads (U.S. Department of Agriculture Natural Resources Conservation Service 1983):

$$\text{SDR} = 0.417762 \times A - 0.134958 - 0.127097$$

A = drainage area (sq. miles)

SDRs were calculated for each individual subwatershed and the median value (0.27) was applied to represent typical conditions within the watershed.

3.1.7 TSS and BOD Simulations

Tetra Tech modified the upland loading rate of TSS to approximate the values presented in SJRWMD's internal document, Bergman 2004 (note that only a single loading value is presented rather than a range as is available for TN and TP). Tetra Tech also compared the simulation of instream TSS and BOD to the available data, and refined the TSS calibration to better match the data. However, the comparisons to BOD₅ were not given much weight since HSPF simulation is more approximate to carbonaceous BOD (CBOD). CBOD reflects the labile (readily available) portion of the organic matter/total organic carbon (TOC). Based on literature (Adey 2005, Vincent 2006, and Murasko 2009, and Ahn, et al 2009), labile carbon was estimated to be 5% to 35% in a north Florida watershed. It was assumed that 20% of TOC/organic matter is labile carbon, which means the refractory (relatively unavailable) portion is 80%. This results in a 1:4 relationship between labile and refractory carbon. Tetra Tech used literature values to determine the carbon to nitrogen ratio of 1:23 and the carbon to phosphorus ratio of 1:500. These ratios were used to estimate the refractory portions of OrgN and OrgP.

3.2 HSPF MODEL CALIBRATION RESULTS

3.2.1 Hydrology Calibration Results

After the additional subwatersheds were delineated and the 2013-2014 meteorological data were added, the updated hydrological model results were compared to the available USGS gage data in the watershed to determine how well the model is performing. The department requested that Tetra Tech use the general calibration/validation targets or tolerances for the HSPF model from Donigian (2002) to evaluate the model results. The targets or tolerances for hydrologic parameters are summarized in **Table 9**.

TABLE 9: DONIGIAN 2002 CALIBRATION/VALIDATION TARGETS OR TOLERANCES FOR HYDROLOGIC PARAMETERS

Category	Range for % Difference in Modeled Versus Observed Results	Range for Nash-Sutcliffe and R ² Values
Very Good	<10%	>0.8
Good	10% - 15%	0.7 - 0.8
Fair	15% - 25%	0.6 - 0.7
Poor	>25%	<0.6

As shown in **Table 10**, the majority of the model results closely match the observed data as evidenced by the “very good” and “good” ratings for the difference between the model and observed data for different statistical evaluations. In addition, **Figure 6** through **Figure 10** show graphically how the model is closely simulating the observed flows at the USGS gages. Additional plots and statistical evaluations of the revised hydrologic calibration are provided in **Appendix A**.

TABLE 10: HYDROLOGIC ERROR STATISTICS FOR STREAM CALIBRATION STATIONS ON PAIRED SIMULATED AND OBSERVED DATA

USGS Gage	Error in Total Volume	Error in Highest 10% Flows	Error in Lowest 50% Flows	Nash-Sutcliffe Coefficient of Efficiency	R ² Value
Gee Creek	7.25%	-1.26%	27.66%	0.85	0.88
(station 02234400)	Very Good	Very Good	Poor	Very Good	Very Good
Soldiers Creek	0.07%	-1.08%	13.23%	0.80	0.84
(station 02234384)	Very Good	Very Good	Good	Good	Very Good
Howell Creek Above Lake Howell	-0.09%	-2.96%	5.23%	0.82	0.91
(station 02234308)	Very Good	Very Good	Very Good	Very Good	Very Good
Howell Creek Below Lake Howell	-2.51%	-4.94%	1.30%	0.84	0.89
(station 02234324)	Very Good	Very Good	Very Good	Very Good	Very Good
Howell Creek Outlet	3.41%	-2.35%	6.64%	0.88	0.94
(station 02234344)	Very Good	Very Good	Very Good	Very Good	Very Good

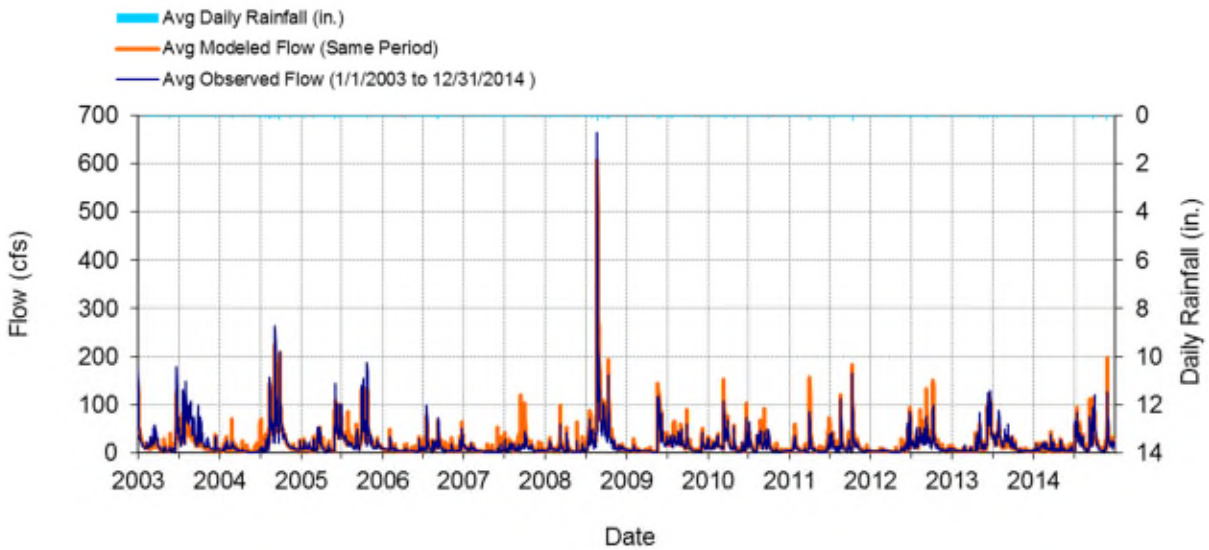


FIGURE 6: TIME SERIES COMPARISON OF MODEL RESULTS TO USGS GAGE 02234400 (GEE CREEK)

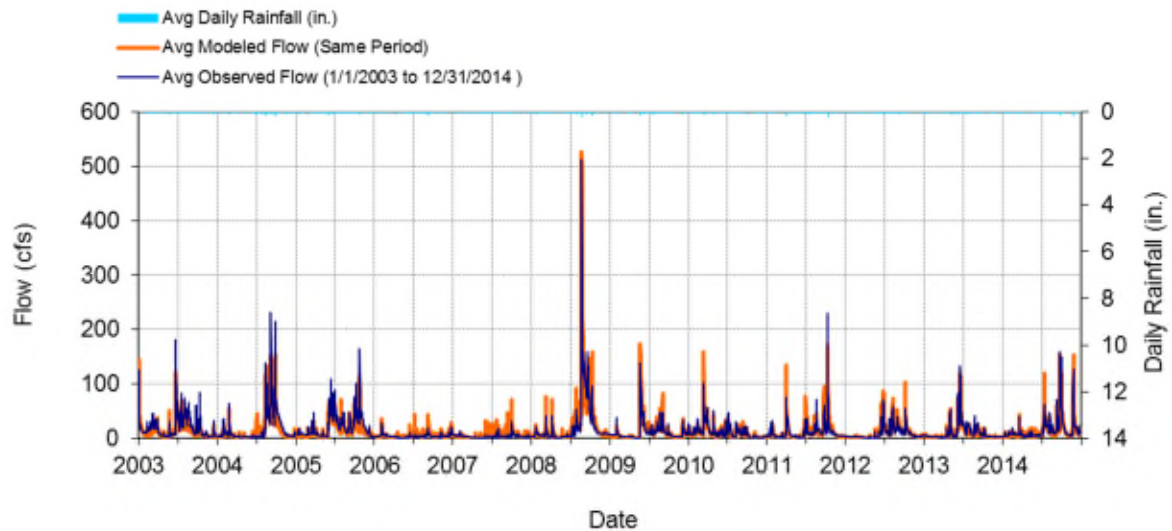


FIGURE 7: TIME SERIES COMPARISON OF MODEL RESULTS TO USGS GAGE 02234384 (SOLDIERS CREEK)

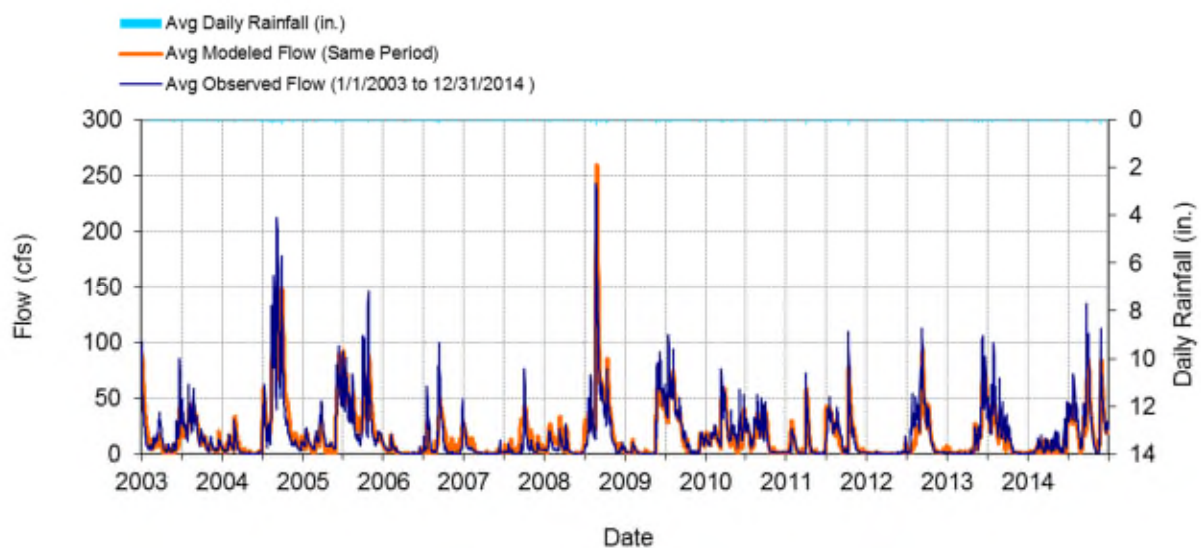


FIGURE 8: TIME SERIES COMPARISON OF MODEL RESULTS TO USGS GAGE 02234308 (HOWELL CREEK)

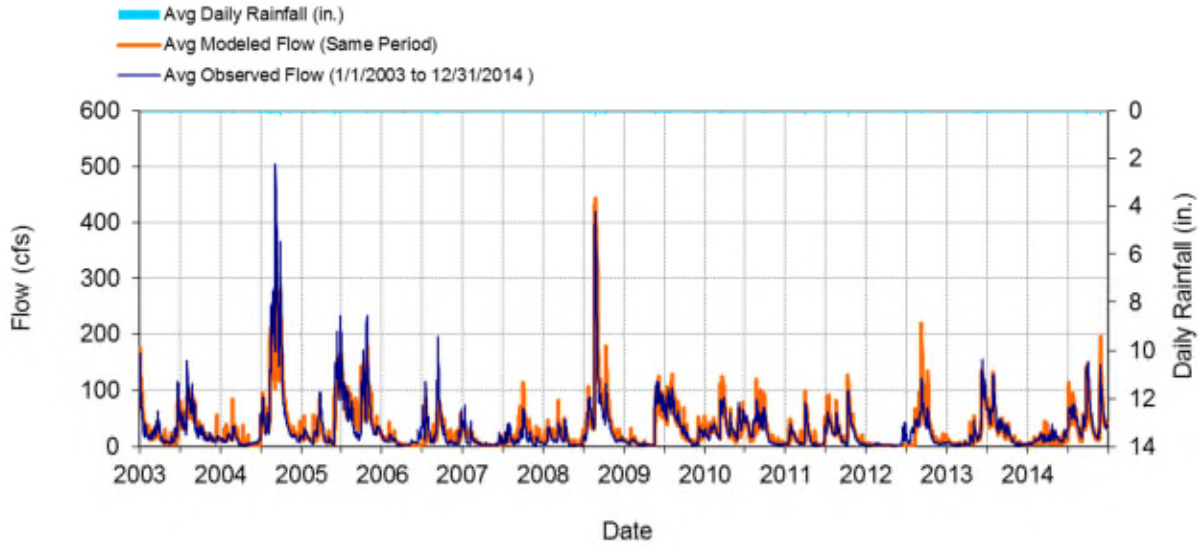


FIGURE 9: TIME SERIES COMPARISON OF MODEL RESULTS TO USGS GAGE 02234324 (HOWELL CREEK)

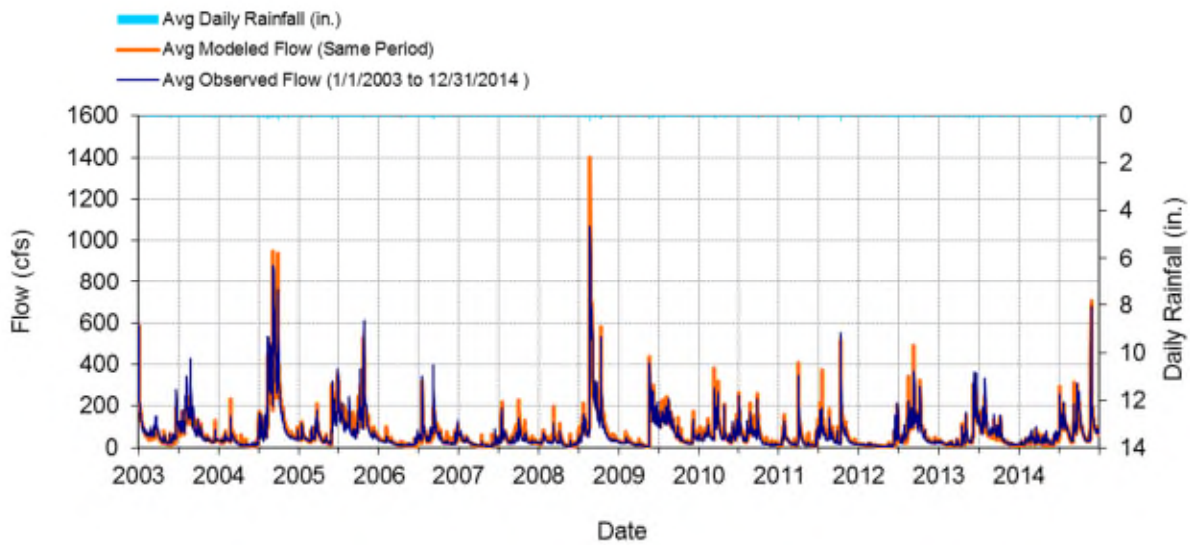


FIGURE 10: TIME SERIES COMPARISON OF MODEL RESULTS TO USGS GAGE 02234344 (HOWELL CREEK)

The department also requested that Tetra Tech use available bathymetry data to create site-specific model F-Tables for the six other impaired lakes in the watershed, as well as key lakes in their chains. Tetra Tech used the bathymetry data that the City of Orlando and Seminole County provided for these lakes, as well as updated bathymetry data that the department collected in the field during October 2015, to update the F-Tables. The first step to create the F-Tables was to combine the available DEM data into one uniform dataset. The 10-meter data from the U.S. Department of Agriculture/Natural Resources Conservation Service and the one-foot contours from Aerial Cartographics of America, Inc. and SJRWMD were used. Tetra Tech then traced the bathymetric contours from Portable Document Format (PDF) files that the stakeholders provided to create GIS files (see **Figure 11**). The surface DEM was combined with the lake DEM to create a “waterless DEM” coverage. Tetra Tech developed a model code to automate the lake

volume and surface area calculations at different elevations. The results from these calculations were used to update the F-Tables for the lakes.

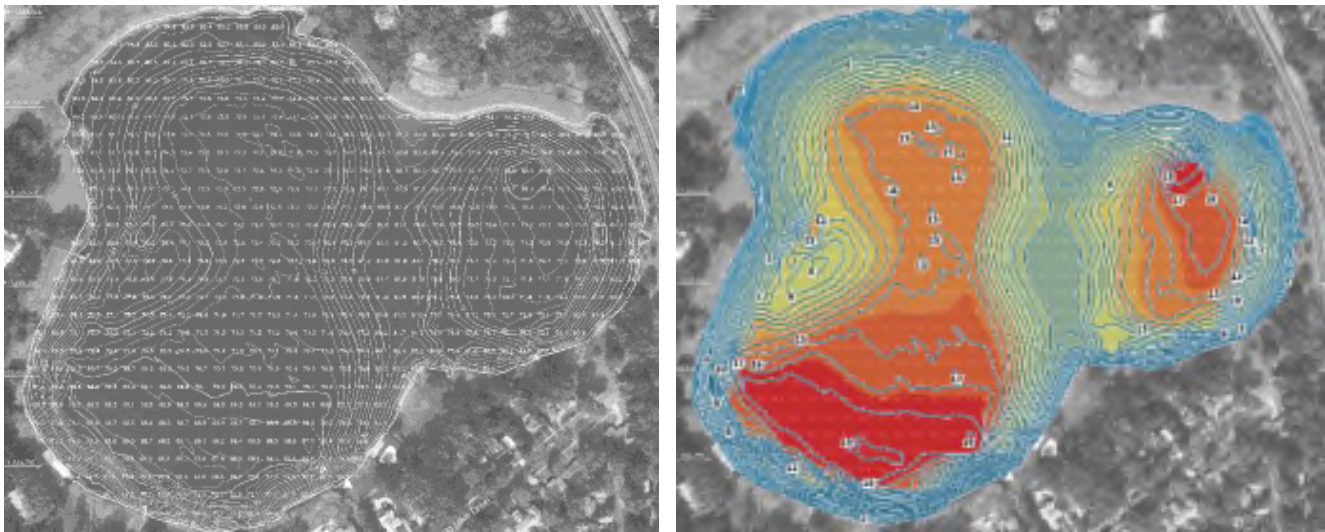


FIGURE 11: EXAMPLE FOR SPRING LAKE OF LAKE BATHYMETRY IN PDF (LEFT) AND LAKE BATHYMETRY CREATED IN GIS (RIGHT)

Tetra Tech then evaluated the model simulated stage data for these lakes and compared the results to available observed stage data, which were provided by the City of Orlando and Seminole County. As shown in **Table 11**, the majority of the model results closely match the observed data as evidenced by the “very good” and “good” ratings for the difference between the model and observed data for different statistical evaluations. In addition, **Figure 12** through **Figure 18** and **Table 12** through **Table 18** illustrate that the modeled stages closely track the observed stage results for these lakes.

**TABLE 11: HYDRAULIC ERROR STATISTICS FOR LAKE CALIBRATION STATIONS ON PAIRED
SIMULATED AND OBSERVED DATA**

Lake	Volume Median Error Percentage	Mean Depth Error Percentage	Maximum Depth Error Percentage
Bear Gully Lake ¹	18.1%	11.7%	15.6%
Bear Gully Lake ¹	Fair	Good	Fair
Lake Howell ¹	6.1%	7.0%	12.8%
Lake Howell ¹	Very Good	Very Good	Good
Lake Rowena	No data	No data	No data
Lake Rowena	No data	No data	No data
Lake Adair ²	-3.7%	5.5%	-39.5%
Lake Adair ²	Very Good	Very Good	Poor
Spring Lake ³	2.5%	1.3%	31.0%
Spring Lake ³	Very Good	Very Good	Poor
Lake Tuskawilla (Little Lake Howell) ¹	8.3%	7.4%	36.4%
Lake Tuskawilla (Little Lake Howell) ¹	Very Good	Very Good	Poor
Lake Alma	No data	No data	No data
Lake Alma	No data	No data	No data
Lake Searcy ¹	8.4%	5.9%	5.4%
Lake Searcy ¹	Very Good	Very Good	Very Good

1 Information on the measured volumes and depths is from the Seminole County Water Atlas (<http://www.seminole.wateratlas.usf.edu/>).

2 Information on the measured volumes and depths was provided by the department.

3 Information on the measured volumes and depths is from Harper 2008.

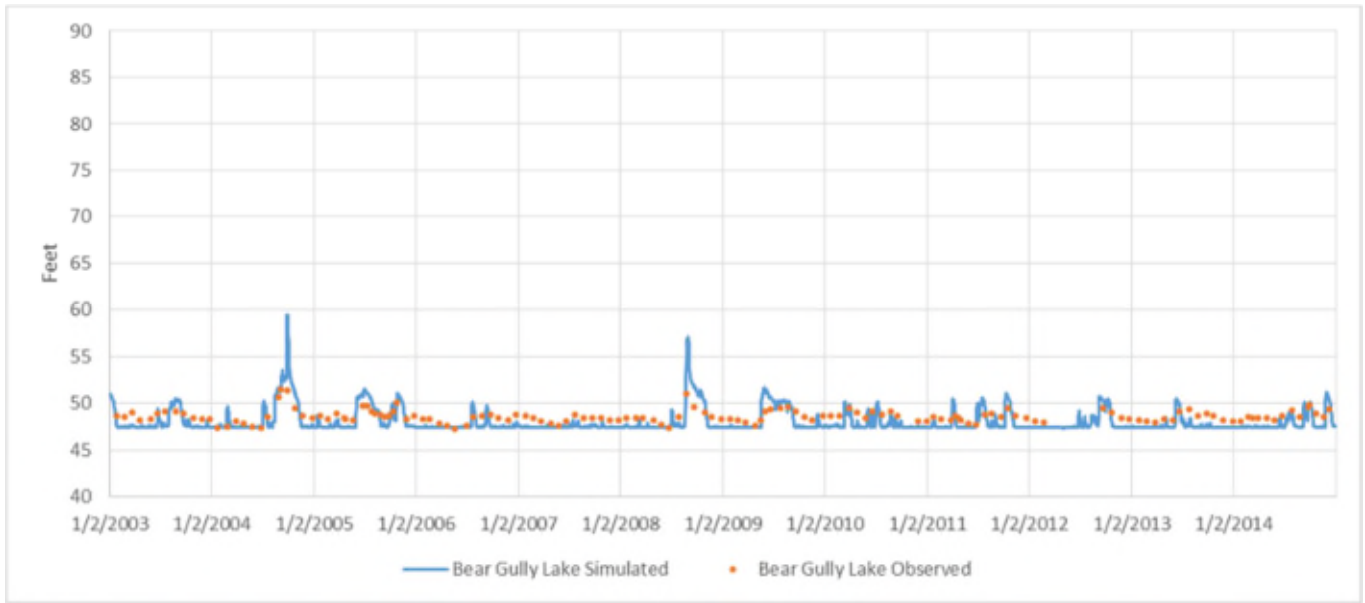


FIGURE 12: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN BEAR GULLY LAKE

TABLE 12: BEAR GULLY LAKE COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2003	47.94	48.65	-1.5%	Very Good
2004	49.57	48.76	1.7%	Very Good
2005	48.57	48.80	-0.5%	Very Good
2006	47.71	48.16	-0.9%	Very Good
2007	47.49	48.24	-1.6%	Very Good
2008	48.84	48.61	0.5%	Very Good
2009	48.66	48.59	0.1%	Very Good
2010	48.05	48.77	-1.5%	Very Good
2011	47.98	48.41	-0.9%	Very Good
2012	47.96	48.53	-1.2%	Very Good
2013	47.71	48.47	-1.6%	Very Good
2014	48.15	48.74	-1.2%	Very Good

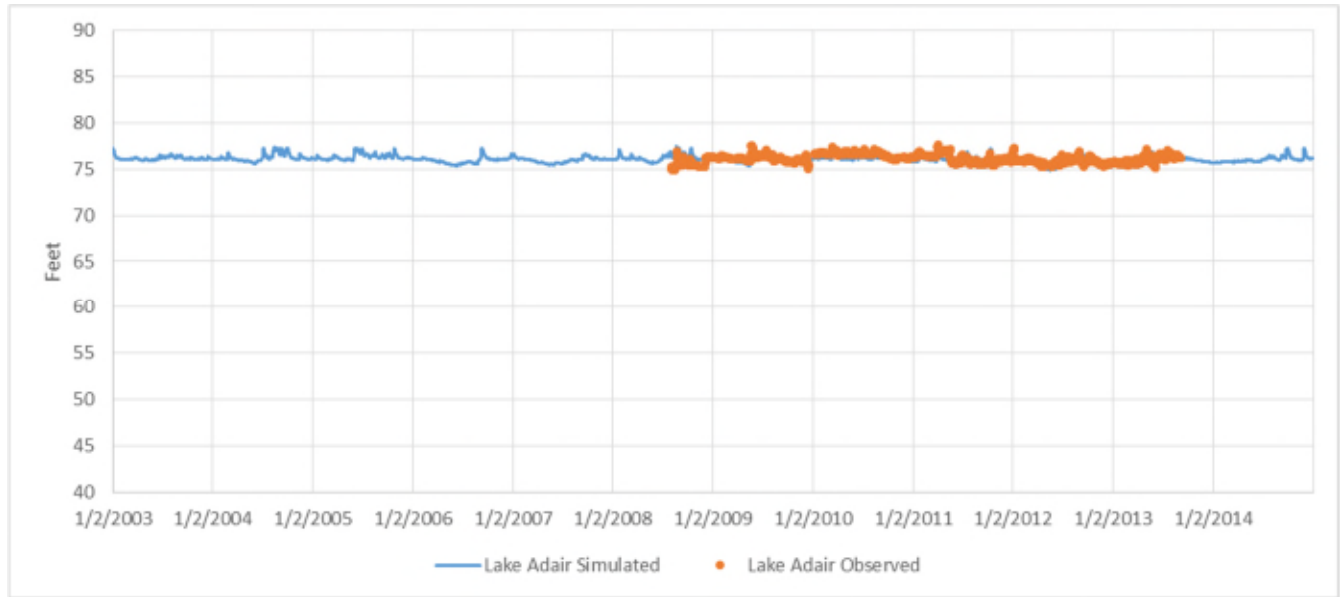


FIGURE 13: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN LAKE ADAIR

TABLE 13: LAKE ADAIR COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2008	76.32	75.67	0.9%	Very Good
2009	76.08	76.18	-0.1%	Very Good
2010	76.17	76.57	-0.5%	Very Good
2011	76.11	76.18	-0.1%	Very Good
2012	75.79	75.87	-0.1%	Very Good
2013	76.08	76.02	0.1%	Very Good

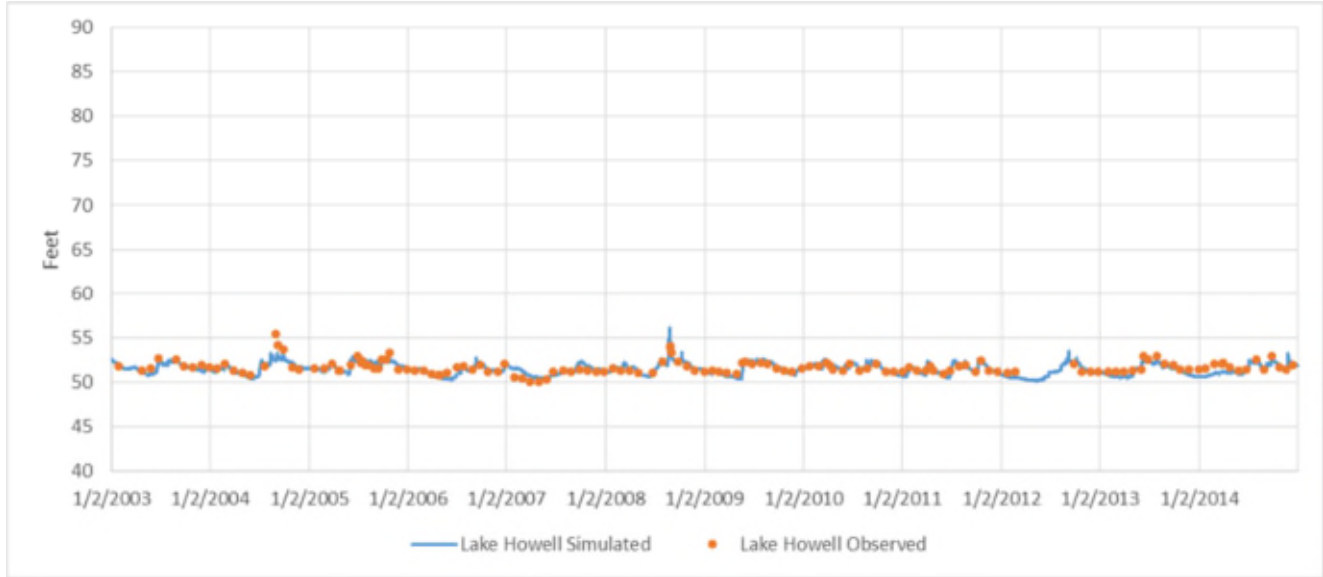


FIGURE 14: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN LAKE HOWELL

TABLE 14: LAKE HOWELL COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2003	51.60	51.89	-0.6%	Very Good
2004	51.81	52.29	-0.9%	Very Good
2005	52.05	51.99	0.1%	Very Good
2006	51.19	51.36	-0.3%	Very Good
2007	51.18	50.87	0.6%	Very Good
2008	52.20	52.04	0.3%	Very Good
2009	51.50	51.61	-0.2%	Very Good
2010	51.77	51.66	0.2%	Very Good
2011	51.42	51.48	-0.1%	Very Good
2012	51.19	51.31	-0.2%	Very Good
2013	51.36	51.77	-0.8%	Very Good
2014	51.44	51.86	-0.8%	Very Good

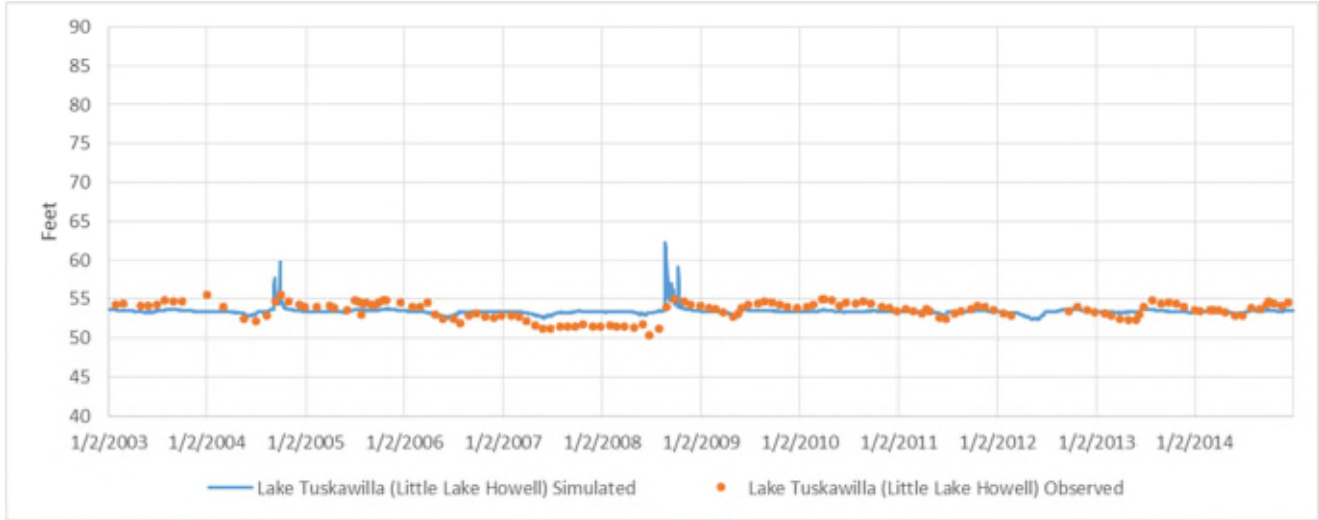


FIGURE 15: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN LAKE TUSKAWILLA

TABLE 15: LAKE TUSKAWILLA COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2003	53.47	54.56	-2.0%	Very Good
2004	53.87	53.82	0.1%	Very Good
2005	53.53	54.30	-1.4%	Very Good
2006	53.25	53.05	0.4%	Very Good
2007	53.19	51.74	2.8%	Very Good
2008	54.06	52.61	2.8%	Very Good
2009	53.38	53.92	-1.0%	Very Good
2010	53.41	54.34	-1.7%	Very Good
2011	53.35	53.42	-0.1%	Very Good
2012	53.45	53.38	0.1%	Very Good
2013	53.39	53.53	-0.3%	Very Good
2014	53.37	53.77	-0.7%	Very Good

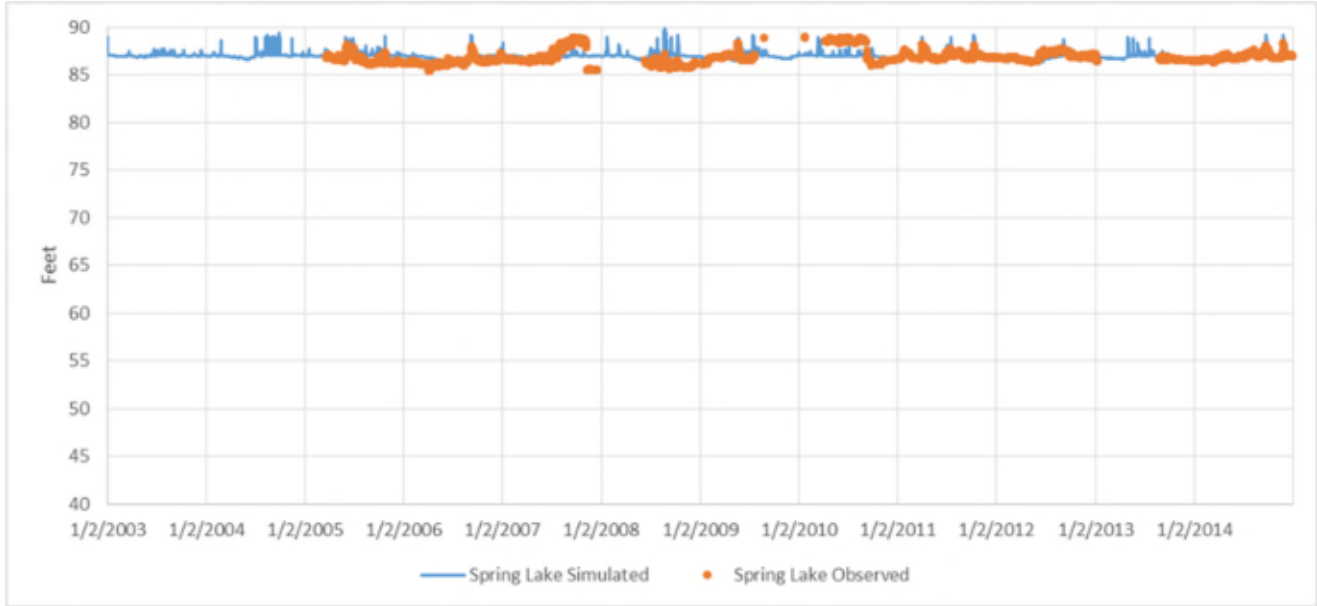


FIGURE 16: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN SPRING LAKE

TABLE 16: SPRING LAKE COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2005	87.19	86.66	0.6%	Very Good
2006	86.87	86.36	0.6%	Very Good
2007	86.89	86.96	-0.1%	Very Good
2008	87.21	86.06	1.3%	Very Good
2009	86.98	86.81	0.2%	Very Good
2010	86.97	87.61	-0.7%	Very Good
2011	86.98	87.01	0.0%	Very Good
2012	86.72	86.96	-0.3%	Very Good
2013	86.90	86.63	0.3%	Very Good
2014	86.98	86.90	0.1%	Very Good

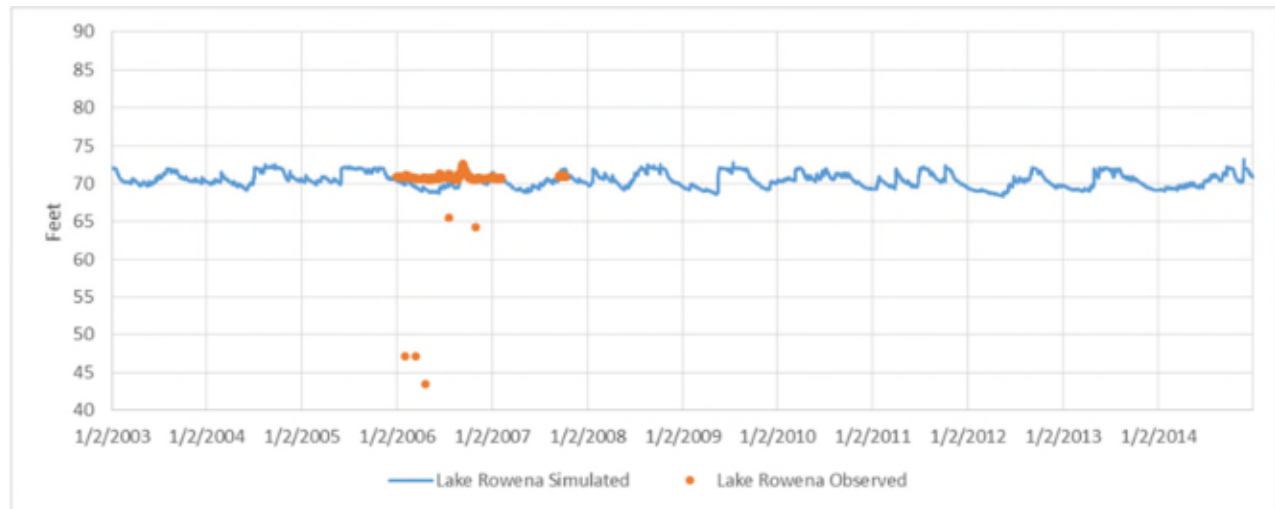


FIGURE 17: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN LAKE ROWENA

TABLE 17: LAKE ROWENA COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2006	69.96	70.58	-0.9%	Very Good
2007	71.25	70.86	0.6%	Very Good

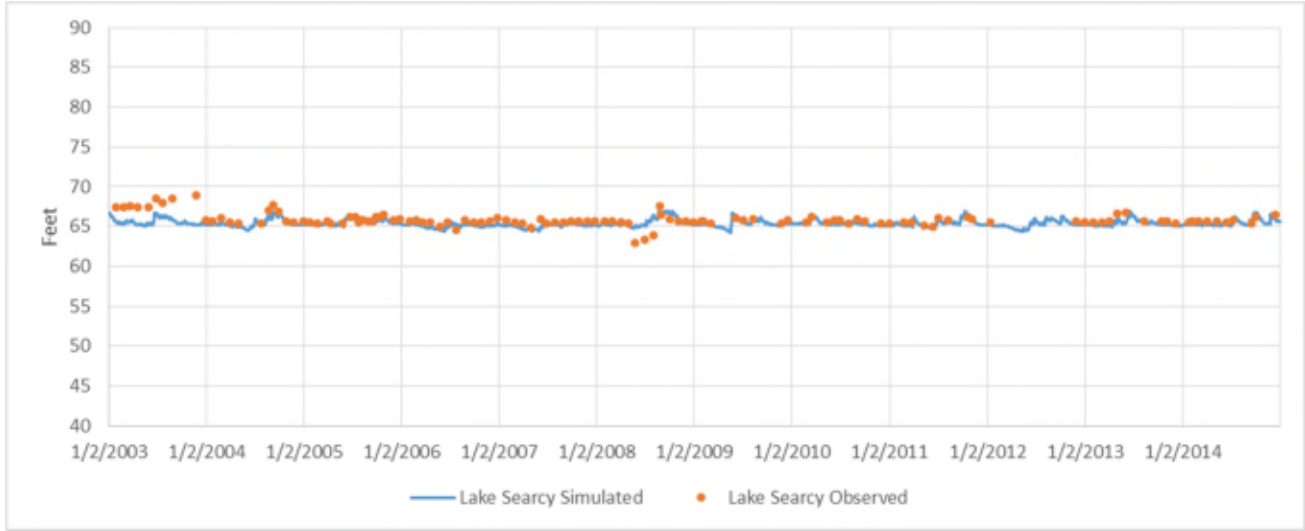


FIGURE 18: COMPARISON OF MODEL RESULTS TO OBSERVED STAGE IN LAKE SEARCY

TABLE 18: LAKE SEARCY COMPARISON OF ANNUAL SIMULATED AND OBSERVED MEAN STAGES

Year	Simulated Mean (ft)	Observed Mean (ft)	% Difference	Result
2003	65.59	67.68	-3.1%	Very Good
2004	65.60	66.04	-0.7%	Very Good
2005	65.52	65.80	-0.4%	Very Good
2006	65.06	65.48	-0.7%	Very Good
2007	65.03	65.52	-0.7%	Very Good
2008	65.67	65.30	0.6%	Very Good
2009	65.48	65.70	-0.3%	Very Good
2010	65.35	65.65	-0.4%	Very Good
2011	65.47	65.61	-0.2%	Very Good
2012	65.19	65.57	-0.6%	Very Good
2013	65.31	65.78	-0.7%	Very Good
2014	65.50	65.72	-0.3%	Very Good

3.2.2 Water Quality Calibration Results

Comparisons of the land use loading rates from the literature and the revised model are shown in **Figure 19** through **Figure 21**. In general, the model matches the loading rates for sediment, TN, and TP fairly well. Literature land use nutrient loading rates for TN and TP represent “edge of field” values (Harper 1994 and SWET 2008). For this model update, the land use nutrient loading rates were assumed to represent “delivered to stream” values for the combination of runoff and baseflow. When the simulated TN and TP loading rates were adjusted to match literature values, Tetra Tech had to balance between land use loading rates and instream concentrations.

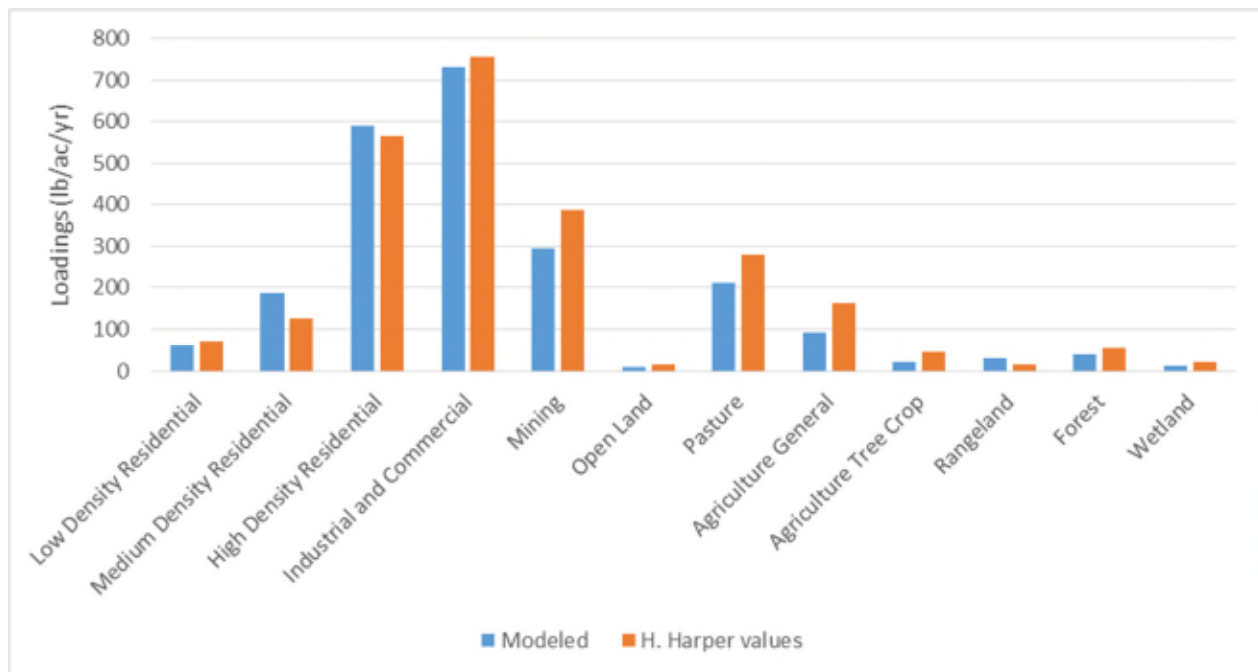


FIGURE 19: COMPARISON OF MODELED AND LITERATURE VALUES (HARPER 1994) FOR ANNUAL SEDIMENT LOADING PER ACRE BY LAND USE TYPE

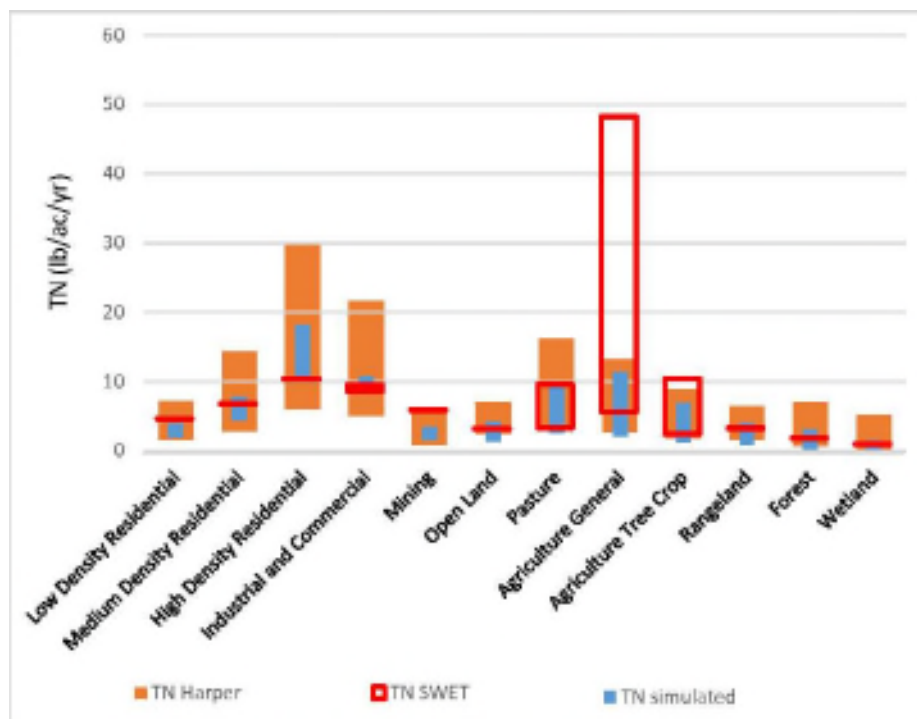


FIGURE 20: COMPARISON OF MODELED AND LITERATURE VALUES (HARPER 1994 AND SWET 2008) FOR ANNUAL TN LOADING PER ACRE BY LAND USE TYPE

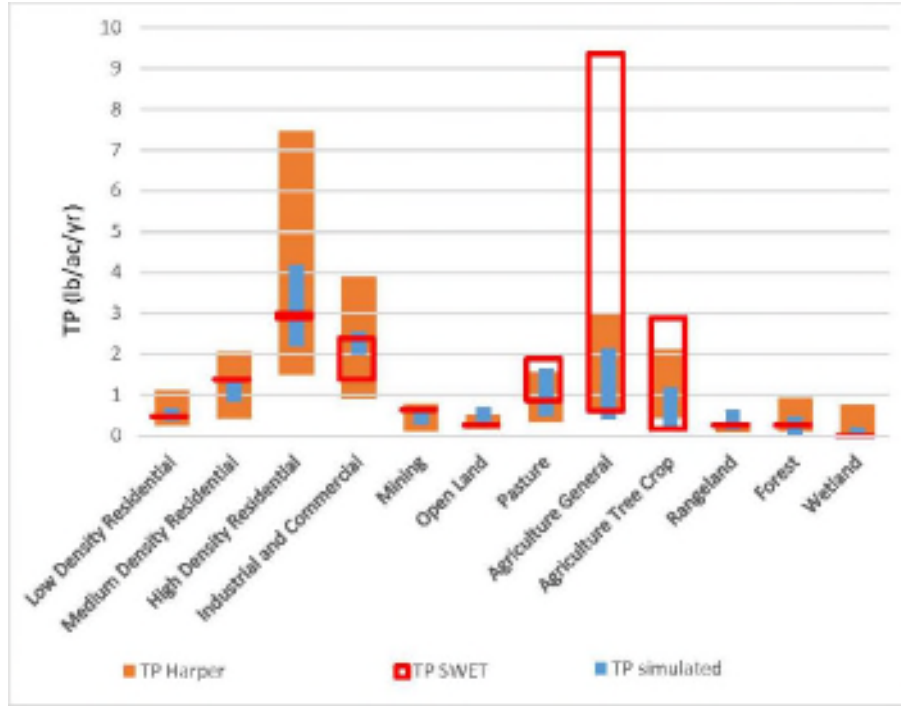


FIGURE 21: COMPARISON OF MODELED AND LITERATURE VALUES (HARPER 1994 AND SWET 2008) FOR ANNUAL TP LOADING PER ACRE BY LAND USE TYPE

Table 19 shows the sub-set of available water quality monitoring stations within the Lake Jesup watershed, which Tetra Tech selected for model calibration and validation. These stations were selected because they are strategically located throughout the watershed. Of the stations listed in the table, Tetra Tech selected eight stations for model calibration and delineated new model subwatersheds for these stations. The stations selected for calibration were either located in the impaired lakes or in areas that were in close proximity to an existing subwatershed outlet. Tetra Tech parameterized the newly created subwatersheds and receiving water reaches associated with each of the calibration stations, and recalibrated and revalidated the hydrology and water quality simulations in the model. The remainder of the stations listed in **Table 19** were used to validate the model results.

TABLE 19: WATER QUALITY STATIONS FOR ADDITIONAL EVALUATION/CALIBRATION

Station ID	Waterbody Type	Rationale	Calibration Station
21FLCEN 20011158	Ditch	Upstream Station	No
21FLORANHB13	Lake	Upstream Station	No
21FLORANHB26	Lake	Upstream Station	No
21FLORANHB32	Lake	Upstream Station	No
21FLORANHB36	Lake	Upstream Station	No
21FLORL ADAIR	Lake	Impaired lake	Yes
21FLORL SUE	Lake	Impaired lake	Yes
21FLSEM ALM	Lake	Impaired lake	Yes
21FLSEM BGU	Lake	Impaired lake	Yes
21FLSEM FAR	Lake	Upstream Station	No
21FLSEM HOW	Lake	Impaired lake	Yes

Station ID	Waterbody Type	Rationale	Calibration Station
21FLSEM ML01	Lake	Upstream Station	No
21FLSEM TUS	Lake	Impaired lake	Yes
21FLKWATSEM-TRIPLETN	Lake	Upstream Station	No
21FLKWATSEM-SEARCY	Lake	Impaired lake	No
21FLSEM SEA	Lake	Upstream Station	No
21FLCEN 20010763	River	Upstream Station	Yes
21FLSEM BERC	River	Upstream Station	No
21FLSEM CHUBB	River	Upstream Station	Yes
21FLSEM HCRB	River	Upstream Station	No
21FLSEM SOLDN-LM	River	Upstream Station	No
Winter Park - Weir at Howell Branch	Creek	Upstream Station	No
21FLSEM PRA	Lake	Upstream Station	No
21FLSEM GEE-CASS	Creek	Upstream Station	No
21FLSEM SOLUP-LM	Creek	Upstream Station	No
21FLSEM NAV	Canal	Upstream Station	No
21FLCEN 20010011	Creek	Upstream Station	No
21FLSEM SOLARY	Canal	Upstream Station	No
21FLORANXBURKTCNL2	Lake	Upstream Station	No
21FLSEM HCCB	Creek	Upstream Station	No
Lake Waumpi	Lake	Upstream Station	No
21FLORL ROWENA	Lake	Upstream Station	No

The department requested that Tetra Tech use the general calibration/validation targets or tolerances for the HSPF model from Donigian (2002) and McCutcheon et al. (1990) to evaluate the model results. The targets or tolerances for water quality parameters are summarized in **Table 20**.

TABLE 20: DONIGIAN 2002 AND MCCUTCHEON ET AL. (1990) CALIBRATION/VALIDATION TARGETS OR TOLERANCES FOR WATER QUALITY PARAMETERS

Category	Water Quality/DO	Nutrients/Chlorophyll-a
Very Good	<15%	<30%
Good	15%-25%	30%-45%
Fair	25%-35%	45%-60%
Poor	>35%	>60%

The department requested that Tetra Tech focus the model calibration on TN and TP, as these parameters will be used for the TMDLs and to determine BMAP allocations. As shown in **Table 21** and **Appendix A**, the revised model performs very well for TN and TP, and the majority of the results are “good” or “very good.” The simulation of TSS, DO, and BOD also compare well to the measured data. Matching all parameters to measured data is difficult due to the complex interaction between nutrients and algae and the limited ability of HSPF to simulate in-lake processes. Refer to **Section 3.2.3** for additional details.

Time series plots for multiple parameters for each of the focus subwatersheds are presented in **Appendix A**.

TABLE 21: SUMMARY OF WATER QUALITY STATISTICS

Waterbody	TN % Difference in Medians	TP % Difference in Medians	TSS % Difference in Medians	DO % Difference in Medians	BOD % Difference in Medians
North Lake Triplet/ Prairie Lake (subwatershed 10)	13% Very Good	-7% Very Good	-17% Good	-11% Very Good	-32% Poor
Fairy Lake (subwatershed 12)	-11% Very Good	19% Very Good	0% Very Good	-14% Very Good	-33% Poor
Gee Creek (subwatershed 15)	-15% Very Good	17% Very Good	-66% Poor	2% Very Good	-15% Good
Greenwood Lake (subwatershed 17)	-51% Fair	19% Very Good	-20% Good	-16% Good	-14% Very Good
Soldiers Creek (subwatershed 18)	-25% Very Good	23% Very Good	-26% Fair	82% Poor	35% Fair
Navy Canal (subwatershed 27)	4% Very Good	23% Very Good	9% Very Good	14% Very Good	5% Very Good
Ditch at Cameron Ave. (subwatershed 30)	34% Good	6% Very Good	-18% Good	3% Very Good	24% Good
Solary Canal/ Sweetwater Creek (subwatershed 38)	8% Very Good	-58% Fair	22% Good	-27% Fair	20% Good
Bear Gully Creek (subwatershed 41)	48% Fair	-44% Good	-25% Good	13% Very Good	10% Very Good
Bear Gully Lake (subwatershed 42)	-22% Very Good	-2% Very Good	-15% Good	6% Very Good	27% Fair
Lake Burkett (subwatershed 44)	-24% Very Good	25% Very Good	60% Poor	76% Poor	19% Good
Howell Creek (subwatershed 45)	22% Very Good	-5% Very Good	-73% Poor	7% Very Good	59% Poor
Lake Howell (subwatershed 46)	-11% Very Good	11% Very Good	0% Very Good	-20% Good	-6% Very Good
Lake Waumpi (subwatershed 49)	-2% Very Good	-1% Very Good	35% Fair	58% Poor	No data No data
Weir at Howell Branch (subwatershed 51)	25% Very Good	-17% Very Good	No data No data	No data No data	2% Very Good
Minnehaha (subwatershed 52)	-26% Very Good	25% Very Good	No data No data	-5% Very Good	No data No data
Lake Gem (subwatershed 53)	9% Very Good	-25% Very Good	-11% Very Good	2% Very Good	25% Good
Lake Sue (subwatershed 61)	-41% Good	7% Very Good	34% Fair	-15% Good	-50% Poor
Lake Rowena (subwatershed 63)	-28% Very Good	24% Very Good	-5% Very Good	-15% Good	-43% Poor
Lake Adair (subwatershed 75)	-1% Very Good	-10% Very Good	10% Very Good	-24% Good	79% Poor
Lake Tuskawilla (subwatershed 91)	-4% Very Good	-19% Very Good	-4% Very Good	-9% Very Good	-26% Fair

Waterbody	TN % Difference in Medians	TP % Difference in Medians	TSS % Difference in Medians	DO % Difference in Medians	BOD % Difference in Medians
Lake Alma	-20%	2%	No data	3%	46%
(subwatershed 93)	Very Good	Very Good	No data	Very Good	Poor
Lake Searcy	2%	-21%	No data	No data	No data
(subwatershed 94)	Very Good	Very Good	No data	No data	No data
Chub Creek	12%	-8%	14%	-19%	25%
(subwatershed 96)	Very Good	Very Good	Very Good	Good	Good
Salt Creek	-30%	-23%	-6%	5%	-3%
(subwatershed 98)	Good	Very Good	Very Good	Very Good	Very Good

Tetra Tech also evaluated the simulated versus measured values for temperature in the three main tributaries to Lake Jesup: Gee Creek, Soldiers Creek, and Howell Creek. The department requested that Tetra Tech use the general calibration/validation targets or tolerances for temperature from Donigian (2002) to evaluate the model results (**Table 22**). As shown in **Figure 22** through **Figure 24** and **Table 23** through **Table 25**, the model is closely simulating the temperatures in the main tributaries as noted by the majority of the statistical results in the “very good” and “good” categories.

TABLE 22: DONIGIAN 2002 CALIBRATION/VALIDATION TARGETS OR TOLERANCES FOR TEMPERATURE

Category	Range
Very Good	<7%
Good	8% - 12%
Fair	13% - 18%
Poor	>18%

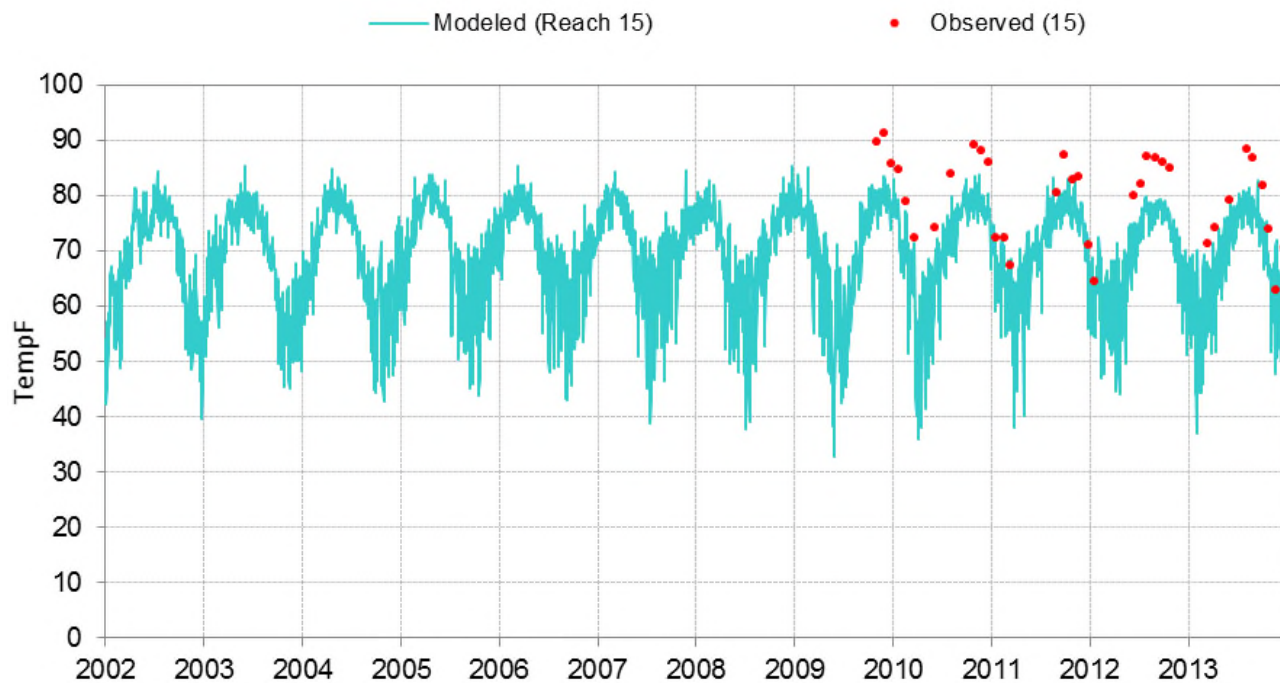


FIGURE 22: TEMPERATURE TIME SERIES FOR GEE CREEK

TABLE 23: TEMPERATURE STATISTICS FOR GEE CREEK

Year	Measured Median	Simulated Median	% Difference	Category
2010	85.145	69.866	-17.9%	Fair
2011	78.998	71.251	-9.8%	Good
2012	81.716	71.786	-12.2%	Good
2013	85.406	70.345	-17.6%	Fair
2014	74.156	69.759	-5.9%	Very Good
Period of Record	82.022	70.9165	-13.5%	Fair

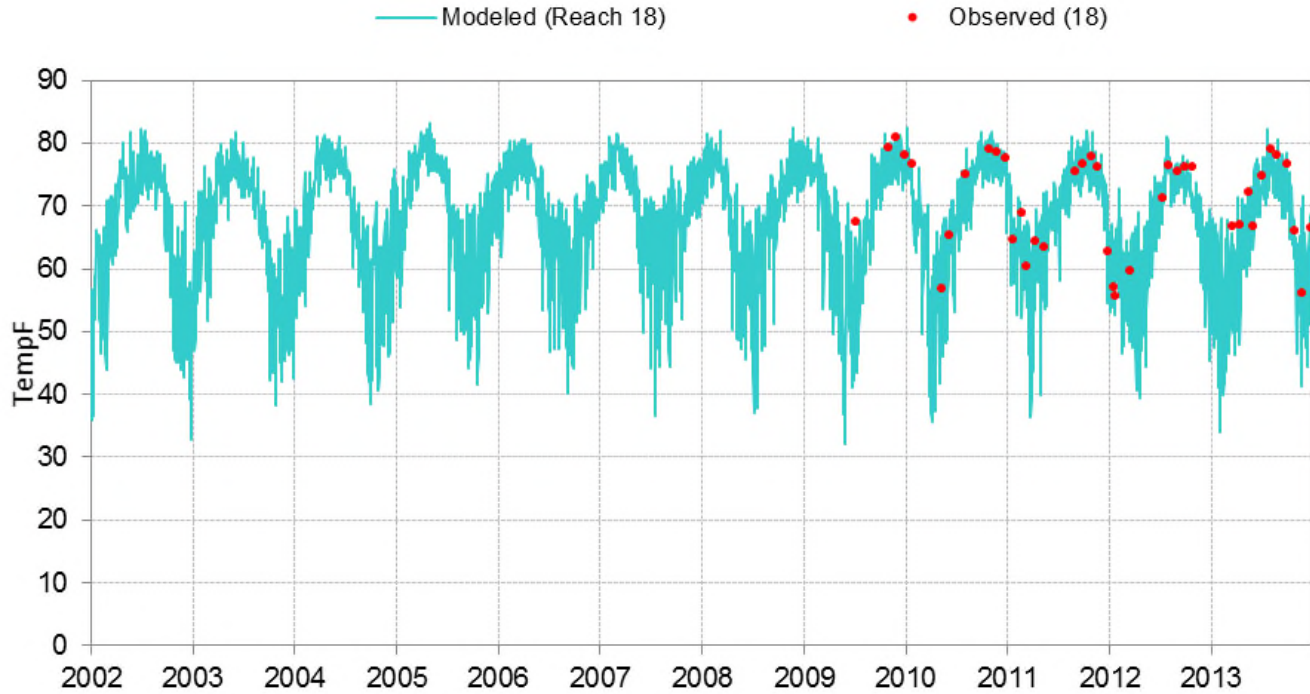


FIGURE 23: TEMPERATURE TIME SERIES FOR SOLDIERS CREEK

TABLE 24: TEMPERATURE STATISTICS FOR SOLDIERS CREEK

Year	Measured Median	Simulated Median	% Difference	Category
2010	78.062	68.64	-12.1%	Good
2011	68.918	70.416	2.2%	Very Good
2012	64.436	70.5705	9.5%	Good
2013	75.9155	67.493	-11.1%	Good
2014	66.902	67.579	1.0%	Very Good
Period of Record	73.5035	69.5445	-5.4%	Very Good

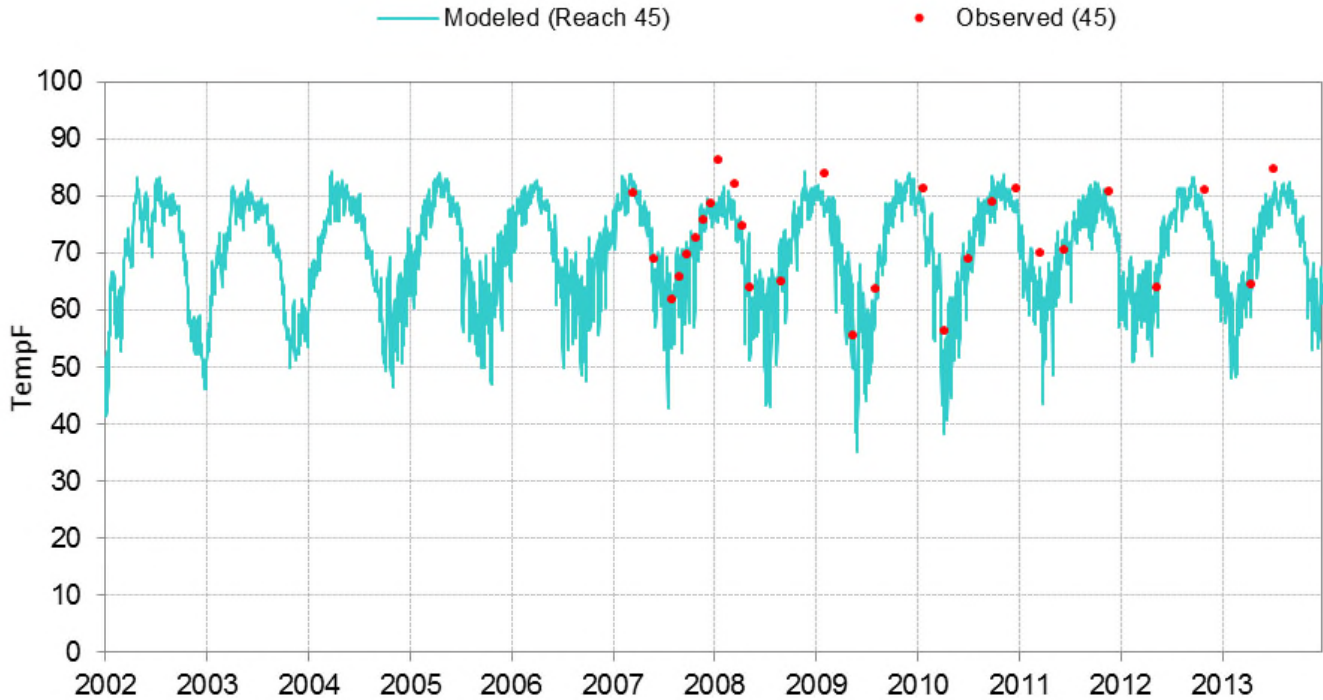


FIGURE 24: TEMPERATURE TIME SERIES FOR HOWELL CREEK

TABLE 25: TEMPERATURE STATISTICS FOR HOWELL CREEK

Year	Measured Median	Simulated Median	% Difference	Category
2010	63.626	70.552	10.9%	Good
2011	74.399	71.896	-3.4%	Very Good
2012	75.542	72.164	-4.5%	Very Good
2013	72.383	72.298	-0.1%	Very Good
2014	74.57	71.399	-4.3%	Very Good
Period of Record	72.554	71.633	-1.3%	Very Good

3.2.3 Calibration Process and Challenges

As noted above, water quality in the Lake Jesup watershed system is a function of complex interactions among nutrients, algae, and the hydrologic/hydraulic conditions. In addition, the one-dimensional representation of the lake waterbody within the HSPF model has a limited ability to simulate in-lake processes, which made it difficult to match the observed data for all water quality parameters. Therefore, the model generally performs well for TN and TP, but not as well for algae and the inorganic components of these nutrients.

Inorganic nutrient balances can be very sensitive to algal uptake, including both planktonic chlorophyll and macrophytes, the latter of which are rarely measured. Also, the HSPF model is a one-dimensional model, so it cannot correctly evaluate the vertical profile in lakes. The prediction from the HSPF model is an average over the depth of the water column, whereas measured chlorophyll would typically be integrated over twice the photic zone. If the lake depth is greater than the photic zone then the two numbers will diverge.

Tetra Tech attempted to first model TN and TP in range (without compromising the match to literature land use loading rates) and then evaluated the total reactive (inorganic) nutrient components. Tetra Tech made minimal to no changes to the Michaelis-Menten parameters (CMMN, etc.) and concentrated instead on the following:

- KBOD20 (BOD decay rate at 20 °C) and KODSET (the rate of BOD settling).
- KTAM20 (ammonia oxidation rate coefficient at 20 °C).
- REFSET (the rate of settling for dead refractory organics).
- EXTB (extinction coefficient).
- MALGR (maximum unit algal growth rate for phytoplankton).
- ALNPR (preference for NO₃ versus ammonia).
- NONREF (the non-refractory portion of nutrients released by algal death or respiration).
- KTAM20 (ammonia oxidation rate coefficient at 20 °C).
- PO₄ simulation through sorption and settling of solids and increasing through sediment scour.
- BRTAM (benthic release rates of ammonia) and BRPO4 (benthic release rates of phosphorous) from sediments.

Tetra Tech evaluated many combinations of parameters based on their recommended ranges. For example, EXTB (light extinction coefficient) is recommended to be about 1.8/secchi depth (meters). However, it was very difficult to obtain a consistently good match to multiple parameters, specifically nutrients. For instance, modifying the parameter to control biochemical cycling often did not meet expected improvement on the nutrient simulation. This is because nutrients are composed of various components of inorganic/organic species including phytoplankton, refractory organic matter, and dissolved inorganic species. Modifying the parameter alters the model results through the biochemical/nutrients cycling within the modeled organic and inorganic storages. However, the parameter changes can be either amplified or masked depending on the interaction with the other selected model parameters. Although a range of parameters were evaluated, selecting the parameter sets that produced a good match to the observed data proved to be challenging.

The model is not simulating the surface layer, or even multiple layers/depths, where algae exist, because it is not a two- or three-dimensional, such as EFDC or CE-QUAL. The HSPF model treats the lake system as a one-dimensional waterbody (i.e., a fully mixed system, both horizontally and vertically). Therefore, data collected near the lake surface where water quality samples are typically taken could present a condition different from what the model is actually simulating.

3.2.4 Summary of Watershed Loading

The annual watershed TN and TP loadings to Lake Jesup come from the three major tributaries (Howell Creek, Gee Creek, and Soldiers Creek), as well as the ungaged portion of the watershed. **Table 26** summarizes the loading from each of these areas.

TABLE 26: SUMMARY OF ANNUAL LOADING TO LAKE JESUP

Area	TN Load (lbs/yr)	TP Load (lbs/yr)
Howell Creek	160,575	9,918
Gee Creek	25,419	1,591
Soldiers Creek	38,776	2,740
Ungaged area	103,976	10,103
Total	328,746	24,352

The organic nutrients from the watershed, OrgN and OrgP are divided into particulate and dissolved fractions using a multiplicative partition coefficient. The partition coefficients for nitrogen are: dissolved OrgN = $0.4 * \text{OrgN}$ and particulate OrgN = $0.6 * \text{OrgN}$. The partition coefficients for phosphorus are: dissolved OrgP = $0.65 * \text{OrgP}$ and particulate OrgP = $0.35 * \text{OrgP}$. The partition coefficients were defined based on the characteristics of the watershed and the lake.

3.3 HSPF MODEL BACKGROUND SIMULATION AND LOADS

Tetra Tech also evaluated the watershed loading under the natural background condition. To create the natural background simulation, Tetra Tech followed the approach used by SJRWMD (Jia 2015). The wetland and water land uses in the current condition simulation were kept the same in the natural background simulation. All anthropogenic land uses in the current condition simulation were converted into forest and wetland land uses in the natural background simulation based on the hydrologic soil group classification. Anthropogenic land uses with class A and B soils were converted to forests and anthropogenic land uses with C, D, and dual category soils were converted to wetlands. The resulting land use coverage is shown in **Figure 25**. The loading from the watershed in the natural background simulation is shown in **Table 27**.

TABLE 27: SUMMARY OF LOADING IN THE NATURAL BACKGROUND SIMULATION

Area	TN Natural Load (lbs/yr)	TP Natural Load (lbs/yr)
Howell Creek	60,141	2,210
Gee Creek	11,184	355
Soldiers Creek	9,710	391
Ungaged	29,496	2,428
Total	110,531	5,384

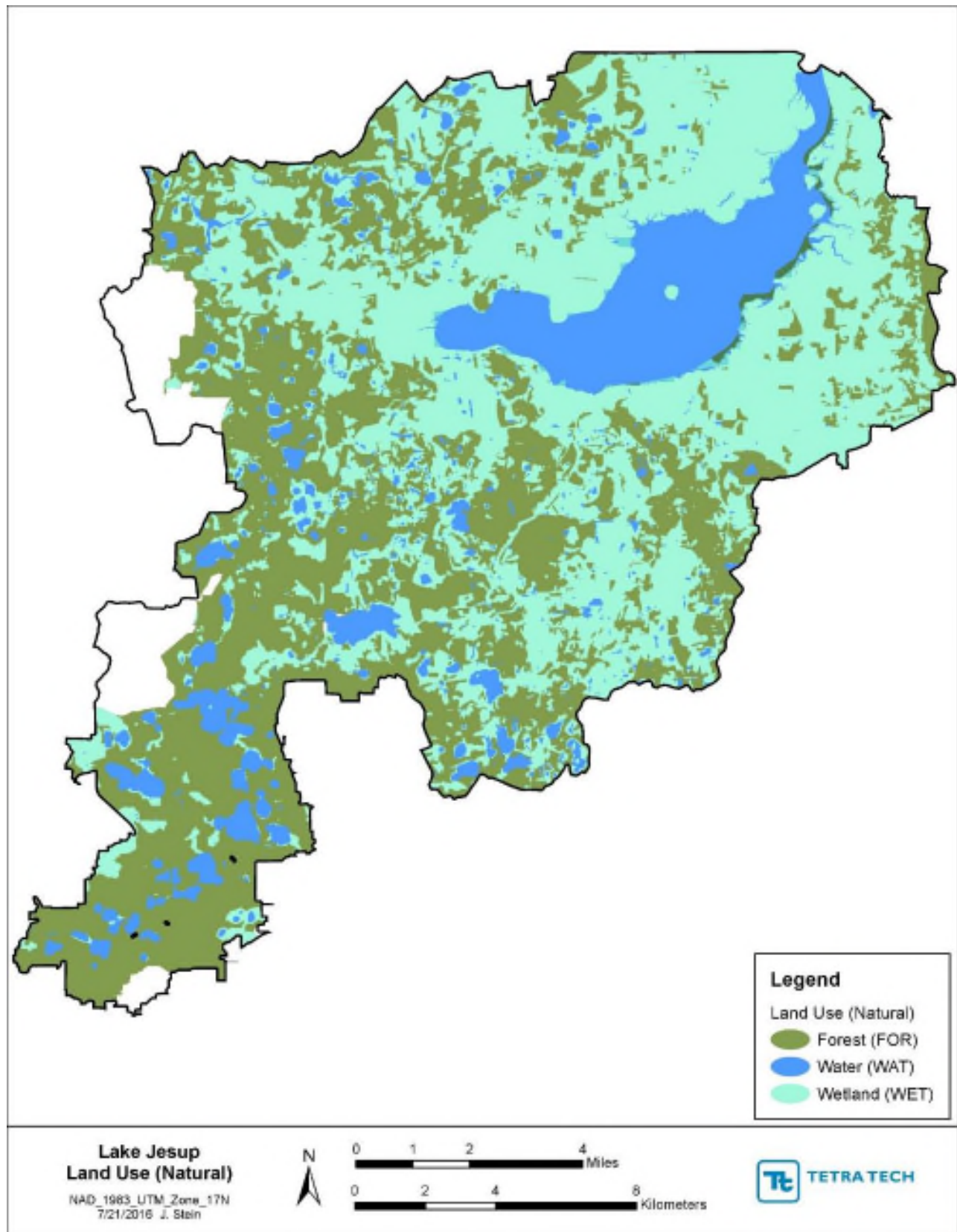


FIGURE 25: NATURAL BACKGROUND SIMULATION LAND USES IN THE LAKE JESUP WATERSHED

Section 4.0 EFDC AND WASP IN-LAKE MODELS

In updating the EFDC and WASP models, Tetra Tech focused on addressing major stakeholder comments as well as addressing the limitations of the original models that affected the information needed for the TMDLs and BMAP. The major modifications made to the EFDC and WASP models are as follows:

- Converted the EFDC model to the public domain version of the model.
- Simulated temperature in the EFDC model, instead of the WASP model, as was done previously.
- Revised the representation of ground water flows.
- Revised the watershed runoff salinities to zero and made the river and ground water the sources of salinity.
- Updated the atmospheric files using nearby weather records.
- Revised the roughness coefficients to more realistic values.
- Forced the model with hourly values of water surface elevations available at USGS 02234435.
- Updated the WASP model to latest version (WASP 7.5.2).
- Activated sediment diagenesis in the WASP model and used this capability to simulate nutrient fluxes in Lake Jesup.

4.1 EFDC MODEL

4.1.1 EFDC Model Revisions

4.1.1.1 Simulation Period

The original simulation period for the EFDC model ended in 2012, and Tetra Tech extended the simulation period through 2014. Tetra Tech gathered the 2013-2014 meteorological data from SJRWMD to update the model simulation period. The current model simulation period is January 1, 2003 through December 31, 2014, including a one-year model spin up period.

4.1.1.2 Temperature

The temperature routine is now used in the EFDC model, and the ASER.inp file was updated to include the appropriate nearby weather data. The temperature time series for the HSPF model generated inflows and ground water inflows was also included. These modifications result in a more realistic representation of heat circulation in the system.

The model currently uses a constant temperature of 22 °C (approximately 72 °F) for the ground water flows. This temperature was defined based on a map (**Figure 26**) of ground water isotherms available from USEPA (http://www3.epa.gov/ceampubl/learn2model/part-two/onsite/ex/jne_henrys_map.html).

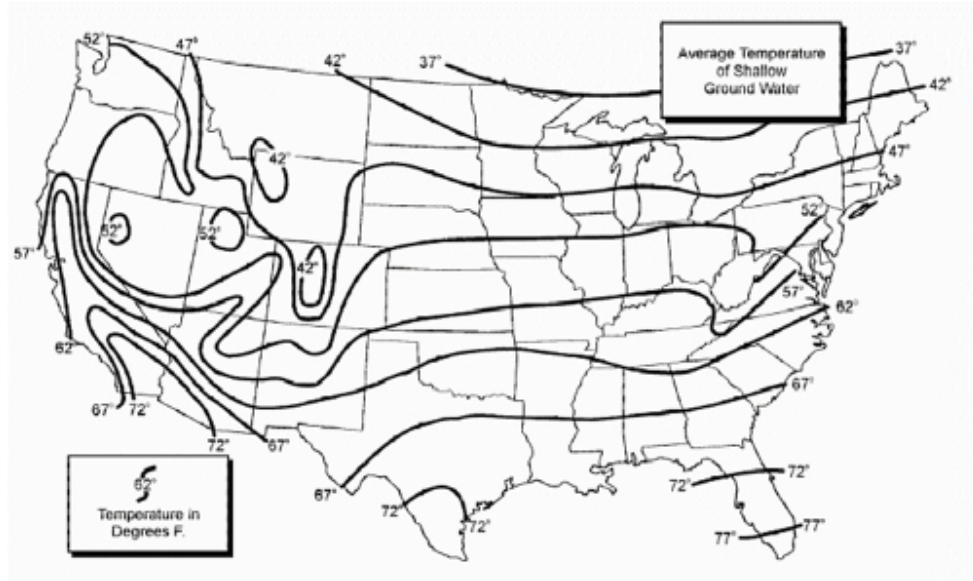


FIGURE 26: MAP OF GROUND WATER ISOTHERMS IN THE U.S.

4.1.1.3 Ground Water Input

The ground water input was removed from the ASER.inp file and added as a set of 10 discrete flow sources to the model grid (**Figure 27**), which were selected to homogeneously distribute the ground water flows throughout the lake. Initially, each of the 10 ground water inputs was assigned a flow of $0.048 \text{ m}^3/\text{s}$ for a total ground water flow into the lake of $0.48 \text{ m}^3/\text{s}$. This flow magnitude was equivalent to Harper's (2013) average estimate of total seepage flow to the lake of $17 \text{ ft}^3/\text{s}$ ($0.48 \text{ m}^3/\text{s}$) and was the same flow magnitude used by Sucsy and Brandt-Williams (2015). The specific magnitude of the ground water flow by cell was adjusted using scaling factors to represent, as best as possible, the variability of ground water flux observed by Harper (2013). Tetra Tech also identified in Harper's 2013 report a mean ground water inflow of $1.37 \text{ L}/\text{m}^2\text{-day}$ from Table 3-2. This flow, which is equivalent to a total inflow rate of $0.53 \text{ m}^3/\text{s}$ (18.6 cfs), replaced the initial inflow rate of $0.48 \text{ m}^3/\text{s}$ included in the model. Under this modification, the final average flow rate by cell input to the model is $0.053 \text{ m}^3/\text{s}$.

Under this new configuration, it is possible to represent the ground water inputs in the EFDC model using the time series of flow, temperature, and salinity via QSER.inp, TSER.inp, and SSER.inp, respectively. These inputs are now individually transferred to the WASP model. Once in the WASP model, the ground water flows are assigned appropriate water quality concentrations, which were based upon the range of seepage water quality measurements reported by Harper (2013). This option is not as uniformly distributed as using precipitation but is more effective in separating out the contributions from the different sources.

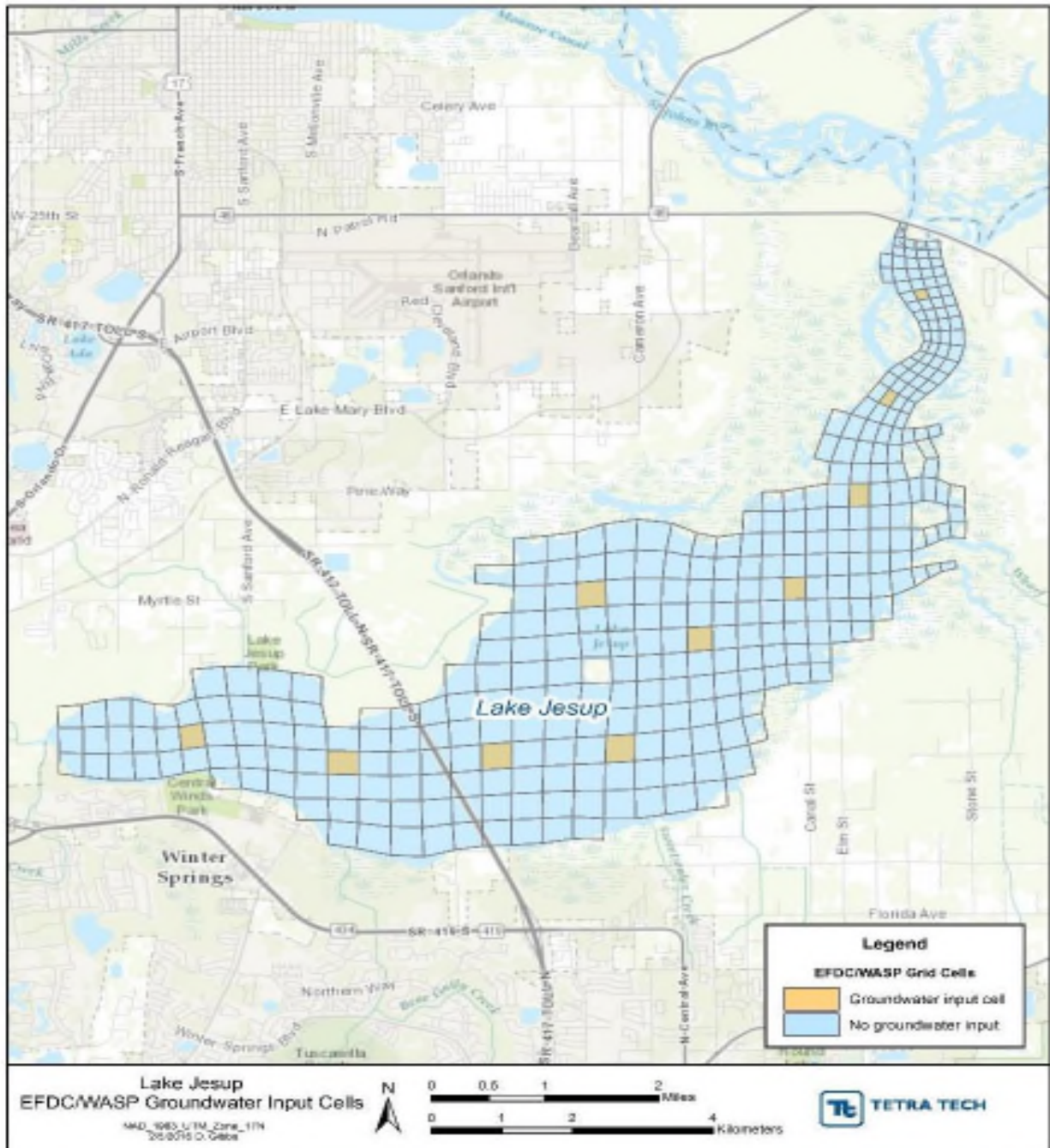


FIGURE 27: SPATIAL DISTRIBUTION OF GROUND WATER CELLS IN THE EFDC MODEL

4.1.1.4 Salinity

The watershed runoff has been set to freshwater with salinity at 0.2 Practical Salinity Unit (PSU). The St. Johns River salinity and ground water chlorides are now the main sources of salinity to the lake. The salinity boundary conditions at the lake's outlet were defined from conductivity measurements available at USGS stations 02234000 and 02234500. A constant salinity concentration of 0.4 PSU was initially assigned to the ground water inputs based on the range of seepage conductivity measured by Harper (2013) (600 – 1,400 $\mu\text{mho/cm}$). In the final model setup, however, the values of salinity prescribed at the lake's

outlet were also used to force the ground water boundaries in order to capture the temporal variability in seepage salinity exhibited by the observations.

4.1.1.5 Boundary Condition

Tetra Tech updated the EFDC model downstream boundary conditions with hourly values of water surface elevation available from October 1, 2007 to December 31, 2014 at USGS station 02234435. The model is driven by the appropriate water level measurement and not the gage height.

4.1.1.6 Sediment Simulation

SJRWMD has a study showing that the impact of sediment resuspension on the water column nutrient concentration is minimal so a dynamic sediment transport model was not used. The sediment diagenesis module in the WASP model simulates nutrient loads from the sediments to the water column through diffusion but it does not simulate nutrient loads from resuspended sediments, which is not needed for Lake Jesup.

TSS is simulated in the WASP model using loadings from the watershed and a settling rate. TSS is an independent variable in the WASP model, which is simulated as the sum of the inorganic solids and detritus. TSS from the watershed is input into the lake through the watershed boundary conditions. Once in the lake, the TSS can settle (sink) or increase due to increase in detritus. However, TSS does not directly impact water quality. The only impact of TSS on water quality is an increase the light extinction coefficients.

The particulate forms of OrgP and OrgN are directly simulated as model variables and not as adsorbed fractions to the sediments. Particulate OrgP and OrgN can settle, where they will be accounted for in the sediment diagenesis module; however, they cannot resuspend to the water column after they have settled in the model. The WASP model requires boundary conditions for both the particulate and dissolved fractions of these nutrients. For Lake Jesup, the loads of organic nutrients from the watershed are fractioned into particulate and dissolved fractions using a partition coefficient.

4.1.2 EFDC Model Calibration and Validation

The department requested that Tetra Tech use the general calibration/validation targets or tolerances for the EFDC model from Donigian (2002) to evaluate the model results. The targets or tolerances for hydrodynamic parameters are summarized in **Table 28**.

TABLE 28: DONIGIAN 2002 CALIBRATION/VALIDATION TARGETS OR TOLERANCES FOR HYDRODYNAMIC PARAMETERS

Category	Range for % Difference in Modeled Versus Observed Results	R ² Values and Index of Agreement
Very Good	<10%	>0.8
Good	10% - 15%	0.7 - 0.8
Fair	15% - 25%	0.6 - 0.7
Poor	>25%	<0.6

The observed and simulated flows from USGS station 02234435 are shown in **Figure 28**. The observed versus simulated flow frequencies for the outflows and inflows at USGS station 02234435 are shown in **Figure 29** and **Figure 30**, respectively. In general, the model is able to reproduce the trends and magnitude of the flows at the lake's outlet. The frequency curves suggest, in particular, that the model closely captures

98% of the observed inflows and outflows while it only over predicts or under predicts about 2% of the flows at the evaluated station.

The differences between the observed and simulated flow at USGS station 02234435 are due to several factors. Some of the most important uncertainties affecting the accurate comparison of timing and magnitude of these flows include the quality of the flow observations (**Table 30**), accuracy of the modeled watershed inflows, geometric representation of the bathymetry (specifically the cross-section geometry at the outlet region), and evaporative fluxes from the lake.

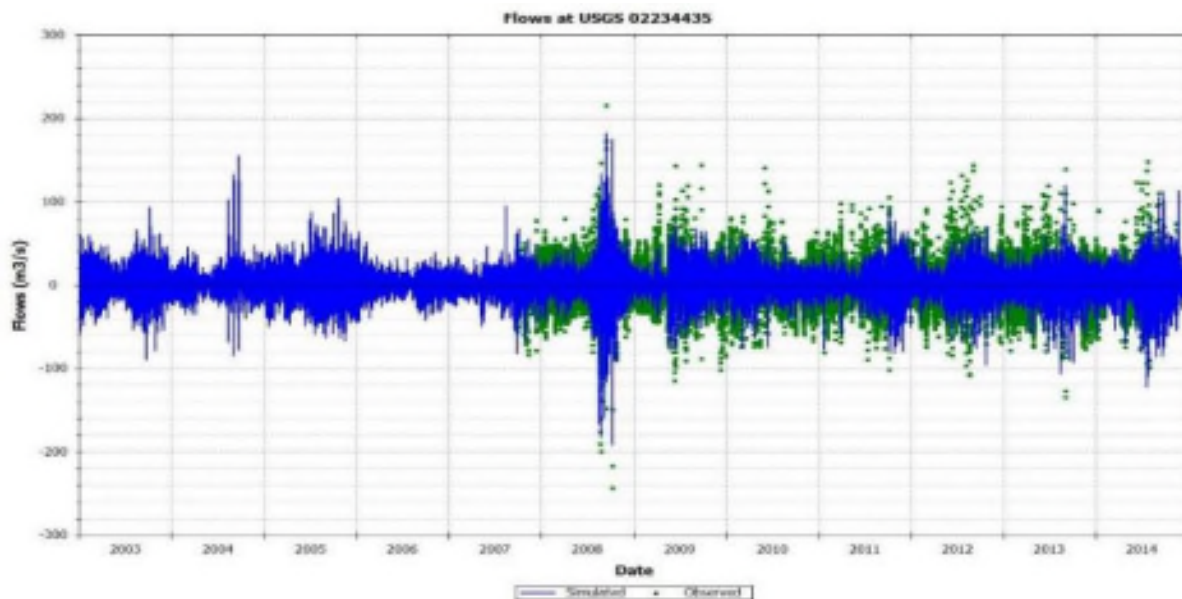


FIGURE 28: OBSERVED VERSUS SIMULATED FLOWS AT USGS STATION 02234435

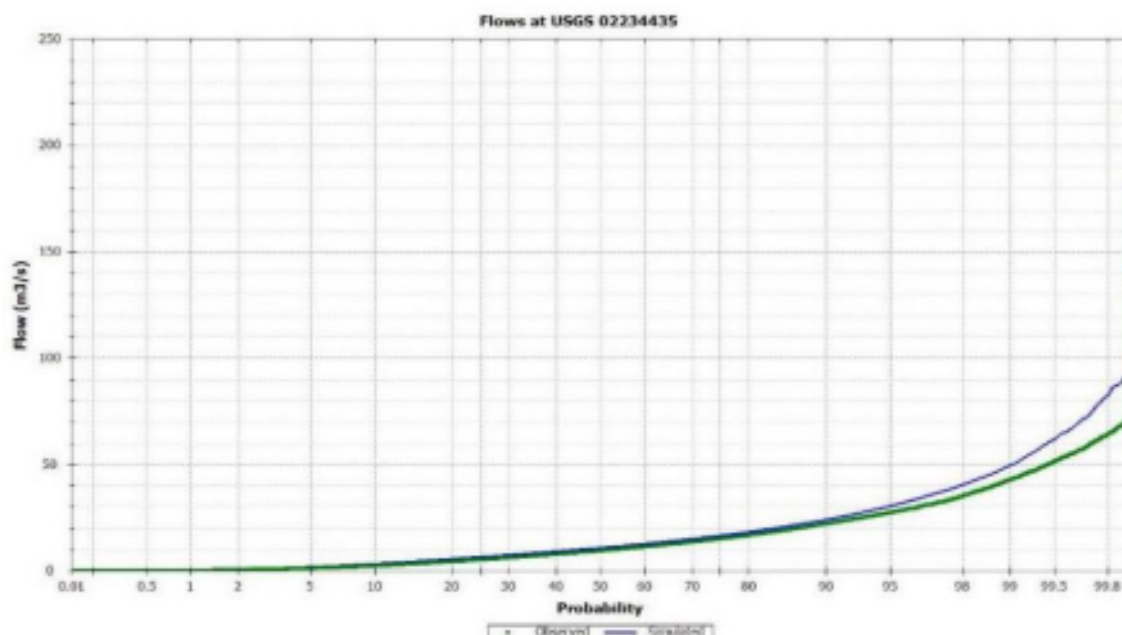


FIGURE 29: OBSERVED VERSUS SIMULATED FLOW FREQUENCY – OUTFLOWS AT USGS STATION 02234435

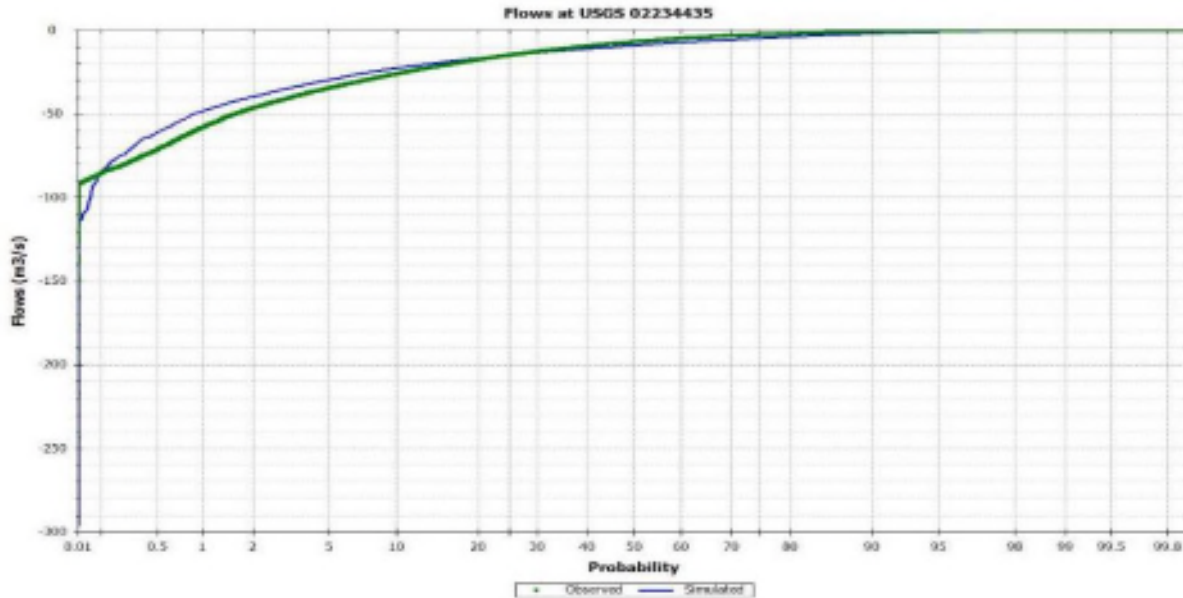


FIGURE 30: OBSERVED VERSUS SIMULATED FLOW FREQUENCY – INFLOWS AT USGS STATION 02334435

Despite the existing sources of uncertainty, as shown in the figures above and **Table 29** below, the model is simulating the flow data from USGS station 02334435 fairly well, especially considering the quality of data from this station (refer to **Table 30**).

TABLE 29: PERFORMANCE STATISTICS FOR THE FLOW CALIBRATION AT USGS STATION 02334425

Error in Median	Error in Minimum	Error in Maximum	Error in 5 th Percentile	Error in 10 th Percentile	Error in 90 th Percentile	Error in 95 th Percentile	Index of Agreement
5.1%	-21.6%	-15.3%	-0.6%	-27.9%	3.7%	-2.1%	0.6
Very Good	Fair	Fair	Very Good	Poor	Very Good	Very Good	Fair

TABLE 30: QUALITY OF FLOW RECORDS AT USGS 02234435 BASED ON USGS WATER-YEAR REPORTS

Year	Quality of Records
2014	Not reported
2013	Poor
2012	Fair
2011	Fair
2010	Fair
2009	Fair
2008	Fair
2007	Fair
2006	Fair
2005	Fair
2004	Fair-Poor
2003	Fair

The EFDC model performance was also compared to measured temperature and salinity values from the in-lake water quality stations. The salinity data used for the calibration were derived from conductivity data collected at the in-lake monitoring stations. The targets or tolerances for temperature are summarized in **Table 31** and for water quality parameters in **Table 20**.

TABLE 31: DONIGIAN 2002 CALIBRATION/VALIDATION TARGETS OR TOLERANCES FOR WATER TEMPERATURE

Category	Range for % Difference in Modeled Versus Observed Results	Range for R ² Values and Index of Agreement
Very Good	<7%	>0.8
Good	8% - 12%	0.7 - 0.8
Fair	13% - 18%	0.6 - 0.7
Poor	>18%	<0.6

TABLE 32: DONIGIAN 2002 CALIBRATION/VALIDATION TARGETS OR TOLERANCES FOR WATER QUALITY PARAMETERS

Category	Range for % Difference in Modeled Versus Observed Results	Range for R ² Values and Index of Agreement
Very Good	<15%	>0.8
Good	15% - 25%	0.7 - 0.8
Fair	25% - 35%	0.6 - 0.7
Poor	>35%	<0.6

As shown in **Table 33**, the model is closely simulating the temperature data, as evidenced by the vast majority of the results in the “very good” category.

TABLE 33: PERFORMANCE STATISTICS FOR THE TEMPERATURE CALIBRATION

Station	Error in Mean	Error in Median	Error in 5 th Percentile	Error in 95 th Percentile	R ²	Index of Agreement
JES	-11.4%	-6.5%	-33.8%	-6.6%	0.91	0.92
JES	Good	Very Good	Poor	Very Good	Very Good	Very Good
JES YSI	-9.5%	-10.6%	-14.5%	-3.9%	0.74	0.82
JES YSI	Good	Good	Fair	Very Good	Good	Very Good
JESUP-E	0.1%	0.3%	0.0%	0.0%	0.94	0.98
JESUP-E	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
JESUP-W	-3.5%	-1.8%	0.0%	0.0%	0.93	0.97
JESUP-W	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
OW2	-2.3%	-3.9%	-3.8%	0.8%	0.97	0.99
OW2	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
OW4	-1.4%	-1.2%	-5.6%	1.6%	0.98	0.99
OW4	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
OW6	-1.1%	-0.4%	-1.6%	3.4%	0.97	0.99
OW6	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
VC-SJ7B	-11.6%	-12.1%	0.0%	0.0%	0.73	0.85
VC-SJ7B	Good	Fair	Very Good	Very Good	Good	Very Good
WEST JES	-4.4%	-4.4%	-6.9%	-2.2%	0.96	0.98
WEST JES	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good

The salinity results vary more widely by station (see **Table 34**). As mentioned above, during the model calibration a constant salinity concentration of 0.4 PSU was initially assigned to the ground water flows. This salinity concentration was defined based on the average seepage flow conductivity measured by Harper (2013) of 829 $\mu\text{mho/cm}$. In the final model run, the time series of salinity prescribed at the outlet boundary was also used for the ground water flows. The reason for this change is that the values of salinity at the outlet boundary also reflect seepage salinity and represent a closer approximation to the magnitude and variability of ground water salinity in other regions of the lake. The average salinity concentration at the outlet is 0.5 PSU, which is similar to what was observed by Harper 2013. However, the salinity values vary between 0.15 PSU and 1.73 PSU. By using this approximation, and a small constant value of 0.2 PSU for the riverine flows, the variability of salinity at stations OW4 and OW6 was substantially improved. These modifications were sufficient to better capture the levels of salinity observed throughout the lake.

Additional information on the temperature and salinity calibrations are included in **Appendix B**.

TABLE 34: PERFORMANCE STATISTICS FOR THE SALINITY CALIBRATION

Station	Error in Mean	Error in Median	Error in 5th Percentile	Error in 95th Percentile	R ²	Index of Agreement
OW2	21.5%	33.3%	20.4%	3.1%	0.64	0.85
OW2	Good	Fair	Good	Very Good	Fair	Very Good
OW4	33.6%	36%	3.1%	44.9%	0.66	0.65
OW4	Fair	Poor	Very Good	Poor	Fair	Fair
OW6	24.3%	25.0%	-24.2%	37.8%	0.65	0.72
OW6	Good	Good	Good	Poor	Fair	Good
VC-SJ7B	-8.5%	11.4%	No data	No data	0.9	0.96
VC-SJ7B	Very Good	Very Good	No data	No data	Very Good	Very Good

4.2 WASP MODEL

4.2.1 WASP Model Revisions

4.2.1.1 Simulation Period

The original simulation period for the WASP model ended in 2012, and Tetra Tech extended the simulation period through 2014. Tetra Tech gathered the 2013-2014 water quality data from SJRWMD for the in-lake monitoring stations, and these data were used to update the model simulation period. The current model simulation period is January 1, 2003 through December 31 2014, including a one-year model spin up period.

4.2.1.2 Sediment Diagenesis

Tetra Tech activated the sediment diagenesis module, and used available Lake Jesup data from several Seminole County studies to recalibrate the model. The sediment diagenesis module computes the nutrient fluxes from the sediments to the water column as a function of organic materials settling to the sediments and the gradients between the dissolved concentrations in the water above the sediments and the pore water in the sediments. The updated model is able to predict the sediment oxygen demand (SOD) and fluxes of TN and TP from the sediments to the water column.

The calibration of the sediment diagenesis module is extremely complex and requires data not available for this project. For instance, the model requires the estimation of rates of mineralization of carbon, nitrogen, and phosphorus in the sediments for three different organic groups. The concentrations of each organic group must be provided to the model as initial conditions. This amount of information is rarely available in most common water quality studies unless there is an explicit intention to simulate sediment diagenesis. In addition, the model must be calibrated to observed nutrient fluxes and SOD measurements, which are not currently available. To overcome the above difficulties, the model has been adjusted to reproduce reasonable estimates of nutrient fluxes and SOD based on existing literature values (Di Toro 2001) and seepage fluxes from Harper (2013). It is important to note, however, that the fluxes reported by Harper (2013) do not make a distinction between what is coming from ground water seepage and what is from the sediments as a diagenetic flux. Furthermore, it is unclear if the nutrient fluxes reported by Harper reflect sediment diagenetic fluxes because the water in the collection bags do not have a direct contact with the sediments. The values reported by Harper were used only as reference values in this project.

Table 35 presents the statistical information for the fluxes for the simulation period of January 1, 2003 – December 31, 2014. These values are computed based on simulations results from all cells of the model.

Harper (2013) estimated annual nutrient loads from ground water seepage of approximately 90 tons/year for TN and 9.5 tons/year for TP. As noted, although these values are not directly comparable to the annual nutrient loads estimated by the sediment diagenesis model shown in **Table 35**, Harper's results suggest that the loads predicted by the model are within a reasonable range for the conditions of Lake Jesup.

TABLE 35: SUMMARY OF SIMULATED NUTRIENT FLUXES

Nutrient/ Variable	Percentile	Flux (mg/m ² -day)	Approximate Load/Year (ton/year)
SOD*	5 th	-0.10	-1.2
SOD*	25 th	-0.18	-2.1
SOD*	Median	-0.28	-3.3
SOD*	75 th	-0.36	-4.3
SOD*	95 th	-0.49	-5.8
TN	5 th	0.20	2.1
TN	25 th	1.70	20.4
TN	Median	3.50	41.9
TN	75 th	5.90	70.4
TN	95 th	9.80	115.9
TP	5 th	0.28	3.3
TP	25 th	0.57	6.8
TP	Median	1.01	12.0
TP	75 th	1.56	18.5
TP	95 th	2.09	24.8

* SOD in gO/m²-day

4.2.1.3 Nitrogen Fixation

Nitrogen fixation is simulated by the updated Lake Jesup model. This option fundamentally inactivates nitrogen to act as a limiting nutrient in the system. Therefore, the maximum phytoplankton growth rate is only affected by phosphorus availability and light conditions (for a more detailed explanation on the factors limiting phytoplankton growth the reader is referred to the WASP model user's manual). In the WASP model, nitrogen fixation has a direct impact on the pool of OrgN given that all the nitrogen fixed

by phytoplankton is used to sustain biomass (i.e. remain in the living organic matter). However, this nitrogen can be recycled to the inorganic nitrogen pool through phytoplankton respiration and death and subsequently through mineralization and nitrification. Once in the inorganic form, this recycled nitrogen becomes available for uptake by phytoplankton.

The rate of phytoplankton growth is simulated as a function of solar radiation, temperature, and nutrient availability/phytoplankton requirements. The WASP model takes into consideration these factors using a linear multiplicative function where the maximum or potential phytoplankton growth at optimum light and nutrient conditions (G_{max} [1/day]) is reduced by dimensionless factors (f) associated with nutrient availability ($0 \leq f_1 \leq 1$), vertical distribution of solar radiation in the water column ($0 \leq f_2 \leq 1$), and temperature (f_3). The mathematical expression to compute the phytoplankton growth (G) is given by:

$$GA = G_{Amax} * f_1 * f_2 * f_3$$

where under optimal conditions of light and nutrient availability, f_1 , f_2 , and f_3 will be close to 1.

Nutrient limitation depends on nutrient requirements and availability, which is simulated using the following Michaelis-Menten kinetics model:

$$f_1 = \text{Min} \left(\frac{N}{K_{mN} + N}, \frac{P}{K_{mP} + P} \right) \quad (1)$$

where K_{mN} and K_{mP} are half saturation concentrations (nutrient concentrations at which the growth rate is reduced by half), N is the concentration of inorganic nitrogen ($\text{NH}_4 + \text{NO}_3$), and P is the concentration of inorganic phosphorous (PO_4)

If nitrogen fixation is activated, then the nitrogen term is removed from f_1 and the nutrient limitation factor is reduced to

$$f_1 = \frac{P}{K_{mP} + P} \quad (2)$$

And then phytoplankton will be only limited by the availability of inorganic phosphorus.

Another important component of the phytoplankton model is the nutrient uptake. As phytoplankton grows, it fixates nutrients and carbon from the water column in the cells. The rate of nutrient fixation is computed from GA , the phytoplankton growth adjusted for light, nutrients, and temperature. Phytoplankton uptakes inorganic nitrogen and phosphorus from the water column and storage these nutrients in the cells. If there is not enough inorganic nutrients, then growth is reduced or ceased according to the limiting factor f_1 (Eq. 1).

When nitrogen fixation is activated in the model, phytoplankton uptake is not limited by the amount of inorganic nitrogen in the water column. The nutrient limiting factor affecting GA in this case becomes Eq. 2, and phytoplankton are able to fixate nitrogen at this new rate. Phytoplankton will first obtain the nitrogen from the inorganic pool in the water column (thus reducing the concentration of inorganic nitrogen in the water column), and once depleted, it will continue fixating nitrogen as if there were an

infinite source of inorganic nitrogen in the system, thus simulating a process similar to the uptake of nitrogen from the atmosphere. This process is repeated until the concentration of inorganic nitrogen in the lake increases again (e.g. due to nutrient pulses or sediment fluxes), in which case the phytoplankton will start consuming the inorganic pool of nitrogen from the water column again.

Currently only one algae group is simulated in the WASP model; therefore, nitrogen fixation is simulated for only the one algae group.

The complexity of the above nutrient cycle means that an accurate estimation of the nitrogen fixed by phytoplankton is quite complex in practice. Nevertheless, an approximate estimate can be obtained by computing the difference between the TN concentrations without and with the nitrogen fixation activated. For the updated Lake Jesup model, without nitrogen fixation, the average TN concentration simulated for the period of January 1, 2003 – December 31, 2014 was approximately 1.7 mg/L. With nitrogen fixation, the average TN concentration was approximately 3.0 mg/L. The difference between these values means that an increment of 1.3 mg/L in the TN concentration occurred through nitrogen fixation. Therefore, that fixed nitrogen represents about 43% of the TN pool. This value is within the ranges estimated by the department.

4.2.2 WASP Model Calibration and Validation

Sediment diagenesis was turned on in the updated model, and **Figure 31** through **Figure 34** show the results from this simulation. The total simulated nutrient fluxes are summarized above in **Table 35**. Additional results from the WASP model are included in **Appendix C**.

The total estimated flux loads from **Table 35** were converted from tons/yr to lbs/yr for comparison to the watershed loading in **Table 26**. As shown in **Table 36**, sediment flux can contribute between 1.3% and 41.4% of the TN loading and between 21.3% and 67.1% of the TP loading.

TABLE 36: COMPARISON OF FLUX AND WATERSHED LOADING

Parameter	Flux Load (lbs/yr)	Watershed Load (lbs/yr)	Flux % of Load
TN	4,200 - 231,800	328,745	1.3% – 41.4% (median 20.3%)
TP	6,600 -49,600	24,352	21.3% – 67.1% (median 49.6%)

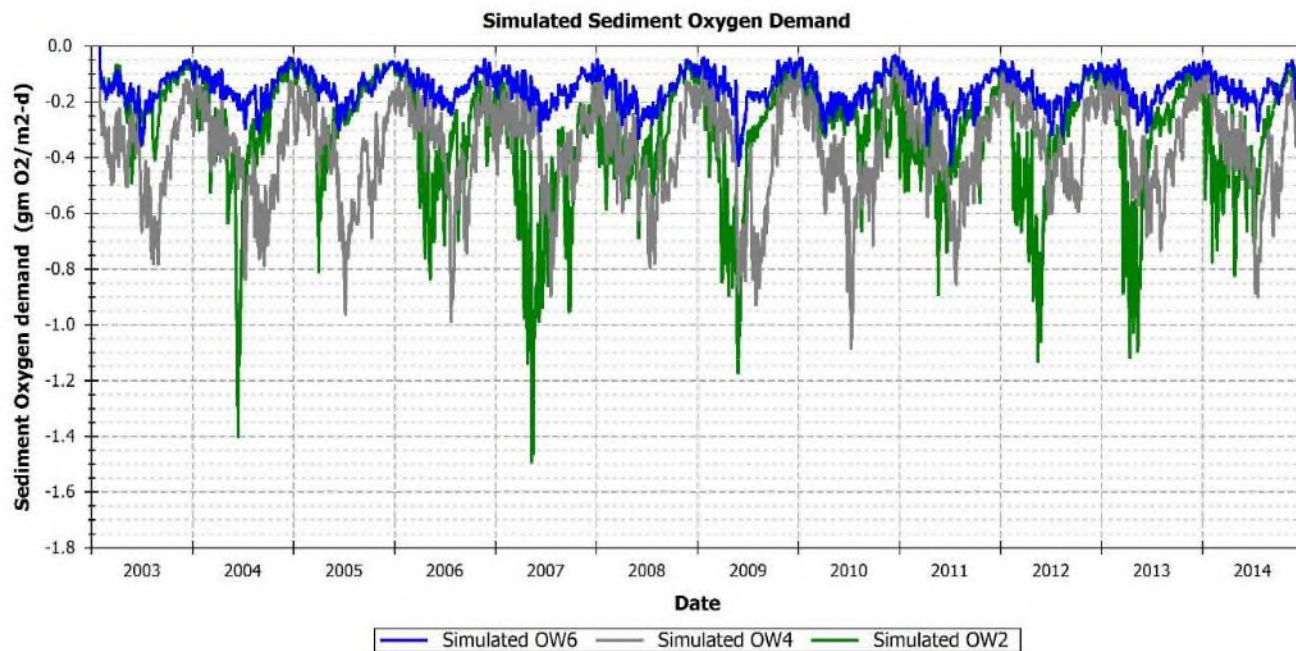


FIGURE 31: SOD SIMULATION

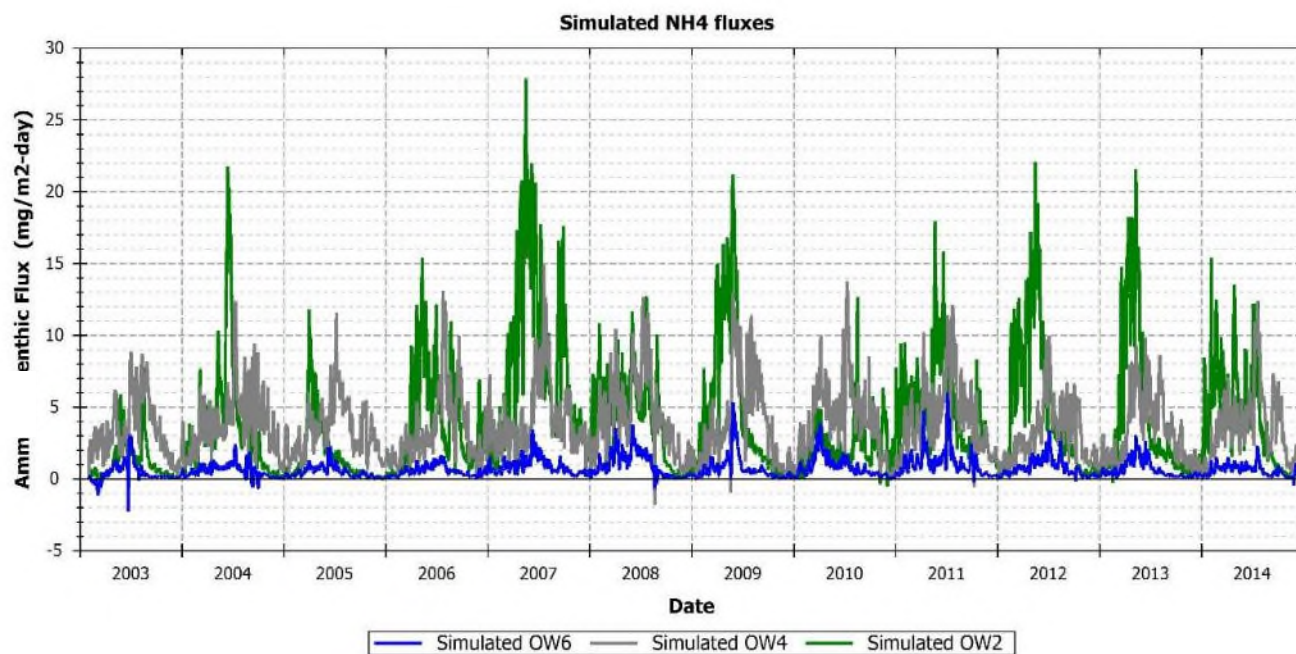


FIGURE 32: SIMULATED NH₄ FLUXES

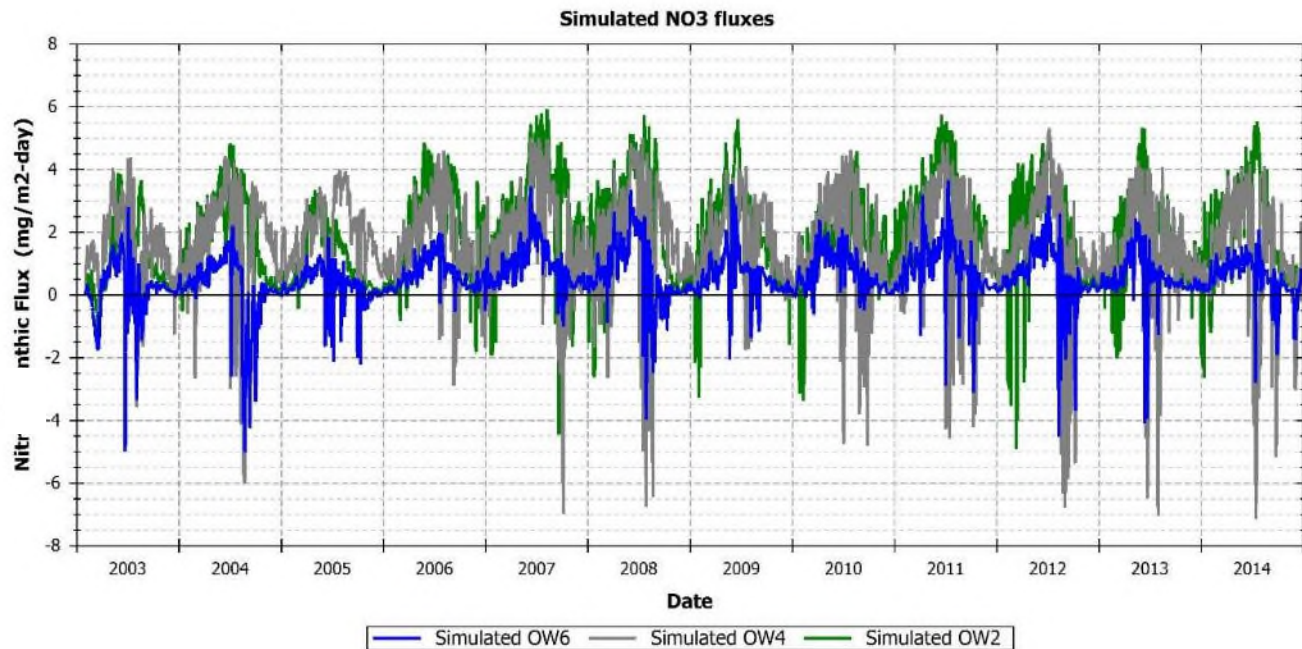


FIGURE 33: SIMULATED NO₃ FLUXES

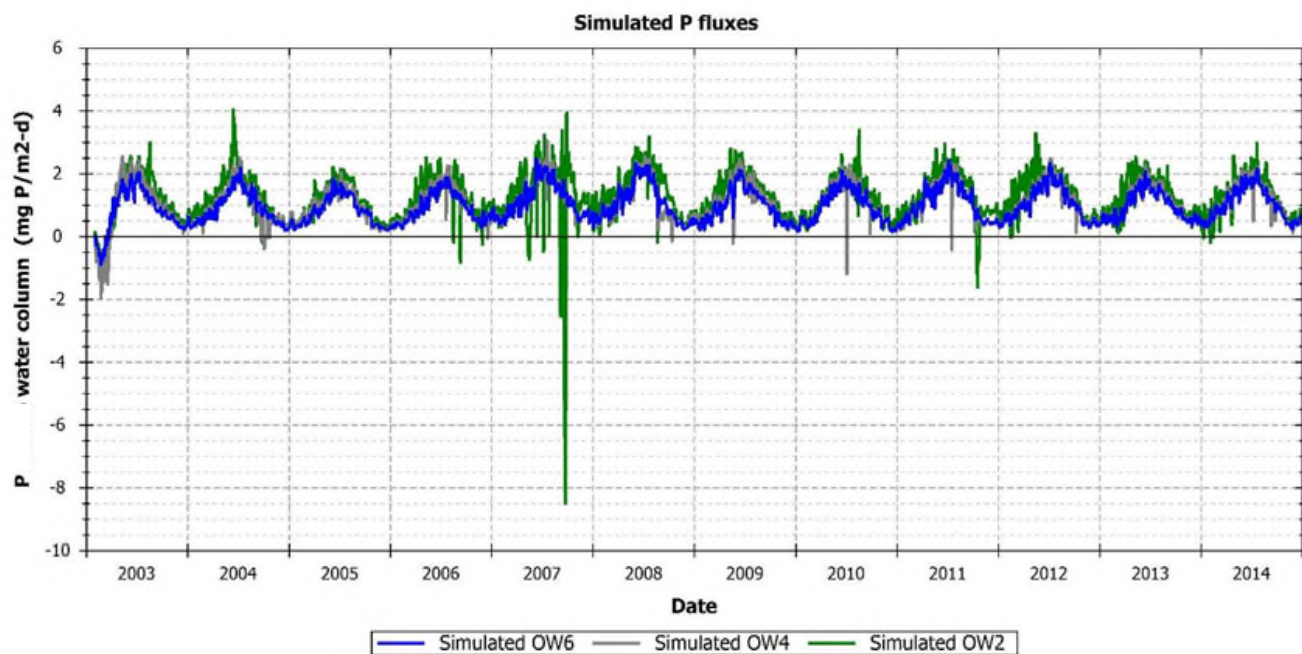


FIGURE 34: SIMULATED TP FLUXES

4.3 ANNUAL LOADING TO LAKE JESUP

Table 37 summarizes the annual loading to Lake Jesup from the watershed, atmospheric deposition, ground water seepage, and sediment flux.

TABLE 37: LOADING TO LAKE JESUP BY SOURCE

Parameter	Watershed Load (lbs/yr)	Atmospheric Deposition Load (lbs/yr)	Ground Water Seepage Load (lbs/yr)	Sediment Flux Load (lbs/yr)
TN	328,746	84,000	103,175	83,800
TP	24,352	9,600	10,907	24,000

4.4 EFDC/WASP MODEL TMDL SCENARIO

After Tetra Tech updated and calibrated the revised HSPF, EFDC, and WASP models, the department requested that Tetra Tech create a TMDL scenario run to determine if the existing Lake Jesup TMDLs, which were adopted in 2006, were still applicable. For this scenario, the calibrated watershed loads were reduced by the TMDL percent reductions, which are 50% for TN and 34% for TP. These reductions were applied to the total load entering Lake Jesup from the watershed. In addition, nitrogen fixation in the WASP model was turned off for this scenario. Based on information in the existing TMDL, the reduction in the watershed loads by the percentages in the TMDL should result in the lake no longer being nitrogen limited; therefore, nitrogen fixation should no longer be occurring. The atmospheric deposition loads, ground water seepage loads, and loads entering Lake Jesup from the St. Johns River were not modified for this scenario run.

The EFDC and WASP models were then run with the reductions in watershed loads and nitrogen fixation turned off. The resulting in-lake TN and TP concentrations were compared to the existing TMDL concentrations of 1.27 mg/L for TN and 0.096 mg/L for TP at three in-lake stations: (1) OW2, (2) OW4, and (3) OW6. The locations of these stations are shown in **Figure 2**.

The resulting TN concentrations are shown in **Table 38**. The TN concentrations in the TMDL scenario run meet the TMDL concentration of 1.27 mg/L in all years and at all three stations except for in 2007 at station OW2. This station is located near the mouth of Lake Jesup and the concentration at this location is influenced by the nutrient loading from the St. Johns River. The TP concentrations are shown in **Table 39**. The TP concentrations meet the TMDL concentration of 0.096 mg/L at stations OW4 and OW6 in all years except for 2007. The TP concentration is not met in any year at station OW2; however, as noted above, this station is influenced by loads from the St. Johns River and the river loading was not reduced as part of this TMDL scenario run. Based on these results, the percent reductions for TN and TP in the existing TMDL are adequate to achieve the TMDL in-lake concentrations. Therefore, the existing TMDL is still applicable to meet water quality targets for Lake Jesup.

TABLE 38: TN CONCENTRATIONS IN LAKE JESUP IN THE TMDL SCENARIO RUN

Year	OW2 Resulting Concentration	OW2 Meet TMDL Concentration?	OW 4 Resulting Concentration	OW4 Meet TMDL Concentration?	OW6 Resulting Concentration	OW6 Meet TMDL Concentration?
2003	1.039	Yes	0.808	Yes	0.808	Yes
2004	0.821	Yes	0.633	Yes	0.611	Yes
2005	0.711	Yes	0.563	Yes	0.578	Yes
2006	1.073	Yes	0.763	Yes	0.748	Yes
2007	1.353	No	0.882	Yes	0.847	Yes
2008	0.846	Yes	0.688	Yes	0.644	Yes
2009	0.930	Yes	0.658	Yes	0.651	Yes

Year	OW2 Resulting Concentration	OW2 Meet TMDL Concentration?	OW 4 Resulting Concentration	OW4 Meet TMDL Concentration?	OW6 Resulting Concentration	OW6 Meet TMDL Concentration?
2010	0.851	Yes	0.674	Yes	0.659	Yes
2011	1.065	Yes	0.738	Yes	0.710	Yes
2012	1.060	Yes	0.793	Yes	0.759	Yes
2013	0.965	Yes	0.724	Yes	0.695	Yes
2014	0.866	Yes	0.682	Yes	0.634	Yes

TABLE 39: TP CONCENTRATIONS IN LAKE JESUP IN THE TMDL SCENARIO RUN

Year	OW2 Resulting Concentration	OW2 Meet TMDL Concentration?	OW 4 Resulting Concentration	OW4 Meet TMDL Concentration?	OW6 Resulting Concentration	OW6 Meet TMDL Concentration?
2003	0.135	No	0.086	Yes	0.085	Yes
2004	0.102	No	0.073	Yes	0.070	Yes
2005	0.096	No	0.062	Yes	0.063	Yes
2006	0.112	No	0.086	Yes	0.086	Yes
2007	0.121	No	0.097	No	0.098	No
2008	0.115	No	0.081	Yes	0.077	Yes
2009	0.109	No	0.076	Yes	0.075	Yes
2010	0.103	No	0.074	Yes	0.076	Yes
2011	0.128	No	0.083	Yes	0.084	Yes
2012	0.112	No	0.092	Yes	0.088	Yes
2013	0.108	No	0.082	Yes	0.080	Yes
2014	0.100	No	0.076	Yes	0.075	Yes

Section 5.0 REFERENCES

- Adey, John. 2005. Development of the partition coefficient (Kd) test method for use in environmental risk assessments. Environment Agency. Bristol, United Kingdom.
- Ahn, Mi-Youn, Andrew Zimmerman, Nick Comerford, James Sickman, and Sabine Grunwald. 2009. Cabon Mineralization and labile organic carbon pools in the Sandy soils of a north Florida watershed. *Ecosystems* (2009)12:672-685.
- Bergman, M.J. 2004. Land use classification table. Internal document. SJRWMD. Palatka, Florida.
- Di Toro, D.M. 2001. Sediment Flux Modeling. Wiley, New York.
- Donigian, A.S. 2002. Watershed model calibration and validation: the HSPF experience. AQUA TERRA Consultants. Mountain View, California.
- Florida Department of Environmental Protection (DEP). 2006. TMDL Report Nutrient and Unionized Ammonia TMDLs for Lake Jesup, WBIDs 2981 and 2981A.
- Florida Department of Health (FDOH). 2013. Onsite sewage treatment and disposal systems statistical data. Available online at <http://www.doh.state.fl.us/environment/ostds/statistics/repairs.htm>.
- Harper, H.H. 1994. Stormwater loading rate parameters for central and south Florida. Environmental Research and Design, Inc. Orlando, Florida.
- Harper, Harvey. 2013. Evaluation of Sediment Impacts on Hydrologic and Nutrient Loadings from Groundwater Seepage to Lake Jesup: Final Report. Environmental Research & Design, Inc. Orlando, Florida.
- Harper, Harvey H. and David M. 2008. Baker. Spring Lake Hydrologic/Nutrient Budget and Management Plan. Environmental Research and Design, Inc. Orlando, Florida.
- Jia, Yanbing. 2015. Hydrologic and Water Quality Modeling of the Lake Jesup Watershed. SJRWMD. Palatka, Florida.
- McCutcheon, Steve C., James L. Martin, and Robert B. Ambrose. 1990. Technical Guidance Manual for Performing Waste Load Allocations, Book III: Estuaries, Part 2: Application of Estuarine Waste Load Allocation Models. U.S. Environmental Protection Agency. Washington, DC.
- Murasko, Susan Mary. 2009. Particulate carbon, nitrogen and phosphorus stoichiometry of south west Florida Waters. University of South Florida. Tampa, Florida.
- Soil and Water Engineering Technology (SWET). 2008. Nutrient Loading Rates, Reduction Factors and Implementation Costs Associated with BMPs and Technologies. Prepared for South Florida Water Management District.
- Stevenson, F. J. and M. A. Cole. 1999. Cycles of Soils: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. ISBN: 978-0-471-32071-5.

- Sucsy, Peter and Brandt-Williams, Sherry. 2015. Water Quality Model Application of the Water Quality Analysis Simulation Program (WASP) to Lake Jesup, FL. SJRWMD. Palatka, Florida.
- United States Environmental Protection Agency (USEPA). 2002. Onsite Wastewater Treatment Manual. EPA 625/R-00/008. National Risk Management Research Laboratory, Office of Water, U.S. Environmental Protection Agency. Washington, DC.
- Vincent, Amelia. 2006. Evaluation of Phosphorus Transport and Transformations in GLEAMS 3.0. Virginia Polytechnic Institute and State University. Blacksburg, Virginia.

APPENDIX A: HSPF MODEL CALIBRATION RESULTS

HYDROLOGY CALIBRATION AND STATISTICAL EVALUATION

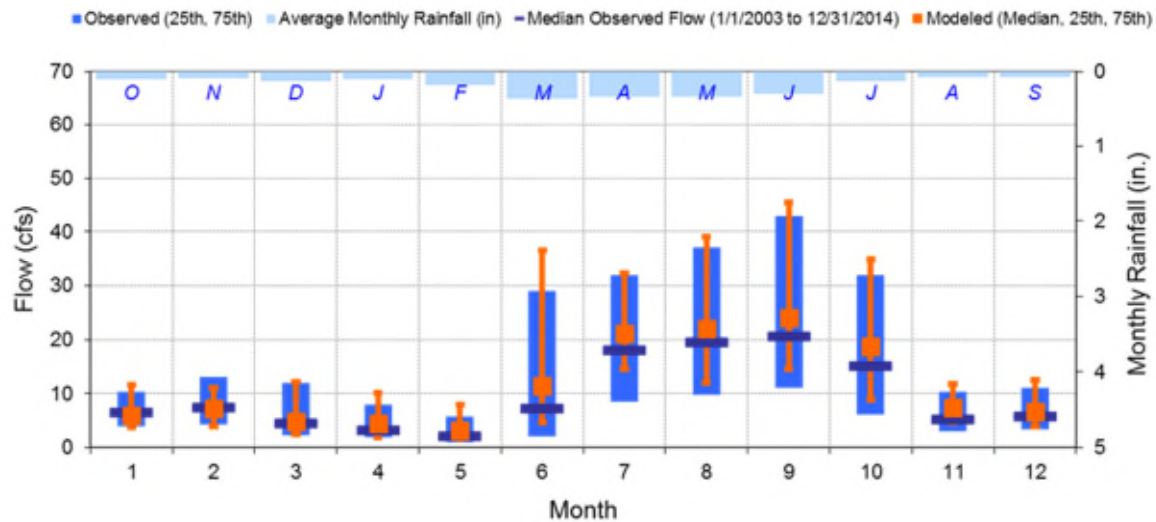


FIGURE A-1: BOX AND WHISKER PLOTS (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234400 (GEE CREEK)

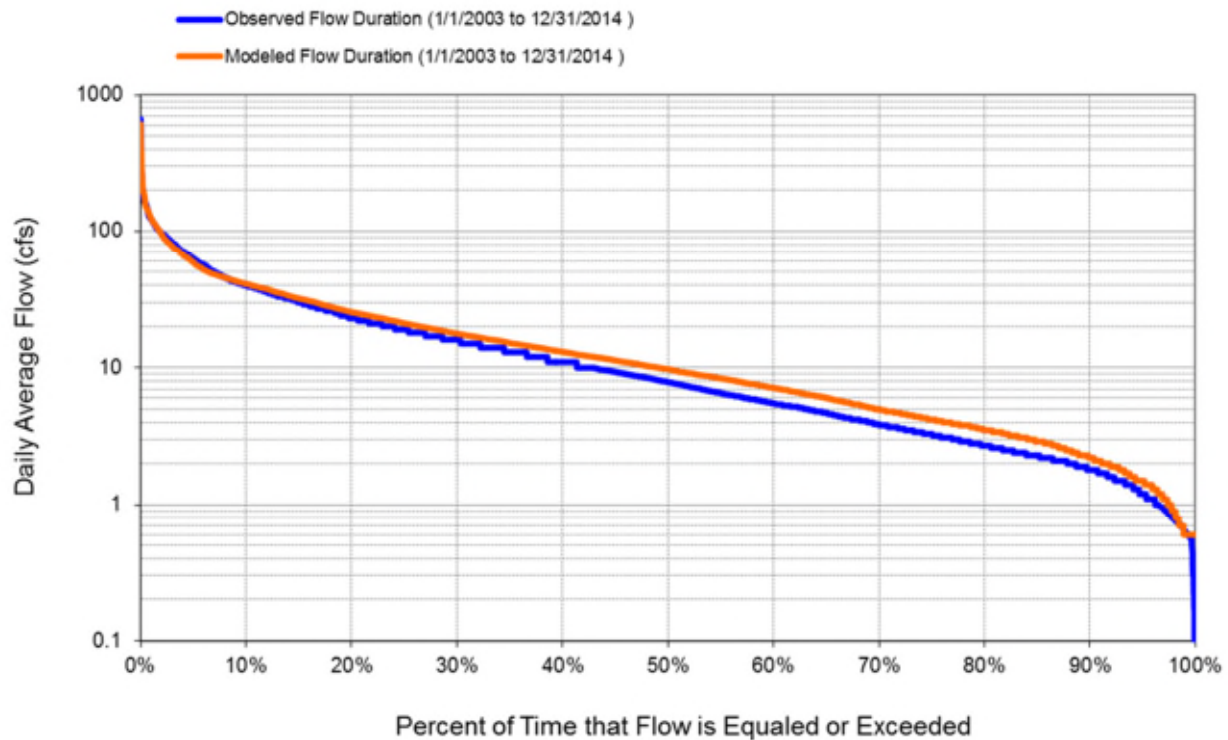


FIGURE A-2: FREQUENCY DISTRIBUTION CURVE (OBSERVED AND SIMULATED DAILY FLOWS) FOR USGS GAGE 02234400 (GEE CREEK)

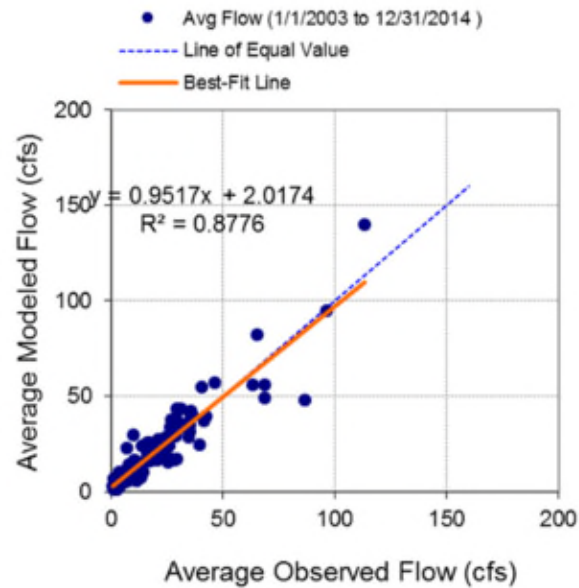


FIGURE A-3: SCATTER PLOT (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234400 (GEE CREEK)

TABLE A-1: ERROR STATISTICS FOR USGS GAGE 02234400 (GEE CREEK)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 115		USGS 02234400 GEE CREEK NEAR LONGWOOD, FL	
12-Year Analysis Period: 1/1/2003 - 12/31/2014 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 03080101 Drainage Area (sq-mi): 12.8	
Total Simulated In-stream Flow:	5.80	Total Observed In-stream Flow:	5.41
Total of simulated highest 10% flows:	2.47	Total of Observed highest 10% flows:	2.50
Total of Simulated lowest 50% flows:	0.74	Total of Observed Lowest 50% flows:	0.58
Simulated Summer Flow Volume (months 7-9):	2.65	Observed Summer Flow Volume (7-9):	2.46
Simulated Fall Flow Volume (months 10-12):	1.28	Observed Fall Flow Volume (10-12):	1.17
Simulated Winter Flow Volume (months 1-3):	0.79	Observed Winter Flow Volume (1-3):	0.80
Simulated Spring Flow Volume (months 4-6):	1.08	Observed Spring Flow Volume (4-6):	0.98
Total Simulated Storm Volume:	1.63	Total Observed Storm Volume:	1.52
Simulated Summer Storm Volume (7-9):	0.73	Observed Summer Storm Volume (7-9):	0.71
Errors (Simulated-Observed)	Error Statistics		
Error in total volume:	7.25		
Error in 50% lowest flows:	27.66		
Error in 10% highest flows:	-1.26		
Seasonal volume error - Summer:	7.78		
Seasonal volume error - Fall:	9.28		
Seasonal volume error - Winter:	-0.95		
Seasonal volume error - Spring:	10.20		
Error in storm volumes:	7.49		
Error in summer storm volumes:	2.69		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.847	Model accuracy increases as E or E' approaches 1.0	

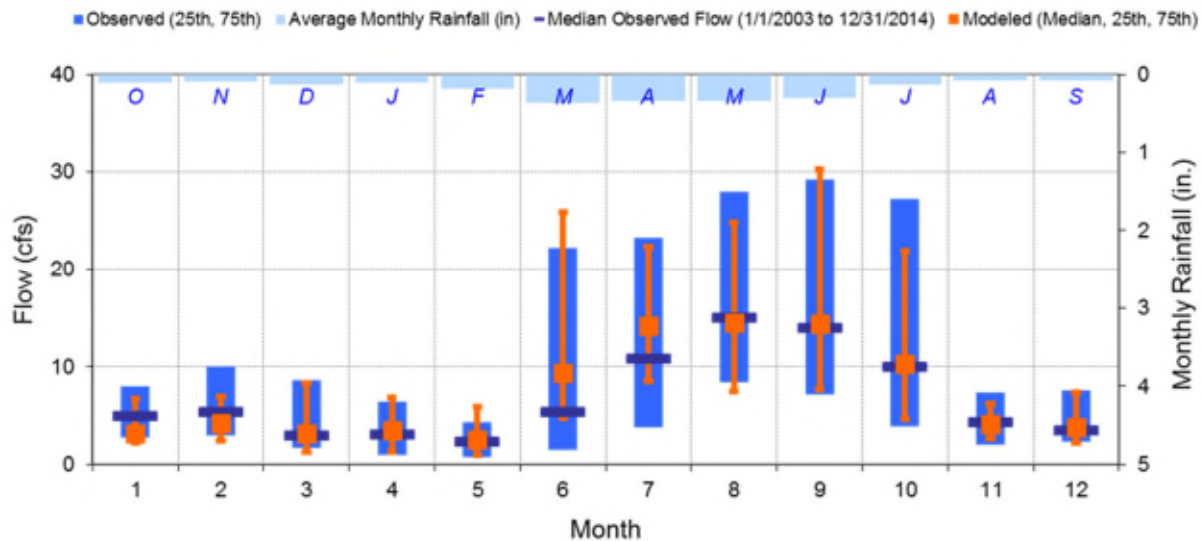


FIGURE A-4: BOX AND WHISKER PLOTS (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234384 (SOLDIERS CREEK)

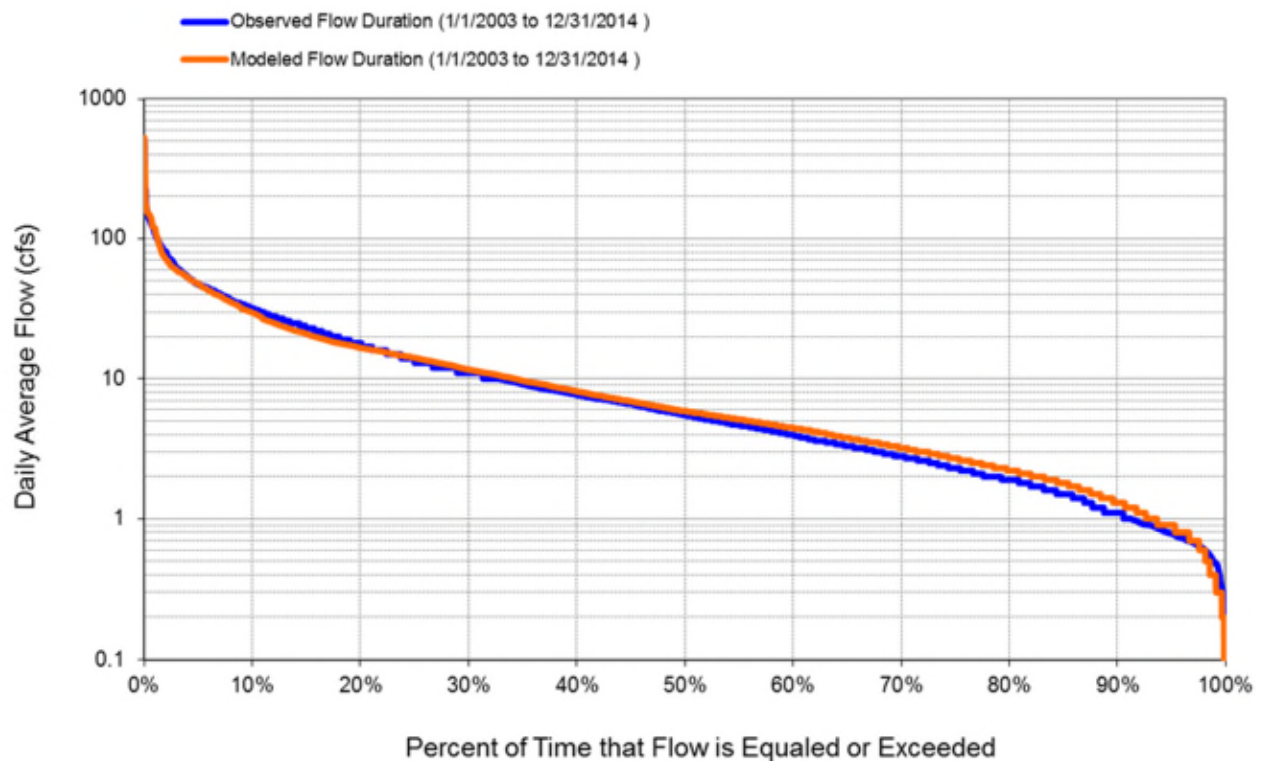


FIGURE A-5: FREQUENCY DISTRIBUTION CURVE (OBSERVED AND SIMULATED DAILY FLOWS) FOR USGS GAGE 02234384 (SOLDIERS CREEK)

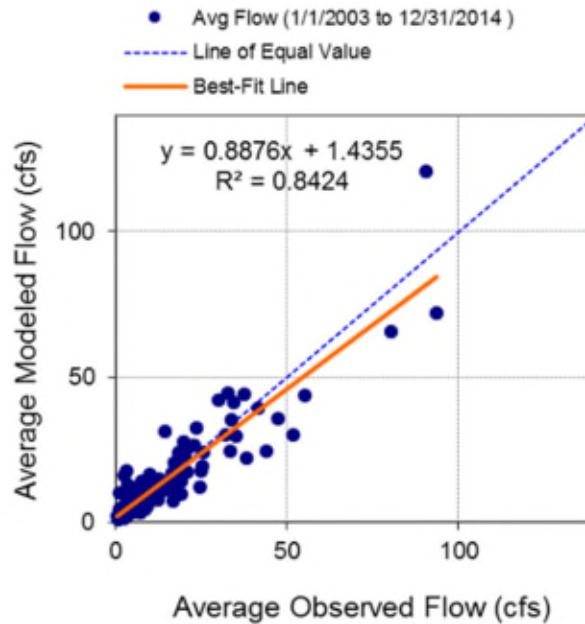


FIGURE A-6: SCATTER PLOT (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234384 (SOLDIERS CREEK)

TABLE A-2: ERROR STATISTICS FOR USGS GAGE 02234384 (SOLDIERS CREEK)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 123		USGS 02234384 SOLDIER CREEK NEAR LONGWOOD, FL	
12-Year Analysis Period: 1/1/2003 - 12/31/2014 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 03080101 Drainage Area (sq-mi): 21.2	
Total Simulated In-stream Flow:	4.16	Total Observed In-stream Flow:	4.15
Total of simulated highest 10% flows:	2.01	Total of Observed highest 10% flows:	2.03
Total of Simulated lowest 50% flows:	0.46	Total of Observed Lowest 50% flows:	0.41
Simulated Summer Flow Volume (months 7-9):	1.90	Observed Summer Flow Volume (7-9):	1.88
Simulated Fall Flow Volume (months 10-12):	0.83	Observed Fall Flow Volume (10-12):	0.88
Simulated Winter Flow Volume (months 1-3):	0.55	Observed Winter Flow Volume (1-3):	0.63
Simulated Spring Flow Volume (months 4-6):	0.88	Observed Spring Flow Volume (4-6):	0.76
Total Simulated Storm Volume:	1.26	Total Observed Storm Volume:	1.10
Simulated Summer Storm Volume (7-9):	0.57	Observed Summer Storm Volume (7-9):	0.51
Errors (Simulated-Observed)	Error Statistics		
Error in total volume:	0.07		
Error in 50% lowest flows:	13.23		
Error in 10% highest flows:	-1.08		
Seasonal volume error - Summer:	1.33		
Seasonal volume error - Fall:	-6.05		
Seasonal volume error - Winter:	-13.74		
Seasonal volume error - Spring:	15.67		
Error in storm volumes:	13.73		
Error in summer storm volumes:	11.12		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.798	Model accuracy increases as E or E* approaches 1.0	

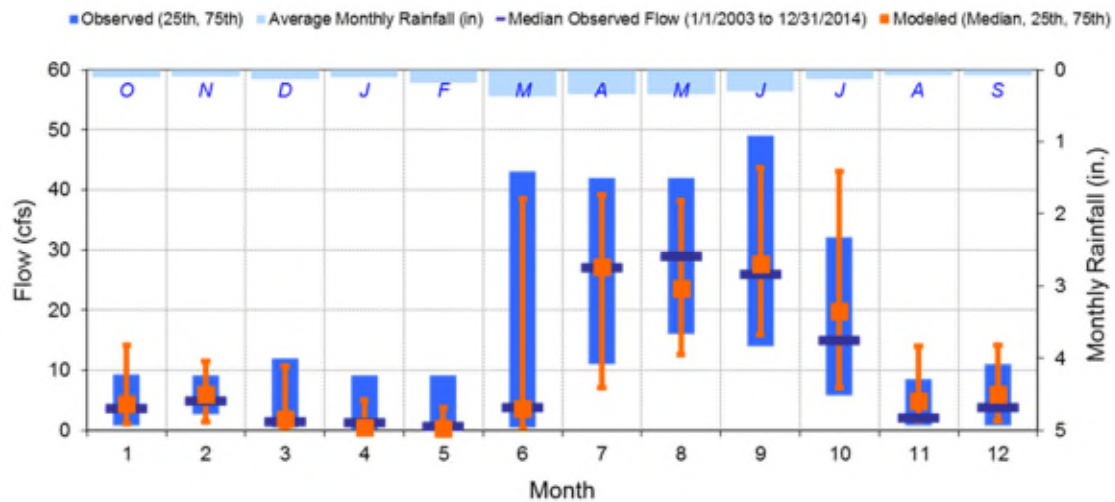


FIGURE A-7: BOX AND WHISKER PLOTS (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234308 (HOWELL CREEK)

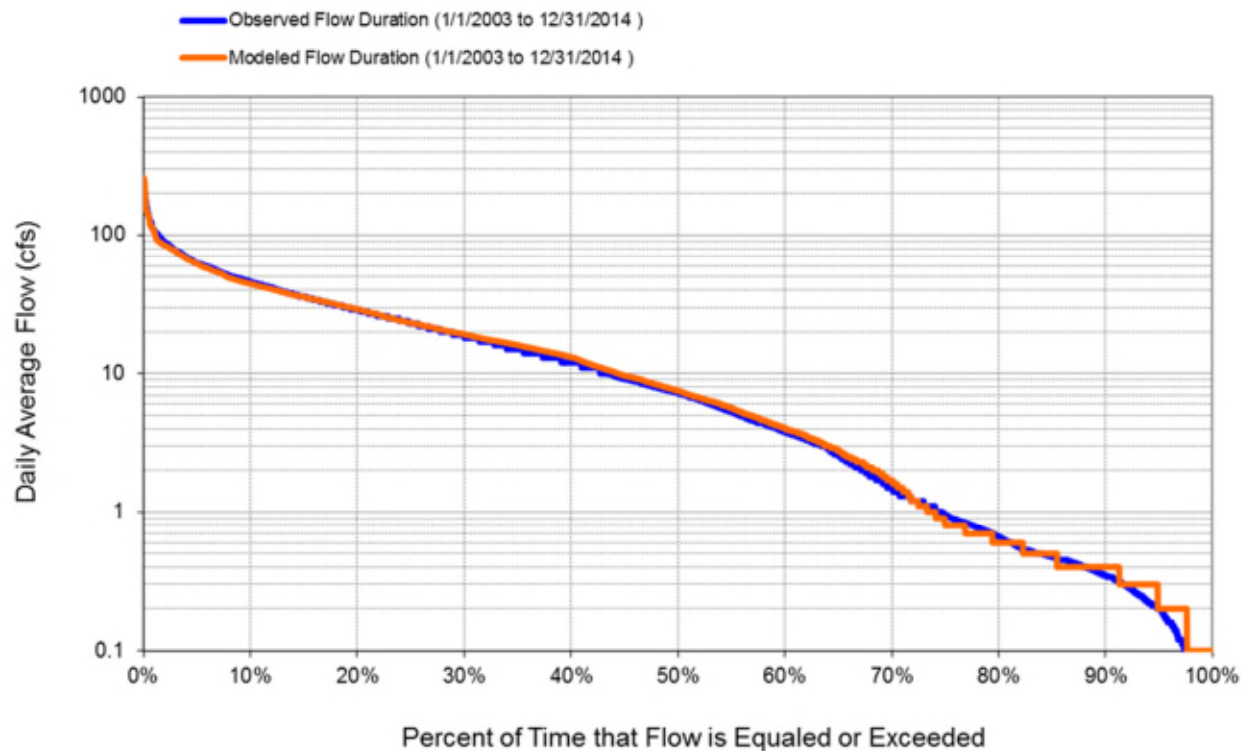


FIGURE A-8: FREQUENCY DISTRIBUTION CURVE (OBSERVED AND SIMULATED DAILY FLOWS) FOR USGS GAGE 02234308 (HOWELL CREEK)

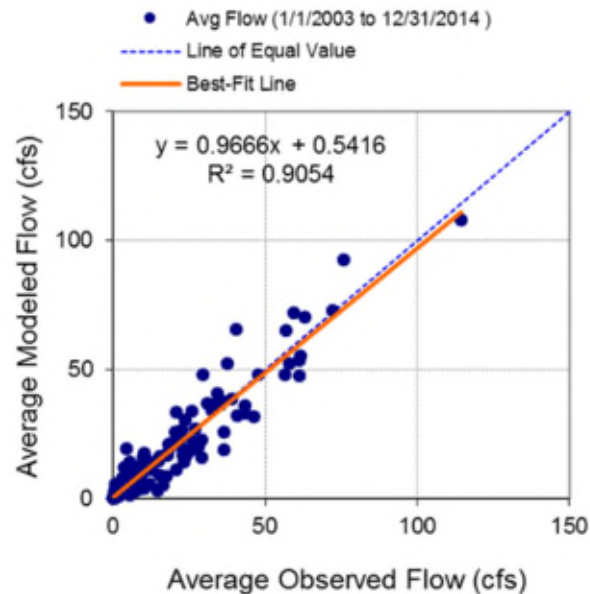


FIGURE A-9: SCATTER PLOT (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234308 (HOWELL CREEK)

TABLE A-3: ERROR STATISTICS FOR USGS GAGE 02234308 (HOWELL CREEK)

HSPF Simulated Flow		Observed Flow Gage	
REA CH OUTFLOW FROM SUBBA SIN 47		USGS 02234308 HOWELL CREEK NEAR ALTAMONTE SPRINGS, FL	
12-Year Analysis Period: 1/1/2003 - 12/31/2014 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 03080101 Drainage Area (sq-mi): 20.6	
Total Simulated In-stream Flow:	5.41	Total Observed In-stream Flow:	5.41
Total of simulated highest 10% flows:	2.32	Total of Observed highest 10% flows:	2.39
Total of Simulated lowest 50% flows:	0.33	Total of Observed Lowest 50% flows:	0.31
Simulated Summer Flow Volume (months 7-9):	2.62	Observed Summer Flow Volume (7-9):	2.79
Simulated Fall Flow Volume (months 10-12):	1.29	Observed Fall Flow Volume (10-12):	1.05
Simulated Winter Flow Volume (months 1-3):	0.70	Observed Winter Flow Volume (1-3):	0.62
Simulated Spring Flow Volume (months 4-6):	0.79	Observed Spring Flow Volume (4-6):	0.95
Total Simulated Storm Volume:	0.72	Total Observed Storm Volume:	1.00
Simulated Summer Storm Volume (7-9):	0.30	Observed Summer Storm Volume (7-9):	0.51
<i>Errors (Simulated-Observed)</i>	<i>Error Statistics</i>		
Error in total volume:	-0.09		
Error in 50% lowest flows:	5.23		
Error in 10% highest flows:	-2.96		
Seasonal volume error - Summer:	-5.92		
Seasonal volume error - Fall:	23.07		
Seasonal volume error - Winter:	13.34		
Seasonal volume error - Spring:	-17.29		
Error in storm volumes:	-28.37		
Error in summer storm volumes:	-40.62		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.821	Model accuracy increases as E or E' approaches 1.0	

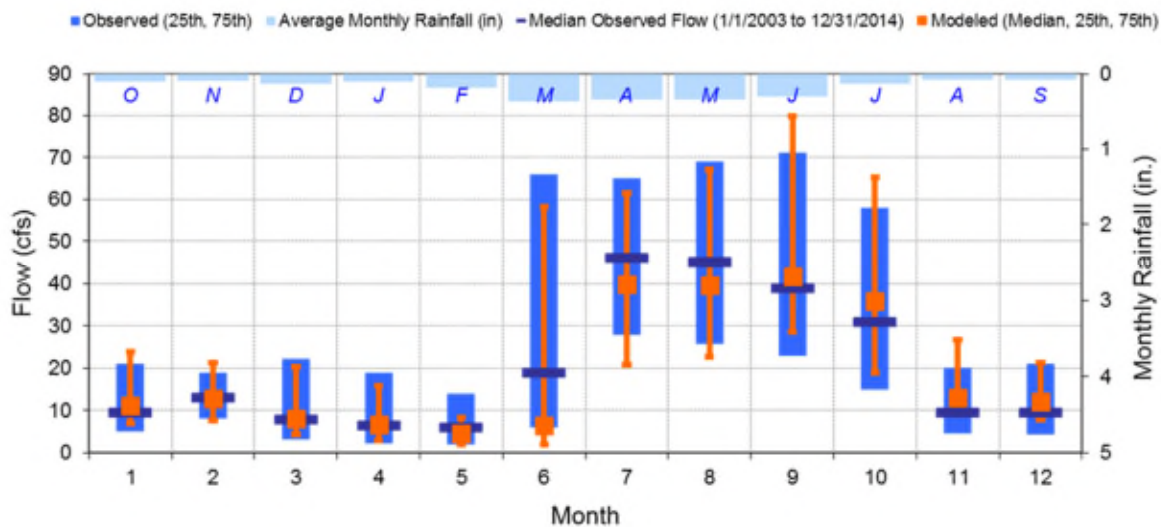


FIGURE A-10: BOX AND WHISKER PLOTS (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234324 (HOWELL CREEK)

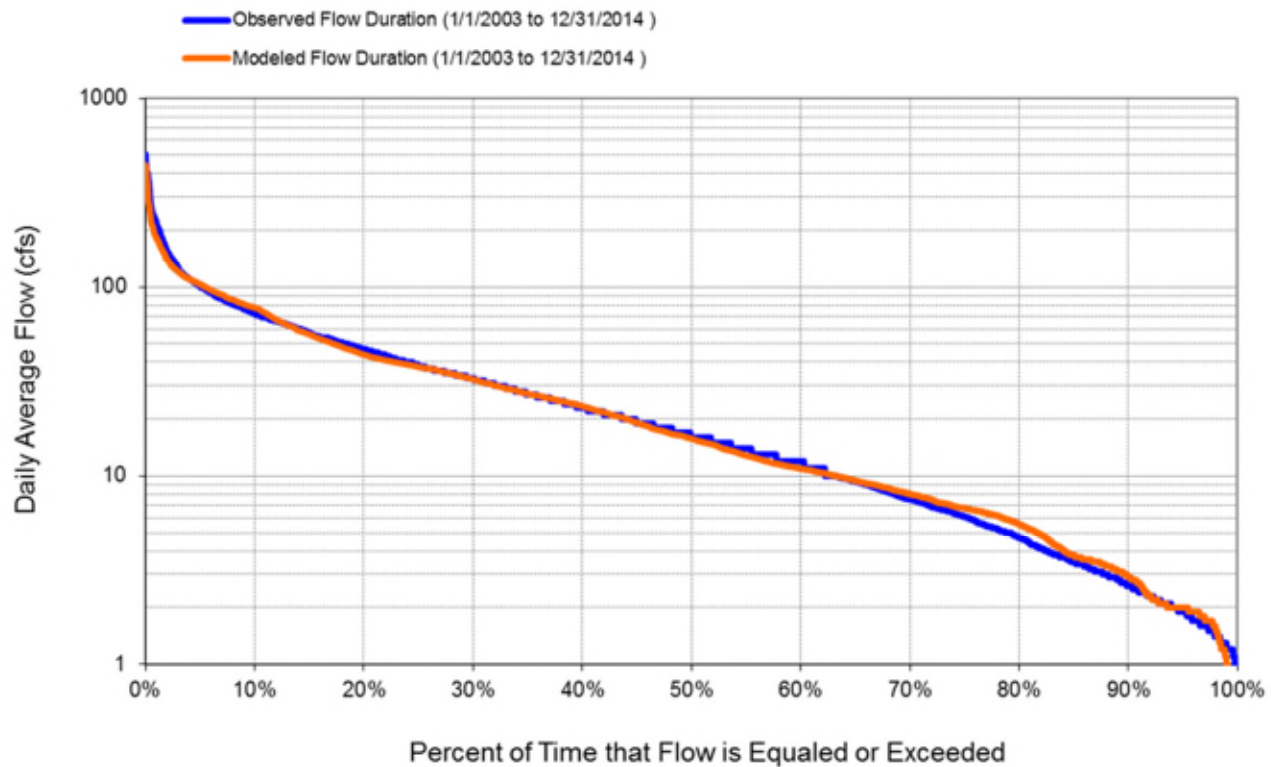


FIGURE A-11: FREQUENCY DISTRIBUTION CURVE (OBSERVED AND SIMULATED DAILY FLOWS) FOR USGS GAGE 02234324 (HOWELL CREEK)

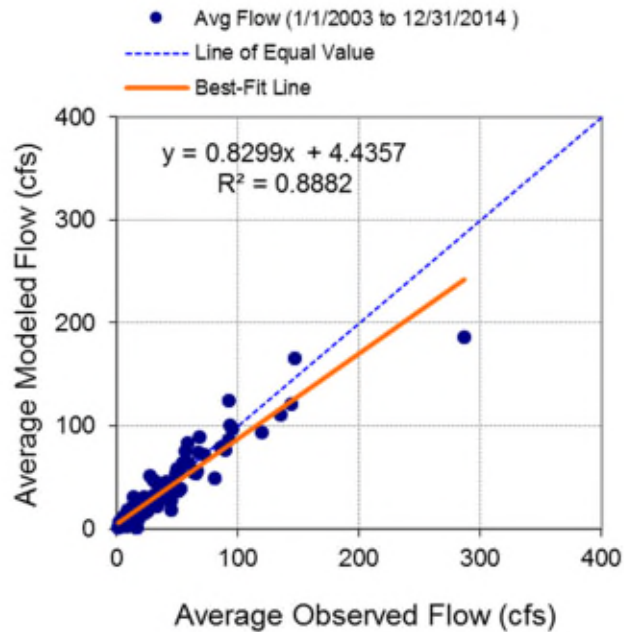


FIGURE A-12: SCATTER PLOT (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234324 (HOWELL CREEK)

TABLE A-4: ERROR STATISTICS FOR USGS GAGE 02234324 (HOWELL CREEK)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 45		USGS 02234324 HOWELL CREEK NEAR SLAVIA, FL	
12-Year Analysis Period: 1/1/2003 - 12/31/2014 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 03080101 Drainage Area (sq-mi): 29.2	
Total Simulated In-stream Flow:	9.66	Total Observed In-stream Flow:	9.91
Total of simulated highest 10% flows:	3.93	Total of Observed highest 10% flows:	4.14
Total of Simulated lowest 50% flows:	1.14	Total of Observed Lowest 50% flows:	1.12
Simulated Summer Flow Volume (months 7-9):	4.50	Observed Summer Flow Volume (7-9):	4.78
Simulated Fall Flow Volume (months 10-12):	2.37	Observed Fall Flow Volume (10-12):	2.10
Simulated Winter Flow Volume (months 1-3):	1.37	Observed Winter Flow Volume (1-3):	1.28
Simulated Spring Flow Volume (months 4-6):	1.41	Observed Spring Flow Volume (4-6):	1.75
Total Simulated Storm Volume:	1.67	Total Observed Storm Volume:	1.49
Simulated Summer Storm Volume (7-9):	0.81	Observed Summer Storm Volume (7-9):	0.72
Errors (Simulated-Observed)	Error Statistics		
Error in total volume:	-2.51		
Error in 50% lowest flows:	1.30		
Error in 10% highest flows:	-4.94		
Seasonal volume error - Summer:	-5.96		
Seasonal volume error - Fall:	13.06		
Seasonal volume error - Winter:	7.79		
Seasonal volume error - Spring:	-19.31		
Error in storm volumes:	11.90		
Error in summer storm volumes:	11.60		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.839	Model accuracy increases as E or E* approaches 1.0	

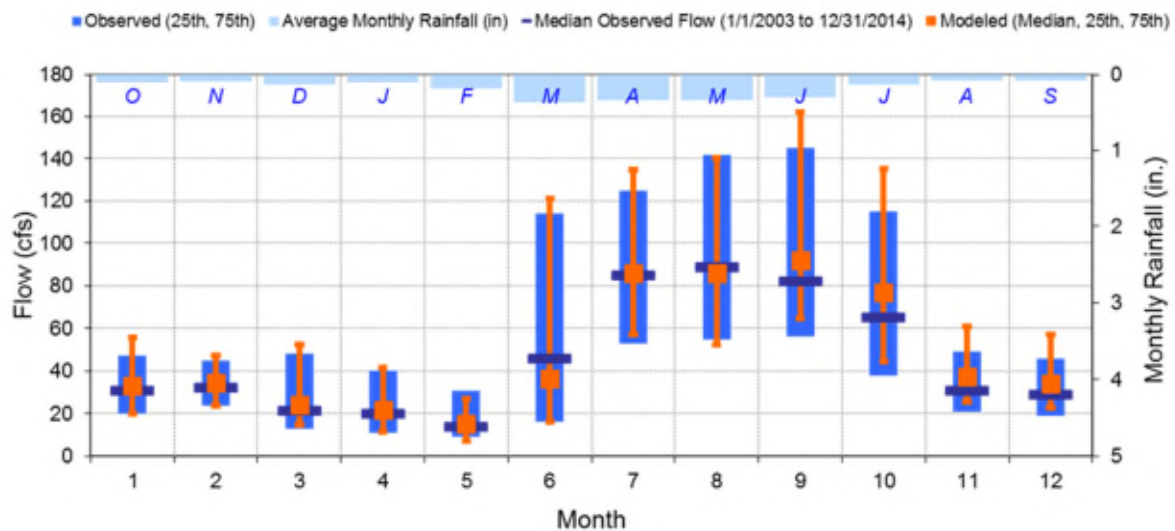


FIGURE A-13: BOX AND WHISKER PLOTS (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234344 (HOWELL CREEK)

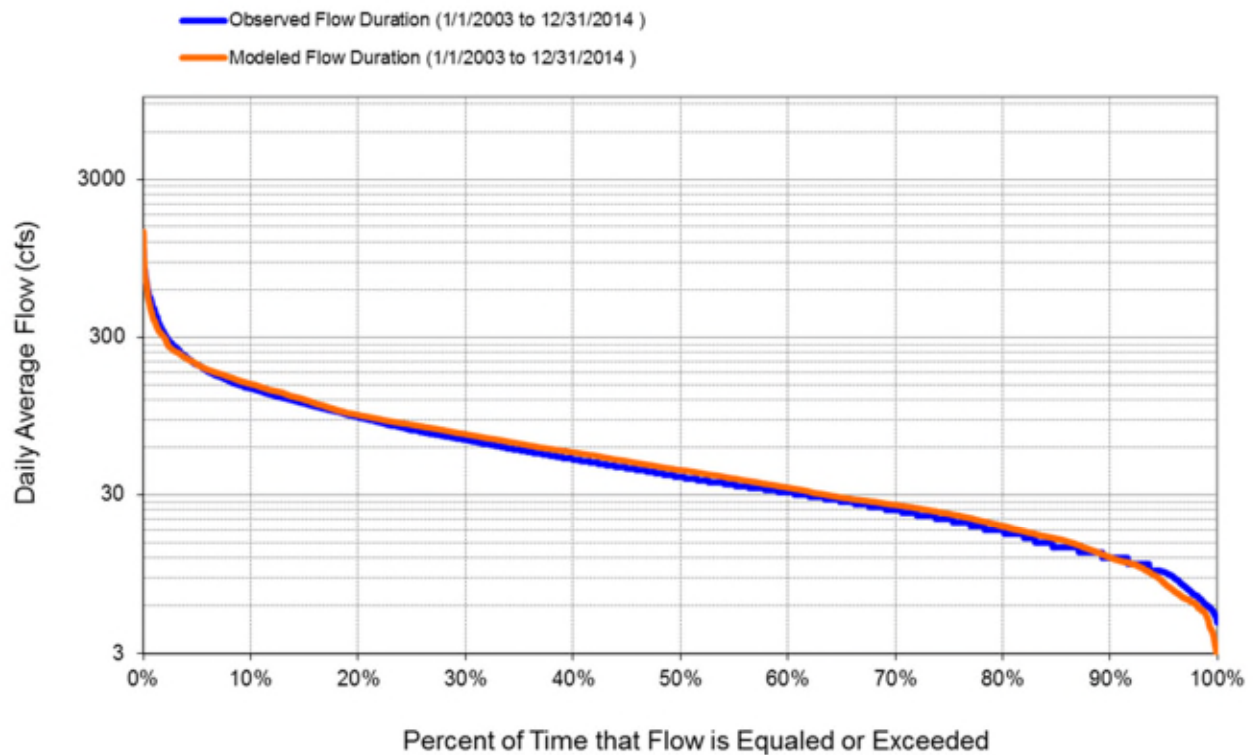


FIGURE A-14: FREQUENCY DISTRIBUTION CURVE (OBSERVED AND SIMULATED DAILY FLOWS) FOR USGS GAGE 02234344 (HOWELL CREEK)

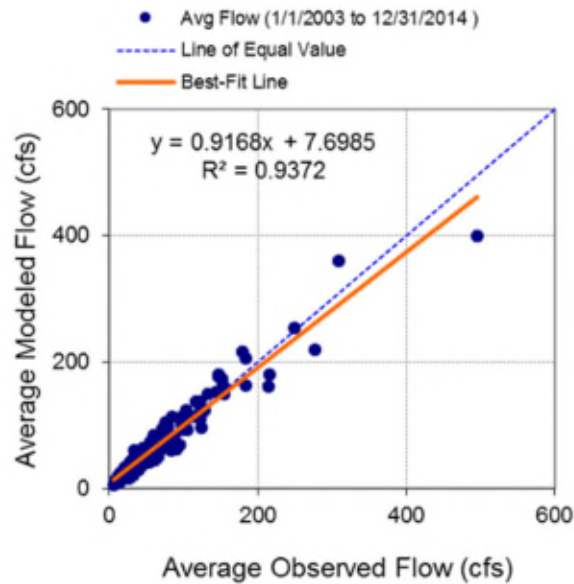


FIGURE A-15: SCATTER PLOT (OBSERVED AND SIMULATED MONTHLY FLOWS) FOR USGS GAGE 02234344 (HOWELL CREEK)

TABLE A-5: ERROR STATISTICS FOR USGS GAGE 02234344 (HOWELL CREEK)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 40		USGS 02234344 HOWELL CREEK AT STATE HWY 434 NEAR OVIEDO, FL	
12-Year Analysis Period: 1/1/2003 - 12/31/2014 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 03080101 Drainage Area (sq-mi): 52.0	
Total Simulated In-stream Flow:	21.96	Total Observed In-stream Flow:	21.24
Total of simulated highest 10% flows:	8.06	Total of Observed highest 10% flows:	8.25
Total of Simulated lowest 50% flows:	3.68	Total of Observed Lowest 50% flows:	3.45
Simulated Summer Flow Volume (months 7-9):	9.67	Observed Summer Flow Volume (7-9):	9.69
Simulated Fall Flow Volume (months 10-12):	5.36	Observed Fall Flow Volume (10-12):	4.79
Simulated Winter Flow Volume (months 1-3):	3.38	Observed Winter Flow Volume (1-3):	3.17
Simulated Spring Flow Volume (months 4-6):	3.55	Observed Spring Flow Volume (4-6):	3.58
Total Simulated Storm Volume:	4.20	Total Observed Storm Volume:	3.89
Simulated Summer Storm Volume (7-9):	1.97	Observed Summer Storm Volume (7-9):	1.87
Errors (Simulated-Observed)	Error Statistics		
Error in total volume:	3.41		
Error in 50% lowest flows:	6.64		
Error in 10% highest flows:	-2.35		
Seasonal volume error - Summer:	-0.23		
Seasonal volume error - Fall:	11.95		
Seasonal volume error - Winter:	6.54		
Seasonal volume error - Spring:	-0.94		
Error in storm volumes:	7.99		
Error in summer storm volumes:	5.44		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.876	Model accuracy increases as E or E' approaches 1.0	

WATER QUALITY CALIBRATION AND STATISTICAL EVALUATION

North Lake Triplet/Prairie Lake (21FLKWATSEM-TRIPLETN-1 and 21FLSEM PRA) – Subwatershed 10

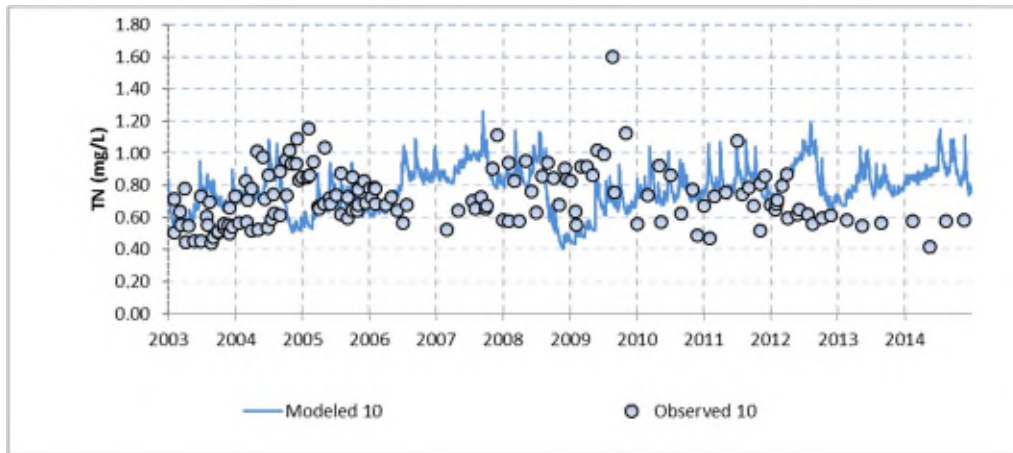


FIGURE A-16: TN TIME SERIES FOR NORTH LAKE TRIPLET/PRAIRIE LAKE

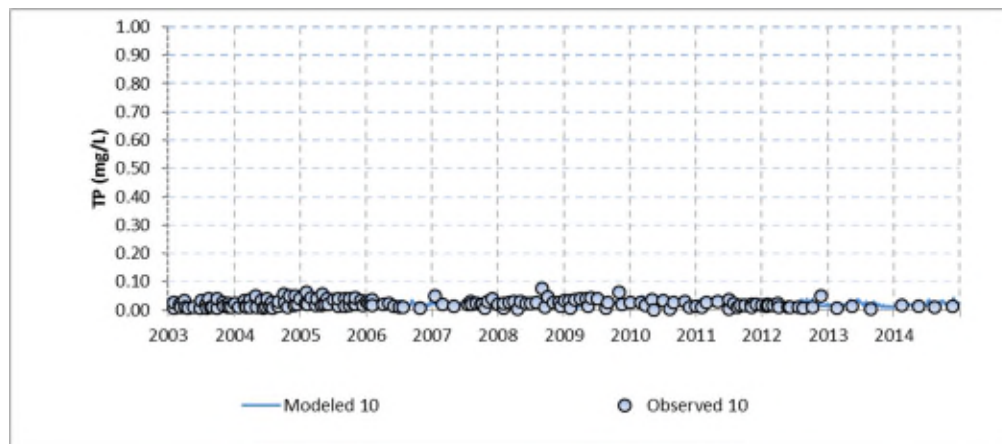


FIGURE A-17: TP TIME SERIES FOR NORTH LAKE TRIPLET/PRAIRIE LAKE

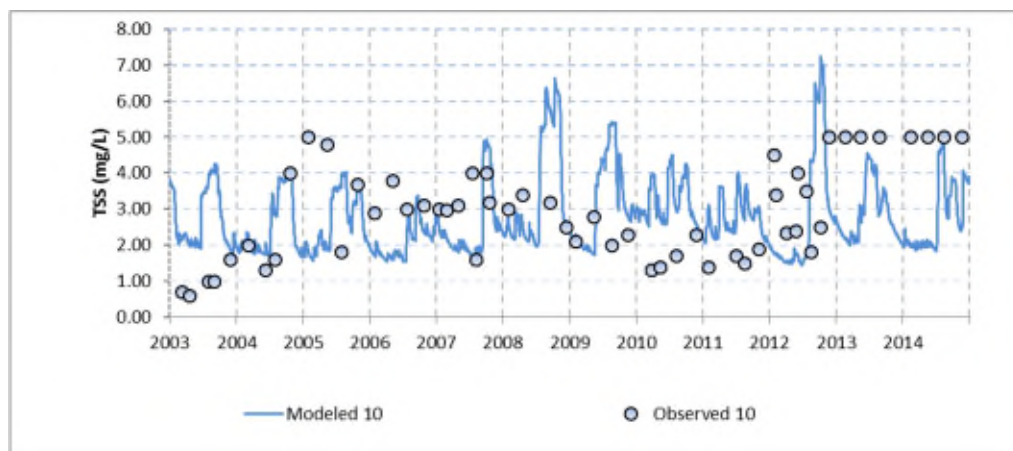


FIGURE A-18: TSS TIME SERIES FOR NORTH LAKE TRIPLET/PRAIRIE LAKE

Fairy Lake (21FLSEM FAR) – Subwatershed 12

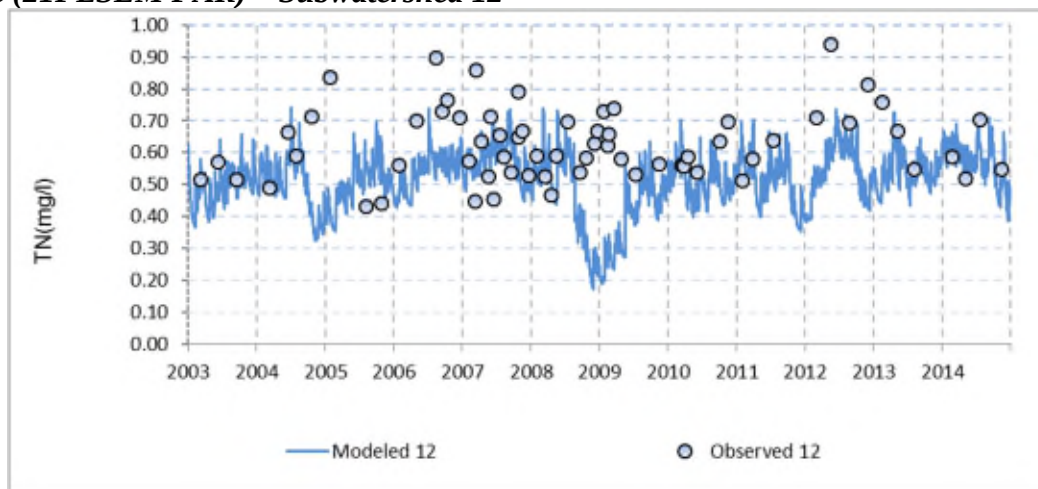


FIGURE A-19: TN TIME SERIES FOR FAIRY LAKE

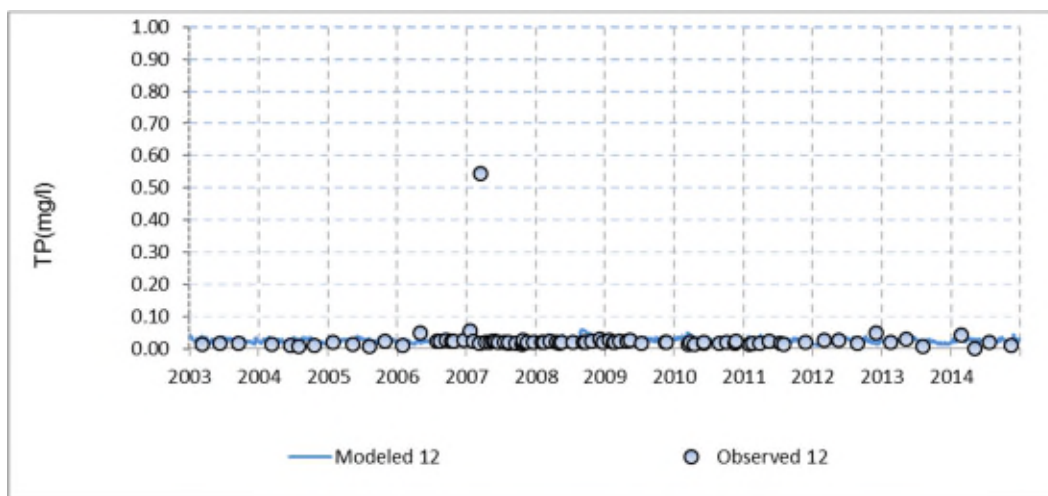


FIGURE A-20: TP TIME SERIES FOR FAIRY LAKE

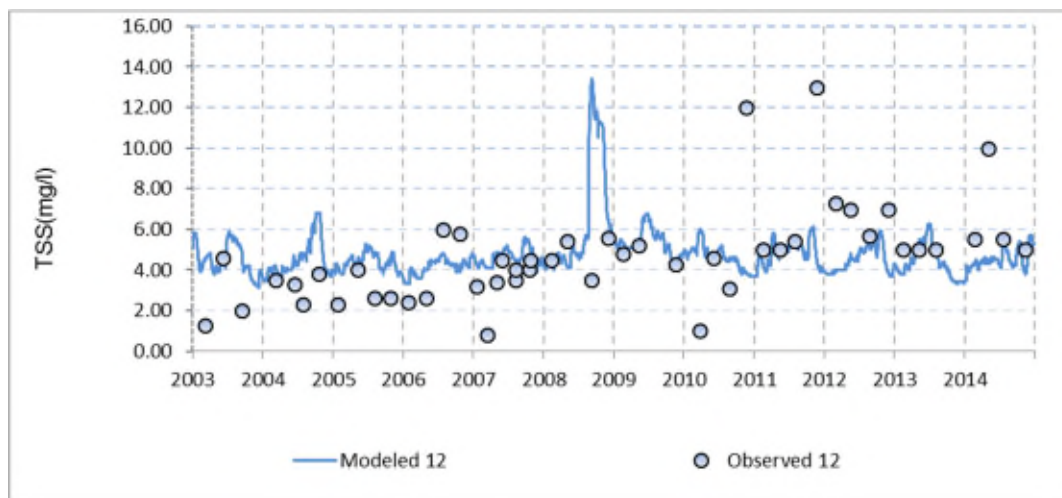


FIGURE A-21: TSS TIME SERIES FOR FAIRY LAKE

Gee Creek (21FLSEM GEE-CASS) – Subwatershed 15

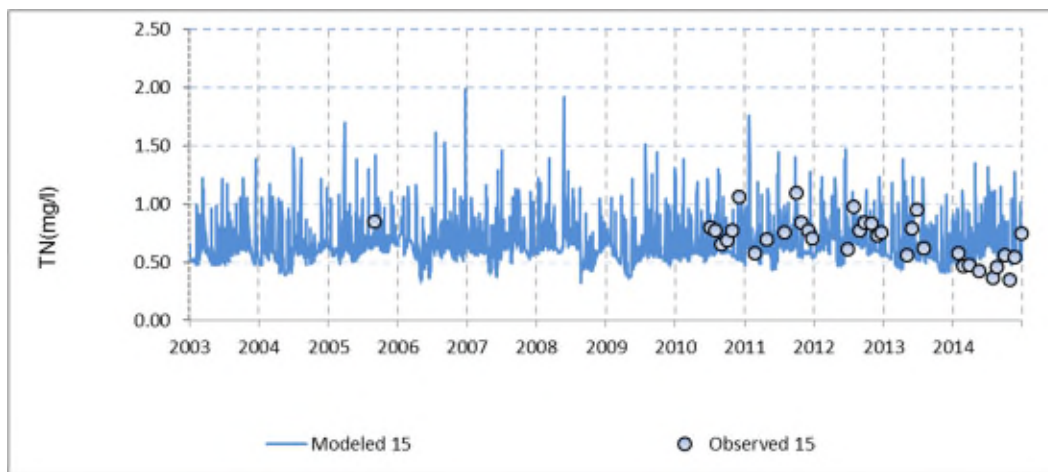


FIGURE A-22: TN TIME SERIES FOR GEE CREEK

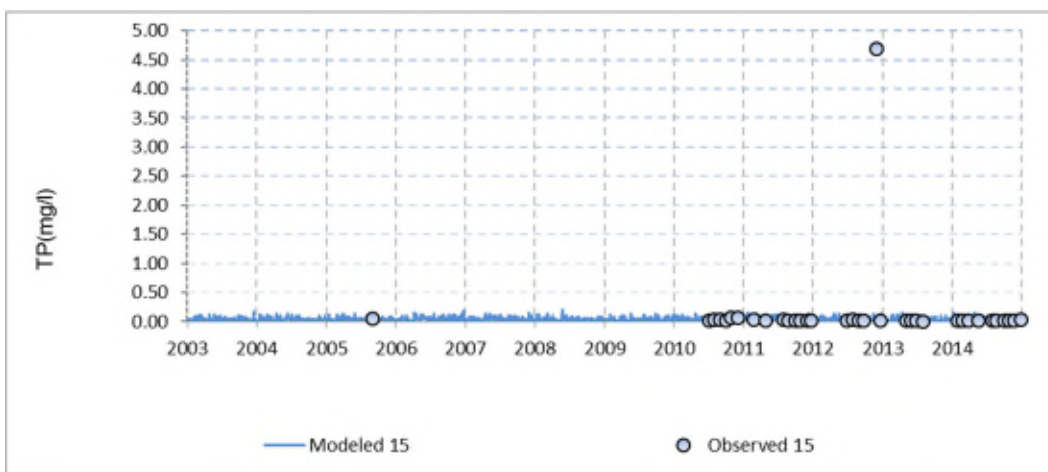


FIGURE A-23: TP TIME SERIES FOR GEE CREEK

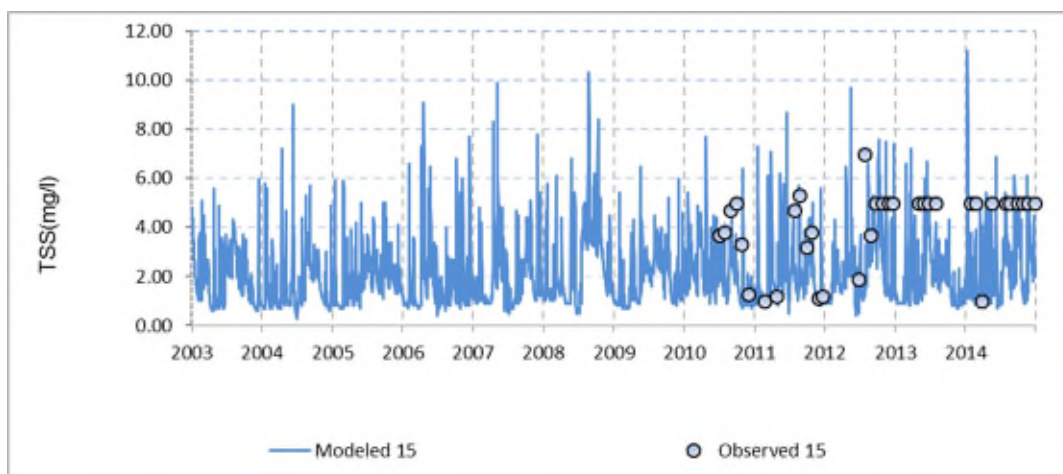


FIGURE A-24: TSS TIME SERIES FOR GEE CREEK

Greenwood Lake (21FLSEM ML01) – Subwatershed 17

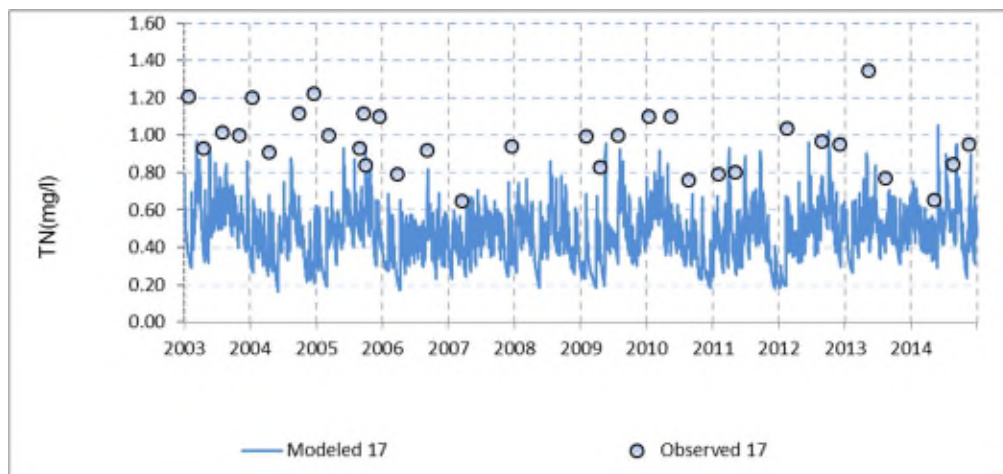


FIGURE A-25: TN TIME SERIES FOR GREENWOOD LAKE

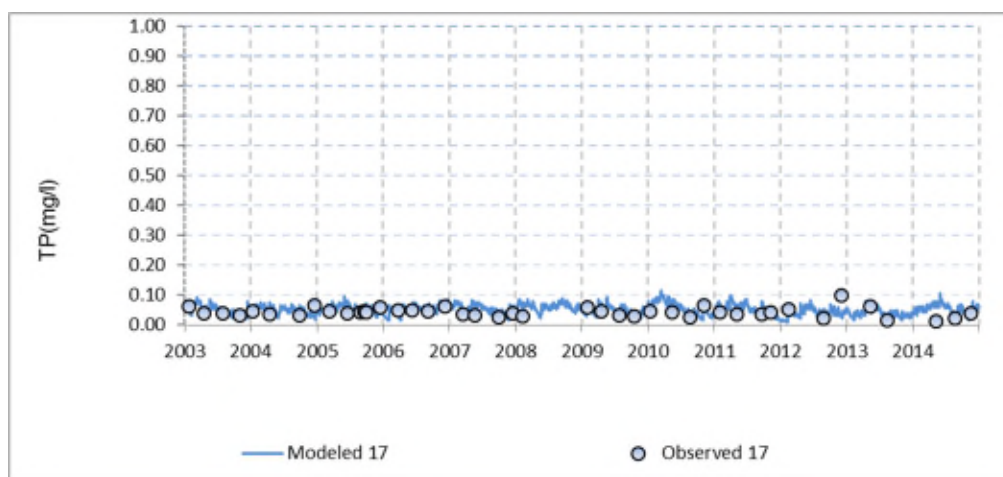


FIGURE A-26: TP TIME SERIES FOR GREENWOOD LAKE

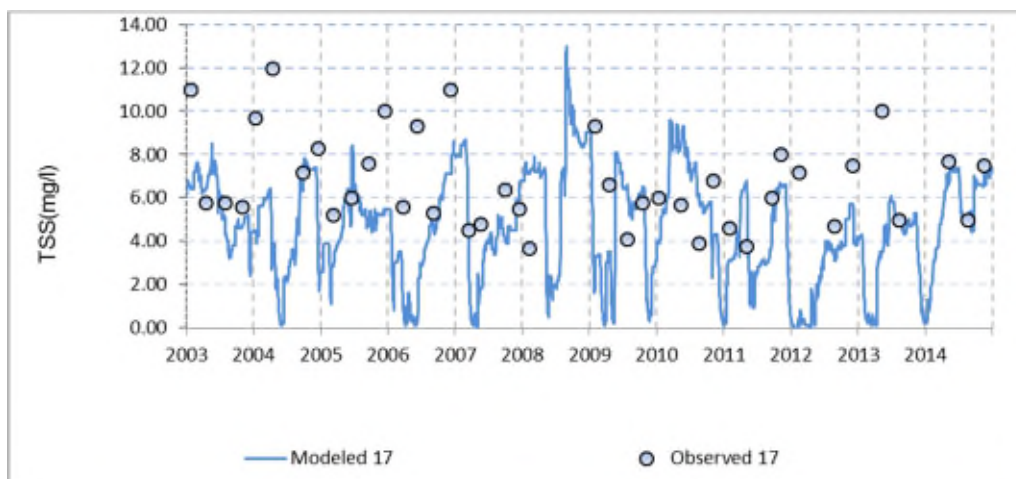


FIGURE A-27: TSS TIME SERIES FOR GREENWOOD LAKE

Soldiers Creek (21FLSEM SOLDN-LM and 21FLSEM SOLUP-LM) – Subwatershed 18

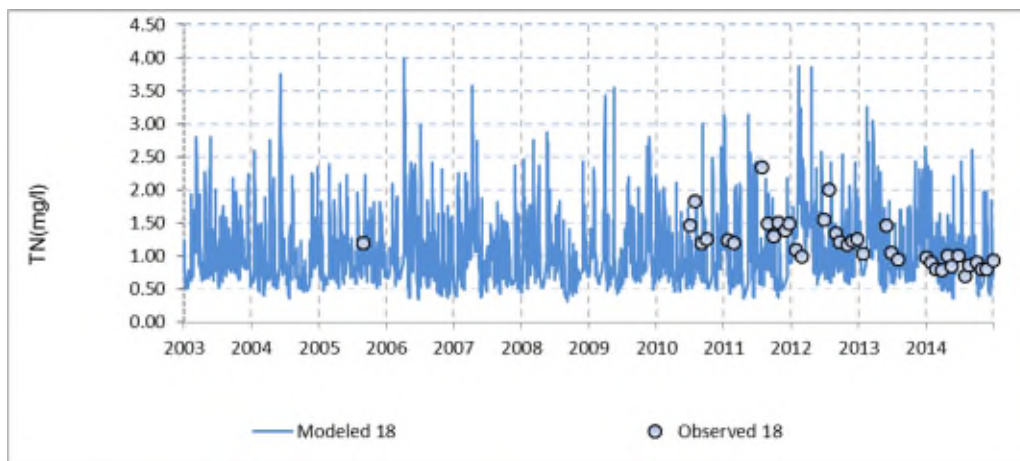


FIGURE A-28: TN TIME SERIES FOR SOLDIERS CREEK

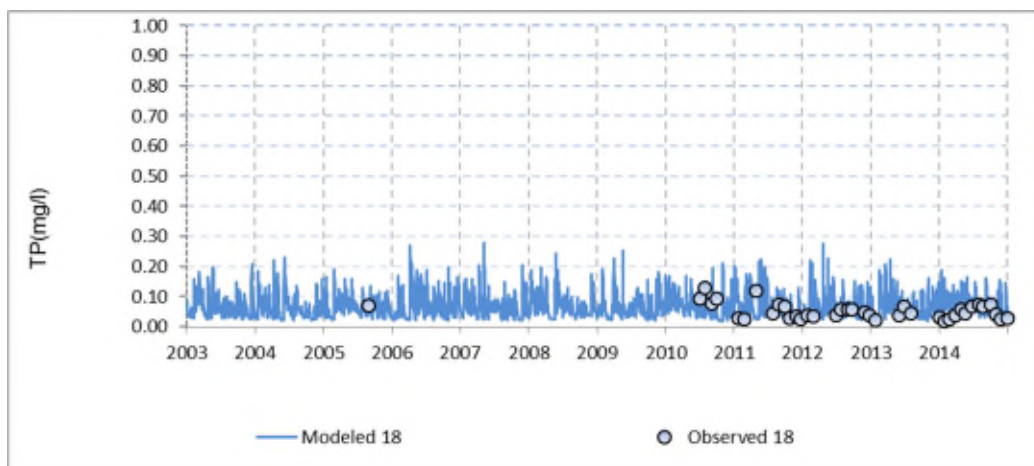


FIGURE A-29: TP TIME SERIES FOR SOLDIERS CREEK

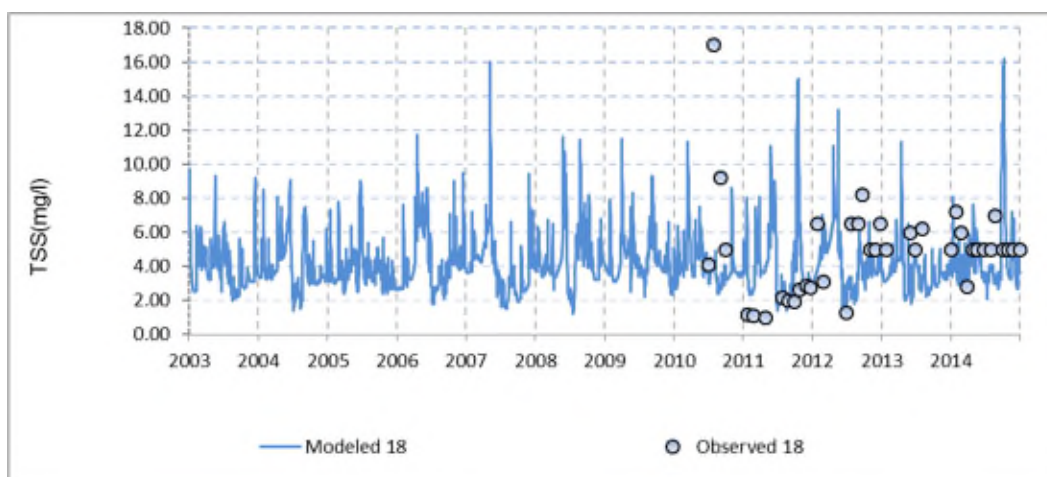


FIGURE A-30: TSS TIME SERIES FOR SOLDIERS CREEK

Navy Canal (21FLSEM NAV) – Subwatershed 27

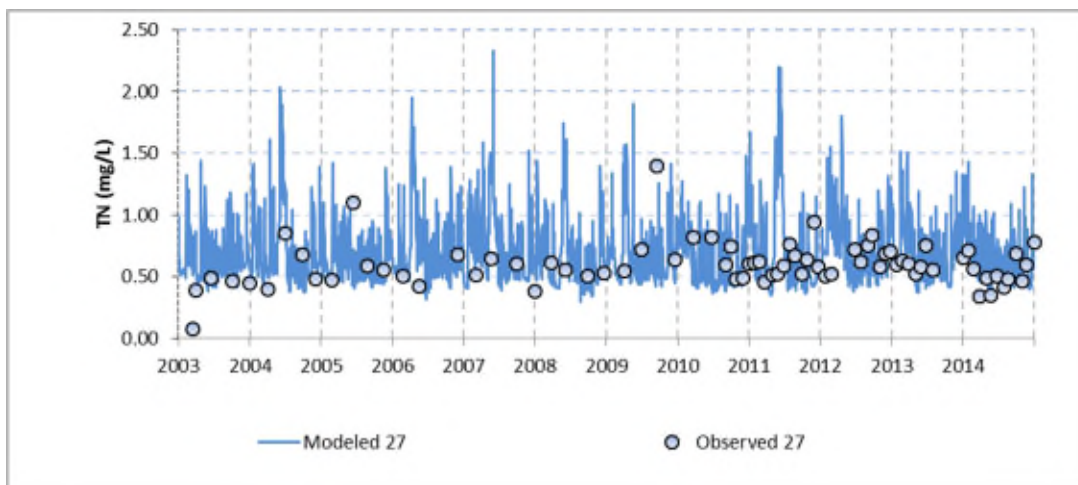


FIGURE A-31: TN TIME SERIES FOR NAVY CANAL

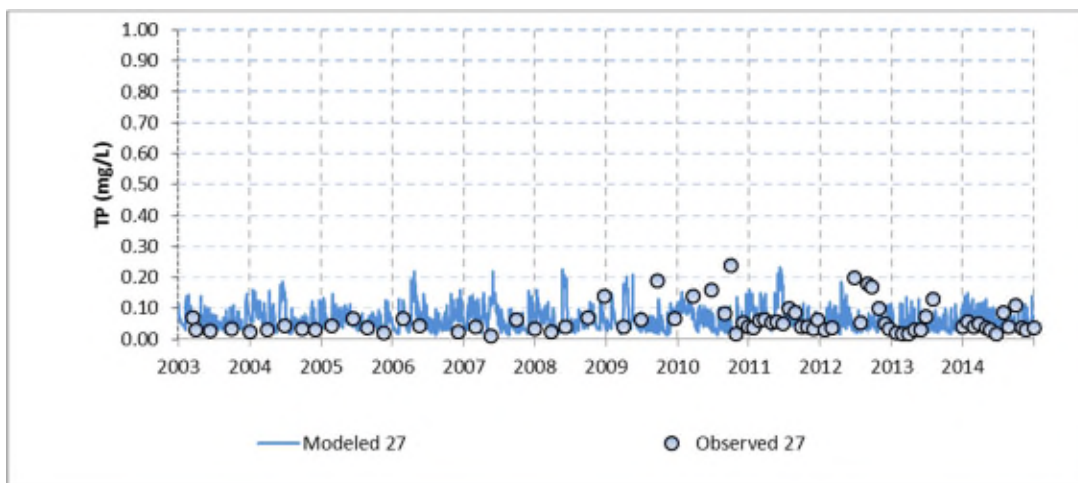


FIGURE A-32: TP TIME SERIES FOR NAVY CANAL

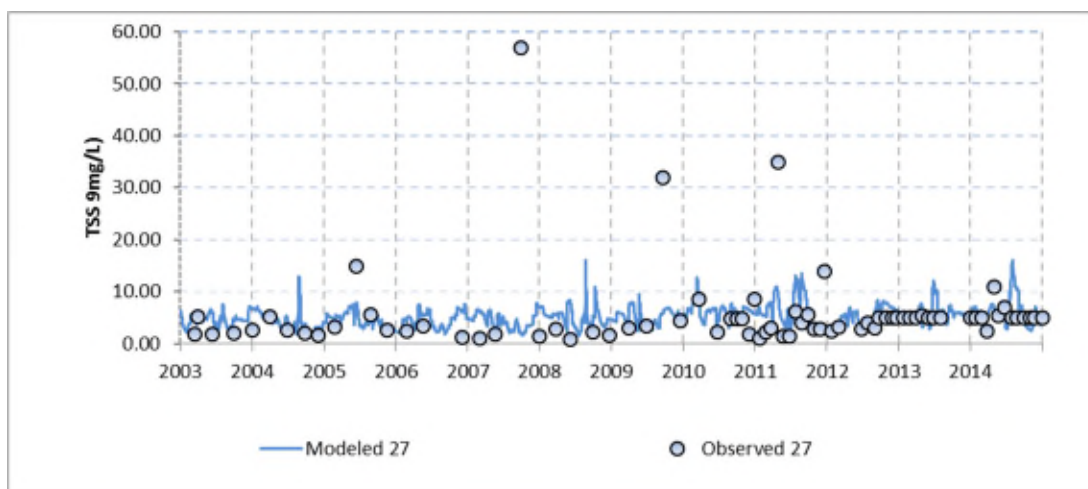


FIGURE A-33: TSS TIME SERIES FOR NAVY CANAL

Ditch at Cameron Ave. (21FLCEN 20011158) – Subwatershed 30

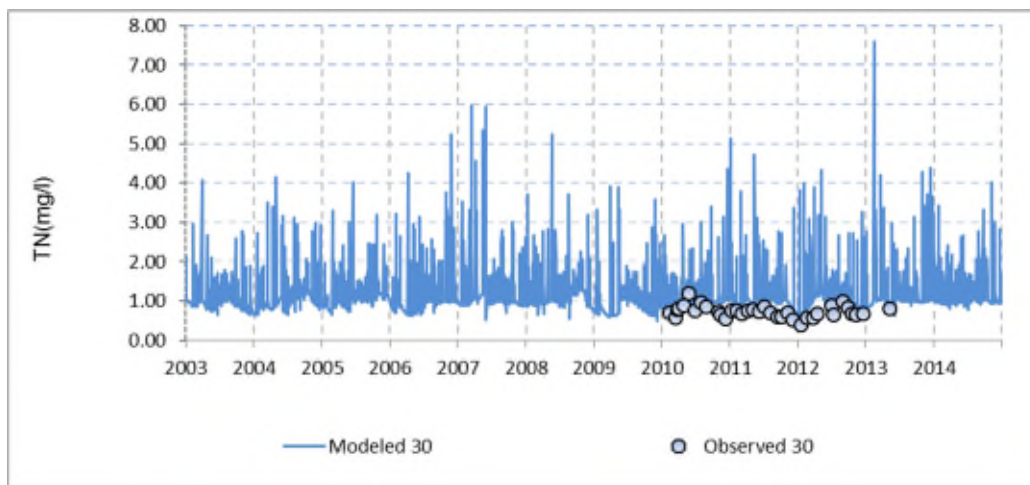


FIGURE A-34: TN TIME SERIES FOR DITCH AT CAMERON AVENUE

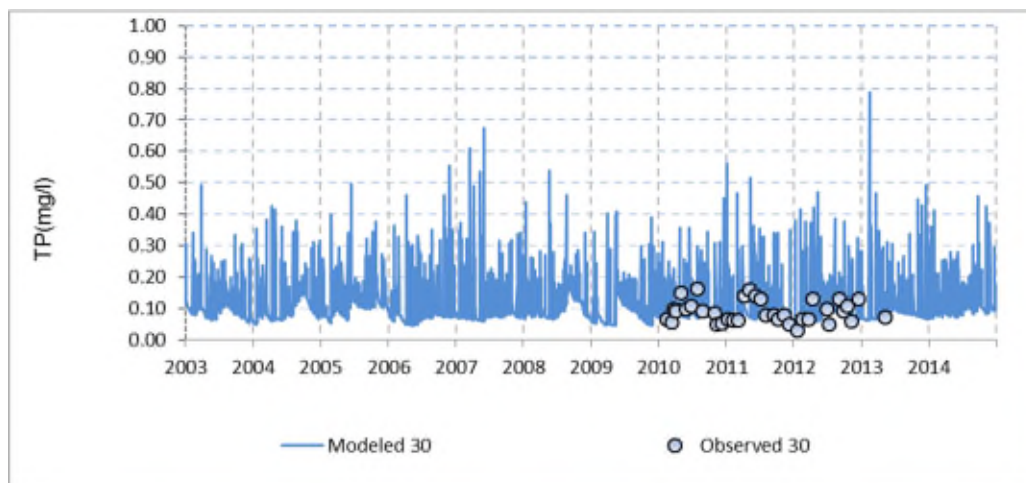


FIGURE A-35: TP TIME SERIES FOR DITCH AT CAMERON AVENUE

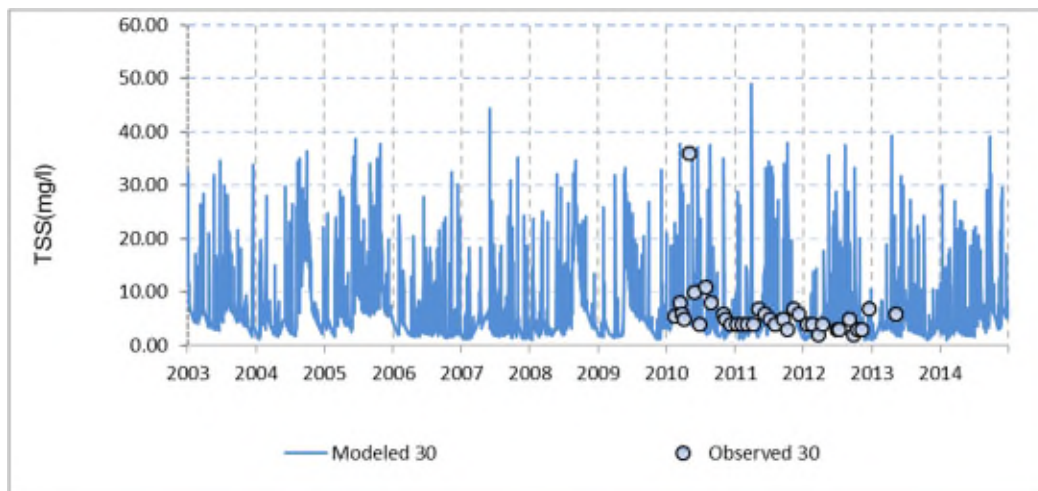


FIGURE A-36: TSS TIME SERIES FOR DITCH AT CAMERON AVENUE

Sweetwater Creek and Solary Canal (21FLCEN 20010011 and 21FLSEM SOLARY) – Subwatershed 38

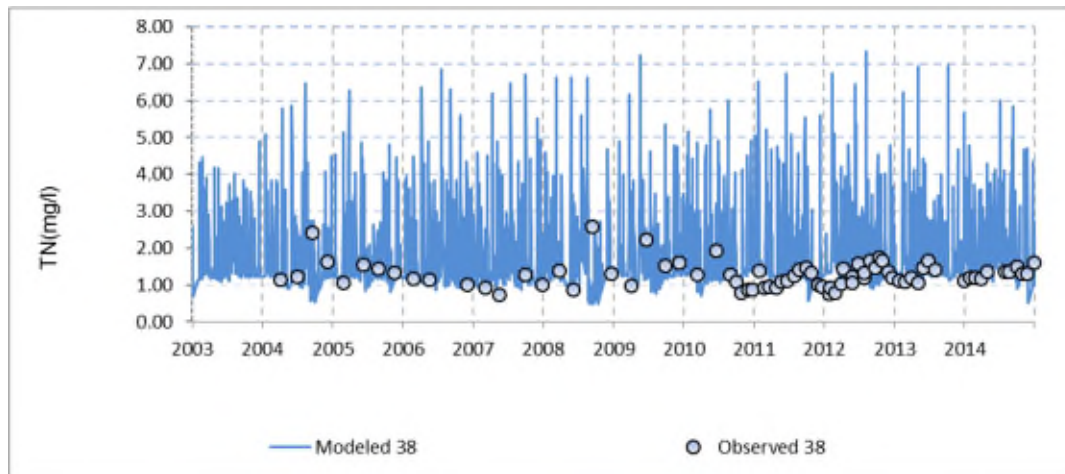


FIGURE A-37: TN TIME SERIES FOR SWEETWATER CREEK AND SOLARY CANAL

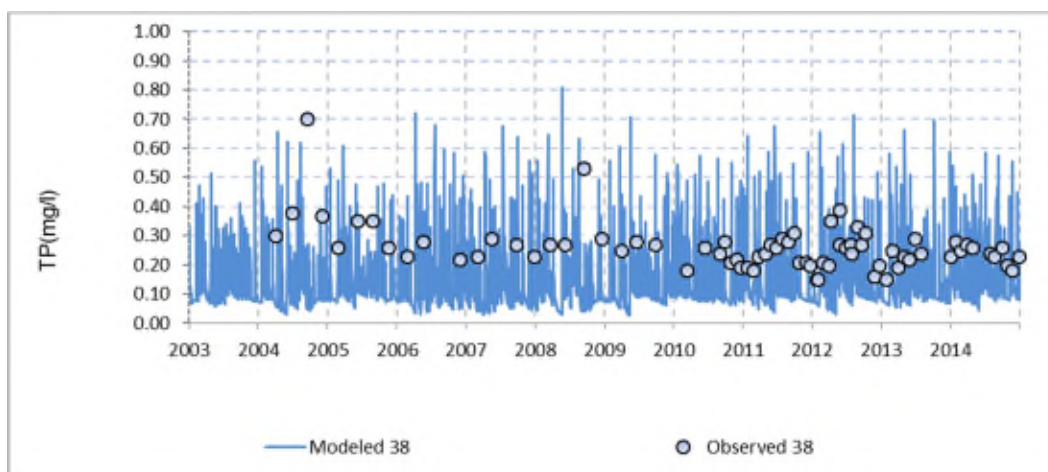


FIGURE A-38: TP TIME SERIES FOR SWEETWATER CREEK AND SOLARY CANAL

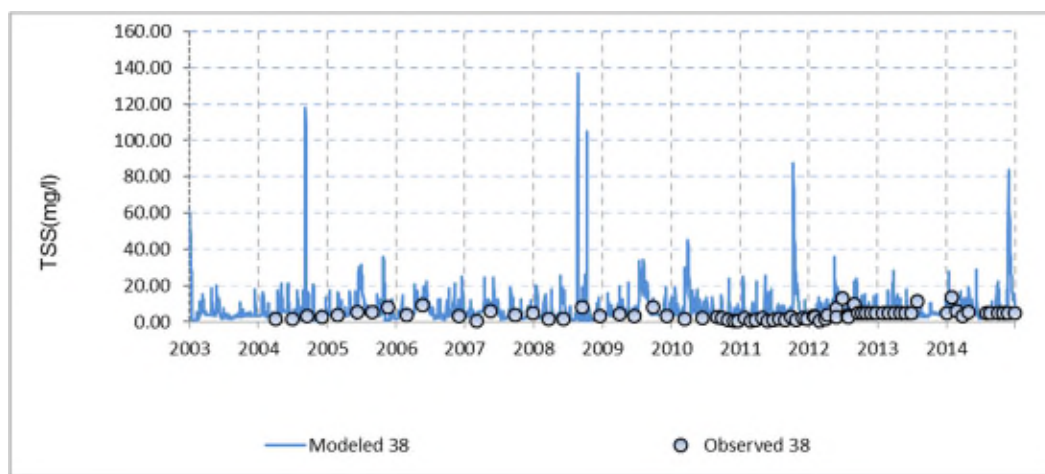


FIGURE A-39: TSS TIME SERIES FOR SWEETWATER CREEK AND SOLARY CANAL

Bear Gully Creek (21FLSEM BERC) – Subwatershed 41

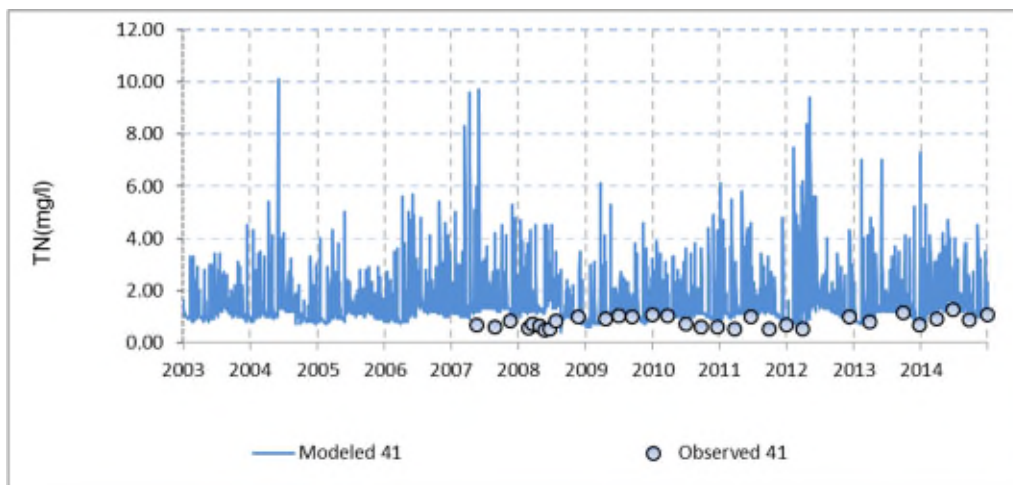


FIGURE A-40: TN TIME SERIES FOR BEAR GULLY CREEK

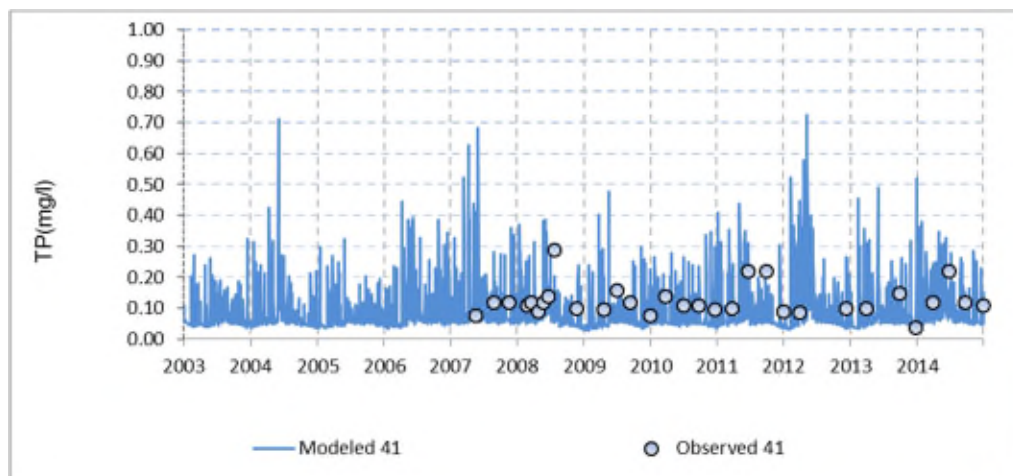


FIGURE A-41: TP TIME SERIES FOR BEAR GULLY CREEK

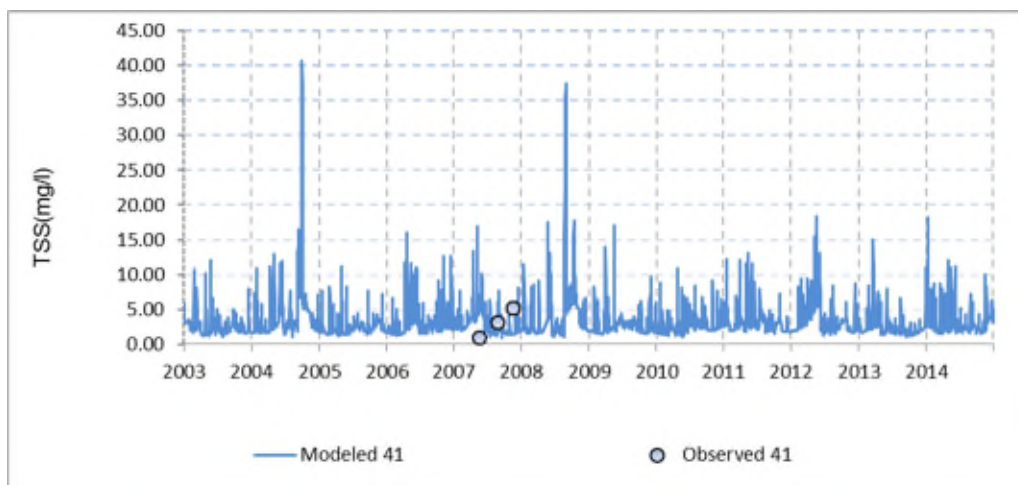


FIGURE A-42: TSS TIME SERIES FOR BEAR GULLY CREEK

Bear Gully Lake (21FLSEM BGU) – Subwatershed 42

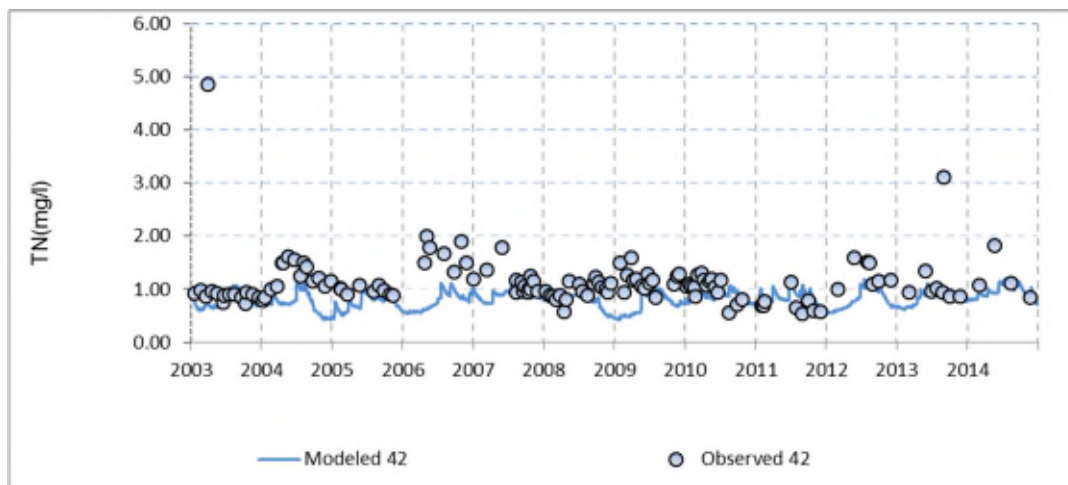


FIGURE A-43: TN TIME SERIES FOR BEAR GULLY LAKE

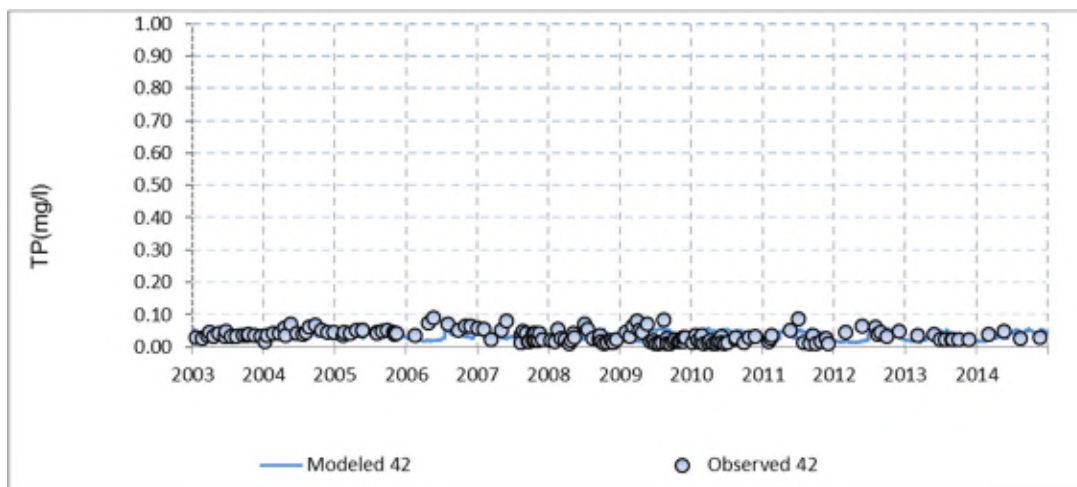


FIGURE A-44: TP TIME SERIES FOR BEAR GULLY LAKE

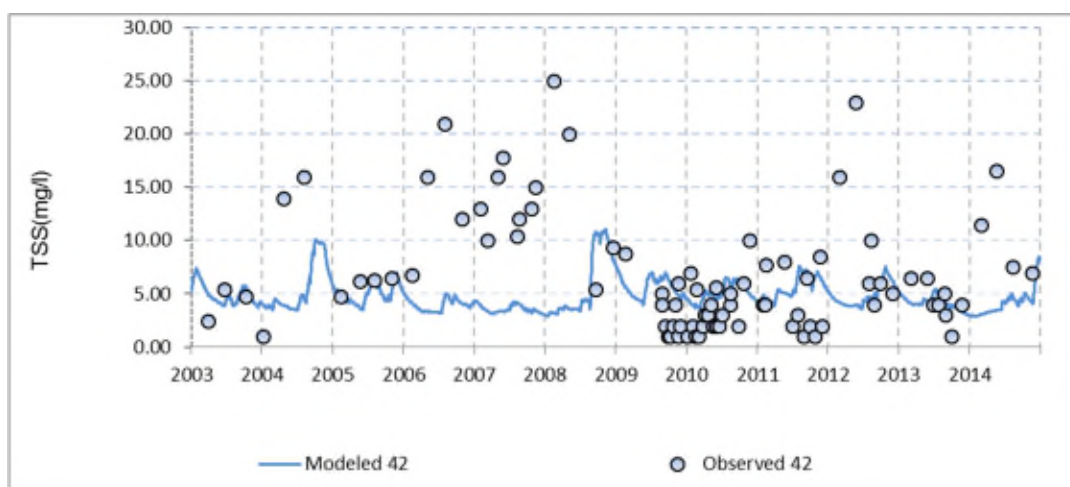


FIGURE A-45: TSS TIME SERIES FOR BEAR GULLY LAKE

Lake Burkett (21FLORANXBURKTCNL2) – Subwatershed 44

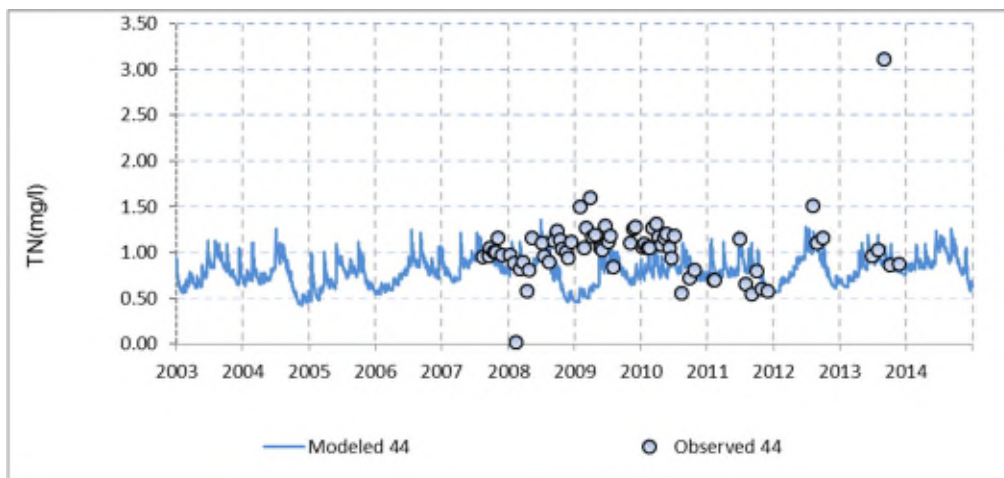


FIGURE A-46: TN TIME SERIES FOR LAKE BURKETT

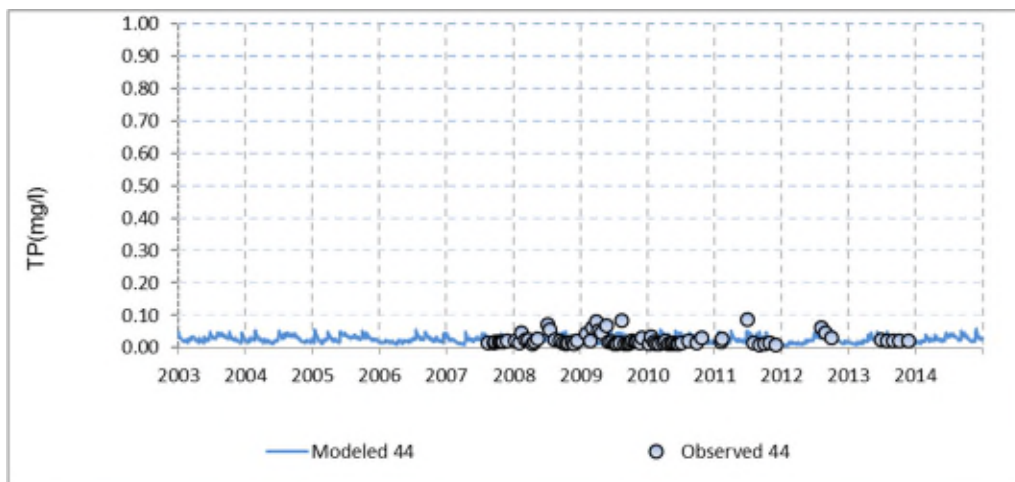


FIGURE A-47: TP TIME SERIES FOR LAKE BURKETT

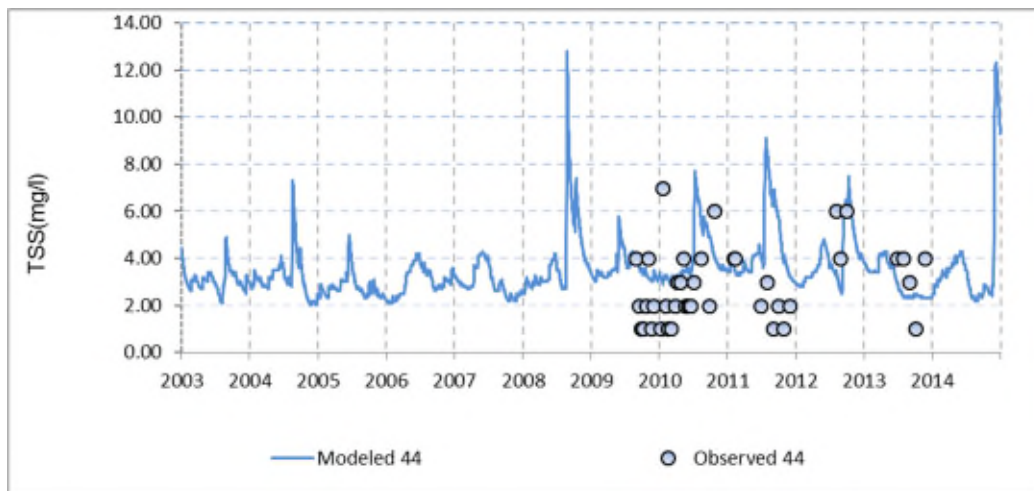


FIGURE A-48: TSS TIME SERIES FOR LAKE BURKETT

Howell Creek (21FLSEM HCRB) – Subwatershed 45

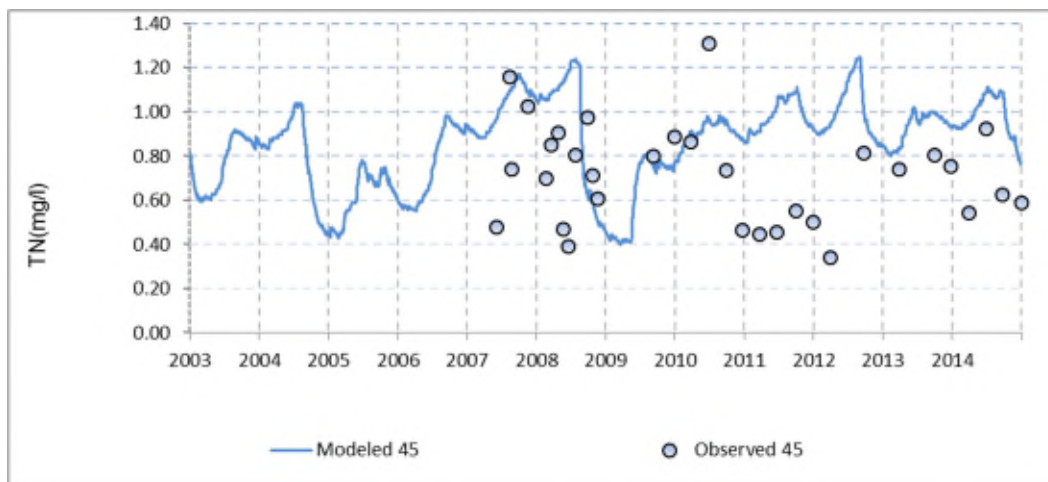


FIGURE A-49: TN TIME SERIES FOR HOWELL CREEK

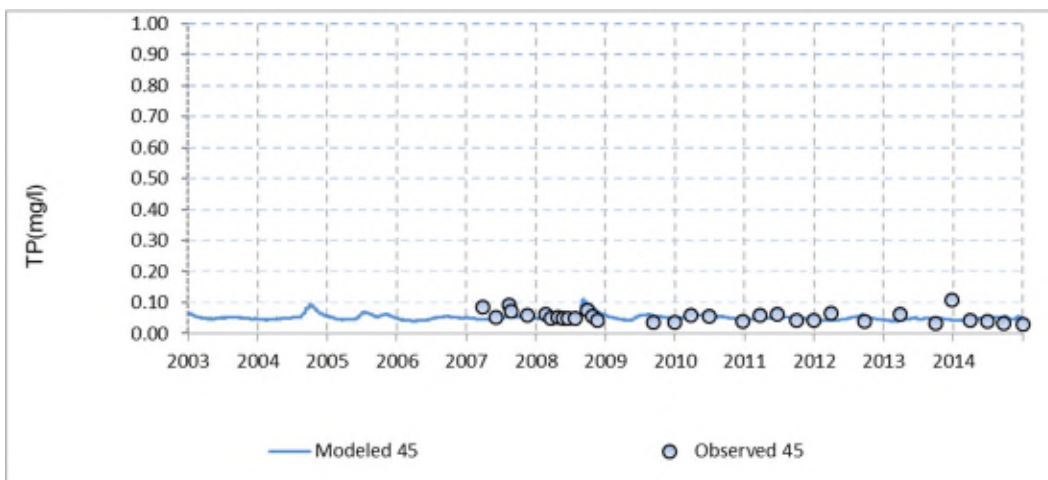


FIGURE A-50: TP TIME SERIES FOR HOWELL CREEK

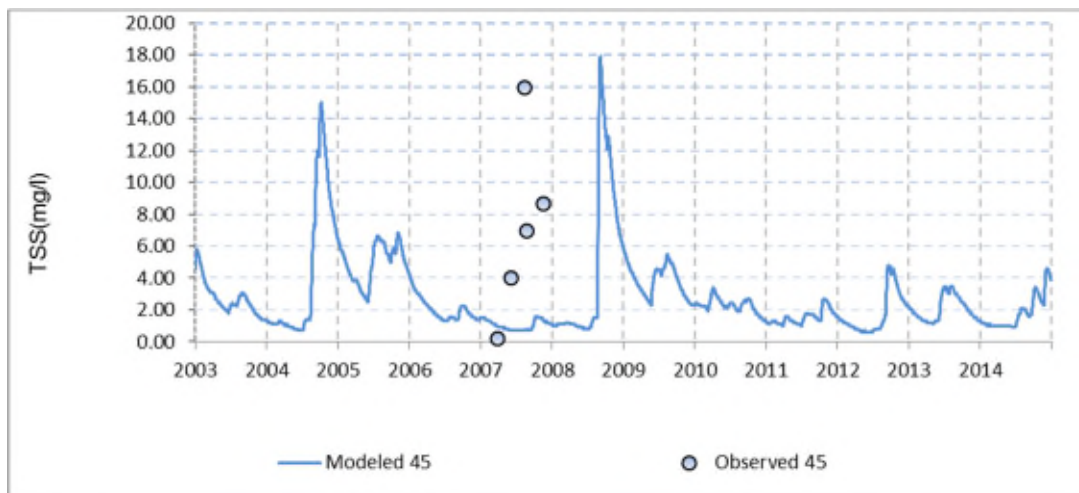


FIGURE A-51: TSS TIME SERIES FOR HOWELL CREEK

Lake Howell (21FLSEM HOW) – Subwatershed 46

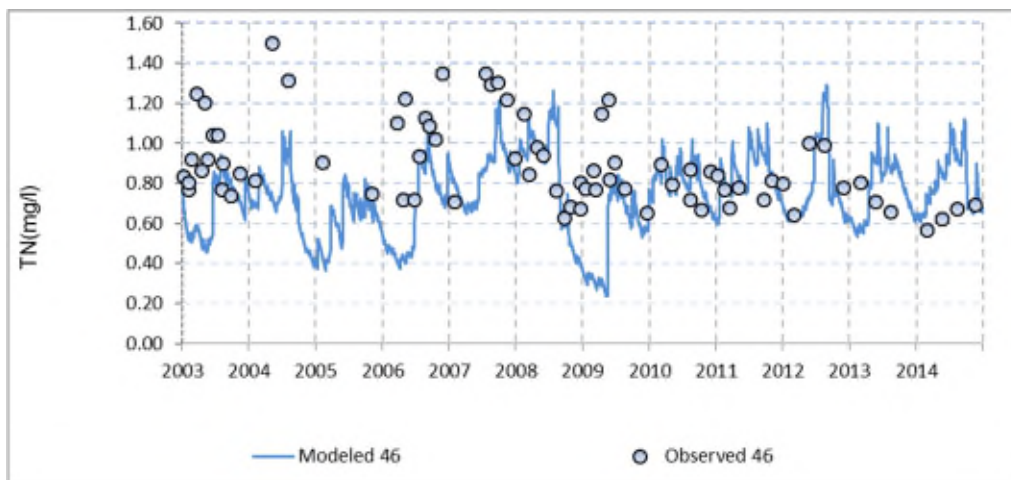


FIGURE A-52: TN TIME SERIES FOR LAKE HOWELL

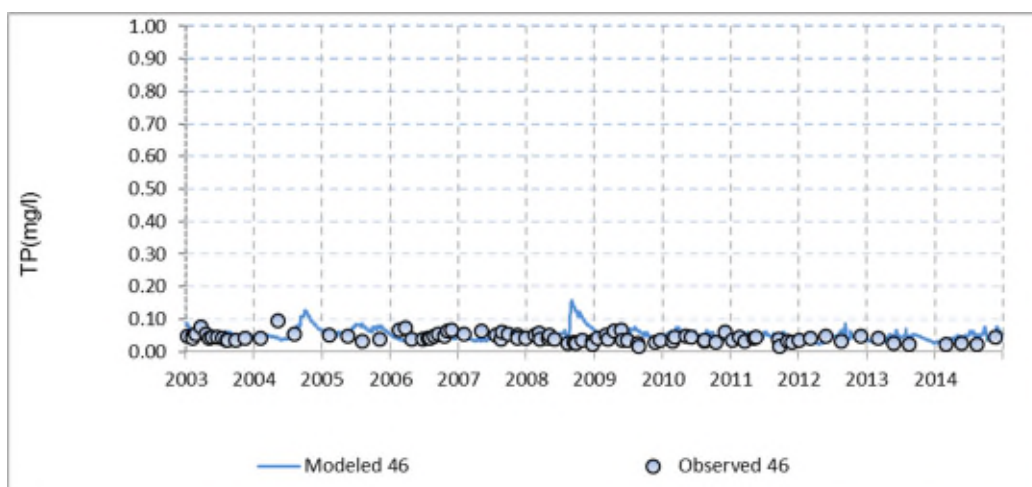


FIGURE A-53: TP TIME SERIES FOR LAKE HOWELL

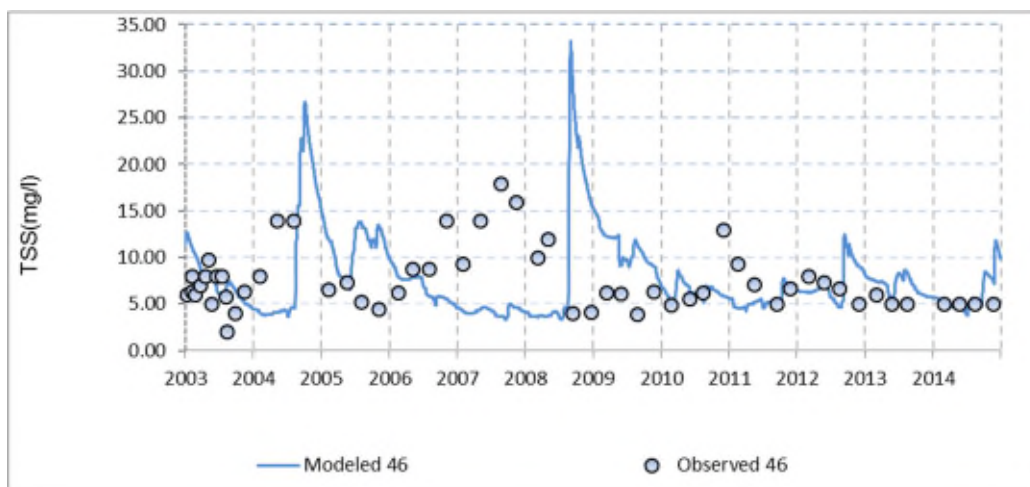


FIGURE A-54: TSS TIME SERIES FOR LAKE HOWELL

Lake Waumpi (Maitland) – Subwatershed 49

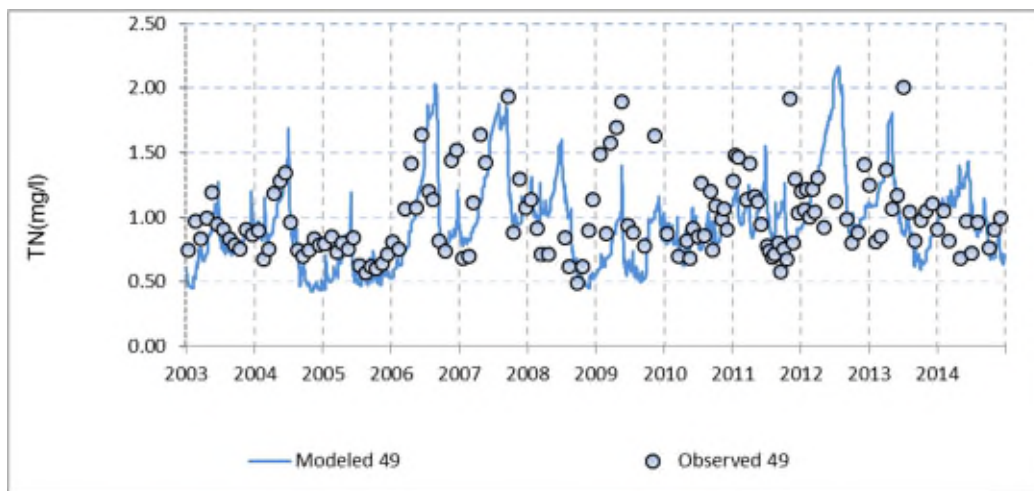


FIGURE A-55: TN TIME SERIES FOR LAKE WAUMPI

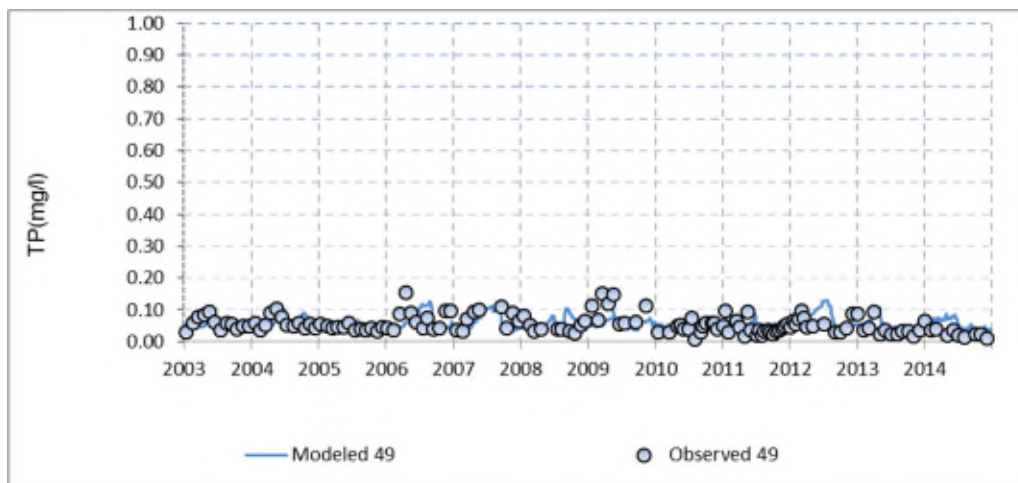


FIGURE A-56: TP TIME SERIES FOR LAKE WAUMPI

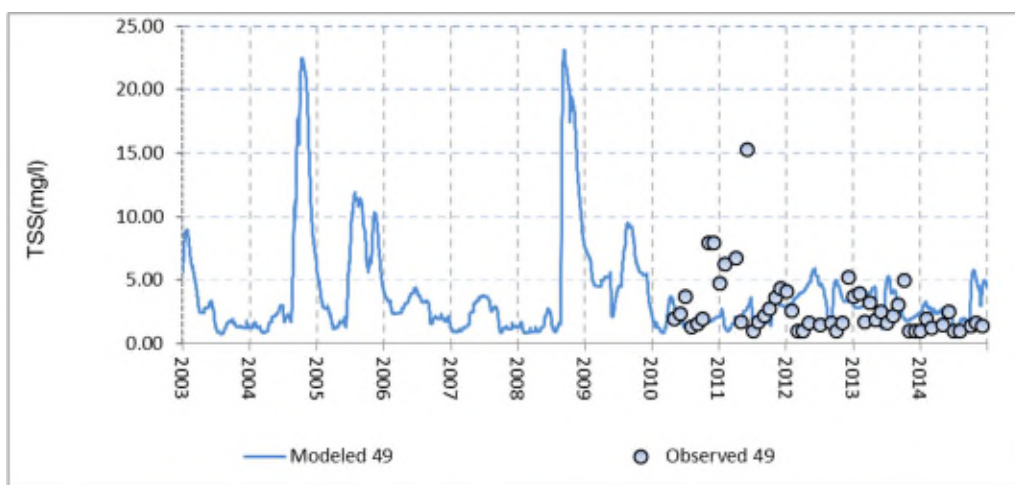


FIGURE A-57: TSS TIME SERIES FOR LAKE WAUMPI

Weir at Howell Branch (Winter Park) – Subwatershed 51



FIGURE A-58: TN TIME SERIES FOR WEIR AT HOWELL BRANCH

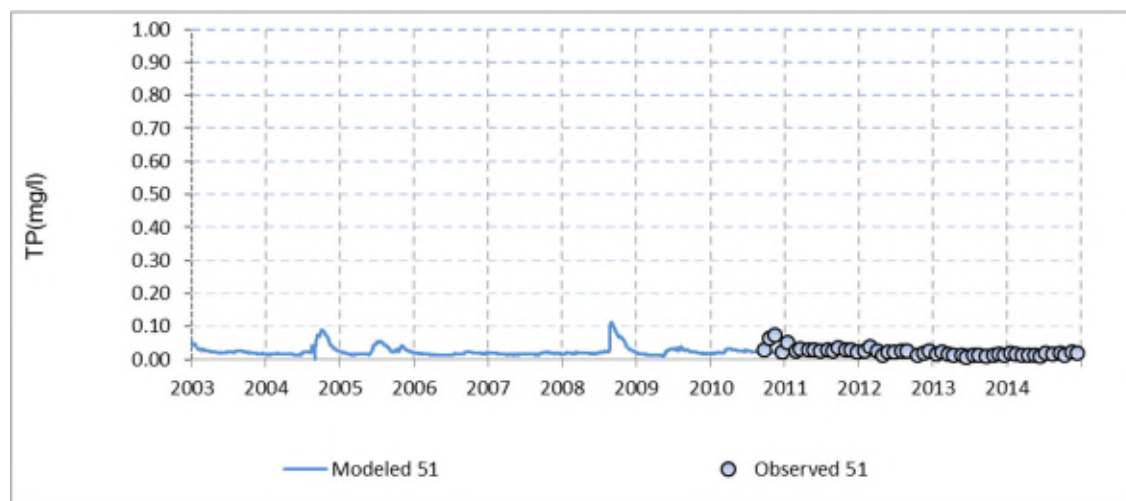


FIGURE A-59: TP TIME SERIES FOR WEIR AT HOWELL BRANCH

Minnehaha (21FLORANHB26) – Subwatershed 52

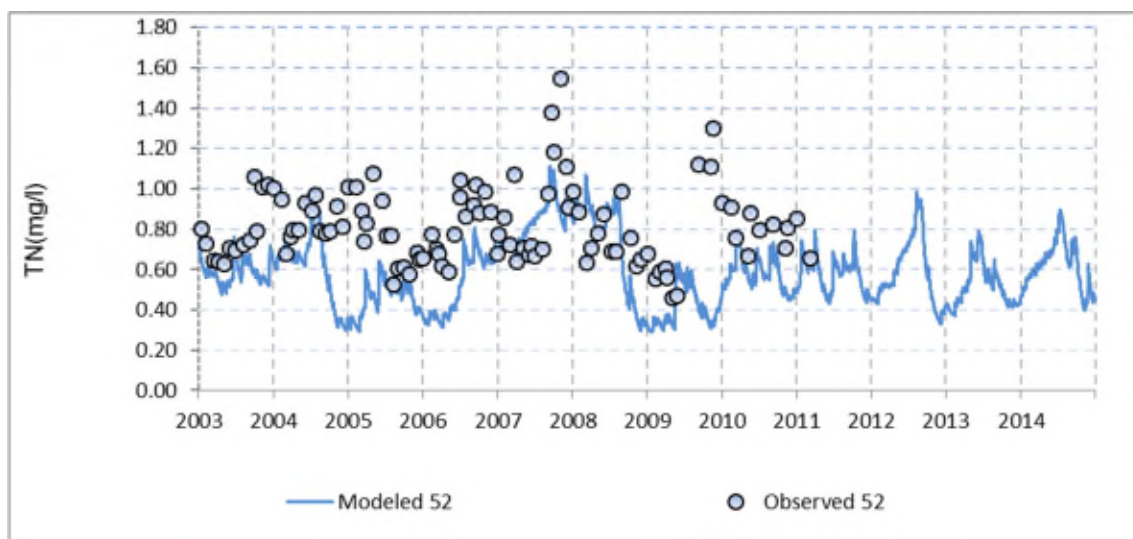


FIGURE A-60: TN TIME SERIES FOR MINNEHAHA

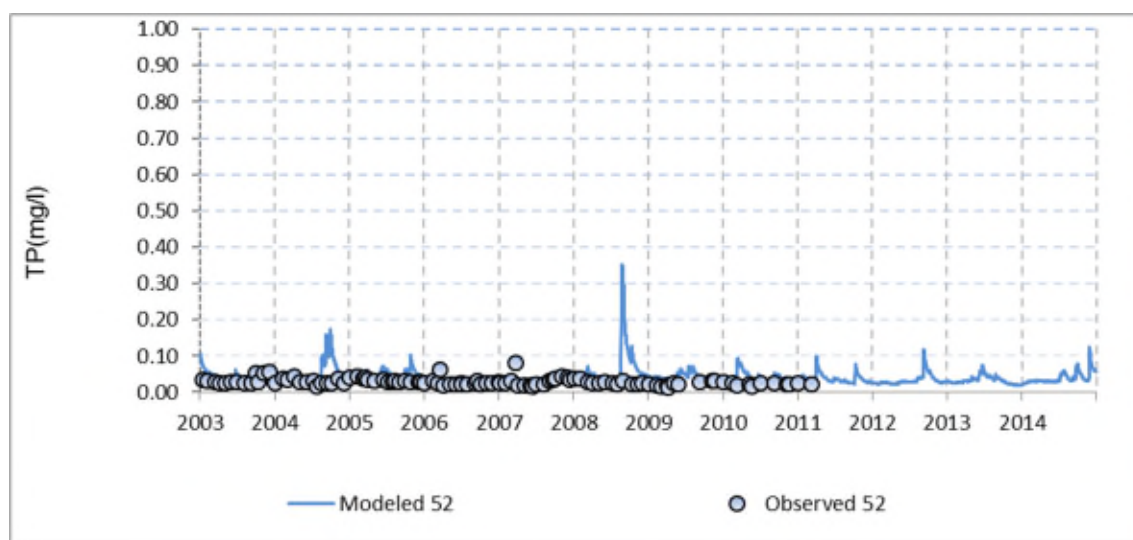


FIGURE A-61: TP TIME SERIES FOR MINNEHAHA

Lake Gem (21FLORANHB13 and 21FLORANHB32) – Subwatershed 53

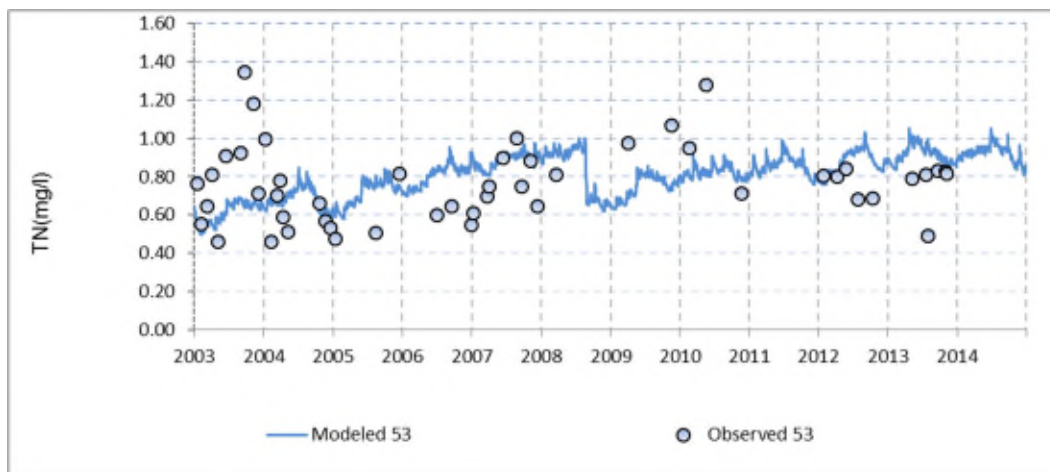


FIGURE A-62: TN TIME SERIES FOR LAKE GEM

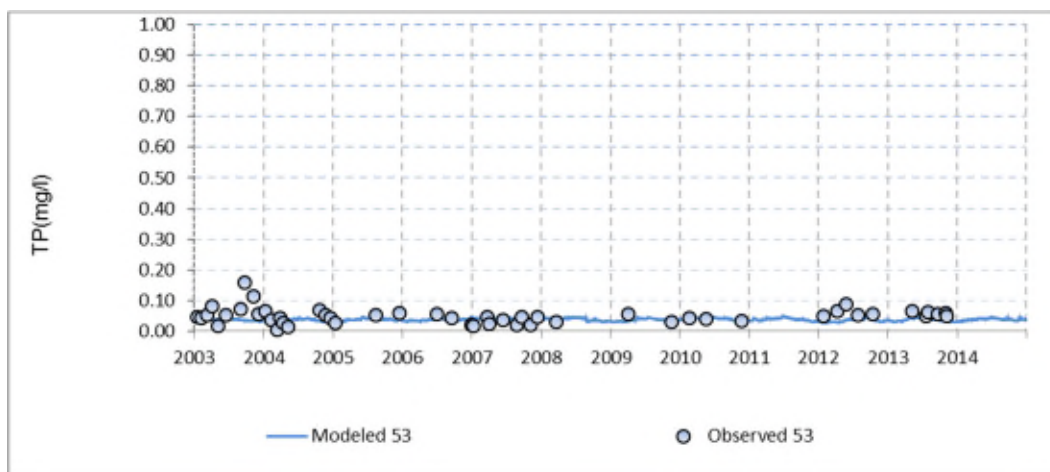


FIGURE A-63: TP TIME SERIES FOR LAKE GEM

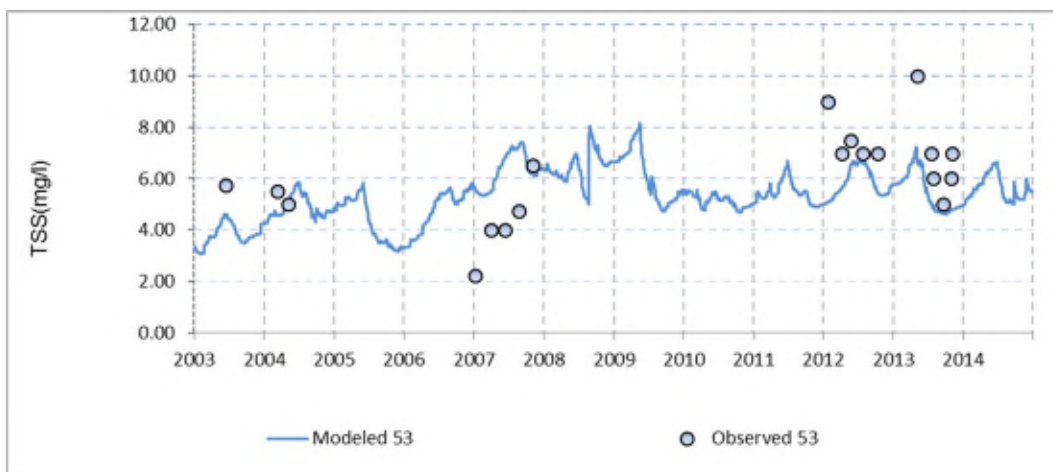


FIGURE A-64: TSS TIME SERIES FOR LAKE GEM

Lake Sue (21FLORANHB36 and 21FLORL SUE) – Subwatershed 61



FIGURE A-65: TN TIME SERIES FOR LAKE SUE

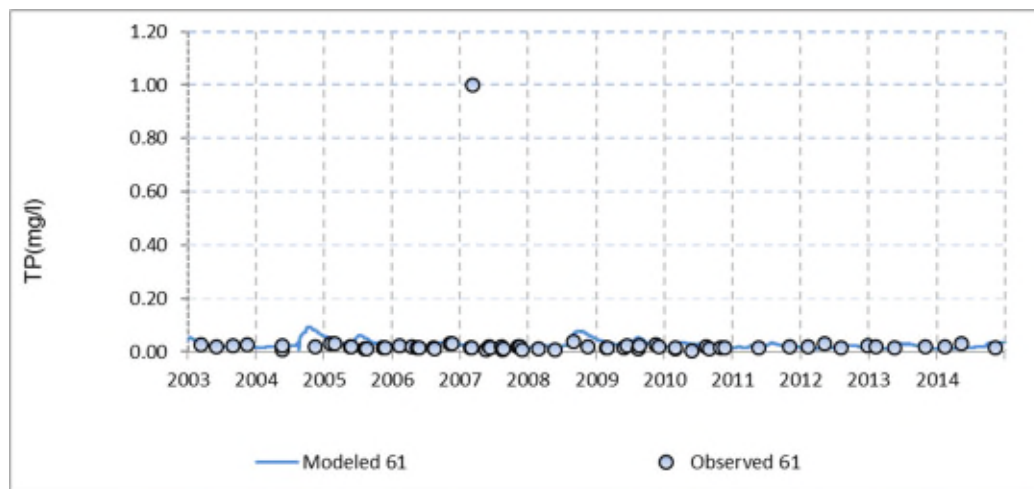


FIGURE A-66: TP TIME SERIES FOR LAKE SUE

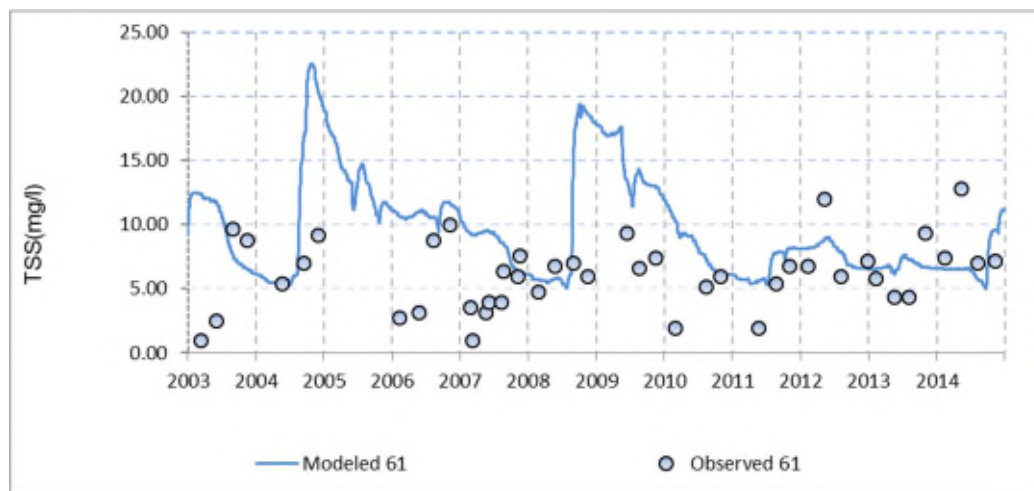


FIGURE A-67: TSS TIME SERIES FOR LAKE SUE

Lake Rowena (21FLORL ROWENA) – Subwatershed 63

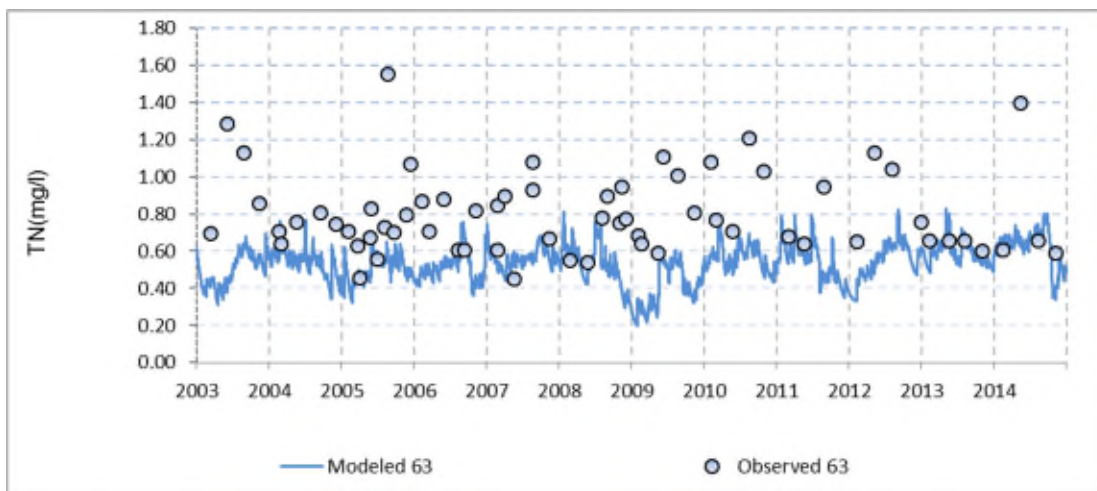


FIGURE A-68: TN TIME SERIES FOR LAKE ROWENA

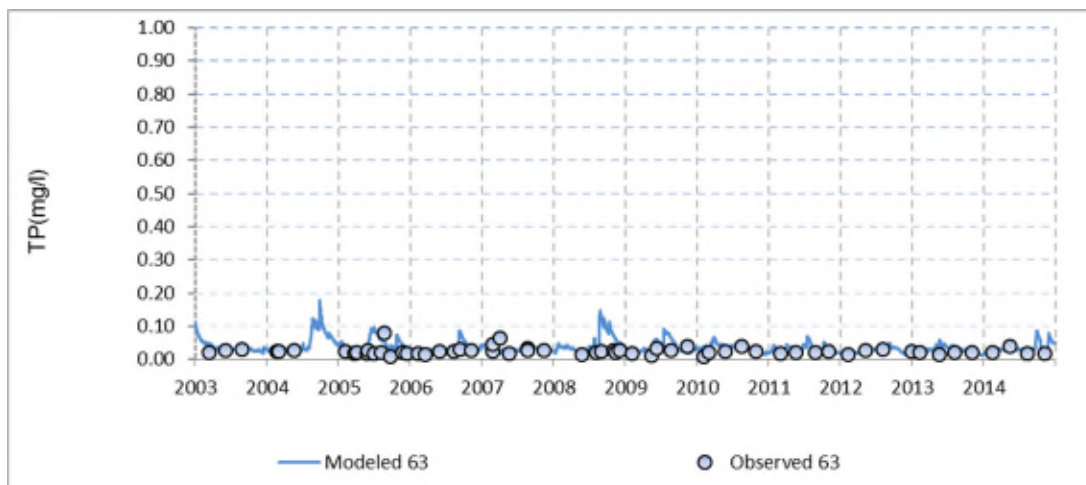


FIGURE A-69: TP TIME SERIES FOR LAKE ROWENA

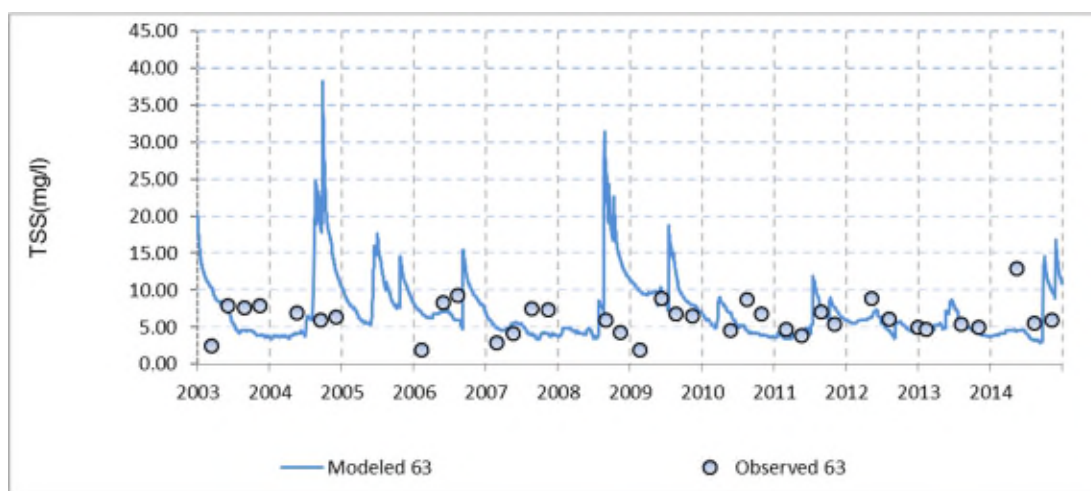


FIGURE A-70: TSS TIME SERIES FOR LAKE ROWENA

Lake Adair (21FLORL ADAIR) – Subwatershed 75

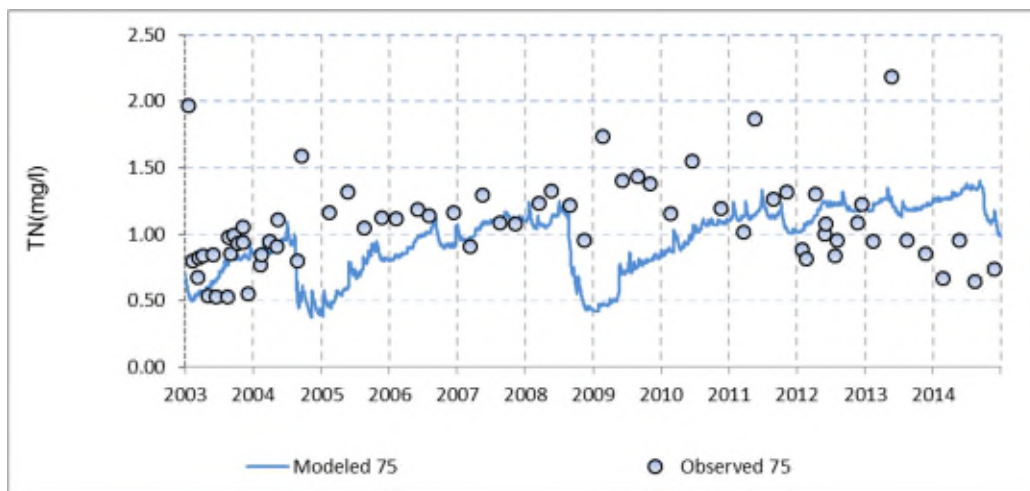


FIGURE A-71: TN TIME SERIES FOR LAKE ADAIR

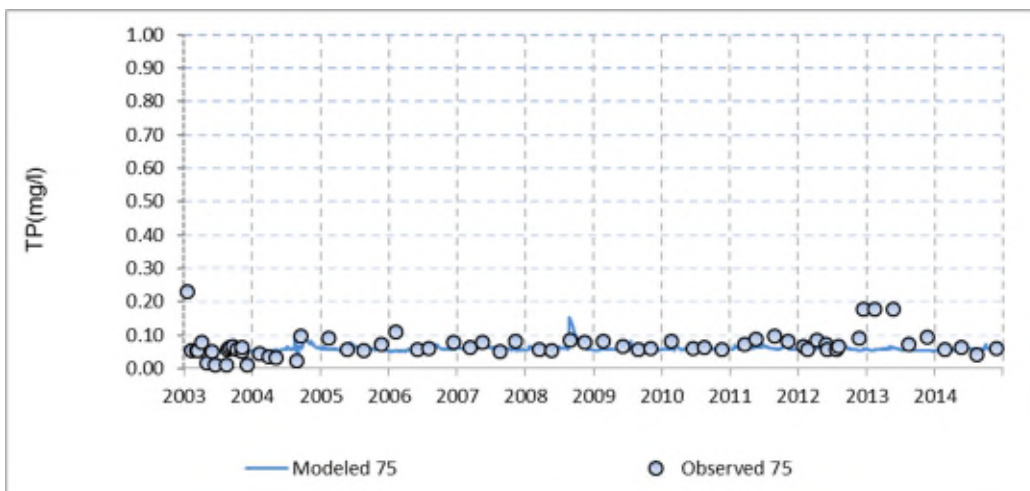


FIGURE A-72: TP TIME SERIES FOR LAKE ADAIR

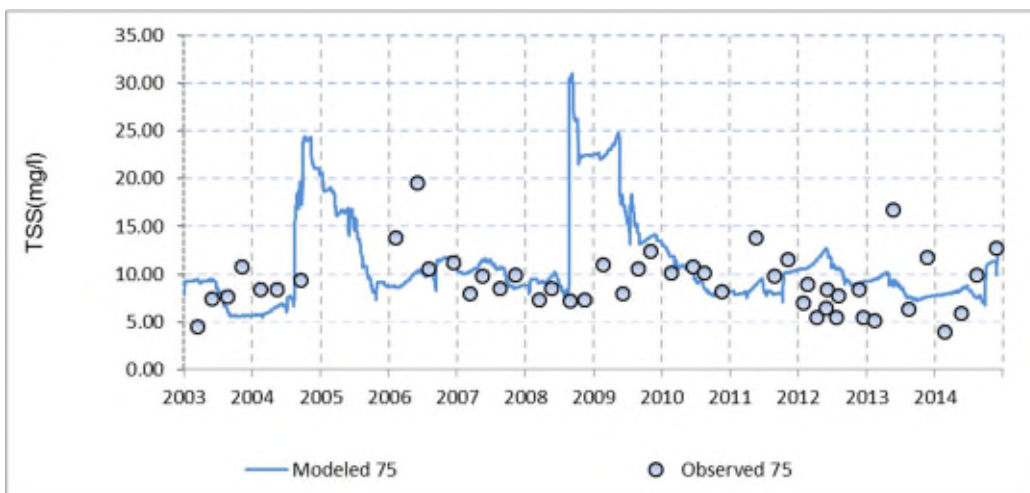


FIGURE A-73: TSS TIME SERIES FOR LAKE ADAIR

Lake Tuskawilla (21FLSEM TUS) – Subwatershed 91

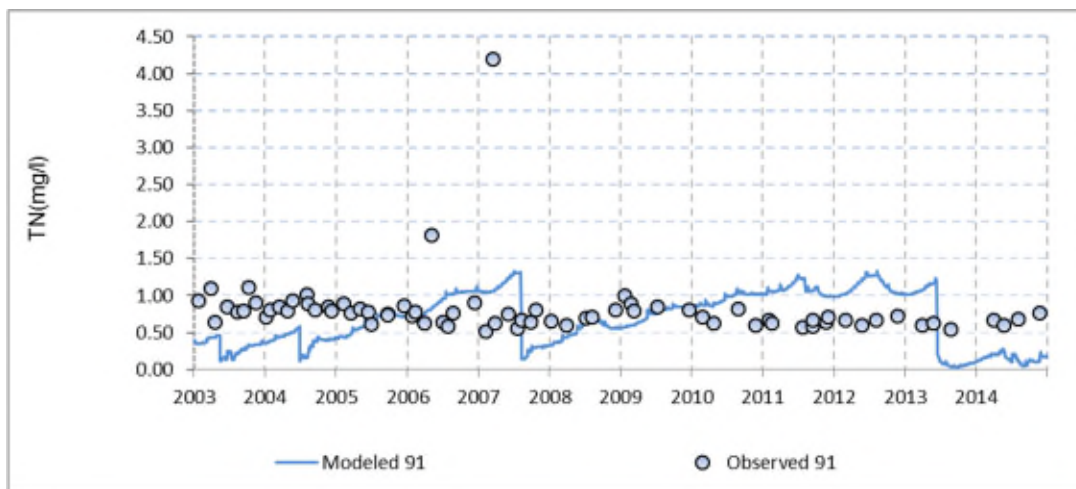


FIGURE A-74: TN TIME SERIES FOR LAKE TUSKAWILLA

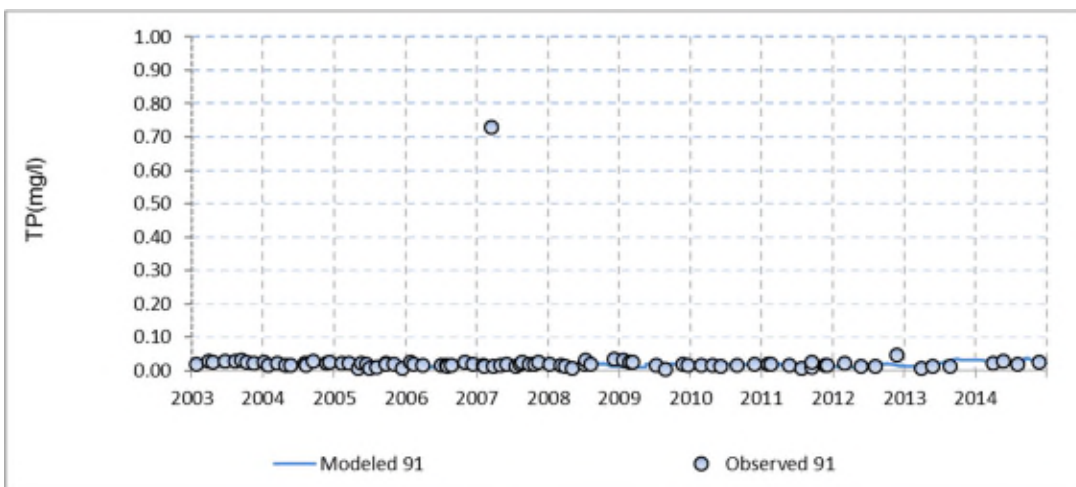


FIGURE A-75: TP TIME SERIES FOR LAKE TUSKAWILLA

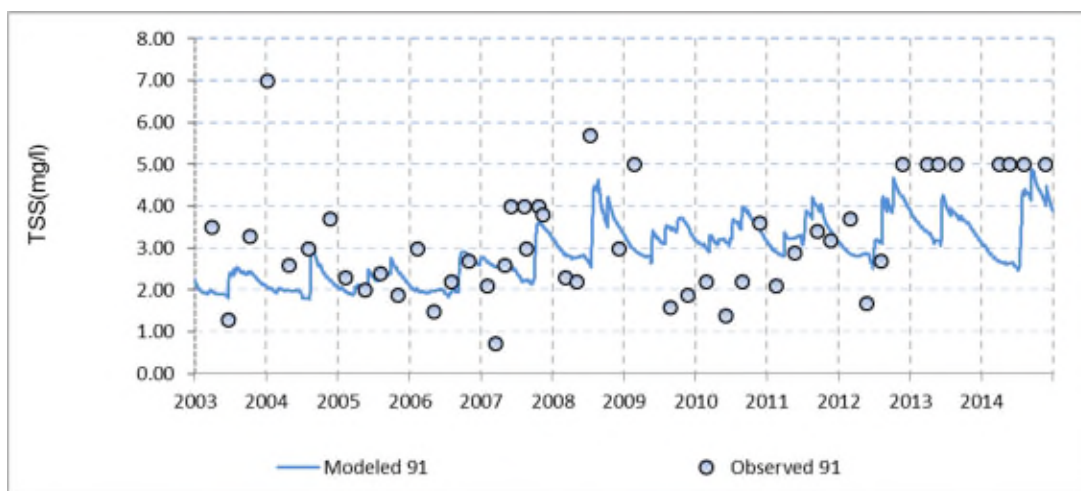


FIGURE A-76: TSS TIME SERIES FOR LAKE TUSKAWILLA

Lake Alma (21FLSEM ALM) – Subwatershed 93

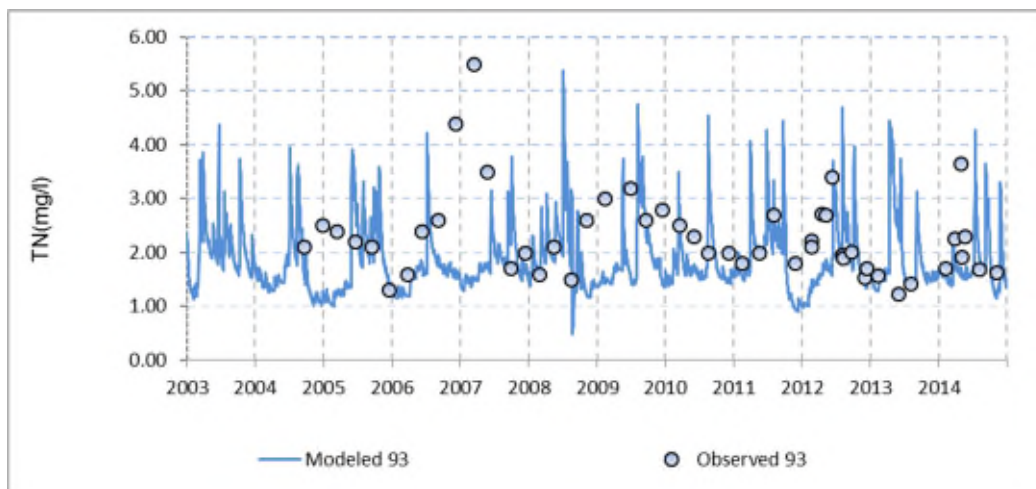


FIGURE A-77: TN TIME SERIES FOR LAKE ALMA

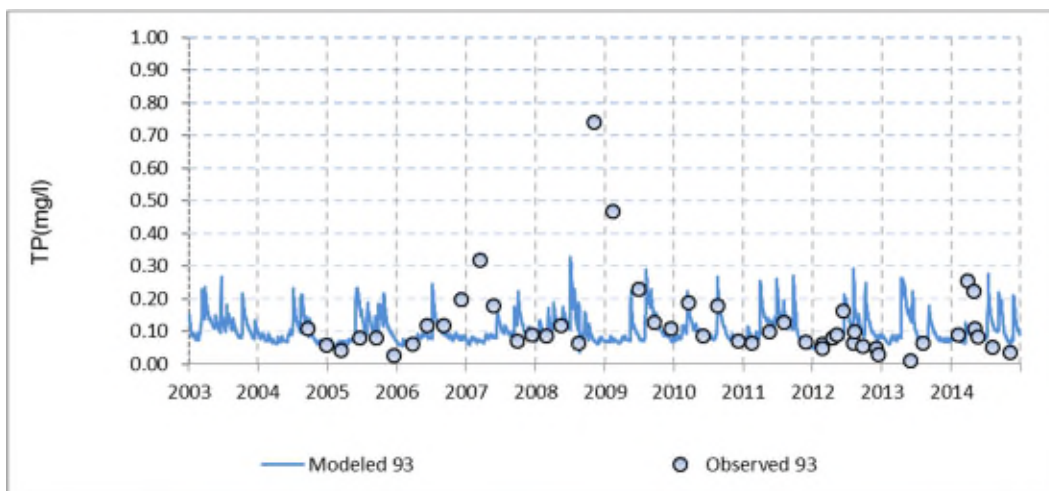


FIGURE A-78: TP TIME SERIES FOR LAKE ALMA

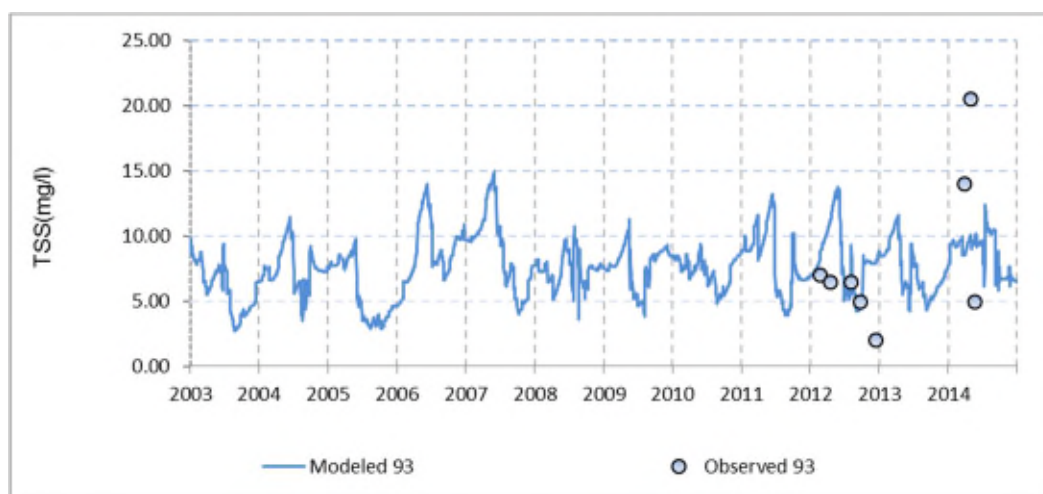


FIGURE A-79: TSS TIME SERIES FOR LAKE ALMA

Lake Searcy (21FLKWATSEM-SEARCY-1 and 21FLSEM SEA) – Subwatershed 94

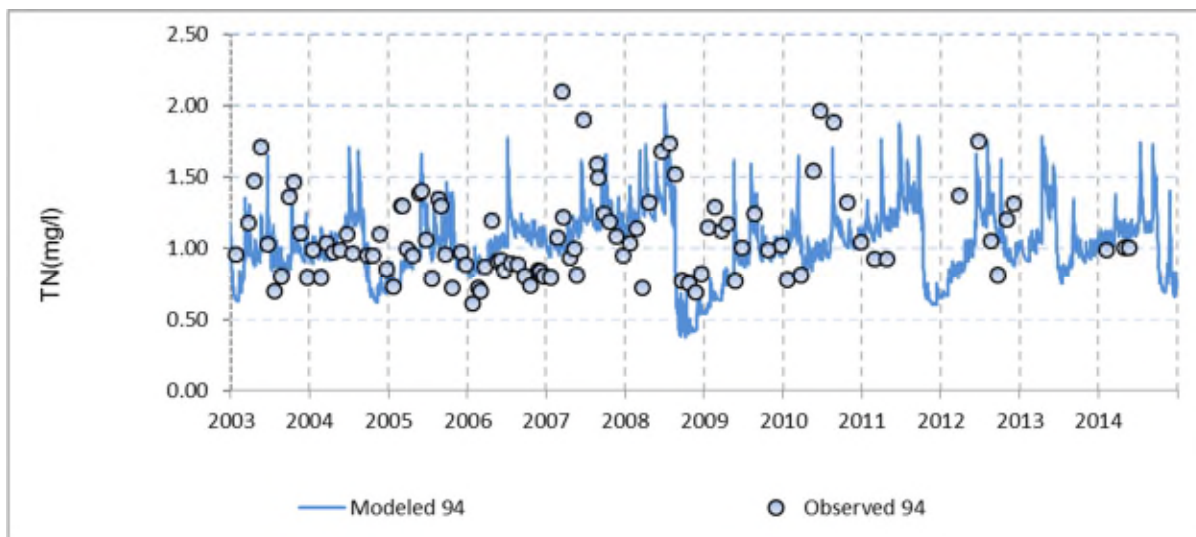


FIGURE A-80: TN TIME SERIES FOR LAKE SEARCY

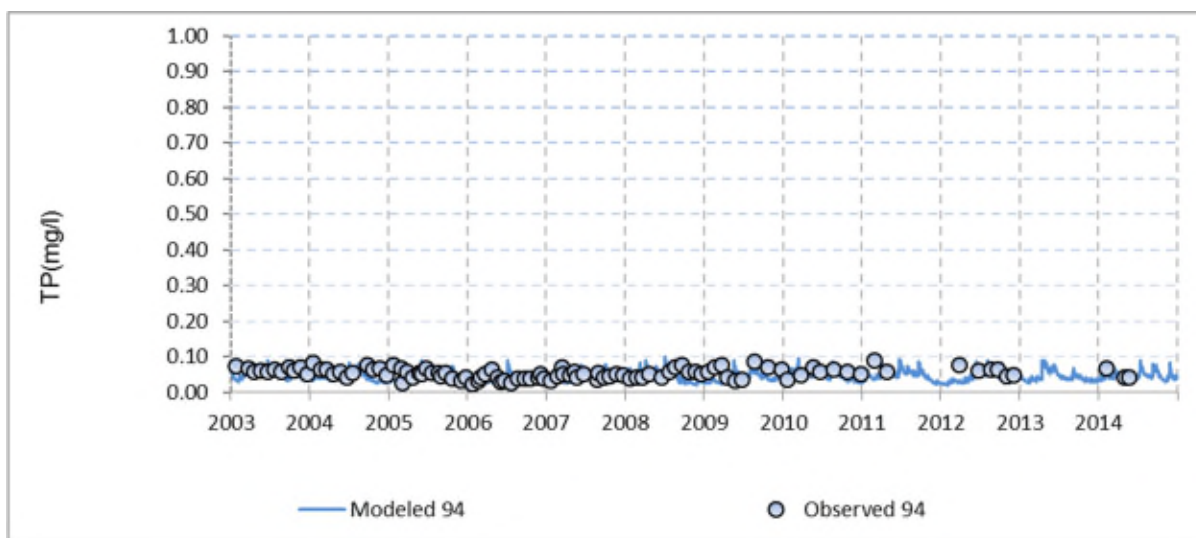


FIGURE A-81: TP TIME SERIES FOR LAKE SEARCY

Chub Creek (21FLSEM CHUB) – Subwatershed 96

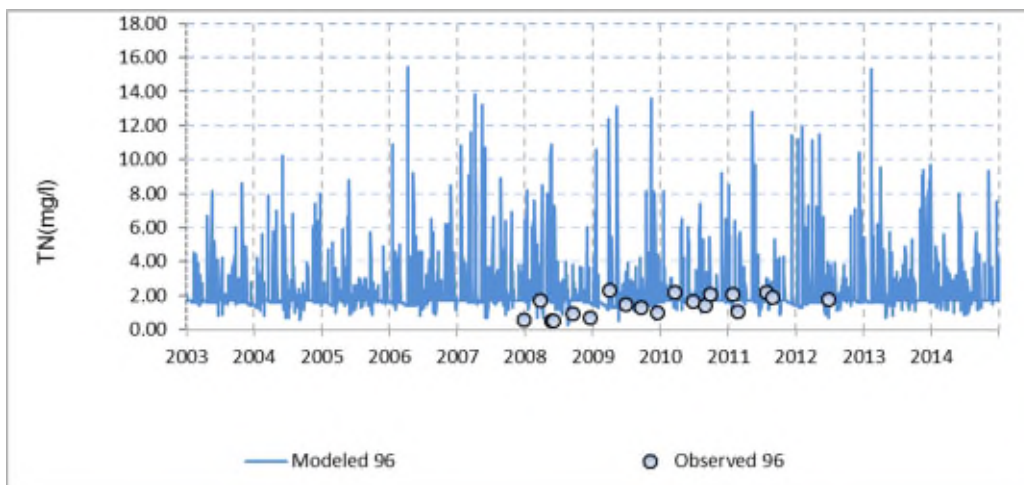


FIGURE A-82: TN TIME SERIES FOR CHUB CREEK

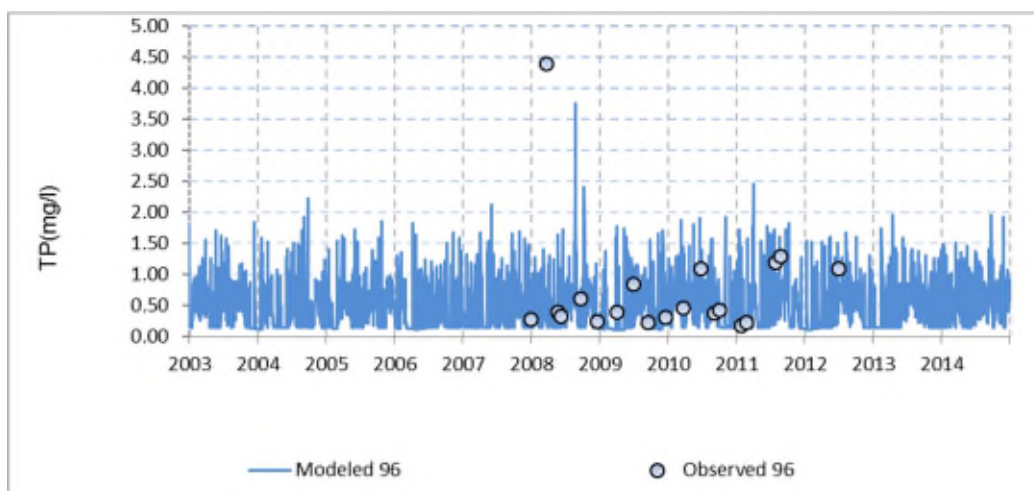


FIGURE A-83: TP TIME SERIES FOR CHUB CREEK

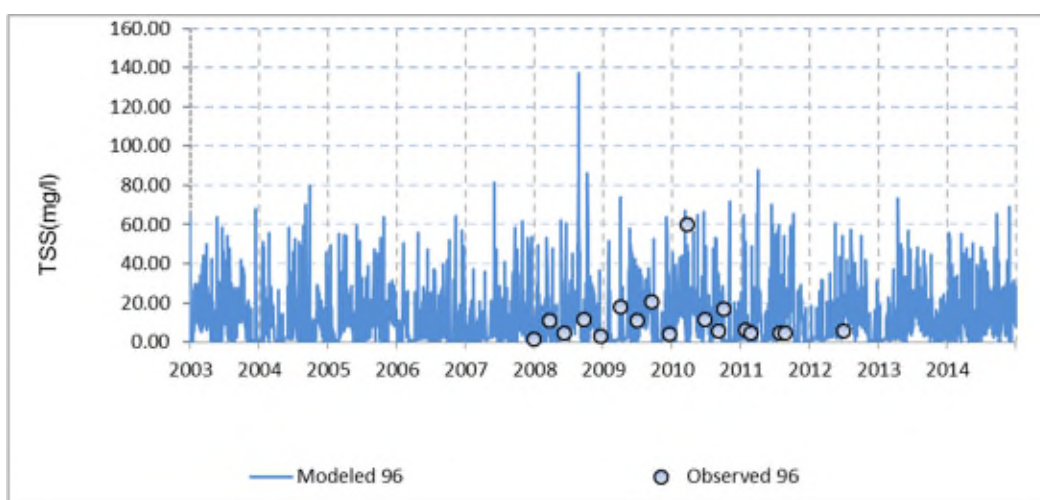


FIGURE A-84: TSS TIME SERIES FOR CHUB CREEK

Salt Creek (21FLCEN 20010763) – Subwatershed 98

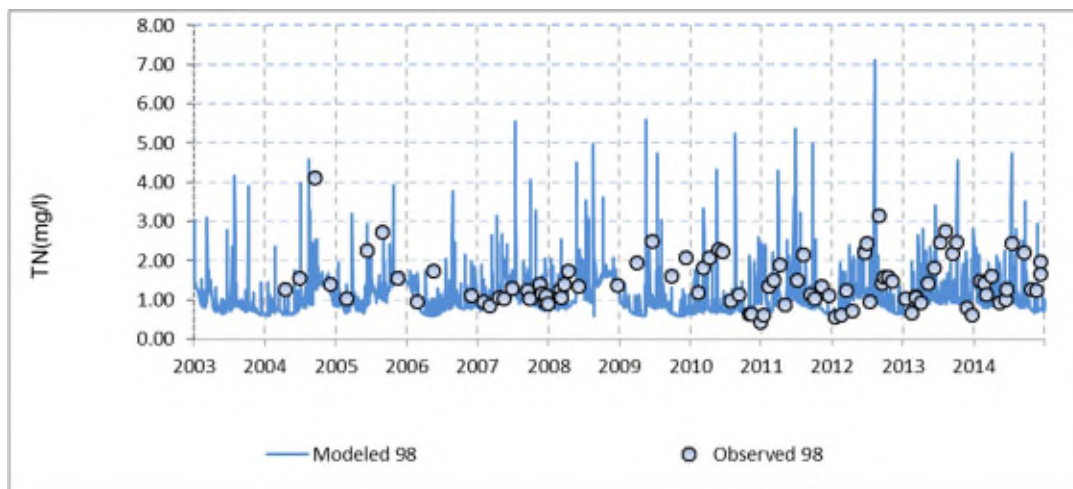


FIGURE A-85: TN TIME SERIES FOR SALT CREEK

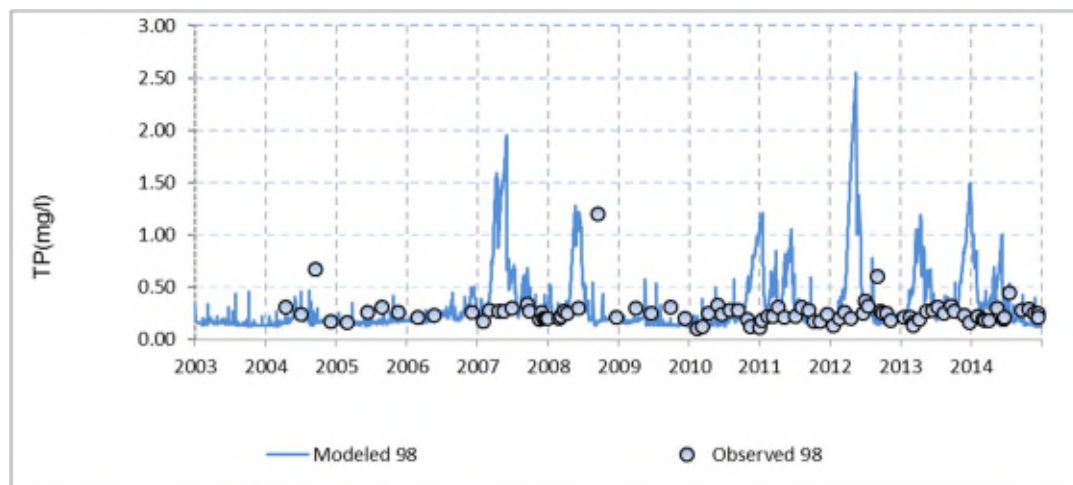


FIGURE A-86: TP TIME SERIES FOR SALT CREEK

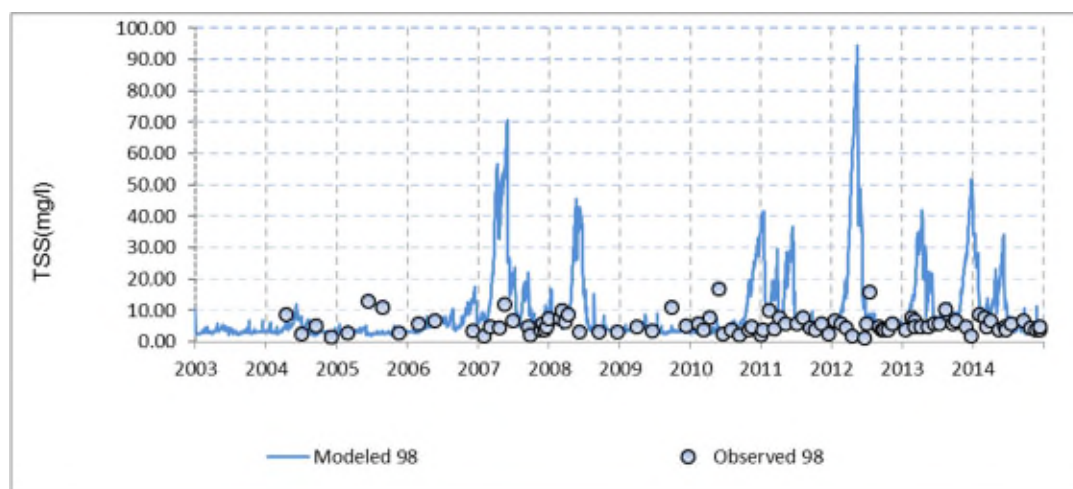


FIGURE A-87: TSS TIME SERIES FOR SALT CREEK

APPENDIX B: EFDC MODEL CALIBRATION RESULTS

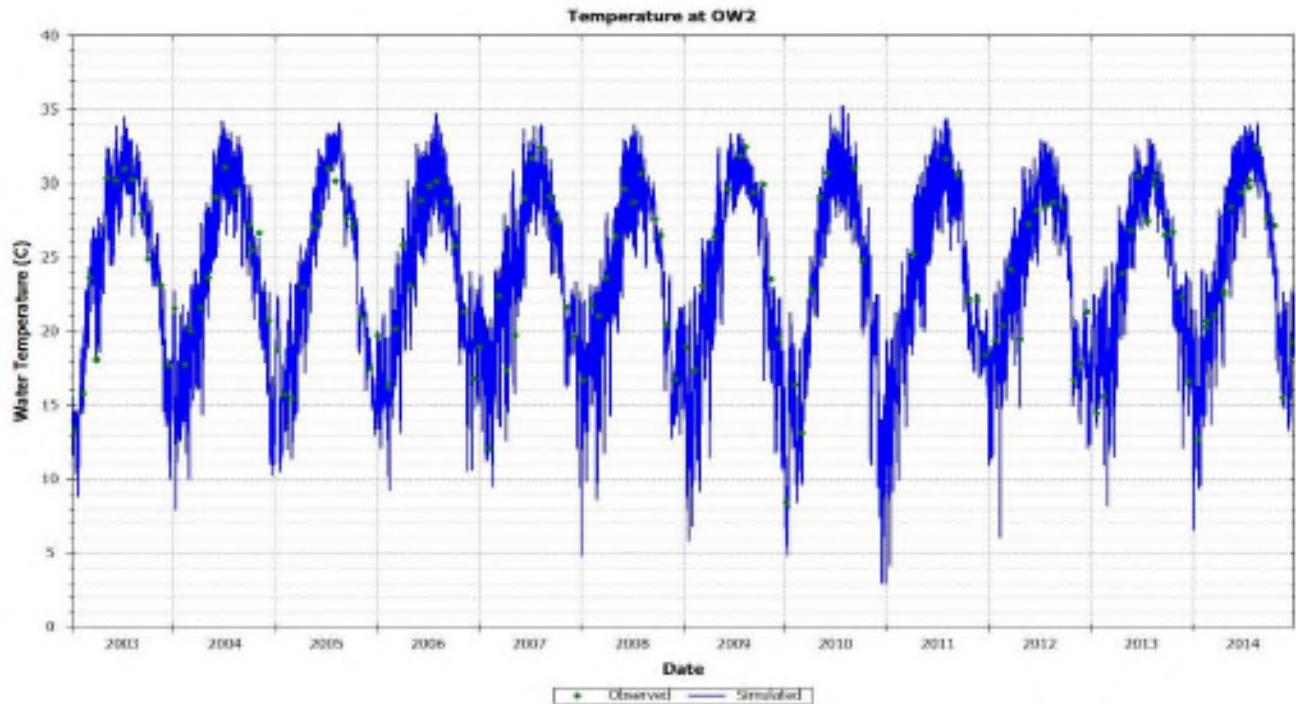


FIGURE B-1: TEMPERATURE SIMULATION FOR STATION OW2, 44055

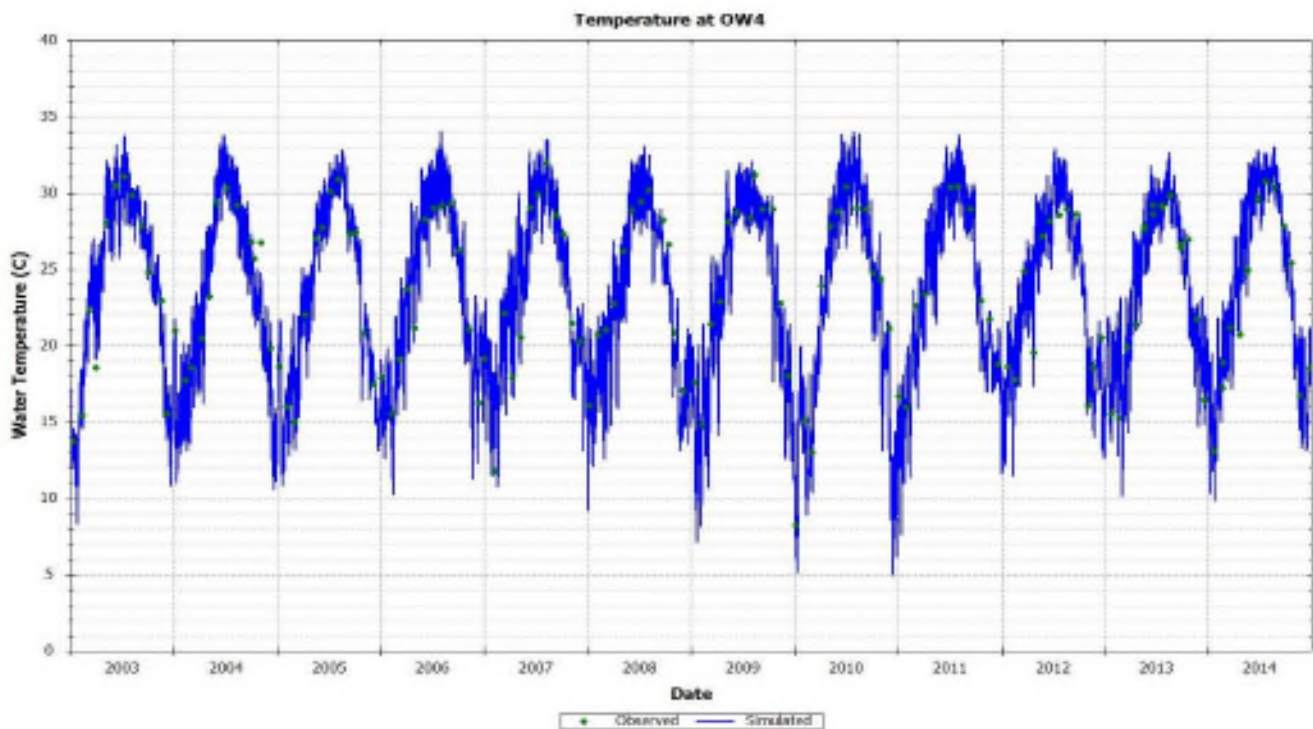


FIGURE B-2: TEMPERATURE SIMULATION FOR STATION OW4, 44057

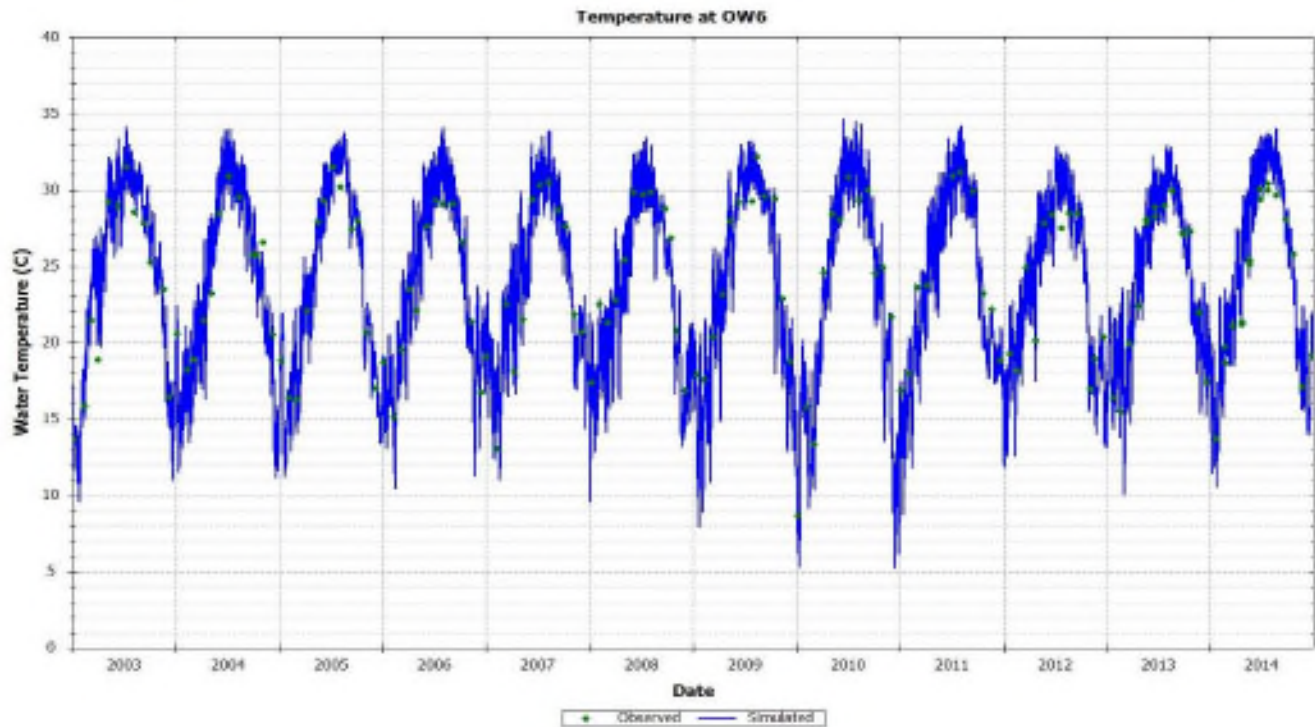


FIGURE B-3: TEMPERATURE SIMULATION FOR STATION OW6, 44059

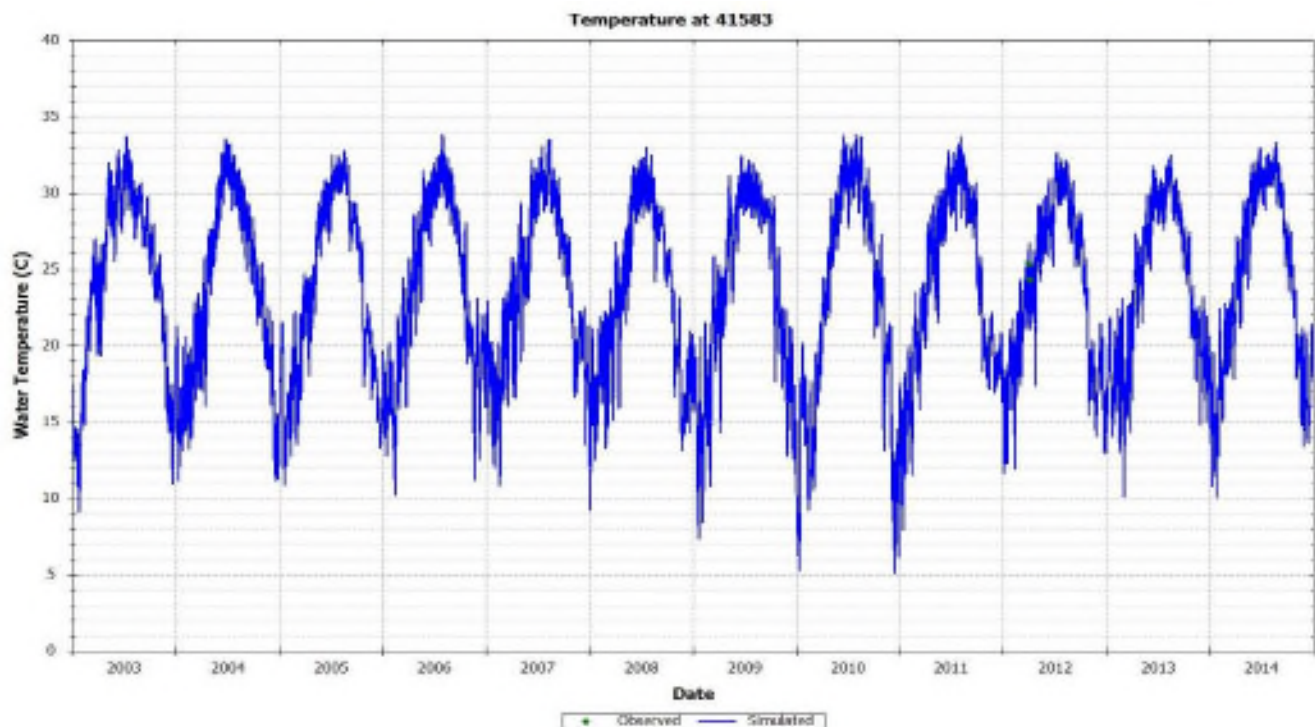


FIGURE B-4: TEMPERATURE SIMULATION FOR STATION 41583

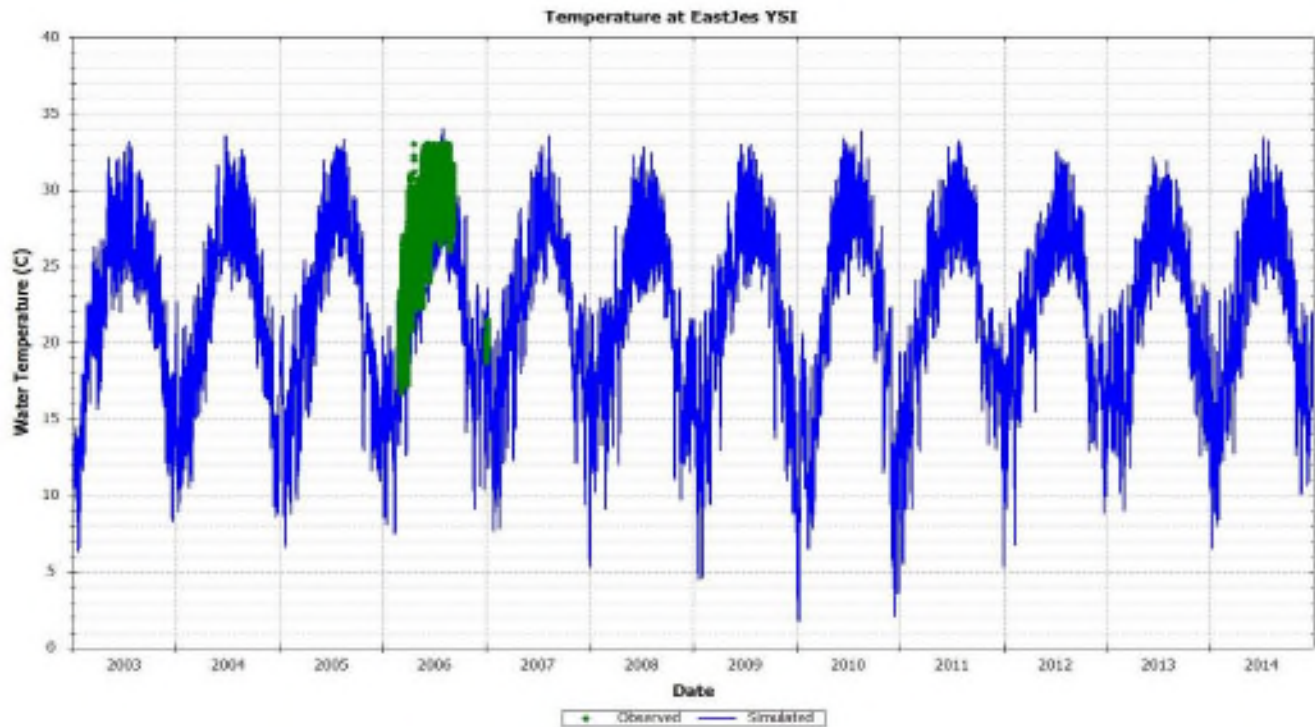


FIGURE B-5: TEMPERATURE SIMULATION FOR STATION EASTJES YSI

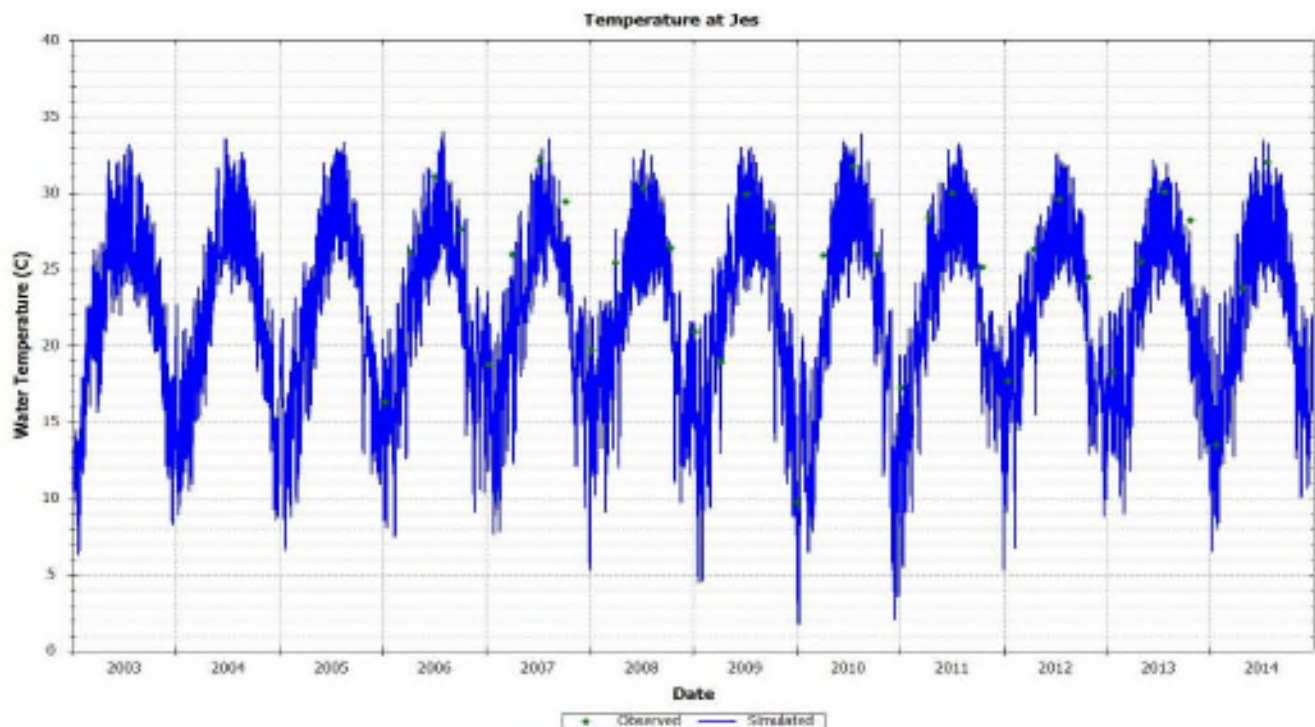


FIGURE B-6: TEMPERATURE SIMULATION FOR STATION JES

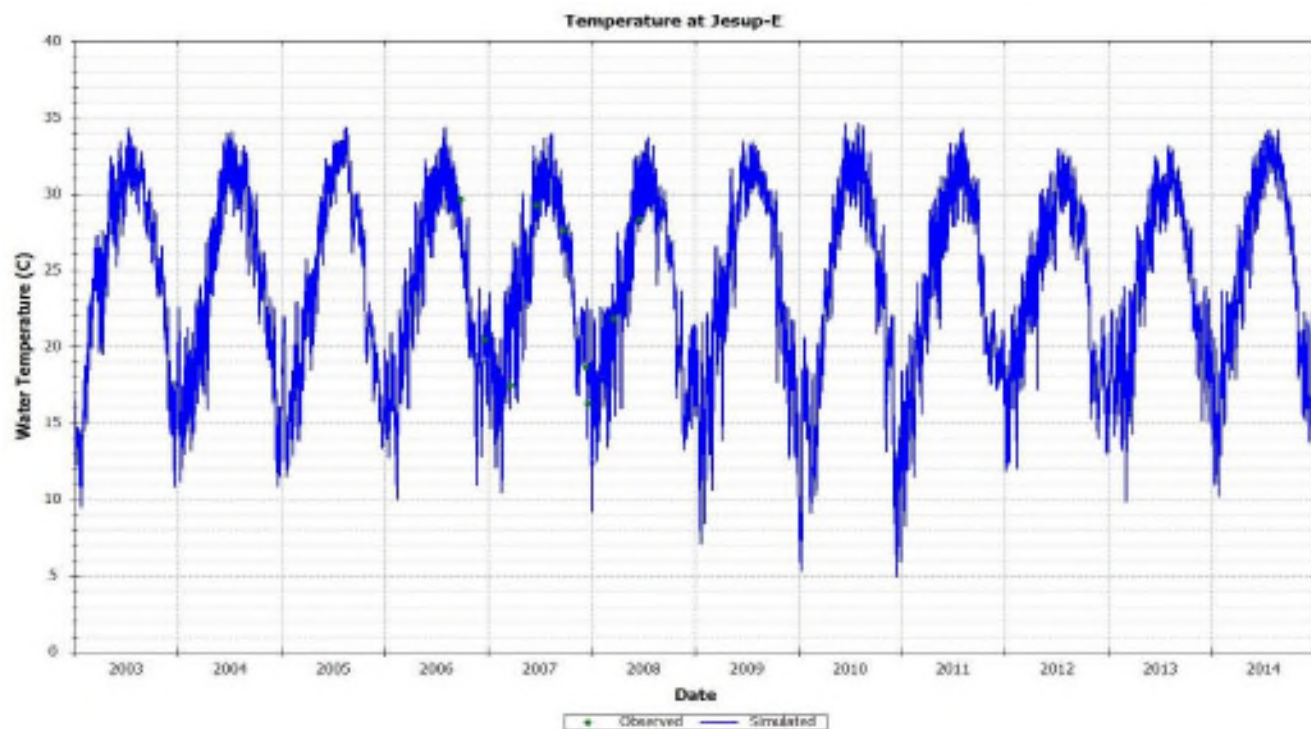


FIGURE B-7: TEMPERATURE SIMULATION FOR STATION JESUP-E

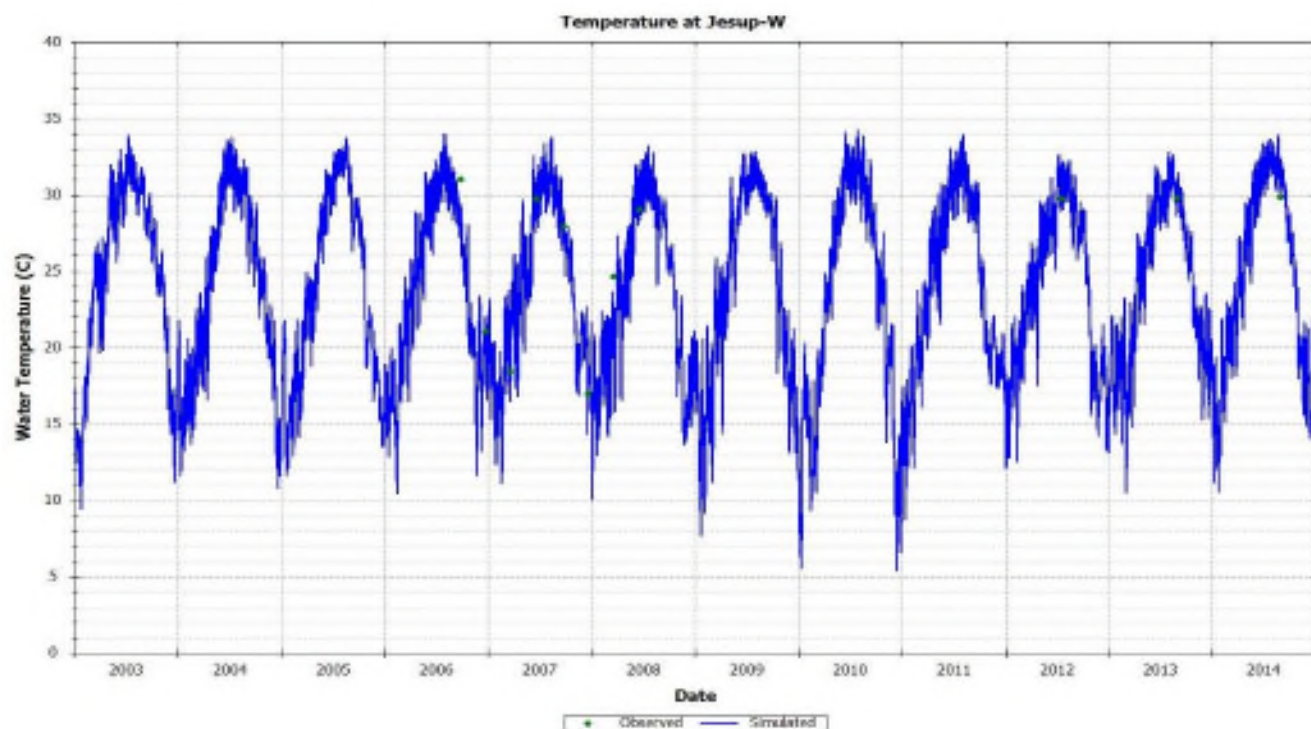


FIGURE B-8: TEMPERATURE SIMULATION FOR STATION JESUP-W

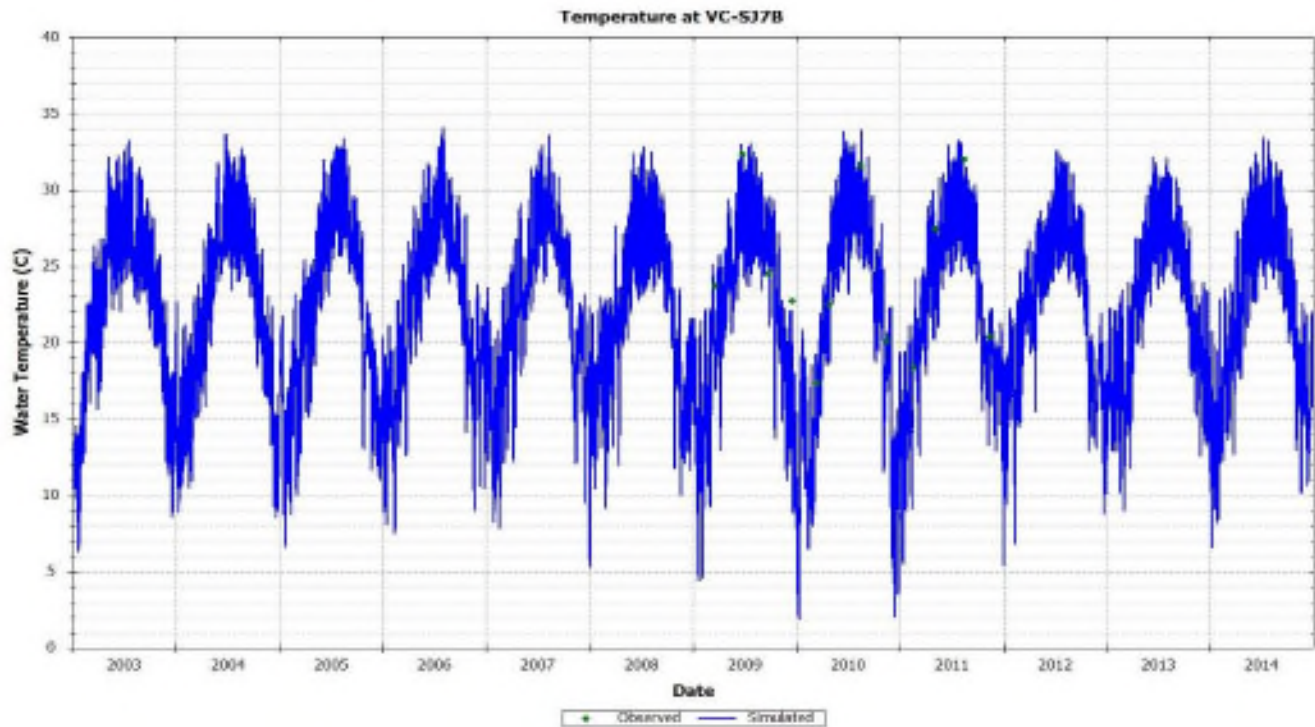


FIGURE B-9: TEMPERATURE SIMULATION FOR STATION VC-SJ7B

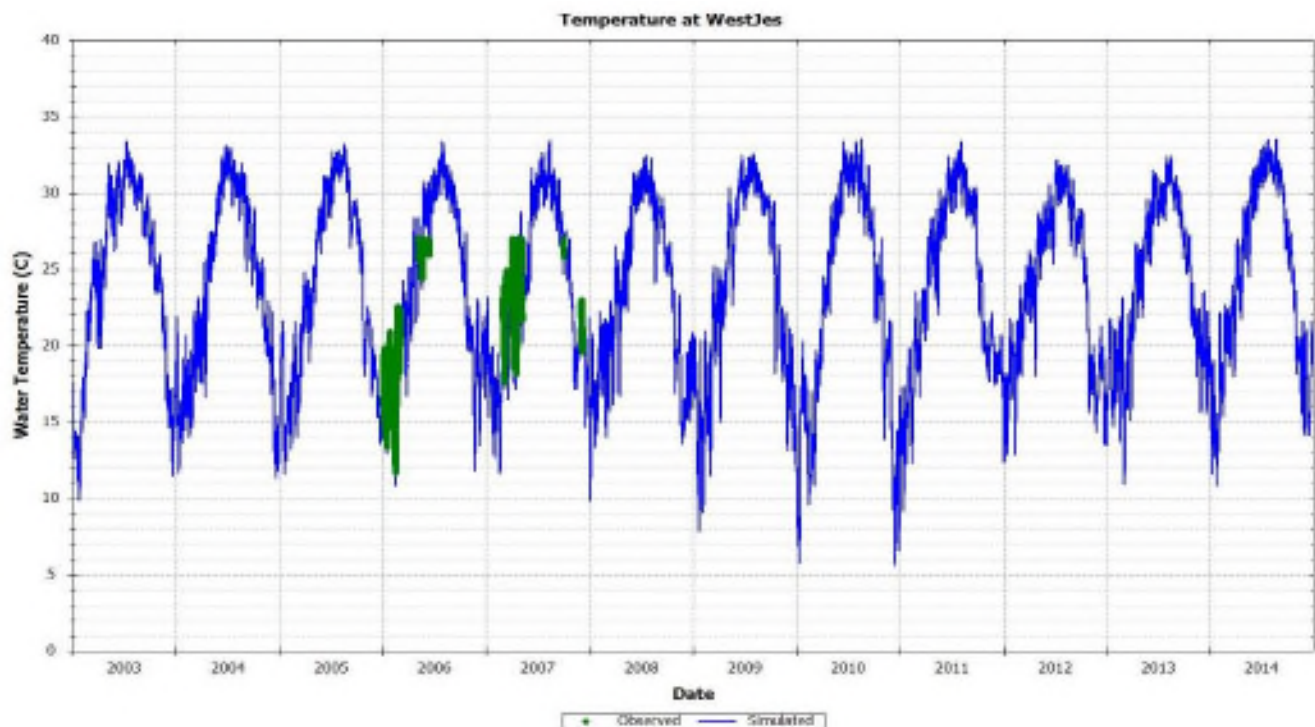


FIGURE B-10: TEMPERATURE SIMULATION FOR STATION WESTJES

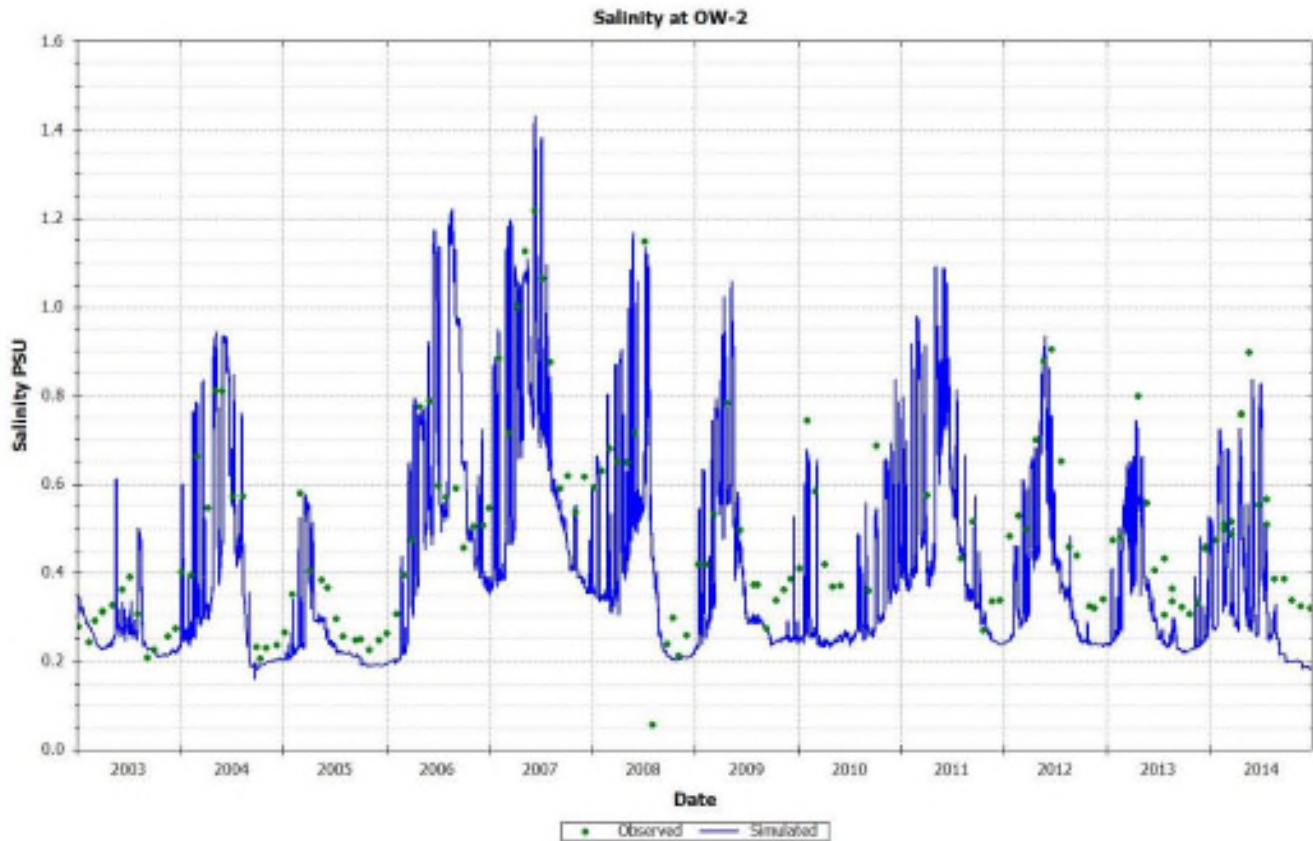


FIGURE B-11: SALINITY SIMULATION FOR STATION OW2, 44055

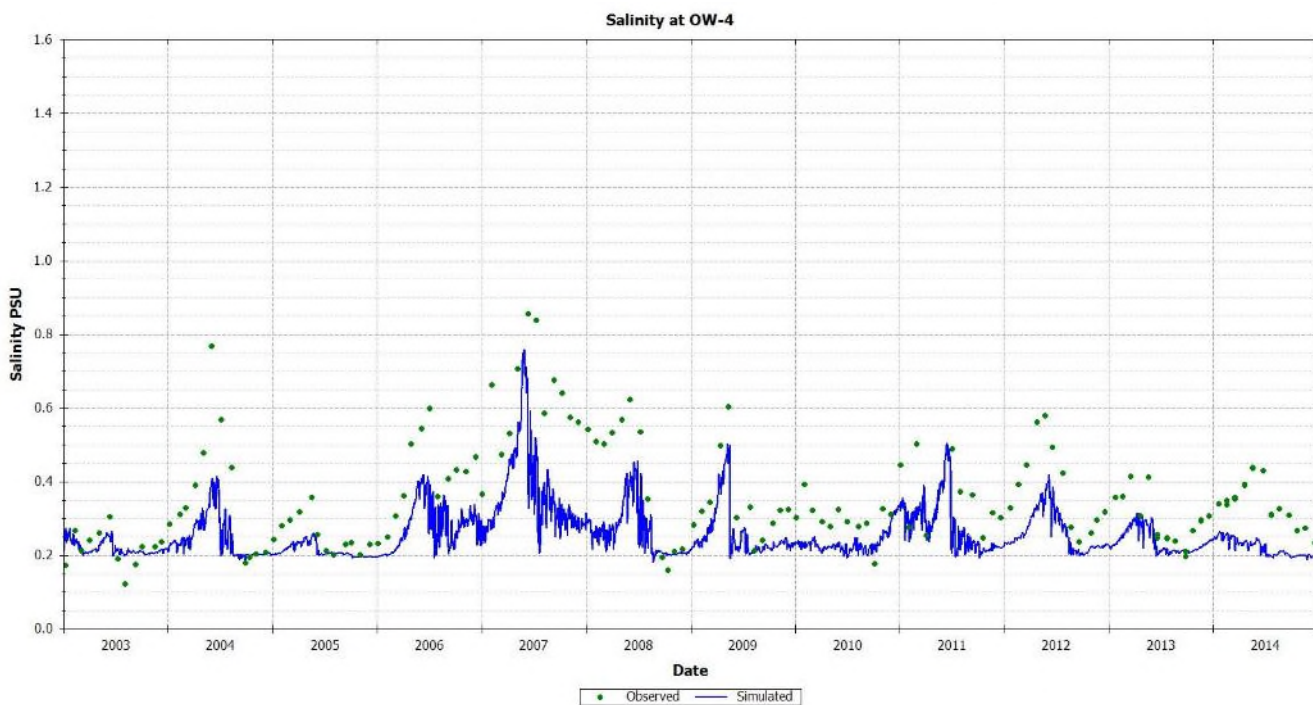


FIGURE B-12: SALINITY SIMULATION FOR STATION OW4, 44057

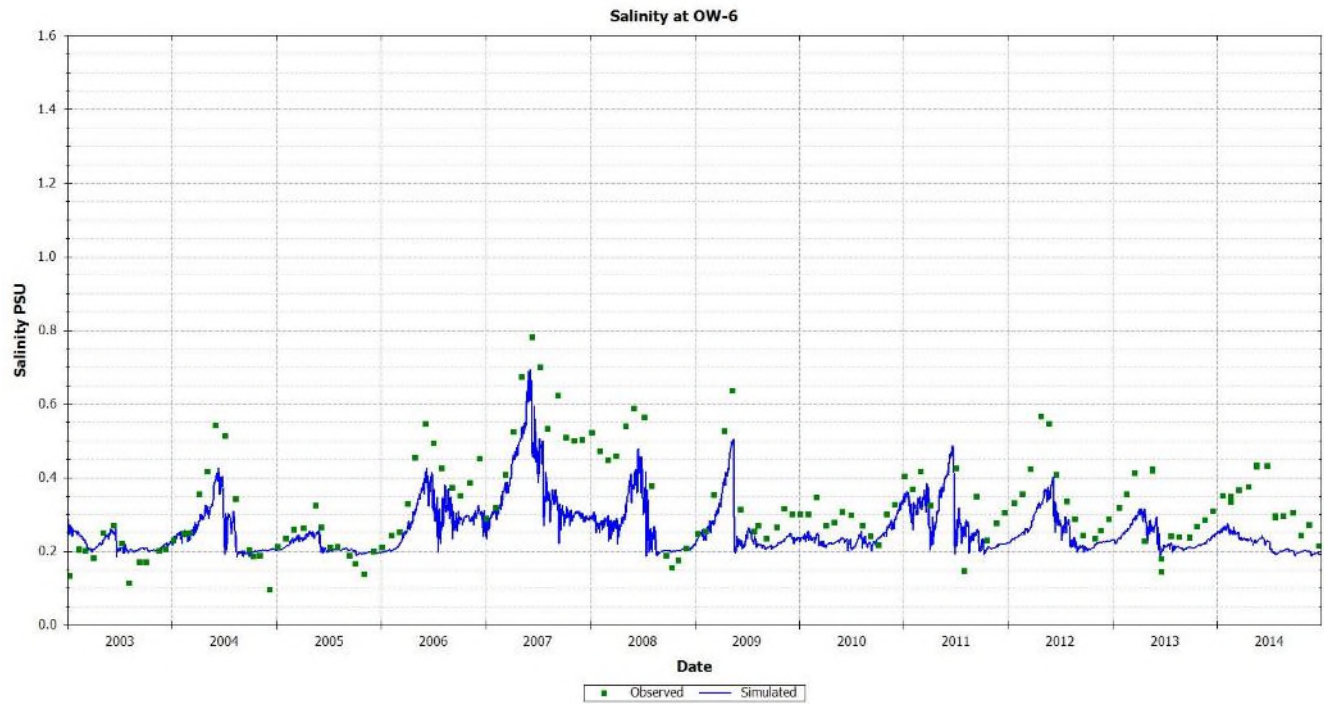


FIGURE B-13: SALINITY SIMULATION FOR STATION OW6, 44059

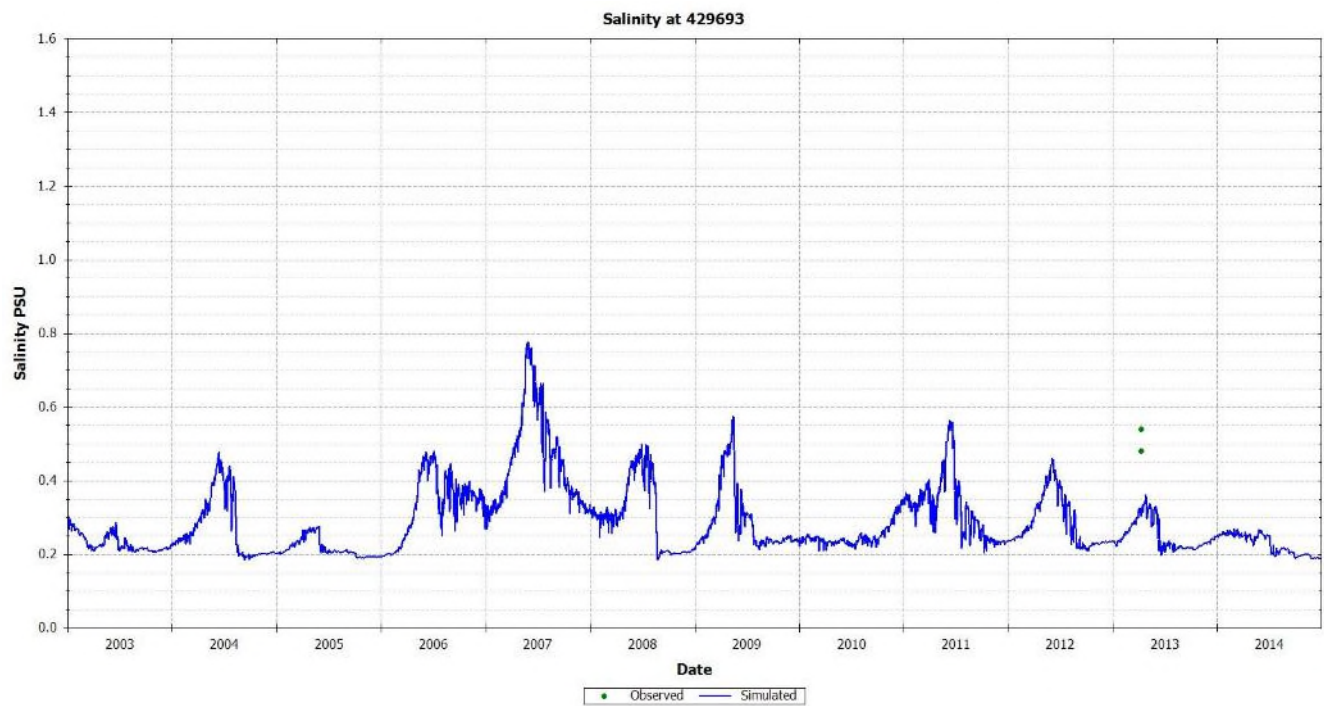


FIGURE B-14: SALINITY SIMULATION FOR STATION 429693

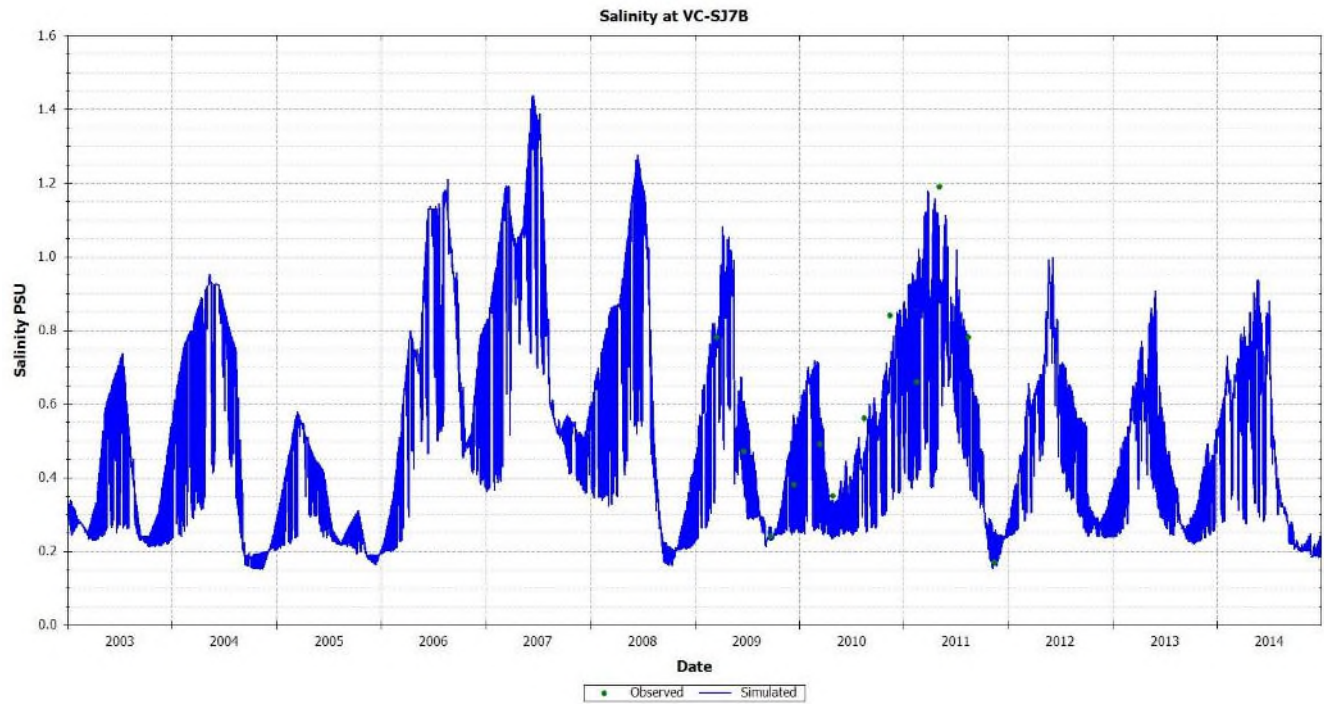


FIGURE B-15: SALINITY SIMULATION FOR STATION VC-SJ7B

APPENDIX C: WASP MODEL CALIBRATION RESULTS

DO RESULTS

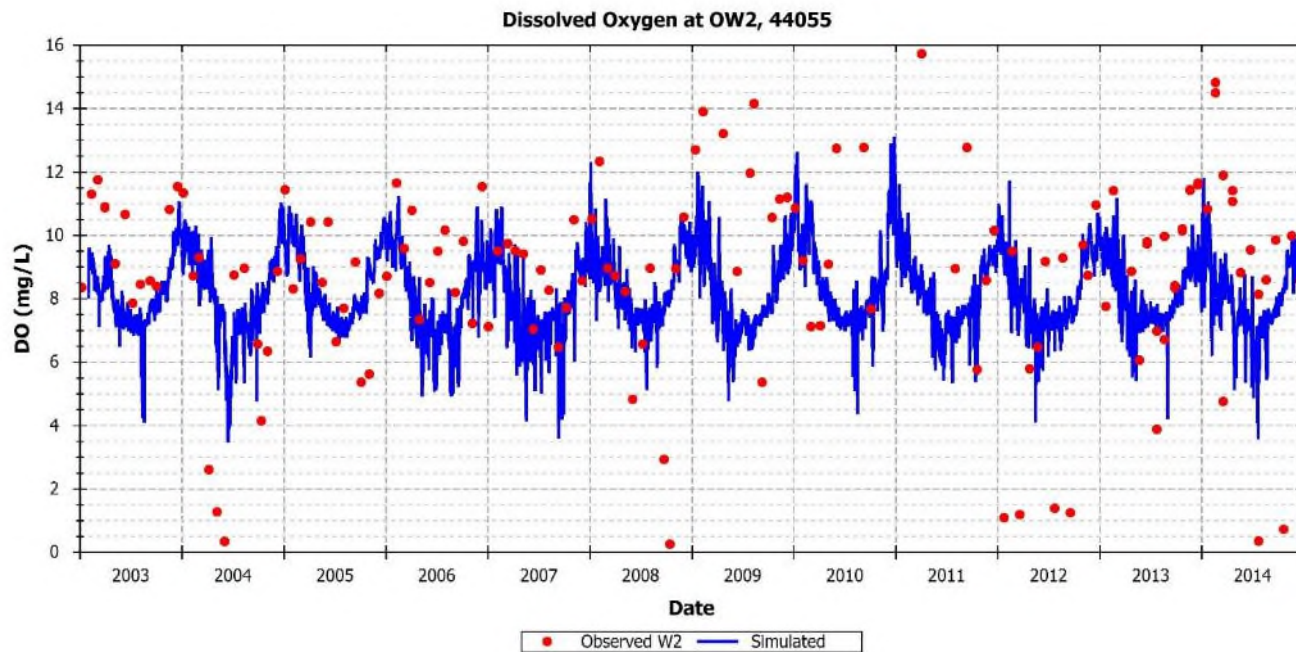


FIGURE C-1: DO SIMULATION FOR STATION OW2, 44055

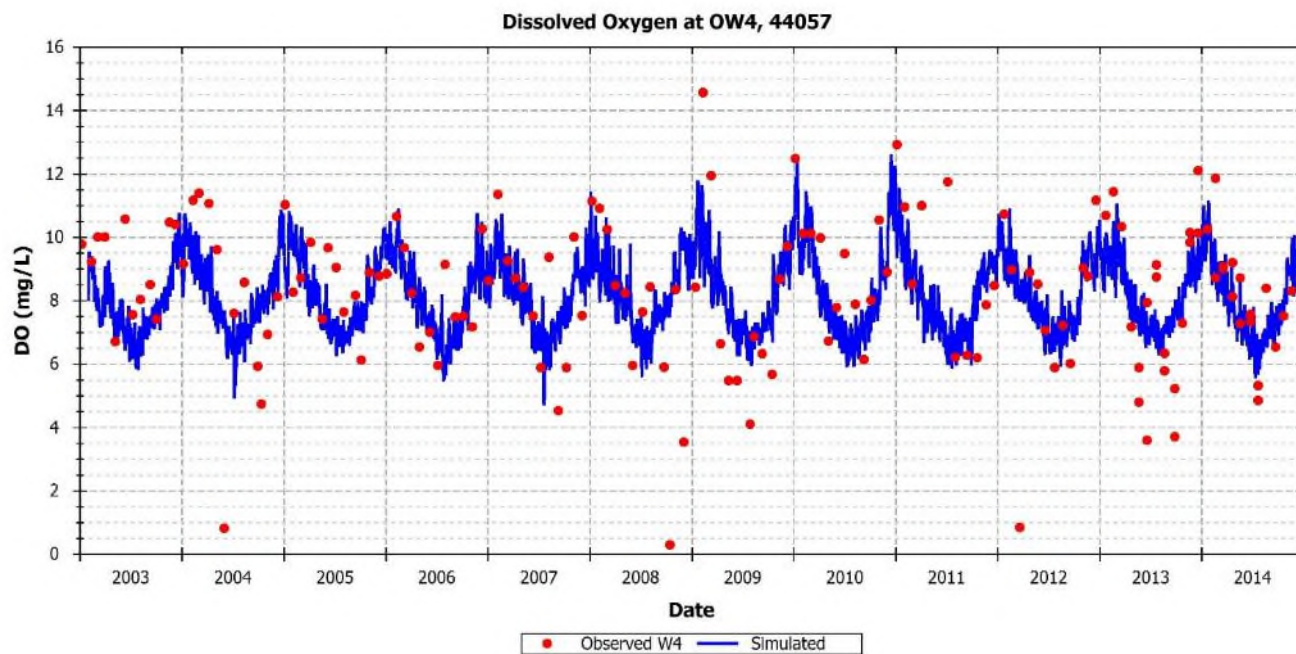


FIGURE C-2: DO SIMULATION FOR STATION OW4, 44057

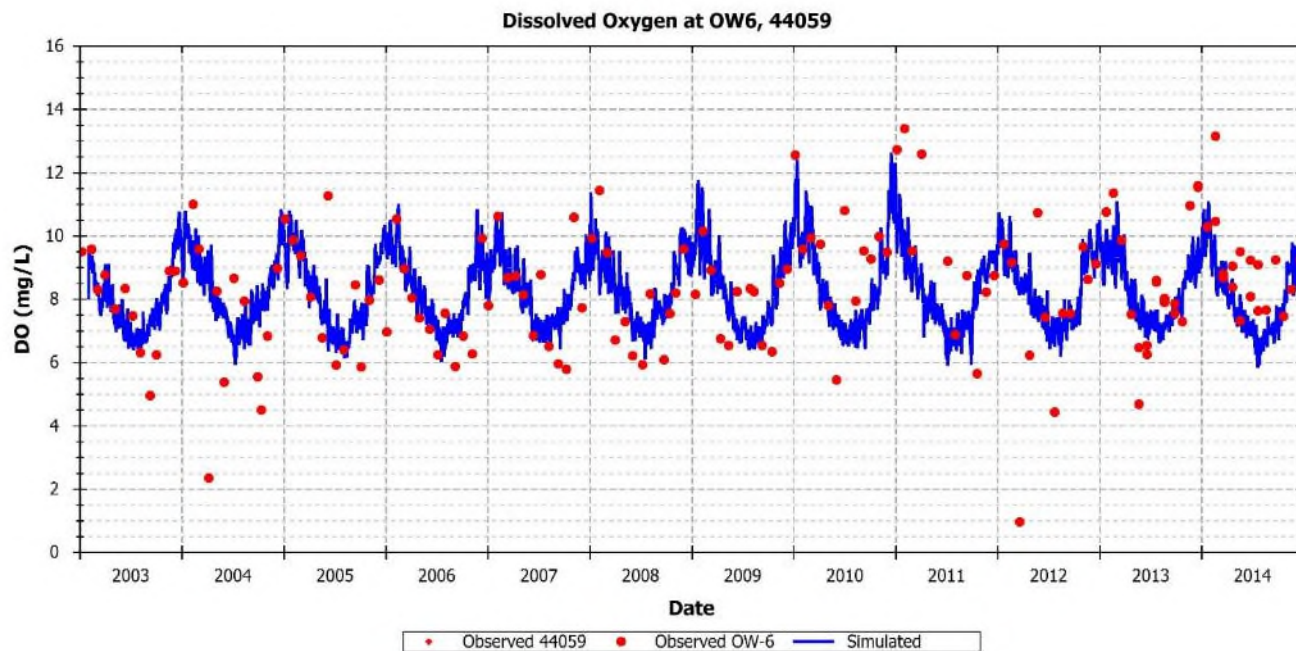


FIGURE C-3: DO SIMULATION FOR STATION OW6, 44059

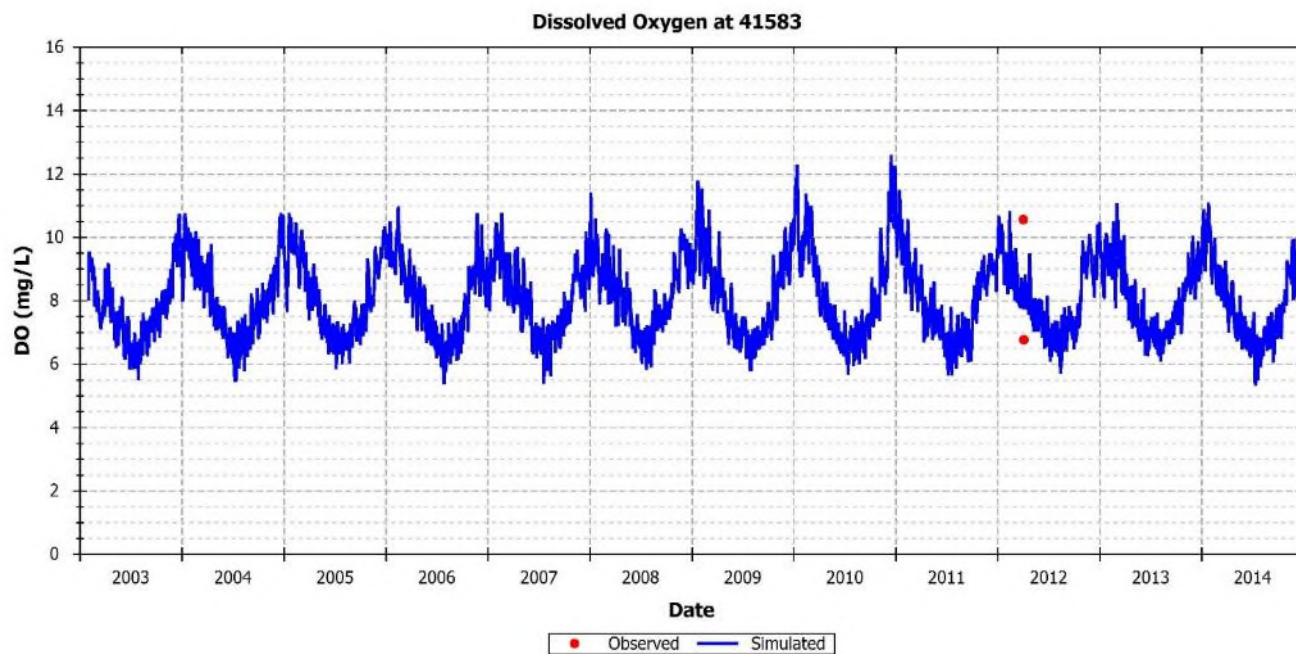


FIGURE C-4: DO SIMULATION FOR STATION 41583

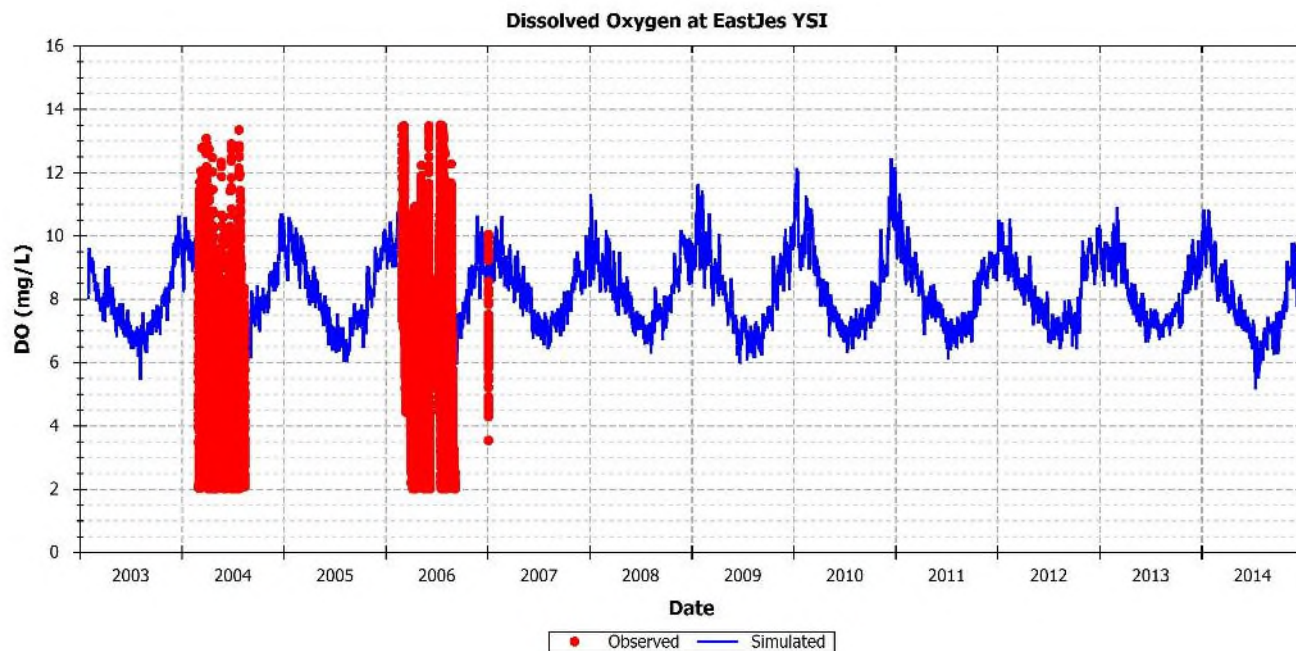


FIGURE C-5: DO SIMULATION FOR STATION EASTJES YSI

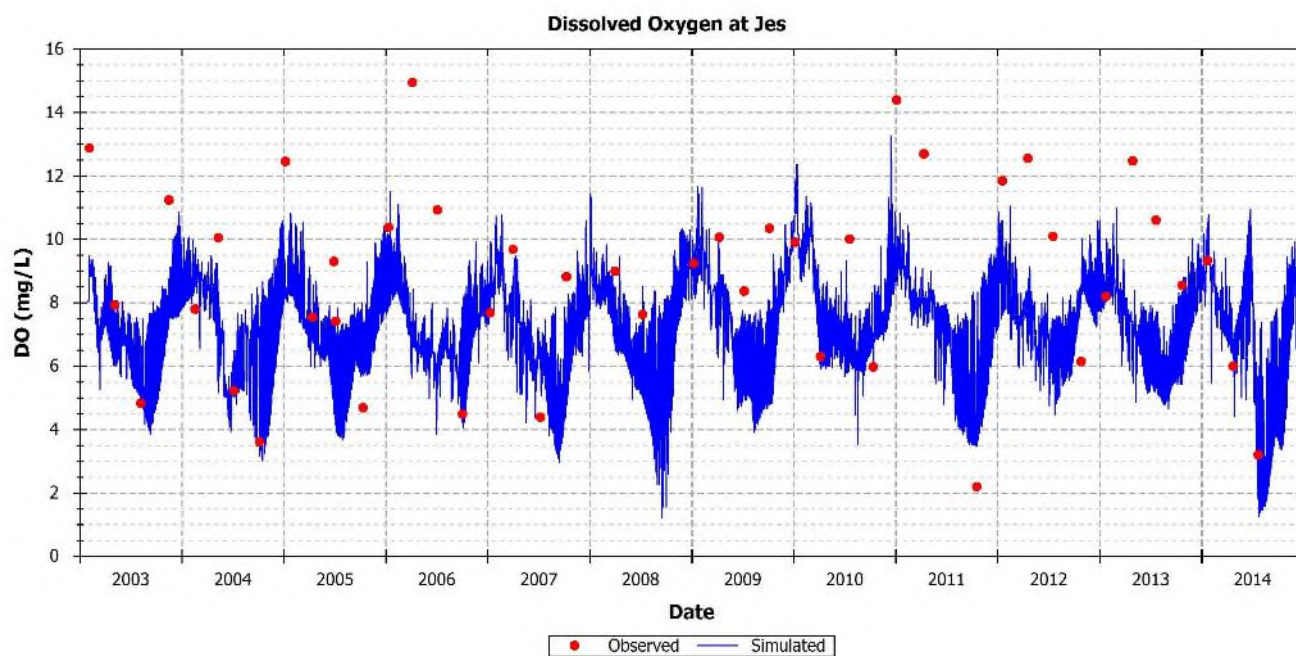


FIGURE C-6: DO SIMULATION FOR STATION JES

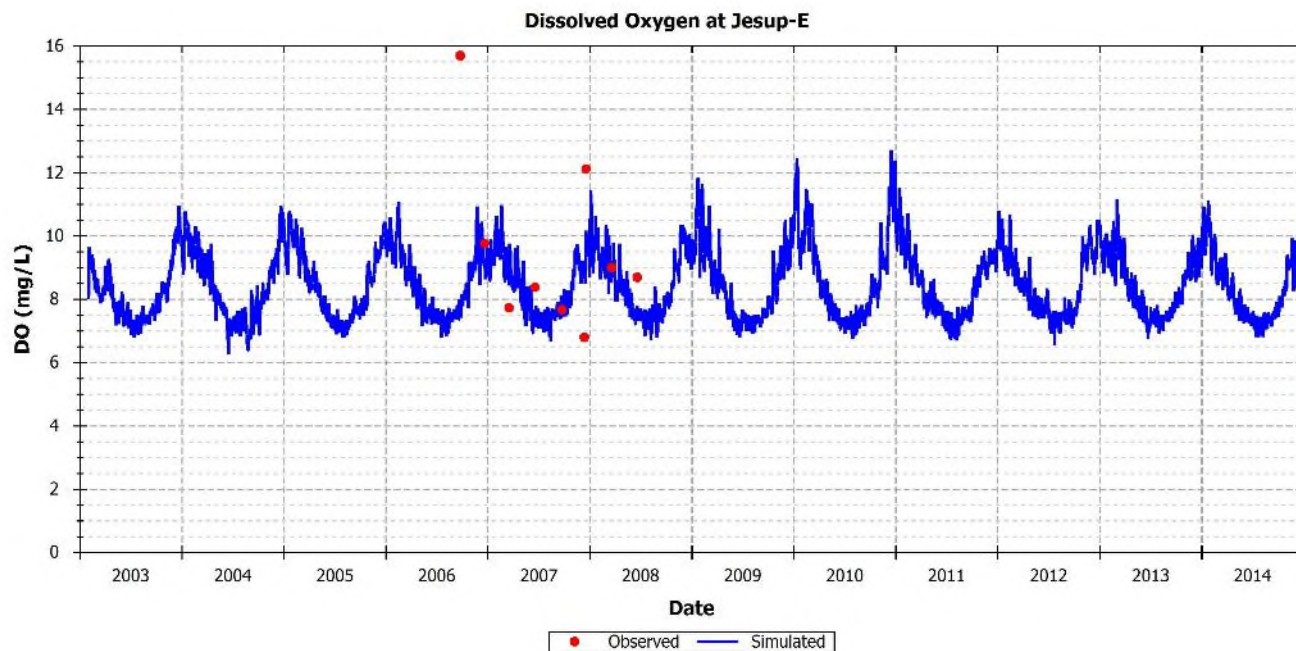


FIGURE C-7: DO SIMULATION FOR STATION JESUP-E

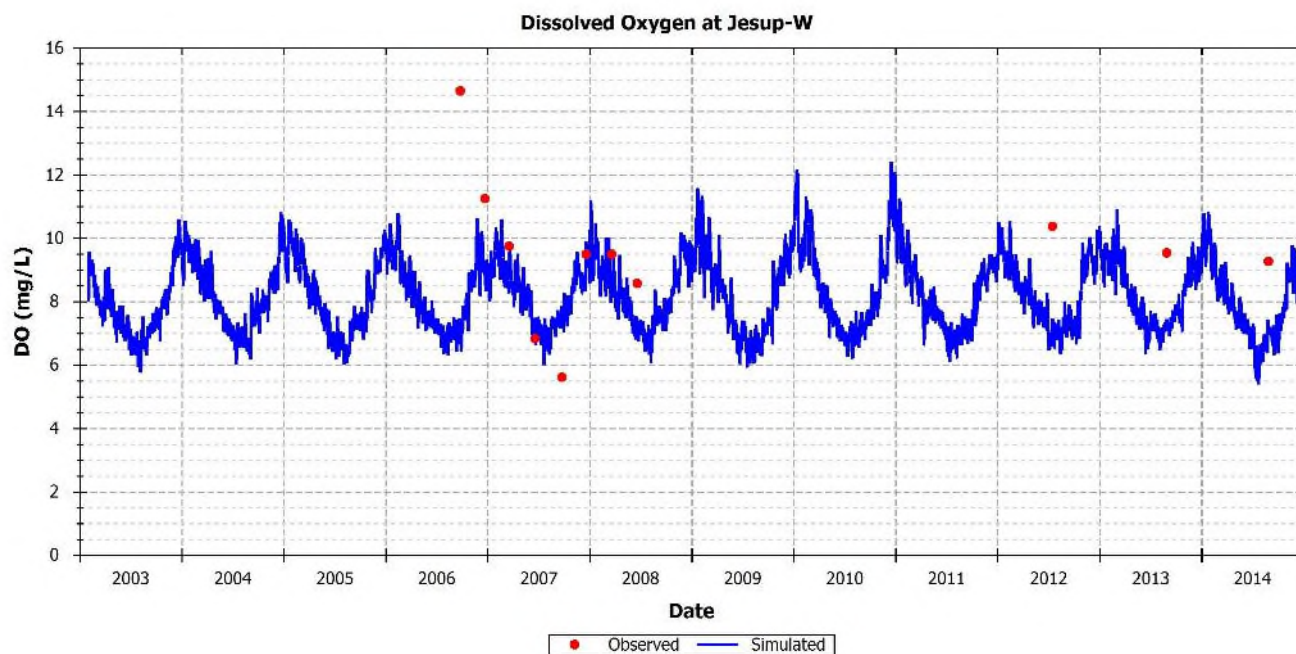


FIGURE C-8: DO SIMULATION FOR STATION JESUP-W

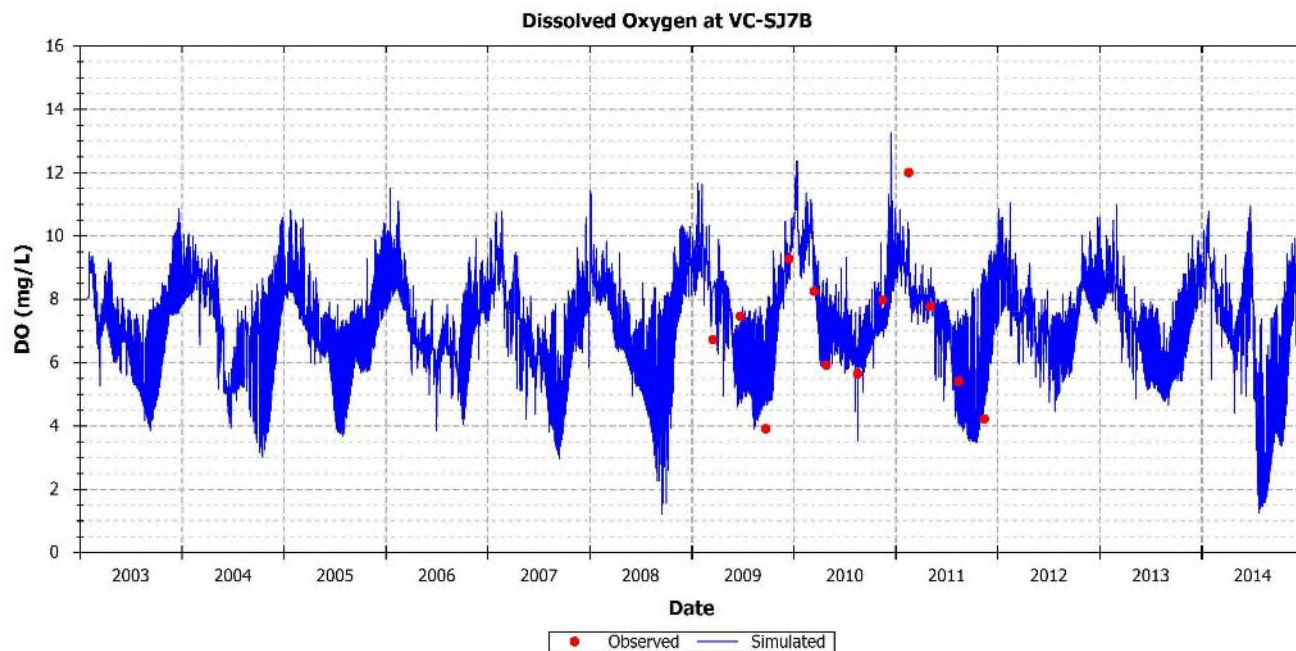


FIGURE C-9: DO SIMULATION FOR STATION VC-SJ7B

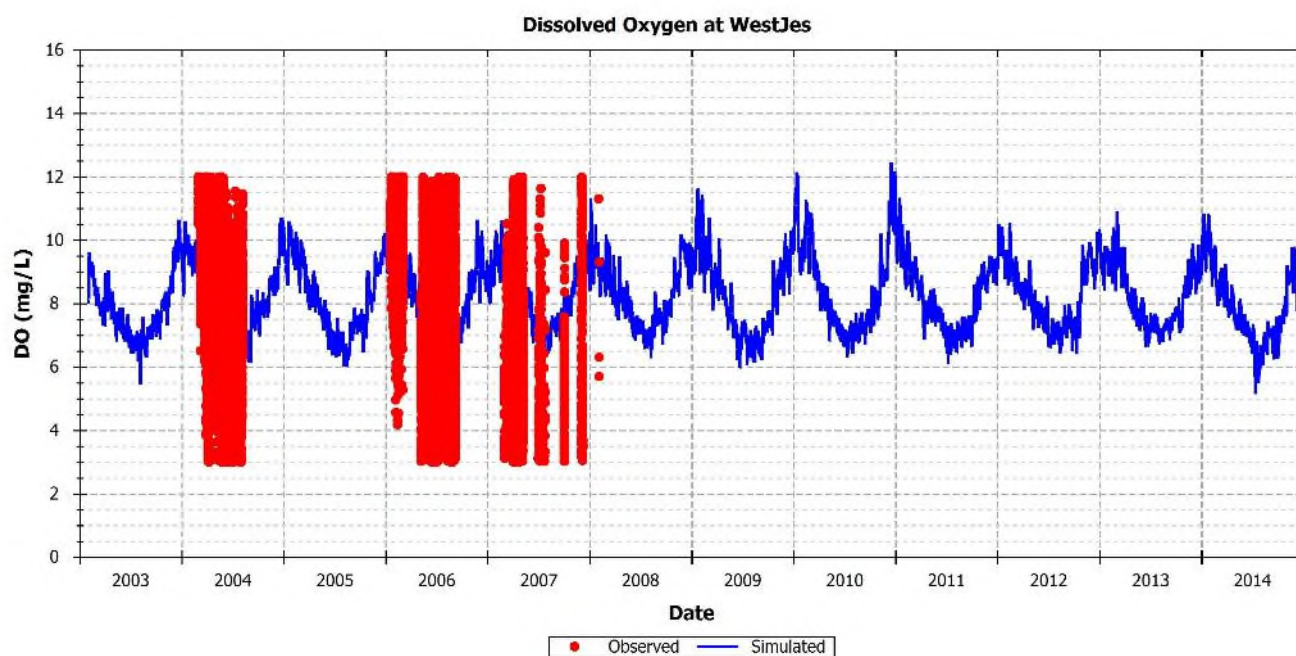


FIGURE C-10: DO SIMULATION FOR STATION WESTJES

BOD RESULTS

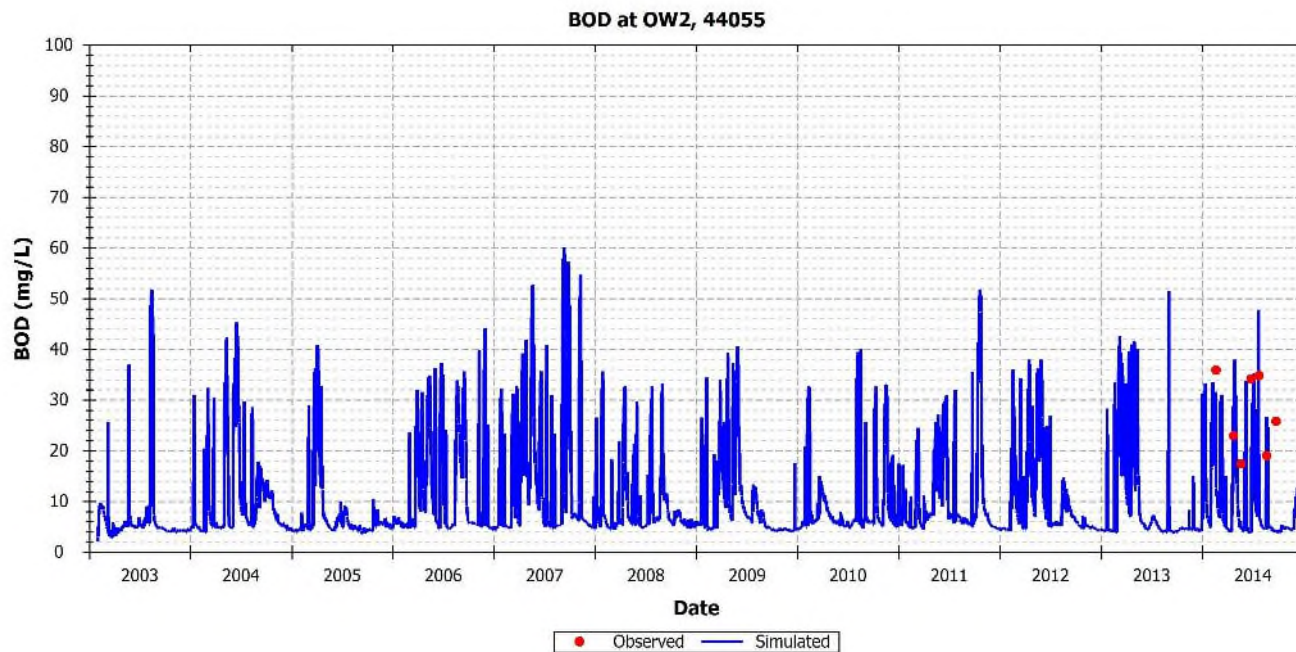


FIGURE C-11: BOD SIMULATION FOR STATION OW2, 44055

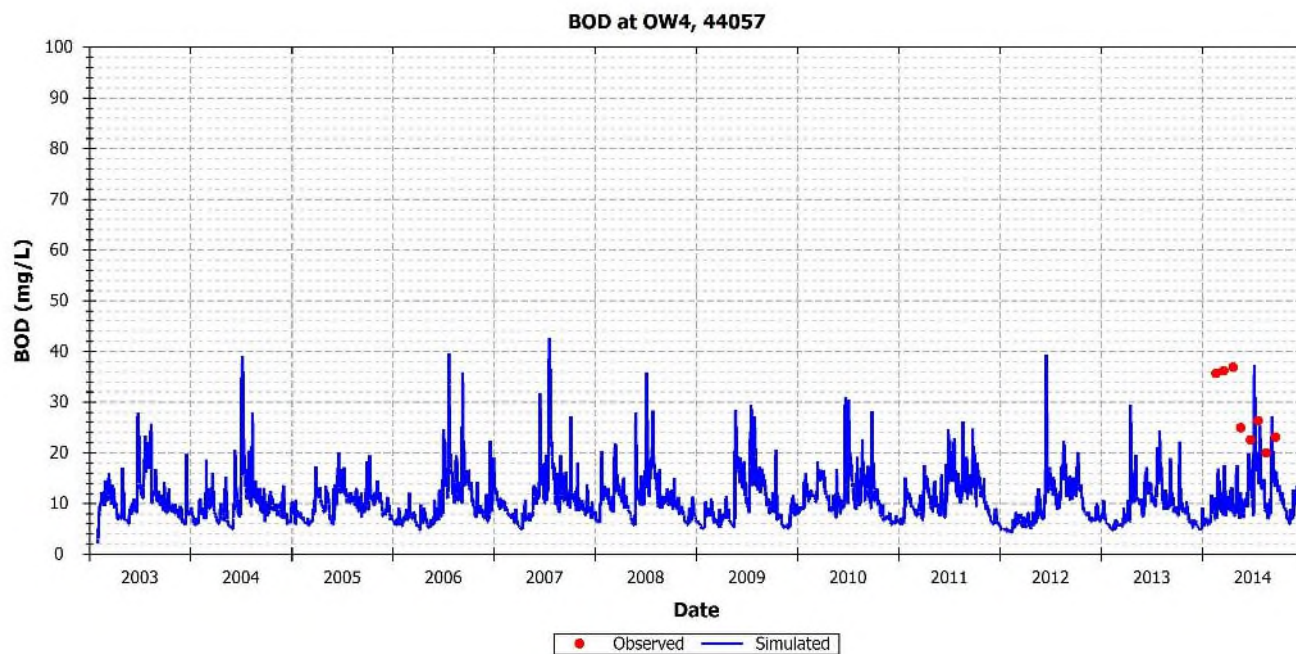


FIGURE C-12: BOD SIMULATION FOR STATION OW4, 44057

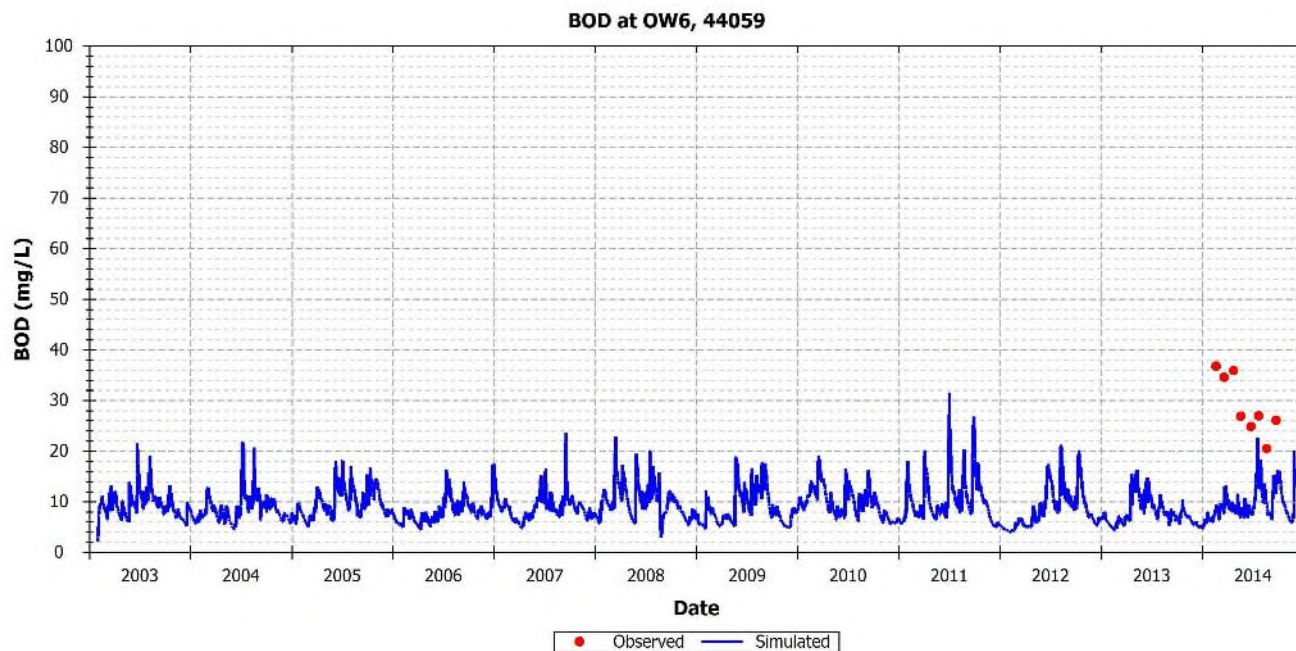


FIGURE C-13: BOD SIMULATION FOR STATION OW6, 44059

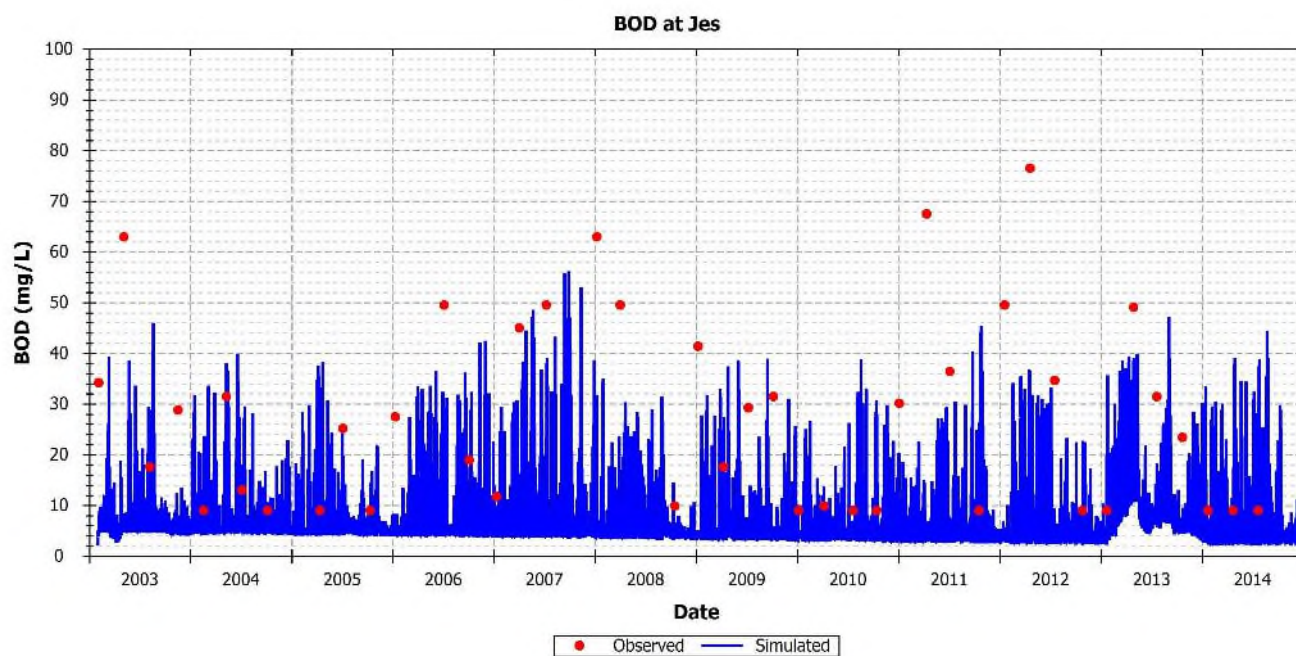


FIGURE C-14: BOD SIMULATION FOR STATION JES

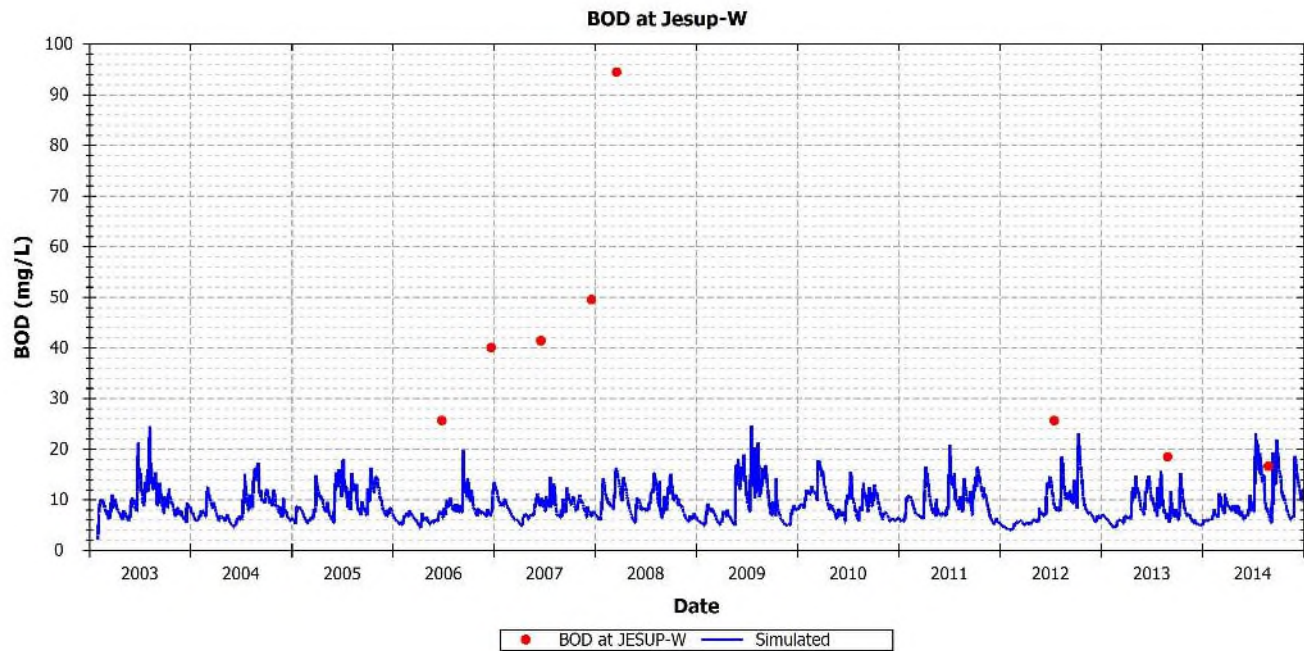


FIGURE C-15: BOD SIMULATION FOR STATION JESUP-W

CHLOROPHYLL-A RESULTS

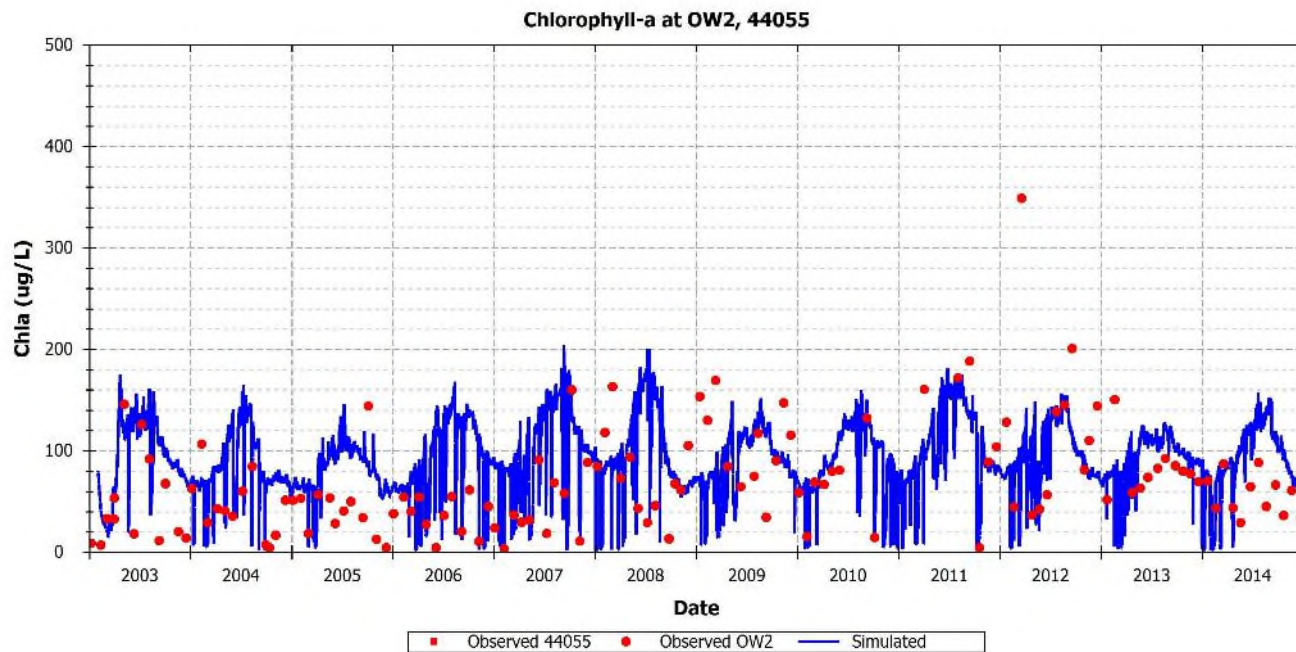


FIGURE C-16: CHLOROPHYLL-A SIMULATION FOR STATION OW2, 44055

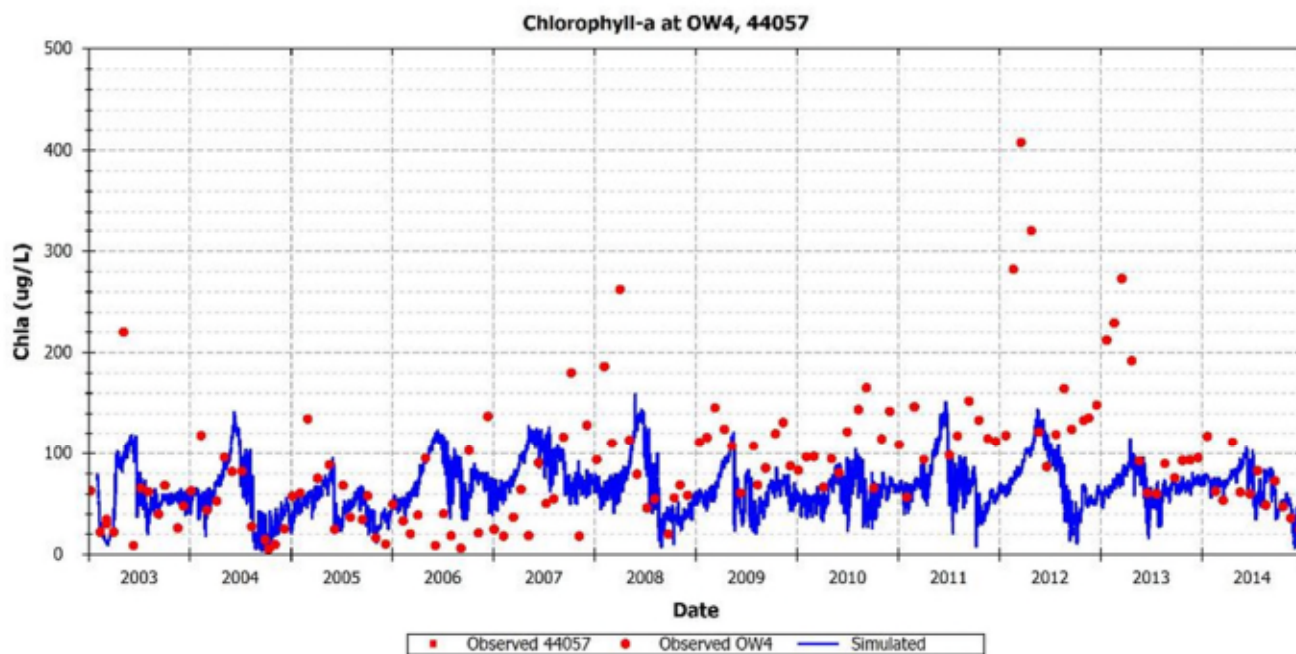


FIGURE C-17: CHLOROPHYLL-A SIMULATION FOR STATION OW4, 44057

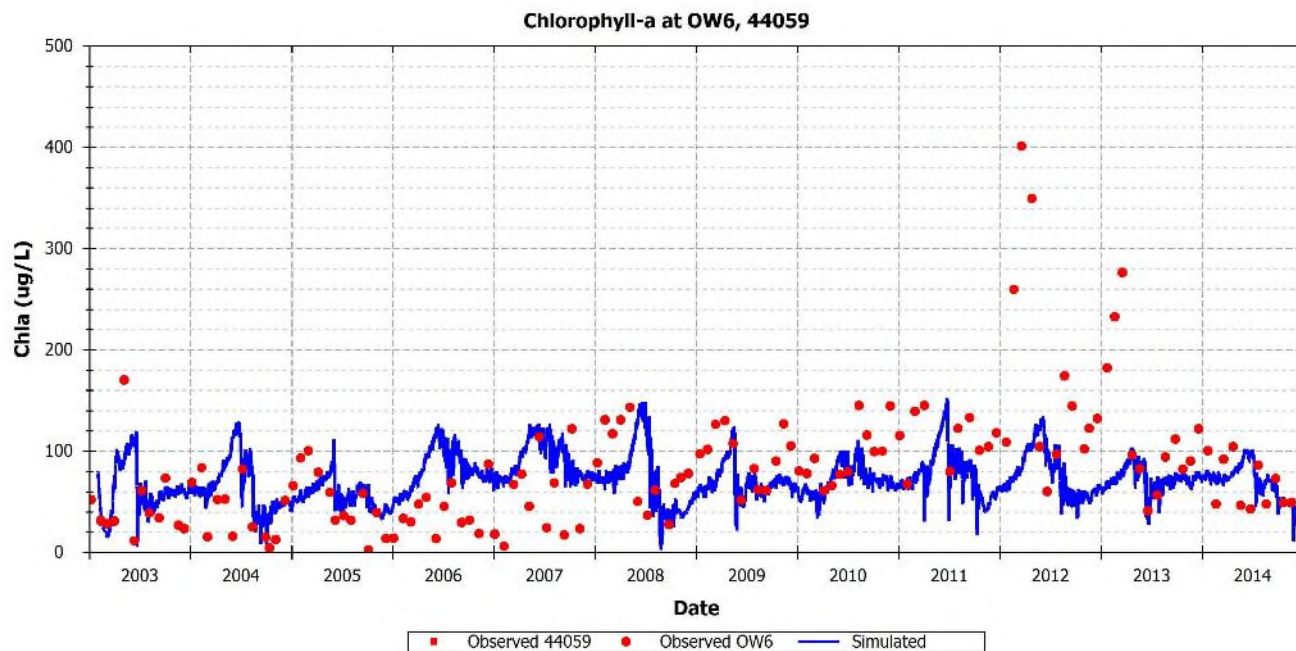


FIGURE C-18: CHLOROPHYLL-A SIMULATION FOR STATION OW6, 44059

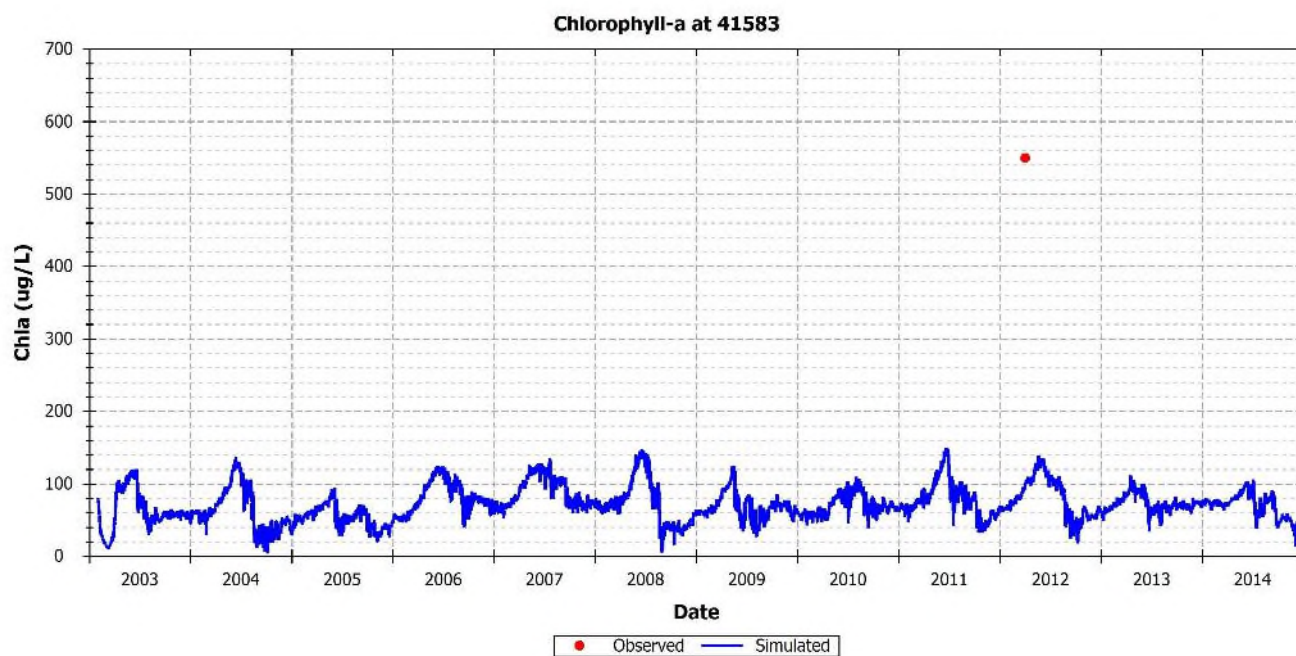


FIGURE C-19: CHLOROPHYLL-A SIMULATION FOR STATION 41583

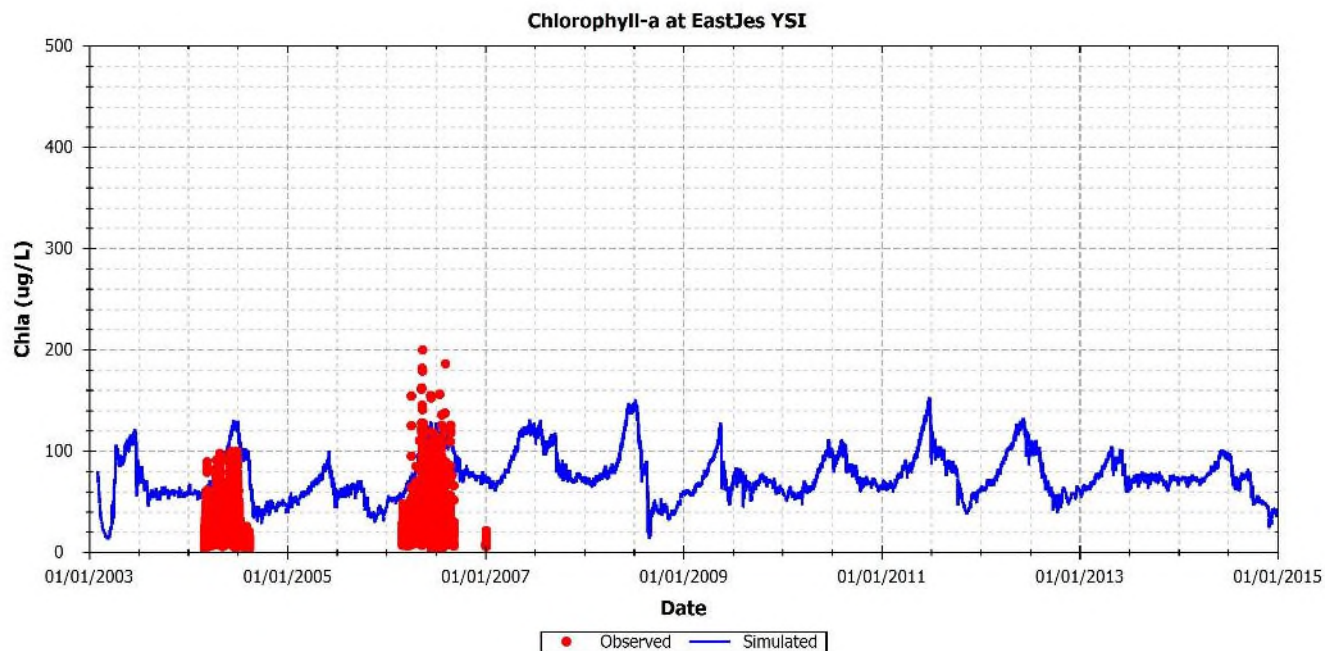


FIGURE C-20: CHLOROPHYLL-A SIMULATION FOR STATION EASTJES YSI

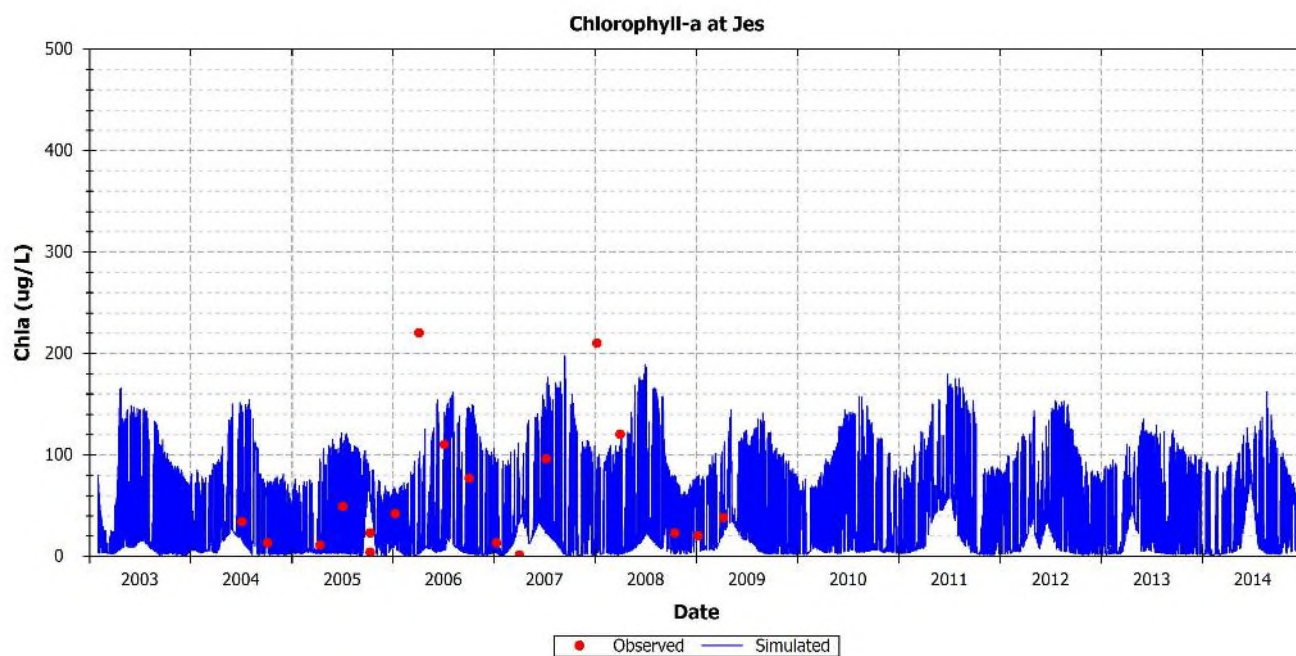


FIGURE C-21: CHLOROPHYLL-A SIMULATION FOR STATION JES

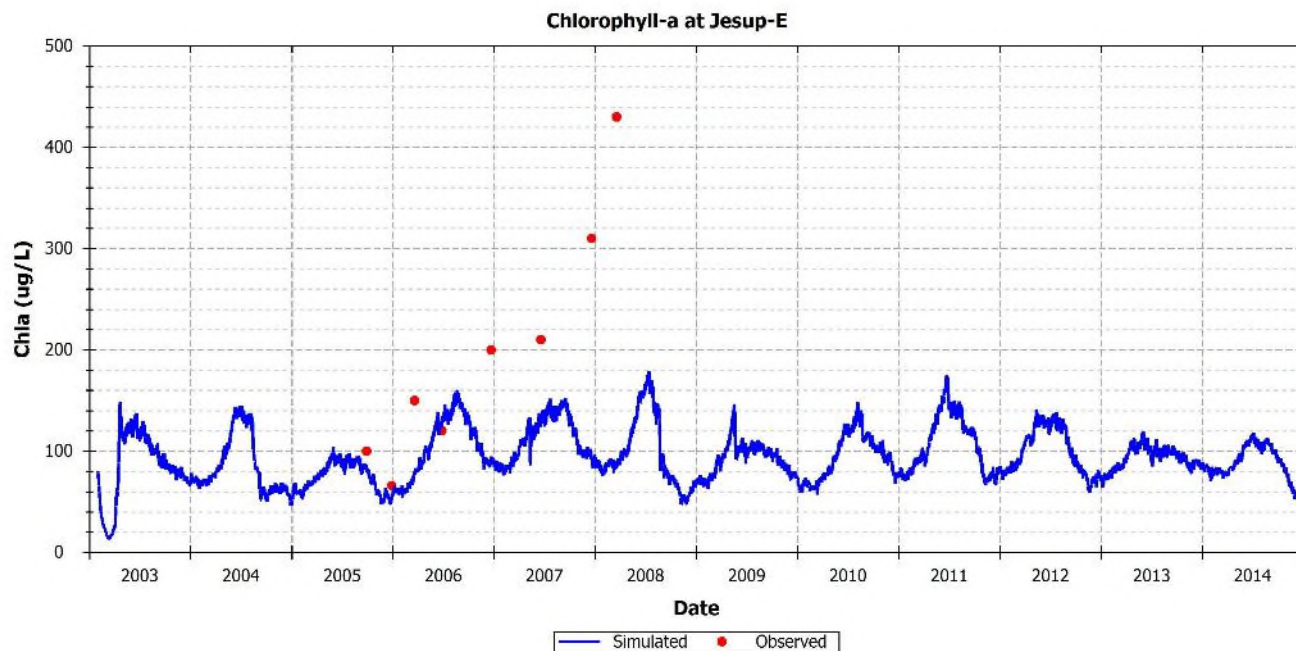


FIGURE C-22: CHLOROPHYLL-A SIMULATION FOR STATION JESUP-E

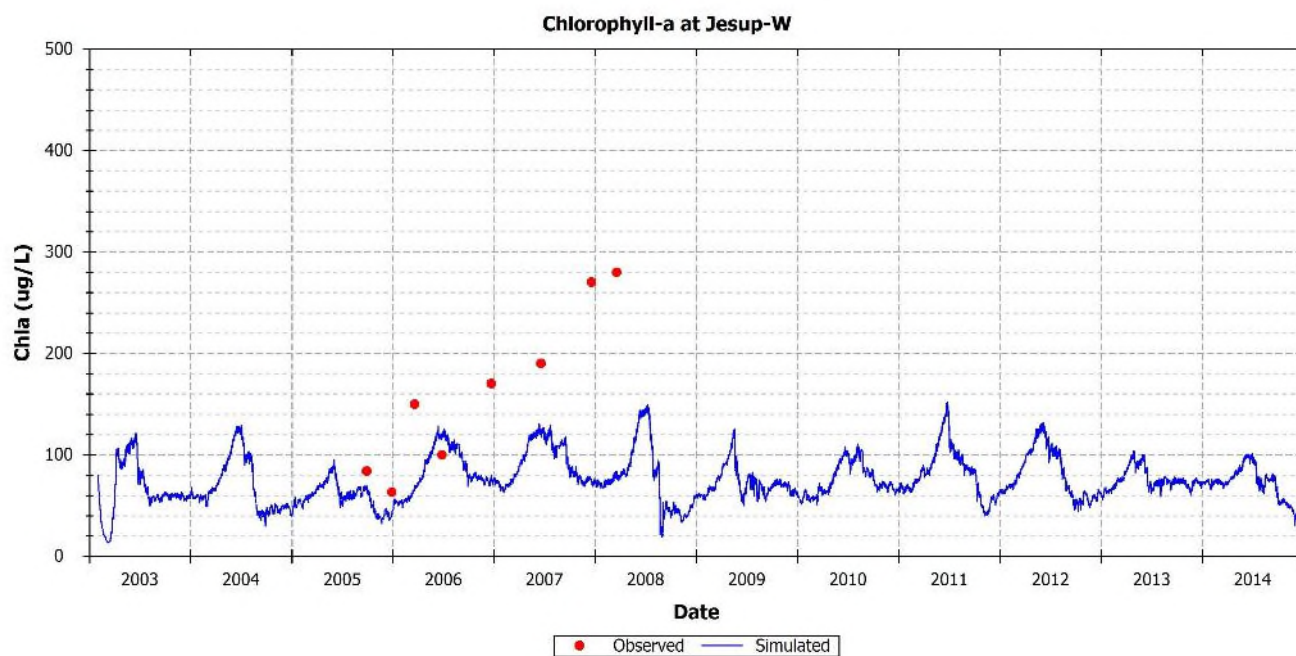


FIGURE C-23: CHLOROPHYLL-A SIMULATION FOR STATION JESUP-W

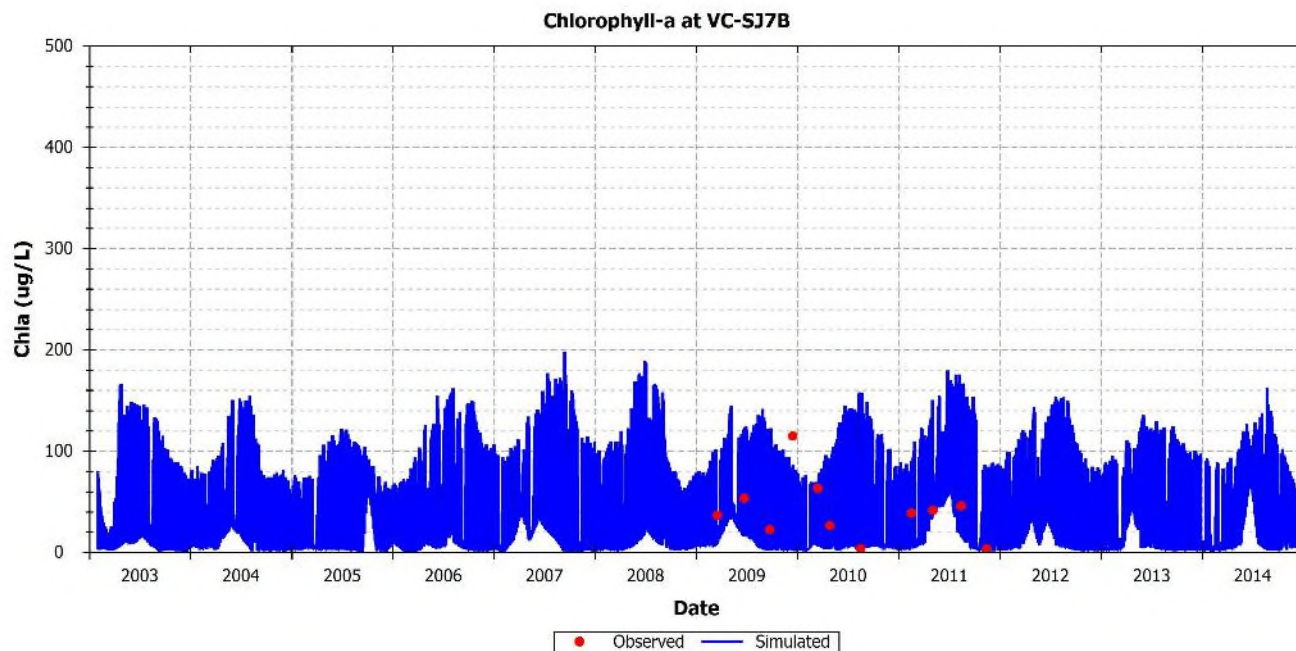


FIGURE C-24: CHLOROPHYLL-A SIMULATION FOR STATION VC-SJ7B

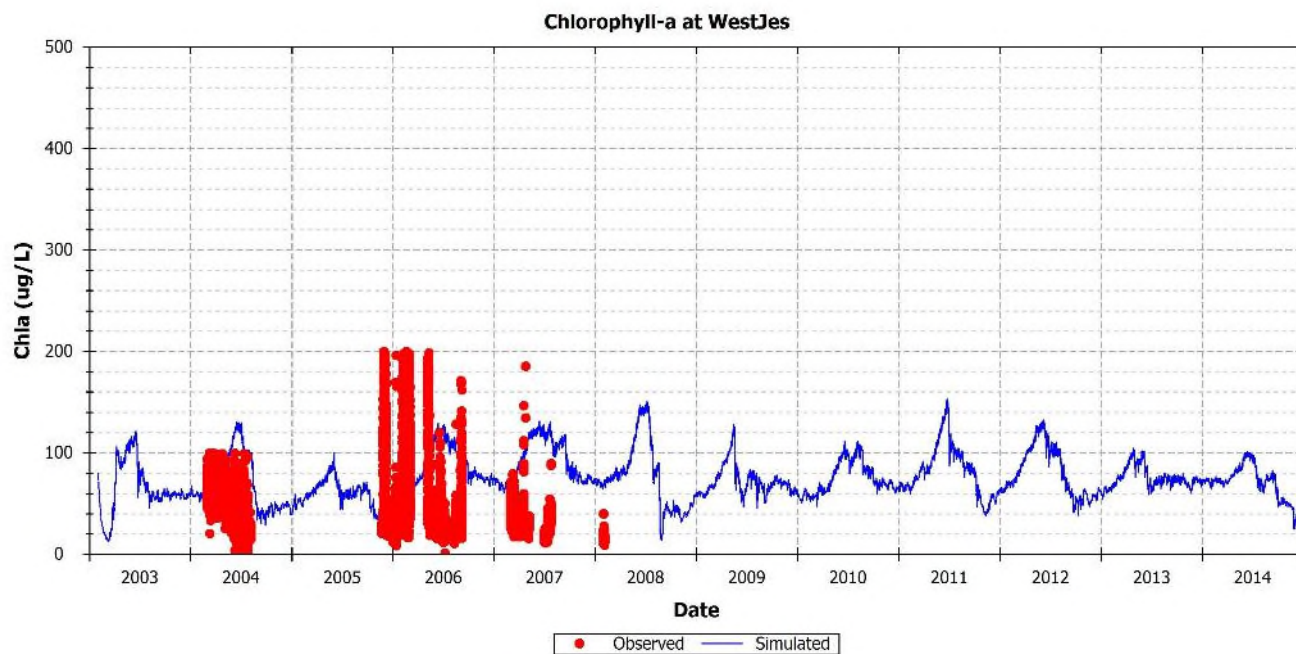


FIGURE C-25: CHLOROPHYLL-A SIMULATION FOR STATION WESTJES

TP RESULTS

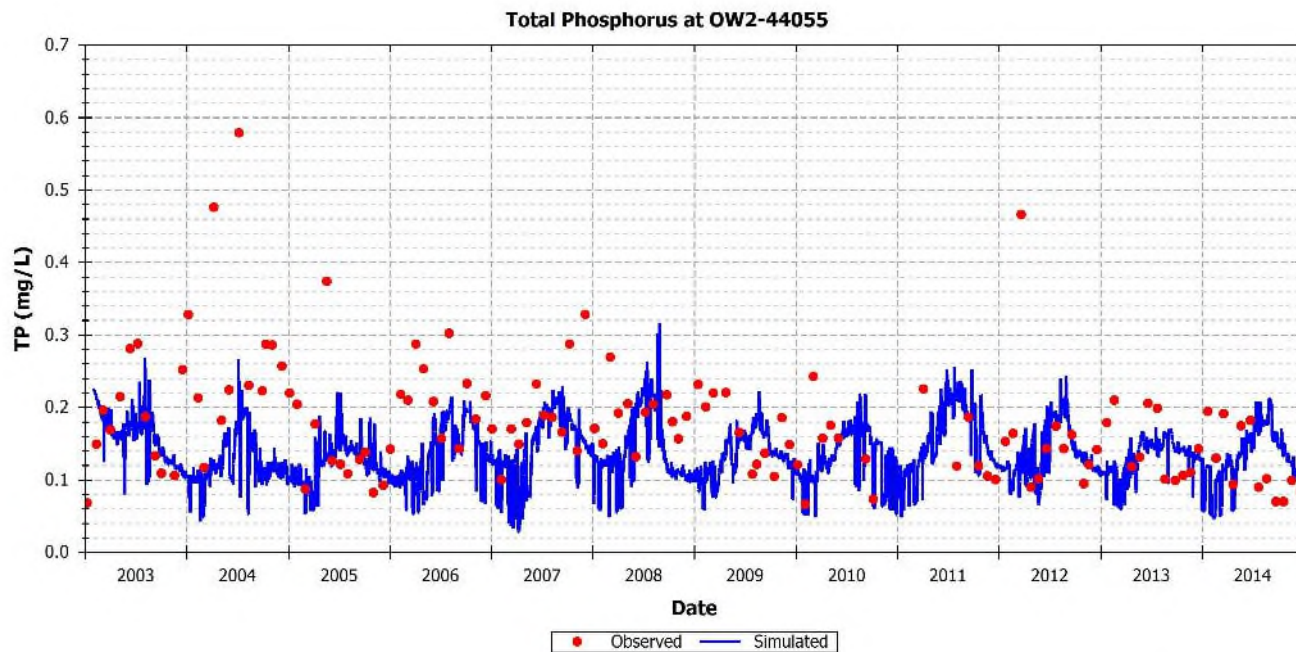


FIGURE C-26: TP SIMULATION FOR STATION OW2, 44055

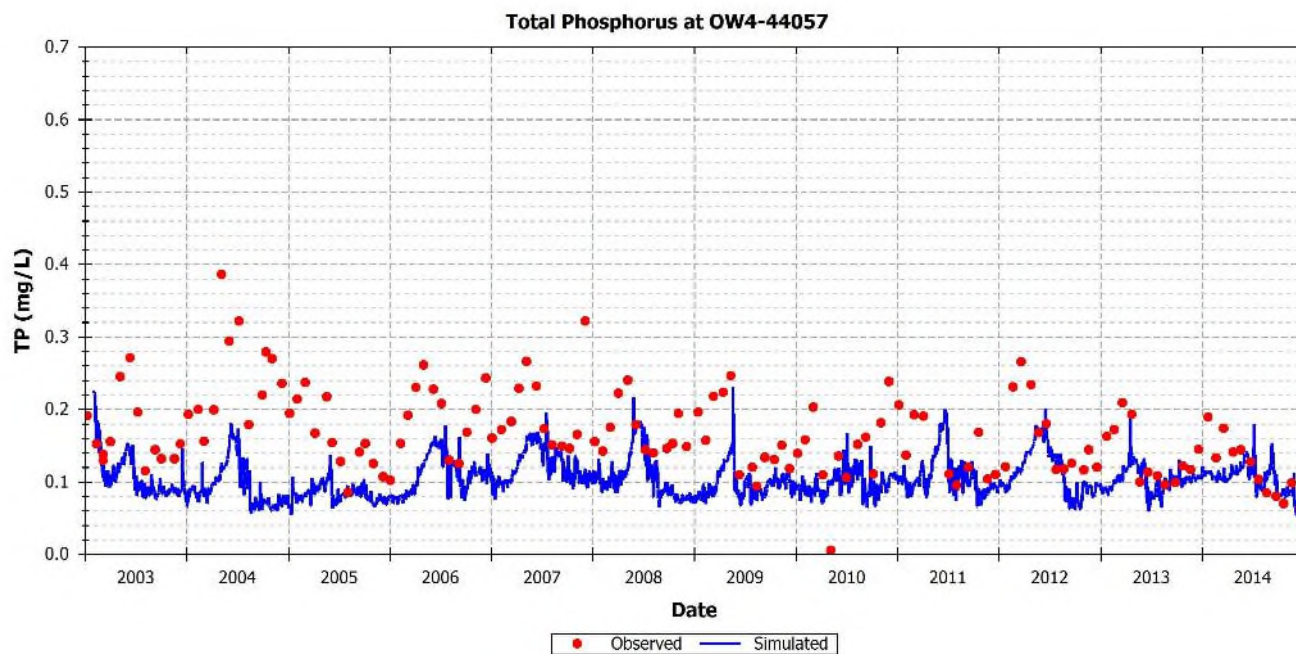


FIGURE C-27: TP SIMULATION FOR STATION OW4, 44057

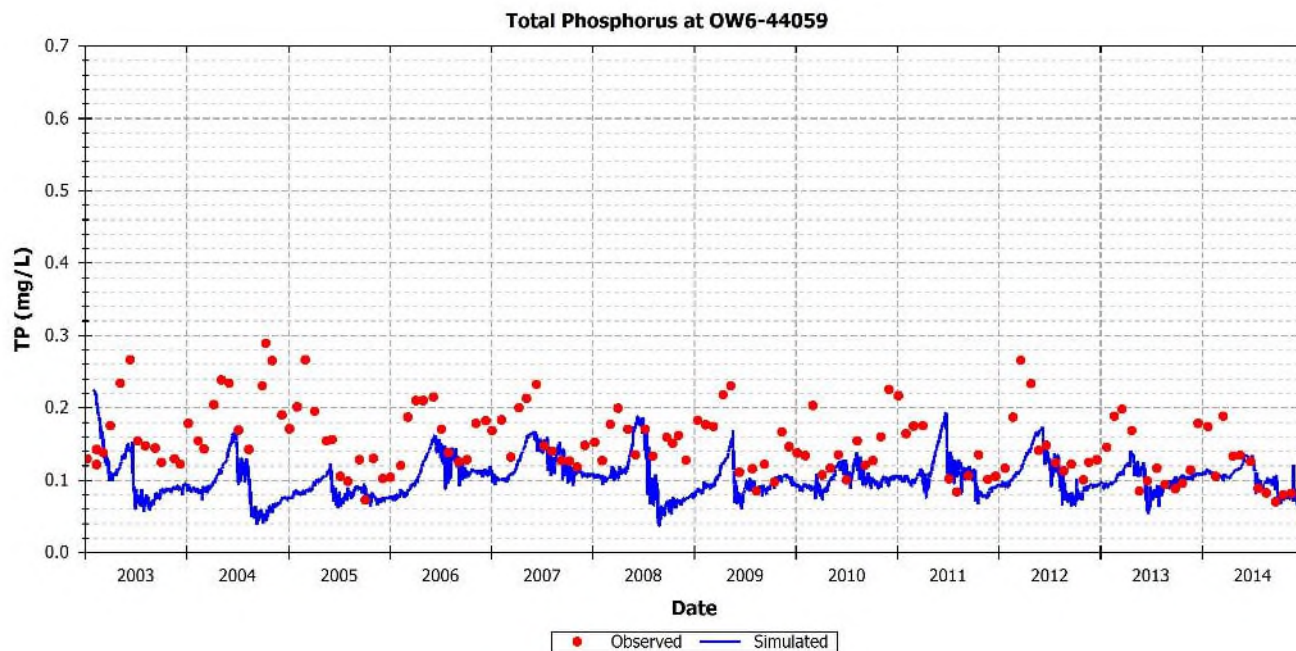


FIGURE C-28: TP SIMULATION FOR STATION OW6, 44059

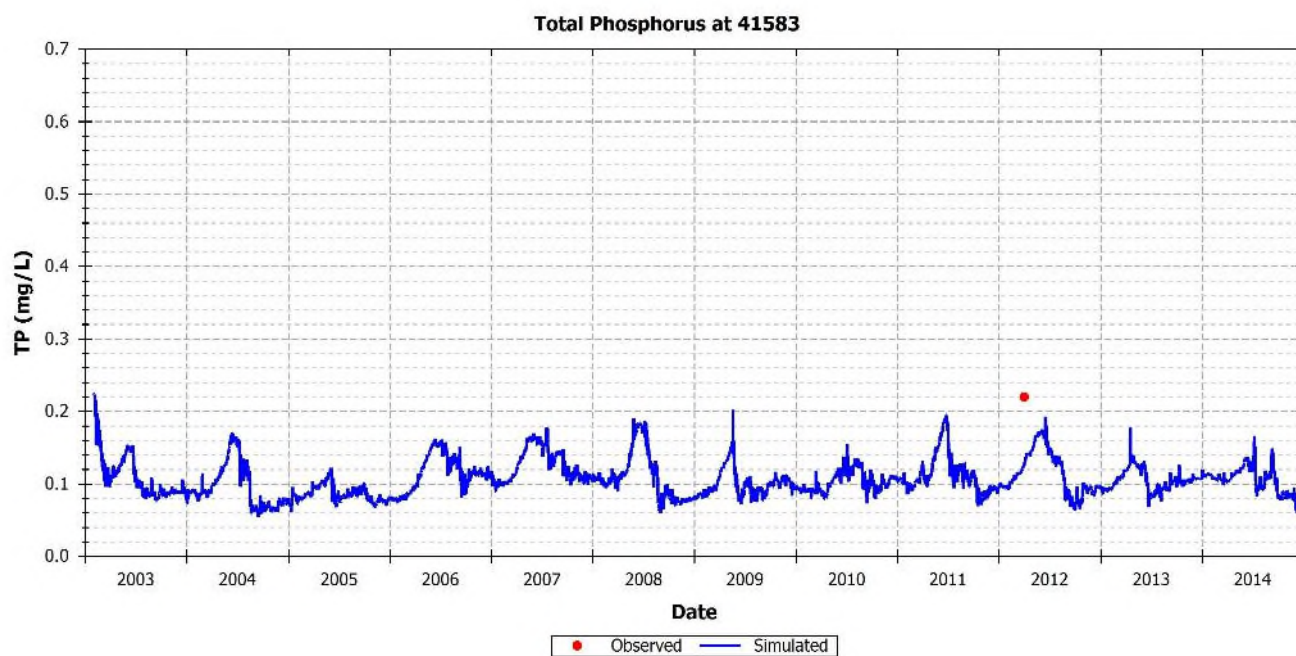


FIGURE C-29: TP SIMULATION FOR STATION 41583

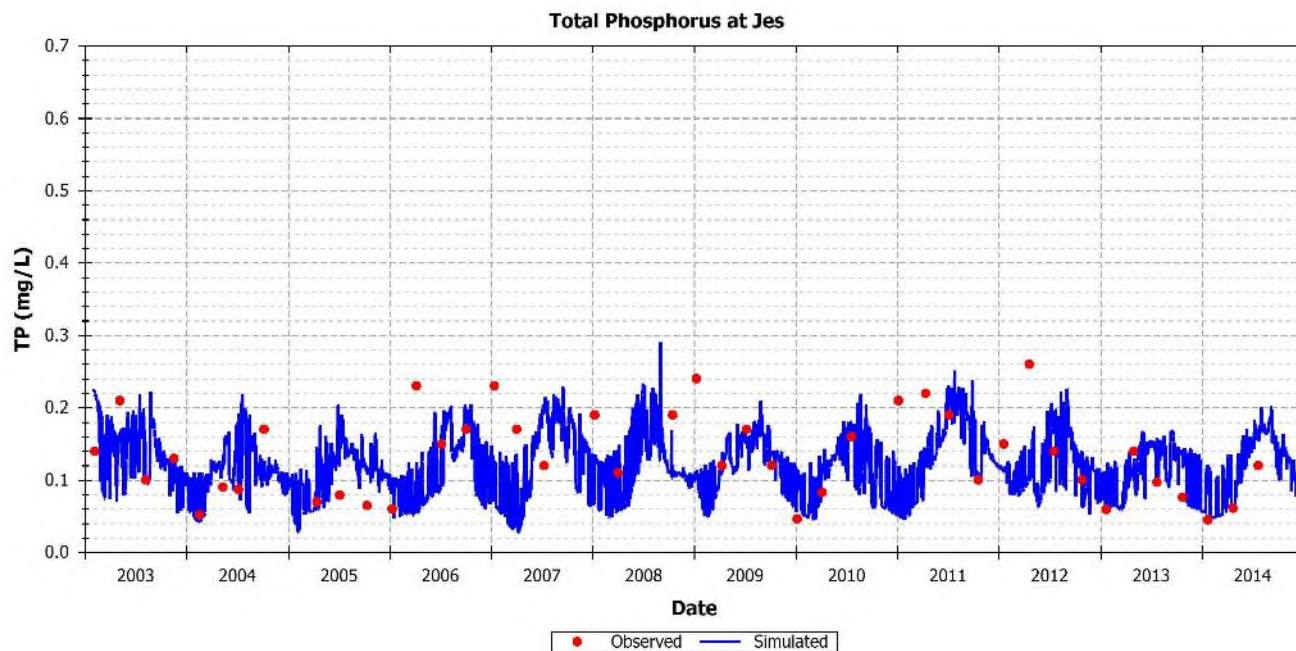


FIGURE C-30: TP SIMULATION FOR STATION JES

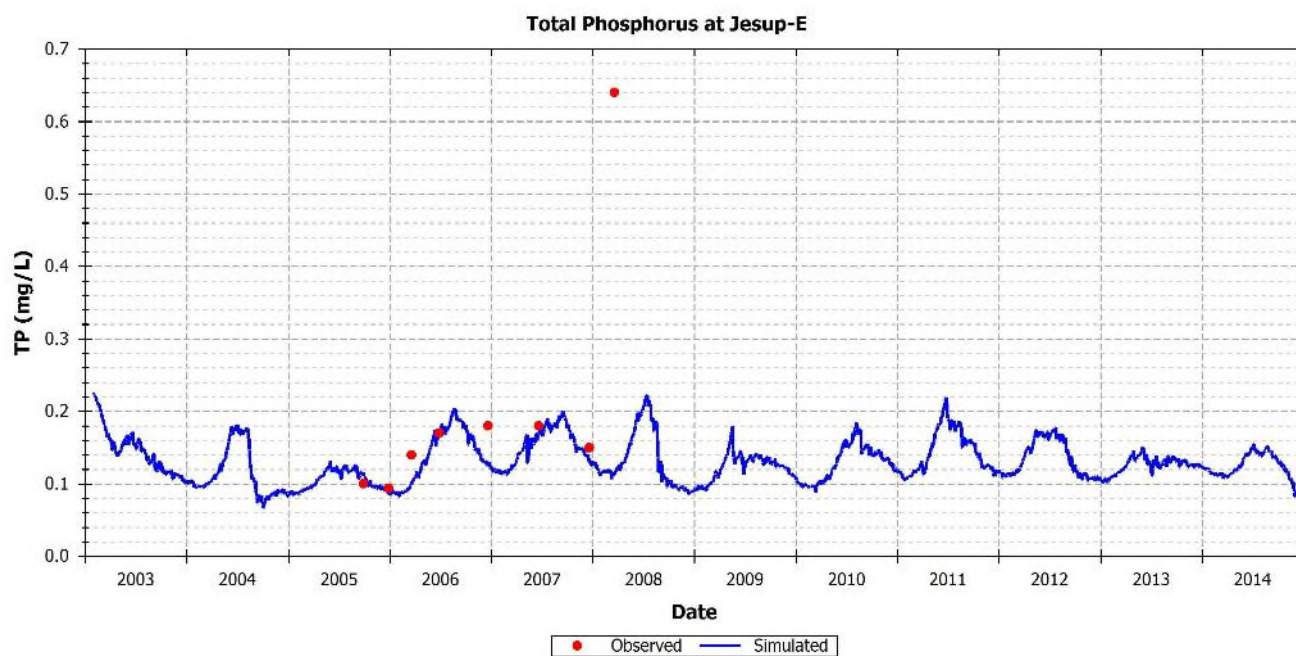


FIGURE C-31: TP SIMULATION FOR STATION JESUP-E

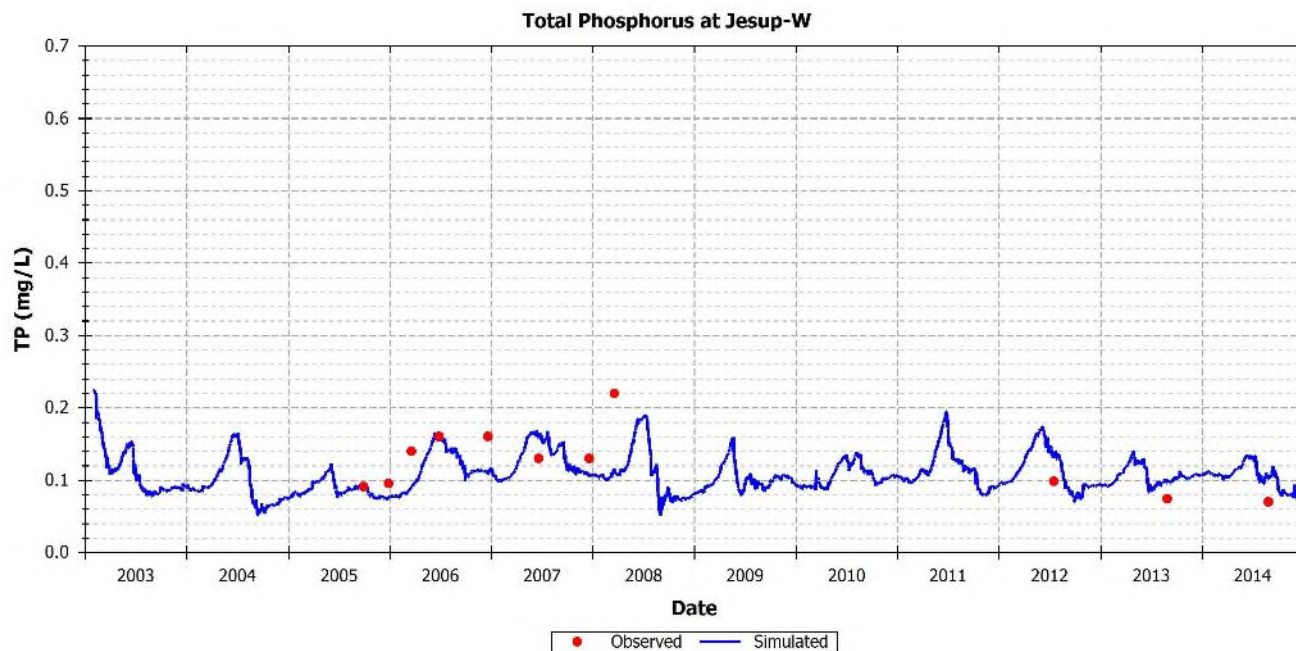


FIGURE C-32: TP SIMULATION FOR STATION JESUP-W

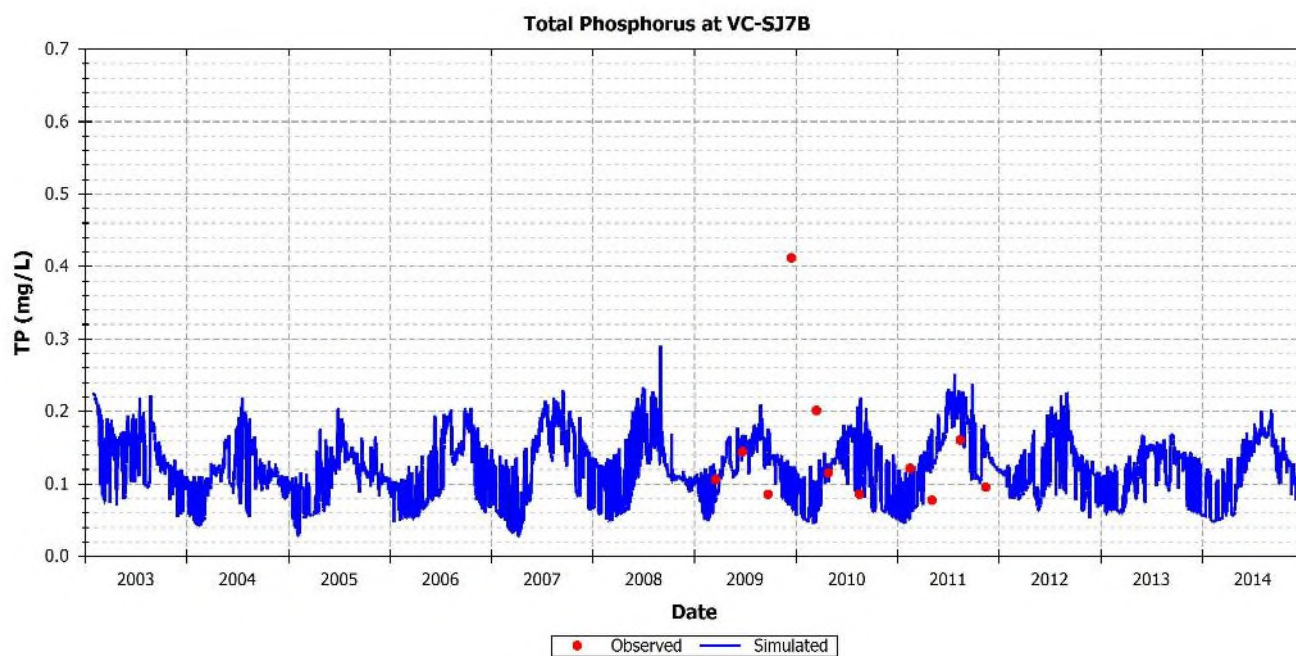


FIGURE C-33: TP SIMULATION FOR STATION VC-SJ7B

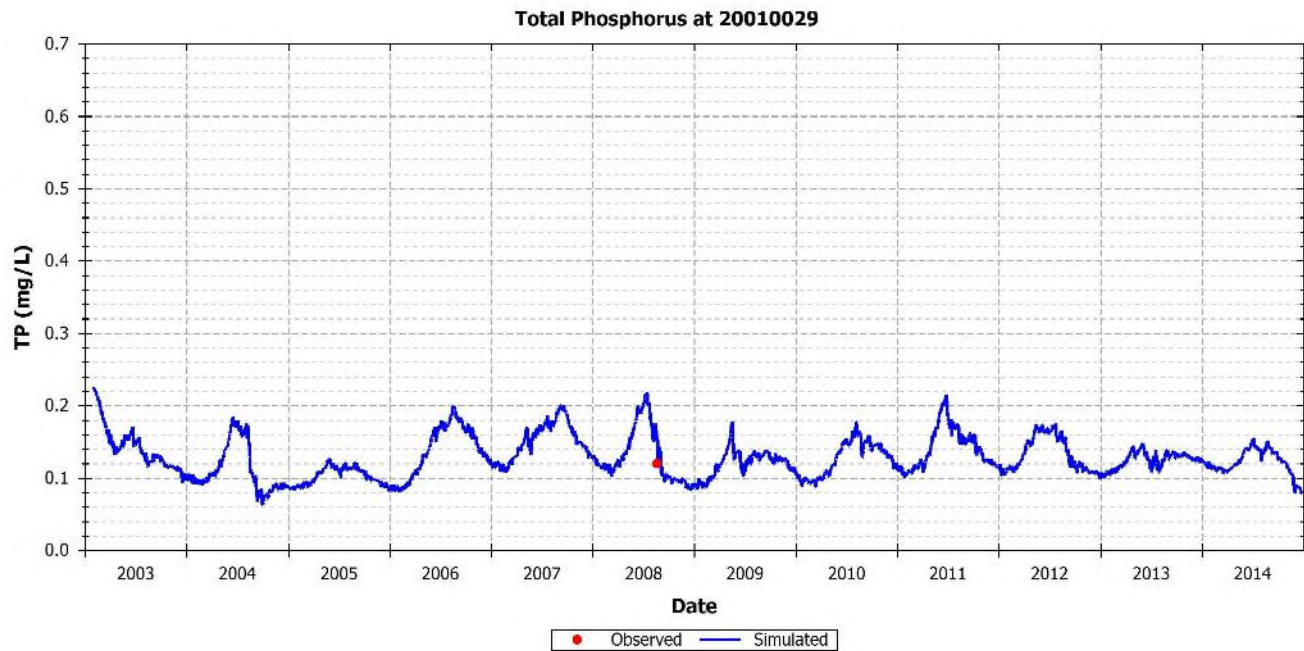


FIGURE C-34: TP SIMULATION FOR STATION 20010029

TN RESULTS

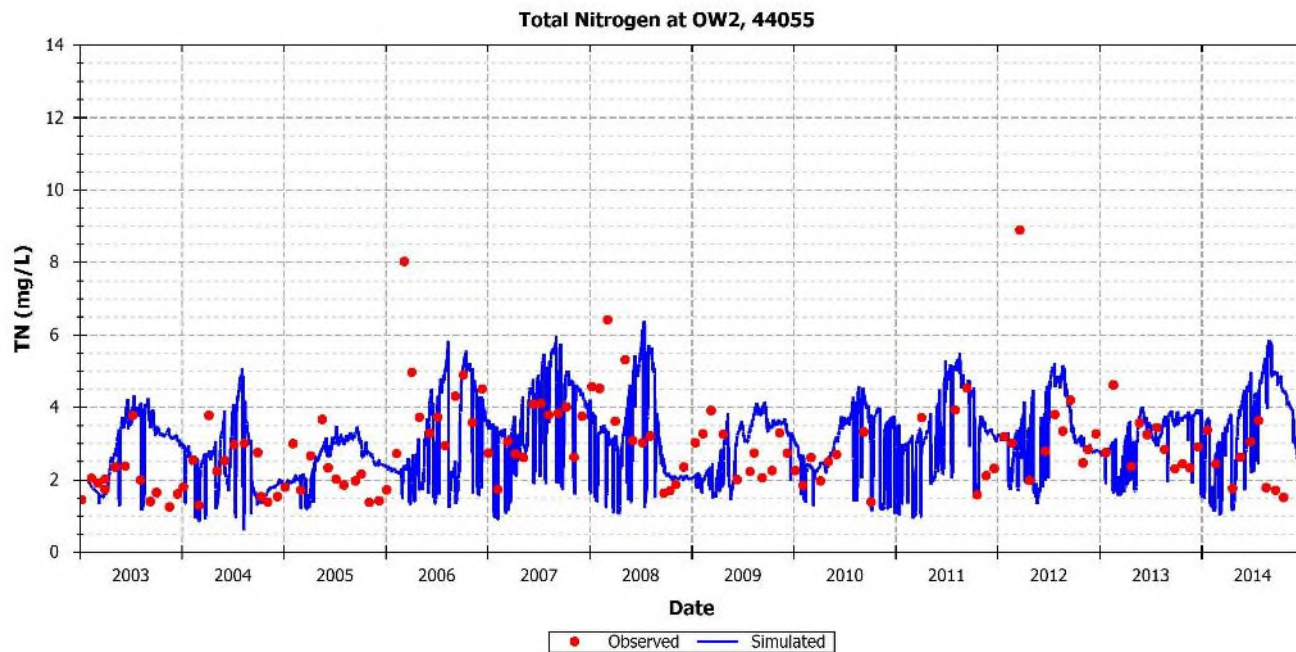


FIGURE C-35: TN SIMULATION FOR STATION OW2, 44055

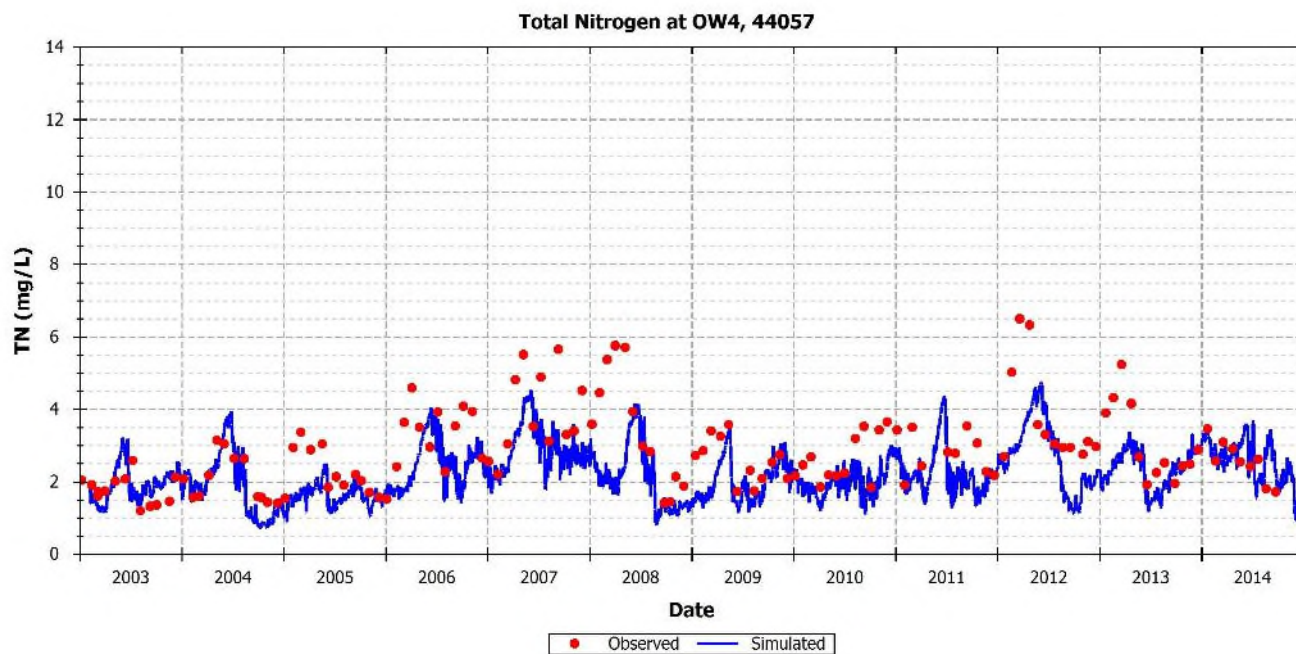


FIGURE C-36: TN SIMULATION FOR STATION OW4, 44057

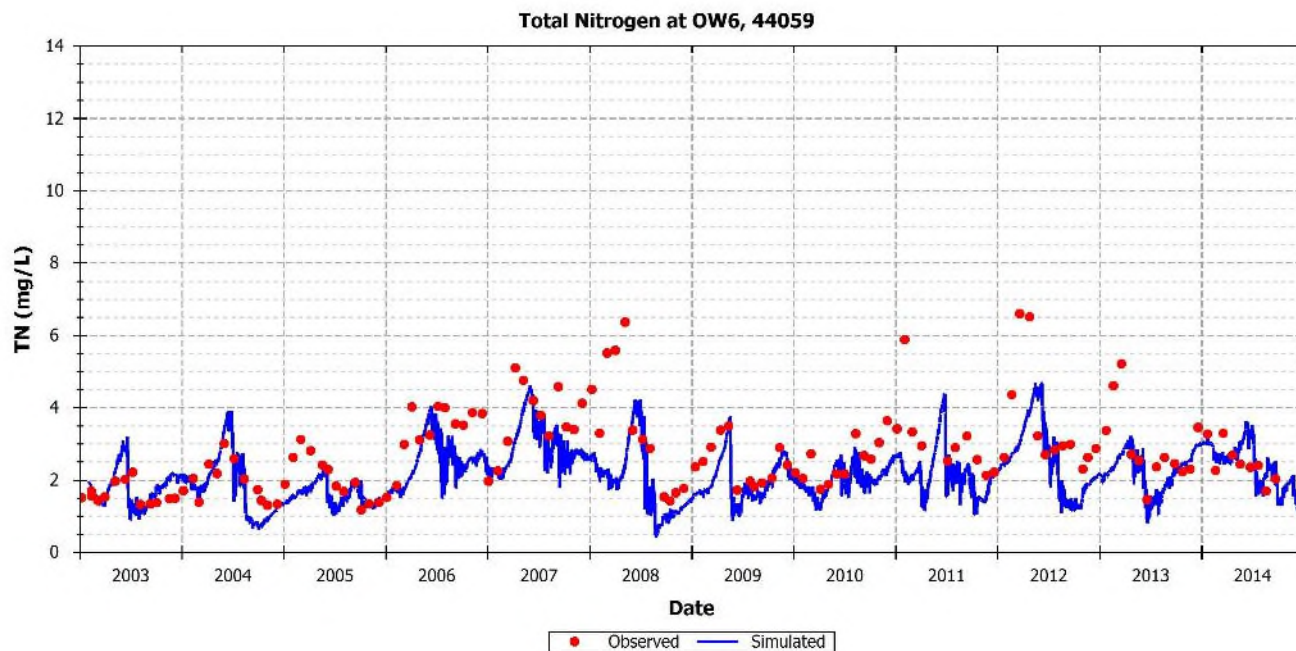


FIGURE C-37: TN SIMULATION FOR STATION OW6, 44059

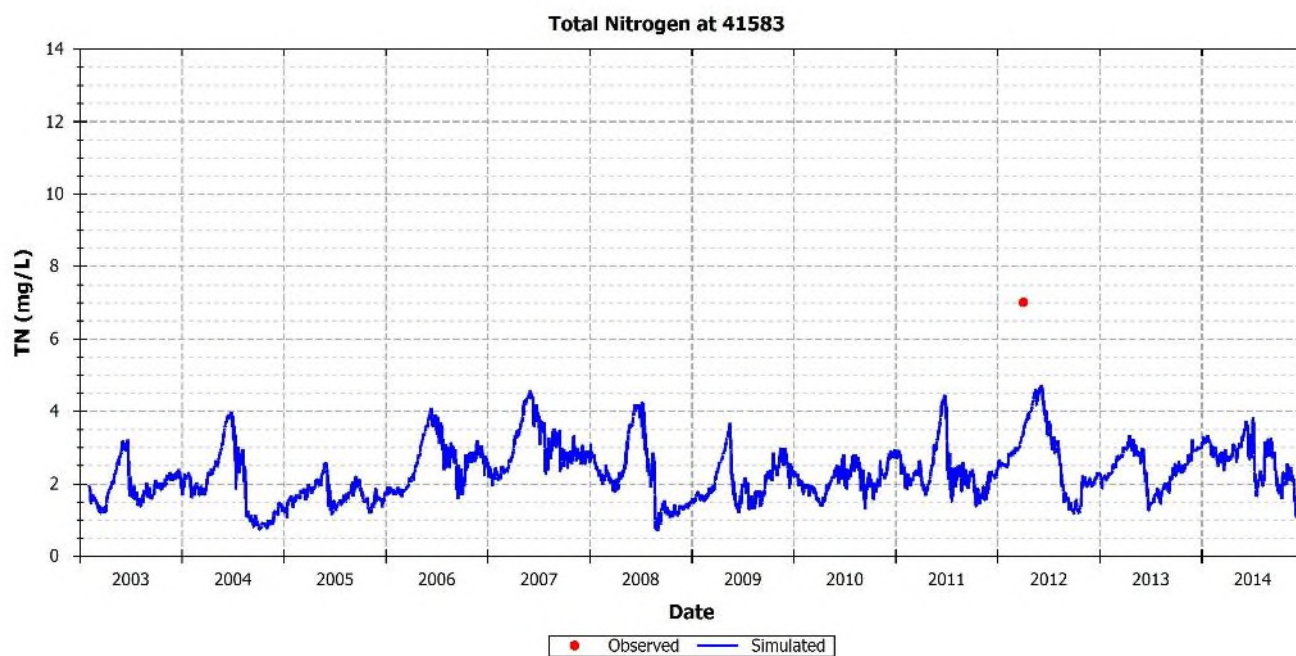


FIGURE C-38: TN SIMULATION FOR STATION 41583

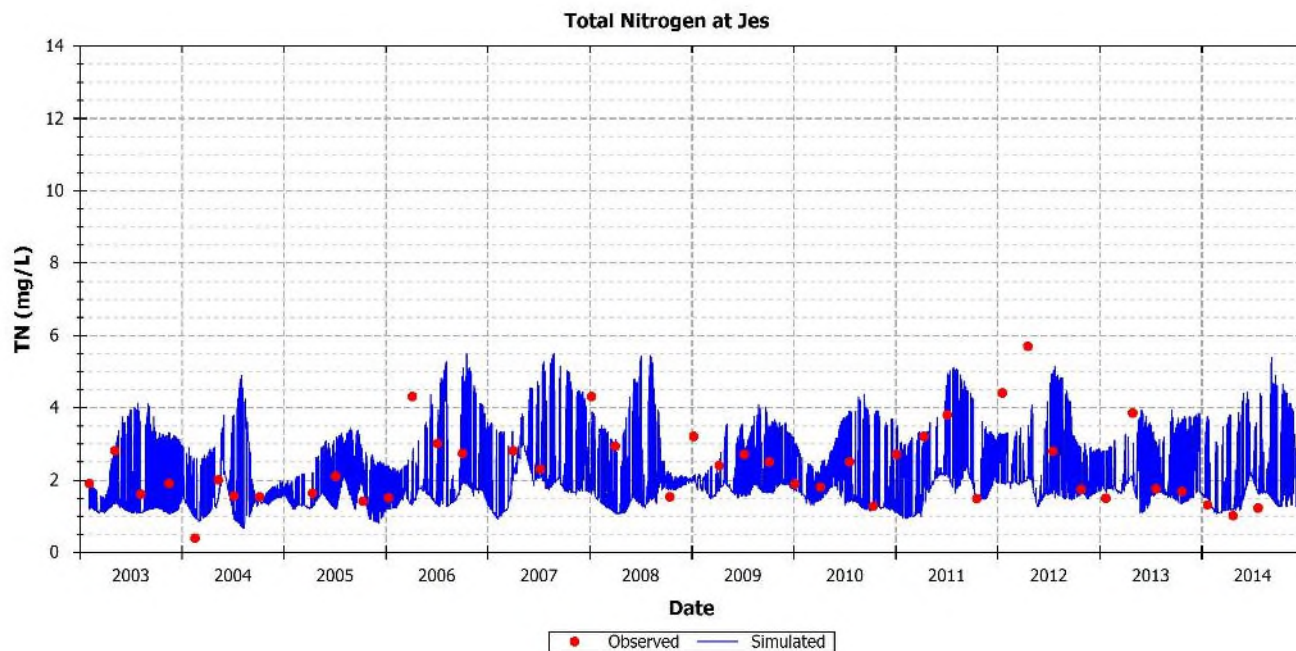


FIGURE C-39: TN SIMULATION FOR STATION JES

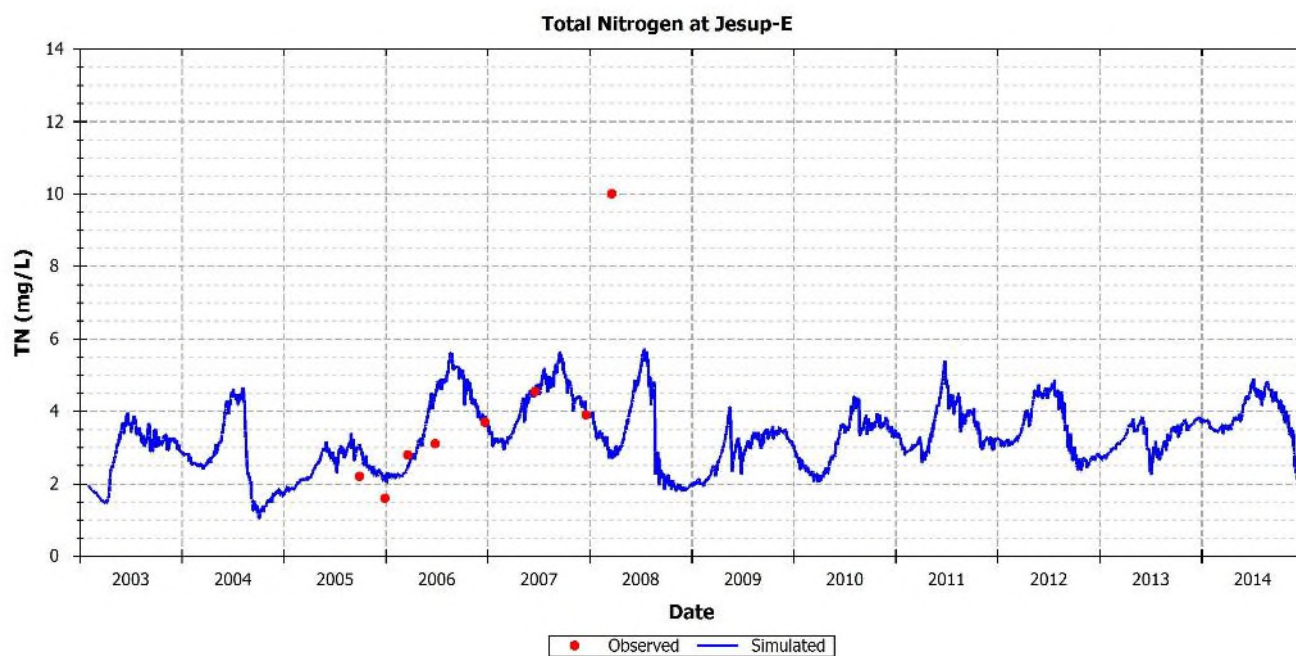


FIGURE C-40: TN SIMULATION FOR STATION JESUP-E

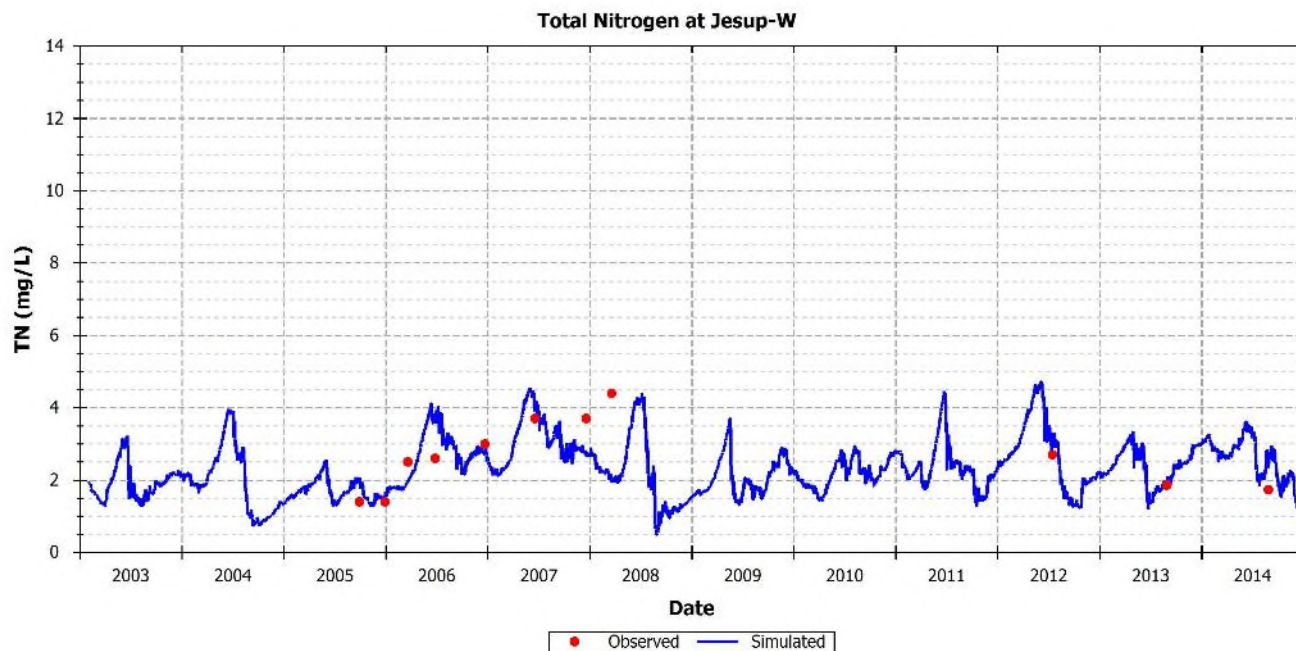


FIGURE C-41: TN SIMULATION FOR STATION JESUP-W

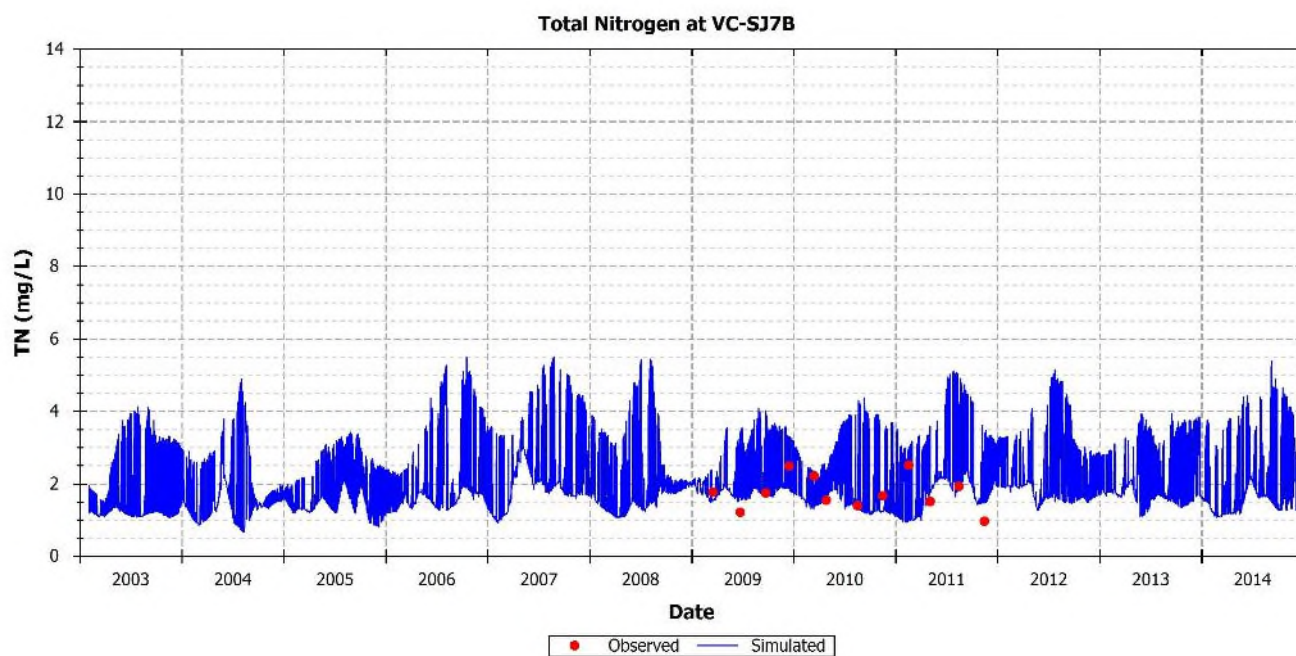


FIGURE C-42: TN SIMULATION FOR STATION VC-SJ7B

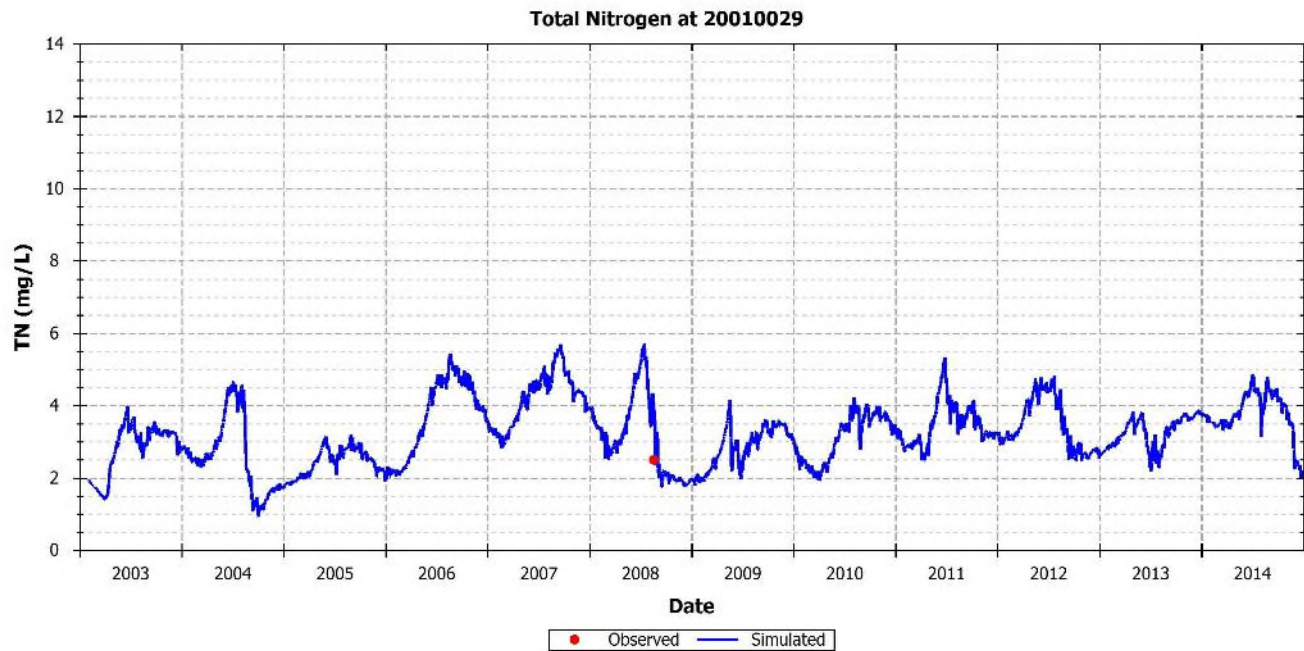


FIGURE C-43: TN SIMULATION FOR STATION 20010029

TSS RESULTS

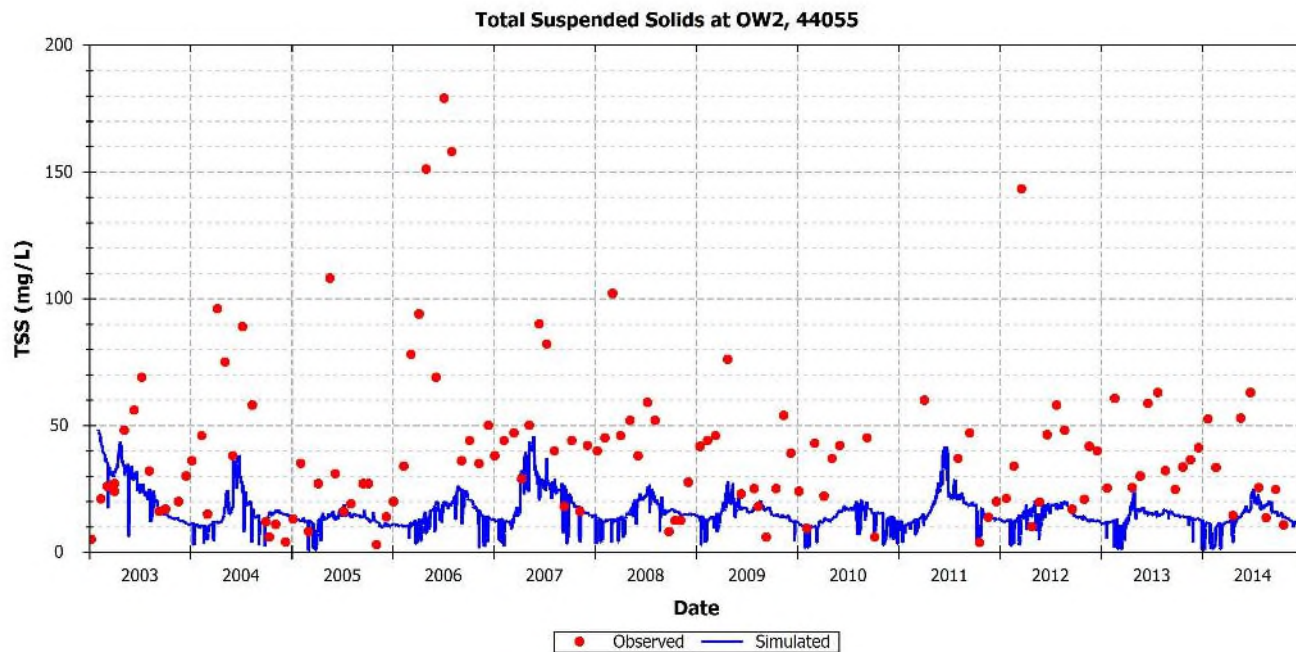


FIGURE C-44: TSS SIMULATION FOR STATION OW2, 44055

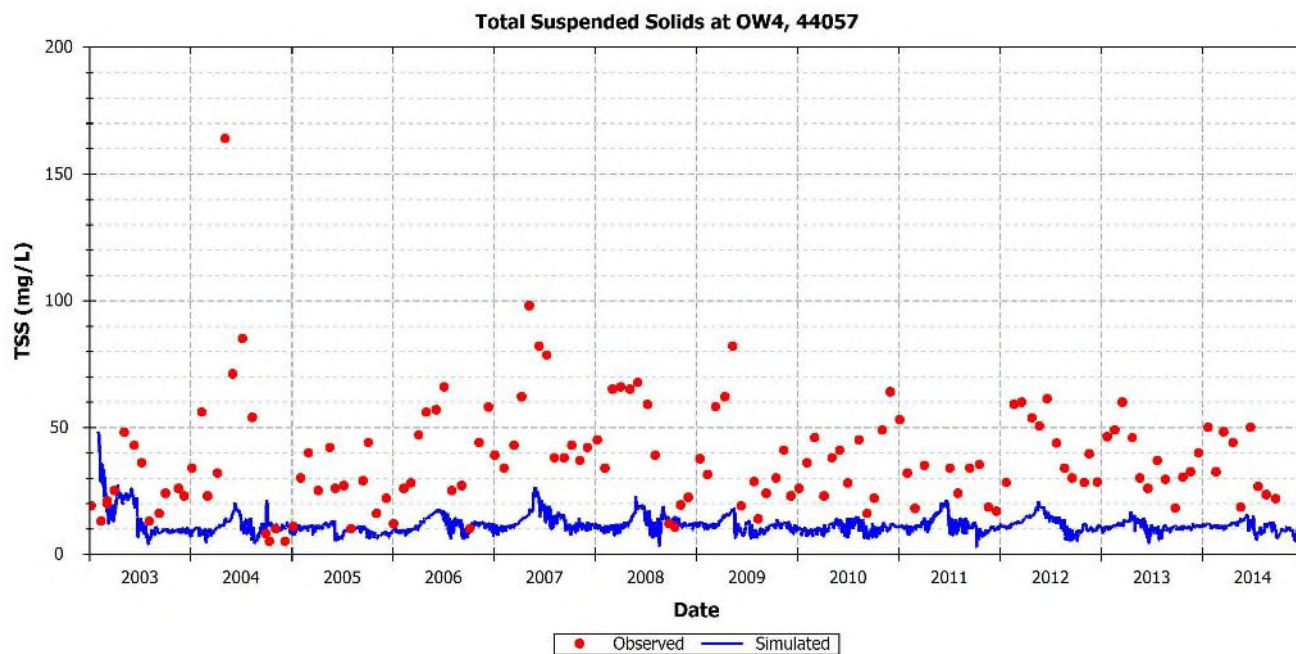


FIGURE C-45: TSS SIMULATION FOR STATION OW4, 44057

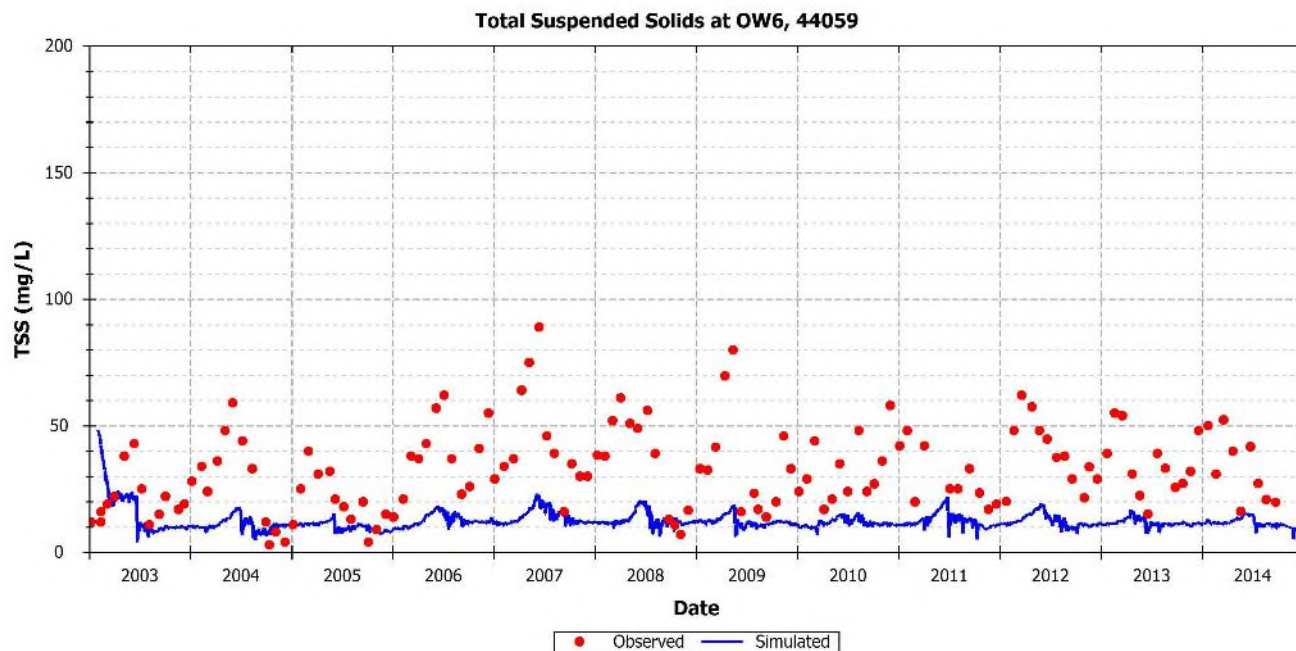


FIGURE C-46: TSS SIMULATION FOR STATION OW6, 44059

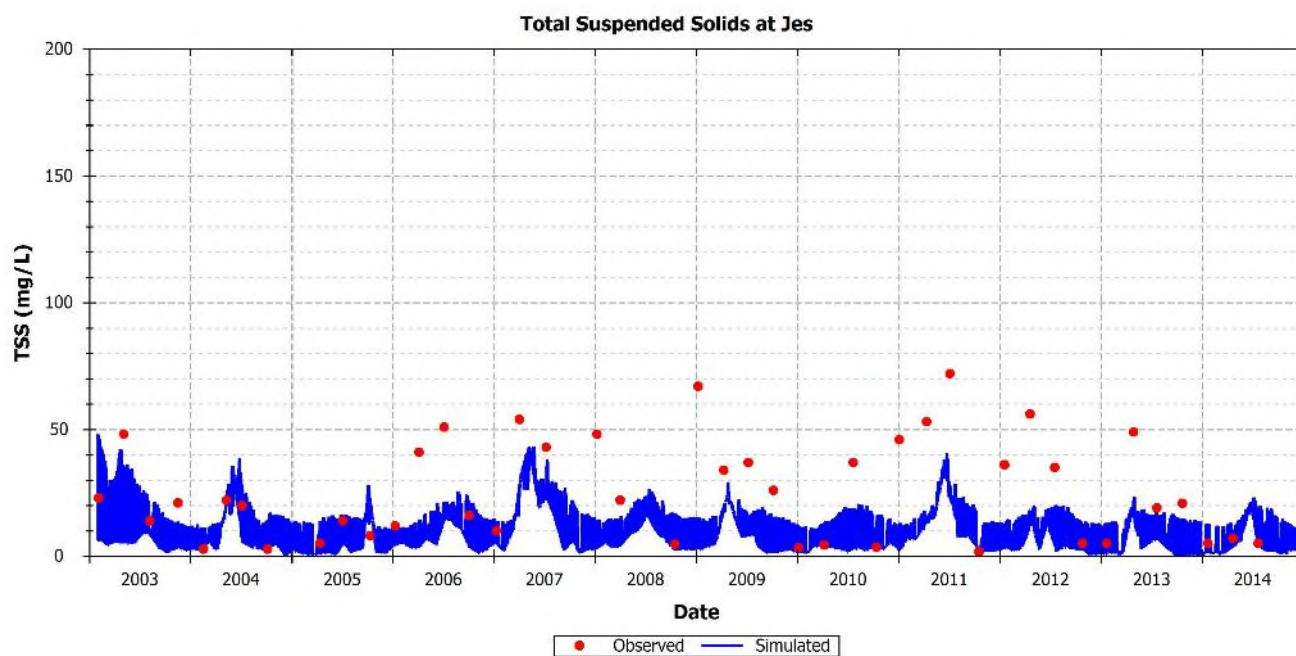


FIGURE C-47: TSS SIMULATION FOR STATION JES

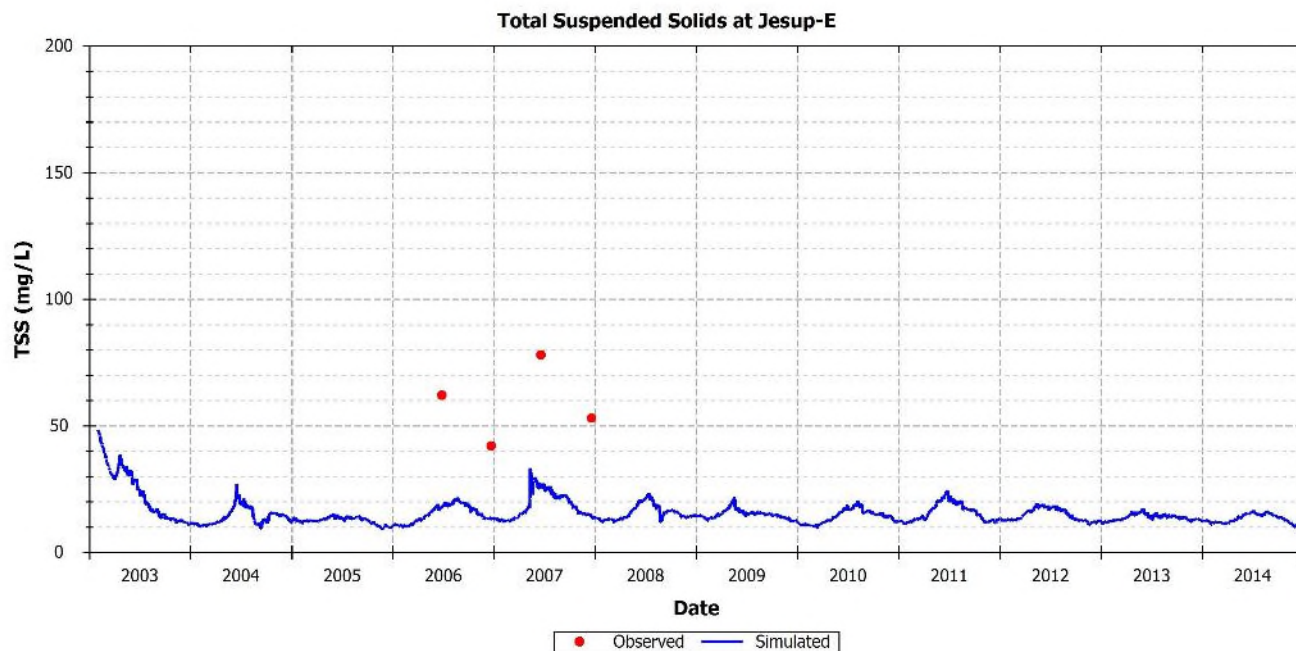


FIGURE C-48: TSS SIMULATION FOR STATION JESUP-E

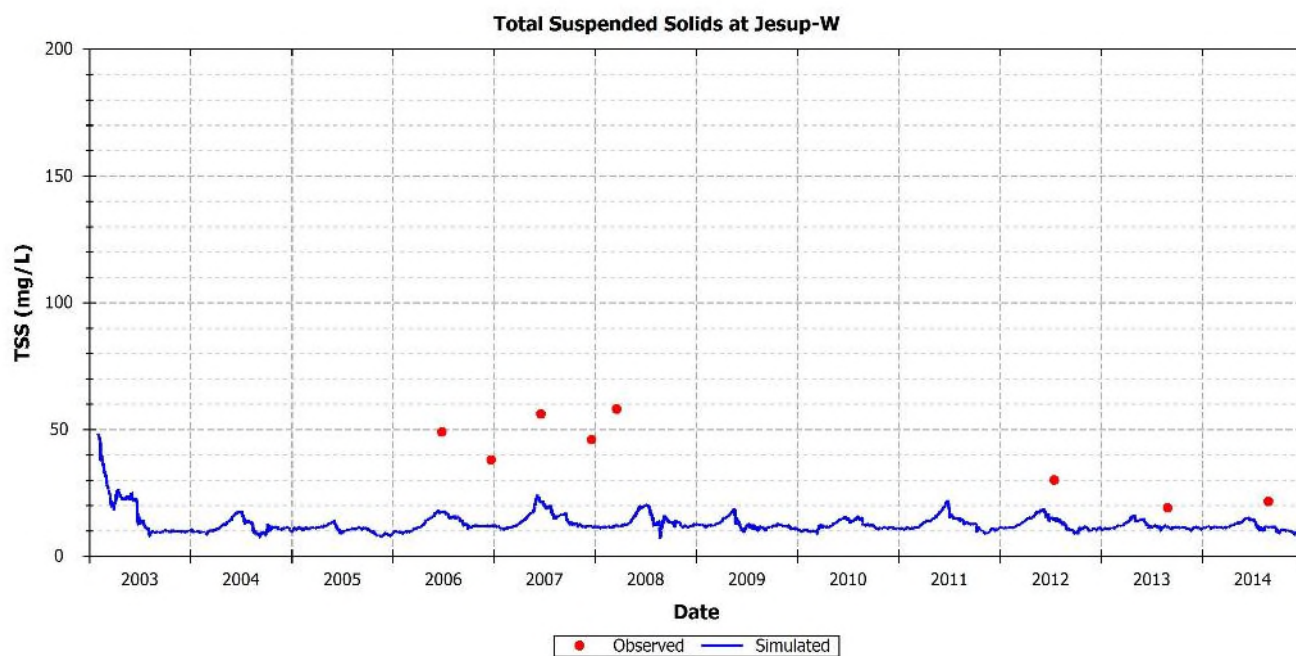


FIGURE C-49: TSS SIMULATION FOR STATION JESUP-W

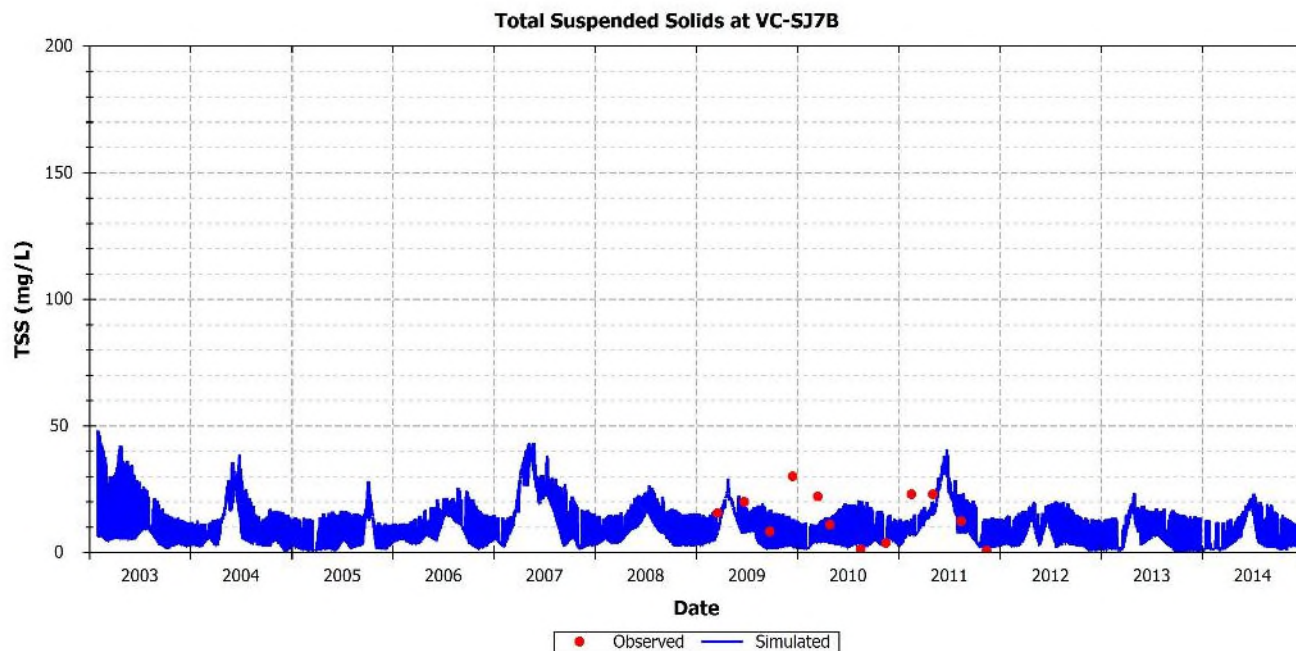


FIGURE C-50: TSS SIMULATION FOR STATION VC-SJ7B

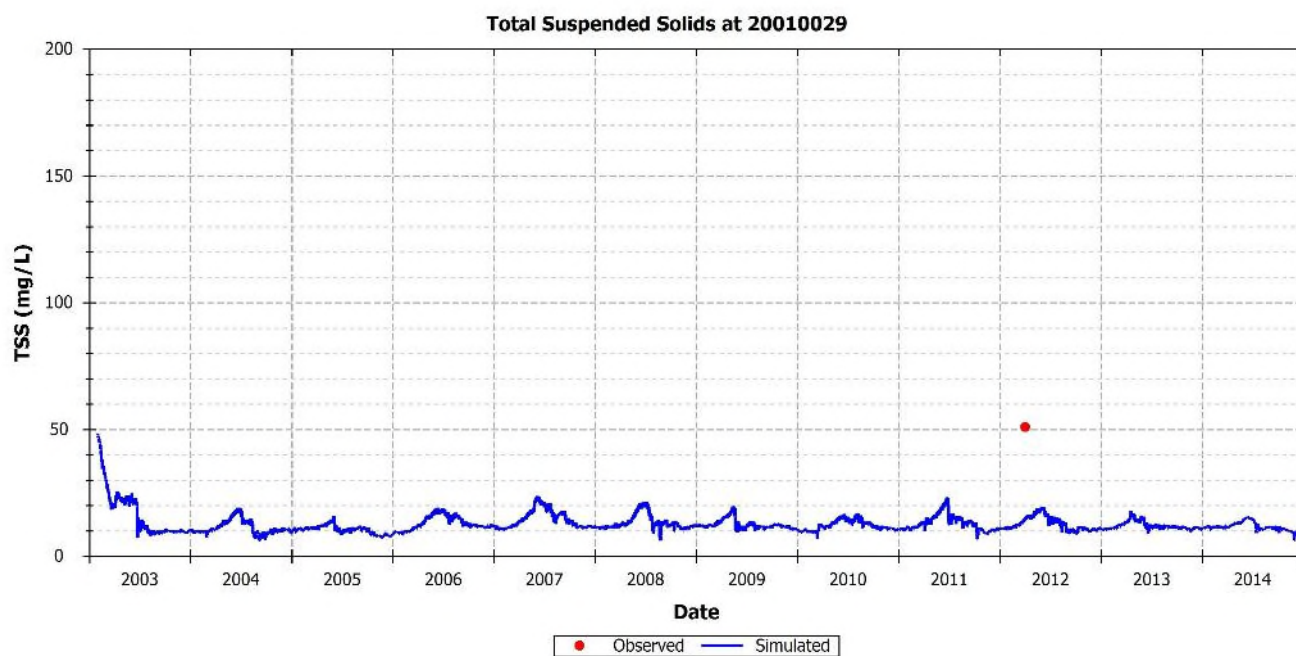


FIGURE C-51: TSS SIMULATION FOR STATION 20010029

APPENDIX D: SJRWMD HSPF MODELING REPORT

Hydrologic and Water Quality Modeling of the Lake Jesup Watershed

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March 31, 2015

Certified as to the hydrology
and water quality modeling of
the Lake Jesup watershed for
the Development of Pollutant
Load Reduction Goals

St. Johns River Water Management District

Palatka, Florida

2015

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1. Project Location and Objective

The Lake Jesup watershed is a sub-basin of the Middle St. Johns River Basin located in Seminole County, Florida, including a small portion of Orange County (Figure 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 itself. Lake Jesup is connected to the St. Johns River through a narrow channel at the northern end of the lake. Lake Jesup is highly eutrophic and is considered impaired due to its elevated nutrient levels. St. Johns River Water Management District is required by the Florida Legislature through Chapter 62-40, Florida Administrative Code to develop Pollutant Load Reduction Goals (PLRGs) for Lake Jesup. The PLRG process will establish the required load reductions in order to restore the designated uses of Lake Jesup. To support the PLRG development, this study develops a Hydrological Simulation Program – FORTRAN (HSPF) model to estimate the loadings of flow and nutrients from the watershed to Lake Jesup under current and pristine conditions. The developed HSPF model is based on the District's previous Lake Jesup watershed HSPF models for the St. Johns River Water Supply Impact Study (Cera et al. 2012) and Lake Jesup PLRG analysis (Jia 2007). The estimated watershed loadings will be used as inputs to the in-lake water quality model for Lake Jesup. In addition, Florida Department of Environmental Protection (FDEP) is currently re-evaluating the Total Maximum Daily Loads (TMDLs) for Lake Jesup originally developed in 2006. The developed HSPF model will be used to estimate the pollutant loadings to Lake Jesup for the TMDL reassessment. In this report, the description of HSPF modeling process and modeling results is organized as follows. Section 2 summarizes the data used for site characterization and HSPF modeling. Section 3 describes the development of HSPF model for hydrologic and water quality simulation of the Lake Jesup watershed. Section 4 presents the modeling results for the current conditions and the pristine conditions. Finally, section 5 summarizes the findings of this study. Graphical comparison between simulated and observed flows and water quality constituents is provided in Appendices A and B. Statistical comparison between simulated and observed water quality constituents is provided in Appendix C. Appendix D compares the estimated watershed loadings in this study with those from the previous Lake Jesup watershed HSPF water quality model developed in 2007 (Jia 2007).

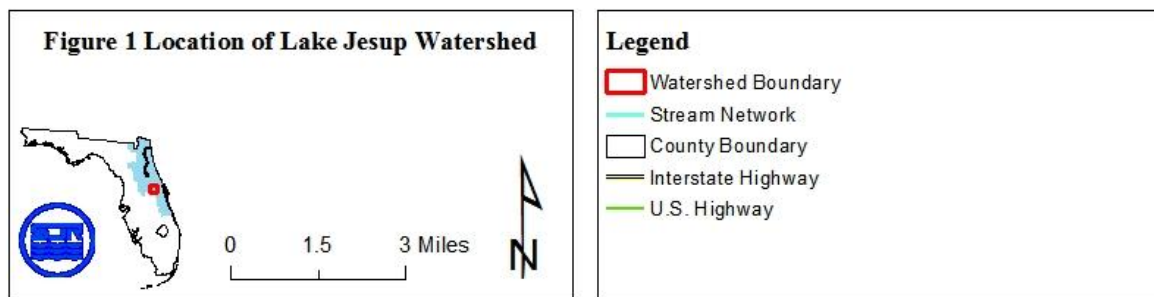
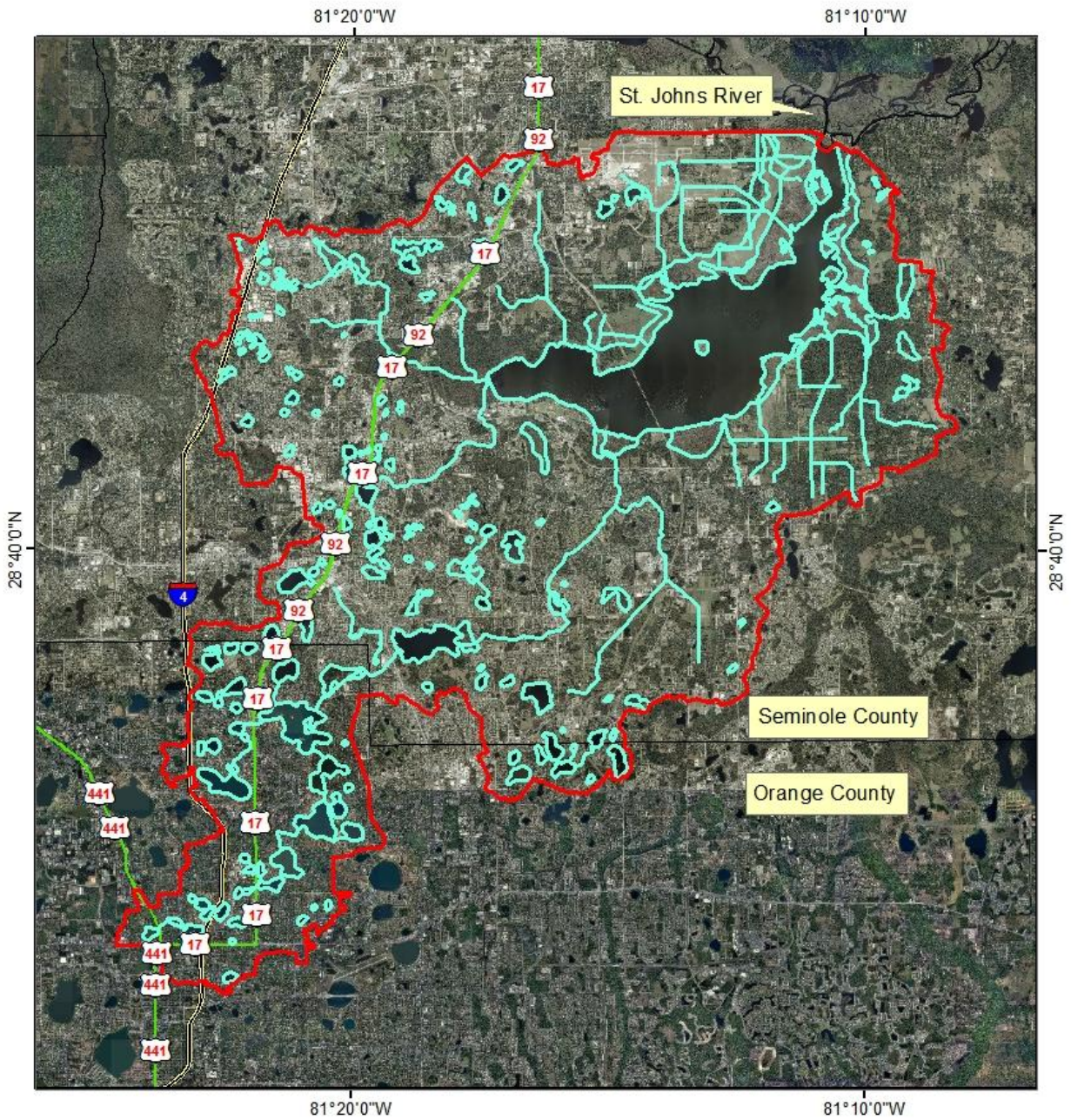


Figure 1 Location of Lake Jesup watershed

2. Data Collection and Evaluation

Various types of data are collected for HSPF watershed modeling, including elevation, land use, soil, regional storm water master plans, aerial photography, meteorological, stage, flow, and water quality data, and the results from the District's previous hydrologic and water quality models.

2.1 Drainage Area Delineation

The Lake Jesup watershed is divided into 39 subwatersheds (Figure 2). 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), and Lake Jesup (subwatershed 39), as shown in Figure 2. 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 hydrodynamic and water quality processes in Lake Jesup will be modeled by the District in a separate study. To differentiate Lake Jesup from its adjacent drainage areas, the areas covered by the District's in-lake model grid are cut out from subwatershed 39 and only the remaining areas are modeled.

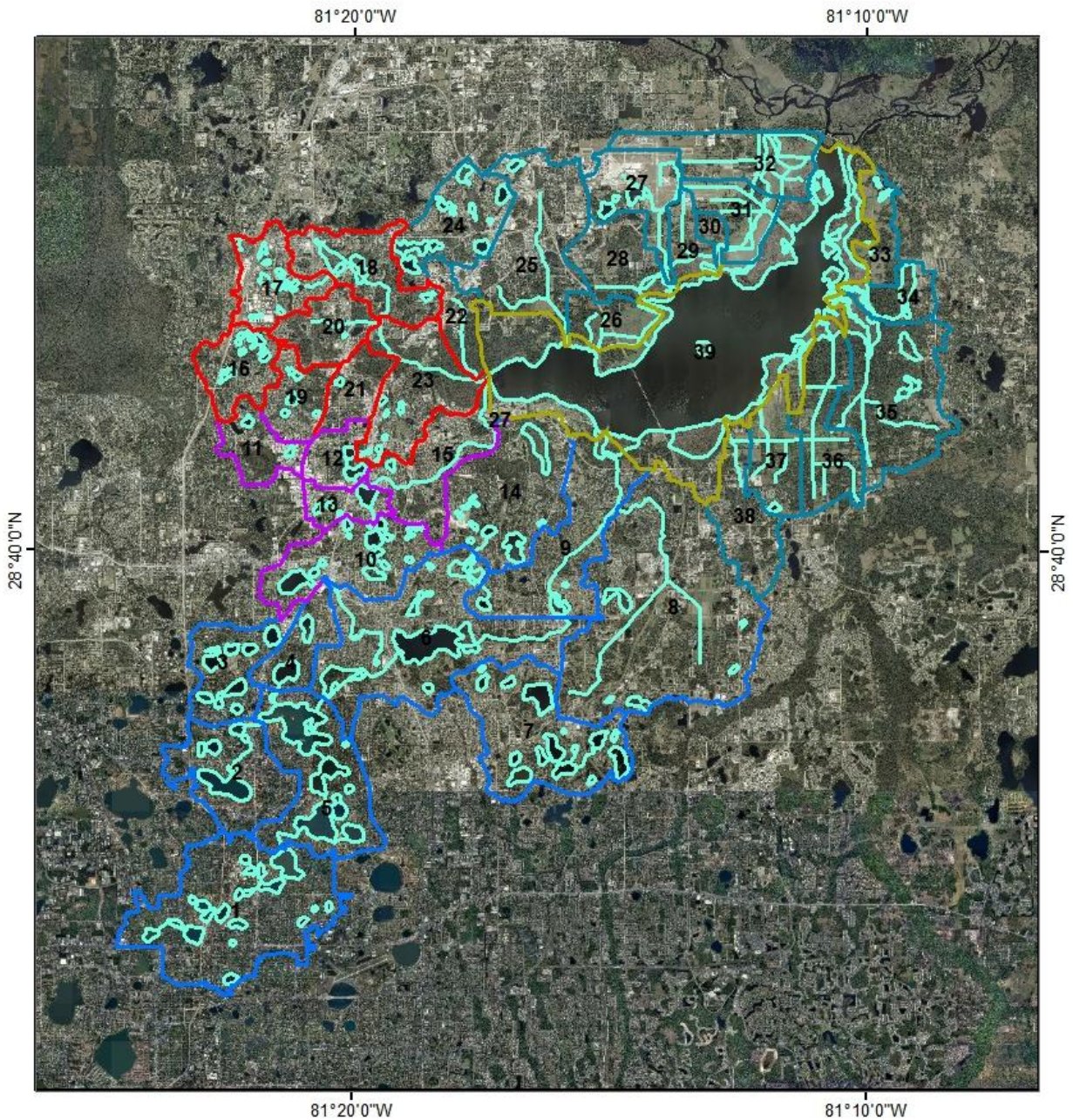


Figure 2 Subwatersheds and major subbasins in the Lake Jesup watershed

2.2 Land Use

The District's 2009 land use and land cover map is used in this study. There are 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 HSPF land use grouping method developed for the St. Johns River Water Supply Impact Study (Cera et al. 2012). Consolidation of the FLUCCS land use classes is mainly based on similarities in hydrologic properties and nutrient loads. Table 1 and Figure 3 show the distribution of these aggregated land uses in the Lake Jesup watershed.

To better represent the impact of wetlands on drainage patterns in the watershed, the wetland land use category is split into two subgroups depending on whether wetlands are riparian (adjacent to streams or lakes) or non-riparian. Figure 4 shows the spatial distribution of riparian and nonriparian wetlands. The areas that drain to nonriparian wetlands are also shown in the map. The surface runoff from these areas will be routed first to the non-riparian wetlands and then to the downstream streams or lakes. The baseflow from these areas will be routed to the downstream streams or lakes directly.

For water quality simulation, the wetland land use could be further divided based on their water quality loading characteristics. In the initial Lake Jesup TMDL study (Gao 2006), wetlands were divided into two categories: impacted and pristine wetlands. The assigned total phosphorus (TP) event mean concentration (EMC) for the impacted wetlands was 50% higher than that for the pristine wetlands. The FDEP's wetland map is reviewed and compared with the wetland map in this study. It shows the impacted wetlands identified by FDEP are mostly overlapped with the riparian wetlands in subwatersheds 14, 26, 30, 31, and 32. Therefore, the HSPF TP loadings parameters for the riparian wetlands in these subwatersheds are adjusted to ensure that the TP loadings from these impacted wetlands are roughly 50% higher than the averaged TP loadings of the riparian wetlands from other subwatersheds.

Table 1 Distribution of the consolidated land uses in the Lake Jesup watershed

Land Use	Acreage	Percent of the Study Area
Low Density Residential (LDR)	5218.2	5.8
Medium Density Residential (MDR)	23432.0	26.0
High Density Residential (HDR)	5431.5	6.0
Industrial and Commercial (IND)	14177.0	15.8
Mining (MIN)	29.2	0.0
Open Land (OPE)	1160.6	1.3
Pasture (PAS)	2770.7	3.1
Agriculture General (AGG)	3135.6	3.5
Agriculture Tree Crop (AGT)	740.8	0.8
Rangeland (RAN)	1439.6	1.6
Forest (FOR)	5323.9	5.9
Water (WAT)	6216.4	6.9
Wetland (WET)	20875.3	23.2
Sum	89950.6	100.0

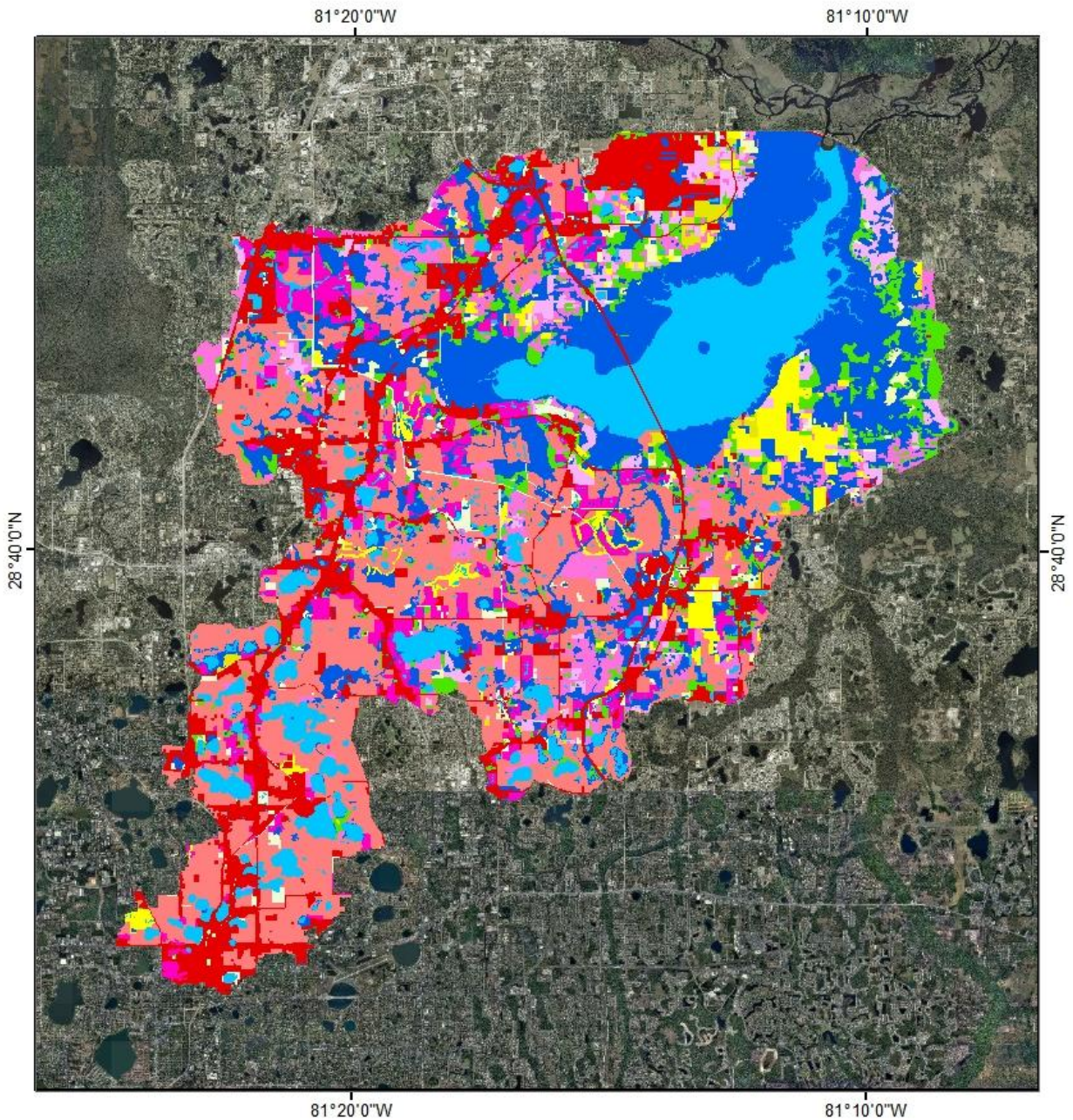


Figure 3 Land Uses in the Lake Jesup Watershed



Figure 3 Consolidated land uses in the Lake Jesup watershed

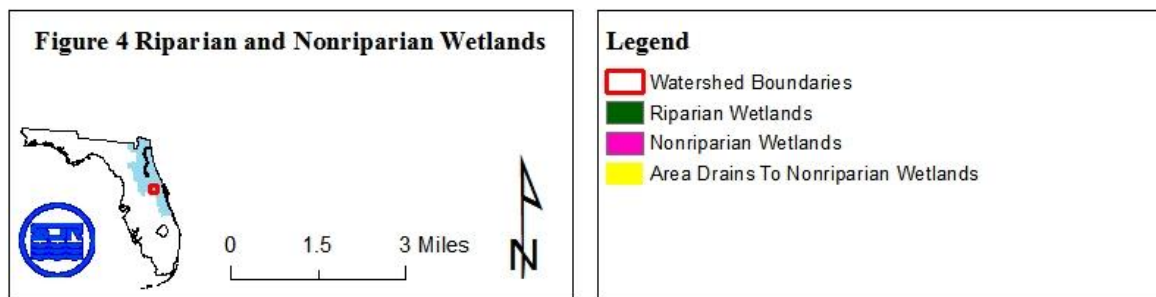
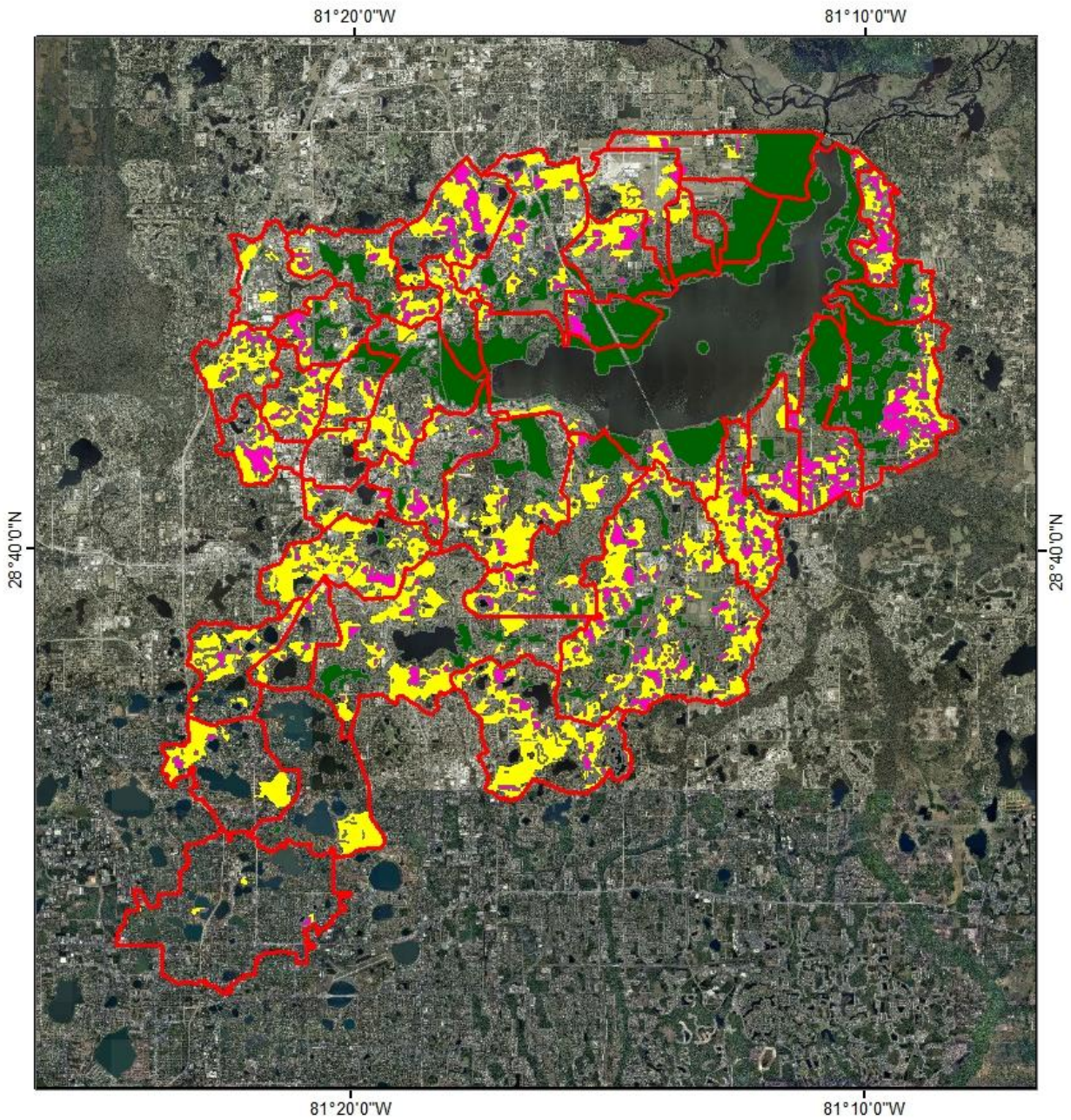


Figure 4 Riparian and nonriparian wetlands

2.3 Best Management Practices

Information on Best Management Practices (BMPs) in the Lake Jesup watershed is based on two BMP maps obtained from FDEP. One map was developed for the development of initial TMDLs for Lake Jesup in 2006. The other map is developed by FDEP during the Basin Management Action Plan (BMAP) process to implementing the adopted TMDLs for Lake Jesup. It is an update to the 2006 BMP map and includes the newly implemented BMPs from 2006 to 2013. Various types of BMPs were identified, including baffle boxes, inlet baskets, continuous deflective separation (CDS), swale, dry detention pond, wet detention pond, Orlando 100% on-site retention, Orlando private BMPs, and lake drainage well. For modeling purposes, these BMPs are grouped into eight categories based on their pollutant removal efficiencies. Table 2 lists the acreage and percentage of watershed area served by each of these BMPs. Figure 5 shows the spatial distribution of BMP treatment areas in the Lake Jesup watershed.

Table 2 Treatment areas served by BMPs in the Lake Jesup watershed

BMP Type	Acreage Served	Percent of the Lake Jesup watershed
Baffle Box, Inlet Basket, CDS	2274.5	2.5
Alum	617.5	0.7
Dry Pond	7945.0	8.8
Dry Pond Treatment Train	452.8	0.5
Swale	443.6	0.5
Wet Pond	12367.3	13.7
Wet Pond Treatment Train	529.5	0.6
Drainage Well, Orlando 100% on-site retention, Orlando private BMPs	2361.4	2.6
Sum	26991.6	30.0

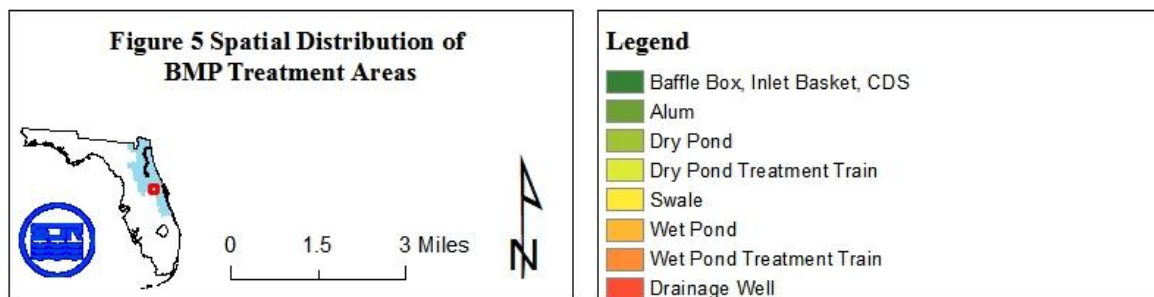
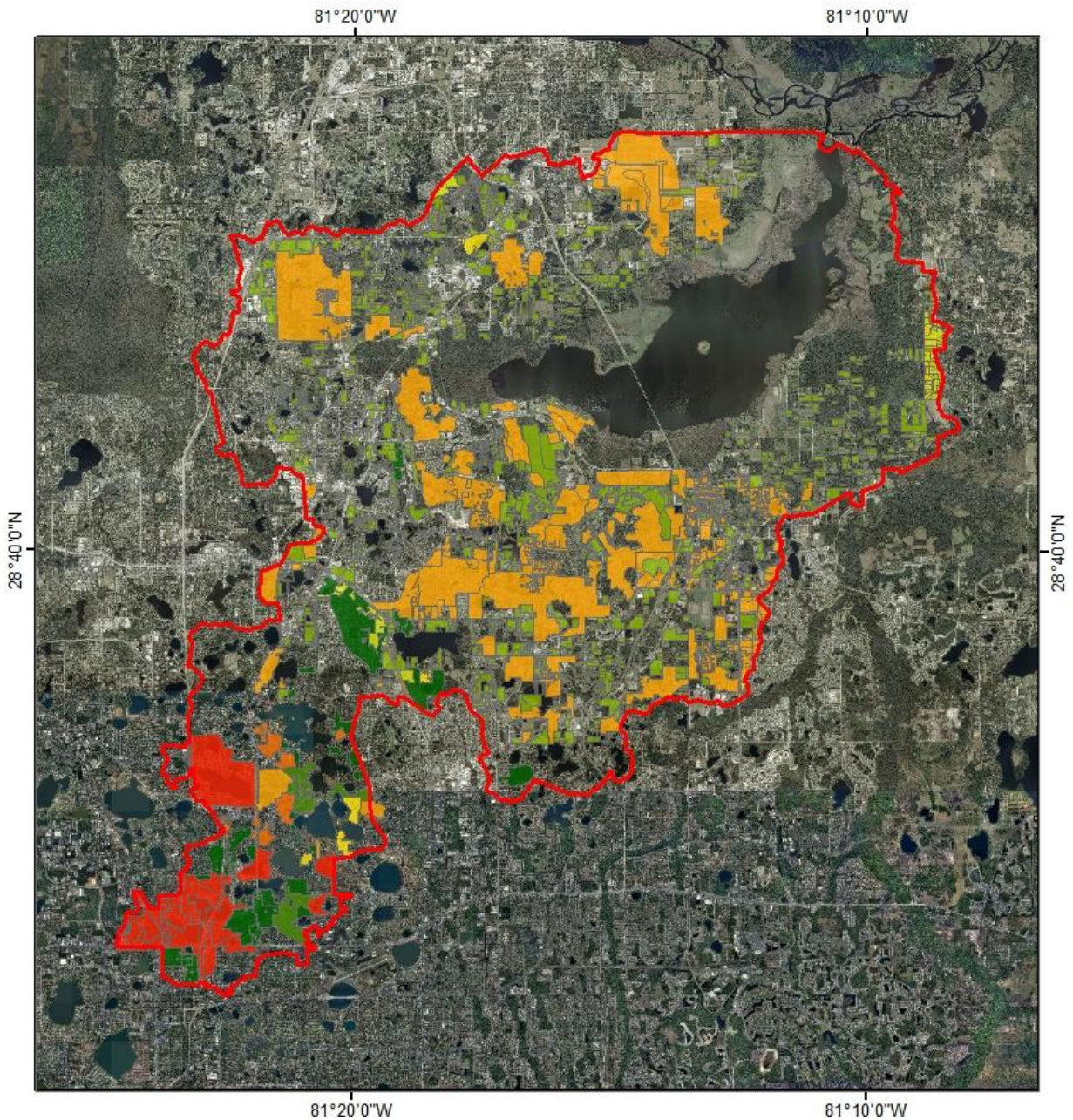


Figure 5 Spatial distribution of BMP treatment areas

2.4 Meteorological Data

Meteorological data required for HSPF modeling include precipitation, potential evaporation, air temperature, wind speed, solar radiation, dew point temperature, and cloud cover. Precipitation data are obtained from the District's NEXRAD Doppler radar rainfall database. The radar rainfall data are collected on a 2×2 km grid and cover the entire SJRWMD area. A GIS tool, Radar Rainfall Tool version 6.0, was developed by the District to calculate the areal weighted radar rainfall. This tool is used in this study to extract the hourly radar rainfall time series for each subwatershed. Potential evapotranspiration data and solar radiation data are from Geostationary Operational Environmental Satellites (GOES) data sets maintained by USGS. The GOES data are daily data and are available in the same grid format as for the District's rainfall data. The District's WHETS tool is used to generate daily potential evaporation and solar radiation time series for each subwatershed in the Lake Jesup watershed. These daily data are disaggregated into hourly data for HSPF modeling using WDMUtil (USEPA 2001), a utility program for managing data for HSPF. Other meteorological data are downloaded from the Integrated Surface Database maintained by National Oceanic and Atmospheric Administration (NOAA). They are point gauge data from the Orland International Airport weather station. Table 3 summarizes the meteorological data used in this study.

Table 3 Meteorological data used for the Lake Jesup watershed HSPF model

Data Type	Data Source	Description
Precipitation	SJRWMD	Doppler 2×2 km radar grid data
Potential Evaporation	USGS	GOES 2×2 km satellite grid data
Solar Radiation	USGS	GOES 2×2 km satellite grid data
Air Temperature	NOAA	Orlando International Airport gauge data
Wind Speed	NOAA	Orlando International Airport gauge data
Dew Point Temperature	NOAA	Orlando International Airport gauge data
Cloud Cover	NOAA	Orlando International Airport gauge data

2.5 Flow and Water Quality Data

Long-term daily flow data have been monitored by USGS at five sites along the main stems of Howell Creek, Gee Creek, and Soldier Creek. The flow data from these sites are directly downloaded from USGS's web site. For water quality calibration, both grab samples and storm water event samples are used. Grab samples are from the District's and Seminole County's stations near the outlets of Howell Creek, Gee Creek, Soldier Creek, Six Mile Creek, Navy Canal, Sweetwater Creek, and Solary Canal. Storm water samples have been collected by Seminole County. They are composite samples collected during storm events. This study uses the summarized storm water sample data sets compiled by ATKINS, Inc. for Seminole County (ATKINS 2014). Figure 6 shows the locations of USGS gauges and water quality sites used for HSPF calibration.

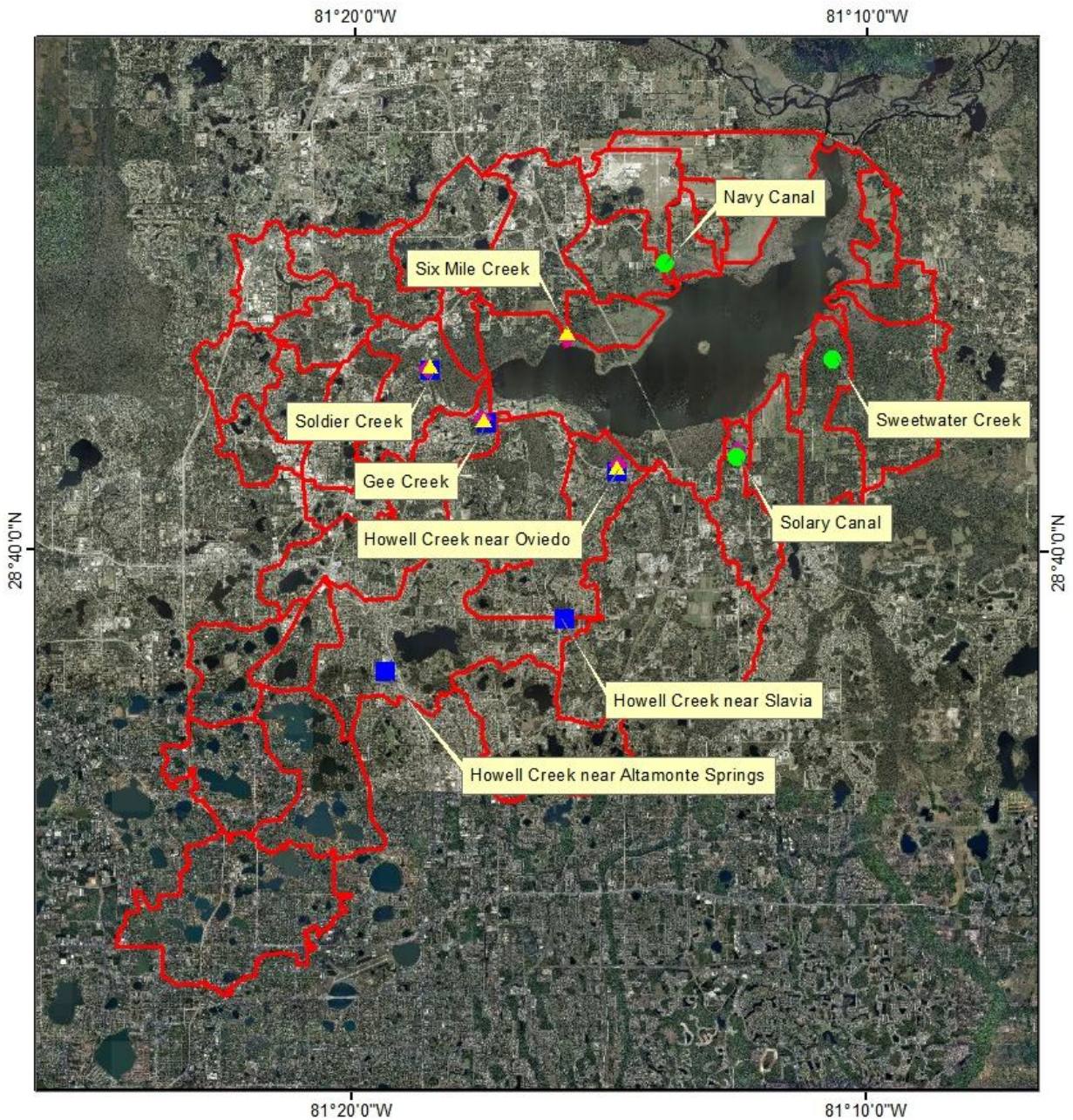
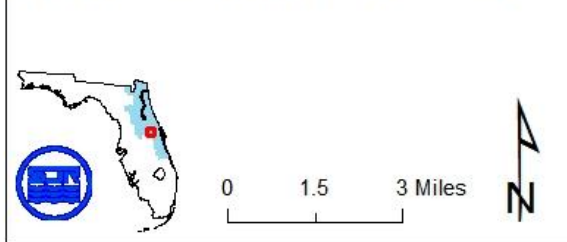


Figure 6 Flow and Water Quality Sampling Sites



Legend

- ▲ SJRWMD Grab Sites
- Seminole County Grab Sites
- ◆ Seminole County Storm Sites
- USGS Flow Sites

Figure 6 Flow and water quality sampling sites

2.6 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. 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 facility (WWTF) (2.01 MGD), Winter Springs West WWTF (1.55 MGD), and Casselberry WWTF (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 (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.

Sanford/North WWTF is located in the Lake Monroe watershed. Although it is outside of the Lake Jesup watershed, it discharges to Lake Jesup through Site 10, a 1800 acre wastewater reuse site located in the north-east shore of Lake Jesup (Figure 7). Site 10 provides additional treatment for the effluents from Sanford/North WWTF through a series of irrigation fields, wetlands, and stormwater treatment ponds. The drainage patterns in Site 10 are evaluated based on the review of previous storm water studies for Site 10 by CPH (1990), Inwood Consulting Engineers (2006), and CDM (2007). District staff also conducted a field trip with the staff from the City of Sanford and CDM to confirm the drainage divides. For modeling purposes, Site 10 is delineated into three parts as shown in Figure 7. The area in blue is outside of the Lake Jesup watershed. This area drains northeastward to Mullet Lake and is not modeled in this study. The area in yellow includes all the reuse water irrigation fields in Site 10 that drain to Lake Jesup. These irrigation fields receive the effluents from Sanford/North WWTF, and the outflow from these irrigation fields is first treated by the stormwater ponds and then discharges to Lake Jesup through the outlet structures. The area in green mainly consists of forested areas and wetlands. Because this area does not receive the reuse water, the flow and water quality loadings from this area are similar to those from nearby forest and wetland areas in subwatersheds 34 and 39. Therefore, this area is lumped into the forest and wetland land uses in subwatersheds 34 and 39 and is not modeled separately. The estimated loadings from Site 10 in this study only refer to the loadings from the yellow area, which includes subwatershed 33 and a small portion of subwatershed 34.

The nutrient loadings from Site 10 to Lake Jesup are estimated using the following equation:

$$L = R_{SI} \times C_{SI} \times (1 - A_{SI}) + R_B \times C_B \times (1 - A_B)$$

Where

L is the pollutant loadings from Site 10 to Lake Jesup;

R_{SI} is the surface runoff and interflow from Site 10;

C_{SI} is the average surface runoff and interflow concentration;

A_{SI} is the attenuation factor for surface runoff and interflow;

R_B is the baseflow from Site 10;

C_B is the average baseflow concentration;

A_B is the attenuation factor for baseflow.

R_{SI} and R_B from Site 10 are simulated in HSPF. Although details operations and hydraulic structures in Site 10 are not explicitly simulated, major hydrologic processes, such as rainfall, irrigation of treated wastewater, infiltration, and evaporation, are included in HSPF. The average inflow from Sanford/North WWTF to the Site 10 is 1.42 MGD over the period from 01/01/2002 to 12/13/2012 based on the permitting compliance data obtained from FDEP. Because approximately 60% of the irrigation fields at Site 10 are located within the Lake Jesup watershed, the inflow goes to the Lake Jesup watershed is estimated to be $1.42 \times 0.6 = 0.85$ MGD.

C_{SI} and C_B are estimated using the observed median concentrations from the stormwater and surficial groundwater sampling sites along the west boundary of subwatershed 33 as shown in Figure 7. It should be noted that the stormwater sampling site is located downstream of the irrigation fields. Therefore, the impact of the irrigation fields and their distribution and collection systems on water quality should be reflected in the stormwater sampling data. The estimated C_{SI} is 3.50 mg N/l for total nitrogen (TN) and 2.05 mg P/l for TP, and the estimated C_B is 2.30 mg N/l for TN and 0.85 mg P/l for TP.

A_{SI} and A_B are used to account for the nutrient attenuation provided by the wet detention ponds in Site 10. The removal efficiency of wet detention ponds is generally between 20% and 30% for TN and between 40% and 50% for TP (CDM 2002). Based on the field evaluation by District staff, the wet detention ponds in Site 10 appear to have limited water quality treatment volumes, and short-circuiting is expected to occur often due to the close proximity between pond inlets and outlets. The removal efficiencies of the Site 10 ponds are likely below the typical removal rates reported in the literature. Therefore, this study assumes that $A_{SI} = 10\%$ for TN and $A_{SI} = 20\%$ for TP, and $A_B = 15\%$ for TN and $A_B = 30\%$ for TP. The nutrient reductions for baseflow are higher due to its long residence time passing through wet detention ponds.

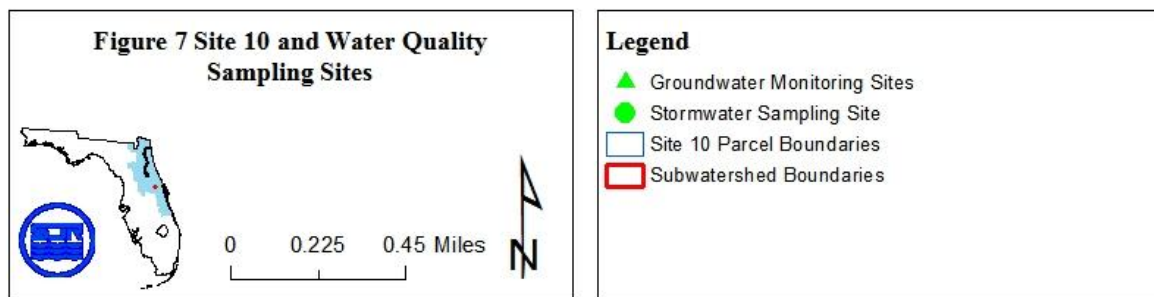
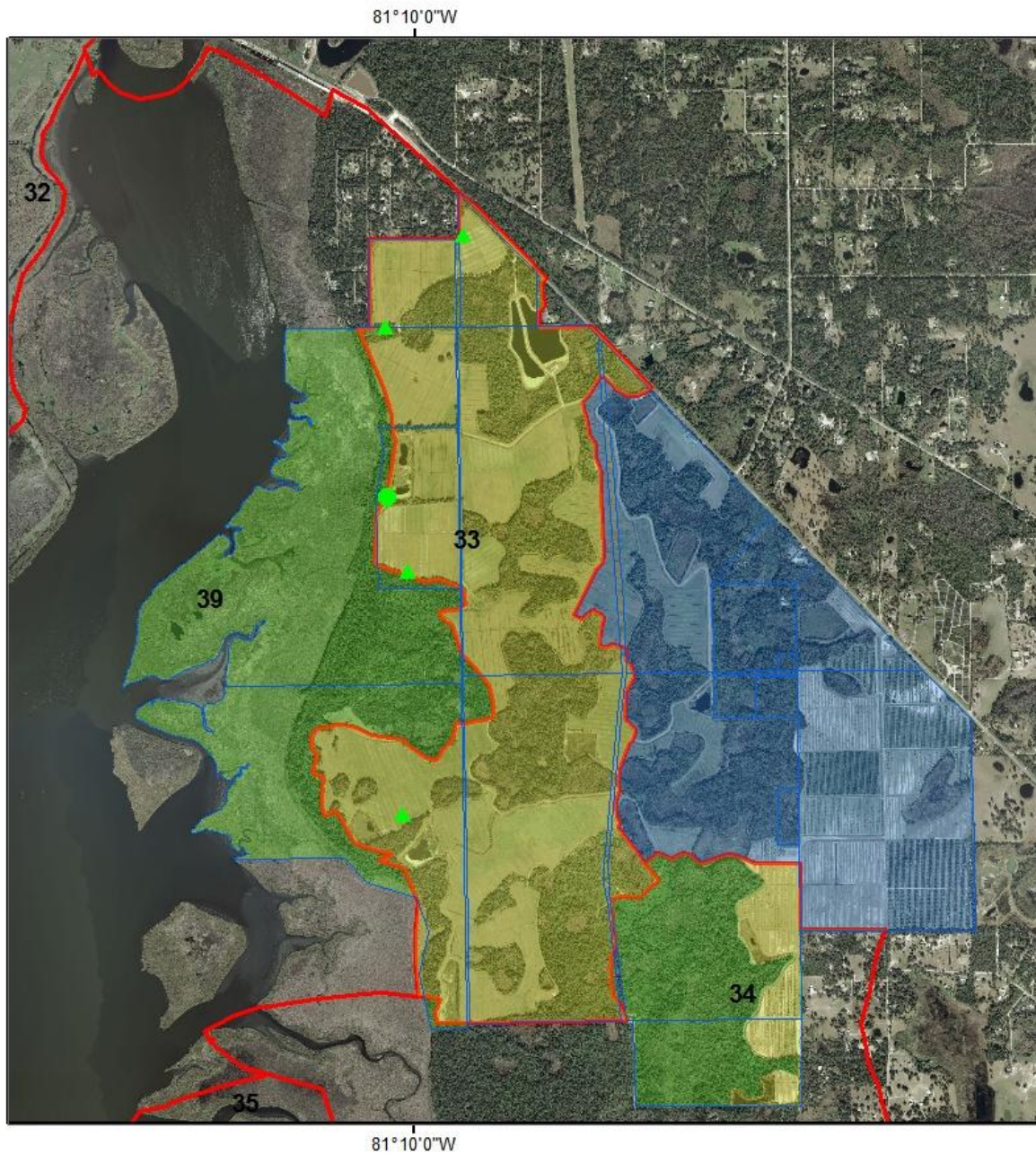


Figure 7 Site 10 and water quality sampling sites

2.7 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 septic tanks data sets obtained from Seminole County, Orange County, and Florida Department of Health (FDOH). Based on the septic tank maps from Seminole County and Orange County, there are 30,730 septic tanks in Seminole County and 74,651 septic tanks in Orange County. The number of annual repairs ranges from 74 to 556 for Seminole County and from 973 to 1199 for Orange County in the period from 2003 to 2012 (FDOH 2013). To account for the possibility that not all failing septic tanks are reported and repaired, the high end values of the reported ranges are used in this study as the average number of failing septic tanks. Using the high end values, the estimated septic tank failure rates for Seminole County and Orange County are 1.8% (556 failures out of 30730 septic tanks) and 1.6% (1199 failures out of 74651 septic tanks), which are reasonable compared with the typically failure rates of 1% to 10% reported in the literature (CDM 2005, Swann 2001, and USEPA 2015).

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 tank parcels more than 50-ft away from streams and lakes, pollutant loadings are handled inexplicitly and are lumped to the pollutant loadings from residential land uses. The septic tank parcels intercepting the 50-ft buffer 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. Based on the septic tank maps from Seminole County and Orange County, roughly 0.7% of septic tank parcels in Seminole County and 0.9% in Orange County are intercepting with the 50-ft buffer of the stream network in the Lake Jesup watershed. Therefore, the number of direct pipes in the watershed is estimated as $0.7\% \times 556 + 0.9\% \times 1199 = 15$. The direct pipes are assigned to 7 subwatersheds was shown in Table 4 based on the distribution of the septic tanks within 50-ft of the stream network among the subwatersheds.

Table 4 Distribution of direct pipes among the subwatersheds

Subwatershed Number	Number of Direct Pipes Modeled
1	1
2	3
6	2
7	6
14	1
24	1
39	1

According to USEPA (1980), per capita flow rate from a failing septic tank is 7.18×10^{-5} cfs. The average number of persons per household in Seminole County is 2.82 (US Census 2010). The estimated flow rate from a failing septic tank is $7.18 \times 10^{-5} \times 2.82 = 2.02 \times 10^{-4}$ cfs. Pollutant concentrations of failing septic tank effluent are assumed to equal the average concentration measurements in Florida complied by Parsons (2000). Table 5 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 5 Pollutant concentrations of failing septic tank effluent

Parameter	Concentration (mg/l)
Biological Oxygen Demand ¹	352.5
Total Suspended Solids ²	161.0
Total Nitrogen ³	39.0
Total Phosphorus ⁴	11.0

Note:

- 1 – According to Parsons (2000), average measured BOD5 = 141 mg/l. This study assumes that BOD = 2.5 BOD5;
- 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. Ammonia (NH₄), NO₃, and PO₄ concentrations of wet deposition are assumed to be 0.15 mg N/l, 0.74 mg N/l, and 0.04 mg P/l, which are the precipitation-weighted mean concentrations of wet deposition for NH₄, NO₃, and TP at the site FL32 of National Atmospheric Deposition Program (<http://nadp.sws.uiuc.edu>) located in Orange County. NH₄, NO₃, and PO₄ dry deposition rates are assumed to be 37 mg N/m²/yr, 149 mg N/m²/yr, and 10 mg P/m²/yr, respectively. These values are based on the District's dry deposition samples measured at Lake Lochloosa in Alachua County. The above annual loadings are evenly allocated as the monthly inputs in the HSPF model.

3. HSPF Model Development

The HSPF model (Bicknell et al. 2001) is used to simulate the hydrologic and water quality processes in the Lake Jesup watershed. The simulation period is from 01/2003 to 12/2012, which includes both wet and dry years and covers a variety of hydrologic conditions.

3.1 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. Among 13 consolidated land uses, four urban land uses are assumed to have impervious areas. The impervious percentages for these land uses are listed in Table 6. The remaining land uses are assumed to be 100% pervious.

Table 6 Percentages of impervious area by land use

Land Use	Percent of Imperviousness
Low Density Residential	5
Medium Density Residential	10
High Density Residential	35
Industrial and Commercial	50

For modeling purposes, the stream network in a subwatershed is grouped together and represented as a RCHRES. A RCHRES could be either a free-flowing stream or a lake. A series of reach segments connects upstream subwatersheds to downstream subwatersheds. Runoffs and water quality constituents are attenuated as they move through the reach segments. The geometric and hydraulic properties of a RCHRES are represented in HSPF by a piecewise-linear function table called an FTABLE, which describes the relationships between stage, surface area, volume, and discharge for the reach segment. The FTABLEs are mainly derived from the modeling results of the ICPR models developed by various consultants for storm water master planning in the study area (Dyer, Riddle, Mills & Precourt 1994; Singhofen & Associates 1996a and 1996b; CDM 2000 and 2011). In addition, cross-section survey data, lake bathymetry, observed stage and discharge relationships are used for FTABLE development. In total, 21 stream reaches and 13 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 39 are assumed to enter Lake Jesup directly because these two watersheds are adjacent to Lake Jesup and there are no major drainage channels.

The reach segment draining a subwatershed receives the runoff and water quality constituents from the land segments in that subwatershed. For the area not drained by nonriparian wetlands, the runoff and water quality constituents are delivered to the reach segment directly. However, for the area drained by nonriparian wetlands (see Figure 5), the surface runoffs and interflows are first delivered to nonriparian wetlands, and then the outflows are delivered to the reach segment. The nonriparian wetlands are modeled by surface FTABLEs in HSPF to represent the high water table and storage effects in nonriparian wetlands. The impacts of nonriparian wetlands on baseflow runoffs and water quality loadings are assumed to be negligible. Consequently, the baseflow and water quality constituents originated from nonriparian wetlands' drainage area are routed to receiving reach segment directly.

The effects of BMPs are simulated by applying a set of removal efficiencies to the water quality loadings from their contributing areas. The removal efficiencies are mainly based on the midpoint values of the reported ranges in Preliminary Data Summary of Urban Storm Water Best Management Practices (USEPA 1999a), 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 midpoint 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. The pollutant removal efficiencies used in the HSPF model are presented in Table 7.

Table 7 Pollutant removal efficiencies used in the HSPF model (%)

	TSS	NH4	NO3	PO4	Organic Nitrogen and Phosphorus
Baffle Box, Inlet Basket, CDS ¹	30	5	5	5	5
Alum ²	30	30	30	60	35
Dry Pond ¹	40	5	5	20	20
Dry Pond Treatment Train ¹	50	10	10	25	25
Swale ¹	40	15	15	15	20
Wet Pond ²	60	25	25	55	30
Wet Pond Treatment Train ²	70	30	30	60	35
Drainage Well ²	64	64	64	64	64

Note:

1 – The removal efficiencies only apply to water quality constituents associated with surface runoff and interflow;

2 – The removal efficiencies apply to water quality constituents associated with surface runoff, interflow, and baseflow.

3.2 HSPF Modules

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.

During a simulation run, the riparian wetland PERLND areas will change as the RCHRES surface expands and contracts. The HSPF Special Actions module is used to account for variable PERLND and RCHRES. Different areas for the water and wetland are used so both the PERLND and RCHRES section in a subwatershed would not use the same area at the same time. For most subwatersheds, the average RCHRES area is subtracted from the PERLND water and wetland area for each subwatershed. This would cause some double counting of rainfall and evaporation when water levels are high and some undercounting when water levels are low. As long as this area is small, this error is considered

insignificant to the overall model. When the variable area within the RCHRES becomes large, however the error becomes significant. The Special Actions for variables PERLND and RCHRES calculate the current RCHRES area and subtract it from the total water and wetland area for the subwatershed. Then the model uses this area as a wetland PERLND in the modeled subwatershed. This action is applied in every subwatershed in this study.

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. Literature values for sediment fractions are mostly from the watersheds in the Chesapeake Bay area, and vary from 4% to 10% for sand, 28% to 70% for silt, and 27% to 65% for clay (USEPA 1999b). Due to the sandy soil conditions in the Lake Jesup watershed, the sediment loads are expected to have a higher sand content and a lower clay content than those in the Chesapeake Bay area. Therefore, this study assumes that the sediment loads contain 20% sand, 50% silt, and 30% 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 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 (NH_4) and PO_4 , 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 nonrefractory (degradable) fraction of the BOD from the watershed. The refractory fraction of BOD is represented as refractory organic N and refractory organic P in the water column. Nonrefractory 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 NH_4 and PO_4 . 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.

3.3 Model Calibration

Calibration of HSPF models involves iterative adjustment of model parameters so that model simulations can closely match the observed flow and water quality data. To assist the calibration process, an automatic parameter estimation tool called PEST (Doherty 2004) is used. PEST uses a nonlinear optimization approach to explore the parameter space defined by the modeler and find the best parameter set for the specified objective function. The objective function typically includes multiple weighted statistical measures, such as mean, median, percentiles, to evaluate the statistical characteristics of model simulations and observations. The modeler needs to adjust these statistical measure and their weights during calibration in order to get the best match between model simulations and observed data.

A variety of HSPF hydrologic parameters relating to watershed storage, infiltration, evaporation, and deep percolation are adjusted in the hydrologic calibration process to match the observed flows at five USGS flow stations. The extents of adjustment for these hydrologic parameters are defined by the HSPF Common Logic developed for the St. Johns River Water Supply Impact Study (Cera et al. 2012). This

HSPF Common Logic was derived from an evaluation of the possible range of model parameters for Florida's unique hydrology, extensive SJRWMD experience, and the parameter ranges common in other parts of the world (USEPA 2000). Various statistic measures are used by PEST to minimize the differences between the predicted and observed flows in terms of mass balance, low flow recession, flow distribution, and seasonal distribution. Table 8 shows the Nash-Sutcliffe efficiencies and the percent mean errors between simulated and observed flow at the five calibration sites. The Nash-Sutcliffe efficiency is a commonly used measure to evaluate the performance of a hydrologic model. It varies from zero to one, where values below 0.5 are generally considered unsatisfactory for hydrologic models, values between 0.5 and 0.65 considered satisfactory, values between 0.65 and 0.75 considered good, and values above 0.75 considered very good (Moriassi et al. 2007). It can be seen that calibration performance can be rated mostly very good for all calibration sites. Figures 8 – 12 compare simulated and observed flows at the five calibration sites over the simulation period. Other calibration plots comparing simulated and observed flow are provided in Appendix A.

Table 8 Calibration performance between simulated and observed flow at five calibration sites

Calibration Site	Percent Error In Total Flow Volume	Percent Error In Lowest 50% Daily Flow Volume	Percent Error In Highest 10% Daily Flow Volume	Nash-Sutcliffe for Daily Flows	Nash-Sutcliffe for Monthly Flows
Howell Creek near Altamonte Springs	-0.2	-3.6	14.0	0.72	0.87
Howell Creek near Slavia	-7.1	-1.2	-7.1	0.83	0.88
Howell Creek near Oviedo	0.0	0.7	-1.5	0.85	0.92
Gee Creek near Longwood	0.0	12.8	-7.9	0.86	0.87
Soldier Creek near Longwood	0.0	7.4	0.0	0.81	0.83

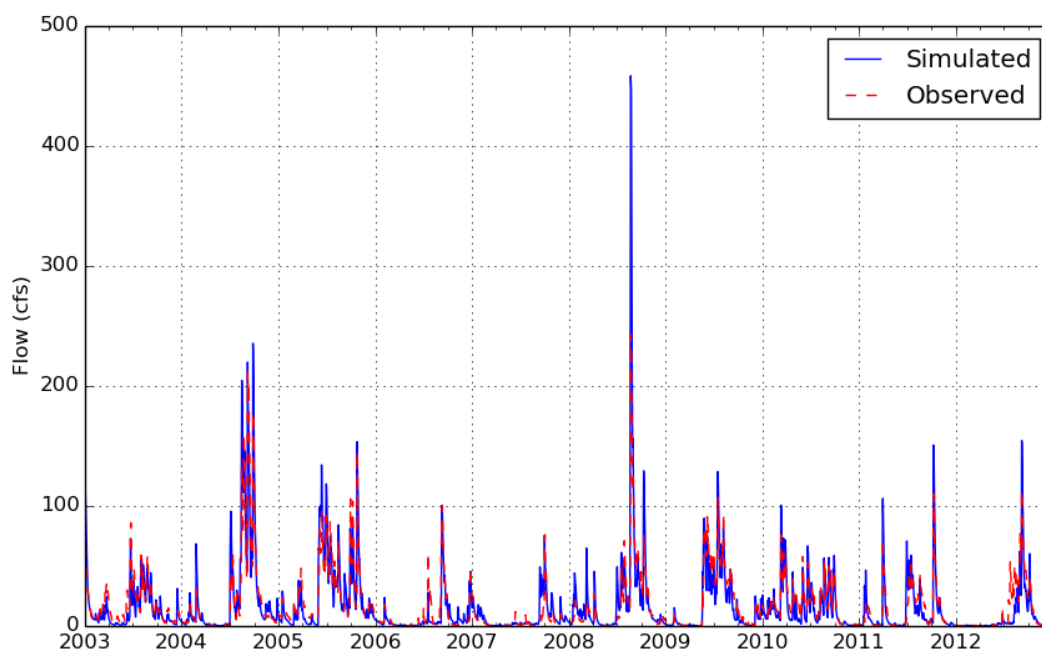


Figure 8 Observed and simulated daily flows for Howell Creek near Altamonte Springs.

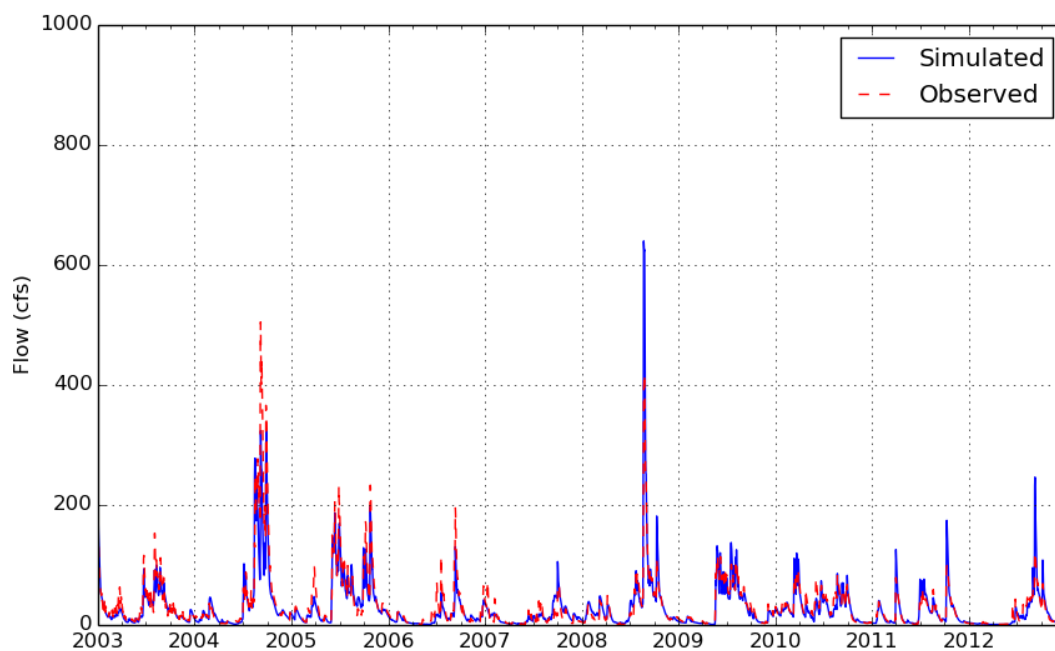


Figure 9 Observed and simulated daily flows for Howell Creek near Slavia.

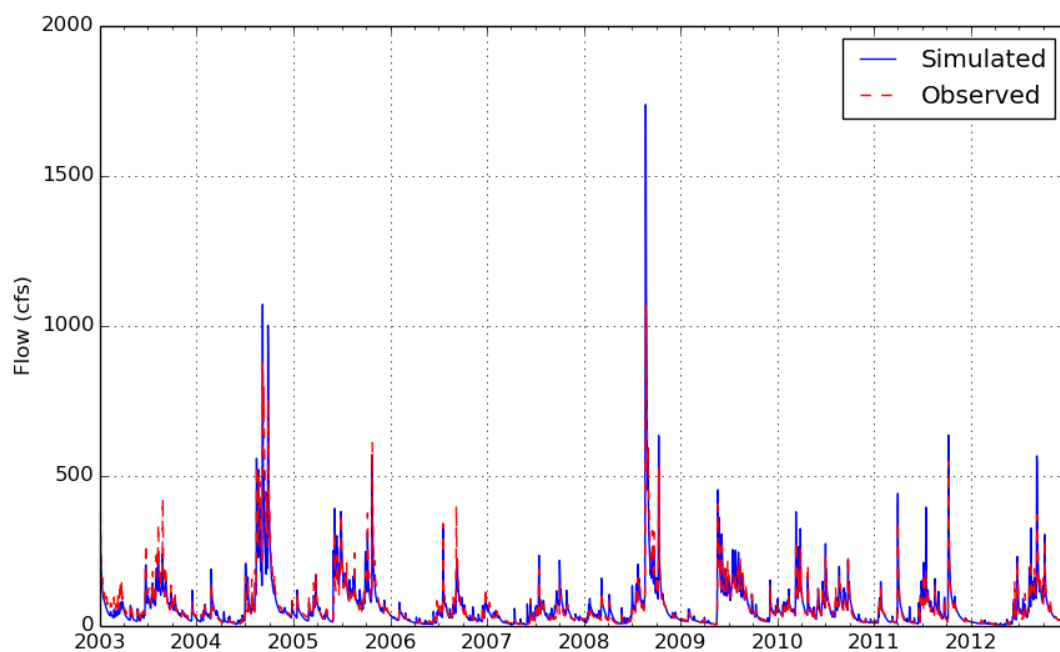


Figure 10 Observed and simulated daily flows for Howell Creek near Oviedo.

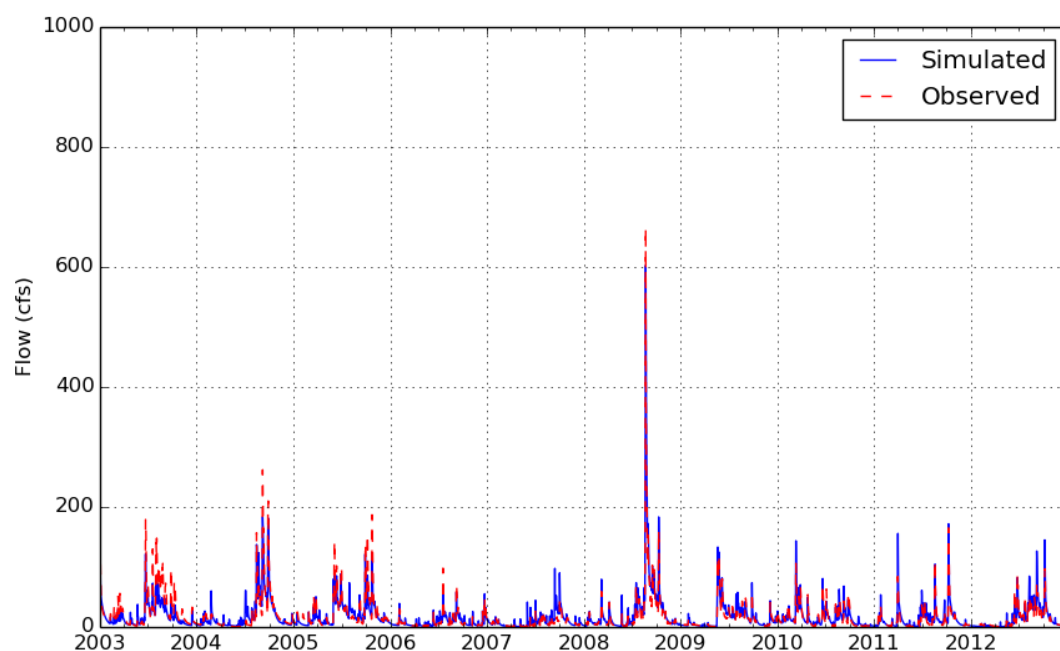


Figure 11 Observed and simulated daily flows for Gee Creek near Longwood.

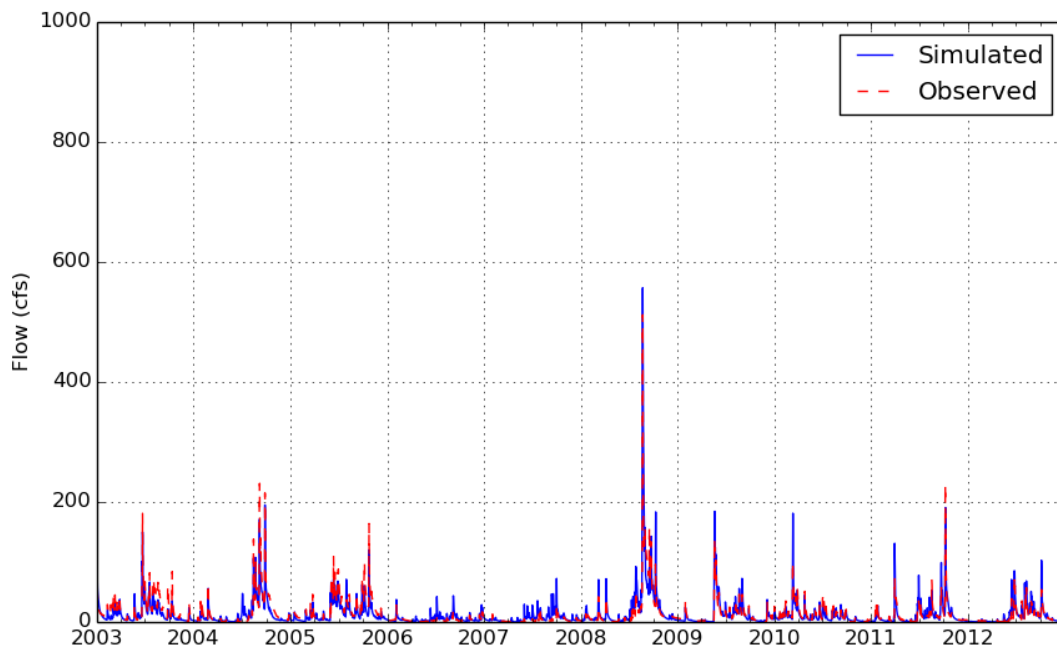


Figure 12 Observed and simulated daily flows for Soldier Creek near Longwood.

Water quality calibration involves two major steps. The first step is to adjust the land use specific parameters (e.g. accumulation rates, depletion/removal rates, wash-off rates, subsurface concentrations) to match land use loadings with the expected loadings reported in the literature. The second step is to select the instream water quality parameters (e.g. re-aeration rate, nitrification rate, phytoplankton growth rate) to match the observed water quality concentrations at calibration sites. These two steps are performed iteratively 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 9 compares HSPF simulated loadings of 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 mostly 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 9 Simulated and expected loading rates by land use (lb/ac/yr).

Land Use	TN		TP	
	Expected	Simulated	Expected	Simulated
Low Density Residential	1.7 - 7.3	3.0 - 5.6	0.26-1.11	0.35 - 0.62
Medium Density Residential	3.0 - 14.4	6.2 - 10.5	0.43-2.07	0.72 - 1.20
High Density Residential	6.1 - 30.1	14.2 - 22.6	1.51-7.45	1.65 - 2.59
Industrial and Commercial	5.2 - 21.7	9.0 - 11.9	0.93-3.89	1.09 - 1.39
Mining	0.9 - 5.5	2.5 - 5.3	0.12-0.77	0.26 - 0.57
Open Land	2.6 - 7.1	2.1 - 5.0	0.18-0.51	0.23 - 0.54
Pasture	3.6 - 16.3	5.1 - 11.0	0.35-1.57	0.53 - 1.22
Agriculture General	2.8 - 13.4	5.3 - 14.9	0.61-2.96	0.55 - 1.65
Agriculture Tree Crop	2.0 - 9.0	3.1 - 9.0	0.46-2.12	0.33 - 0.99
Rangeland	1.7 - 6.5	1.5 - 5.2	0.09-0.33	0.07 - 0.25
Forest	0.8 - 7.2	0.8 - 4.2	0.11-0.92	0.04 - 0.20
Water	0.0 - 5.3	0.3 - 2.5	0.00-0.76	0.02 - 0.11
Wetland	0.0 - 5.3	0.3 - 2.5	0.00-0.76	0.02 - 0.11

Figures 13 – 15 compare the observed TP concentrations with the simulated concentrations at the three calibration sites of Howell Creek, Gee Creek, and Soldier Creek. Simulated TP concentrations closely match the observed values, except that the HSPF model under-predicts a few observed storm event concentrations above 0.5 mg P/l, particularly at Howell Creek. The observed high concentrations for these storm events are considered as outliers because they are several times higher than the observed concentrations for other storm events with similar rainfalls and antecedent moisture conditions. These outliers are likely caused by sampling errors or by some sporadic nutrient wash-off and sediment nutrient release events that are not captured by the HSPF model. Graphical and statistical comparisons for other water quality constituents are provided in Appendices B and C. In general, there is good agreement between the simulated and observed water quality concentrations, indicating that the HSPF water quality model is well calibrated.

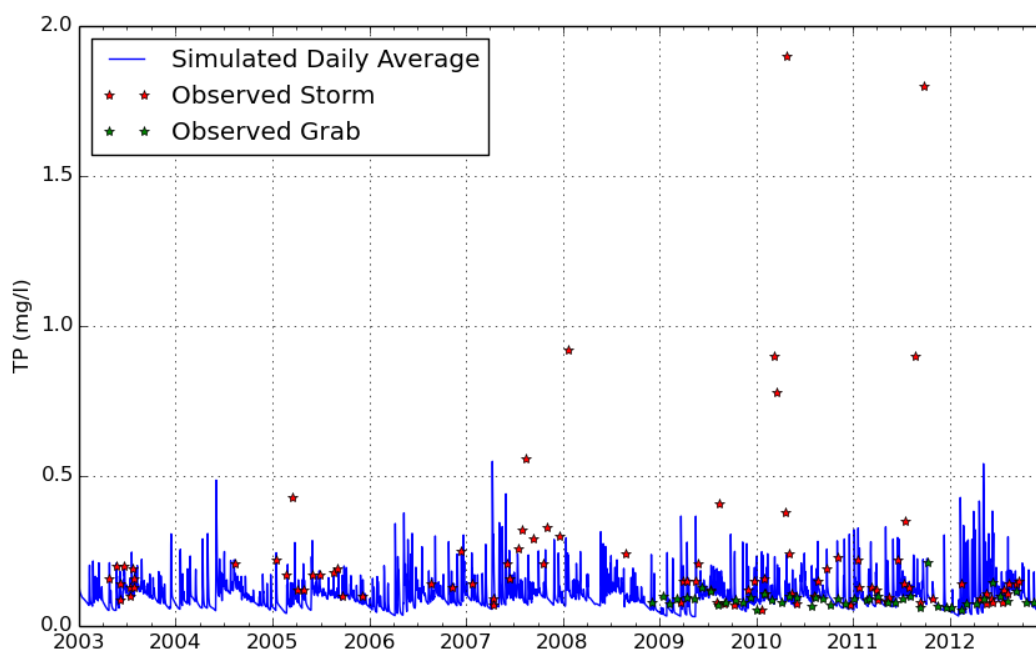


Figure 13 Observed and simulated TP concentrations at Howell Creek near Oviedo (2003 - 2012)

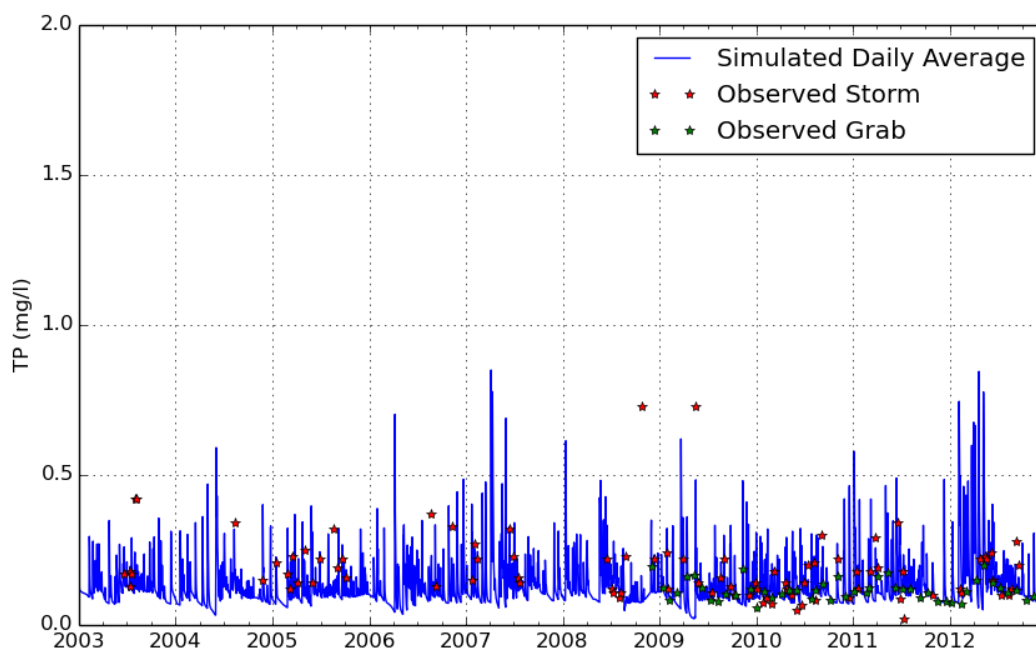


Figure 14 Observed and simulated TP concentrations at Gee Creek near Longwood (2003 - 2012)

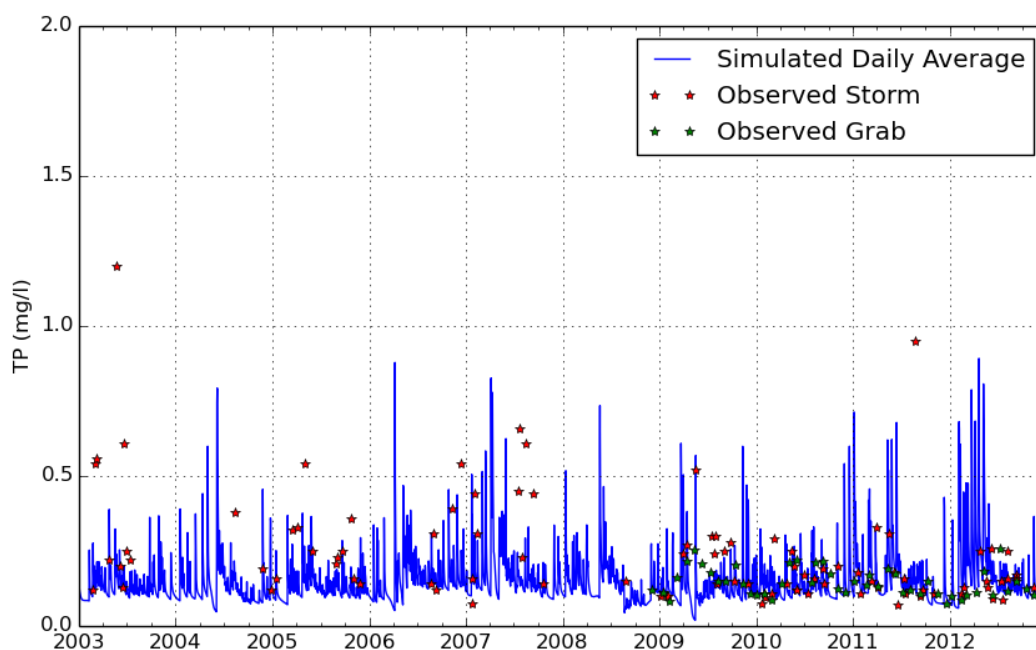


Figure 15 Observed and simulated TP concentrations at Soldier Creek near Longwood (2003 - 2012)

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. Major adjustments of calibrated parameters for the Ungauged watershed are discussed below.

The observed TN and TP concentrations at Navy Canal (subwatershed 27) are notably lower than the concentrations observed at other water quality sampling sites. For example, the median of observed TP grab concentrations at Navy Canal is only 0.05 mg/l, while the median of observed TP grab concentrations at Howell Creek, Gee Creek, Soldier Creek is 0.09 mg/l, 0.11 mg/l, 0.14 mg/l, respectively. The TN and TP loads to Navy Canal mainly come from Sanford International Airport, which is classified as the industrial and commercial (IND) land use in the HSPF model, and accounts for about 57% of the drainage area of Navy Canal. It is likely that the nutrient loadings from the airport land use are lower than the typical IND areas in the gauged watersheds, which include a broad range of industrial and commercial land uses. Direct application of the calibrated IND loading parameters would lead to the over-prediction of the nutrient concentrations at Navy Canal. Therefore, the calibrated nutrient loading parameters are adjusted for the Sanford International Airport area, generally represented by the IND land uses for subwatersheds 27, 29, and 30, to better match the observed TN and TP concentrations at Navy Canal.

The observed PO₄ concentrations at Solary Canal (0.22 mg/l) and Sweetwater Creek (0.26 mg/l) are a few times higher than those at Howell Creek (0.04 mg/l), Gee Creek (0.06 mg/l), and Soldier Creek (0.09 mg/l). This is likely caused by high phosphate loadings from the pasture and agriculture land uses or by the sediment released from the phosphate-rich Hawthorn aquifer layers in this area. The baseflow PO₄ contributions from the pasture and agriculture areas for this area are adjusted higher so that the HSPF model can reproduce the elevated PO₄ and TP concentrations for Solary Canal and Sweetwater Creek.

Because Site 10 receives a significant amount of nutrient loadings from Sanford North WWTF, the calibrated parameters are not considered representative of the nutrient characteristics at Site 10. As discussed in section 2.6, only hydrology simulation is performed. The irrigation of the treated wastewater is simulated by applying the treated wastewater uniformly to land surface of the irrigation fields in Site 10. The water quality loadings from the Site 10 are calculated by multiplying the simulated flow with the observed water quality concentrations. Table 10 shows the simulated surface and baseflow flow from Site 10 and the estimated TN and TP loads.

Table 10 Estimated flow, TN, and TP loads from Site 10

	Simulated Flow (cfs)	TN Loads (lbs/year)	TP Loads (lbs/year)
Surface Runoff	0.16	993	517
Baseflow	2.03	7,796	2,373
Total	2.19	8,789	2,890

The performance of HSPF simulation in the Ungauged watershed is evaluated by comparing the simulated and observed TN and TP concentrations at Six Mile Creek, Navy Canal, Sweetwater Creek, and Solary Canal (Figures B.34 – B.69 in Appendix B). 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.

4. Scenario Analysis

Two scenarios, including current conditions and pristine conditions, are analyzed in this study. The current conditions refer to the 2009 land uses. The pristine conditions are defined as the pre-development conditions with minimal human induced land use changes. The land uses in the pristine conditions are developed based on discussions between the District and FDEP. All the wetland and water land uses in the current conditions are assumed to be the same land uses in the pristine conditions. Other land uses in the current conditions are converted into forests and wetlands according to their Hydrologic Soil Group classification: areas with A and B soils are converted to forests and the areas with other soil types, including C, D, and dual categories such as B/D, are converted to wetlands. Figure 10 shows the distribution of land uses in the pristine conditions. The HSPF simulation is

performed for the two scenarios over the period from 01/2003 to 12/2012. The estimated annual watershed loadings of flow, TN, and TP are listed in Tables 11 and 12.

Table 11 Contributions of flow (ac.ft/yr), TN (lbs N/yr), and TP (lbs P/yr) for current conditions

	Howell	Gee	Soldier	Ungauged	Total
Flow	47,925	12,902	11,300	28,344	100,470
TN	139,716	42,736	34,831	105,377	322,659
TP	15,523	4,748	4,081	15,008	39,361

Table 12 Contributions of flow (ac.ft/yr), TN (lbs N/yr), and TP (lbs P/yr) for pristine conditions

	Howell	Gee	Soldier	Ungauged	Total
Flow	23,388	4,773	3,234	13,401	44,796
TN	49,553	12,641	7,999	36,427	106,621
TP	2,055	608	373	1,753	4,789

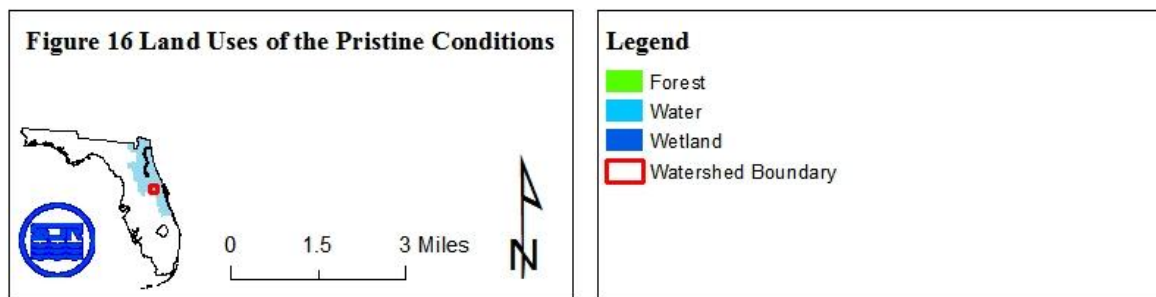
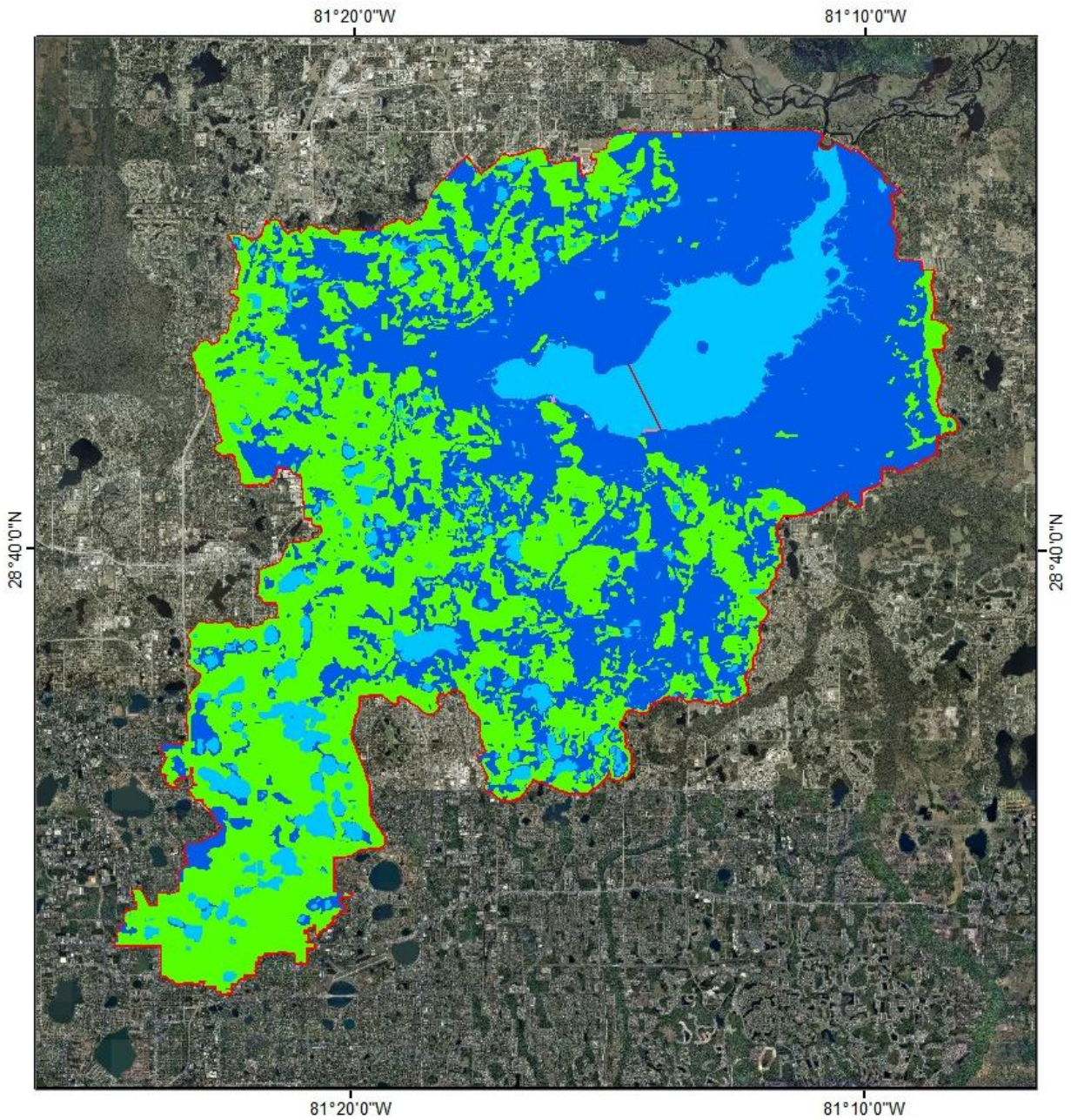


Figure 16 Land uses of the pristine conditions

5. Conclusions

This study develops a HSPF watershed simulation model for 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 HSPF 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 predict the flow and nutrient loads to Lake Jesup for PLRG and TMDL assessment.

Two scenarios, including current conditions and pristine conditions, are evaluated in this study. The results show that the watershed loadings of flow, TN, and TP are 100,470 ac.ft/yr, 322,659 lbs N/yr, 39,361 lbs P/yr under current conditions. Under pristine conditions, the average loadings of flow, TN, and TP are 44,796 ac.ft/yr, 106,621 lbs N/yr, 4,789 lbs P/yr, which are about 45%, 33%, and 12% of their current levels, respectively.

References

- ATKINS. 2014. Lake Jesup storm event sampling and analysis 2000 – 2012. Final report to Seminole County, Florida.
- Bergman, M.J. 2004. Land use classification table. Internal document, SJRWMD, Palatka, FL.
- Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., T.H. Jobes, and A.S. Donigian, Jr. 2001. Hydrological Simulation Program - Fortran (HSPF), user's manual for release 12. U.S. Environmental Protection Agency (USEPA) National Exposure Research Laboratory, Athens, GA, in cooperation with U.S. Geological Survey, Water Resources Division, Reston, VA.
- CDM. 2000. Lake Jesup basin engineering study and drainage. Final report to Seminole County, Florida.
- CDM. 2002. Literature review of stormwater Best Management Practices. Final report to SJRWMD, Palatka, FL.
- CDM. 2005. Wekiva Parkway and Protection Act master stormwater management Plan Support. Draft report to SJRWMD, Palatka, FL.

CDM. 2007. Memorandum: City of Sanford Site 10 data evaluation. Prepared for City of Sanford, Florida.

CDM. 2011. Howell Creek basin watershed management plan. Final report to Seminole County, Florida.

Center for Watershed Protection (CWP). 2000. National pollutant removal database for stormwater treatment practices, 2nd Edition. Prepared by the Center for Watershed Protection, Ellicott City, MD, Tetra Tech, Inc., Fairfax, VA, and the USEPA Office of Science and Technology, Washington, DC.

Cera, T., Smith, D.S., Cullum, M.G., Adkins, M., Amoha, J., Clapp, D., Freeman, R., Hafner, M., Huang, X., Jia, Y., Jobes, T., and Mao, M. 2012. St. Johns River water supply impact study, chapter 3: watershed hydrology. St. Johns River Water Management District, Palatka, FL.

CPH. 1990. Sheet #3 – Site plan: Water reuse systems Site 10. Site plan for City of Sanford.

Doherty, J. 2004. PEST, Model-independent parameter estimation, user manual: 5th Edition. Watermark Numerical Computing.

Dyer, Riddle, Mills & Precourt. 1994. Howell Creek basin drainage inventory engineering study. Prepared for Seminole County Government, Florida.

Florida Department of Environmental Protection (FDEP). 2003. Basin status report: Middle St. Johns. Division of Water Resource Management, FDEP.

Florida Department of Health (FDOH). 2013. Onsite sewage treatment and disposal systems statistical data. Available online at <http://www.doh.state.fl.us/environment/ostds/statistics/repairs.htm>.

Gao, X. 2006. Nutrient and unionized ammonia TMDLs for Lake Jesup. FDEP.

Harper, H.H. 1994. Stormwater loading rate parameters for central and south Florida. Environmental Research and Design, Inc., Orlando, Florida

Inwood Consulting Engineers. 2006. Technical Memorandum: Mullet Lake Park road stormwater Improvements. Prepared for Seminole County, Florida.

Jia, Y. 2007. Hydrologic and water quality modeling of the Lake Jesup watershed using Hydrological Simulation Program – Fortran (HSPF). SJ2007-SP2. St. Johns River Water Management District, Palatka, FL.

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bigner, R. D. Harmel, and T. L. Veith. 2007. "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations." Transactions of ASABE, American Society of Agricultural and Biological Engineers, 2007: vol 50, #3, 885-900.

Parsons. 2000. Lake Jesup water and nutrient budget report. Prepared for SJRWMD, Palatka, FL.

Singhofen & Associates. 1996a. Gee Creek basin engineering study and drainage inventory. Prepared for Seminole County Government, Florida.

Singhofen & Associates. 1996b. Soldier Creek basin engineering study and drainage inventory. Prepared for Seminole County Government, Florida.

Swann, C. 2001. The influence of septic systems at the watershed level. Urban Lake Management, 821-834.

Wenger, S. 1999. A review of scientific literature on riparian buffer width, extend and vegetation. Report to Office of Public Service & Outreach, Institute of Ecology, University of Georgia.

U.S. Census Bureau. 2010. Seminole County quick facts. Available online at <http://quickfacts.census.gov/qfd/states/12/12117.html>.

USEPA. 1980. Design manual—onsite wastewater treatment and disposal systems. Office of Water, USEPA, Washington, DC.

USEPA. 1999a. Preliminary data summary of urban storm water Best Management Practices. EPA-821-R-99-012, Office of Water, USEPA, Washington, DC.

USEPA. 1999b. HSPFParm – an interactive database of HSPF model parameters, version 1.0. EPA-823-R-99-004, Office of Water, USEPA, Washington, DC.

USEPA. 2000. BASINS technical note 6: estimating hydrology and hydraulic parameters for HSPF. EPA-823-R-00-012. Office of Water, USEPA, Washington, DC.

USEPA. 2001. WDMUtil version 2.0: a tool for managing watershed modeling time series data, user's manual. Office of Water, USEPA, Washington, DC.

USEPA. 2015. Preventing septic system failure, <http://water.epa.gov/polwaste/npdes/swbmp/Preventing-Septic-System-Failure.cfm>.

Appendix A Plots of Hydrologic Calibration

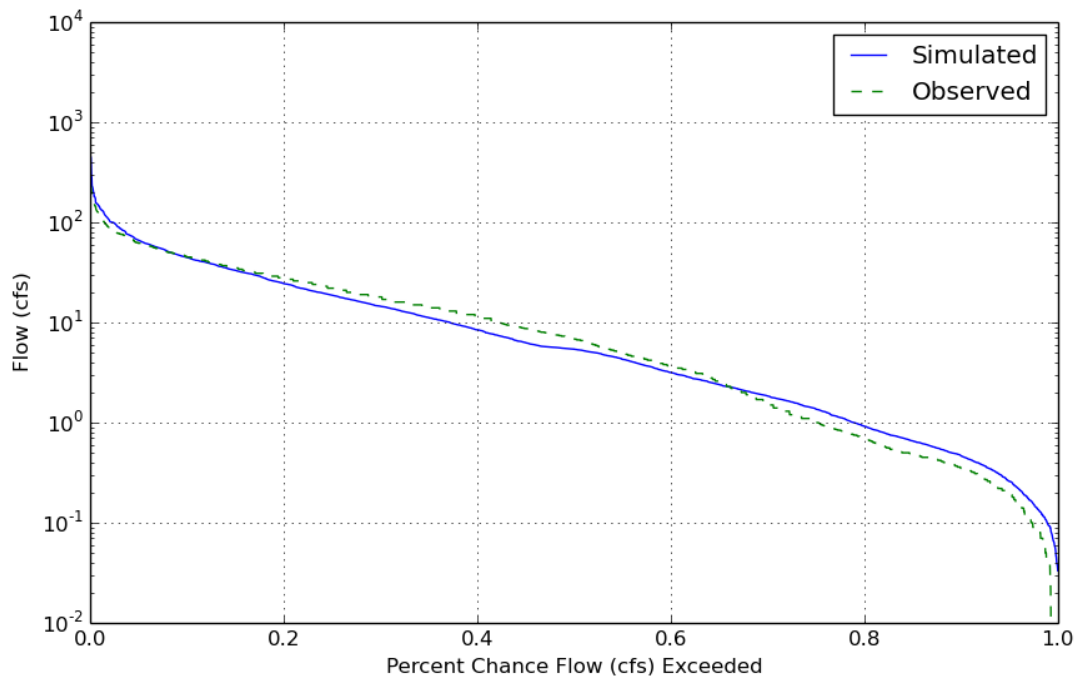


Figure A. 1 Observed and simulated daily flow frequency curves for Howell Creek near Altamonte Springs

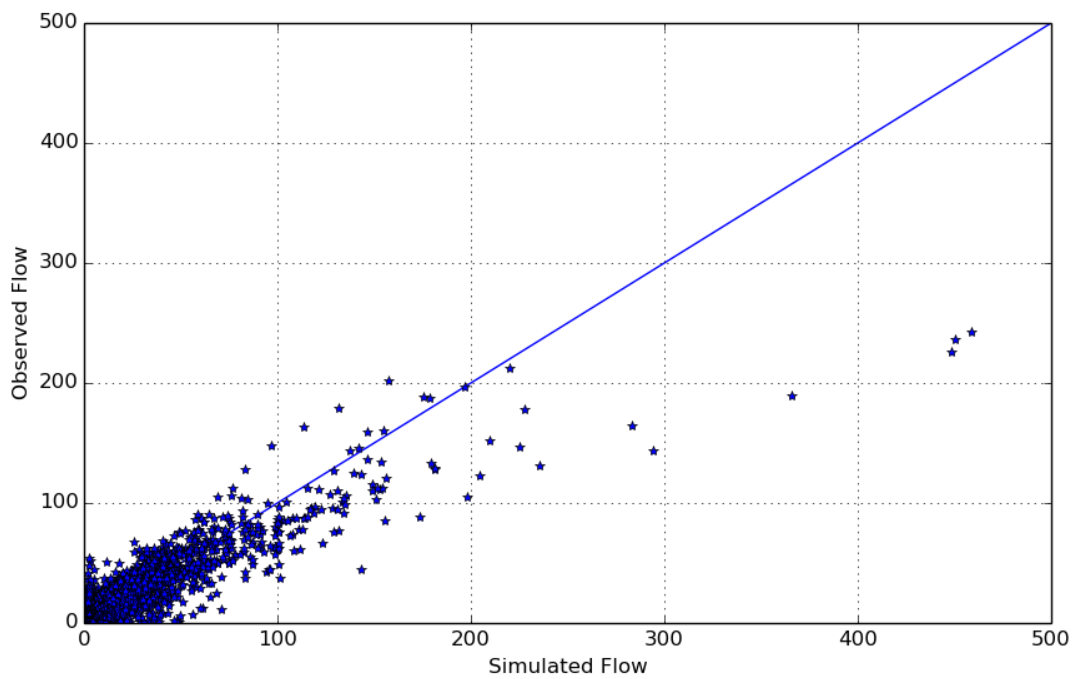


Figure A. 2 Scatter plot of observed and simulated daily flows for Howell Creek near Altamonte Springs

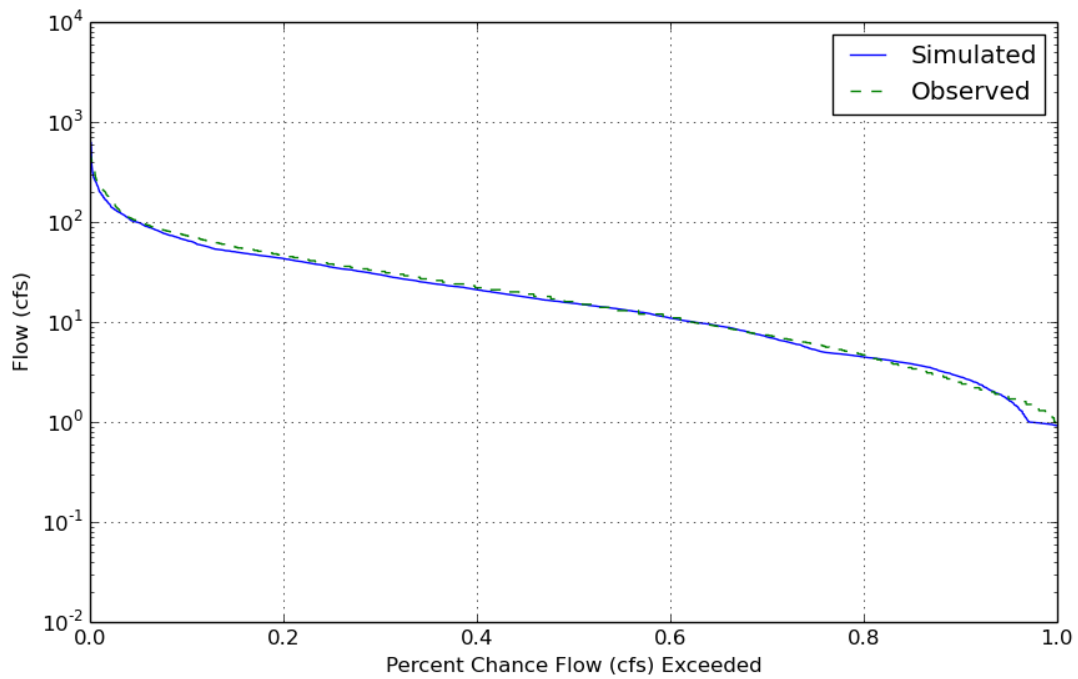


Figure A. 3 Observed and simulated daily flow frequency curves for Howell Creek near Slavia

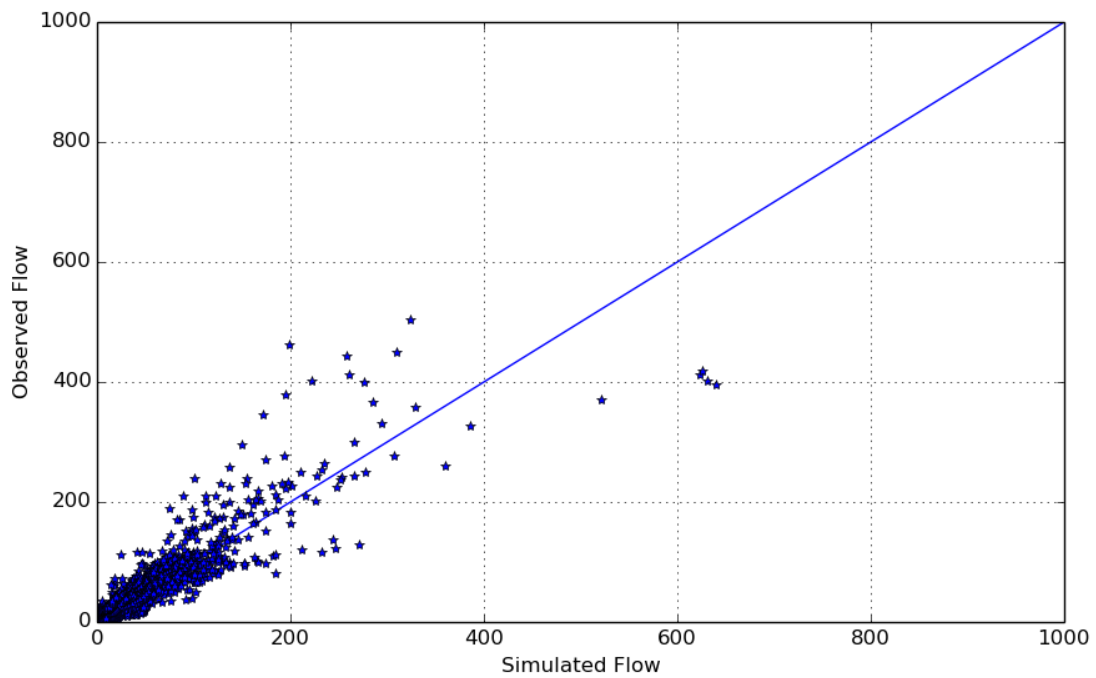


Figure A. 4 Scatter plot of observed and simulated daily flows for Howell Creek near Slavia

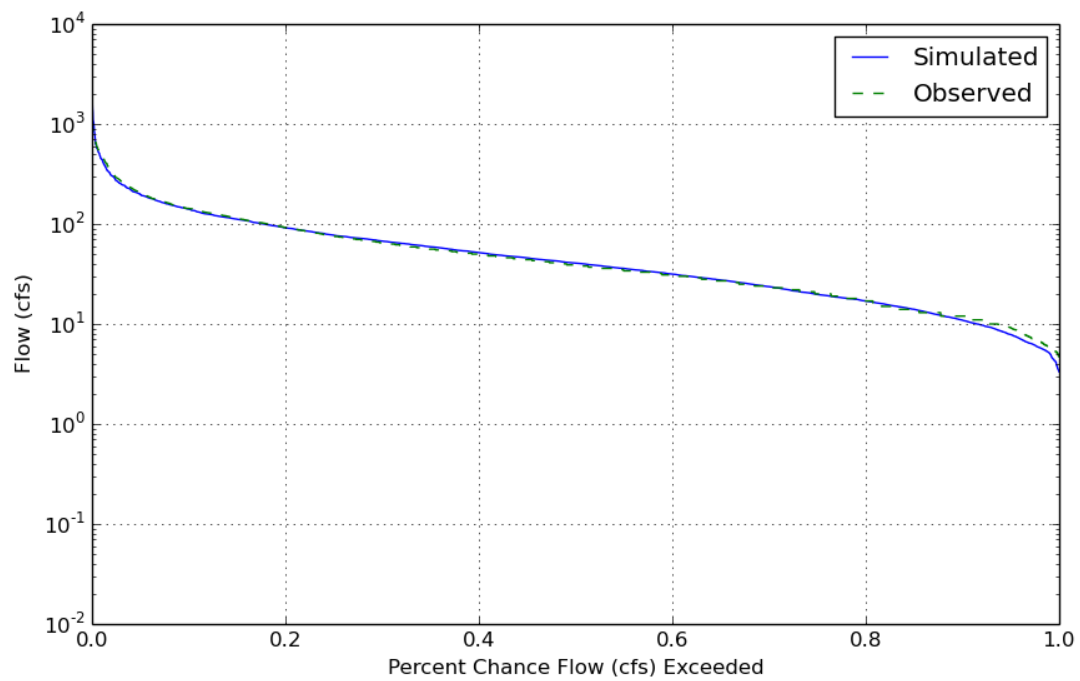


Figure A. 5 Observed and simulated daily flow frequency curves for Howell Creek near Oviedo

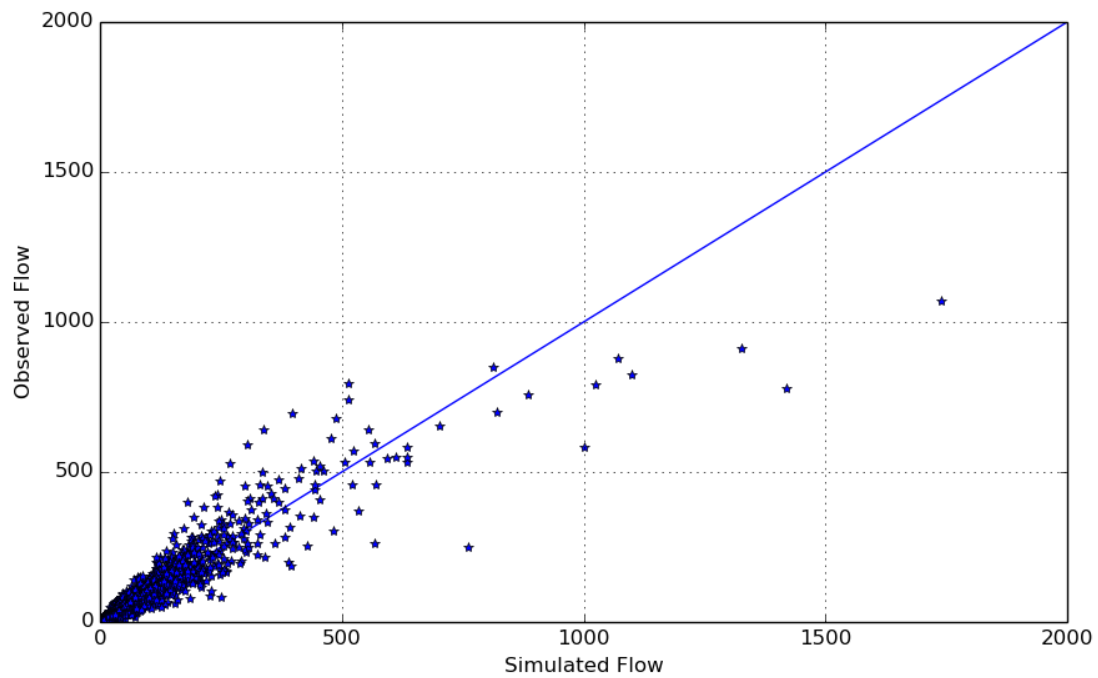


Figure A. 6 Scatter plot of observed and simulated daily flows for Howell Creek near Oviedo

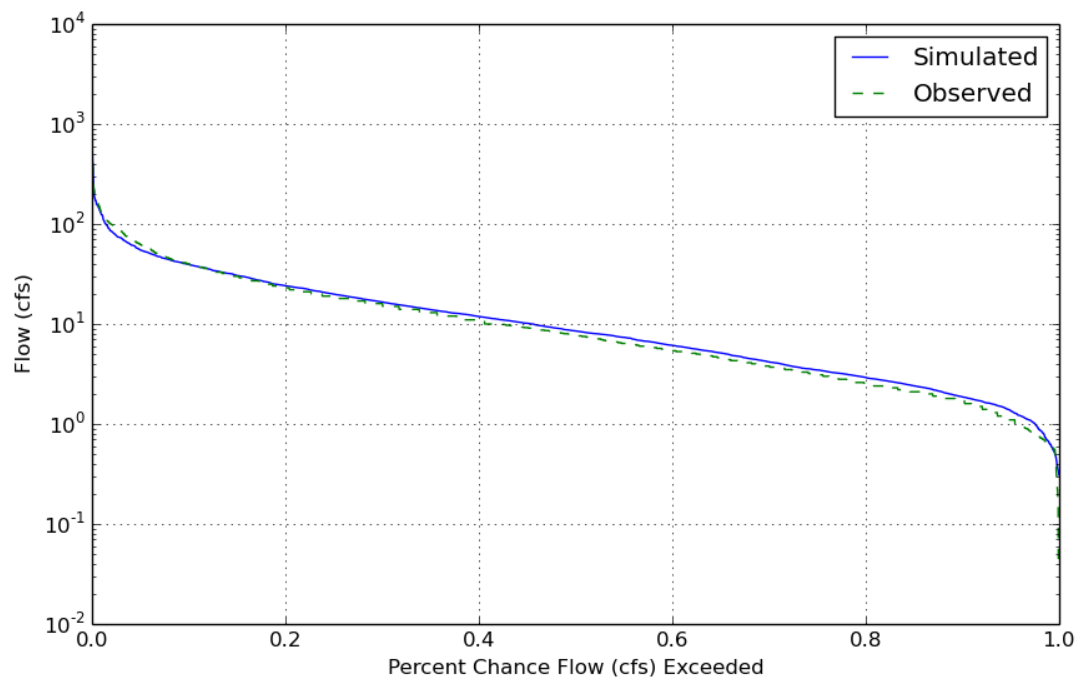


Figure A. 7 Observed and simulated daily flow frequency curves for Gee Creek near Longwood

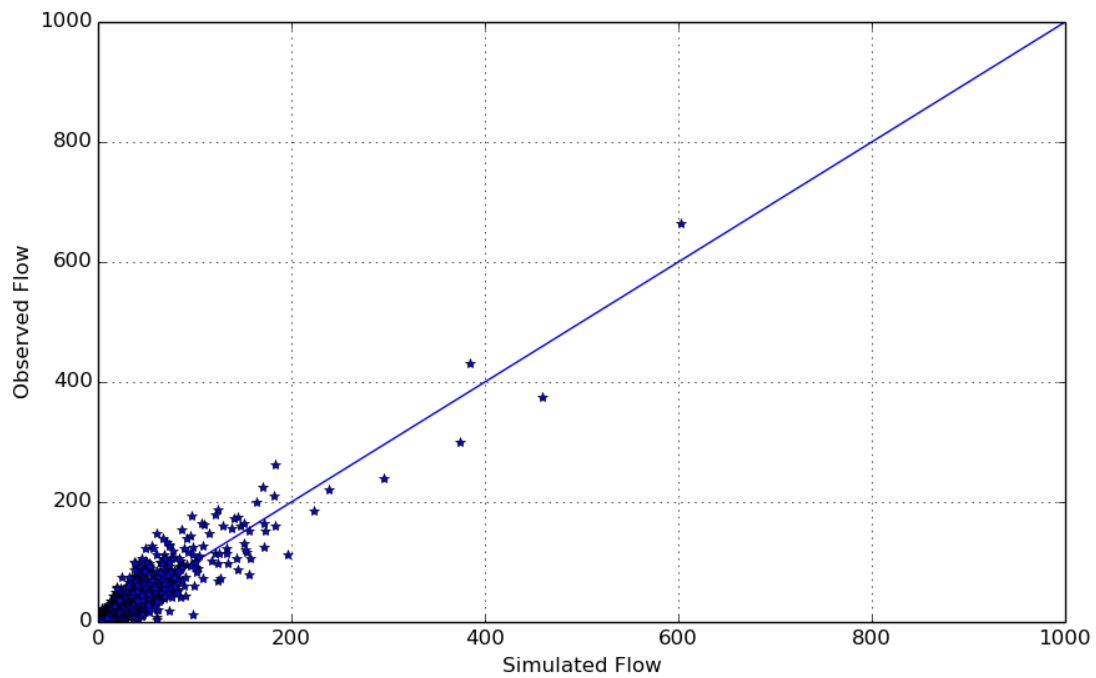


Figure A. 8 Scatter plot of observed and simulated daily flows for Gee Creek near Longwood

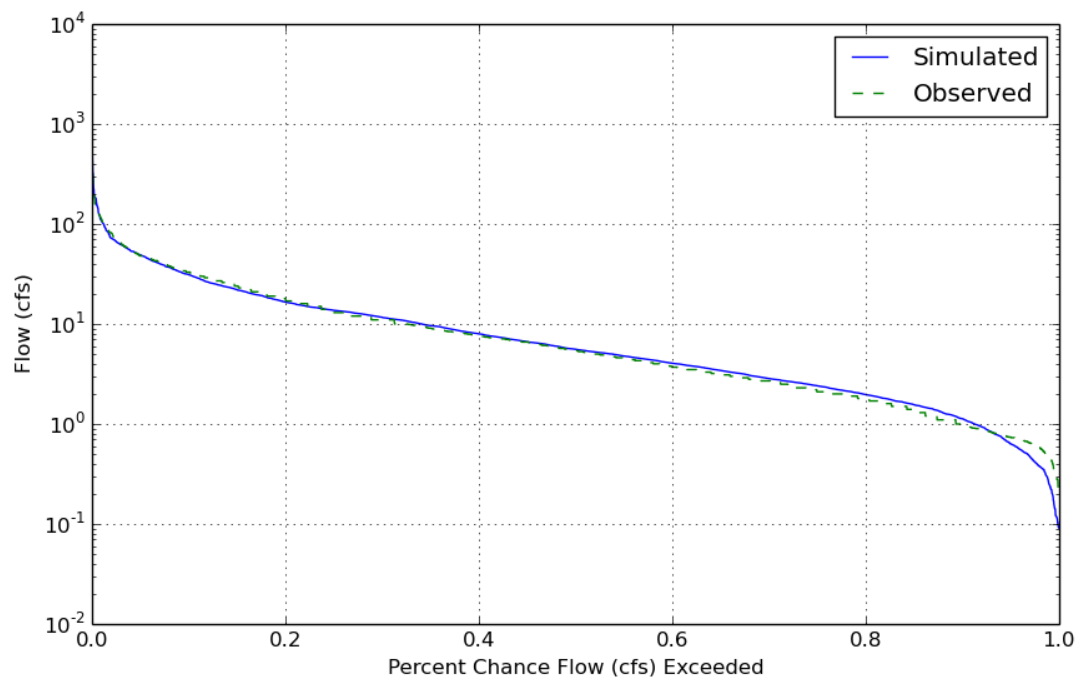


Figure A. 9 Observed and simulated daily flow frequency curves for Soldier Creek near Longwood

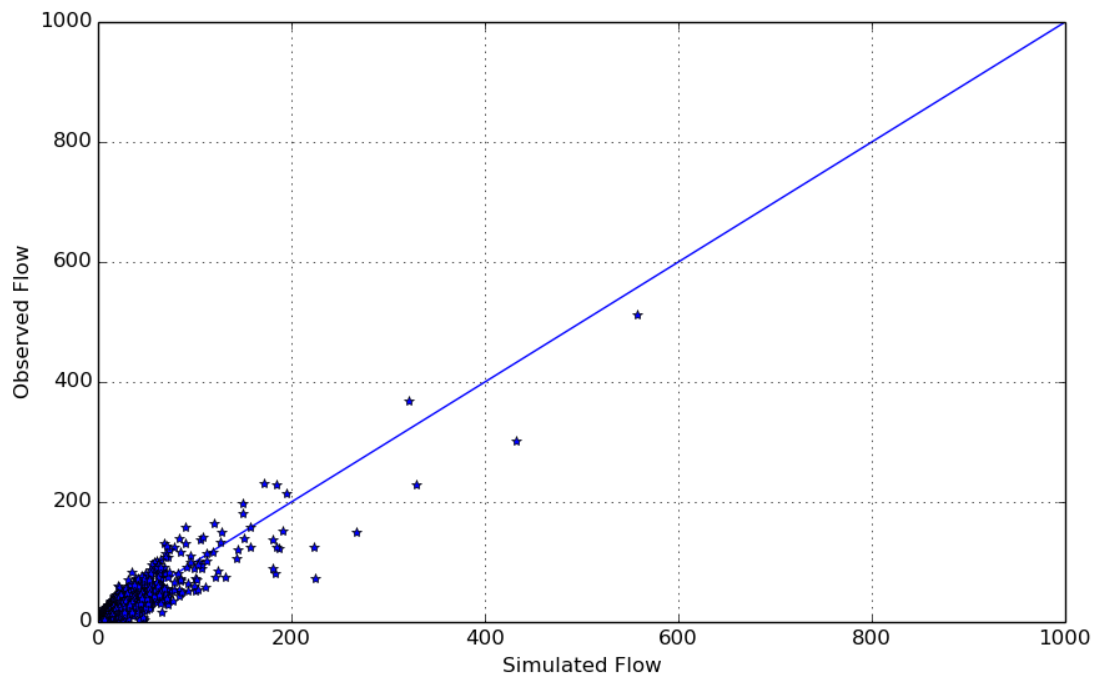


Figure A. 10 Scatter plot of observed and simulated daily flows for Soldier Creek near Longwood

Appendix B Plots of Water Quality Calibration

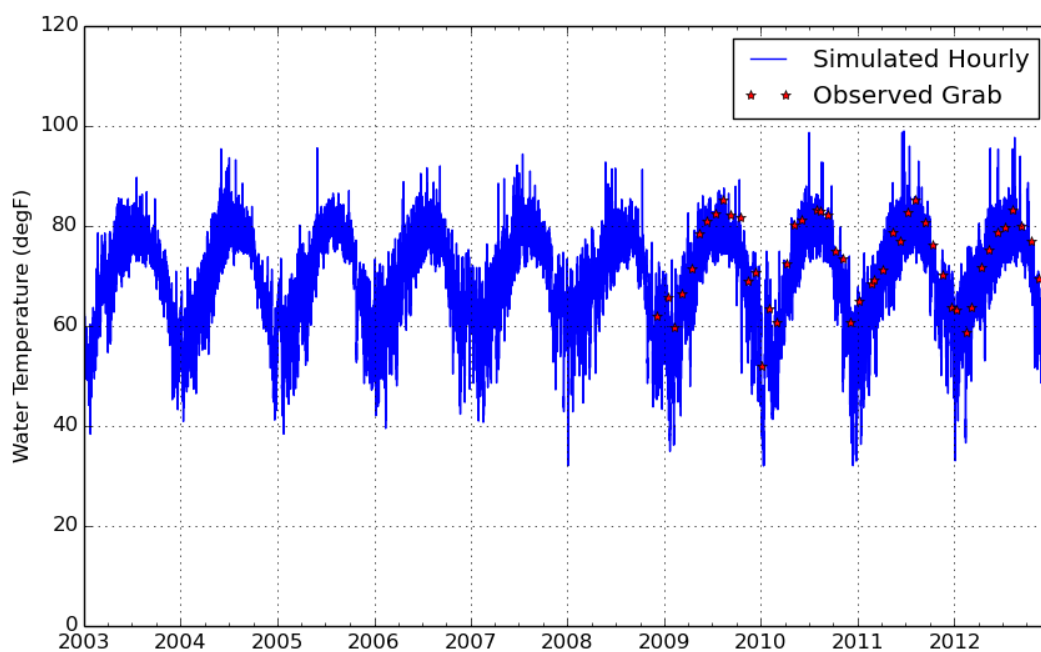


Figure B. 1 Observed grab sample and simulated hourly water temperature for Howell Creek near Oviedo

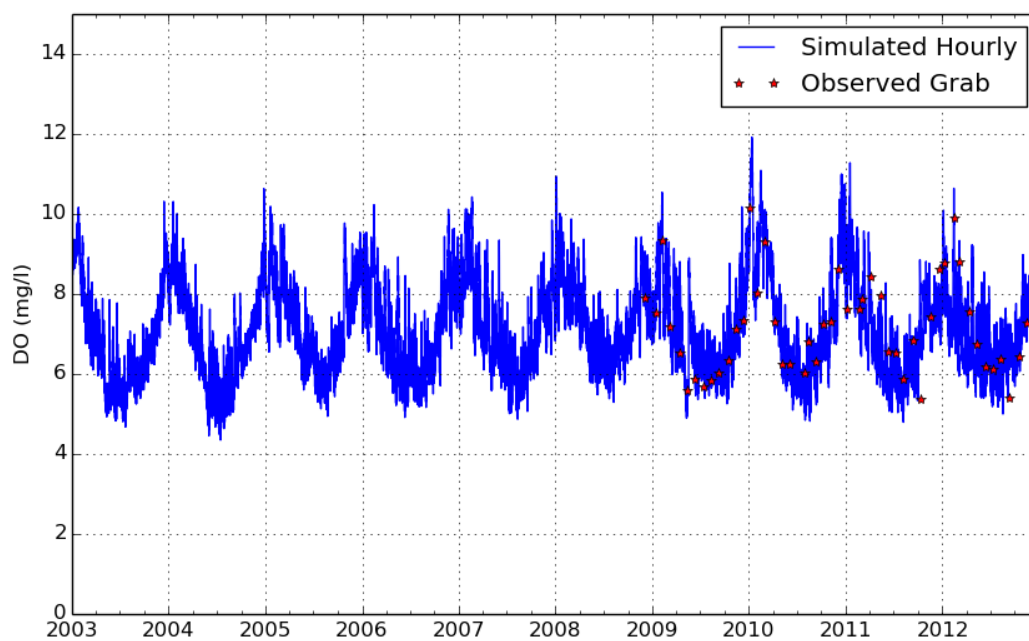


Figure B. 2 Observed grab sample and simulated hourly DO concentrations for Howell Creek near Oviedo

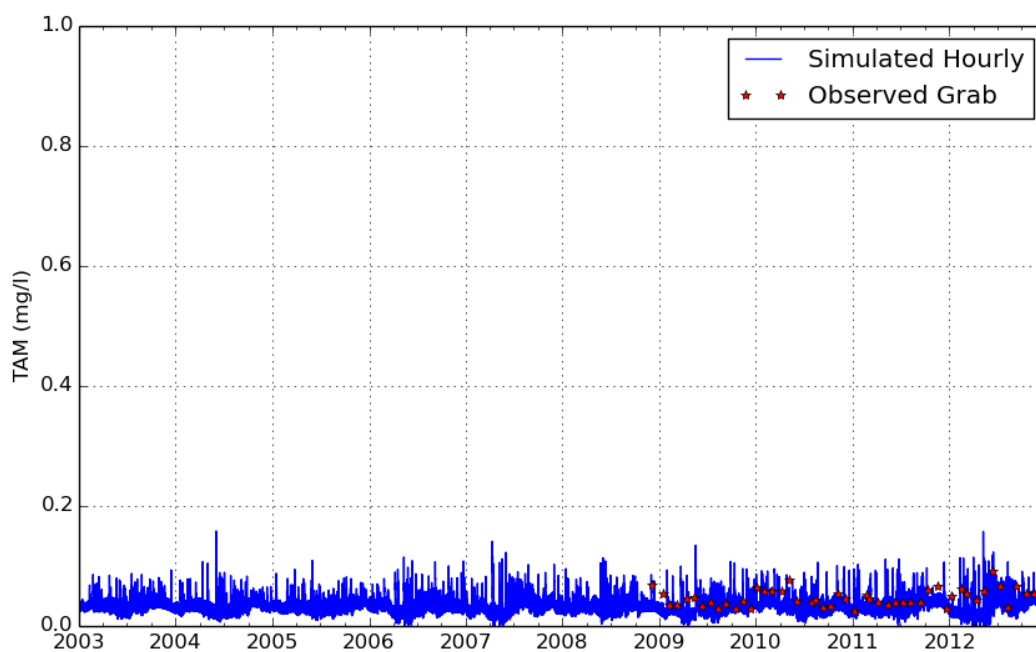


Figure B. 3 Observed grab sample and simulated hourly TAM concentrations for Howell Creek near Oviedo

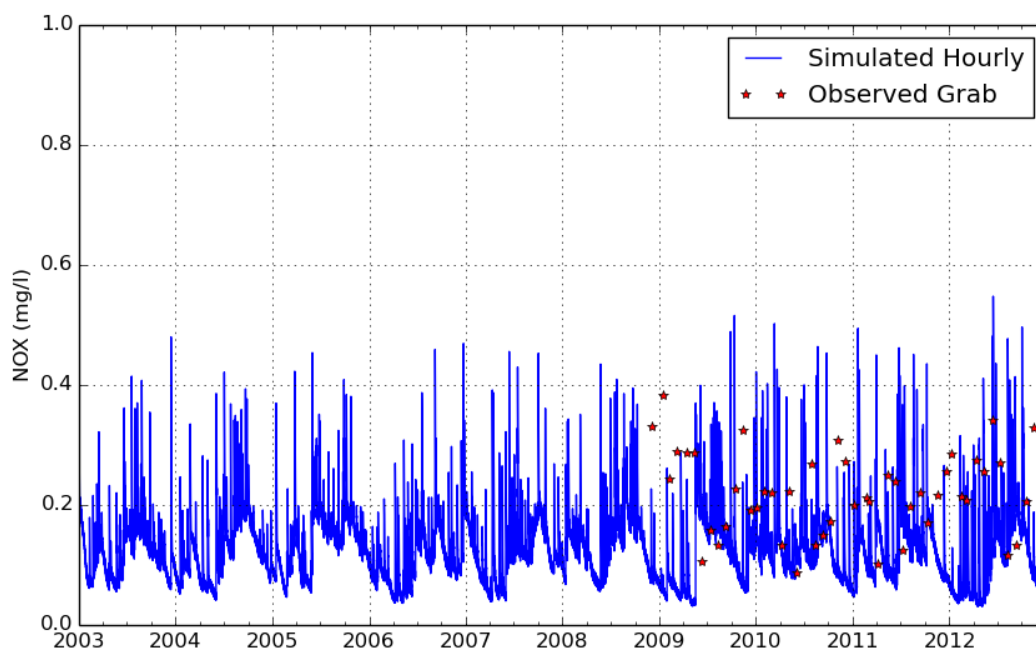


Figure B. 4 Observed grab sample and simulated hourly NOX concentrations for Howell Creek near Oviedo

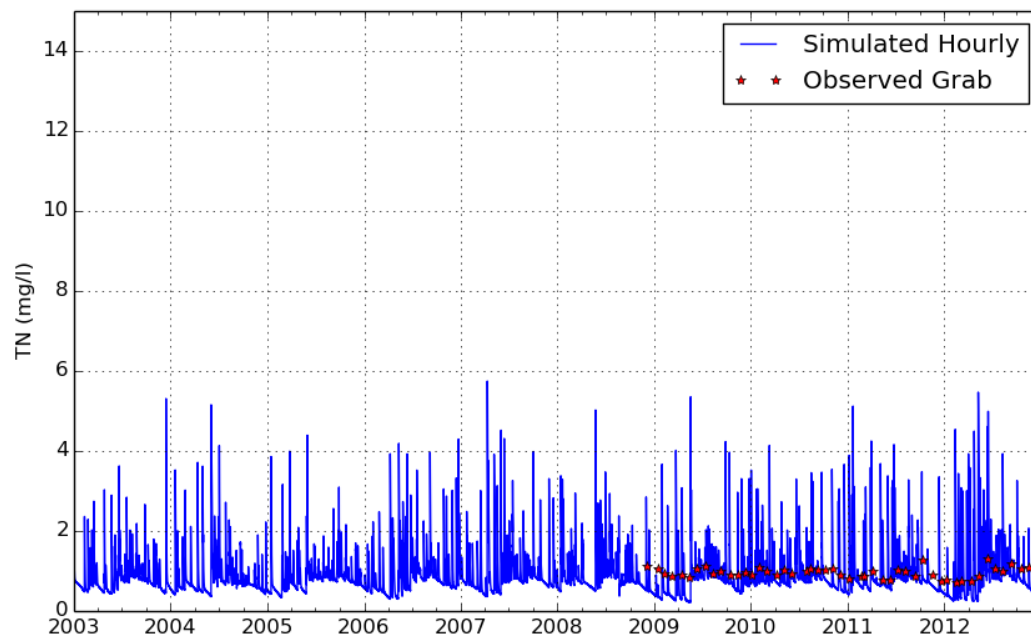


Figure B. 5 Observed grab sample and simulated hourly TN concentrations for Howell Creek near Oviedo

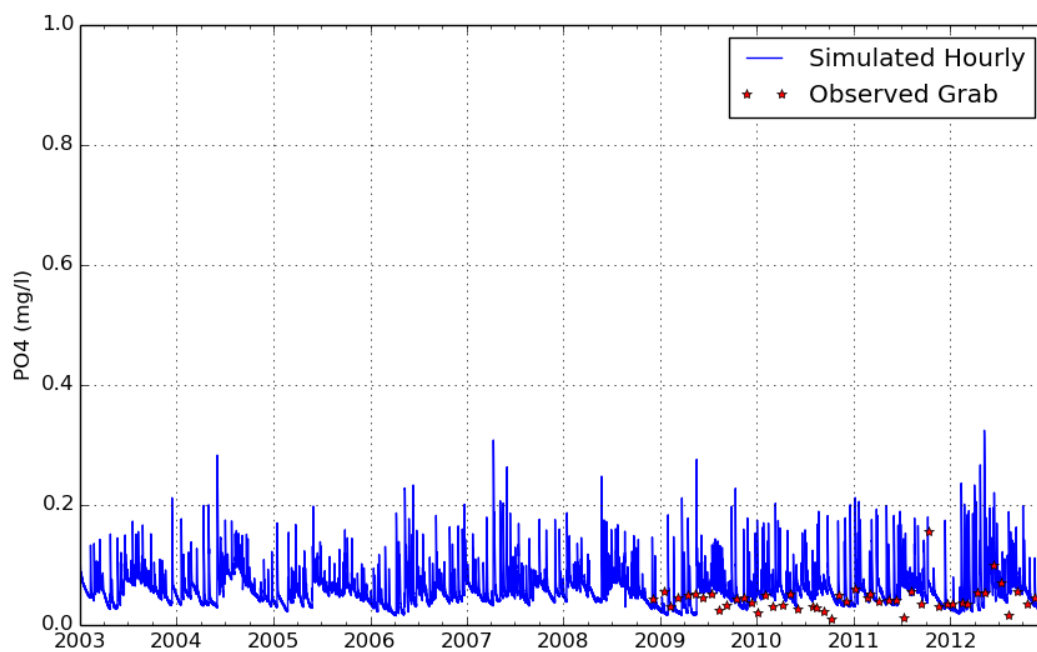


Figure B. 6 Observed grab sample and simulated hourly PO4 concentrations for Howell Creek near Oviedo

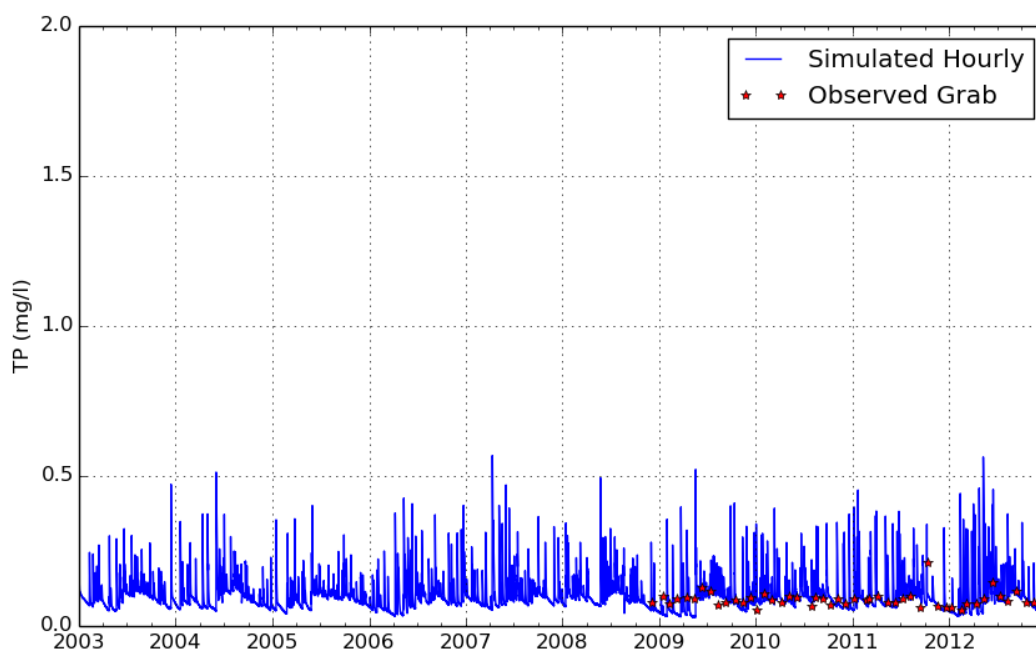


Figure B. 7 Observed grab sample and simulated hourly TP concentrations for Howell Creek near Oviedo

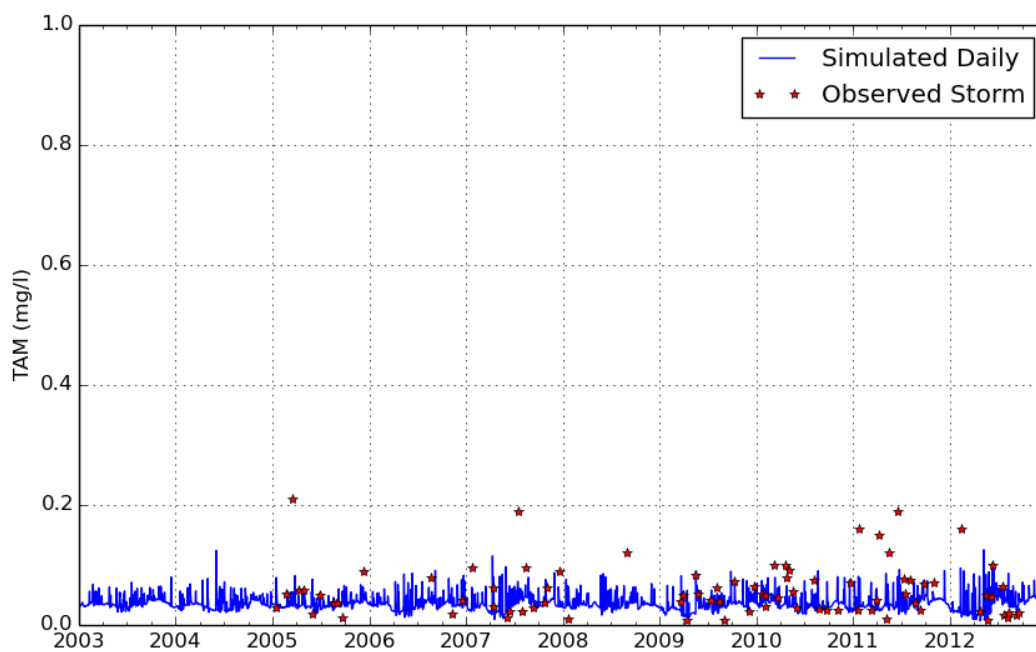


Figure B. 8 Observed storm sample and simulated daily TAM concentrations for Howell Creek near Oviedo

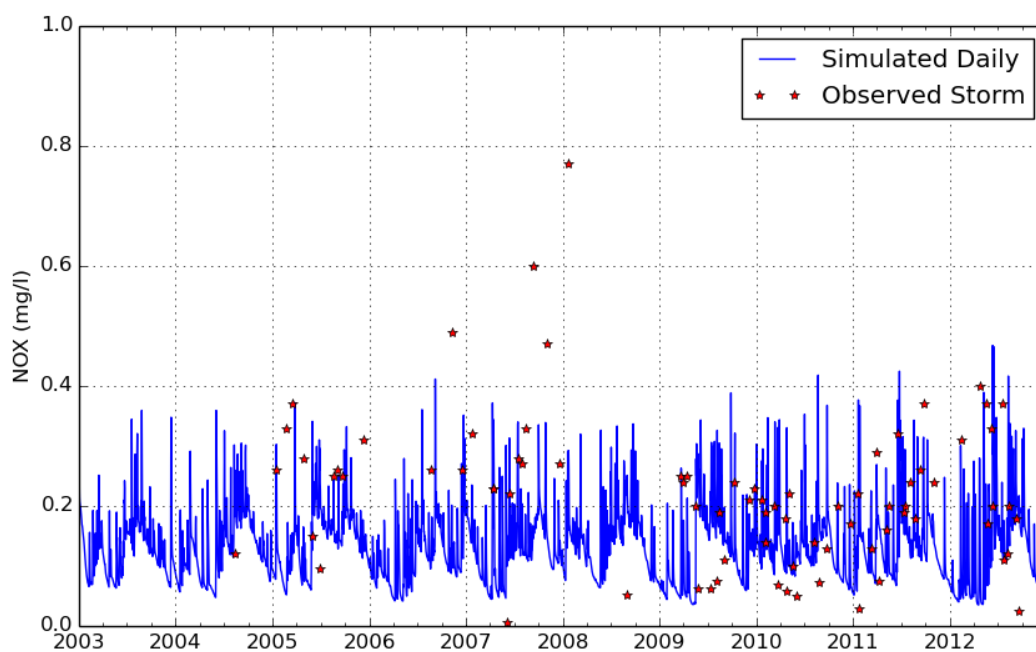


Figure B. 9 Observed storm sample and simulated daily NOX concentrations for Howell Creek near Oviedo

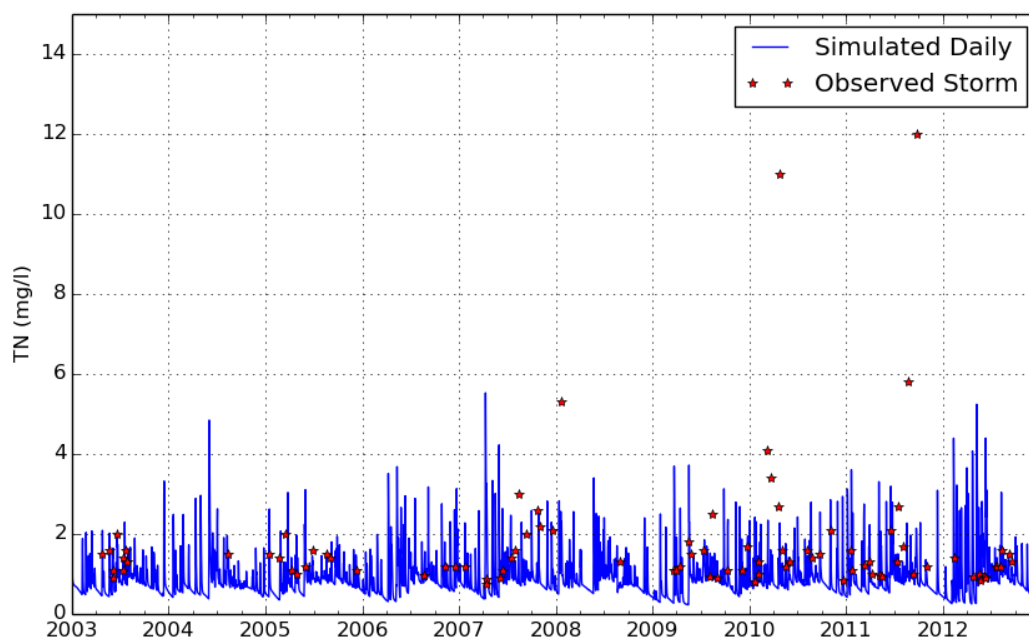


Figure B. 10 Observed storm sample and simulated daily TN concentrations for Howell Creek near Oviedo

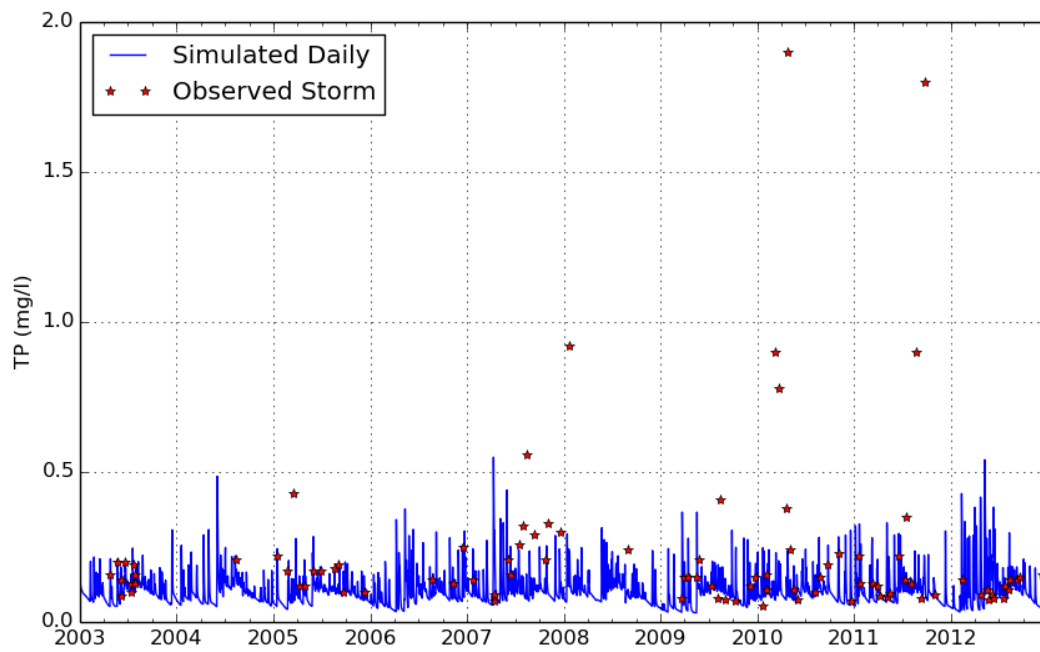


Figure B. 11 Observed storm sample and simulated daily TP concentrations for Howell Creek near Oviedo

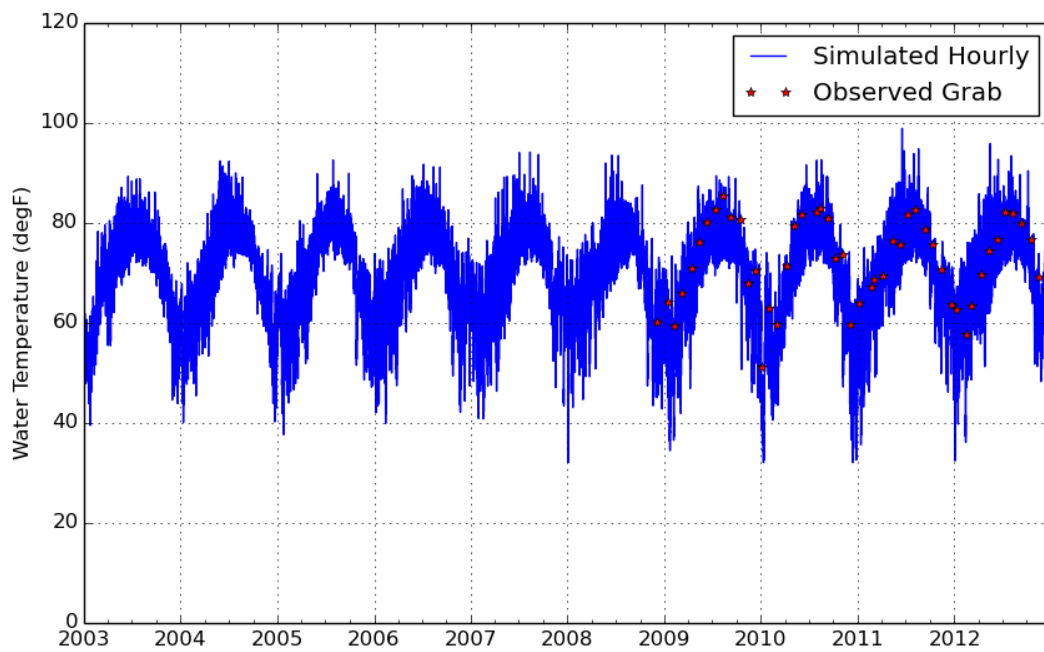


Figure B. 12 Observed grab sample and simulated hourly water temperature for Gee Creek near Longwood

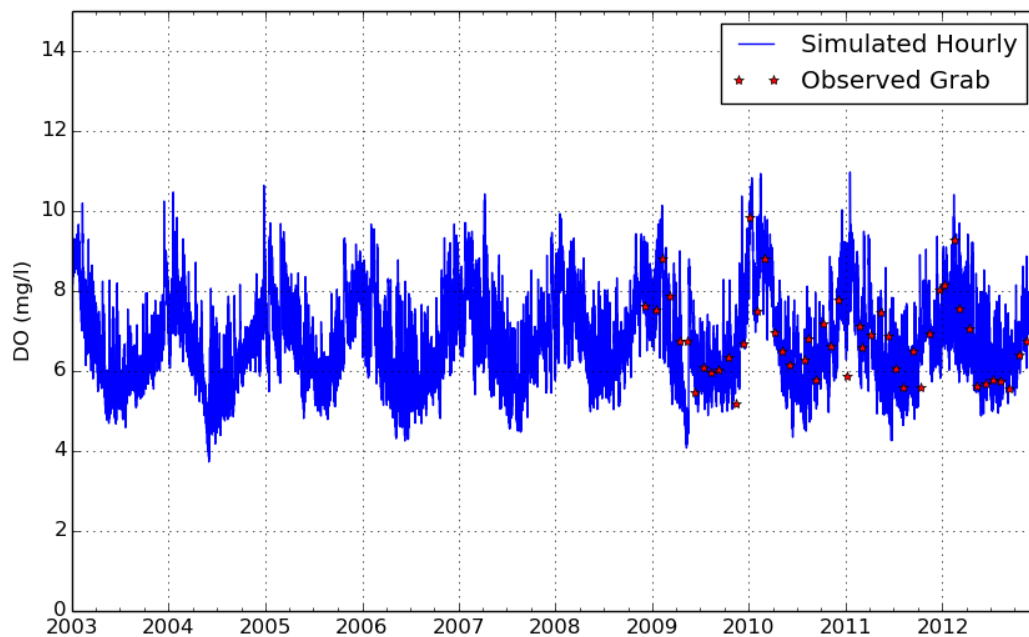


Figure B. 13 Observed grab sample and simulated hourly DO for Gee Creek near Longwood

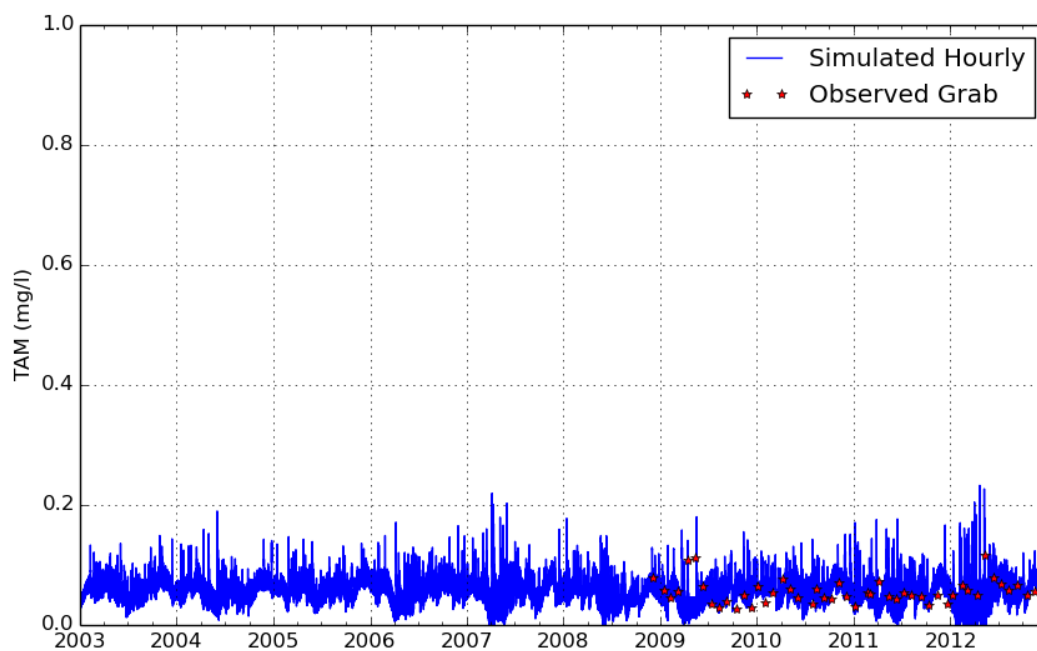


Figure B. 14 Observed grab sample and simulated hourly TAM for Gee Creek near Longwood

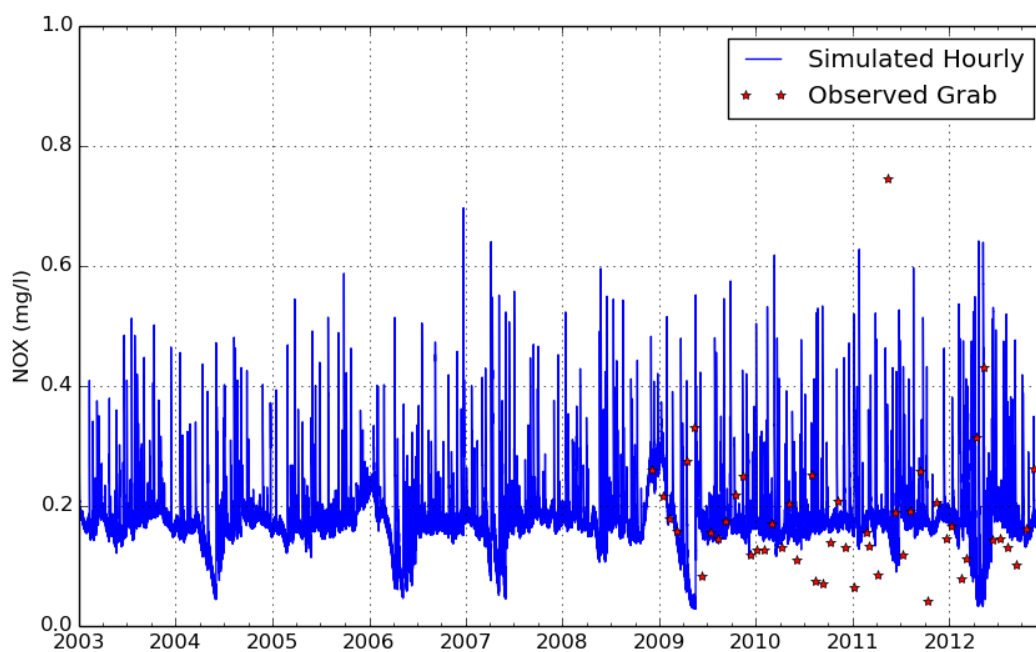


Figure B. 15 Observed grab sample and simulated hourly NOX for Gee Creek near Longwood

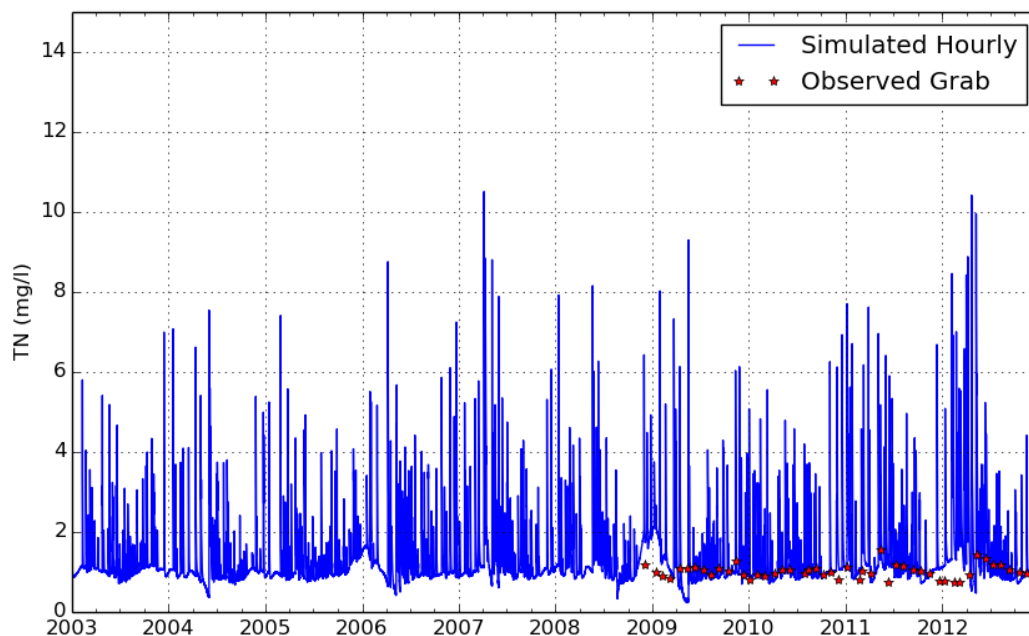


Figure B. 16 Observed grab sample and simulated hourly TN for Gee Creek near Longwood

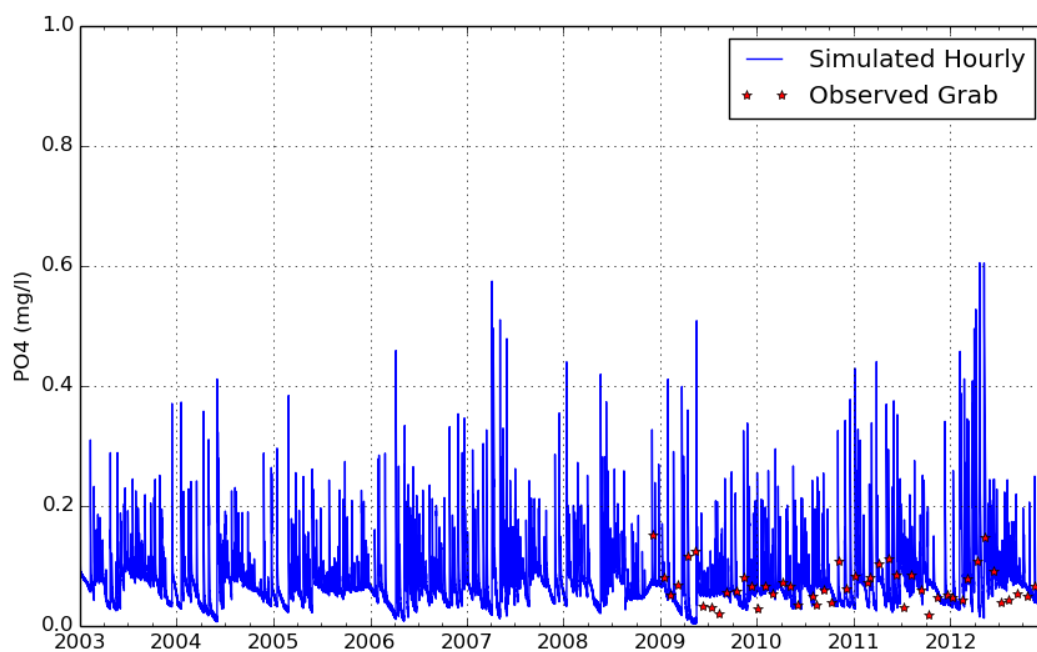


Figure B. 17 Observed grab sample and simulated hourly PO4 for Gee Creek near Longwood

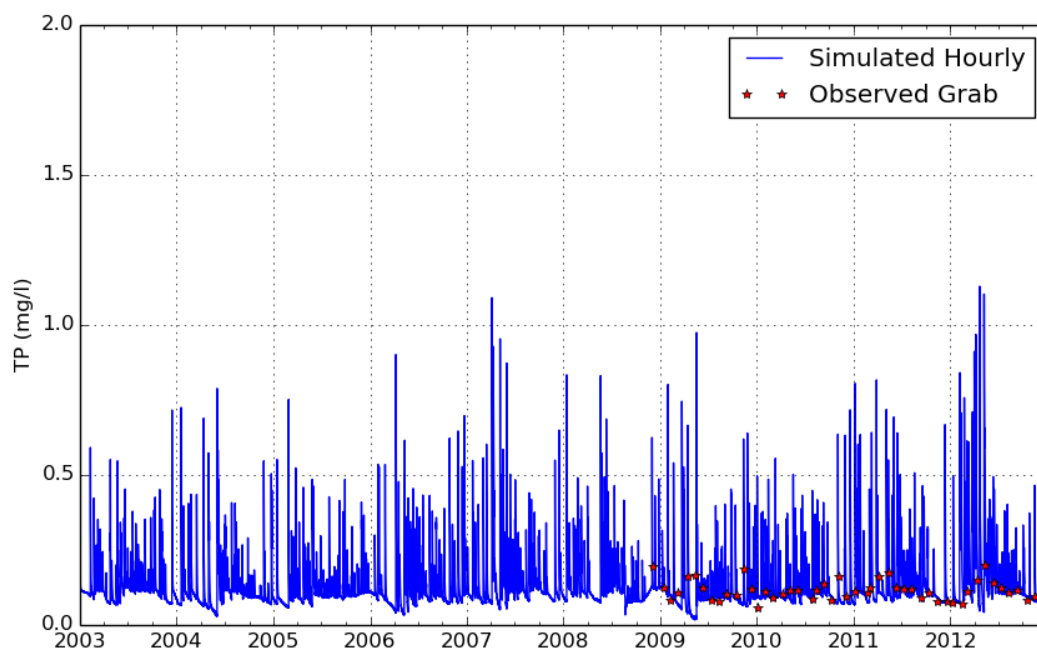


Figure B. 18 Observed grab sample and simulated hourly TP for Gee Creek near Longwood

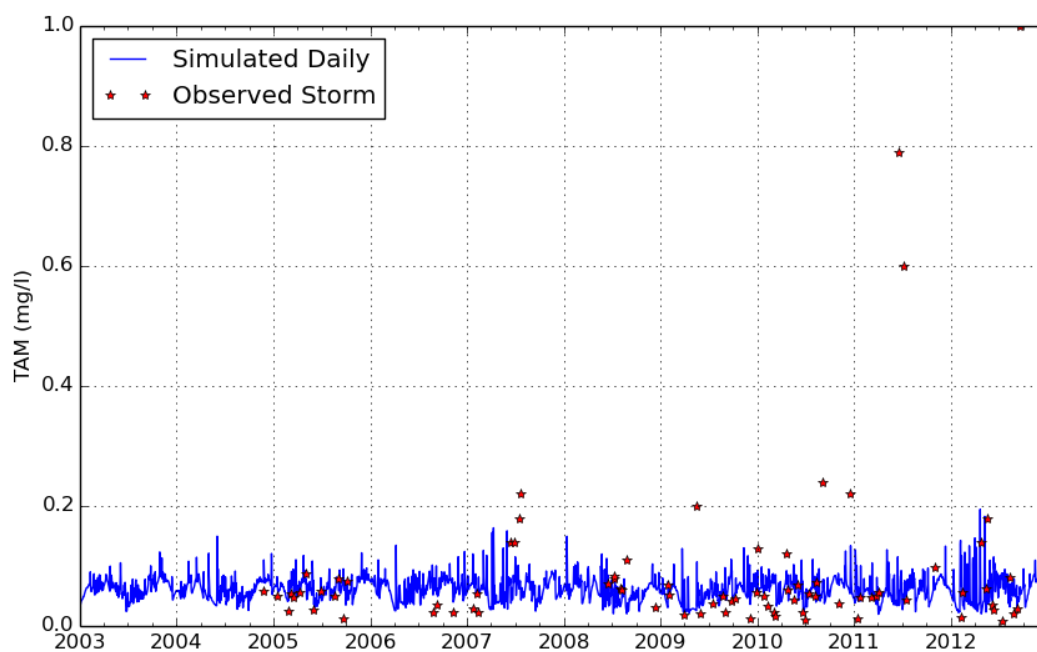


Figure B. 19 Observed storm sample and simulated daily TAM concentrations for Gee Creek near Longwood

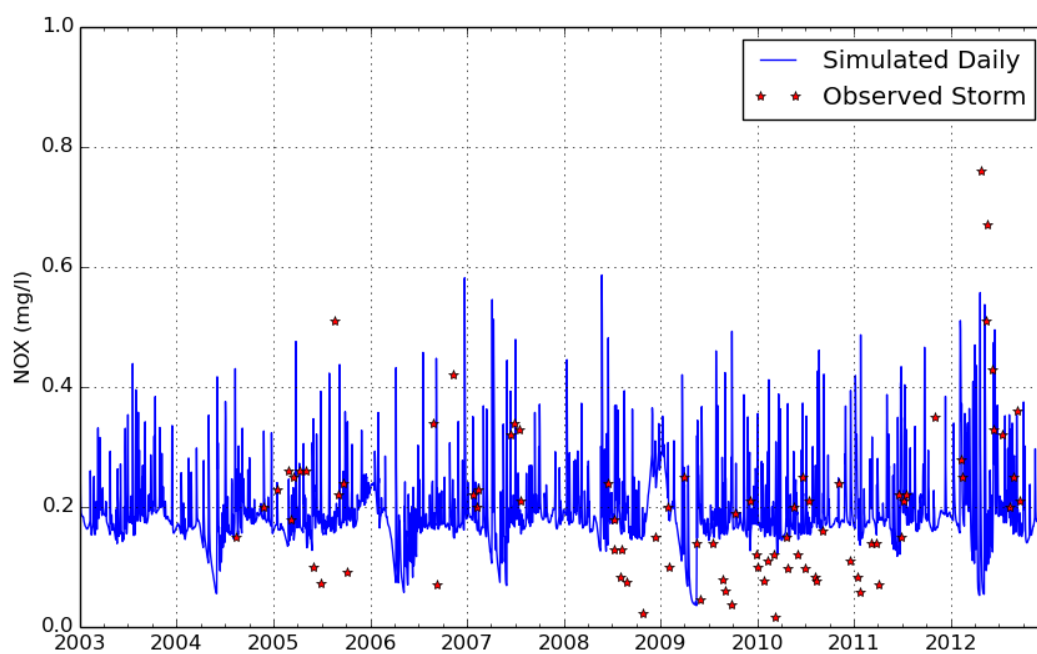


Figure B. 20 Observed storm sample and simulated daily NOX concentrations for Gee Creek near Longwood

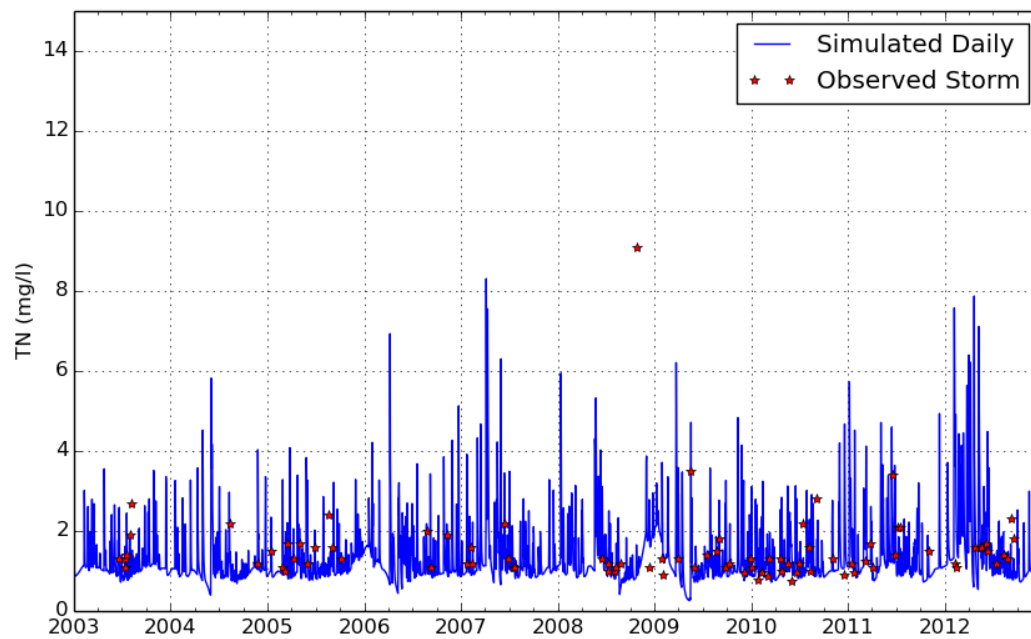


Figure B. 21 Observed storm sample and simulated daily TN concentrations for Gee Creek near Longwood

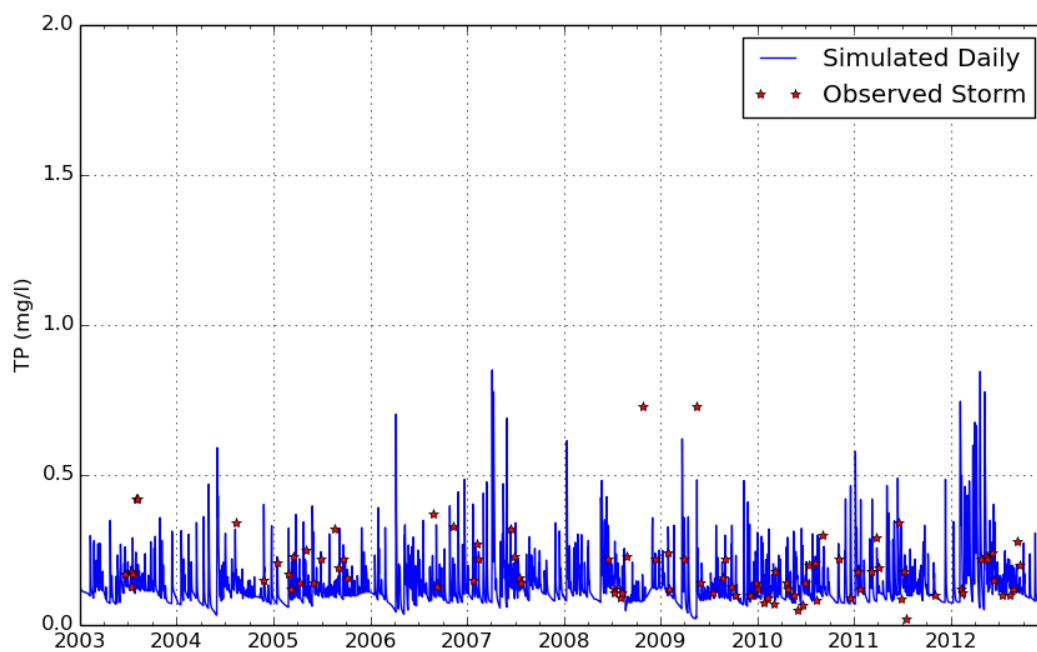


Figure B. 22 Observed storm sample and simulated daily TP concentrations for Gee Creek near Longwood

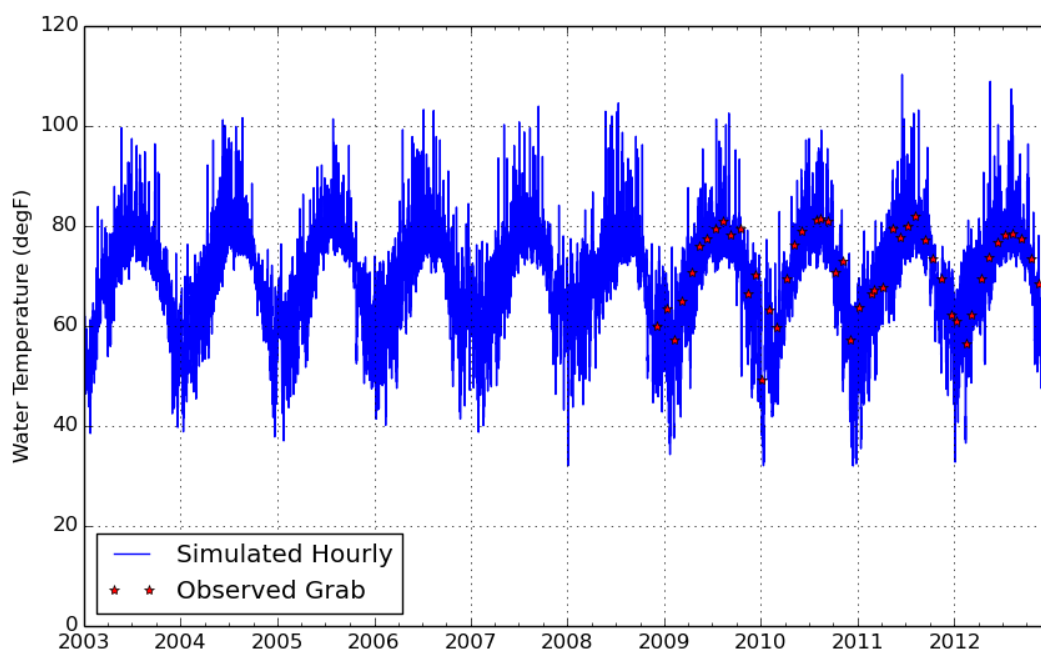


Figure B. 23 Observed grab sample and simulated hourly water temperature for Soldier Creek near Longwood

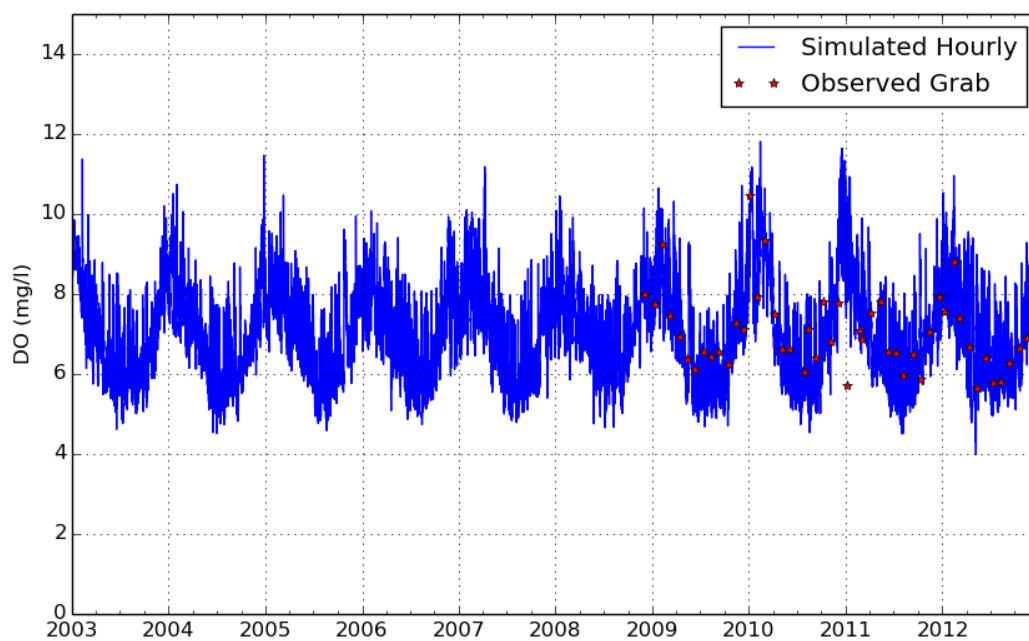


Figure B. 24 Observed grab sample and simulated hourly DO for Soldier Creek near Longwood

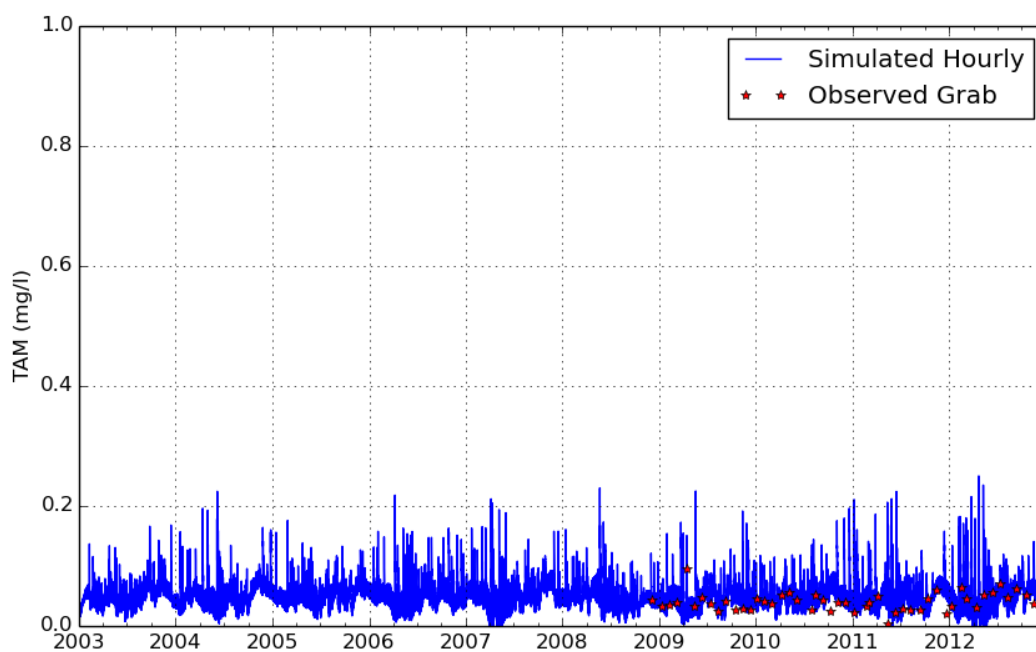


Figure B. 25 Observed grab sample and simulated hourly TAM for Soldier Creek near Longwood

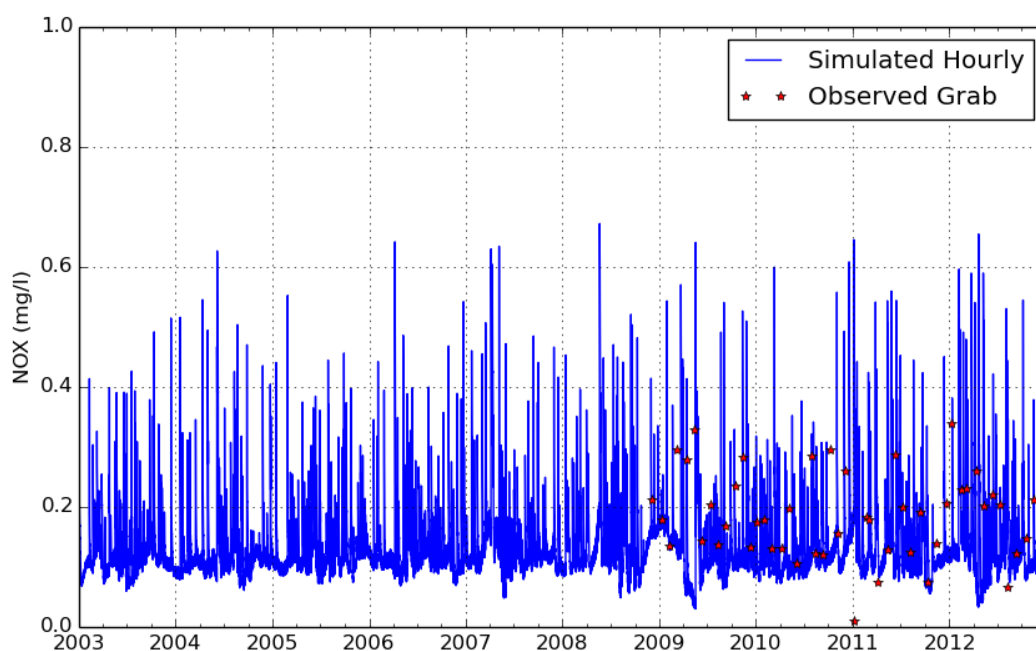


Figure B. 26 Observed grab sample and simulated hourly NOX for Soldier Creek near Longwood

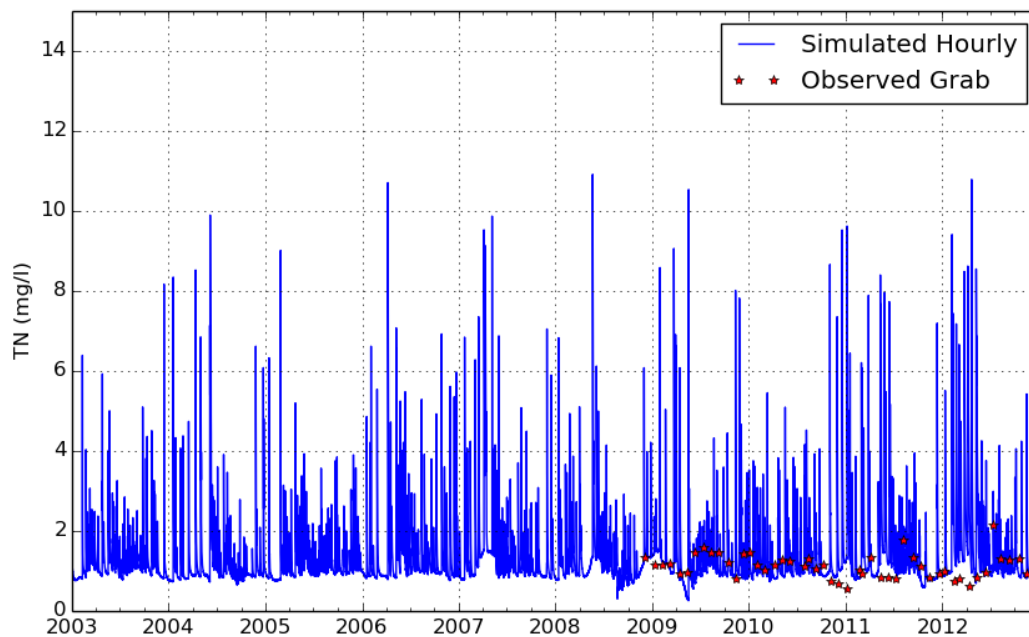


Figure B. 27 Observed grab sample and simulated hourly TN for Soldier Creek near Longwood

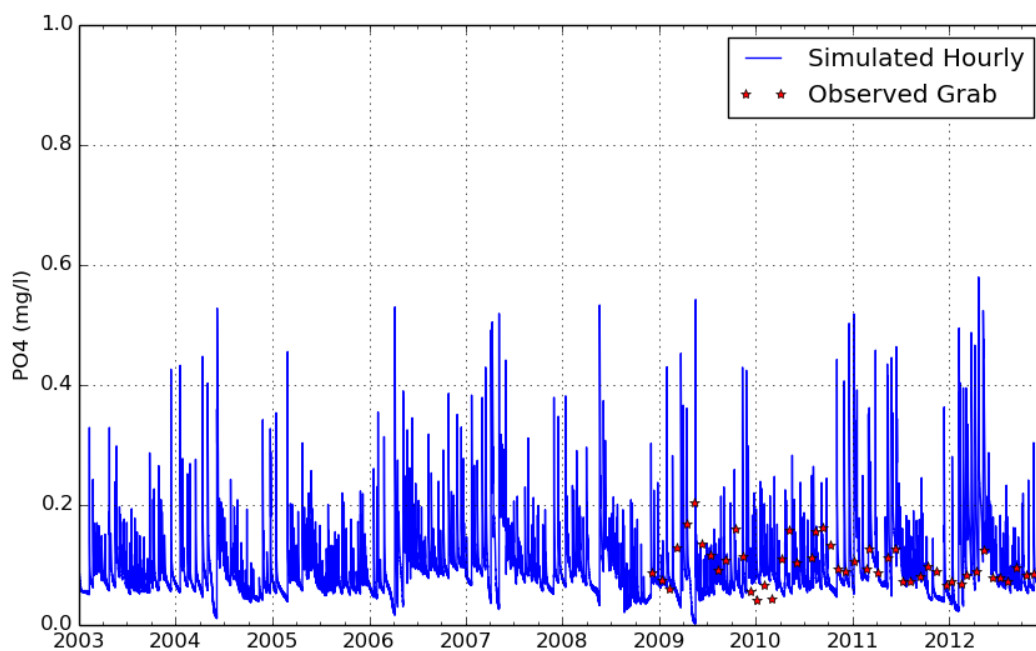


Figure B. 28 Observed grab sample and simulated hourly PO4 for Soldier Creek near Longwood

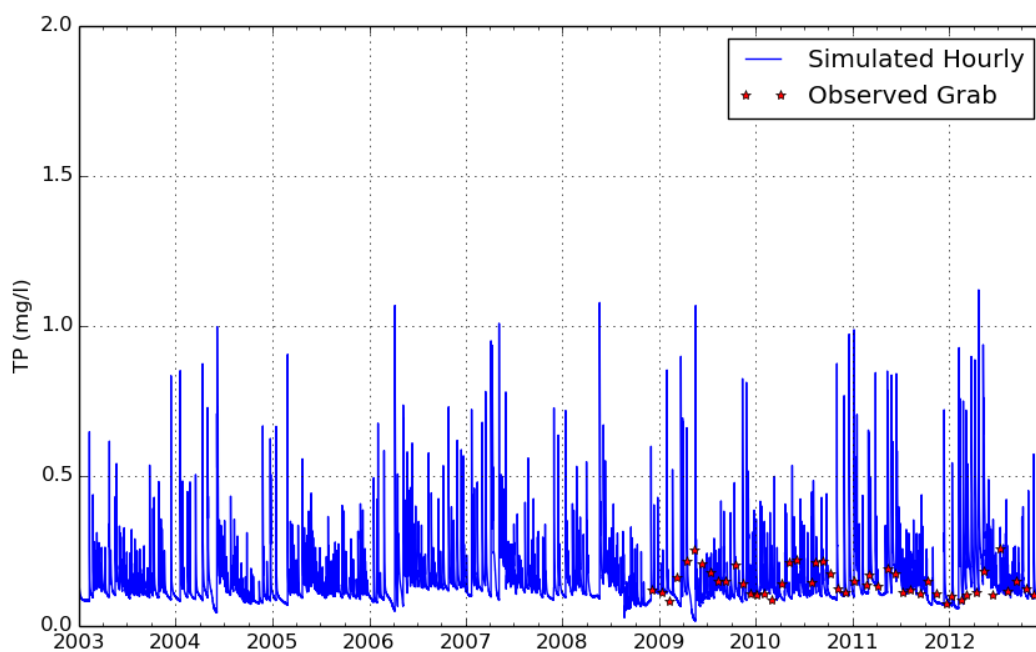


Figure B. 29 Observed grab sample and simulated hourly TP for Soldier Creek near Longwood

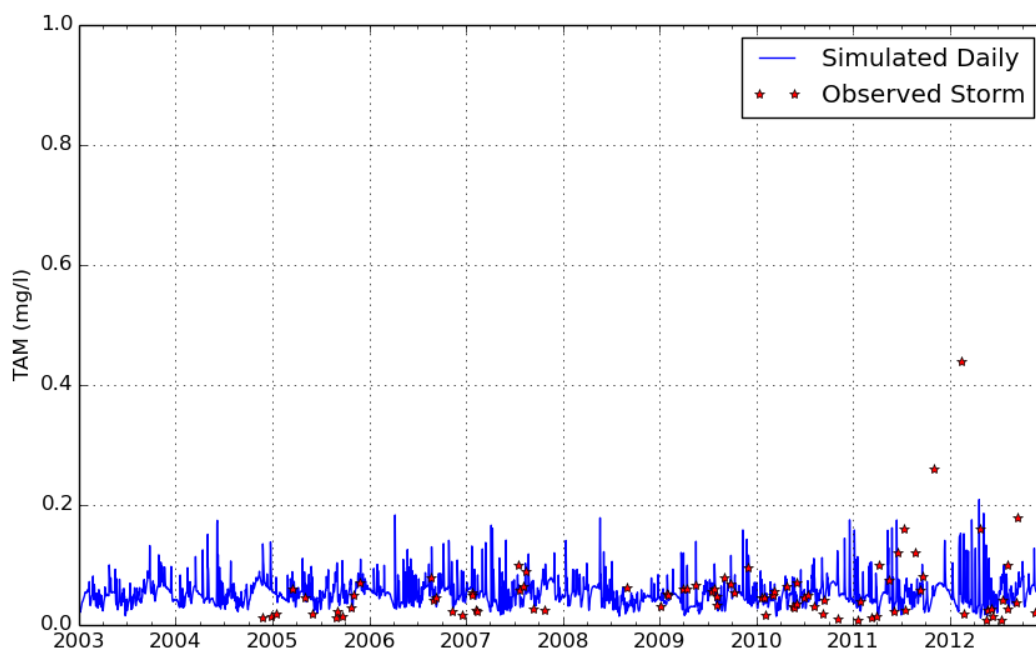


Figure B. 30 Observed storm sample and simulated daily TAM for Soldier Creek near Longwood

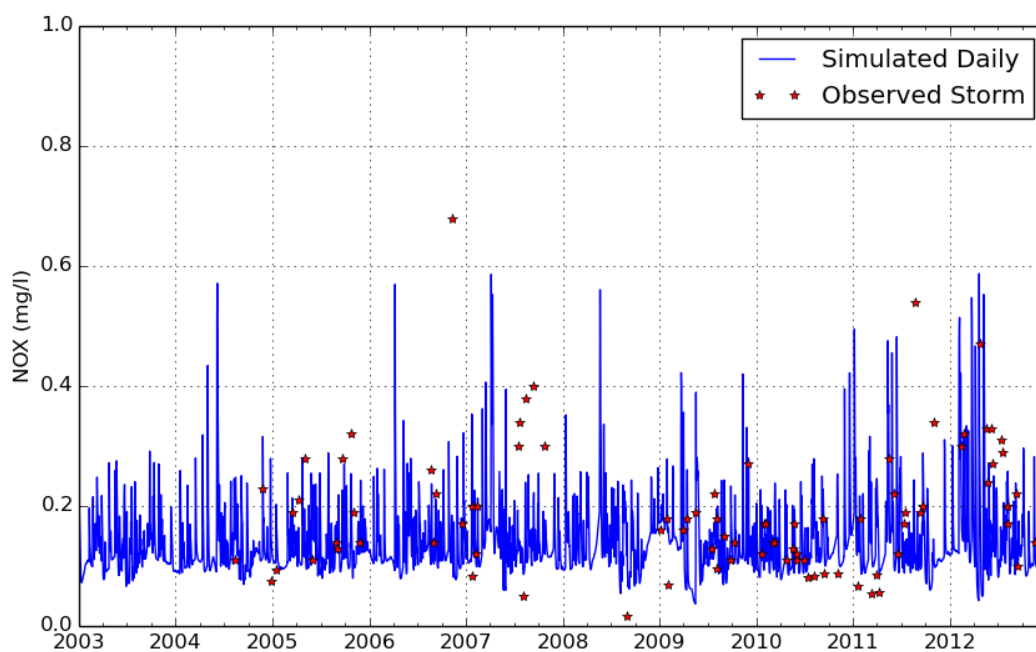


Figure B. 31 Observed storm sample and simulated daily NOX for Soldier Creek near Longwood

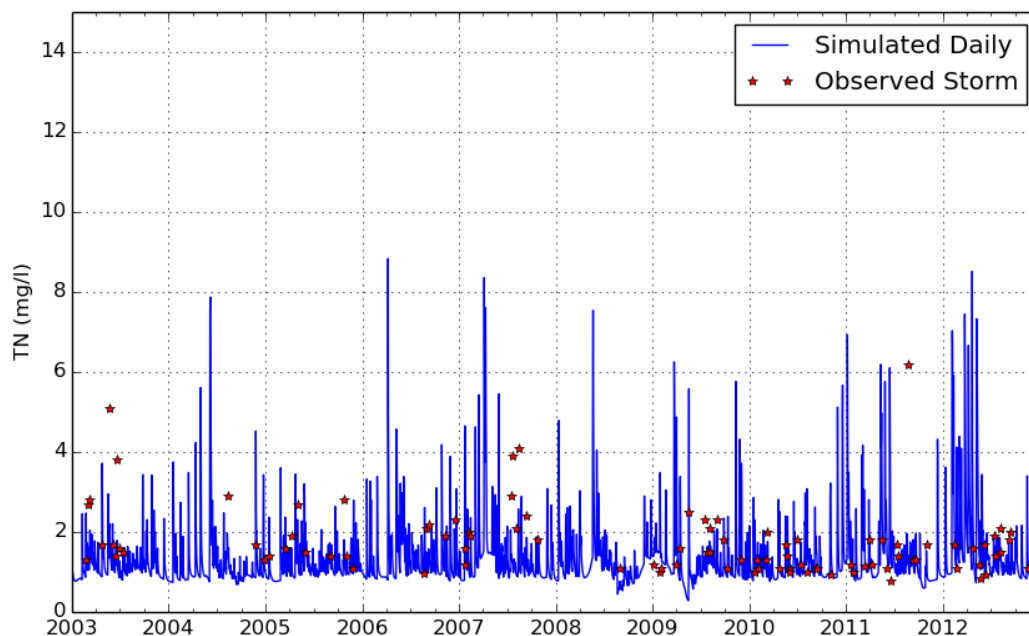


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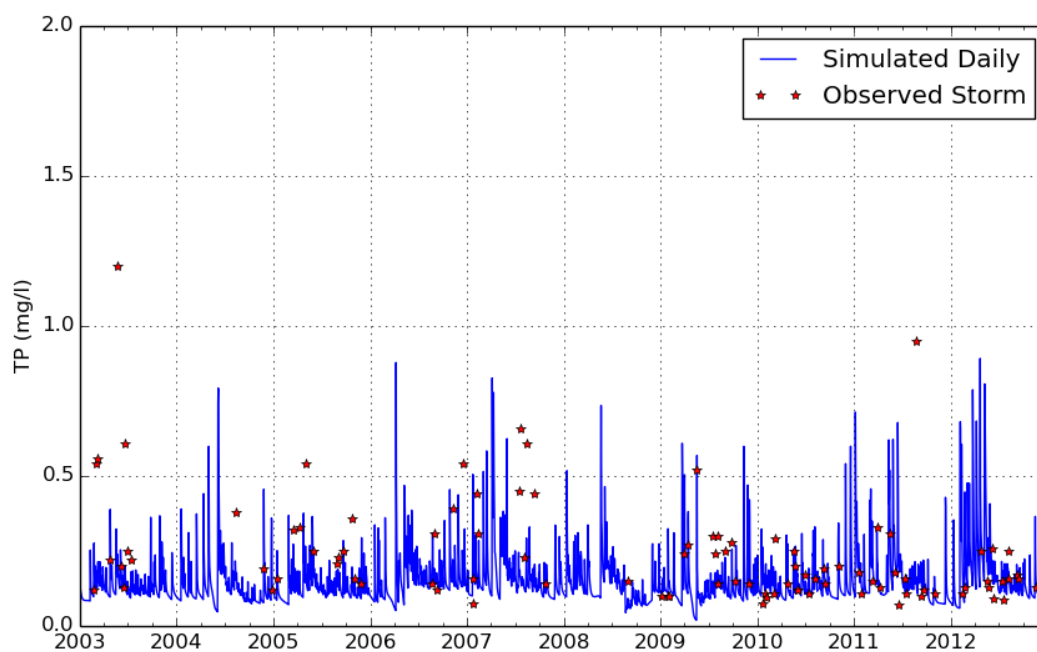


Figure B. 33 Observed storm sample and simulated daily TP for Soldier Creek near Longwood

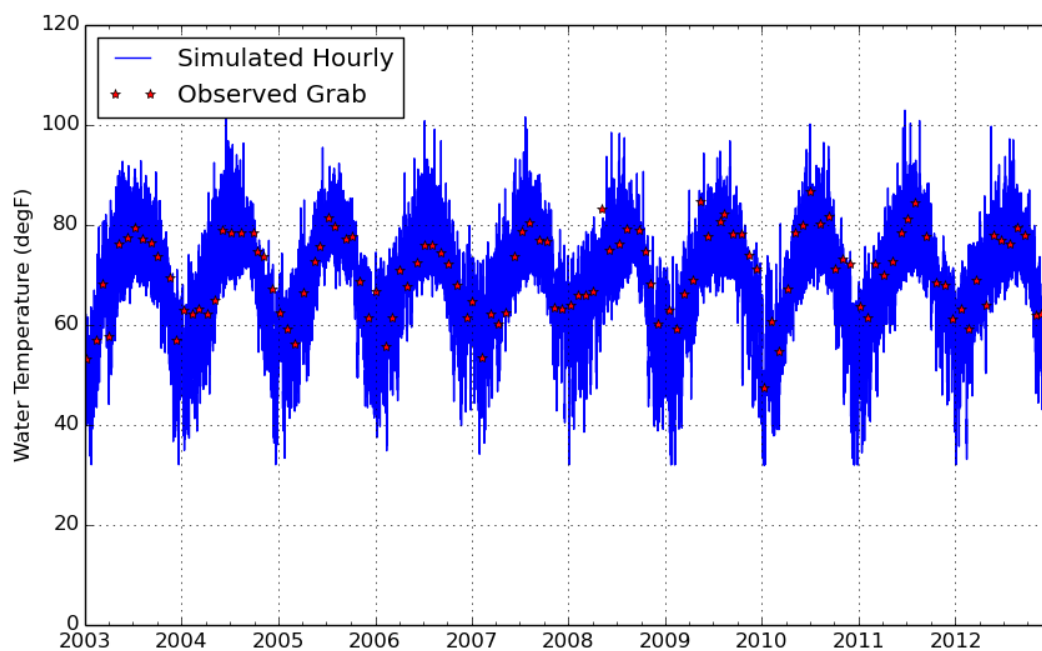


Figure B. 34 Observed grab sample and simulated hourly water temperature for Six Mile Creek

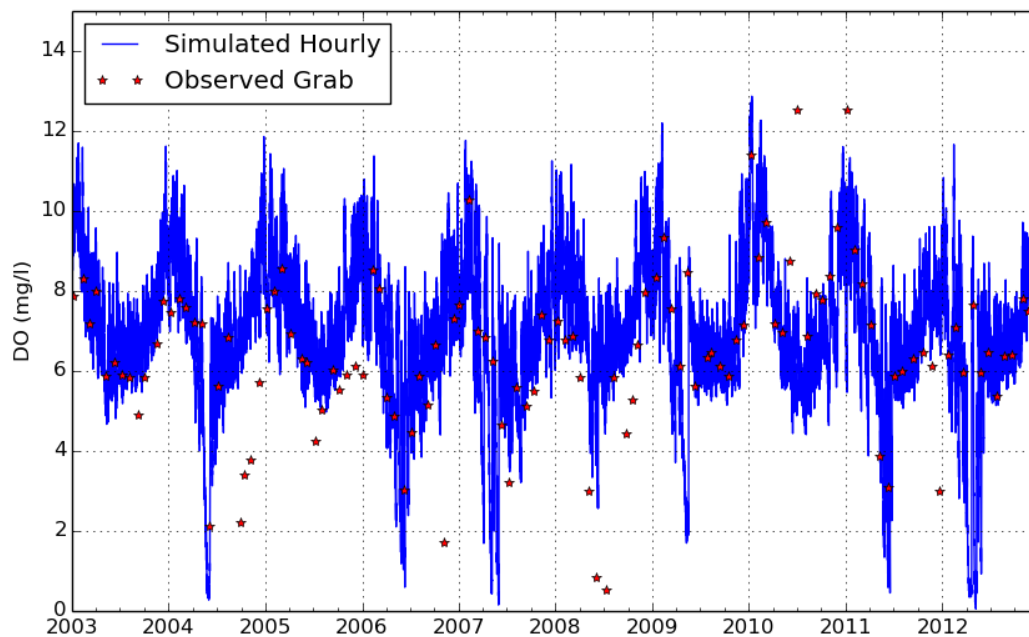


Figure B. 35 Observed grab sample and simulated hourly DO for Six Mile Creek

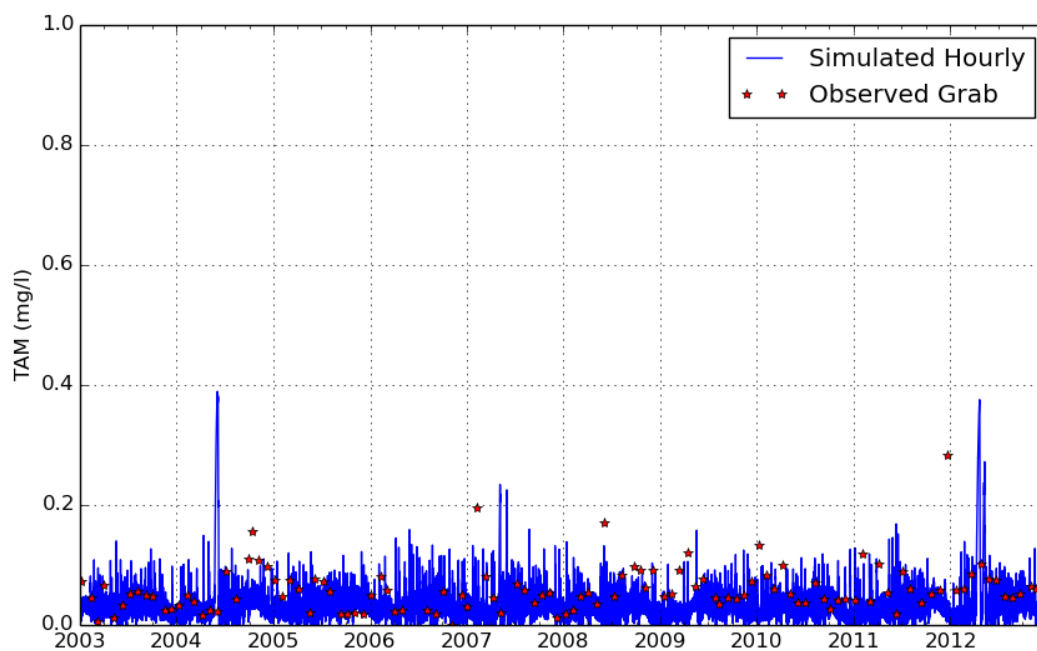


Figure B. 36 Observed grab sample and simulated hourly TAM for Six Mile Creek

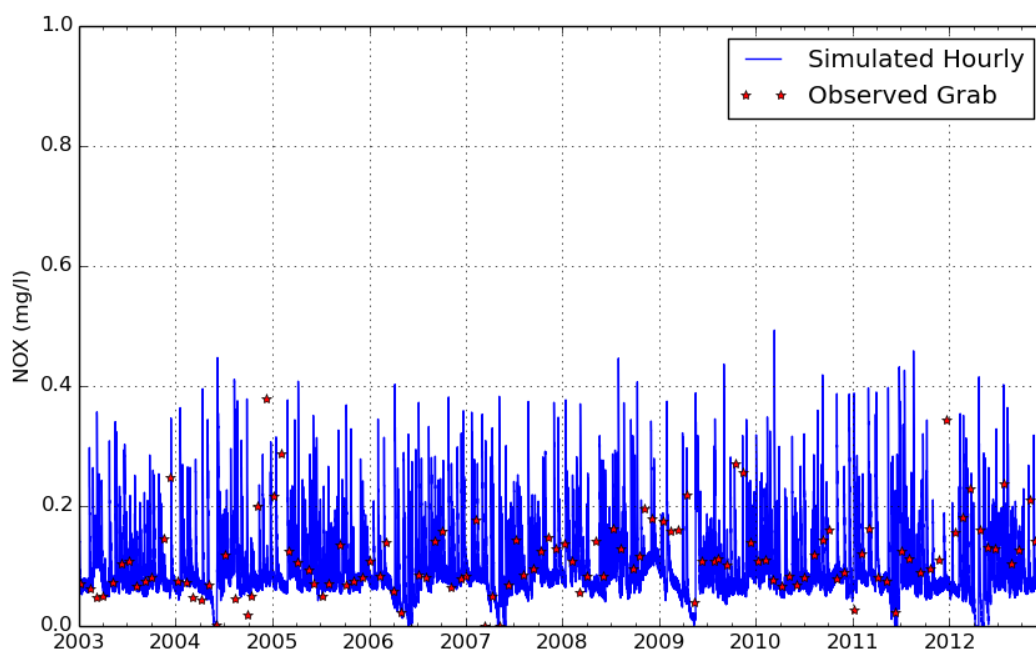


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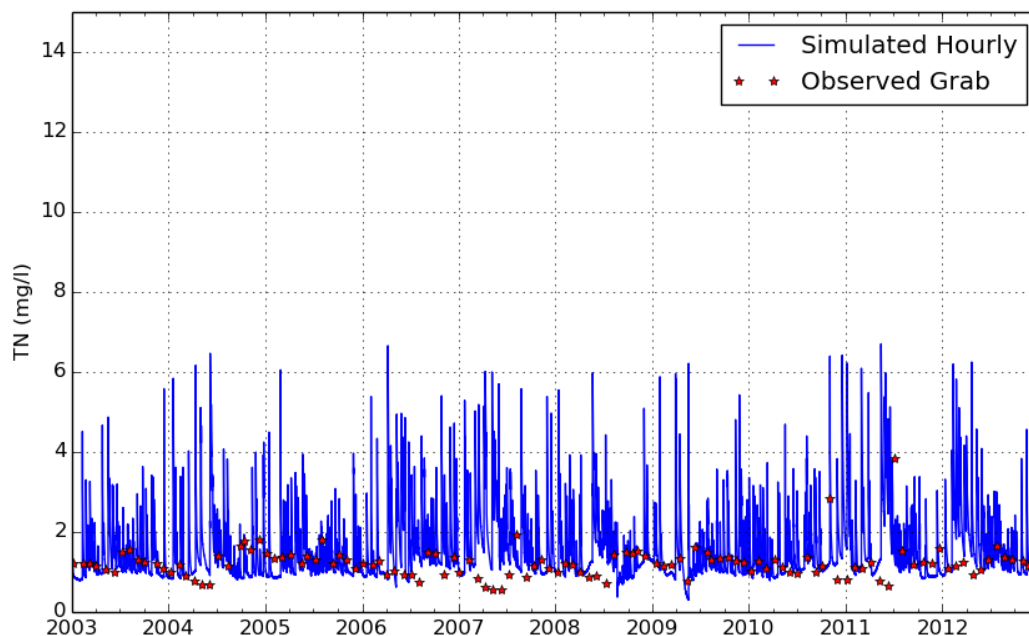


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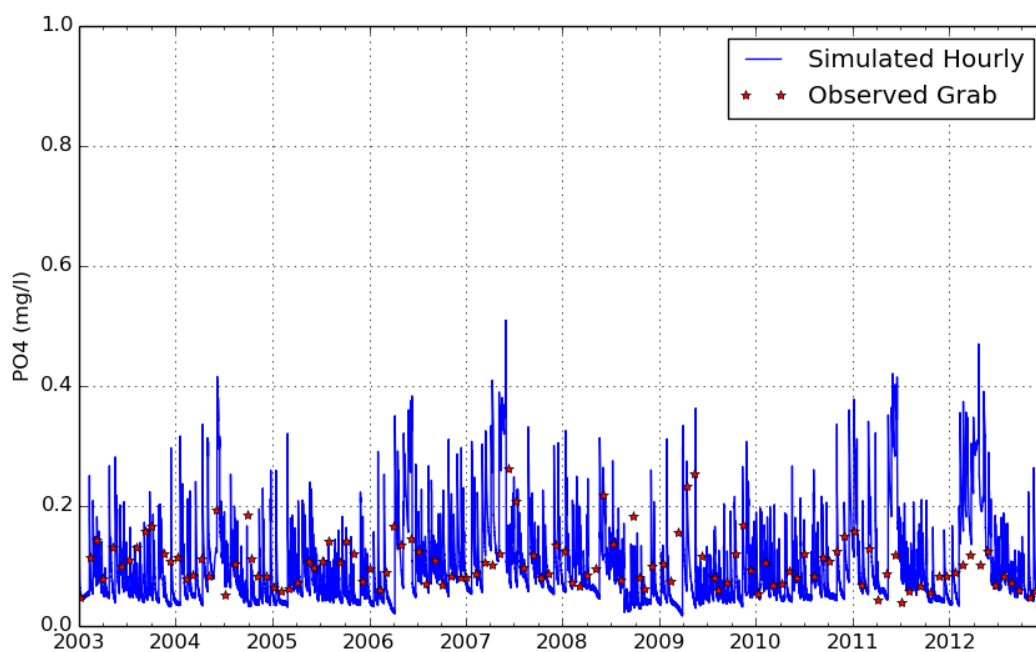


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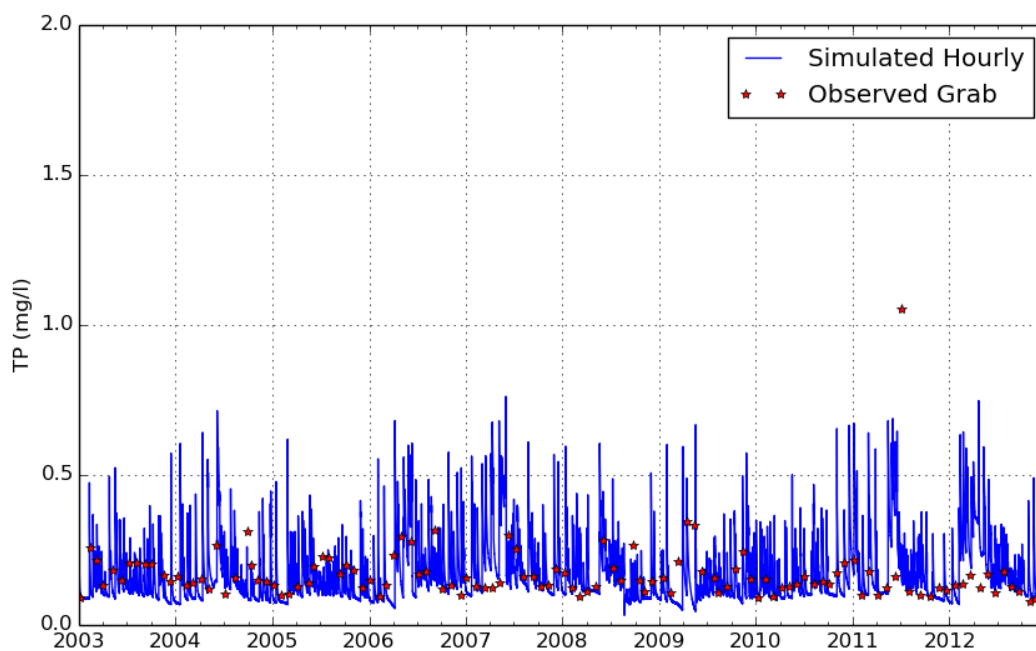


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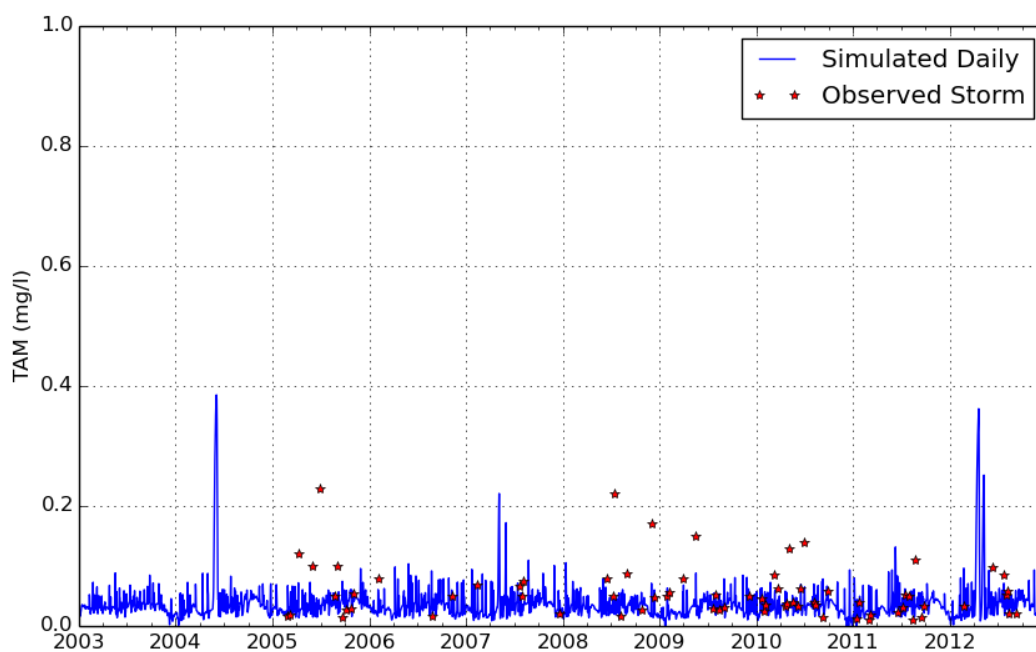


Figure B. 41 Observed storm sample and simulated daily TAM for Six Mile Creek

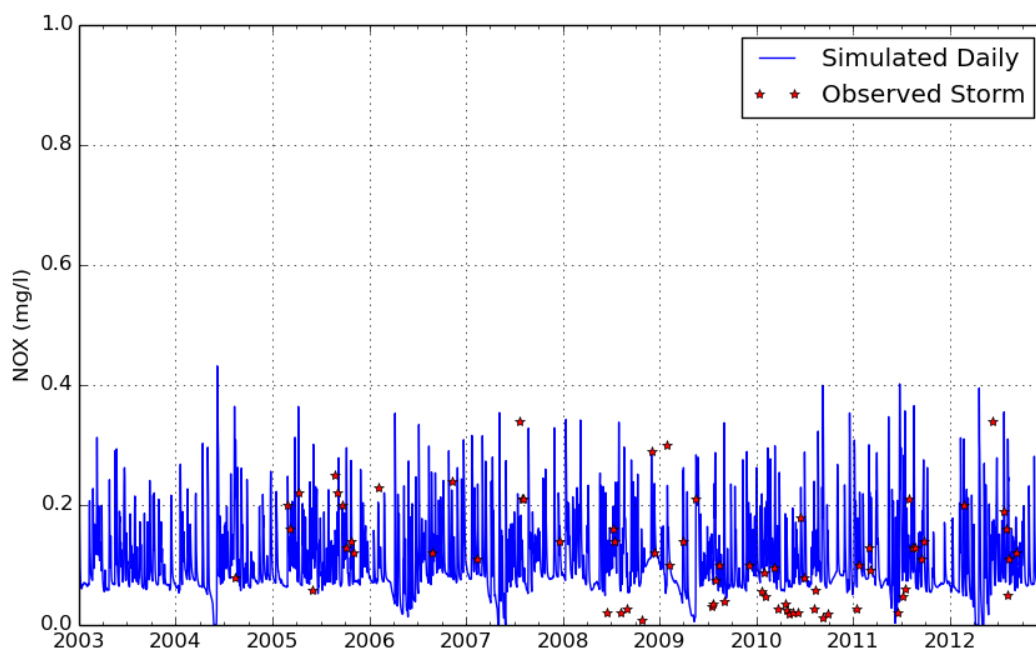


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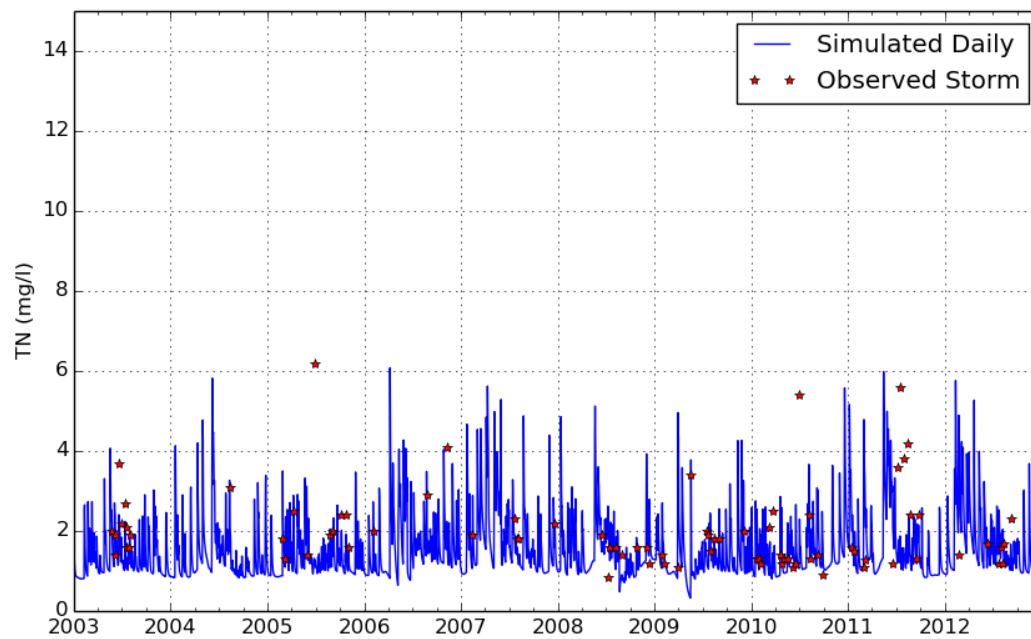


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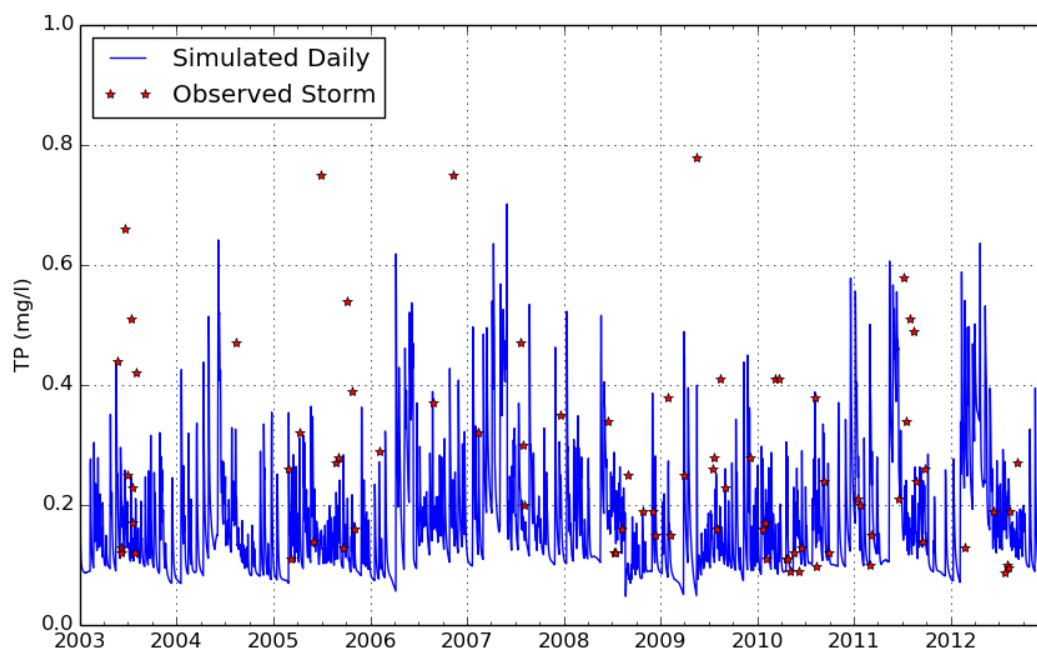


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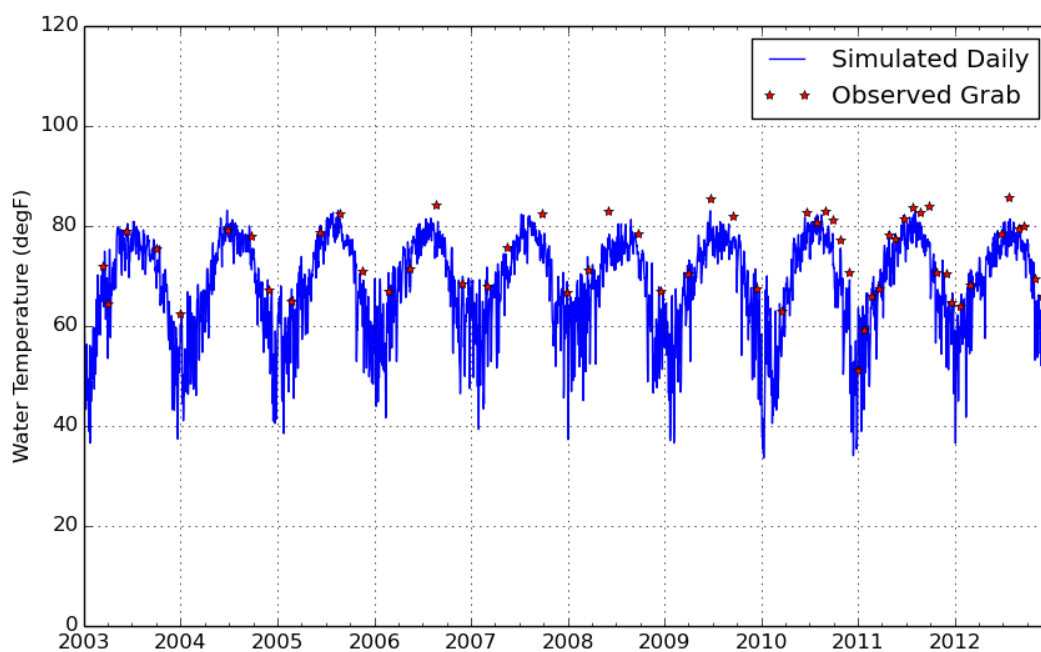


Figure B. 45 Observed grab sample and simulated daily water temperature for Navy Canal

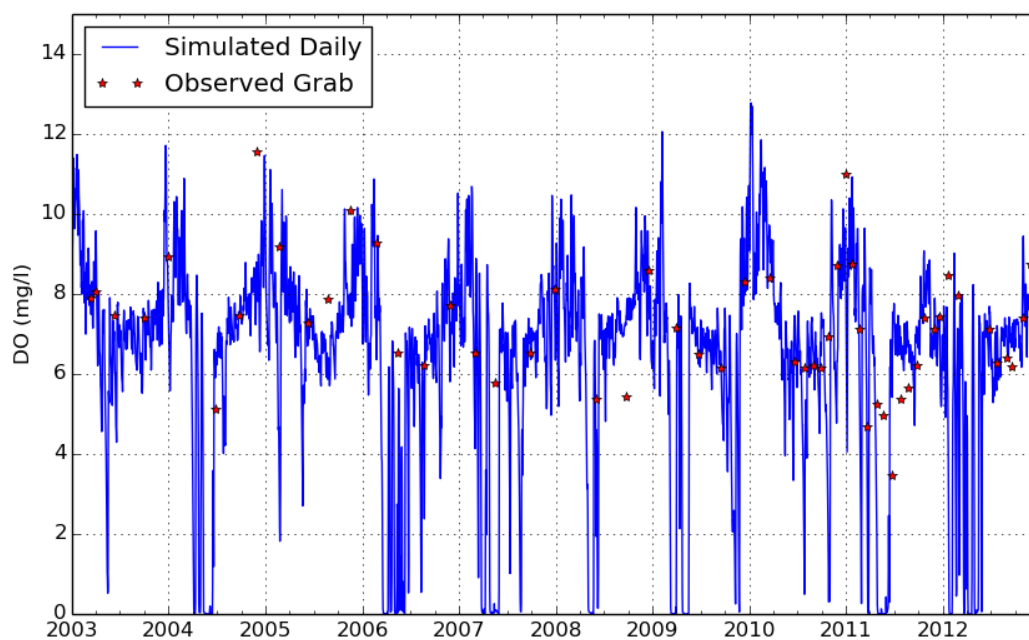


Figure B. 46 Observed grab sample and simulated daily DO for Navy Canal

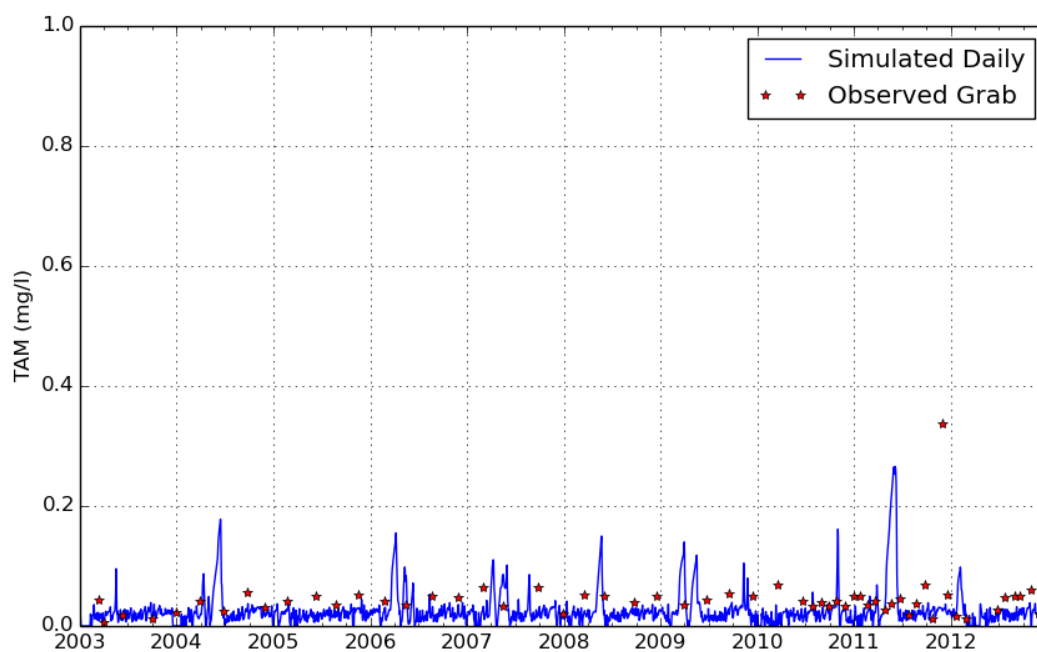


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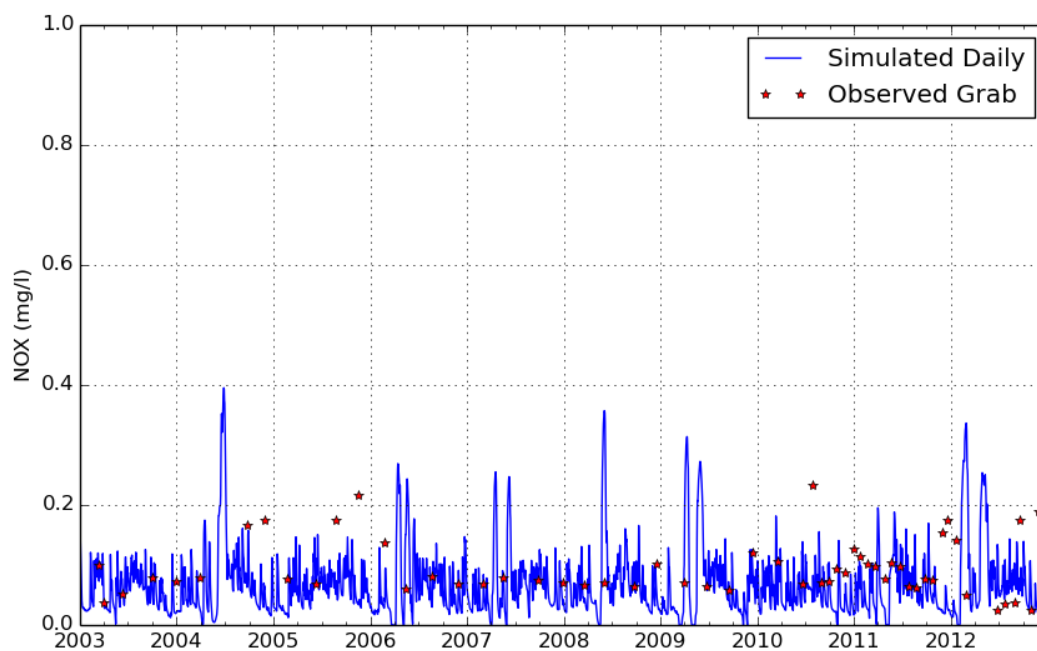


Figure B. 48 Observed grab sample and simulated daily NOX for Navy Canal

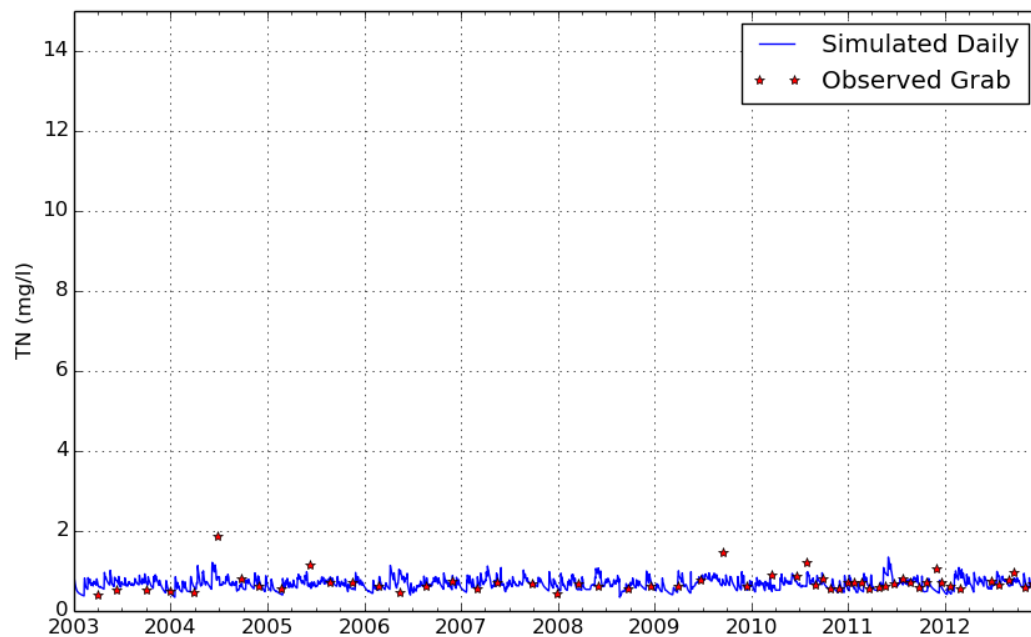


Figure B. 49 Observed grab sample and simulated daily TN for Navy Canal

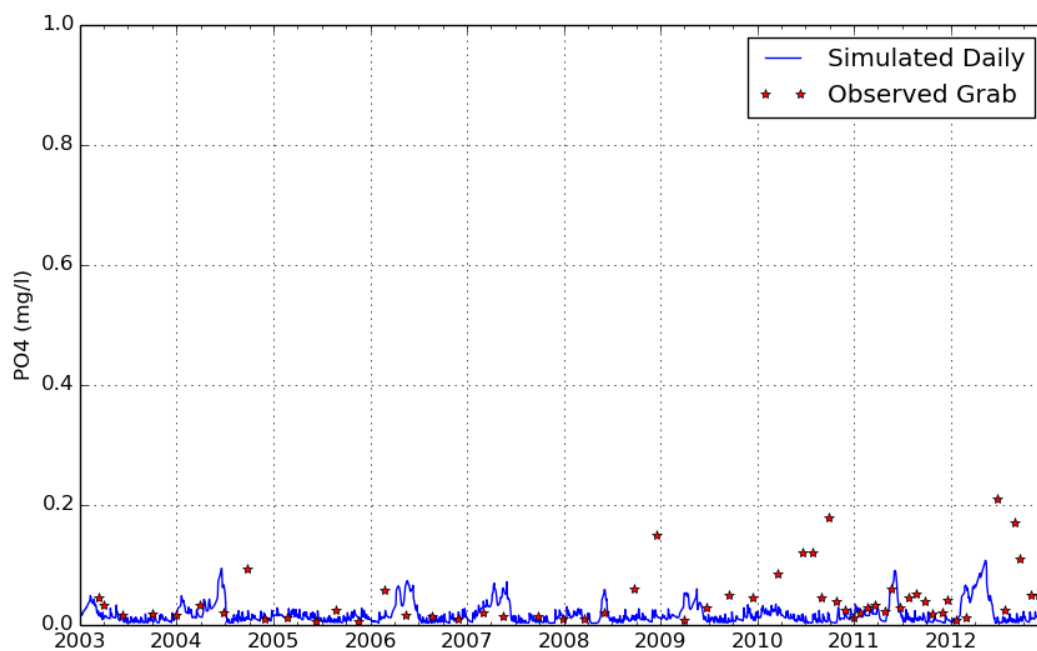


Figure B. 50 Observed grab sample and simulated daily PO4 for Navy Canal

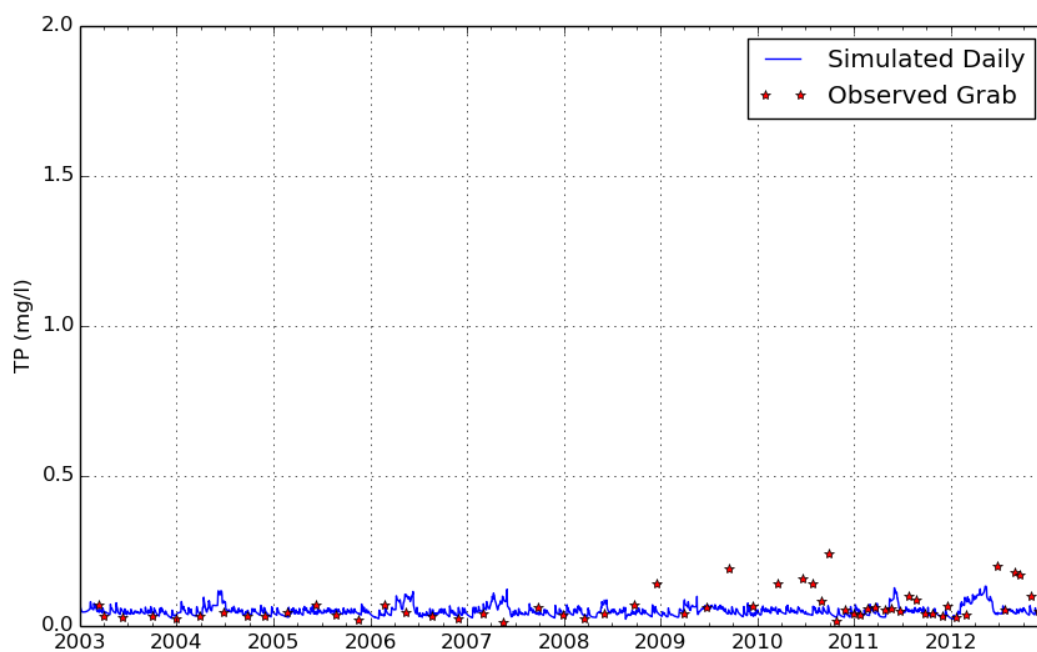


Figure B. 51 Observed grab sample and simulated daily TP for Navy Canal

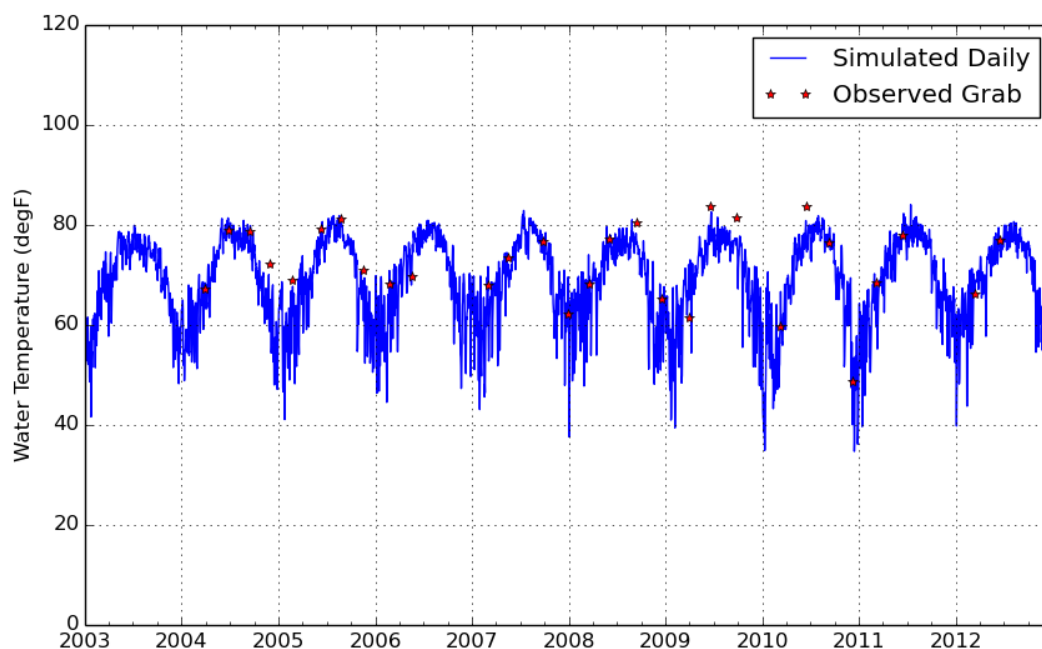


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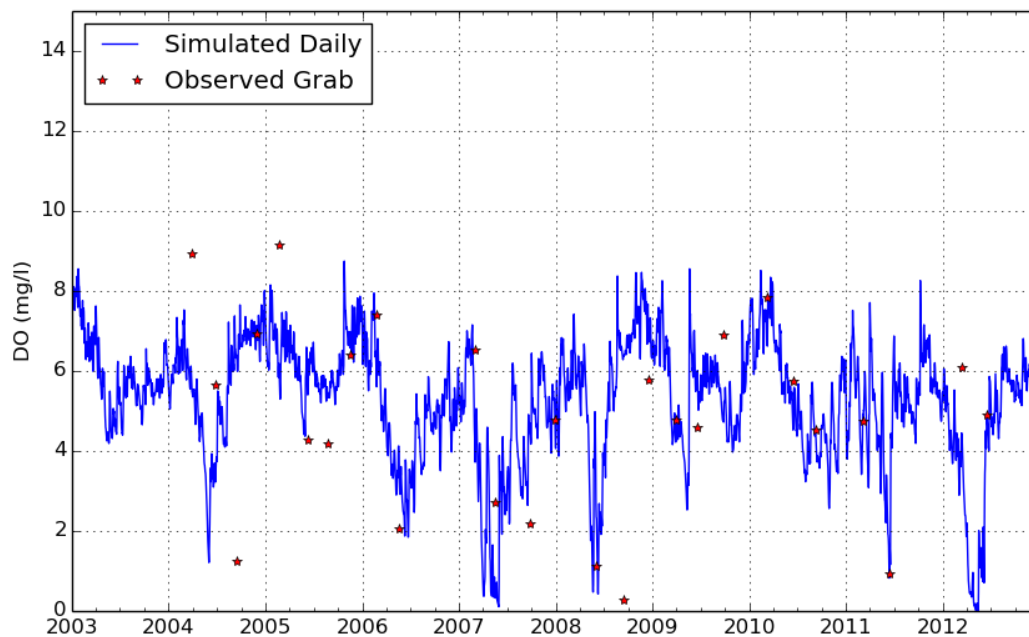


Figure B. 53 Observed grab sample and simulated daily DO for Sweetwater Creek

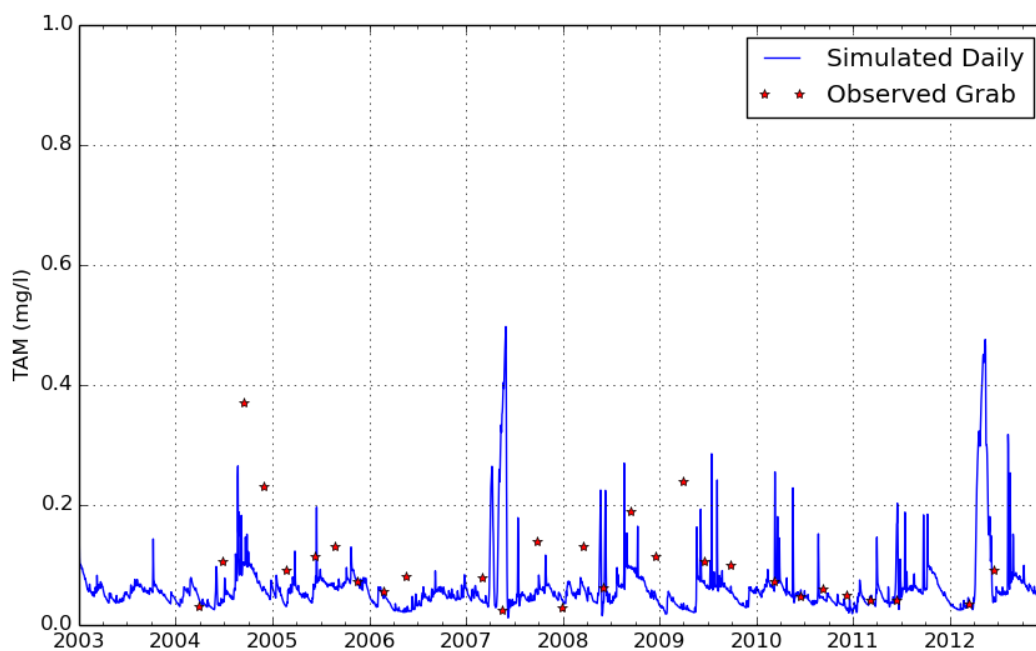


Figure B. 54 Observed grab sample and simulated daily TAM for Sweetwater Creek

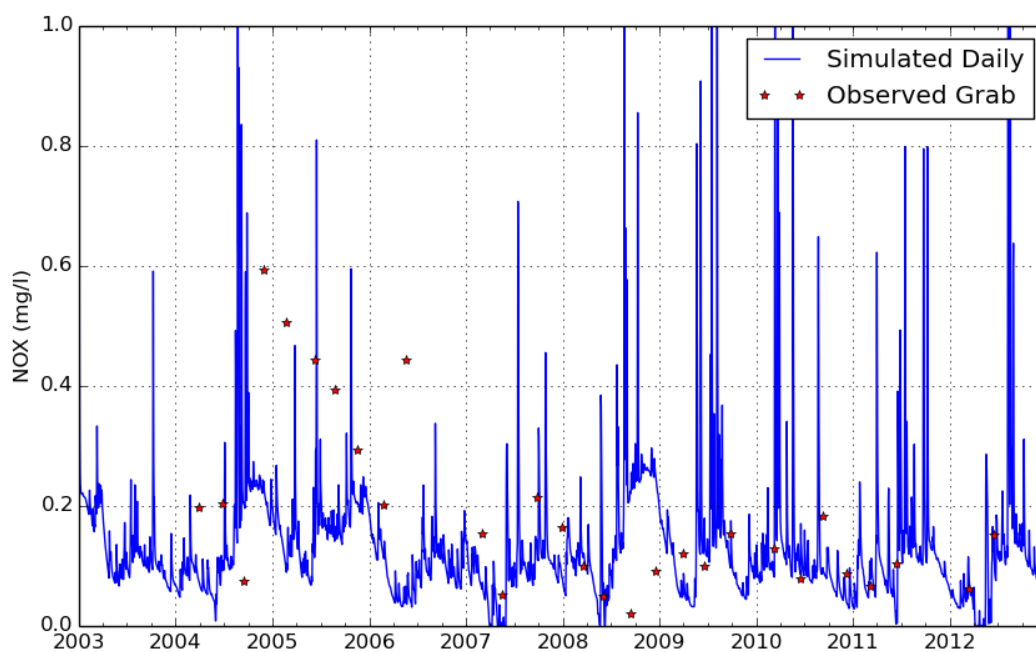


Figure B. 55 Observed grab sample and simulated daily NOX for Sweetwater Creek

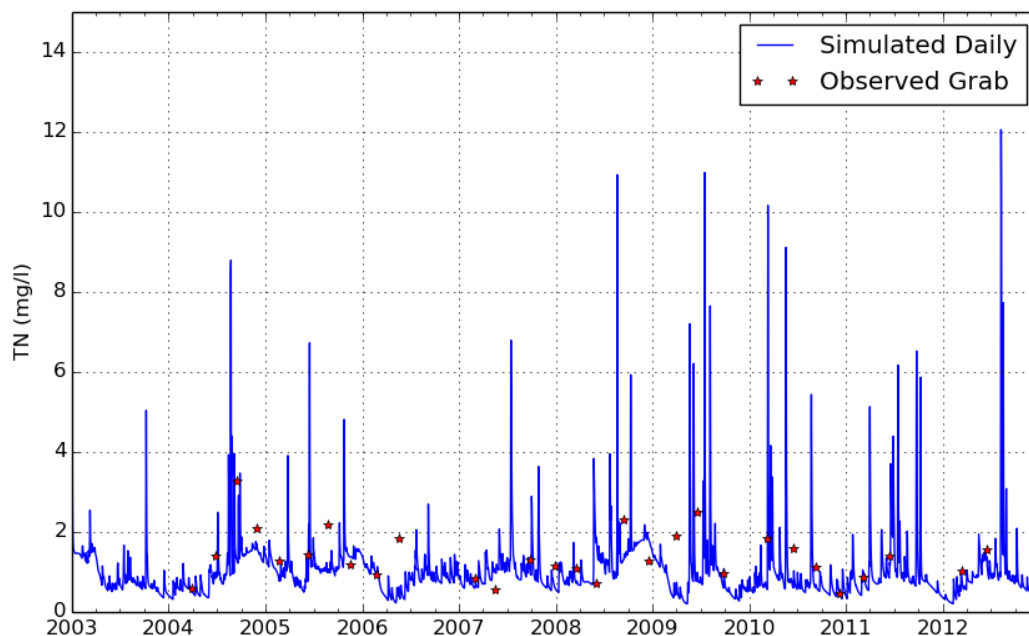


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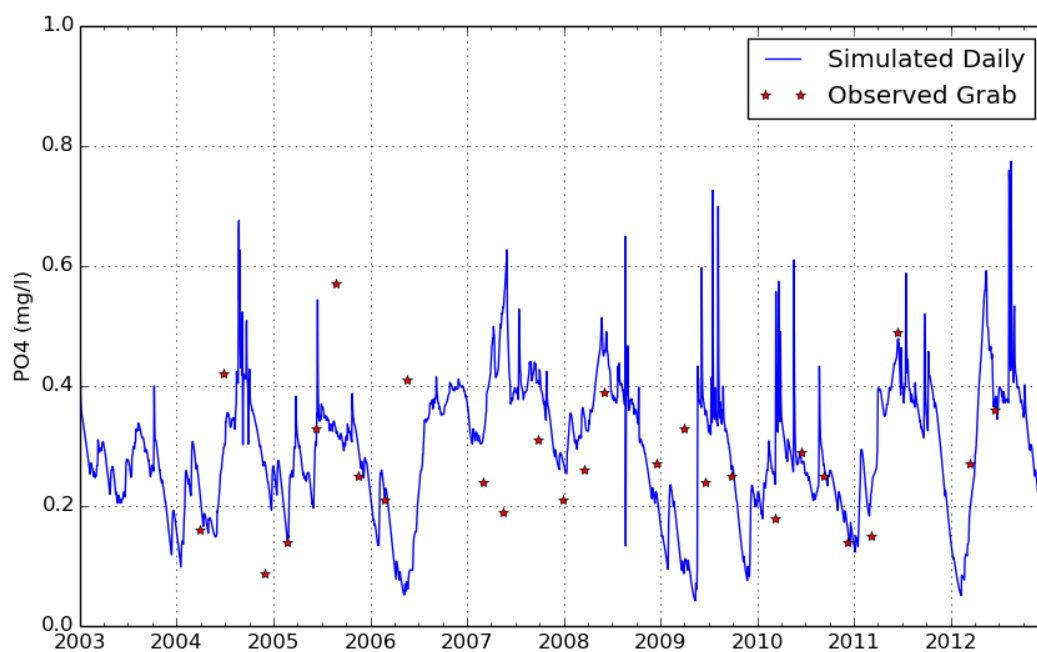


Figure B. 57 Observed grab sample and simulated daily PO4 for Sweetwater Creek

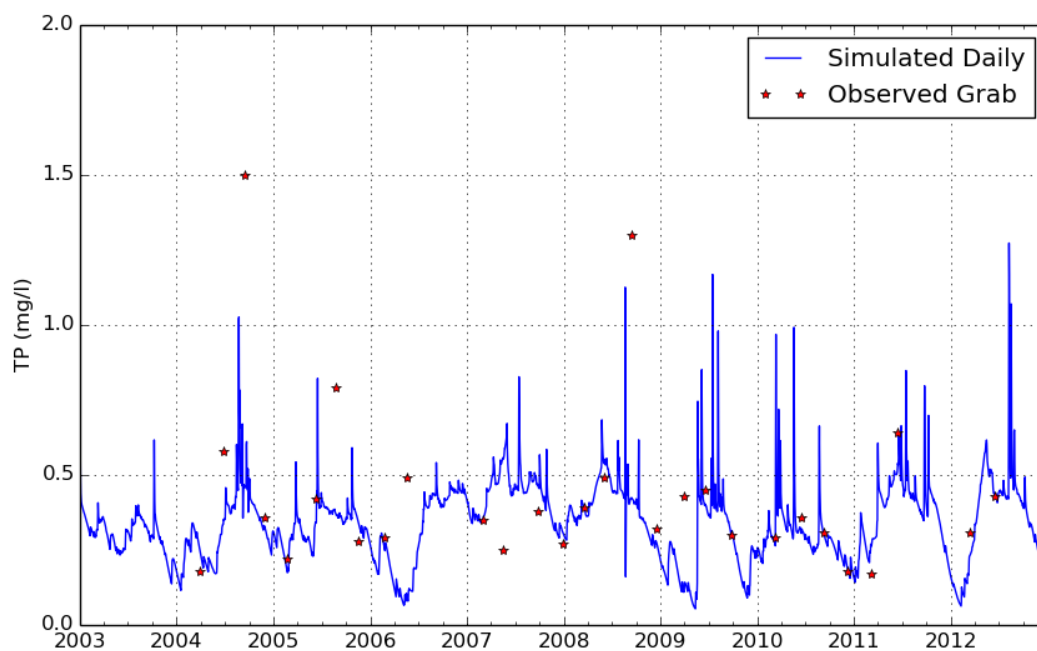


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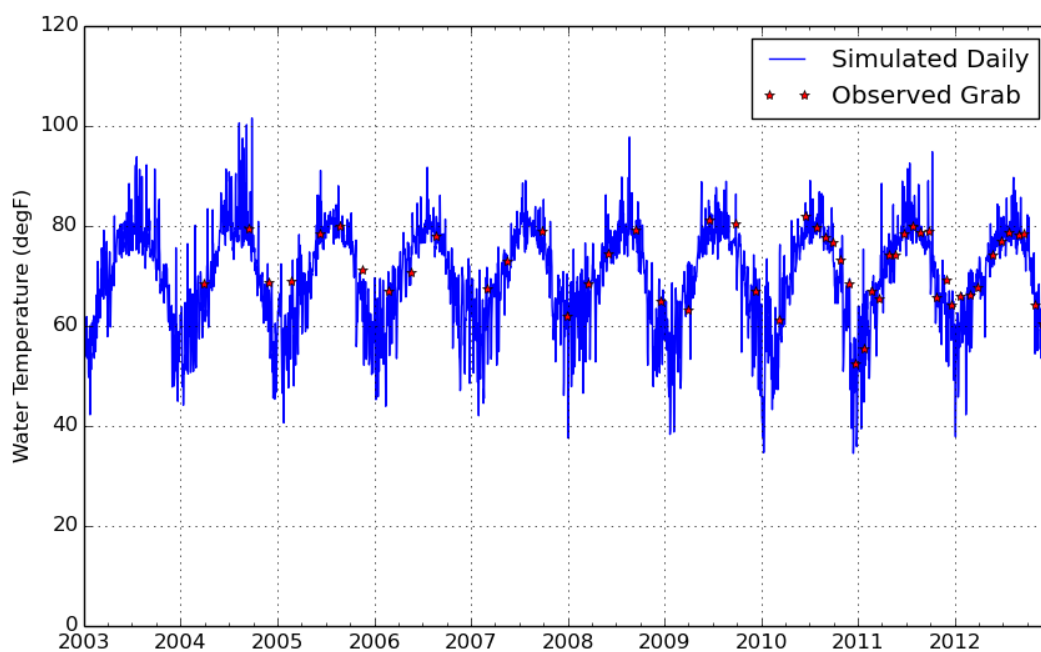


Figure B. 59 Observed grab sample and simulated daily water temperature for Solary Canal

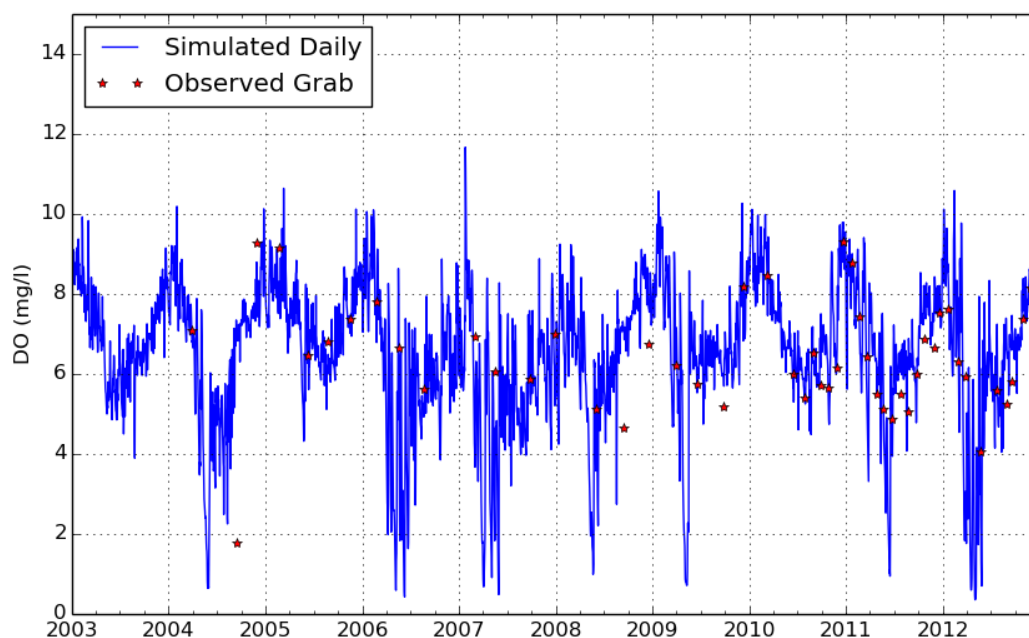


Figure B. 60 Observed grab sample and simulated daily DO for Solary Canal

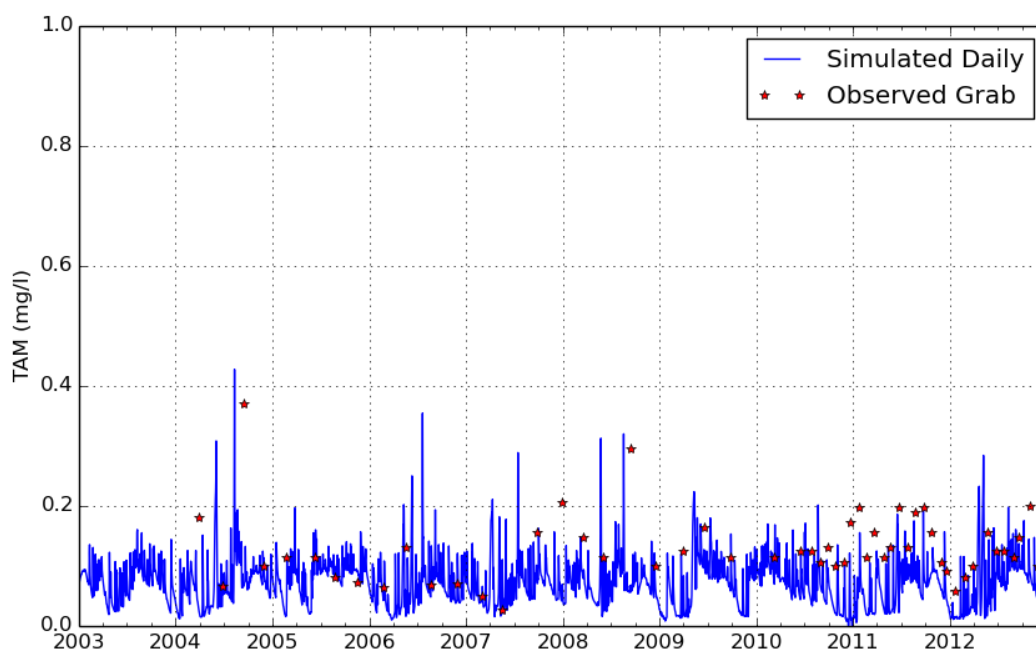


Figure B. 61 Observed grab sample and simulated daily TAM for Solary Canal

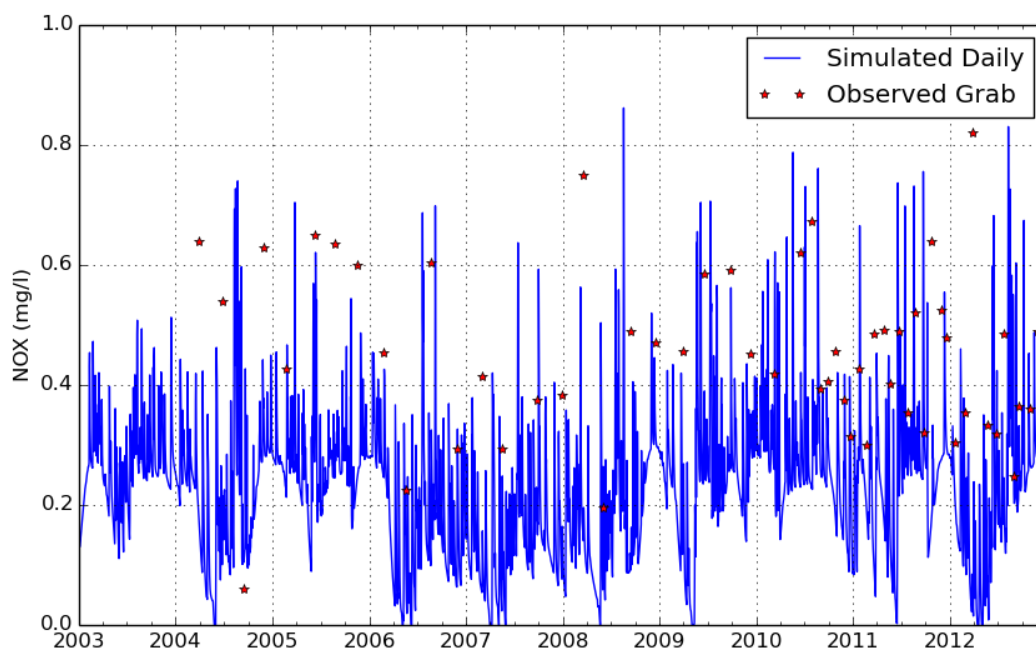


Figure B. 62 Observed grab sample and simulated daily NOX for Solary Canal

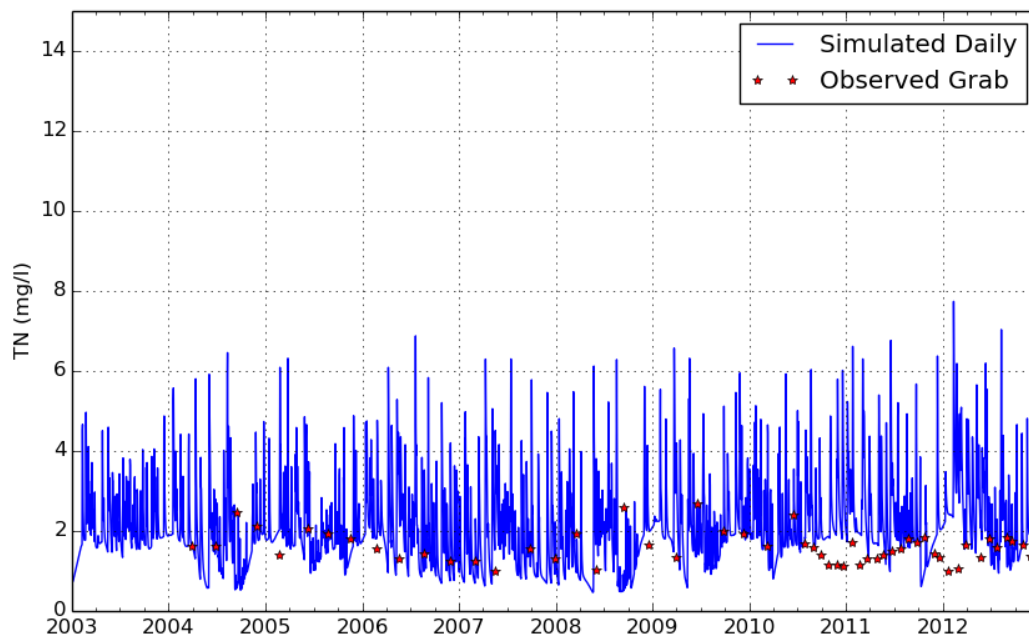


Figure B. 63 Observed grab sample and simulated daily TN for Solary Canal

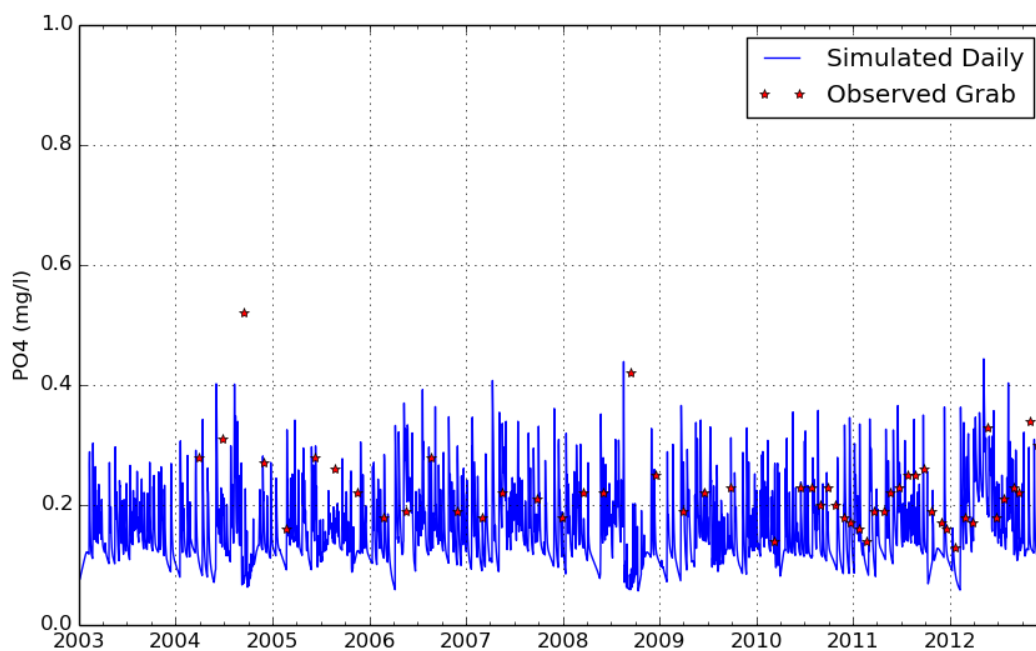


Figure B. 64 Observed grab sample and simulated daily PO4 for Solary Canal

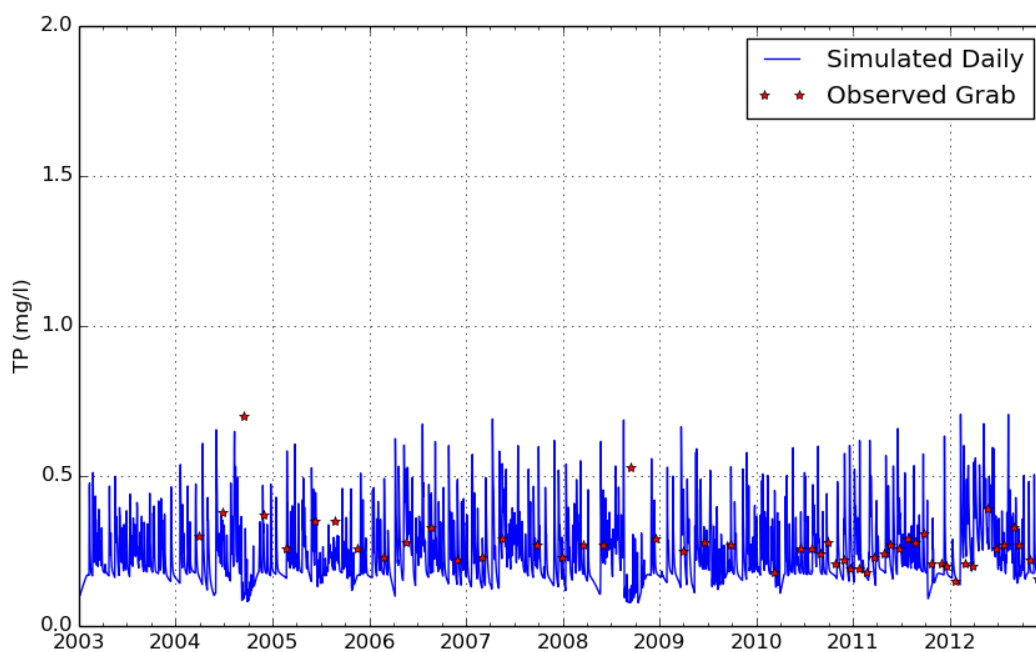


Figure B. 65 Observed grab sample and simulated daily TP for Solary Canal

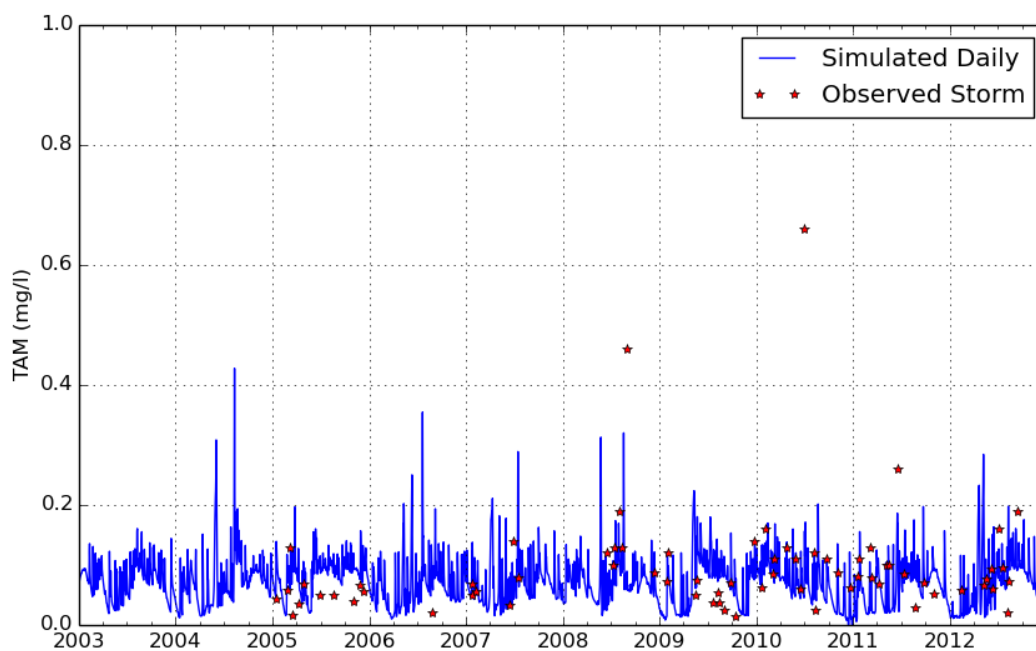


Figure B. 66 Observed storm sample and simulated daily TAM for Solary Canal

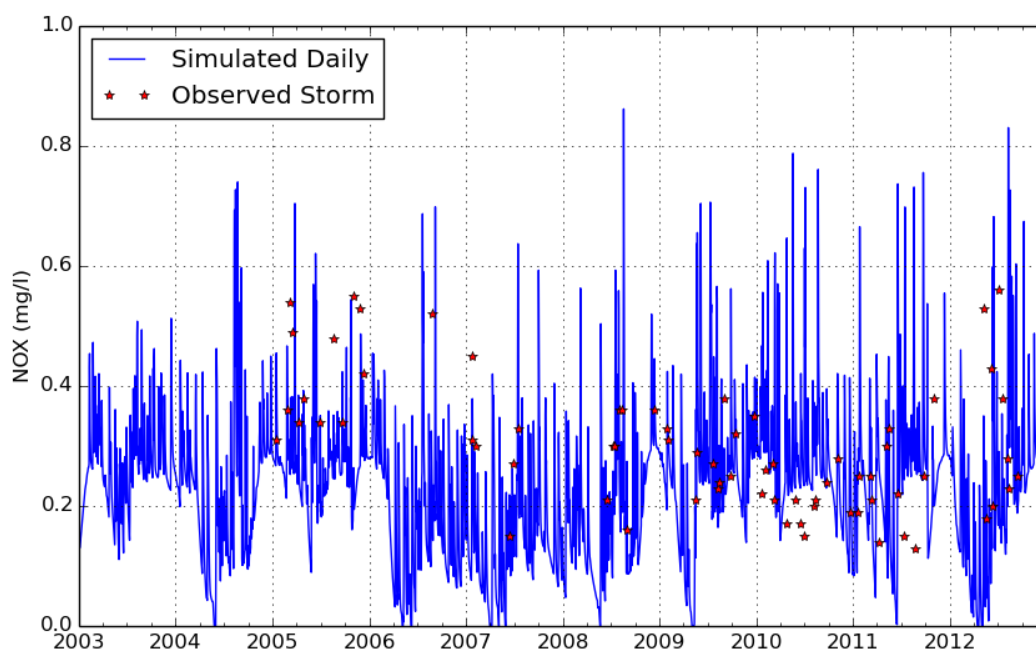


Figure B. 67 Observed storm sample and simulated daily NOX for Solary Canal

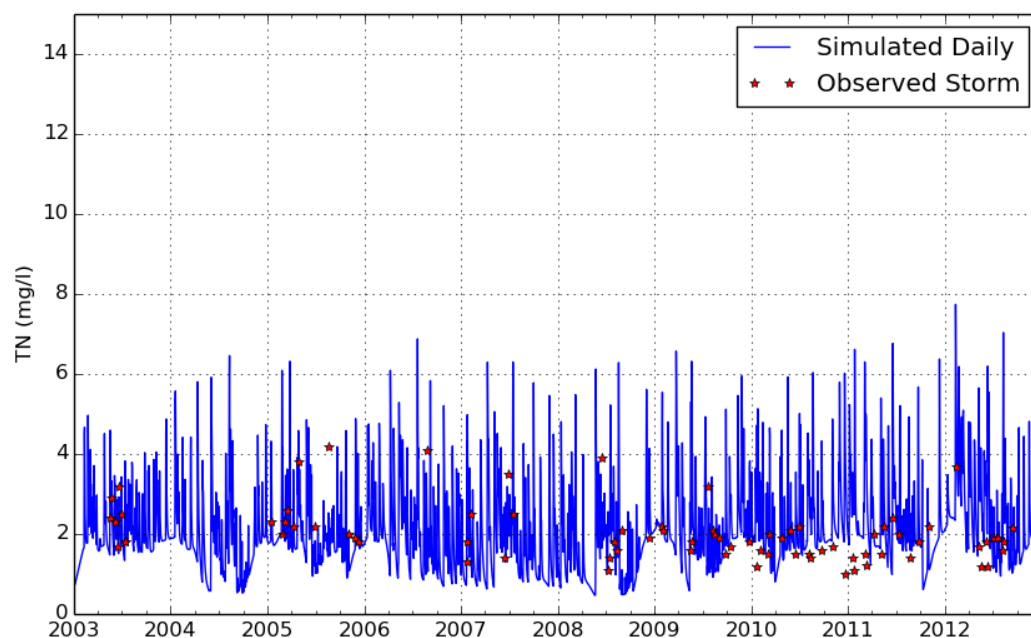


Figure B. 68 Observed storm sample and simulated daily TN for Solary Canal

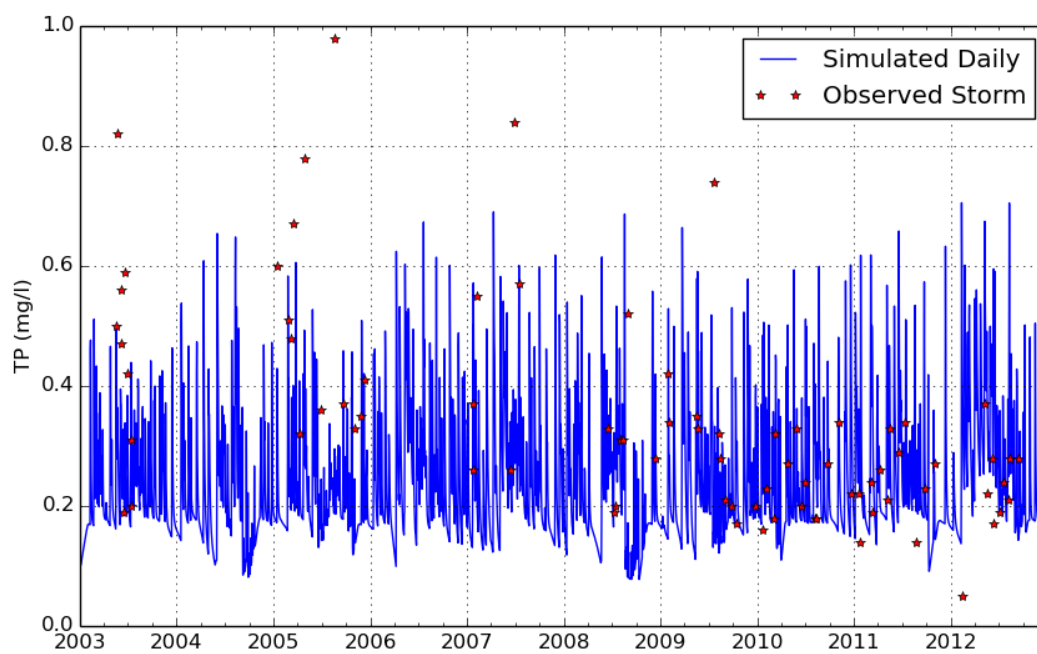


Figure B. 69 Observed storm sample and simulated daily TP for Solary Canal

Appendix C Statistical Comparison of Water Quality Constituents

Table C 1 Median values of observed grab and simulated hourly water quality concentrations (mg/l)

Water Quality Constituents	Howell Creek near Oviedo		Gee Creek near Longwood		Soldier Creek near Longwood	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
DO	7.2	7.3	6.7	6.9	6.8	7.0
TAM	0.05	0.03	0.05	0.05	0.04	0.05
NOX	0.22	0.14	0.16	0.17	0.18	0.11
TN	0.95	0.90	1.01	0.97	1.14	0.96
PO4	0.04	0.06	0.06	0.07	0.09	0.08
TP	0.09	0.10	0.11	0.10	0.14	0.13

Table C 2 Median values of observed storm and simulated daily water quality concentrations (mg/l)

Water Quality Constituents	Howell Creek near Oviedo		Gee Creek near Longwood		Soldier Creek near Longwood	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
TAM	0.05	0.05	0.05	0.07	0.05	0.07
NOX	0.21	0.18	0.20	0.20	0.17	0.15
TN	1.30	1.32	1.30	1.45	1.50	1.44
TP	0.14	0.14	0.17	0.16	0.18	0.18

Appendix D Comparison With The Previous Lake Jesup Watershed HSPF Model

Table D 1 Comparison of flow, TN and TP loadings under current conditions between this study and Jia 2007

	Flow (ac.ft/yr)		TN (lbs/yr)		TP (lbs/yr)	
	This Study	Jia 2007	This Study	Jia 2007	This Study	Jia 2007
Howell Creek	47,925	47,530	139,716	127,391	15,523	18,727
Gee Creek	12,902	11,873	42,736	36,476	4,748	4,746
Soldier Creek	11,300	11,237	34,831	39,117	4,081	4,774
Ungauged	28,344	24,842	105,377	107,164	15,008	13,010
Total	100,470	95,482	322,659	310,148	39,361	41,257

APPENDIX E: SJRWMD EFDC AND WASP MODELING REPORT

WATER QUALITY MODEL APPLICATION OF THE WATER QUALITY ANALYSIS SIMULATION PROGRAM (WASP) TO LAKE JESUP, FL

by

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St. Johns River Water Management District
Palatka, Florida

2014

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ACRONYMS, ABBREVIATIONS, AND CONVERSION FACTORS

CBOD	Carbonaceous oxygen demand
C:CHL	Carbon to chlorophyll mass ratio
CDOM	Colored dissolved organic matter
Chl- <i>a</i>	Chlorophyll- <i>a</i>
CFS	Cubic feet per second
DEM	Digital Elevation Model
D.O.	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EFDC	Environmental Fluid Dynamics Code model
EPA	Environmental Protection Agency
FAWN	Florida Automated Weather Network
FDEP	Florida Department of Environmental Protection
HSPF	Hydrologic Simulation Program–FORTRAN
K_D	Light extinction coefficient
LiDAR	Light detection and ranging
MODFLOW	Modular ground water flow model
NAVD88	North American Vertical Datum of 1988
N:C	Nitrogen to carbon mass ratio
NH ₄	Ammonia
NLDAS	Nasa Land Data Assimilation System
N-fixation	Nitrogen fixation
NO ₃	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NO _x	Nitrate + Nitrite
<i>NRECS</i>	Number of records
P:C	Phosphorus to carbon mass ratio
PO ₄	Phosphate
ppt	Parts per thousand
PSS78	Practical Salinity Scale 1978
Q	Discharge
r^2	Coefficient of determination
S	Salinity
SJRWMD	St. Johns River Water Management District
TAM	Total Ammonia
TKN	Total Keldahl Nitrogen
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TP	Total Phosphorus

TSS	Total Suspended Solids
USGS	United States Geological Survey
WASP	Water Quality Analysis Simulation Program
WQMN	Water Quality Monitoring Network
WSIS	Water Supply Impact Study

1 INTRODUCTION

This report describes a calibration and confirmation of an application of the Water Quality Analysis Simulation Program (WASP) to Lake Jesup, Florida. The calibration period was a four-year period from 2004 to 2006. The confirmation period was a three-year period from 2007 to 2009. The model was also set-up for the period 2010 to 2012, but this period is not considered for water quality analyses other than the annual phosphorus budget. This period was not used because it differs in two ways from the 2003 to 2009 period. First, this period is reportedly dominated by the cyanobacteria *Cylindrospermopsis Raciberski* and different algal parameters are likely required to represent this shift in algal composition. Second, this period followed a structural change to the connection of the lake with the St. Johns River with a bridge span replacing a causeway. This modeling was done by the St. Johns River Water Management District, Division of Water Resources, to assist the Florida Department of Environmental Protection with a revision of the Basin Management Action Plan for Lake Jesup.

The application of the WASP surface water quality model (Ambrose et al., 1993) to Lake Jesup simulates the response of Lake Jesup to time- and spatially-varying nutrient loads entering the lake. Lake circulation, mixing, and flushing are accounted for by linking the WASP surface water quality model with a hydrodynamic model, Environmental Fluid Dynamics Code (EFDC). The EFDC hydrodynamic model (Hamrick, 1992) simulates lake stages and velocities, from tributary discharge, ground water discharge, rainfall, evaporation, and surface winds. Nutrient loads are primarily supplied by linkage of WASP with a hydrology model, Hydrologic Simulation Program FORTRAN (HSPF) (Bicknell et al., 1997) that simulates nutrient loads based on rainfall, land-use, soils and other hydrologic parameters needed to complete a hydrologic budget of the lake's watershed. Nutrient loads from atmospheric deposition and diffuse ground water are also included. The primary variable of interest for the WASP surface water quality model application to Lake Jesup is phytoplankton biomass, represented as concentration of chlorophyll-*a*.

2 DESCRIPTION OF STUDY AREA

Lake Jesup is a broad, shallow off-line lake of the St. Johns River in Seminole County, Florida, about 15 miles northeast of Orlando. The lake is about 8000 acres in area and oblong. Its length is about 10 miles and its width ranges from 2 ½ miles near the lake center to only 500 yards within a narrow throat in the northeast end of the lake that leads to its mouth. The lake outlet discharges to the St. Johns River at a location downstream of Lake Harney and upstream of Lake Monroe. The primary outlet to the St. Johns River is through a narrow 250 ft channel, although since replacement of a former causeway with a bridge in 2009, flow at higher river stages can pass under the newly constructed, 3600 ft bridge span.

The average lake depth is 4.0 ft and the average bottom elevation is -3.0 ft, NAVD88. Interestingly, the bottom of Lake Jesup is lower than mean sea level at Mayport, Fl (-0.6 ft, NAVD88).

2.1 PRECIPITATION AND EVAPORATION

Lake Jesup lies within a humid, subtropical climate zone. Average rainfall averaged 49.6 in. yr⁻¹ during the model simulation period of 2003 to 2012. Over half of the annual rainfall occurred in the summer and early autumn, from June to September. Evaporation rates averaged 54.3 in. yr⁻¹ over this same period, slightly exceeding rainfall. Table 2–1 shows total annual rainfall, evaporation, and net rainfall (rainfall - evaporation) for the 10-year model simulation period.

Table 2–1. Annual rainfall, evaporation, and net rainfall (inches per year) over Lake Jesup for the model simulation period of 2003 – 2012.

Year	Rain (R)	Evaporation (E)	Net Rain (R-E)
2003	45.3	49.9	-4.6
2004	57.4	52.1	+5.3
2005	59.7	51.8	+7.9
2006	36.6	56.8	-20.2
2007	36.0	55.4	-19.4
2008	66.1	53.2	+12.9
2009	48.6	54.8	-6.2
2010	45.3	55.2	-9.9
2011	51.8	57.4	-5.6
2012	49.3	56.0	-6.7
Annual Average	49.6	54.3	-4.7

Note 1: Rainfall was obtained from the SJRWMD Doppler radar rainfall dataset, averaged over Lake Jesup (SJRWMD, 2014).

Note 2: Evaporation (as potential evaporation) was obtained from the U.S. Geological Survey satellite-derived, gridded data set (Jacobs et al., 2008).

2.2 SURFACE WATER DISCHARGE

Mean surface discharge (Jia, 2014) for the simulation period (2003 – 2012) was 141.7 cfs based on simulated HSPF discharges to Lake Jesup. Six tributaries (Howell Creek, Gee Creek, Soldier Creek, Sixmile Creek, Phelps Creek, and Salt Creek) account for 87% of the total surface water discharge (Table 2–2). The four largest tributaries, accounting for 79% of the total surface water discharge, are all located in the western end of the lake and farthest from the mouth.

Total daily surface water discharge into Lake Jesup ranged from a low of 6.2 cfs (6 May 2012) to a high of 4130 cfs (22 August 2008) over the simulation period (Figure 2–1). The maximum monthly averaged discharge was 941 cfs in August 2008 and 12.8 cfs in April 2012.

Table 2–2. Mean annual surface water discharge to Lake Jesup, 2003 – 2012. (Discharge is from HSPF simulated surface runoff to Lake Jesup; Jia, 2014).

Tributary	Average Discharge, cfs (2003-2012)	Percentage of Total Tributary Discharge
Howell Creek	66.8	47.1
Gee Creek	18.4	13.0
Soldier Creek	15.9	11.2
Sixmile Creek	11.3	8.0
Phelps Creek	7.1	5.0
Salt Creek	4.0	2.8
Other Tributaries	16.9	11.9
Clifton Spring	1.4	1.0
TOTAL	141.8	100.0

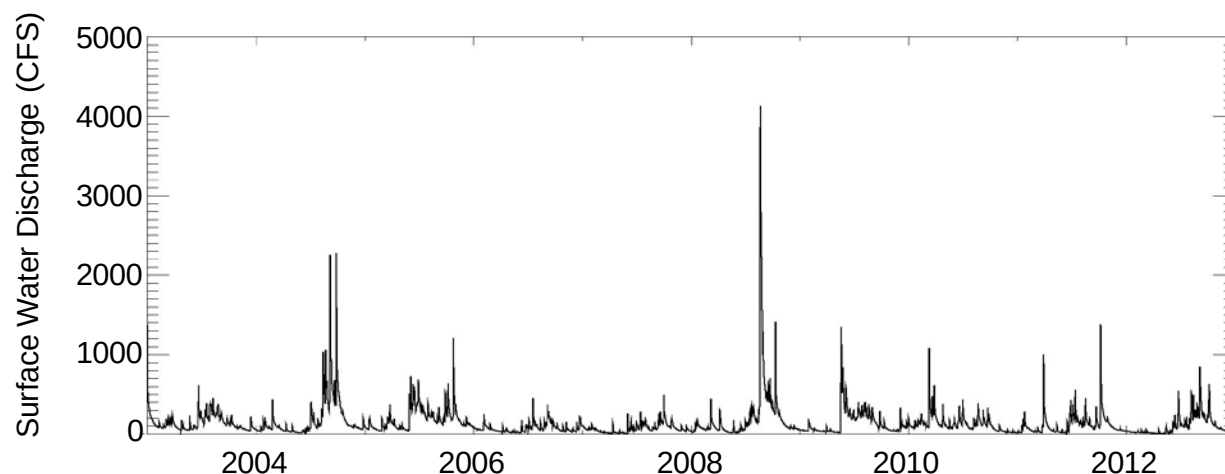


Figure 2–1. Daily-averaged surface water discharge entering Lake Jesup during the model simulation period of 2003 to 2012. Discharge is from simulated HSPF surface water runoff for Lake Jesup (Jia, 2014).

2.3 LAKE STAGE AND ST. JOHNS RIVER WATER LEVEL

Lake Jesup is connected directly to the St. Johns River at the lake mouth. The water level of the St. Johns River exhibits relatively large seasonal variability in response to varying river discharge. As a result, the water level of the St. Johns River dominates, and can be said to determine, lake stage.

Water elevation at the mouth ranged nearly 9 ft during the model simulation period, from a minimum of -1.2 to a maximum of 7.6 ft NAVD88 (Figure 2–2, from USGS gauge 02234435 at Lake Jesup mouth). As a result, the spatially averaged lake depth varied from 2.8 to 11.6 ft.

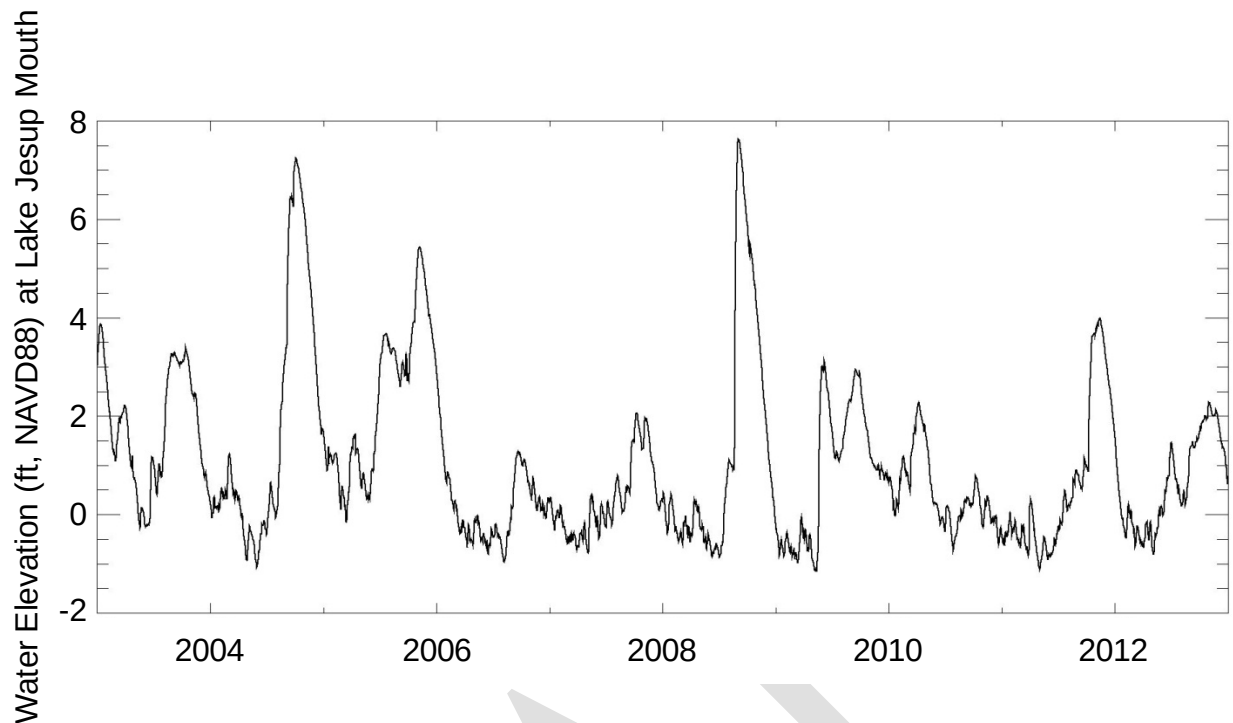


Figure 2–2. Daily-averaged surface water elevation at mouth of Lake Jesup during the model simulation period of 2003 to 2012. (USGS gauge 02234435 at Lake Jesup mouth).

2.4 DIFFUSE GROUND WATER DISCHARGE AND RELICT SEAWATER

A broad expanse of the St. Johns River between Lake George and Lake Poinsett maintains oligohaline conditions because of the influence of relict seawater that enters the river and lakes through both springs and diffuse ground water discharge (Belaine, 2012). Diffuse ground water discharge is an important source of relict seawater to Lake Jesup. The lake is situated in a region where the underlying confining unit (the Hawthorn Formation) is thin and the underlying ground water contains appreciable chloride (Figure 2–3). The influence of diffuse, salty ground water entering the lake causes lake salinity to achieve oligohaline conditions during periods of low rainfall (Figure 2–4).

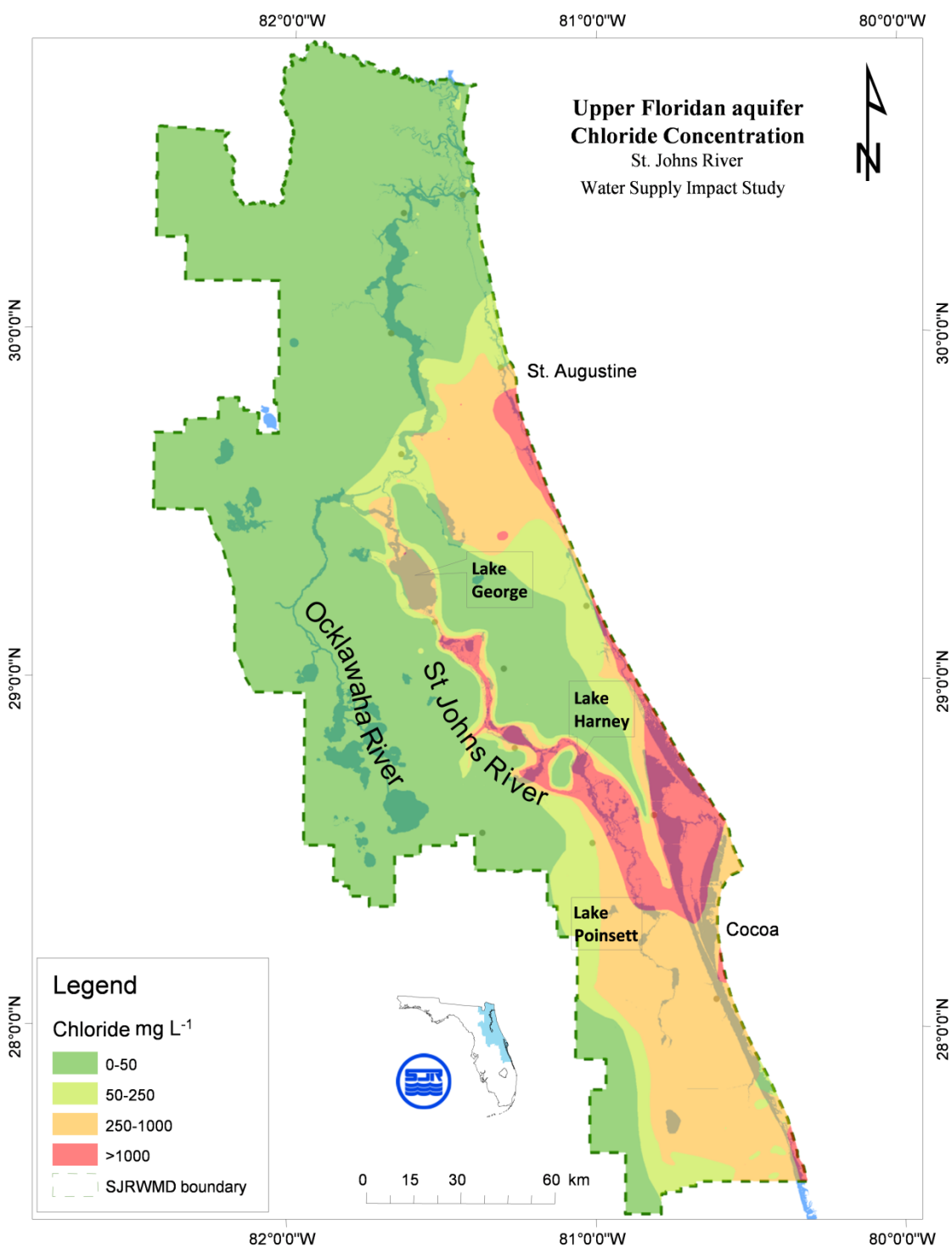


Figure 2–3. Chloride concentration in the Upper Floridan aquifer (UFA) within the St. Johns River Water Management District (SJRWMD). High chloride concentrations occur directly along the path of the SJR between Lake Poinsett and Lake George and underlie the Lakes Monroe, Harney, and Jesup in the middle St. Johns River.

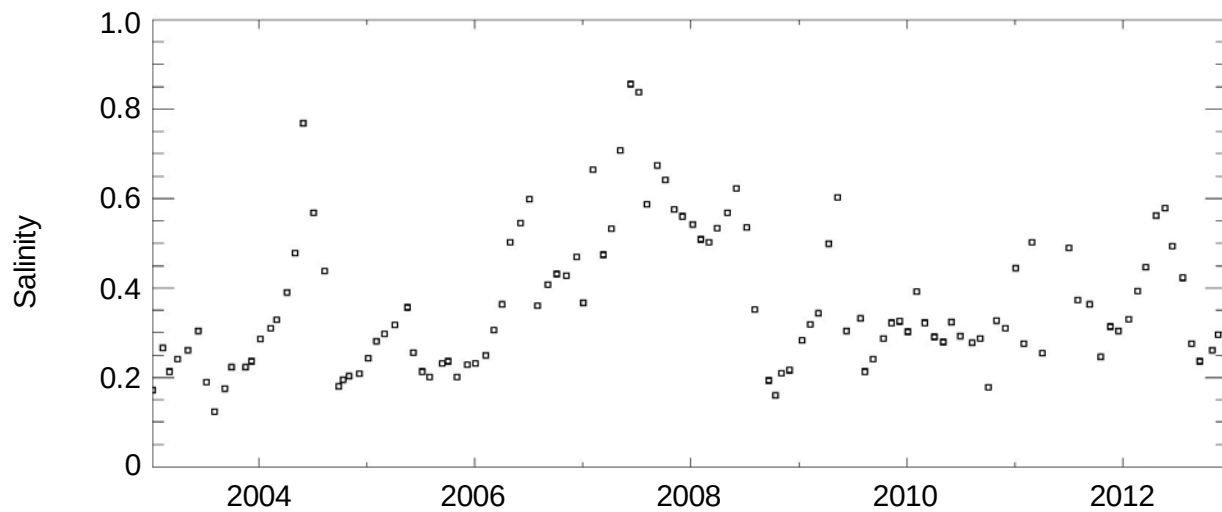


Figure 2–4. Salinity at west end of Lake Jesup (Station OW-4, see Figure 3–1) during the model simulation period of 2003 to 2012.

2.5 TOTAL PHOSPHORUS AND CHLOROPHYLL-A

Lake Jesup is a hypereutrophic lake with very high levels of both total phosphorus and chlorophyll-a. Total phosphorus at station OW-4 in the west end of the lake is shown in Figure 2–5. Mean total phosphorus for this period was $175 \mu\text{g L}^{-1}$ and rarely fell below $100 \mu\text{g L}^{-1}$.

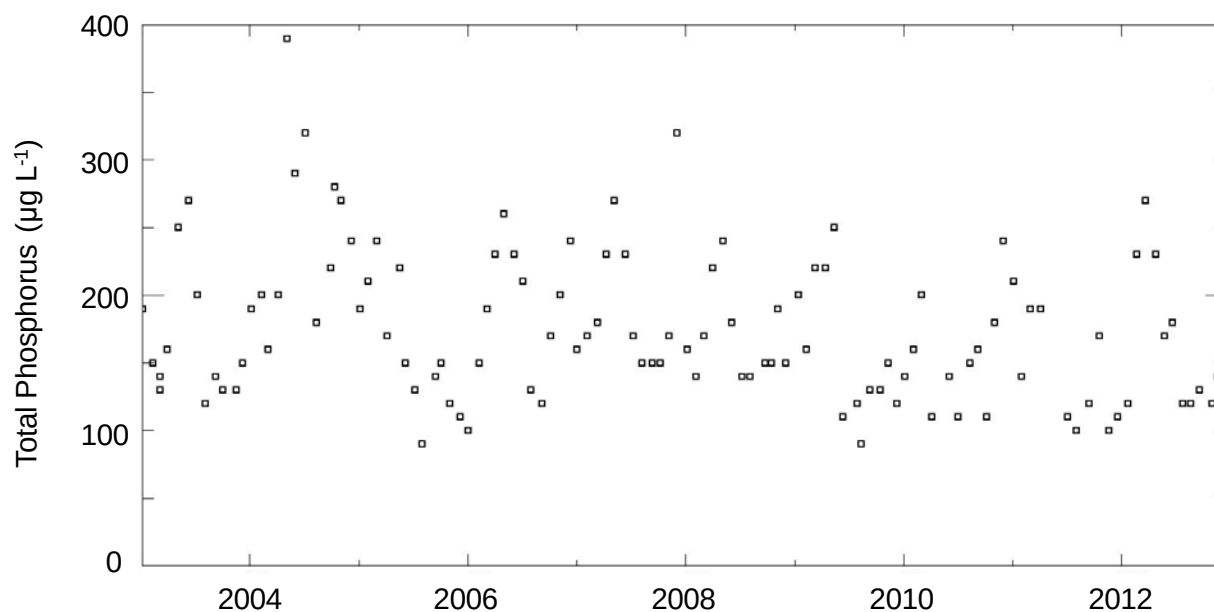


Figure 2–5. Total phosphorus at west end of Lake Jesup (Station OW-4, see Figure 3–1) during the model simulation period of 2003 to 2012.

Chlorophyll-*a* varies over a wide range, from lower than $10 \mu\text{g L}^{-1}$ during extreme wet periods to over $200 \mu\text{g L}^{-1}$ (Figure 2–6). Mean chlorophyll-*a* was $70 \mu\text{g L}^{-1}$ over the model simulation period of 2004 to 2009 and $87 \mu\text{g L}^{-1}$ over the period 2003 to 2012. Chlorophyll-*a* consistently exceeded $50 \mu\text{g L}^{-1}$ over the 3-year span of 2009 to 2012 when *Cylindrospermopsis Raciberski* became dominate.

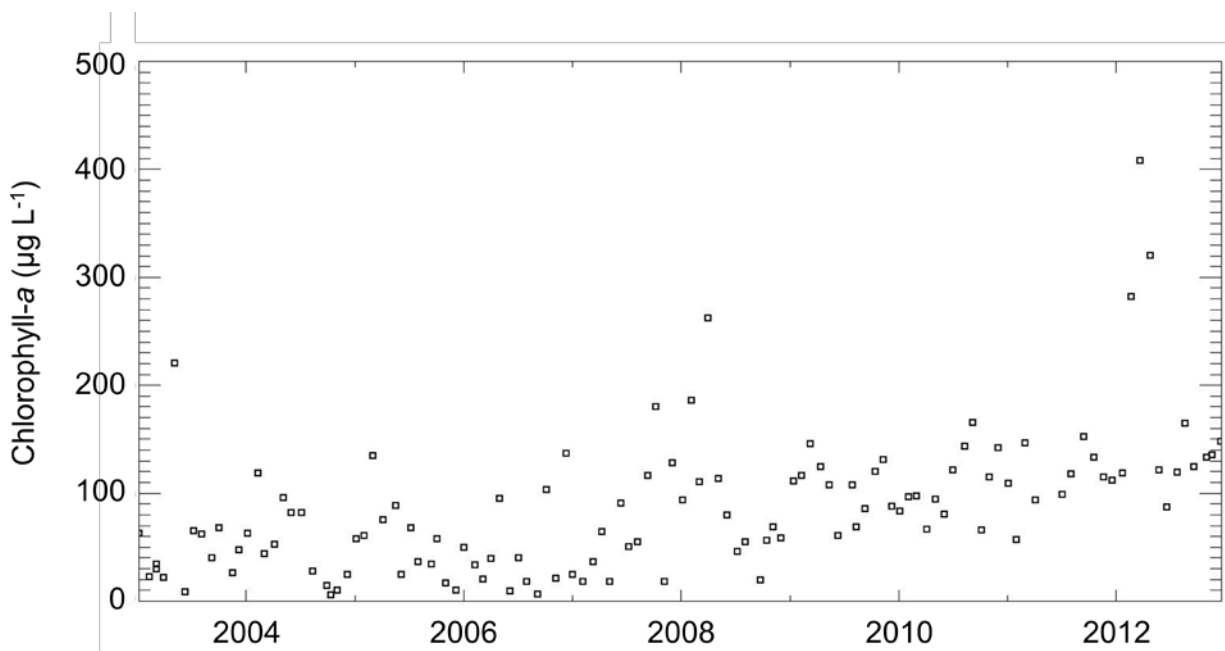


Figure 2–6. Chlorophyll-*a* at west end of Lake Jesup (Station OW-4, see Figure 3–1) during the model simulation period of 2003 to 2012.

3 OBSERVED DATA

3.1 WATER QUALITY AND WATER LEVEL STATIONS

Observed data are required for setting model boundary conditions and for comparison with model results for model calibration and confirmation. The WASP model application for Lake Jesup relied on four water quality stations and two water elevation stations (Figure 3–1). The water quality stations, shown as circles in the figure, are maintained by SJRWMD and are a subset of the Water Quality Monitoring Network (Keller, 2004). Several water quality variables are collected at the water quality stations. For this study, I used chlorophyll-*a* (Chl-*a*), dissolved organic carbon (DOC), dissolved oxygen (D.O.), ammonium (NH₄), nitrate+nitrite (NO_x), phosphate (PO₄), total Keldhal nitrogen (TKN), total organic carbon (TOC), total phosphorus (TP), total suspended solids (TSS), salinity (S), and water temperature. The water level stations are shown as squares in Figure 3–1. The water elevation station at the lake mouth is maintained by the U.S. Geologic Survey (USGS). The water level station inside the lake at Oviedo is maintained by SJRWMD.

Table 3–1 provides a statistical summary of key water quality variables for each of the four water quality stations. Distribution percentages indicate the percentage of observations equal to or less than the given value. (Units are mg L⁻¹ except chlorophyll-*a* has units of µg L⁻¹). In general, the in-lake stations (OW-2, OW-4, and OW-6) exhibit similar distributions of these water quality variables. The only exception is a slightly lower tendency for chlorophyll-*a* at station OW-2 as compared to stations OW-4 and OW-6. The St. Johns River station (OW-SJR-1), however,

exhibits considerably lower values of chlorophyll-*a*, total phosphorus, total Keldahl nitrogen, and total suspended solids than the Lake Jesup stations. The St. Johns River station also has slightly greater values of dissolved organic carbon than the Lake Jesup stations, indicative of higher color for the St. Johns River.

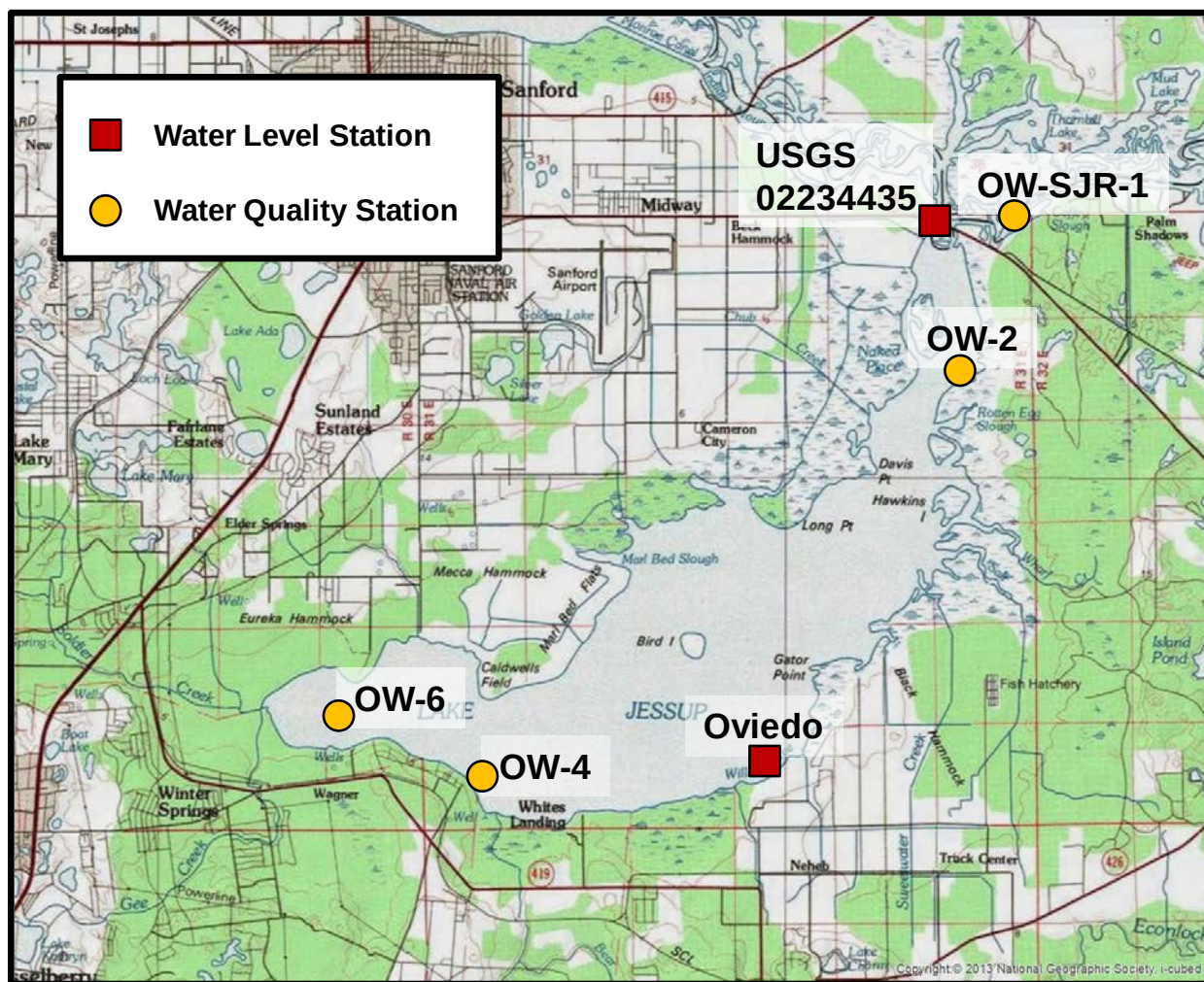


Figure 3–1. Locations of water quality stations and water level stations used for WASP model development and calibration of Lake Jesup.

Table 3–1. Statistical summary of key water quality variables for each of four water quality stations used for modeling water quality of Lake Jesup. NRECS = number of records. Distribution percentages indicate the percentage of observations equal to or less than the given value. Units are mg L⁻¹ except Chl-*a* has units of µg L⁻¹.

Parameter	Station	NRECS	10%	25%	50%	75%	90%
Chl-a	OW-SJR-1	180	1.0	1.8	3.8	11.3	34.1
	OW-2	166	16.8	37.9	64.6	112.0	150.1
	OW-4	175	24.7	54.6	90.4	134.4	196.0
	OW-6	183	24.0	45.5	77.6	122.2	182.0
DOC	OW-SJR-1	183	18.2	20.1	23.9	28.2	30.6
	OW-2	166	15.8	17.0	19.2	20.9	22.8
	OW-4	174	14.3	15.7	17.3	18.8	21.0
	OW-6	181	14.4	16.2	17.5	19.5	21.2
TP	OW-SJR-1	183	0.05	0.06	0.08	0.11	0.14
	OW-2	167	0.10	0.12	0.16	0.21	0.27
	OW-4	176	0.11	0.13	0.16	0.20	0.24
	OW-6	183	0.10	0.12	0.14	0.18	0.22
PO4	OW-SJR-1	83	0.01	0.02	0.03	0.04	0.08
	OW-2	83	0.01	0.02	0.03	0.05	0.09
	OW-4	82	0.01	0.02	0.03	0.05	0.06
	OW-6	89	0.01	0.02	0.03	0.04	0.06
TKN	OW-SJR-1	183	1.0	1.2	1.4	1.7	2.0
	OW-2	166	1.6	2.0	2.7	3.8	4.6
	OW-4	176	1.6	2.1	2.8	3.8	4.9
	OW-6	183	1.5	1.9	2.7	3.6	4.7
TSS	OW-SJR-1	175	1	2	4	9	14
	OW-2	167	11	18	36	51	76
	OW-4	176	16	24	35	54	68
	OW-6	183	13	19	31	44	58

3.2 DIGITAL ELEVATION MODEL

Lake bathymetry was obtained from a digital elevation model (DEM) of the area developed by SJRWMD for a previous modeling study, the St. Johns River Water Supply Impact Study, (Sucsy et al., 2012). The DEM pictured below contains 2000 x 2000 cells at 10-m spacing (Figure 3–2).

Note how the adjacent St. Johns River channel is clearly visible because of its greater depth than Lake Jesup. Note also the greater depth of Lake Monroe, a portion of which is visible in the upper left-hand corner of the plot, as compared to Lake Jesup.

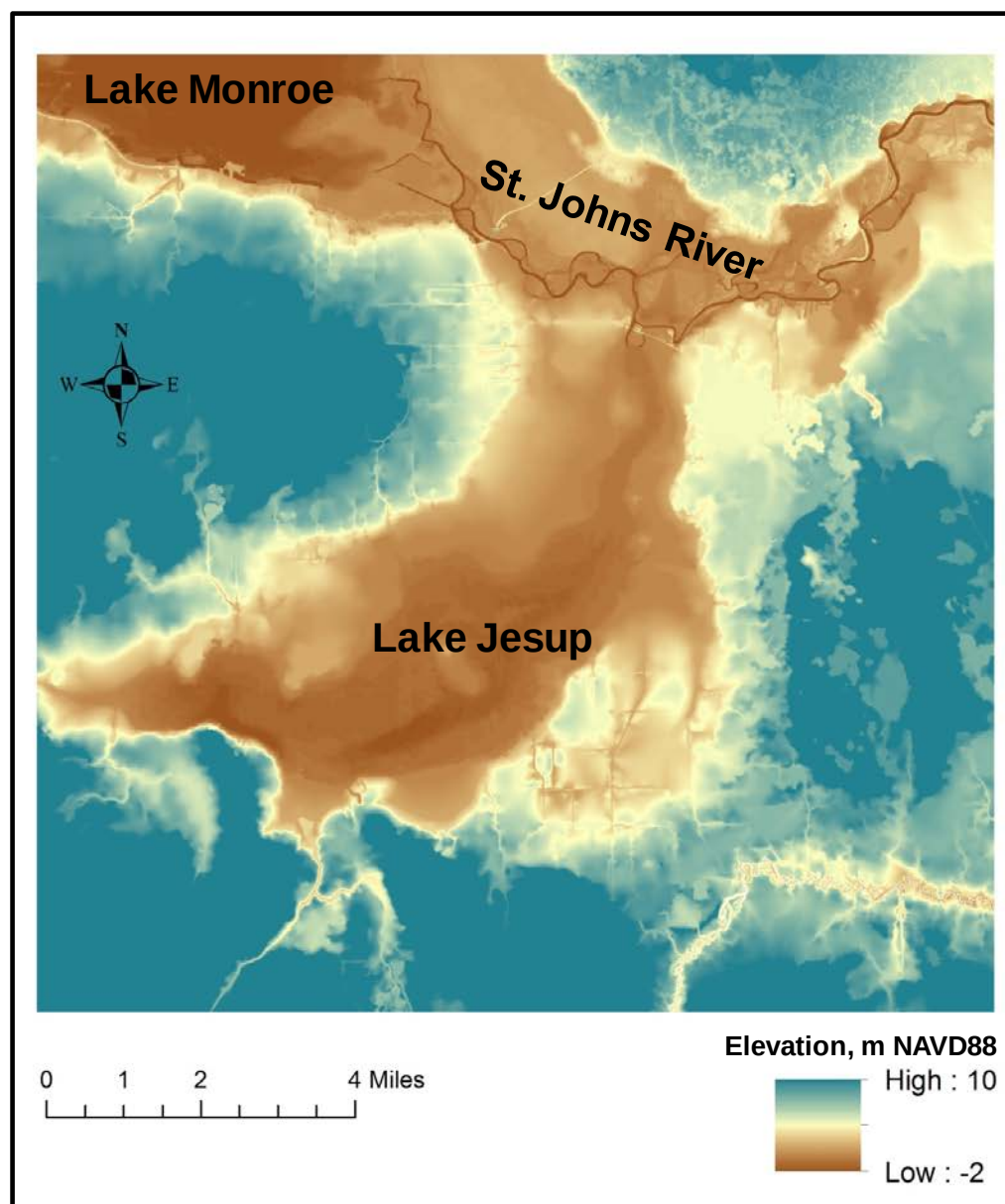


Figure 3–2. Final Digital Elevation Model (DEM) of lower and middle St. Johns River used to assign depths and shorelines for the EFDC hydrodynamic model.

3.3 METEOROLOGICAL DATA

The EFDC hydrodynamic model and WASP surface water quality model both require meteorological variables for model input. The EFDC hydrodynamic model requires daily rainfall and evaporation to maintain its mass budget and hourly winds to simulate wind-driven lake circulation and mixing. The WASP surface water quality model requires daily solar radiation and fraction of daylight hours for simulating phytoplankton growth. Daily water temperature is required by the WASP surface water quality model for modification of chemical reaction rates and growth and respiration of phytoplankton. Since daily water temperature data were not available, water temperature was simulated using the Equilibrium Temperature Method (Martin & McCutcheon, 1999). The Equilibrium Temperature Method requires daily values of solar radiation, wind speed, air temperature, and relative humidity to simulate water temperature.

Daily time-series of solar radiation, evaporation, wind speed, air temperature, and relative humidity were obtained from USGS satellite-based evapotranspiration estimates that are available over Florida on a 2-km grid (<http://fl.water.usgs.gov/et/>). Time-series of hourly wind speed and direction were obtained from the NASA Land Data Assimilation System (NLDAS; Mitchell et al., 2004).

4 THE EFDC HYDRODYNAMIC MODEL

The Environmental Fluid Dynamics Code (EFDC) is a three-dimensional hydrodynamic model capable of simulating water level, velocity, turbulence, salinity, and water temperature (Hamrick, 1992). This model was applied to Lake Jesup to simulate transport and mixing of materials within the lake. The output from EFDC is linked to the WASP surface water quality model to provide the spatially- and temporally-varying motions needed to simulate water quality using the WASP model.

The application of the EFDC hydrodynamic model to Lake Jesup is based on an existing calibrated EFDC model of the larger middle St. Johns River, from Astor to Lake Harney, which includes Lake Jesup (Figure 4–1). The Lake Jesup model grid and bathymetry were extracted from this larger model. The calibrated EFDC model of the middle St. Johns River was completed in 2011 as part of the St. Johns River Water Supply Impact Study (WSIS) (Sucsy et al., 2012). This model received extensive review by the National Research Council of the National Academy of Sciences. The grid resolution, bathymetry, inflow locations, and bottom roughness for the Lake Jesup EFDC model are identical to the EFDC WSIS model and calibration of the EFDC WSIS model is described in detail in Sucsy et al, 2012.

The grid for the Lake Jesup EFDC model is shown in Figure 4–2, below. The grid contains 333 horizontal cells. The Lake Jesup EFDC application is vertically averaged, using one cell in the vertical. HSPF discharge (and one spring) is input to the Lake Jesup EFDC model at 14 locations shown as green circles in Figure 4–2. The mean surface discharge for the simulation period (2003 – 2012) was 141.7 cfs (Jia, 2014). Six tributaries (Howell Creek, Gee Creek, Soldier Creek, Sixmile Creek, Phelps Creek, and Salt Creek) account for 87% of the total surface water discharge. The four largest tributaries, accounting for 79% of the total surface water discharge, are all located in the western end of the lake and farthest from the mouth.

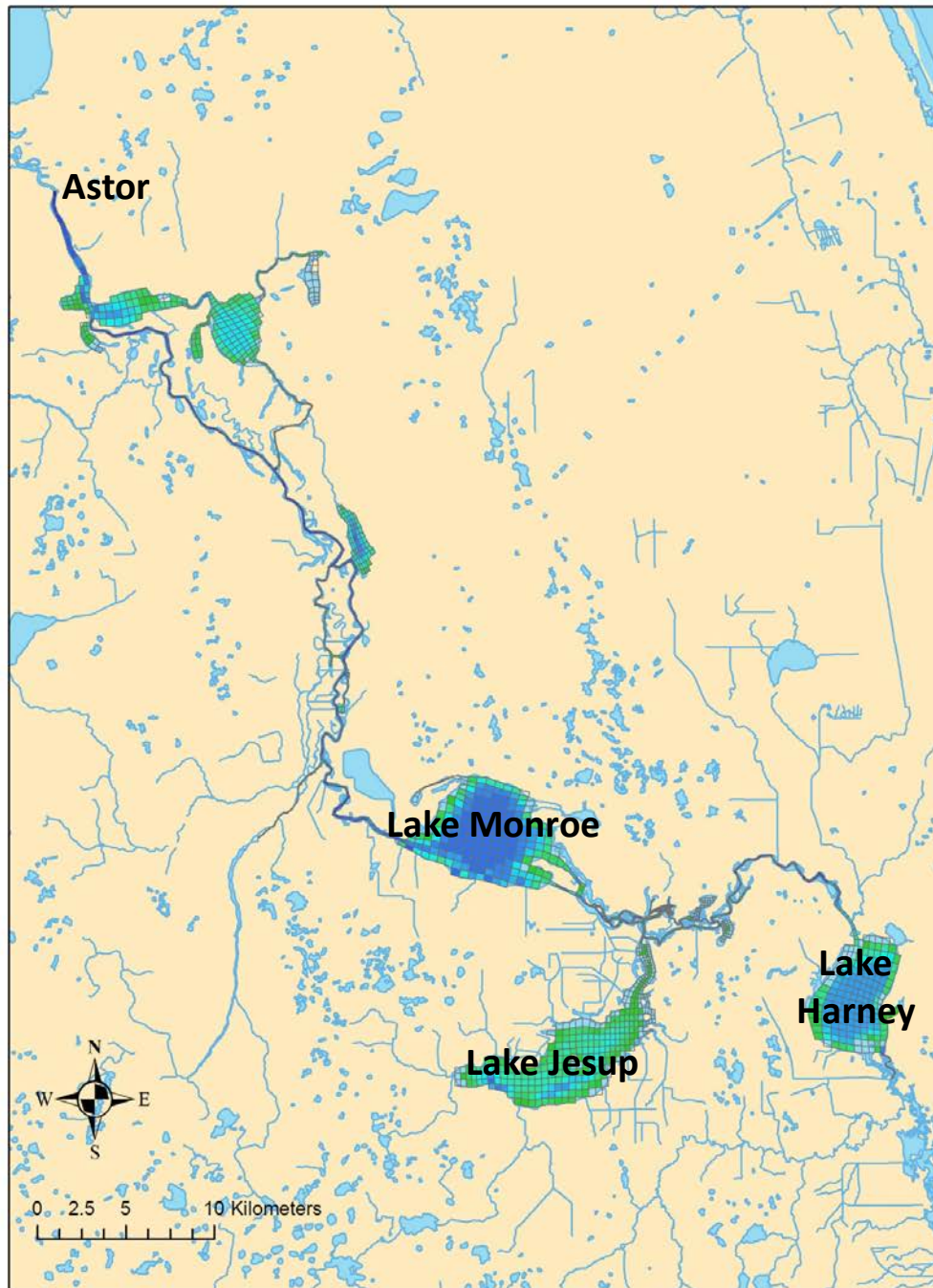


Figure 4–1. Model grid for the EFDC WSIS model used to simulate hydrodynamics of the middle St. Johns River from Astor to Lake Harney and including Lake Jesup (Sucsy et al., 2012).

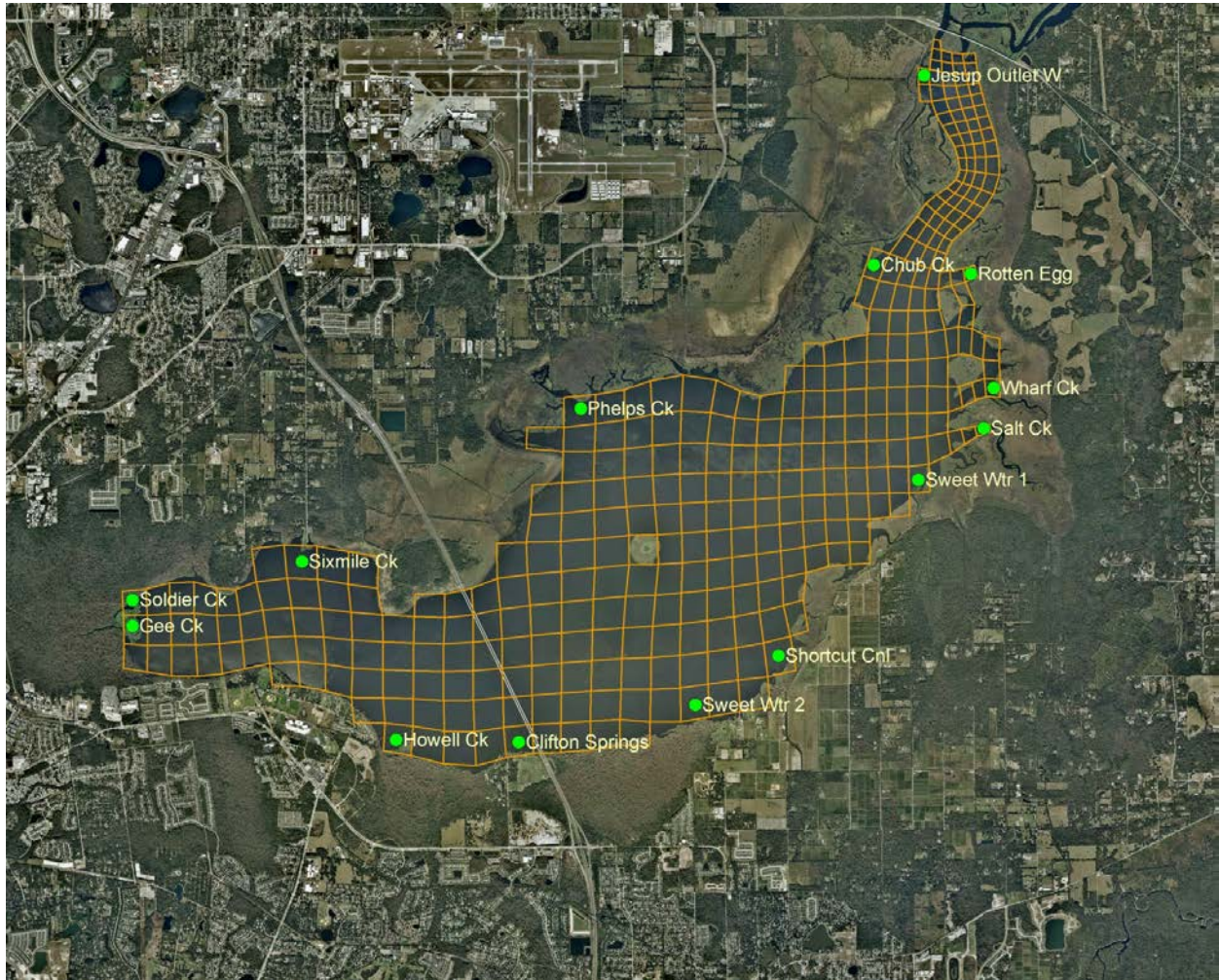


Figure 4–2. Model grid of the Lake Jesup EFDC model used to simulate hydrodynamics of Lake Jesup for linkage with a WASP surface water quality model.

The Lake Jesup EFDC model deviates from the EFDC WSIS model in the following ways:

- The Lake Jesup EFDC model is stand-alone so that a water level time-series is used as an open model boundary condition at the lake outlet. The EFDC WSIS model has a water level boundary condition at Astor.
- Diffuse ground water entering the Lake Jesup EFDC model was reduced compared with the EFDC WSIS model to match recent ground water flow estimates derived from seepage meter observations (Harper, 2013)
- Diffuse ground water flow was input to the Lake Jesup EFDC model as additional rainfall in the *user.inp* file. The EFDC WSIS model was modified to allow ground water flow into the bottom layer cells.
- The Lake Jesup EFDC model was run in 2D, vertically-averaged mode (one vertical layer). The EFDC WSIS model used six vertical layers.

- The Lake Jesup EFDC model uses tributary inflows from a more recent update of the WSIS HSPF hydrology models (Jia, 2014) than the HSPF models used for the St. Johns River Water Supply Study (Cera et al., 2012).
- Hourly winds used to extend the simulation period for the Lake Jesup EFDC model through 2012 were obtained from the NOAA Land Data Assimilation System (Mitchell et al., 2004). The EFDC WSIS model used various wind stations from NOAA and the Florida Automated Weather Network (FAWN).

The open model boundary at the lake mouth uses daily-averaged water level primarily from observed data at USGS station 02234435. Missing records at 02234435 were filled by correlation with USGS station 02234500 located near Sanford at the mouth of Lake Monroe. Daily water level at these two stations is highly correlated ($r^2 = 0.988$). The linear equation to calculate water level at Lake Jesup (H_{4435}) from water level at Lake Monroe (H_{4500}) is $H_{4435} = 1.117 \cdot H_{4500} + 0.105$.

The EFDC WSIS model used diffuse ground water flow into Lake Jesup derived from a steady-state MODFLOW ground water model using 1995 conditions (Belaine et al., 2012). The 1995 steady-state ground water discharge was estimated as 35 cfs. Harper (2013) recently used seepage meters to estimate mean ground water seepage to Lake Jesup of about 17 cfs. Given the inherent uncertainty in estimating ground water seepage and expected interannual variability, these groundwater inflow rates agree reasonably well. The Lake Jesup EFDC model uses the (lower) Harper estimate of seepage because (a) it is based on observed data, (b) Harper shows that rainfall during his 15-month period was relatively close to a long-term average, and (c) it allows consistency with using Harper's ground water nutrient load estimates for the WASP water quality model.

The volume flow from groundwater seepage is entered into the Lake Jesup EFDC model by an additional term of 0.001265 meters per day to rainfall in the *aser.inp* file. This value follows from an assumed constant seepage flux of 17 cfs over a model lake area of $32.8 \times 10^6 \text{ m}^2$.

The EFDC WSIS model used six vertical layers throughout the model domain because this vertical resolution was necessary to capture the dynamics of estuarine circulation in the lower St. Johns River. However, the Lake Jesup EFDC model uses one vertical layer because Lake Jesup is a shallow, unstratified, well-mixed lake where a vertically-averaged assumption is appropriate for water quality. Since the Lake Jesup EFDC model uses one cell in the vertical, addition of groundwater seepage to the model surface is identical to addition of groundwater seepage to the model bottom.

The updated HSPF tributary results for surface water inflows (Jia, 2014) are quite similar to previous estimates of surface water inflow and were updated as part of this TMDL re-assessment.

Hourly winds from the NOAA Land Data Assimilation System (Mitchell et al., 2004) are nearly identical to local FAWN stations but have the advantage of having no missing records and having expert quality assurance by national meteorological laboratories.

A comparison of simulated with observed water level at Oviedo (Figure 4–3) is shown below as a check on these modifications to the Lake Jesup EFDC model. The simulated water level generally matches the observed water level quite well. The Lake Jesup EFDC model slightly overpredicted water level during the extreme event in the Fall of 2004 that resulted from a succession of hurricanes impacting the Florida peninsula. This could be caused by not allowing for storage on the flood plains during this large event. These results demonstrate that the model is capable of capturing the monthly variations in lake depth necessary for simulating water quality.

The EFDC model generally simulates salinity, but since the EPA version of the source code does not allow for input of salt loads from ground water, the simulated salinity from the Lake Jesup EFDC model is low compared with observed values. The salinity calibration for Lake Jesup was instead achieved using WASP and these results, along with the salinity simulated by EFDC without inclusion of ground water, are presented in Section 5 of this report.

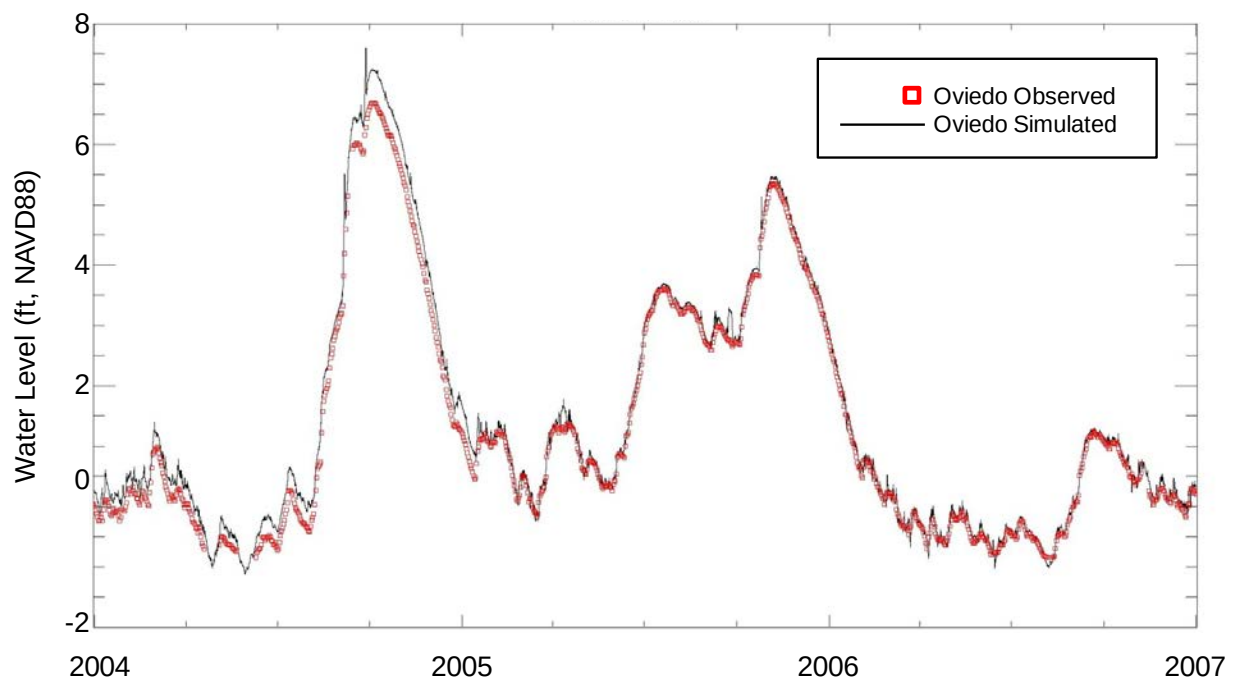


Figure 4–3. Comparison of simulated and observed water level (ft, NAVD88) at Oviedo on the south shore of Lake Jesup.

5 THE WASP WATER QUALITY MODEL

The Lake Jesup WASP (Water Quality Analysis Simulation Program) model is an application of WASP 7.3. WASP 7.3 (Ambrose et al., 1993) available from EPA (<http://www.epa.gov/athens/wwqtsc/html/wasp.html>). WASP is a dynamic compartment-modeling program capable of addressing a range of water quality issues. The Lake Jesup WASP model is primarily aimed at simulating the effect of phosphorus loading on phytoplankton biomass. The WASP model is linked to the EFDC hydrodynamic model to account for lake circulation and mixing by tributary inflows, dynamically-varying river stage, and surface winds.

The Lake Jesup WASP model uses the Advanced Eutrophication model type, one of eight model types presently available within WASP 7.3, with fourteen state variables: ammonia nitrogen, nitrate nitrogen, dissolved organic nitrogen, inorganic phosphate, dissolved organic phosphorus, three classes of CBOD, dissolved oxygen, detrital carbon, nitrogen, and phosphorus, inorganic solids, and phytoplankton. The linkage with EFDC provides all tributary inflows, rainfall, evaporation, and ground water seepage to WASP. Time-varying nutrient concentrations, derived from HSPF, are associated with each tributary boundary. Atmospheric deposition and ground water nutrient loads are input as constant sources distributed uniformly over the entire lake. Water temperature, solar radiation, fraction of daylight, and wind speed are input as daily time-series.

The Lake Jesup WASP model integrates all these disparate data sources to obtain a comprehensive picture of water quality dynamics within Lake Jesup for the 6-year period of 2004 to 2009.

5.1 TESTING OF LINKAGE BETWEEN EFDC AND WASP

The EFDC hydrodynamics model creates a linkage with the WASP surface water quality model. This linkage was tested by comparing salinity simulated from EFDC with salinity simulated independently by WASP using identical boundary concentrations. The state variable “Dissolved Organic Phosphorus” was used in WASP as a conservative tracer to independently simulate salinity for this test. This redefinition of the state variable was necessary because the automated linkage between EFDC and WASP passes simulated salinity from EFDC directly to WASP’s salinity state variable. The salinity state variable in WASP, then, cannot be used independently when WASP is linked to EFDC.

Simulated salinity was compared for EFDC and WASP at three locations corresponding to the locations of Water Quality Monitoring Network (WQMN) stations OW-2, OW-4, and OW-6. Comparisons were made for hourly time-series over a three-year simulation period of 1999 to 2001. These salinity simulations are not compared with observed salinity because the boundary concentrations do not include ground water seepage entering the lake. The simulated salinity tested here, then, is lower than actual salinity since ground water seepage is an important source of chloride to the lake.

These tests showed nearly identical results between salinity simulated using EFDC and WASP, thus verifying the correctness of the hydrodynamic linkage between the two models (Figure 5–1, Figure 5–2, and Figure 5–3). Small differences likely result from the coarser temporal resolution of hydrodynamics in WASP compared to EFDC because EFDC simulates salinity at a 60-second

time step, while WASP receives output from EFDC at a one-hour time step. Differences in the numerical scheme used to solve the advection-diffusion equation (Appadu, 2013) could also cause small differences between the WASP and EFDC model results.

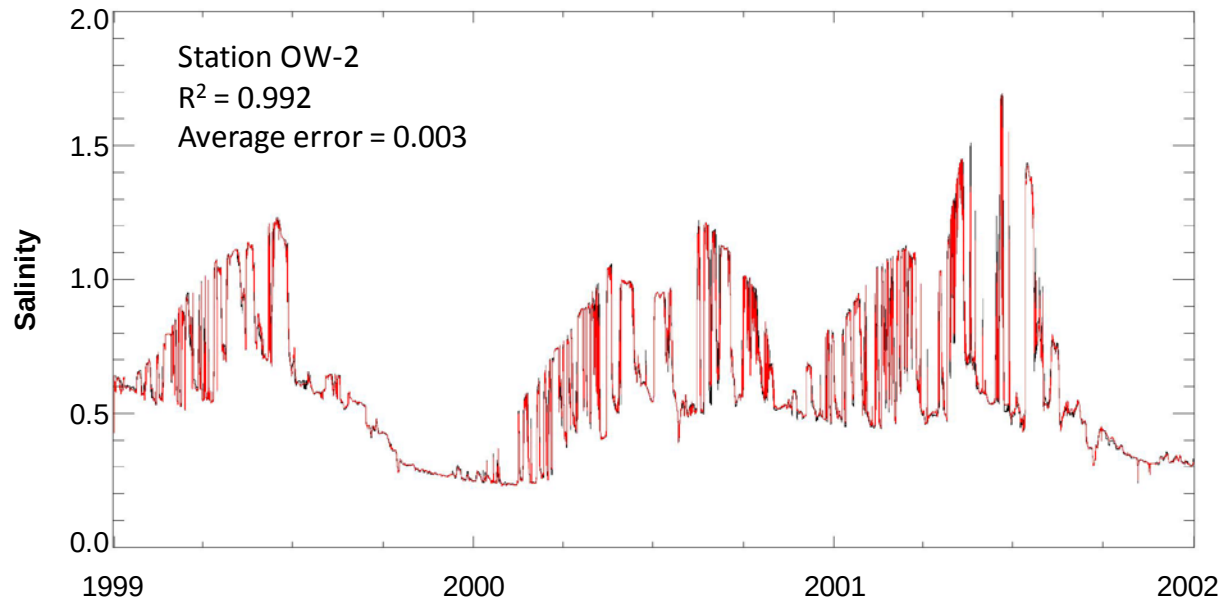


Figure 5–1. Comparison of hourly salinity simulated at Station OW-2 using WASP (black line) and EFDC (red line).

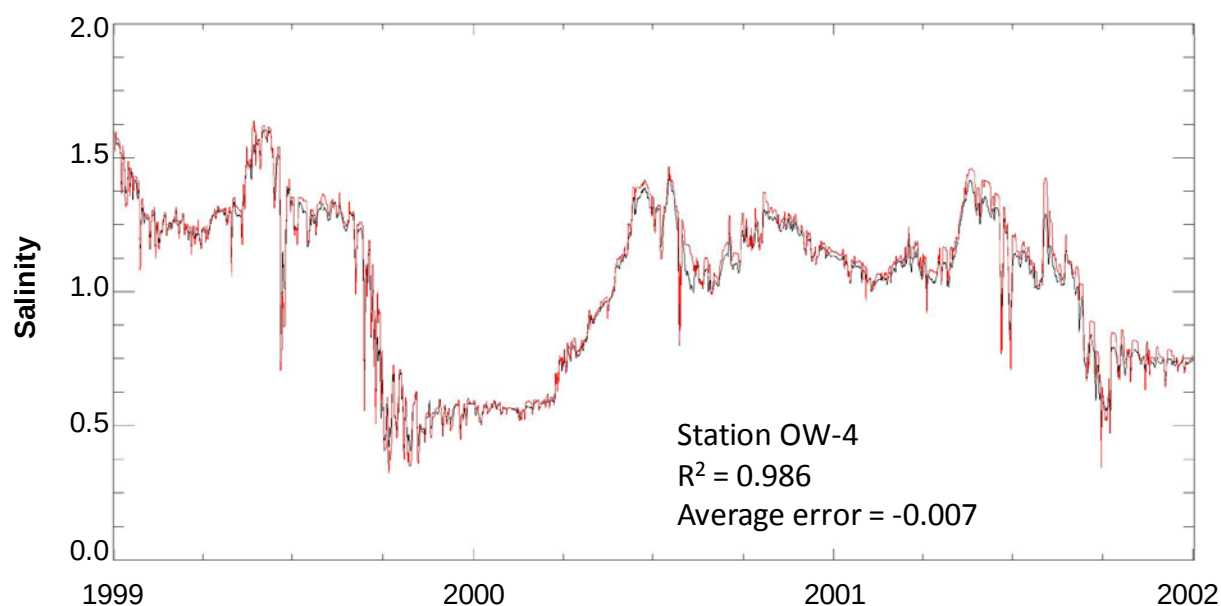


Figure 5–2. Comparison of hourly salinity simulated at Station OW-4 using WASP (black line) and EFDC (red line).

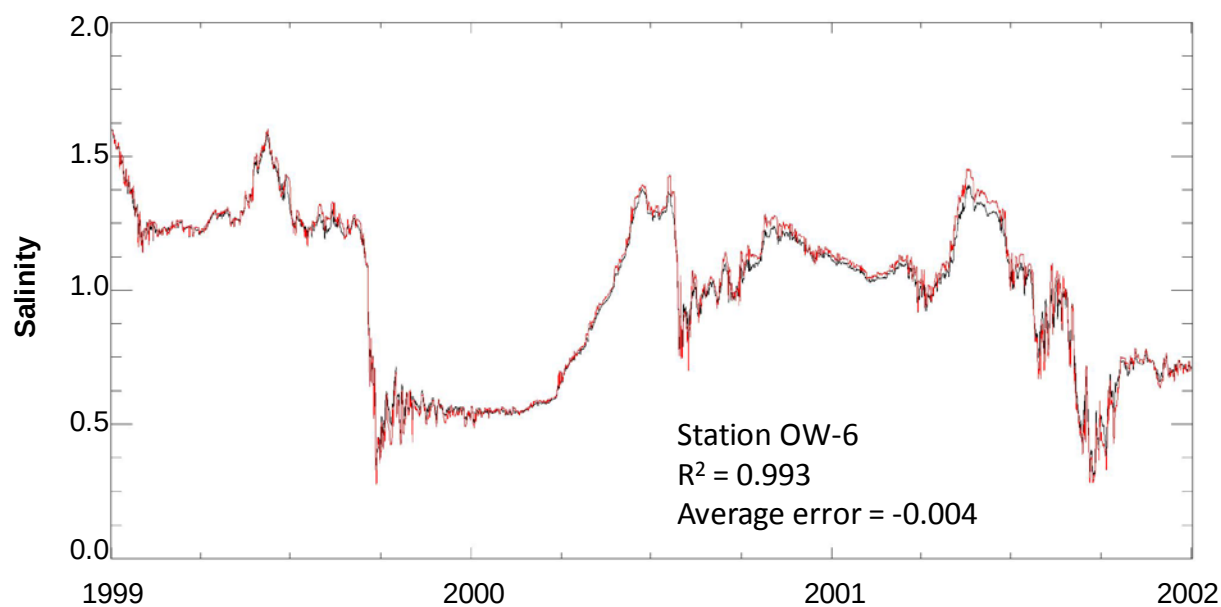


Figure 5–3. Comparison of hourly salinity simulated at Station OW-6 using WASP (black line) and EFDC (red line).

5.2 TESTING OF WASP MODEL SPIN-UP TIME

Initial conditions, or the concentrations of state variables at the beginning of a model simulation, can be a source of uncertainty in model simulations. This uncertainty is largely eliminated if the model is run for a long enough time for the initial conditions to no longer influence the solution. The required time is often termed model spin-up time.

The appropriate length of model spin-up time was estimated by use of a conservative tracer in the WASP model. The entire lake was initialized with a tracer concentration of 100 and all boundary concentrations for the tracer were set to zero. Tracer concentration then decreased over time as the tracer was flushed from the lake. Tracer concentration was examined at the same locations used for salinity. Only Station OW-6 is shown below, because areas farthest from the lake mouth exhibited the slowest flushing of the tracer. The simulation period begins with two dry years (1999 and 2000) so that the estimated spin-up time found using these years is conservatively long. 95% of the tracer was flushed from the west end of the lake in nine months (Figure 5–4), showing that a nine to twelve month spin-up time is sufficient to eliminate initial conditions as a source of model uncertainty.

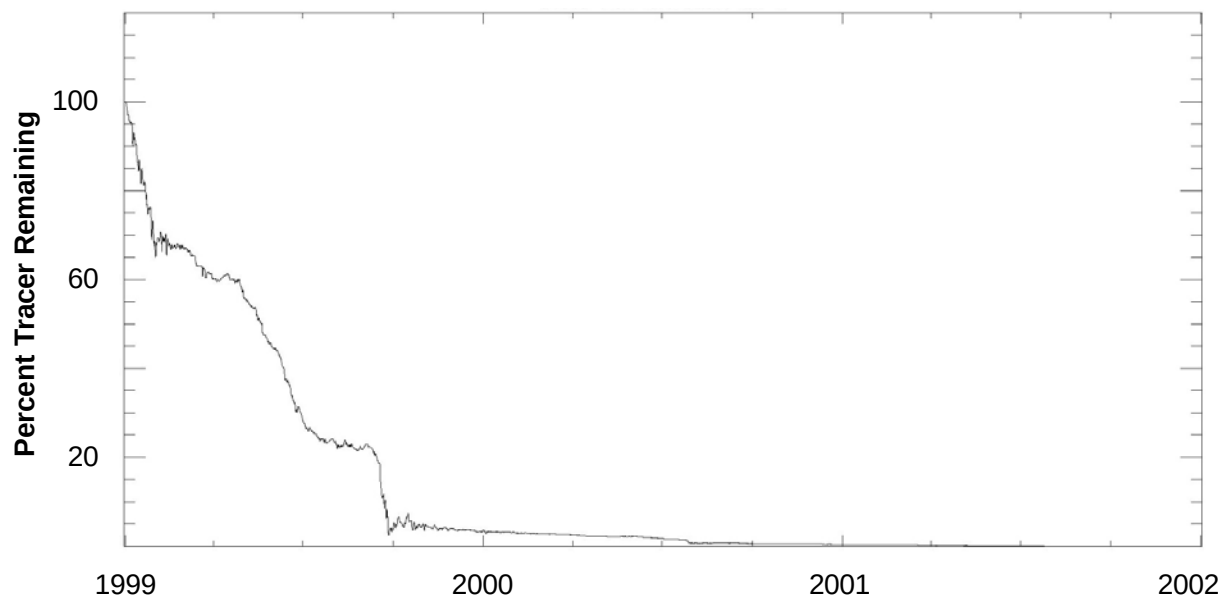


Figure 5–4. Percent tracer remaining at Station OW-6 in the west end of Lake Jesup. A model spin-up time of about one year is sufficient to eliminate uncertainty in initial conditions.

5.3 SIMULATING SALINITY: A NATURAL CONSERVATIVE TRACER

Salinity is an important output variable for calibration because salinity is a conservative tracer that integrates the hydrodynamic effects of circulation and mixing throughout the model domain. Salinity was simulated using a separate WASP application from the WASP water quality

application to validate transport and mixing. This separation was necessary because the linkage of EFDC with WASP requires that salinity be passed to WASP from EFDC. Because salinity loads from ground water cannot be simulated with the EPA-version of EFDC, the effect of ground water on salinity was simulated separately with a WASP salinity application.

A constant value of salinity was assigned to each of fourteen tributaries entering the lake (Sucsy et al., 2012). Ground water loads were assigned to each of the 333 cells in the WASP surface water quality model in four groups corresponding to the west, middle, mid-east, and east portions of the lake (Sucsy et al., 2012). Salinity assigned to each tributary and the ground water segments are shown in

Table 5–1, along with mean discharge and cell identifiers (I and J integer values) from the EFDC/WASP model grid. Ground water discharge is distributed uniformly over the lake at a constant total discharge of 17 cfs from Harper (2013).

The mean flow-weighted salinity (including ground water seepage) for Lake Jesup inflows is 0.43 for the period 2003 to 2012. The mean observed salinity for this period, obtained from combining all observations at stations OW-2, OW-4, and OW-6, was 0.39. The mean for each station individually was 0.48, 0.36, and 0.33 for OW-2, OW-4, and OW-6, respectively, showing a decreasing east-west gradient of salinity. This salinity gradient is likely because the three largest tributaries (Howell, Gee, and Soldier) enter the west end of the lake with salinity near 0.1 and dilute salinity from ground water. Without the influence of ground water, the mean flow-weighted salinity would drop to 0.29, a 30% decline. Ground water then is an important contributor to mean salinity. During periods of drought when tributary flows are low, ground water is the dominant source of lake salinity.

The mean simulated salinity for this same period and combining stations OW-2, OW-4, and OW-6 is 0.44, nearly identical to the flow-weighted mean of the inflows. This result shows the reasonableness of the Harper (2013) ground water seepage measurements, since this magnitude of ground water discharge, coupled with aquifer salinity, results in a better match with observed salinity than would be obtained by neglecting ground water seepage.

Table 5–1. Average discharge and salinity for individual inflows to Lake Jesup (2003 to 2012).

Tributary Name	Q(cfs)	Salinity	I/J Identifier
Rotten Egg Slough	2.7	0.11	36/18
Wharf Creek	1.3	0.11	37/13
Salt Creek	4.0	0.98	36/11
Sweet Water 1	2.9	1.5	32/10
Sweet Water 2	2.8	1.5	22/3
Shortcut Canal	2.3	1.5	25/4
Howell Creek	66.8	0.12	12/2
Gee Creek	18.4	0.11	2/6
Soldier Creek	15.9	0.11	2/7
Sixmile Creek	11.3	0.98	9/8
Phelps Creek	7.1	0.11	18/13
Jesup Westside	3.2	0.24	29/33
Chub Creek	1.6	0.30	29/18
Clifton Spring	1.4	0.35	15/2
GW Segment 1	4.3	1.25	West lake
GW Segment 2	4.3	1.25	Midde lake
GW Segment 3	4.3	1.50	Mid-east lake
GW Segment 4	4.3	1.80	East lake
Total	158.9	0.42	

A graphical comparison of simulated and observed salinity at station OW-4 are shown below for the entire simulation period (Figure 5–5, Figure 5–6, and Figure 5–7). For these plots, the black line shows the simulated salinity with ground water seepage, the red line shows simulated salinity without ground water seepage, and the blue circles show observed salinity. The

simulated salinity with ground water seepage shows a better match to observations than the simulated salinity without ground water seepage for nearly all periods. One notable exception is the spring of 2009. The few periods when the model overpredicts observations could be due to the assumption of a temporally constant ground water source. These results, however, demonstrate that the inclusion of ground water seepage at the rate observed by Harper (2013) is reasonable and improves the salt budget of the lake compared to a model that neglects ground water seepage.

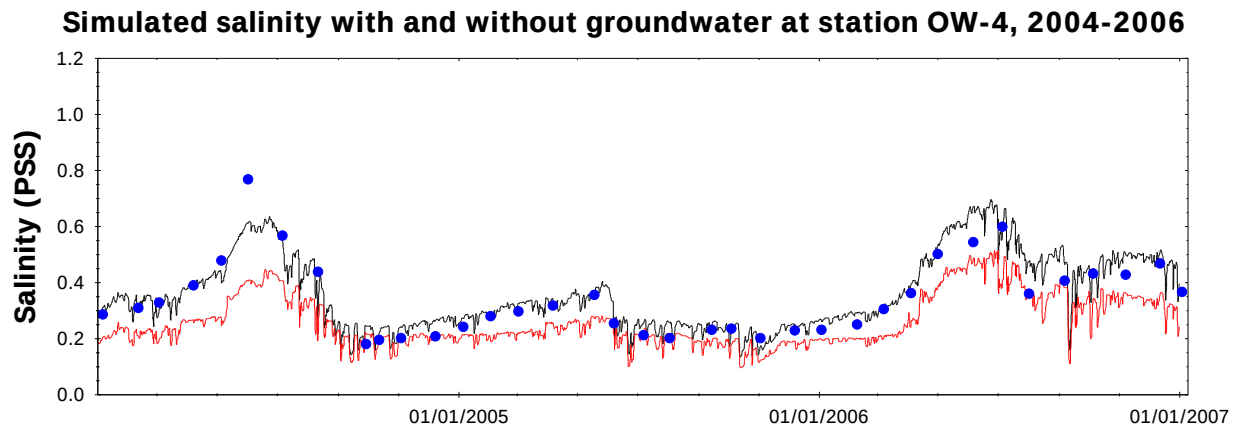


Figure 5–5. Comparison of simulated and observed salinity at station OW-4 in the west end of Lake Jesup, 2004-2006. The black line is simulated salinity with ground water seepage. The red line is simulated salinity without ground water seepage. The blue circles are observed salinity.

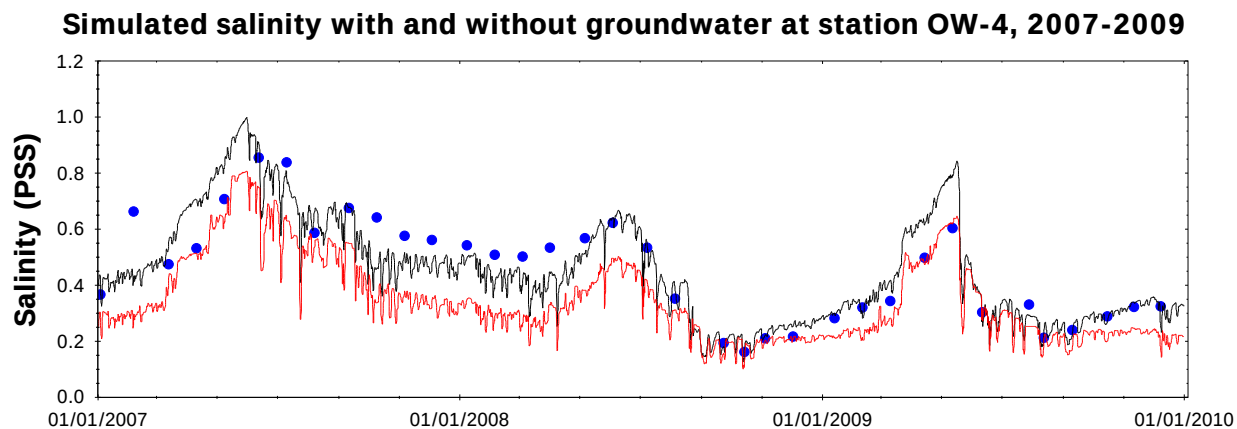


Figure 5–6. Comparison of simulated and observed salinity at station OW-4 in the west end of Lake Jesup, 2007-2009. The black line is simulated salinity with ground water seepage. The red line is simulated salinity without ground water seepage. The blue circles are observed salinity.

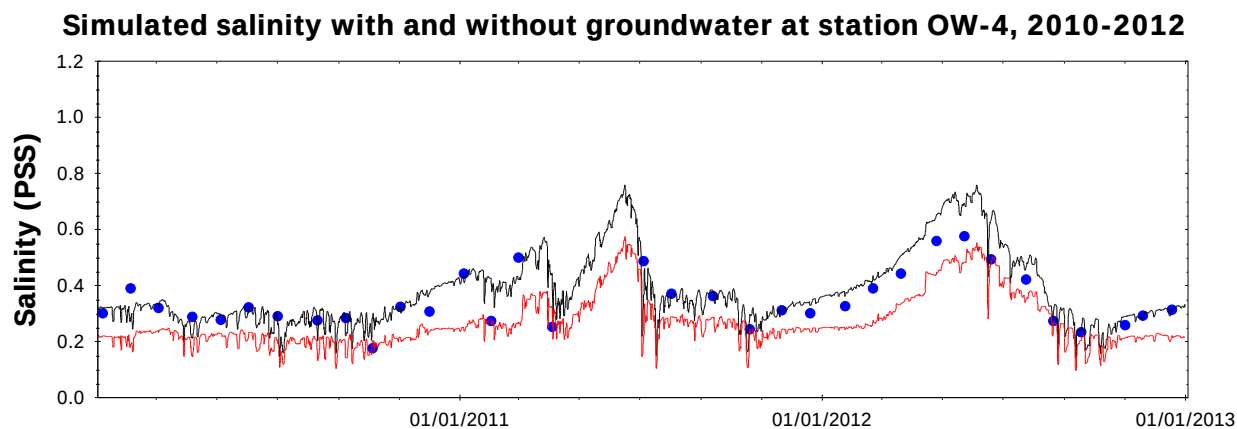


Figure 5–7. Comparison of simulated and observed salinity at station OW-4 in the west end of Lake Jesup, 2010-2012. The black line is simulated salinity with ground water seepage. The red line is simulated salinity without ground water seepage. The blue circles are observed salinity.

5.4 WASP MODEL BOUNDARY CONDITIONS

5.4.1 NUTRIENT LOADS

Tributary Loads

The HSPF watershed model provided daily values of dissolved oxygen, total ammonium, nitrate, inorganic phosphate, total nitrogen, and total phosphorus for each of the thirteen tributaries input to the WASP surface water quality model (Jia, 2014). The tributaries simulated by HSPF are the first thirteen tributaries listed in

Table 5–1 above. Nutrient concentrations for Clifton Spring and ground water seepage were not provided by HSPF, but were obtained from observation. The nutrient concentrations for the HSPF state variables were assigned to WASP state variables as shown in Table 5–2.

Table 5–2. Assignment of HSPF state variables to WASP state variables for tributaries entering Lake Jesup.

WASP State Variable	HSPF State Variables
Ammonia Nitrogen	Total ammonium (TAM)
Nitrate Nitrogen	Nitrate (NO3)
Dissolved Organic Nitrogen	Calculated from Total Nitrogen (TN) <i>minus</i> TAM <i>minus</i> NO3
Inorganic Phosphate	Phosphate (PO4)
Dissolved Organic Phosphorus	Calculated from Total Phosphorus (TP) <i>minus</i> PO4
Dissolved Oxygen	Dissolved Oxygen (D.O.)

The average annual tributary load to Lake Jesup for the period 2003 to 2012 was 146 MT yr⁻¹ for total nitrogen and 17.9 MT yr⁻¹ for total phosphorus.

Ground Water Seepage and Spring Loads

Ground water nutrient loads from seepage were estimated by Harper (2013) as 89 MT yr⁻¹ for total nitrogen and 9.5 MT yr⁻¹ for total phosphorus. Clifton Springs adds a relatively trivial load of 0.0126 MT yr⁻¹ for total nitrogen and 0.0063 MT yr⁻¹ for total phosphorus. Nutrient loads from ground water seepage were entered into the WASP model as constant rates of benthic ammonia and phosphate flux.

Atmospheric Deposition

Ammonia (NH₄), nitrate (NO₃) and phosphate (PO₄) concentrations of wet deposition are taken as 0.15 mg N L⁻¹, 0.74 mg N L⁻¹, and 0.04 mg P L⁻¹, respectively. These concentrations are the precipitation-weighted mean concentrations of wet deposition for site FL32 of the National Atmospheric Deposition Program (<http://nadp.sws.uiuc.edu>) located in Orange County. Dry deposition rates are from SJRWMD dry deposition samples measured at Lake Lochloosa in Alachua County. NH₄, NO₃, and PO₄ dry deposition areal rates are 37 mg N m⁻² yr⁻¹, 149 mg N m⁻² yr⁻¹, and 10 mg P m⁻² yr⁻¹, respectively.

The annual load of total nitrogen contributed by wet atmospheric deposition is 36 MT yr⁻¹ and by dry deposition is six MT yr⁻¹. The annual load of total phosphorus for wet and dry atmospheric deposition is 1.6 MT yr⁻¹ and 0.32 MT yr⁻¹, respectively.

Both wet and dry deposition is input to the WASP model as constant areal rates. This choice is a model simplification for wet deposition since its load distribution varies with direct precipitation.

However, wet deposition accounts for only 13% of the total nitrogen load (even excluding nitrogen fixation within the lake) and 5% of the total phosphorus load. This simplification is justified because of the relatively greater effect of surface runoff and ground water loads to the lake nutrient concentrations.

The constant wet deposition is averaged over the period 2003 to 2012, which results in constant areal wet deposition rates of 0.517, 2.553, and 0.138 mg m⁻² day⁻¹ for NH₄, NO₃, and PO₄, respectively. Dry deposition rates in these same units are 0.101, 0.408, and 0.027 mg m⁻² day⁻¹ for NH₄, NO₃, and PO₄, respectively.

Open Boundary Condition at the Lake Mouth

Water quality concentrations are specified at the lake mouth using observed monthly observations at Station OW-SJR-1 in the adjacent St. Johns River. As noted in Table 3–1, total phosphorus and total nitrogen concentrations are generally much lower for the St. Johns River than within Lake Jesup.

5.4.2 SIMULATED LAKE WATER TEMPERATURE

Water temperature observations in Lake Jesup are available at monthly intervals, but this temporal resolution cannot capture synoptic-scale weather events such as the passage of winter cold fronts. Daily water temperature was thus simulated using the Equilibrium Temperature Method (Martin & McCutcheon, 1999). Daily values of satellite-derived air temperature, wind speed, relative humidity, and solar radiation were obtained from the USGS Florida Water Science Center (Paech et al., 2009). These data were then used to obtain daily values of equilibrium temperature and coefficient of heat exchange by the Equilibrium Temperature Method (Martin & McCutcheon, 1999). Finally, the net heat flux (watts m⁻²) to the lake for each day was approximated by finite difference using the difference between the equilibrium temperature and the previous day's simulated temperature multiplied by the coefficient of heat exchange. The net daily energy (joules) to the lake is then the net heat flux multiplied by the lake area with an appropriate conversion from seconds to days. The change in lake temperature from the previous day is estimated by dividing the net daily energy by the lake mass and specific heat of water.

This calculation requires use of both the lake area and lake volume (or mass) for each day. A simplification was to hold area and volume constant. Although volume, in particular, can more than double during high stage events in the St. Johns River, this simplification produced reasonable values of simulated water temperature over a range of conditions as shown in Figure 5–8 for the calibration period and Figure 5–9 for the remaining simulation period.

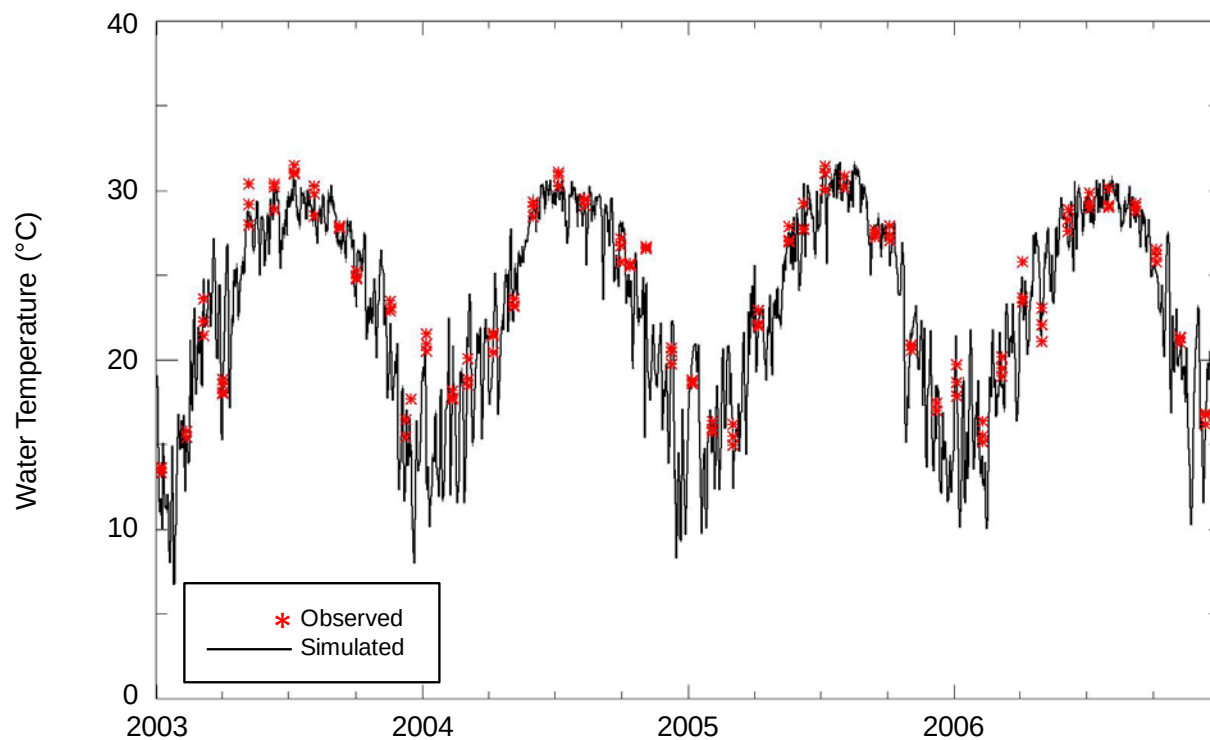


Figure 5–8. Comparison of simulated and observed water temperature in Lake Jesup, 2003-2006. Observed values are combined from stations OW-2, OW-4, and OW-6.

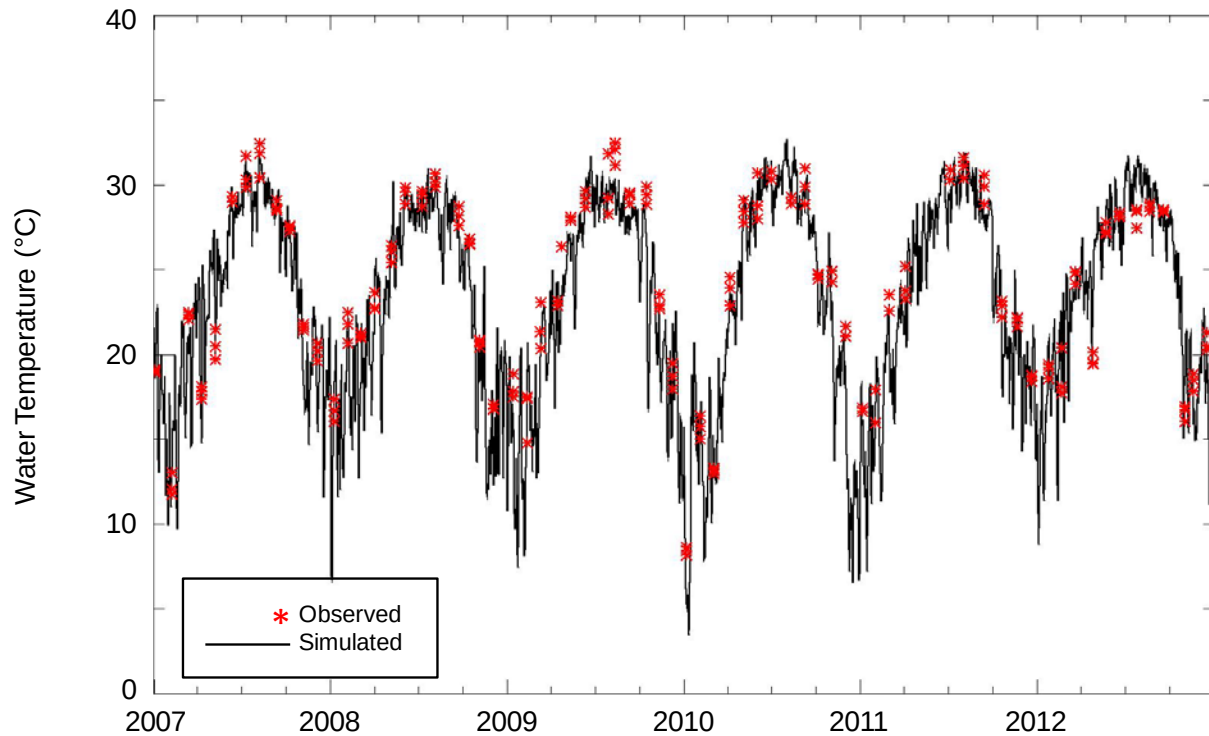


Figure 5–9. Comparison of simulated and observed water temperature in Lake Jesup, 2007-2012. Observed values are combined from stations OW-2, OW-4, and OW-6.

Finally, Figure 5–10 compares simulated and observed water temperature for the winter period of October 2003 to March 2004. Note that simulated water temperature is often appreciably colder than observed values because the six monthly sampling trips happened to occur during warmer periods. Simulating daily water temperature was necessary to capture the true water temperature variability, particularly in winter when daily temperature variability is greatest.

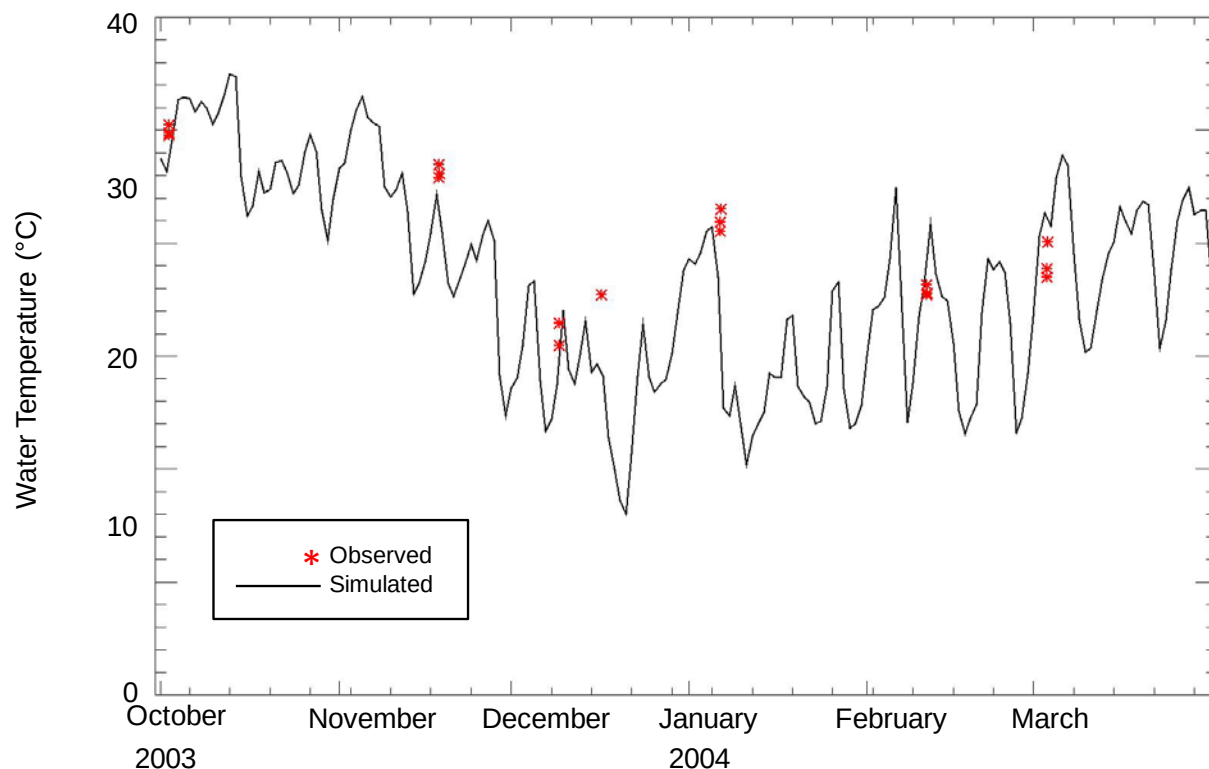


Figure 5–10. Comparison of simulated and observed water temperature in Lake Jesup, October 2003 to March 2004. Monthly sampling did not capture cold events during the 2003-04 winter.

5.5 DESCRIPTION OF WASP MODEL SET-UP FOR LAKE JESUP

WASP 7.3 uses a pre-processor organized into thirteen data entry screens. These data entry screens are used to define parameters and input data that control major functions of WASP. The thirteen data entry screens are *Data set*, *Systems*, *Segments*, *Parameters*, *Constants*, *Exchanges*, *Flows*, *Loads*, *Boundaries*, *Time functions*, *Print interval*, *Output control*, and *Input network*. Not all these data entry screens are used for the Lake Jesup WASP model. The linkage of WASP with EFDC automatically controls the *Exchanges*, *Flows* and *Input network* data entry screens. The *Loads* data entry screen was not used because the Lake Jesup WASP model did not require input of temporally-varying nutrient loads; these are simulated as the product of discharge and concentration within the *Boundaries* data entry screen.

5.5.1 DATA SET SCREEN

Table 5–3 lists the key parameters defined within the *Data set* data entry screen along with their defined values for set-up of the Lake Jesup WASP application.

Table 5–3. Parameters and values entered into the *Data set* data entry screen.

Parameter	Value	Comment
Model Type	Advanced Eutrophication	
Start Date	1/1/2003	See note 1 below
End Date	1/1/2007	See note 1 below
Skip Ahead to Date	1/1/2003	Same as Start Date
Hydrodynamics	Hydrodynamic Linkage	Uses EFDC linkage file
Solution Technique	COSMIC	
Max Time Step	9.9	This value triggers auto-stepping

Note 1: The Start Date and End Date are tied to a particular EFDC Hydrodynamics Linkage file. There are two such files corresponding to the overlapping 4-yr periods of 2003-2006 and 2006-2009. The first year of each EFDC Linkage file is used as model spin-up. Dividing the simulations into two different periods was used to keep the sizes of input and output files from becoming excessively large.

5.5.2 SYSTEMS SCREEN

The Systems data entry screen was used to select the relevant state variables for the Lake Jesup WASP application. Table 5–4 shows which state variables available with the Advanced Eutrophication Model Type are simulated for the Lake Jesup WASP application.

The table reflects the following key decisions about the conceptual model framework for Lake Jesup:

- All internally-created CBOD decays at the same rate (CBOD 1)
- Color is simulated by CBOD with a very low decay rate (CBOD 3) with its source from tributary inflow
- There are no other sources of CBOD (CBOD 2 is simulated but there are no defined inputs)
- The range of lake salinity (0.2 – 0.8) is not important to phytoplankton dynamics
- Lake production is dominated by phytoplankton
- Inorganic solids are only simulated as a wash load for their average effect on light extinction
- The algal community is characterized by a single phytoplankton group
- Phytoplankton dynamics are unaffected by the range of lake pH

Table 5–4. State variables selected through the *Systems* data entry screen.

State Variable	Simulated?	Comment
Ammonia Nitrogen	Yes	
Nitrate Nitrogen	Yes	
Dissolved Organic Nitrogen	Yes	
Inorganic Phosphorus	Yes	
Dissolved Organic Phosphorus	Yes	
Inorganic Silica	Yes	Included but insensitive for Lake Jesup
Dissolved Organic Silica	Yes	Included but insensitive for Lake Jesup
CBOD 1	Yes	Internally created by phytoplankton
CBOD 2	Yes	Reserved for tributary inflows, but unused.
CBOD 3	Yes	Proxy for color (refractory DOC)
Dissolved Oxygen	Yes	
Detrital Carbon	Yes	Internally created by phytoplankton
Detrital Nitrogen	Yes	Internally created by phytoplankton
Detrital Phosphorus	Yes	Internally created by phytoplankton
Detrital Silica	Yes	Internally created by phytoplankton
Total Detritus	Yes	Internally created by phytoplankton
Salinity	Yes	Passed from EFDC
Benthic Algae	No	All production assumed to be by phytoplankton in water column
Periphyton Cell Quota Nitrogen	No	All production assumed to be by phytoplankton in water column
Periphyton Cell Quota Phosphorus	No	All production assumed to be by phytoplankton in water column

Inorganic Solids 1	Yes	Used to represent a background wash load to simulate effect on light extinction; no dynamic sediment model
Inorganic Solids 2	No	No dynamic sediment model
Inorganic Solids 3	No	No dynamic sediment model
Phytoplankton 1	No	Only 1 algal group is used for Lake Jesup
Phytoplankton 2	Yes	
Phytoplankton 3	No	Only 1 algal group is used for Lake Jesup
pH	No	Toxics and ammonia toxicity not considered
Alkalinity	No	Toxics and ammonia toxicity not considered

5.5.3 SEGMENTS SCREEN

The Segments data entry screen has four tabs: *Segments*, *Parameters*, *Initial Conditions*, and *Fraction Dissolved*.

The *Segments* tab is automatically set by the EFDC linkage. The *Parameters* tab identifies that water temperature, solar radiation, and wind speed are input to WASP as external time-series. Settling rates are unused in the *Segments* tab. This reflects a conservative assumption that there is no net loss of nutrients to the sediments by burial or denitrification. This assumption also discounts seasonal variability in storage and release of nutrients from sediments.

The *Parameters* tab is used also to set the benthic ammonia and phosphate flux, here used to represent ground water seepage, as $7.54 \text{ mg m}^{-2} \text{ d}^{-1}$ of nitrogen and $0.8 \text{ mg m}^{-2} \text{ d}^{-1}$ of phosphorus. These values are based on mean seepage nutrient fluxes measured by Harper (2013) of 244 kg TN d^{-1} and 26 kg TP d^{-1} divided by an estimated model area of 32.36 million m^2 . (This model area is slightly less than the total model area of 32.8 million m^2 because I omitted cells adjacent to the lake mouth). These nutrient fluxes are assumed to represent ground water seepage as a new source of nutrients to the lake. These fluxes do not represent recycled (diagenetic) nutrient fluxes. Diagenetic fluxes are not simulated in the model, instead all nutrients entering the lake remain in the water column.

The *Initial Concentrations* tab provides initial concentrations for each active state variable. The model, however, uses a one-year spin-up time so the model simulation is insensitive to these selected values.

The *Fraction Dissolved* tab allows specification of particulate fractions of nutrients. Following the assumption of zero net settling (that is all nutrients entering the lake remain in the water column) all nutrient forms are simulated as dissolved for the Lake Jesup WASP model. (This simply means that the model does not associate nutrients with suspended sediment that can deposit to the sediment bed).

5.5.4 PARAMETERS SCREEN

For the Lake Jesup WASP model, the *Parameters* data entry screen simply switches on the input of water temperature, solar radiation, and wind speed and ensures the units of these specified time-series are correct. Settling rates are switched on in this data entry screen, but the settling rates are set to zero in the *Segments* data entry screen. This screen also activates benthic flux of ammonia and phosphate used to represent new nutrient fluxes from groundwater seepage.

5.5.5 CONSTANTS SCREEN

The *Constants* data entry screen contains a large number of tabs and the associated parameters set most of the kinetic rates and related parameters that control the WASP model. The tabs are addressed here in order of their appearance in WASP 7.3.

Globals

This tab sets the constant nutrient loading rates that are used in the Lake Jesup WASP application to account for the combined loads from atmospheric deposition and ground water inflow (Table 5–5).

Table 5–5. Constants defined in the *Globals* tab of the *Constants* data entry screen.

Constant	Value	Comment
Waterbody Type Used to Drive Reaeration Rate	2	This type is applicable for wind-dominated reaeration in lakes
Atmospheric Deposition of Nitrate (mg/m²/day)	2.958	0.405 dry deposition + 2.553 wet deposition
Atmospheric Deposition of Ammonia (mg/m²/day)	0.618	0.101 dry deposition + 0.517 wet deposition
Atmospheric Deposition of Orthophosphate (mg/m²/day)	0.166	0.027 dry deposition + 0.138 wet deposition
Atmospheric Deposition of CBOD1 (mg/m²/day)	0.0	
Atmospheric Deposition of Organic Nitrogen (mg/m²/day)	0.0	
Atmospheric Deposition of Organic Phosphorus (mg/m²/day)	0.0	

Inorganic Nutrient Kinetics

The *Inorganic Nutrient Kinetics* tab controls the rates of nitrification and denitrification (Table 5–6).

Table 5–6. Constants defined in the *Inorganic Nutrient Kinetics* tab of the *Constants* data entry screen.

Parameter	Value	Comment
Nitrification Rate Constant @20°C (1/day)	0.1 d ⁻¹	WASP Manual 9-22
Nitrification Temperature Coefficient	1.08	WASP Manual 9-22
Half Saturation Constant for Nitrification Oxygen Limit (mg O ₂ /L)	2 mg/L	WASP Manual 9-22
Minimum Temperature for Nitrification Reaction (°C)	0.5	GMM & Assoc. (2006)
Denitrification Rate Constant @20°C (1/day)	0.09 d ⁻¹	WASP Manual 9-23
Denitrification Temperature Coefficient	1.04	WASP Manual 9-23
Half Saturation Constant for Denitrification Oxygen Limit (mg O ₂ /L)	0.1	WASP Manual 9-23

Inorganic Nutrient Partitioning

This tab is not used because dissolved and particulate nutrient forms are not distinguished for the Lake Jesup WASP application.

Organic Nutrients

The *Organic Nutrient Kinetics* tab controls the rates of mineralization of organic material to inorganic forms (Table 5–7).

Table 5–7. Constants defined in the *Organic Nutrient Kinetics* tab of the *Constants* data entry screen.

Parameter	Value	Comment
Detritus Dissolution Rate (1/day)	0.1	Ambrose and Wool (2010)
Temperature Correction for detritus dissolution	1.08	Butcher Pen Creek (1.07-1.08)
Dissolved Organic Nitrogen Mineralization Rate Constant @20°C (1/day)	0.025	Determined through calibration of total nitrogen
Dissolved Organic Nitrogen Mineralization Temperature Coefficient	1.08	WASP Manual 9-22
Dissolved Organic Phosphorus Mineralization Rate Constant @20°C (1/day)	0.22	WASP Manual 9-17
Dissolved Organic Phosphorus Mineralization Temperature Coefficient	1.08	WASP Manual 9-17
Dissolved Organic Silica Mineralization Rate Constant @20°C (1/day)	0.25	Not Used
Dissolved Organic Silica Mineralization Temperature Coefficient	1.07	Not Used
Phytoplankton Half-Sat. for Mineralization Rate (mg Phyt C/L)	1.0	WASP Manual 9-17

CBOD

The *CBOD* tab controls the rates of decay of three CBOD classes (Table 5–8). CBOD1 is used as a sink for carbonaceous material resulting from phytoplankton death and has a moderate, labile decay rate. CBOD2 shows parameters, but is not used in this application. CBOD3 is used as a proxy for color in determining light extinction. It has a low decay rate representative of refractory dissolved organic carbon.

Table 5–8. Constants defined in the *CBOD* tab of the *Constants* data entry screen.

Parameter	Value	Comment
CBOD(1) Decay Rate Constant @20°C (1/day)	0.05	Source is phytoplankton
CBOD(1) Decay Rate Temperature Correction Coefficient	1.047	WASP Manual 8-4
CBOD(1) Half Saturation Oxygen Limit (mg O ₂ /L)	0.5	WASP Manual 8-4
Fraction of Detritus Dissolution to CBOD(1)	1	Model formulation
Fraction of CBOD(1) Carbon Source for Denitrification	1	Model formulation
CBOD(2) Decay Rate Constant @20°C (1/day)	0.1	Reserved for runoff but not used
CBOD(2) Decay Rate Temperature Correction Coefficient	1.047	WASP Manual 8-4
CBOD(2) Half Saturation Oxygen Limit (mg O ₂ /L)	0.5	WASP Manual 8-4
Fraction of Detritus Dissolution to CBOD(2)	0.0	Not used
Fraction of CBOD(2) Carbon Source for Denitrification	0	Not used
CBOD(3) Decay Rate Constant @20°C (1/day)	0.005	Proxy for color; source is tributaries
CBOD(3) Decay Rate Temperature Correction Coefficient	1.047	WASP Manual 8-4
CBOD(3) Half Saturation Oxygen Limit (mg O ₂ /L)	0.5	WASP Manual 8-4
Fraction of Detritus Dissolution to CBOD(3)	0	Source is tributaries
Fraction of CBOD(3) Carbon Source for Denitrification	0	Considered too refractory to be available for denitrification

Dissolved Oxygen

The *Dissolved Oxygen* tab sets the stoichiometric ratio for oxygen to carbon respiration and the reaeration method (Table 5–9).

Table 5–9. Constants defined in the *Dissolved Oxygen* tab of the Constants data entry screen.

Parameter	Value	Comment
Oxygen to Carbon Stoichiometric Ratio	2.67	WASP Manual 8-4
Calc Reaeration Option (0=Covar,2=Owens, 3=Churchill, 4=Tsivoglou)	0	WASP Manual 8-6
Theta -- Reaeration Temperature Correction	1.024	Chapra (1997)

Sediment Diagenesis

This tab is not used. All nutrient forms are retained in the water column.

Light

The *Light* tab primarily sets the parameters that determine a light extinction coefficient from suspended solids, dissolved organic carbon, and algal self-shading (Table 5–10).

Table 5–10. Constants defined in the *Light* tab of the Constants data entry screen.

Parameter	Value	Comment
Light Option (1 uses input light; 2 uses calculated diel light)	2	Diel light
Multiplier for Self Shading (Mult * TCHLA ^{Exp})	0.0587	WASP Manual
Exponent for Self Shading (Mult * TCHLA ^{Exp})	0.778	WASP Manual
Include Algal Self Shading Light Extinction in Steele (0=Yes, 1=No)	0	ON
Background Light Extinction Coefficient (1/m)	0.3	CEQUAL [0.1]
Detritus & Solids Light Extinction Multiplier	0.05	CEQUAL [0.2]
DOC Light Extinction Multiplier (Values Below Modify Global Value)	0.10	CEQUAL [0.2]
Percent Light in Segment to Define Photic Zone	0.01	1% light defines photic zone

Note: A reviewer suggested that the self-shading algorithm was not appropriate for chlorophyll-a concentrations exceeding 300 µg L⁻¹. This condition is rare in Lake Jesup. Chlorophyll-a observations at OW-2, OW-4, and OW-6 exceeded this level only six times of 524 observations during 1999 to 2013. That is, chlorophyll-a was observed below 300 µg L⁻¹ for 98.5% of the time.

Solids

This tab is not used because a dynamic sediment model is not used for the Lake Jesup WASP application. All material is retained in the water column.

Benthic Algae

This tab is not used because phytoplankton is assumed to dominate production for the Lake Jesup WASP application.

Phytoplankton

The *Phytoplankton* tab primarily set parameters that define the behavior of phytoplankton (Table 5–11). The Lake Jesup WASP application uses one algal group (*Phytoplankton 2*). Parameters set in the *Phytoplankton 1* and *Phytoplankton 3* tabs are not used by the model.

Table 5–11. Constants defined in the *Phytoplankton* tab of the Constants data entry screen.

Parameter	Value	Comment
Phytoplankton Detritus to Carbon Ratio (mg D/mg C)	3.2	Platt & Irwin, 1972 (3.2 to 5)
Phytoplankton Nitrogen to Carbon Ratio (mg N/mg C)	0.175	Redfield (0.13-0.25)
Phytoplankton Phosphorus to Carbon Ratio (mg P/mg C)	0.025	Redfield (0.023-0.031)
Phytoplankton Silica to Carbon Ratio (mg Si/mg C)	0.01	Set to an arbitrarily small value
Phytoplankton Carbon to Chlorophyll Ratio (mg C/mg Chl)	40	WASP Manual 9-15 (20-50)
Phytoplankton Maximum Growth Rate Constant @20°C (1/day)	2	WASP Manual 9-15
Optimal Temperature for Growth (°C)	20	Determined by calibration
Shape parameter for below optimal temperatures	0.025	Determined by calibration
Shape parameter for above optimal temperatures	0.005	Determined by calibration
Phytoplankton Respiration Rate Constant @20°C (1/day)	0.1	WASP Manual 9-15 (0.05-0.2)
Phytoplankton Respiration Temperature Coefficient	1.045	WASP Manual 9-15 (1.06)
Phytoplankton Death Rate Constant (Non-Zoo Predation) (1/day)	0.06	WASP Manual 9-15 (0.02-0.06)
Phytoplankton Zooplankton Grazing Rate Constant (1/day)	0.02	WASP Manual 9-13 (0.0-1.5)
Grazability (0 to 1)	1	One algal group
Phytoplankton Half-Saturation Constant	0.01	WASP Manual 9-15 (0.03)

for N Uptake (mg N/L)		
Phytoplankton Half-Saturation Constant for P Uptake (mg P/L)	0.005	Determined from calibration.
Nitrogen fixation option (0 no, 1=yes)	1	N-fixation is on
Phytoplankton Optimal Light Saturation (Ly/day)	175	Determined from calibration. Recommended range in WASP Manual 9-15 (200-500); low value here may reflect adaptation of phytoplankton to low light levels in darkwater lake.
Fraction of Phytoplankton Death Recycled to Organic N	1	Forces Respiration to Dissolved Organic; Death all goes to Particulate
Fraction of Phytoplankton Death Recycled to Organic P	1	(See above)

5.5.6 EXCHANGES SCREEN

The *Exchanges* data entry screen is set automatically by the linkage with the EFDC hydrodynamics model.

5.5.7 FLOWS SCREEN

The *Flows* data entry screen is set automatically by the linkage with the EFDC hydrodynamics model.

5.5.8 LOADS SCREEN

The *Loads* data entry screen is not used for the Lake Jesup WASP application.

5.5.9 BOUNDARIES SCREEN

The *Boundaries* data entry screen provides the linkage with the HSPF hydrologic watershed model through time-series of daily nutrient concentrations. Observed time-series of nutrient concentrations at the lake mouth and for Clifton Springs is set here as well.

5.5.10 TIME FUNCTIONS SCREEN

The *Time Functions* data entry screen provides time-series of daily water temperature, simulated by the Equilibrium Temperature Method, and observed time-series of solar radiation and wind speed. A time-series for fraction of daylight hours for each day is also provided here and was estimated from the equations outlined by Martin & McCutcheon (1999).

5.6 MASS BALANCE AND NUTRIENT BUDGETS

5.6.1 TOTAL PHOSPHORUS MASS BALANCE

An annual mass balance for total phosphorus was calculated for the six-year period of 2004 to 2009. This analysis shows that the model maintains mass balance by successfully tracking mass entering and exiting the model domain. The basic equation for mass balance is:

$$\text{Mass In} = \text{Mass Out} + \Delta \text{Storage},$$

where *Mass In* is the total mass entering the model domain, *Mass Out* is the total mass exiting the model domain, and $\Delta \text{Storage}$ is the increase in mass within the model domain over a particular period.

The mass of phosphorus entering the Lake Jesup WASP model (*Mass In*) comes from three sources: surface runoff, ground water seepage, and atmospheric deposition. Phosphorus leaves the model only by flow exiting the lake mouth. (We have assumed zero loss of phosphorus to the sediments.) Phosphorus leaving the model is estimated by integrating the product of discharge at the mouth with either (a) total phosphorus concentration at the model cell interior to the mouth if discharge is exiting the model, or (b) total phosphorus concentration at the open model boundary if discharge is entering the model. Storage is estimated by summing the product of total phosphorus concentration with volume for each cell over the entire model domain. The change in storage is defined as the beginning storage subtracted from the end storage over the period of interest, so that a positive value of $\Delta \text{Storage}$ indicates an increase of mass within the lake.

Table 5–12 contains mass balance terms for total phosphorus (TP) for each of nine years. Mass balance requires that:

$$TP_{\text{Surface Runoff}} + TP_{\text{Ground Water Seepage}} + TP_{\text{Atmospheric Deposition}} = TP_{\text{Discharge Out Mouth}} + \Delta TP_{\text{Storage}}.$$

Mass input rates of total phosphorus from ground water seepage and atmospheric deposition are constants at 9.5 and 2.0 MT yr⁻¹, respectively, whereas the mass input rate from surface runoff ranges from 9.8 to 24.8 MT yr⁻¹. Mass storage changes are relatively small, ranging from -3.5 to 3.3 MT yr⁻¹. Mass inputs balance mass outputs for total phosphorus to within a few percent error. The greatest source of error is likely the temporal resolution used for the numerical integration of the mass discharge of total phosphorus exiting the lake.

On average, surface water contributed 61.4% of the total phosphorus loading to the lake. Ground water seepage was appreciable, contributing 31.9% of the total phosphorus load. Atmospheric deposition accounted for the remaining 6.7% of total phosphorus entering the lake.

Table 5–12. Total Phosphorus nutrient budget in Metric Tons per Year, 2004 to 2009.

	Inputs			Outputs			
Year	Surface Runoff	Ground Water Seepage	Atmospheric Deposition	Δ Storage	Discharge Out Mouth	Net Balance	Error
2004	23.4	9.5	2.0	1.3	35.1	-1.5	4.3%
2005	24.1	9.5	2.0	2.2	34.3	-0.9	2.5%
2006	9.8	9.5	2.0	-2.7	24.3	-0.3	1.4%
2007	10.0	9.5	2.0	0.7	21.5	-0.7	3.3%
2008	24.8	9.5	2.0	-3.5	41.2	-1.4	3.8%
2009	17.7	9.5	2.0	3.3	26.6	-0.7	2.4%
Average	18.3	9.5	2.0				
% Contribution	61.4	31.9	6.7				

5.6.2 TOTAL NITROGEN NUTRIENT BUDGET

The mass balance for total nitrogen (TN) is complicated by the addition of nitrogen fixation (N-fixation) and denitrification as source and sink terms of nitrogen, respectively. Nitrogen fixation is the mass of nitrogen added to the model by phytoplankton from N₂ gas in the atmosphere. Denitrification is the conversion by bacteria of nitrate back to N₂ gas that then leaves the model system. For total nitrogen, the mass balance is:

$$TN_{\text{Surface Runoff}} + TN_{\text{Ground Water Seepage}} + TN_{\text{Atmospheric Deposition}} + TN_{\text{N-fixation}} = TN_{\text{Discharge Out Mouth}} + TN_{\text{Denitrification}} + \Delta TN_{\text{Storage}}.$$

The N-fixation rate was estimated by running the Lake Jesup WASP model with and without the N-fixation algorithm and taking the difference between the two model runs of the mass of total nitrogen that either left the lake or was placed into storage within the lake. Since the mass balance for total phosphorus, shown above, verified the accuracy of the methodology used to estimate mass leaving the lake, a mass balance for total nitrogen can be used to estimate denitrification rate as the final missing term in the above mass balance equation.

On average, nitrogen fixation by cyanobacteria contributed 45% of the total nitrogen load entering the lake, while surface water contributed 29.3%. Ground water seepage contributed less as a percentage (17.5%) for nitrogen than it did for phosphorus because of the large contribution of nitrogen fixation. Atmospheric deposition accounted for the remaining 8.2% of total nitrogen entering the lake.

Table 5–13 shows mass balance for total nitrogen for each of the six years, 2004 to 2009. The mass rate for nitrogen inputs from surface runoff ranges from 83.0 to 200.0 MT yr⁻¹. Ground water seepage and atmospheric deposition mass rates are assumed constant at 89.2 and 42.3 MT yr⁻¹, respectively. N-fixation rate is appreciable and ranges from 197.1 to 265.0 MT yr⁻¹.

The balance of nitrogen inputs with discharge and storage results in an estimate of denitrification loss rate of 0.0 to 14.9 MT yr⁻¹. However, because the model does not include sediment diagenesis mechanisms, denitrification loss rates in the sediments could be considerably greater. This additional loss term would have to be compensated by even greater nitrogen fixation by algae.

On average, nitrogen fixation by cyanobacteria contributed 45% of the total nitrogen load entering the lake, while surface water contributed 29.3%. Ground water seepage contributed less as a percentage (17.5%) for nitrogen than it did for phosphorus because of the large contribution of nitrogen fixation. Atmospheric deposition accounted for the remaining 8.2% of total nitrogen entering the lake.

Table 5–13. Total Nitrogen nutrient budget in Metric Tons per Year, 2004 to 2009.

Year	Inputs				Outputs		
	Surface Runoff	Ground Water Seepage	Atmospheric Deposition	N Fixation	Δ Storage	Discharge Out Mouth	Denitrification
2004	175.6	89.2	42.3	203.3	-3.8	521.5	14.9
2005	200.0	89.2	42.3	265.0	53.1	549.0	5.6
2006	87.0	89.2	42.3	197.1	-33.3	451.3	2.4
2007	83.0	89.2	42.3	228.5	16.2	426.8	0.0
2008	196.8	89.2	42.3	228.0	-78.4	636.3	(0.0)
2009	151.9	89.2	42.3	251.5	71.1	458.5	5.3
Average	149.1	89.2	42.3	228.9			
% Contribution	29.3	17.5	8.2	45.0			

5.7 WASP MODEL CALIBRATION AND CONFIRMATION

The simulation period for the WASP surface water quality model of 2003 to 2009 was determined by the available simulated input data from the HSPF hydrologic model simulation period (Jia, 2014) of 2003 to 2012 and the additional restriction to periods before modification of the Lake Jesup mouth after 2009. The simulation period was broken into two periods for model calibration and confirmation. The calibration period was the 3-year period of 2004 to 2006, and the confirmation period was the 3-year period from 2007 to 2009. The year 2003 is used as a spin-up year for the model calibration.

5.7.1 TOTAL PHOSPHORUS

Simulated and observed annual averaged total phosphorus shows a good match for four of six years of the calibration and confirmation periods (Figure 5–11). A good match of total phosphorus was found for the years 2005, 2006, 2008, and 2009. The model underpredicts total phosphorus during 2004 and overpredicts total phosphorus during 2007. The year 2004 was not unusually wet overall, but the lake was affected by several large hurricanes during August and September of that year. The hurricanes might have increased total phosphorus load to the lake either by an unusual flush of phosphorus from the land caused by rainfall intensity, or by mobilization of sediments by hurricane force winds. The year 2007 falls at the end of the largest two-year rainfall deficit and this discrepancy might indicate an overprediction of phosphorus from diffuse ground water since this source is a constant in the model.

One clear pattern shown in Figure 5–11 is the general underprediction of total phosphorus in the lake when phosphate flux from diffuse ground water is not considered (red triangles).

Average total phosphorus for the six-year period was $181.6 \mu\text{g L}^{-1}$. The simulated average including diffuse ground water was $190.0 \mu\text{g L}^{-1}$. The average total phosphorus without diffuse ground water was $137.5 \mu\text{g L}^{-1}$. Diffuse groundwater thus contributes about 25% of phosphorus load to the lake, consistent with Table 5–12.

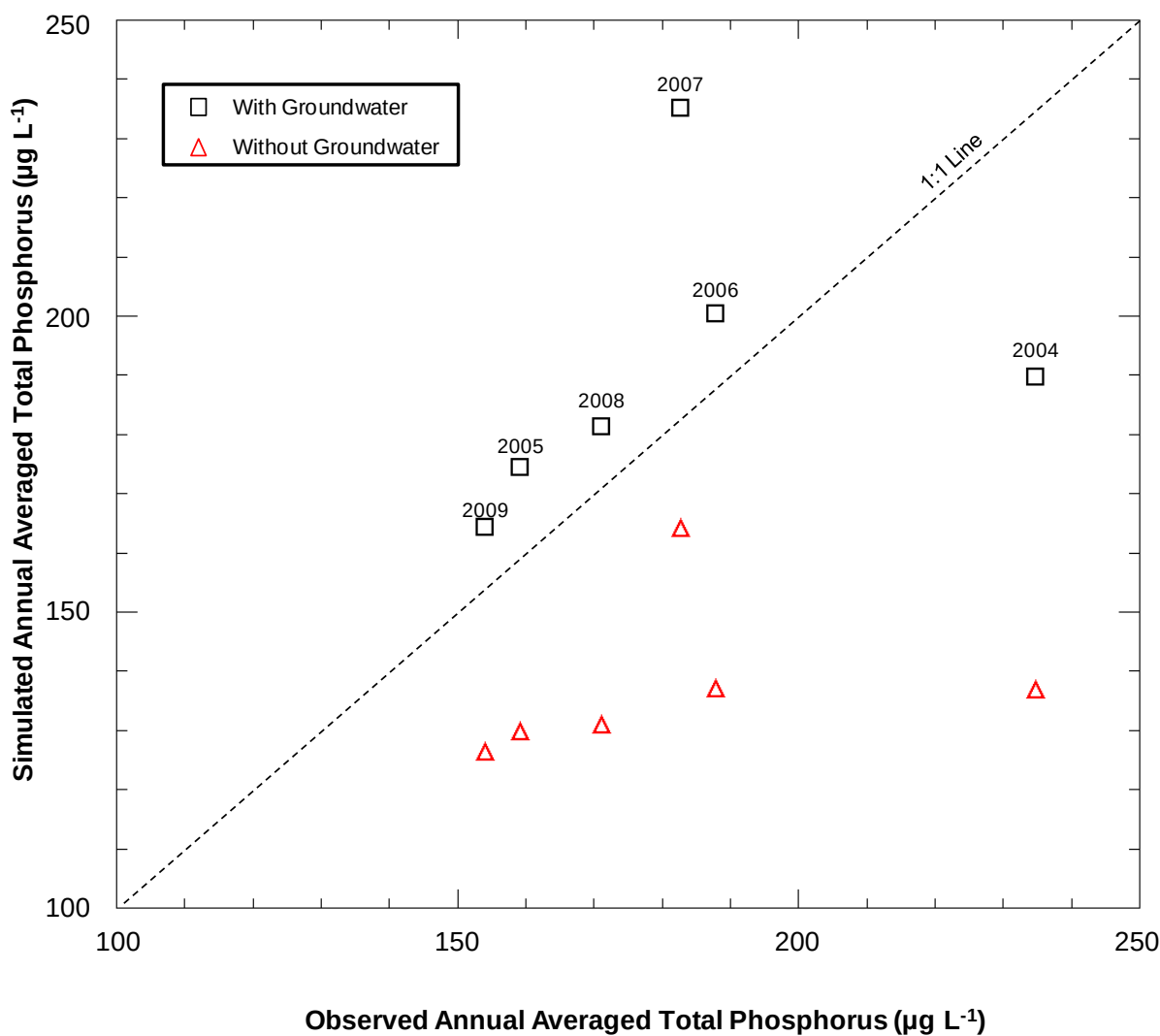


Figure 5–11. Comparison of annual averaged simulated and observed total phosphorus over the simulation period of 2004 to 2009. The black squares include a phosphate flux from diffuse ground water, while the red triangles do not include diffuse ground water. The solid line is a 1:1 line of perfect fit between model and data. The black squares have year identifiers.

The temporal variability of simulated and observed total phosphorus is compared in Figure 5–12 through Figure 5–17 for the calibration and confirmation periods at stations OW-2, OW-4, and OW-6. The black line shows simulated total phosphorus with an included flux of phosphorus from diffuse ground water and the red line shows simulated total phosphorus with no diffuse ground water. The underprediction of total phosphorus is clearly shown at all three stations during the fall of 2004 and early winter of 2005, following the passage of hurricanes in August and September of 2004. During 2005 and 2006 of the calibration period, observed total phosphorus generally falls within the two lines but a phosphorus flux from diffuse ground water is needed to explain the doubling of total phosphorus at stations OW-4 and OW-6 during the first six months of 2006. Similarly, ground water phosphorus flux is needed to explain the increase of total phosphorus between fall of 2008 and spring of 2009. However, during the fall of both 2007 and 2009 total phosphorus is better simulated by the model with no diffuse ground water phosphorus flux. It seems possible that diffuse ground water inflow to the lake could vary in response to variation in rainfall at seasonal to interannual timescales and that this variability could explain, at least in part, the deviation between simulated and observed total phosphorus in the lake.

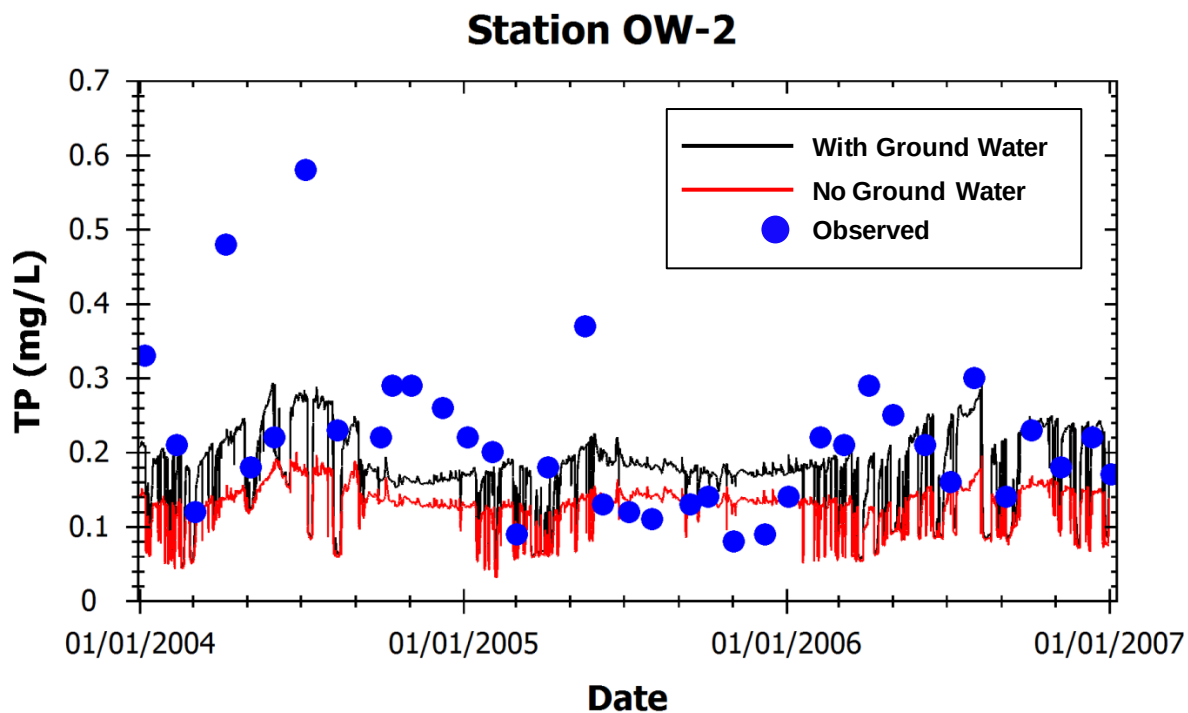


Figure 5–12. Comparison of simulated and observed total phosphorus at station OW-2 during calibration period of 2004 to 2006. The black line is the model with inclusion of a phosphate flux from diffuse ground water. The red line is the model without diffuse ground water.

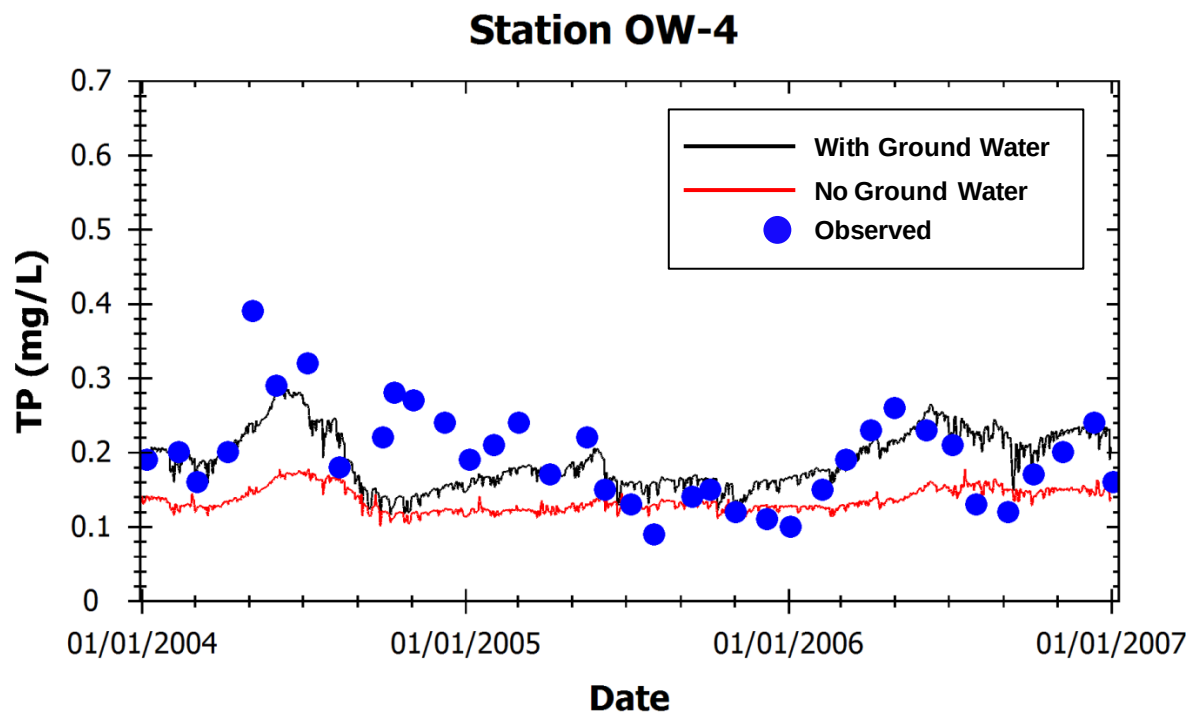


Figure 5–13. Comparison of simulated and observed total phosphorus at station OW-4 during calibration period of 2004 to 2006. The black line is the model with inclusion of a phosphate flux from diffuse ground water. The red line is the model without diffuse ground water.

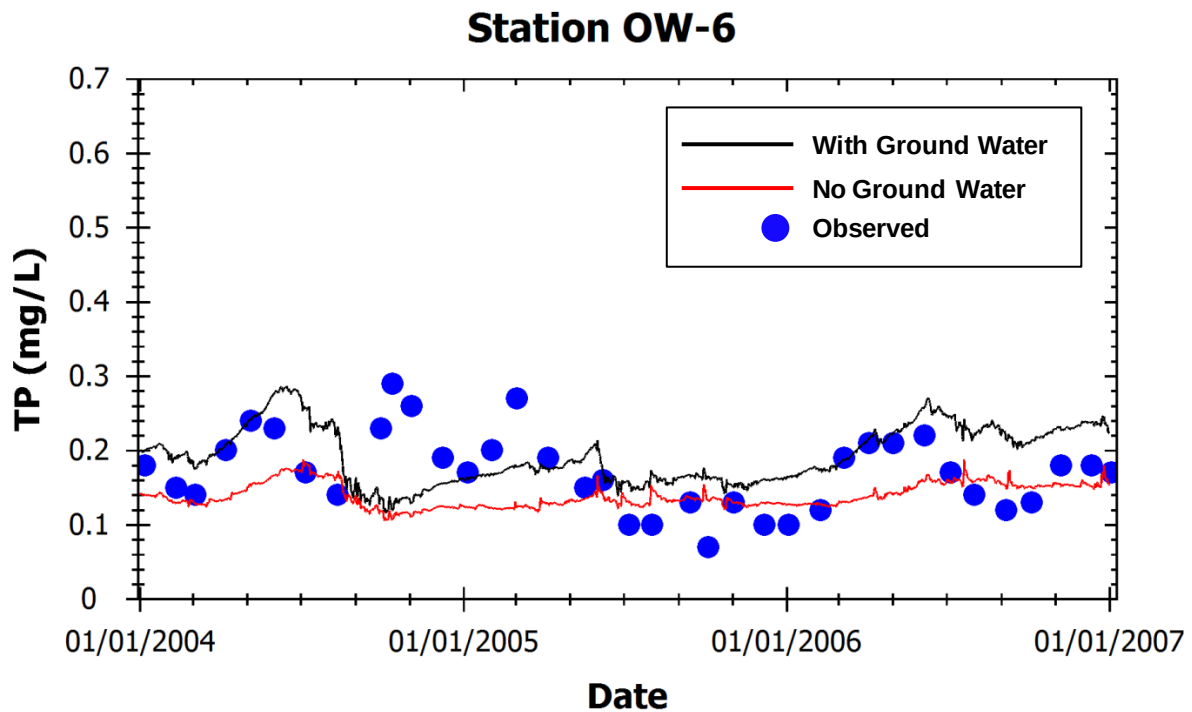


Figure 5–14. Comparison of simulated and observed total phosphorus at station OW-6 during calibration period of 2004 to 2006. The black line is the model with inclusion of a phosphate flux from diffuse ground water. The red line is the model without diffuse ground water.

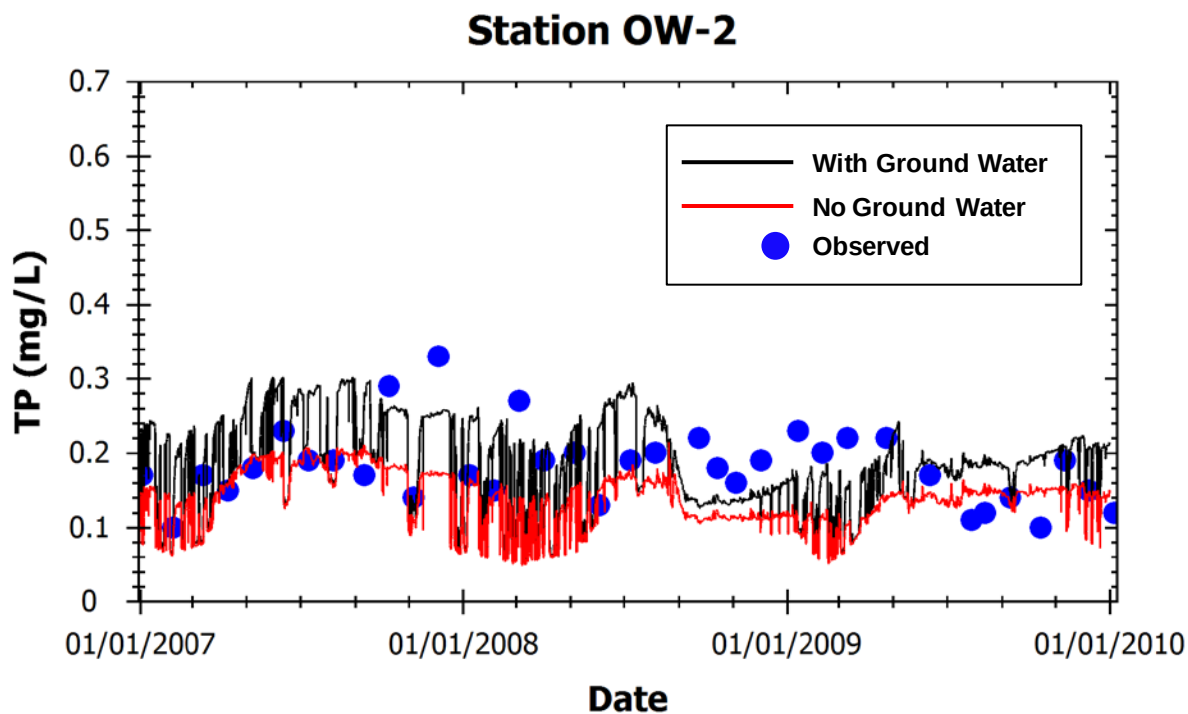


Figure 5–15. Comparison of simulated and observed total phosphorus at station OW-2 during confirmation period of 2007 to 2009. The black line is the model with inclusion of a phosphate flux from diffuse ground water. The red line is the model without diffuse ground water. Blue circles are observed values.

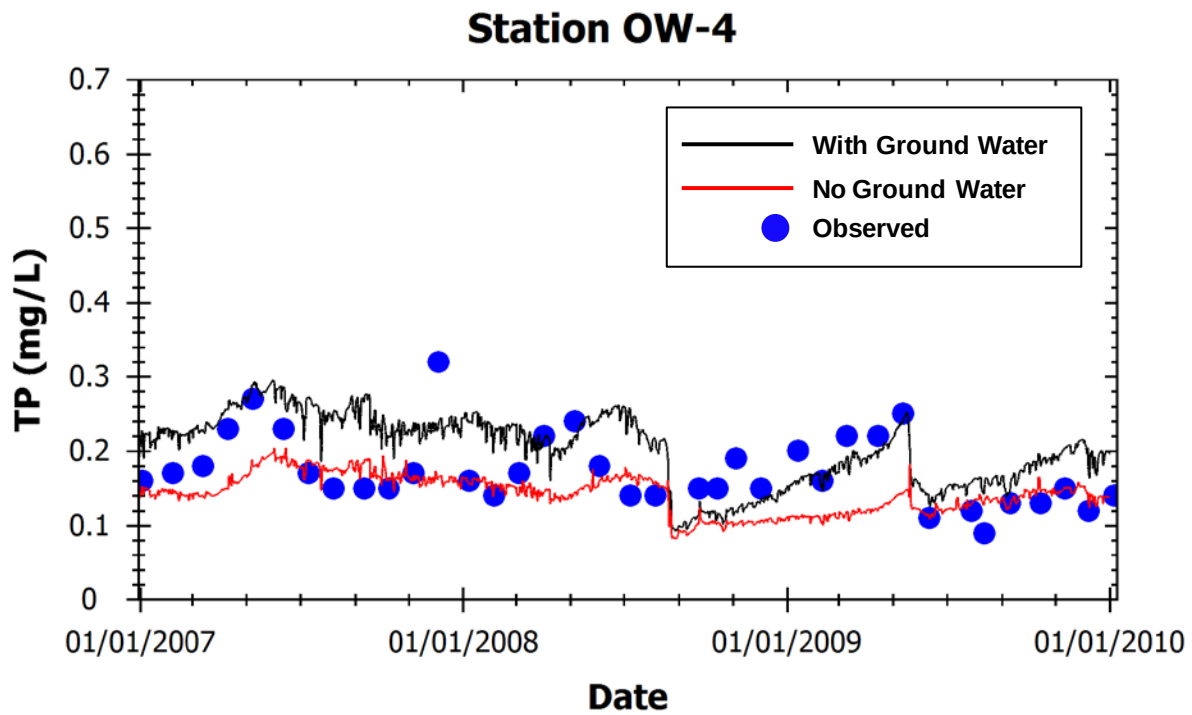


Figure 5–16. Comparison of simulated and observed total phosphorus at station OW-4 during confirmation period of 2007 to 2009. The black line is the model with inclusion of a phosphate flux from diffuse ground water. The red line is the model without diffuse ground water. Blue circles are observed values.

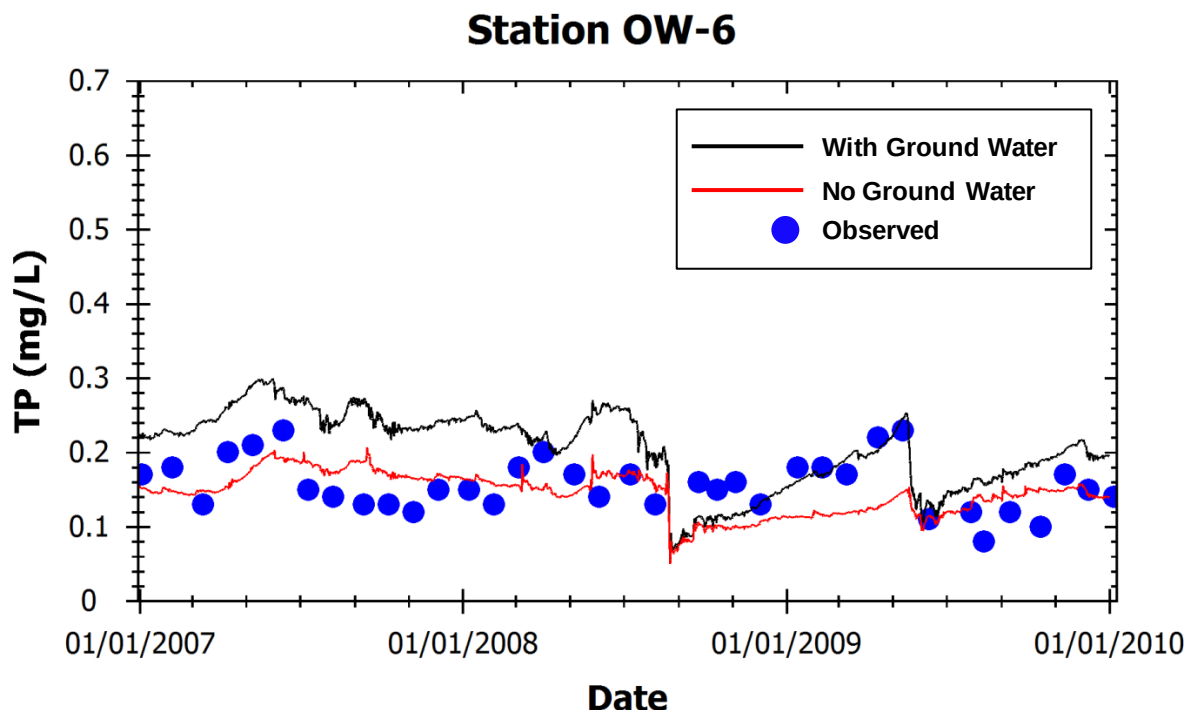


Figure 5–17. Comparison of simulated and observed total phosphorus at station OW-6 during confirmation period of 2007 to 2009. The black line is the model with inclusion of a phosphate flux from diffuse ground water. The red line is the model without diffuse ground water. Blue circles are observed values.

5.7.2 TOTAL NITROGEN

Simulated and observed annual averaged total nitrogen generally match well, with the model slightly overpredicted total nitrogen (Figure 5–18). On average, simulated total nitrogen was 14.8% greater than observed total nitrogen.

Nitrogen fixation within the model was an important mechanism for prediction of total nitrogen. The model without nitrogen fixation shown in Figure 5–18 (red triangles) underpredicts total nitrogen by 29%. If nitrogen from diffuse ground water flux is also excluded (Figure 5–18, Blue x-crosses), the predicted total nitrogen is 47.7% lower than observed. These results indicate that in the absence of N-fixation and diffuse ground water surfaces, surface water and atmospheric loading of nitrogen would maintain the lake at a total nitrogen level of about 1.5 mg L^{-1} . This value would likely be even lower, since the model does not account for loss of nitrate nitrogen through denitrification in the sediments.

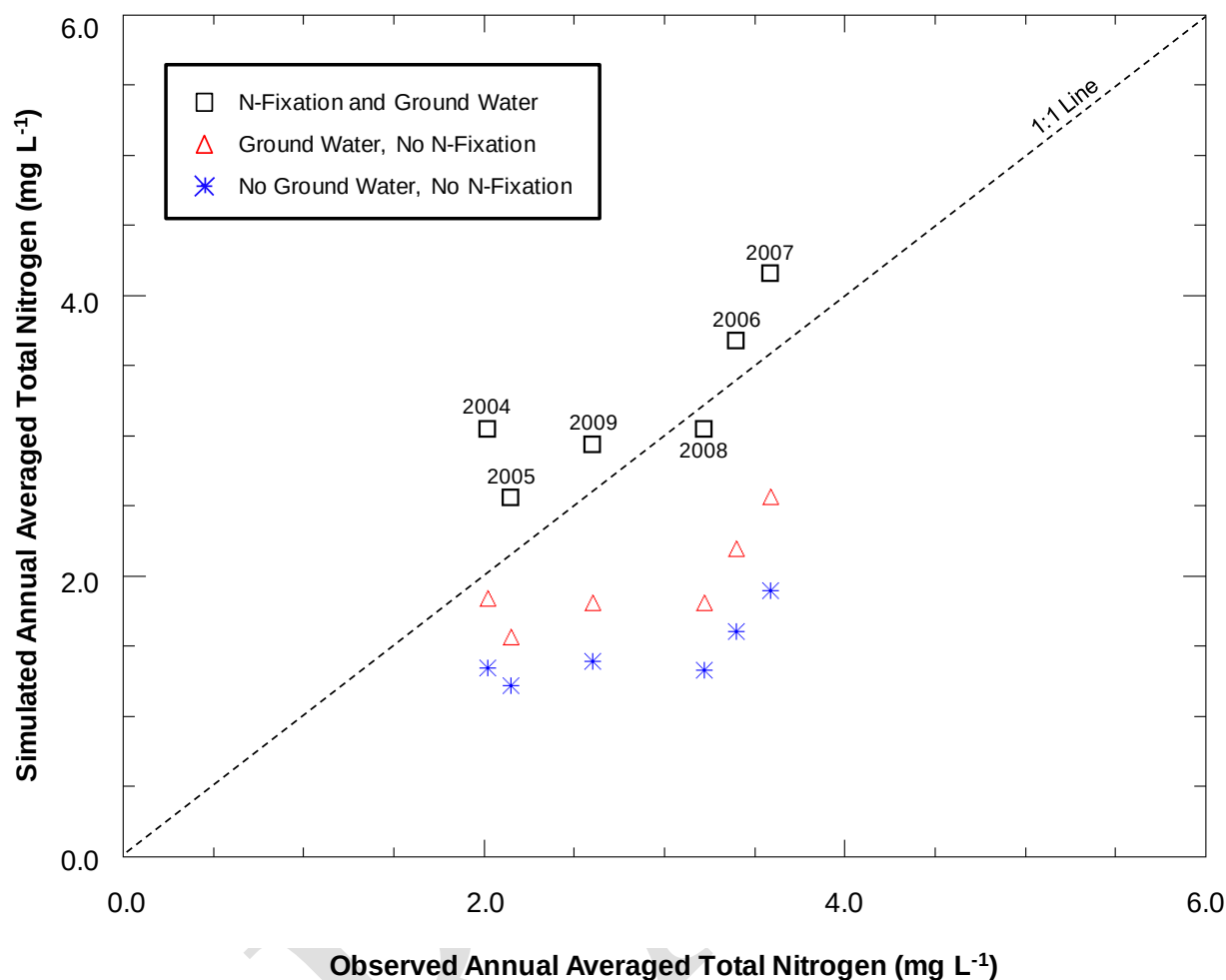


Figure 5–18. Comparison of annual averaged simulated and observed total nitrogen over the simulation period of 2004 to 2009. The black squares include both nitrogen fixation by phytoplankton and nitrate flux from diffuse ground water. The red triangles do not include nitrogen fixation, but do include diffuse ground water. The blue X-crosses do include neither nitrogen fixation nor diffuse ground water. The solid line is a 1:1 line of perfect fit between model and data. The black squares have year identifiers.

A comparison of simulated and observed total nitrogen as time-series plots (Figure 5–19 and Figure 5–20) show that the model’s nitrogen fixation algorithm does a reasonably good job of explaining trends in observed total nitrogen that cannot be explained by external sources of total nitrogen alone. (Because the three in-lake stations have similar characteristics, only OW-4 is shown for the remainder of the report. Plots for stations OW-2 and OW-6 are found in the Appendix beginning on page 97).

Phytoplankton species data (S. Brandt-Williamson, *personal communication*) were available for the calibration period and the first six months of 2007. These data indicate an extended period, from April to October of 2004, with an absence of nitrogen-fixing species. This period is shaded in Figure 5–19. The extended absence of nitrogen-fixers in 2004 likely caused the overprediction of total nitrogen in 2004. Note that total nitrogen predicted by the model without N-fixation (green line, Figure 5–19) matches observed values in 2004 quite closely, including the winter to summer increase of over 1 mg L^{-1} during that year.

Diffuse ground water flux of nitrogen is necessary to explain observed values during periods when N-fixation is not occurring. Note that the model without diffuse ground water (red line) underpredicts total nitrogen in 2004.

All three models converge during the high discharge and stage event in Fall 2004, indicating that N-fixation and diffuse ground water flux of nitrogen become relatively small factors to the nitrogen budget during periods of extreme discharge.

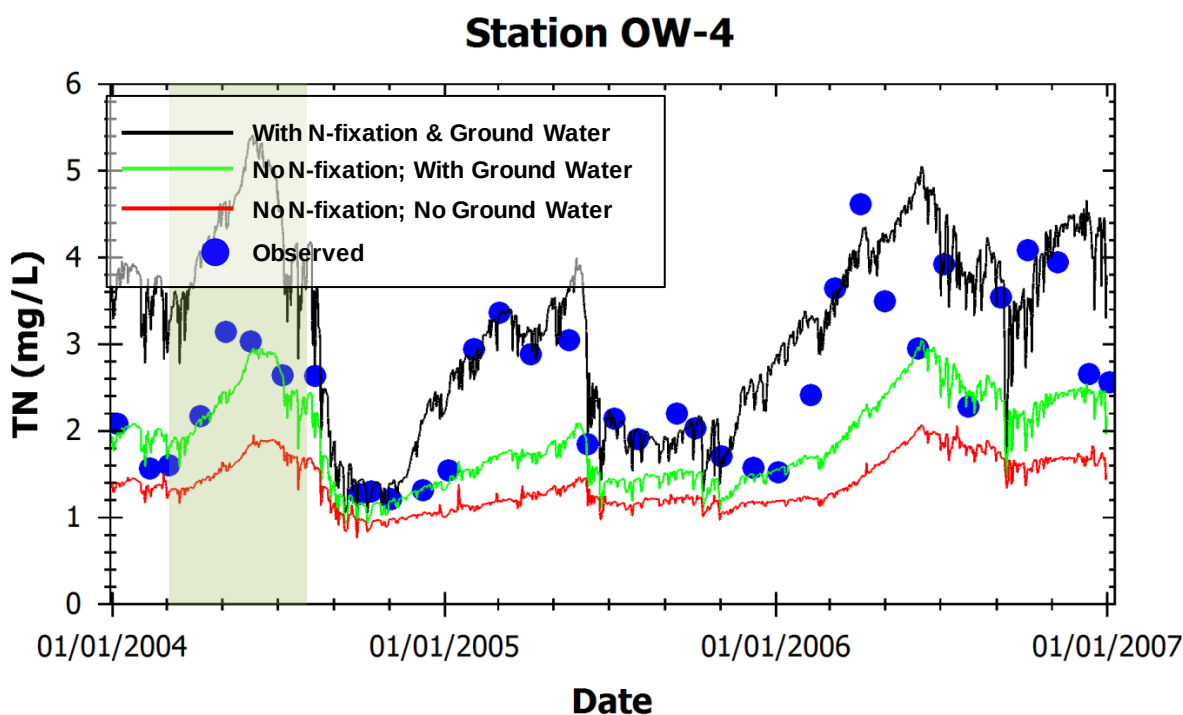


Figure 5–19. Comparison of simulated and observed total nitrogen at station OW-4 during calibration period of 2004 to 2006. The black line is the model with inclusion of nitrogen fixation and nitrogen flux from diffuse ground water. The green line is the model without nitrogen fixation but with diffuse ground water. The red line has neither nitrogen fixation nor diffuse ground water. Blue circles are observed values. The shading during 2004 indicates and extended period when no nitrogen-fixing species were observed in the lake.

For the confirmation period, the model with N-fixation (black line, Figure 5–20) generally matches observed values well. This good match indicates a well-established N-fixing phytoplankton community during this period. Similarly to Fall 2004, an extreme discharge and stage event in Fall 2008 resulted in the three models converging to low values of total nitrogen.

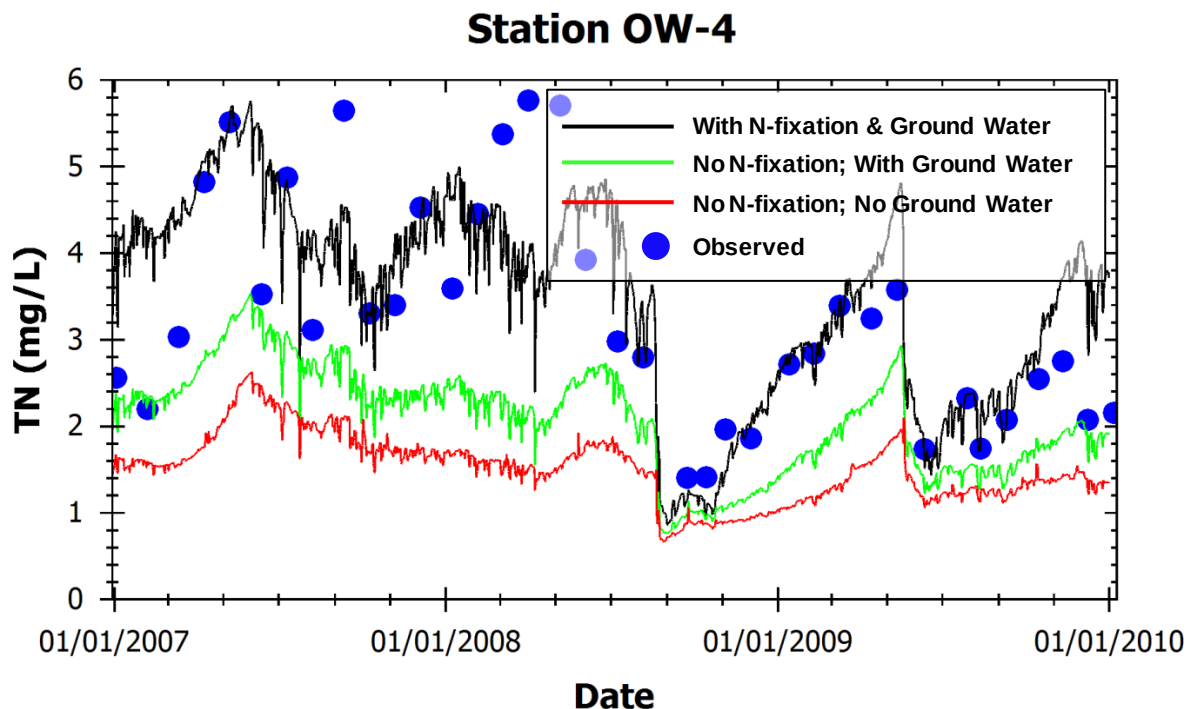


Figure 5–20. Comparison of simulated and observed total nitrogen at station OW-4 during confirmation period of 2007 to 2009. The black line is the model with inclusion of nitrogen fixation and nitrogen flux from diffuse ground water. The green line is the model without nitrogen fixation but with diffuse ground water. The red line has neither nitrogen fixation nor diffuse ground water. Blue circles are observed values.

5.7.3 LIGHT

Light is a critical parameter for simulating phytoplankton production in Lake Jesup, because light often becomes the limit to phytoplankton growth for the model. In WASP, simulation of light requires modeling light extinction coefficients (K_D) as a function of total suspended solids (TSS), dissolved organic carbon (DOC), and phytoplankton self-shading.

A comparison of simulated and observed light extinction coefficients is shown in Figure 5–21 for the calibration period. Observed values of light extinction coefficients are derived from observed values of total suspended solids, chlorophyll-*a*, and color using a comprehensive spectral light model developed by Gallegos (2005). The simulated values of light extinction coefficients fall

within a range of 3 to 6 m^{-1} , similar to ranges in the highly-colored areas of the St. Johns River, which has a mean light extinction coefficient of $3.75 \pm 0.1 \text{ m}^{-1}$.

The observed extinction coefficients for Lake Jesup are generally similar to simulated values for the calibration period (Figure 5–21). The greater variability of the observed values is likely due to the greater variability of observed total suspended solids, since the model does not simulate wind-wave resuspension and deposition of sediments. The confirmation period (Figure 5–22) similarly showed reasonably good agreement between observed and simulated light extinction coefficients. The underprediction of light extinction in the beginning of 2009 (Figure 5–22) results from the underprediction of chlorophyll-*a* during that period.

Light Extinction Coefficient (K_D)

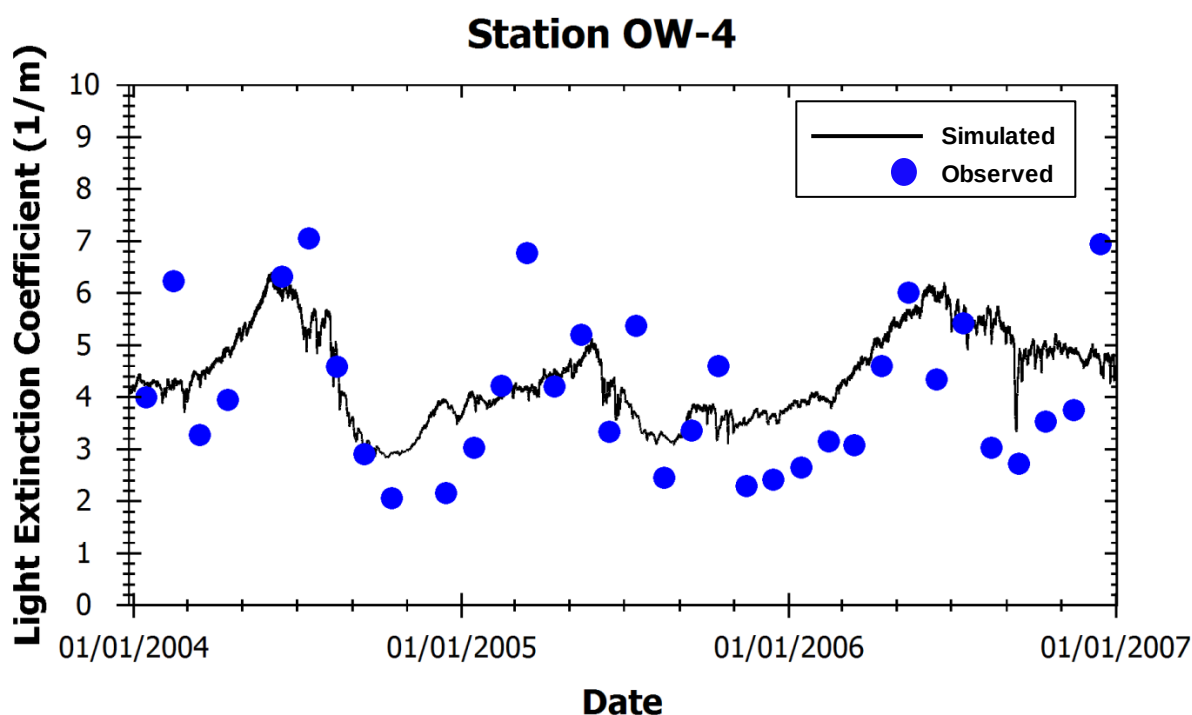


Figure 5–21. Comparison of simulated and observed light extinction coefficient (K_D) at station OW-4 for the calibration period of 2004 to 2006.

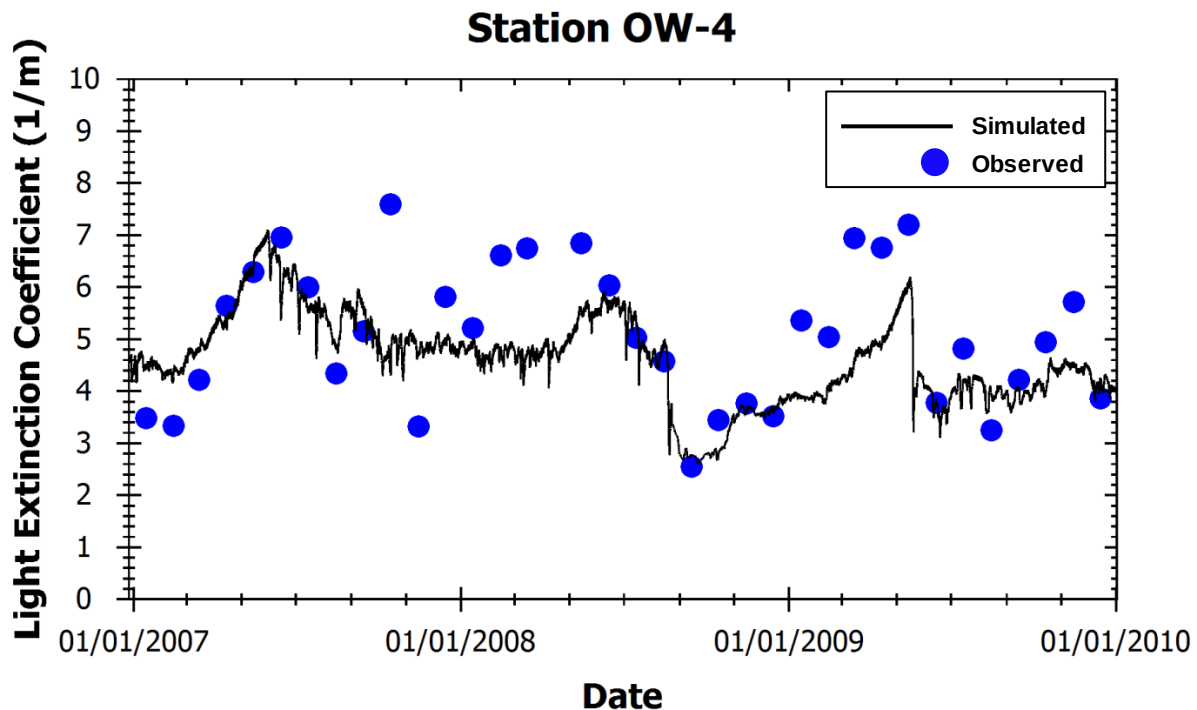


Figure 5–22. Comparison of simulated and observed light extinction coefficient (K_D) at station OW-4 for the confirmation period of 2007 to 2009.

Total light extinction coefficient in WASP is the sum of four partial light extinction coefficients. Three partial light extinction coefficients are modeled as functions of DOC, TSS, and Chl-*a* (algal self-shading). The fourth term is a small (0.3 m^{-1}) background constant. For perspective, Figure 5–23 shows the partial components of light extinction coefficients together with the total for the calibration period. (A background extinction coefficient of 0.3 m^{-1} is not shown). Color is an important component of light attenuation over all periods. Although TSS is quite high in Lake Jesup, this variable is not as important as either color or chlorophyll-*a* in determining sub-surface light. Algal self-shading has the greatest seasonal variability among the light attenuation factors and drives large seasonal changes in light extinction coefficients.

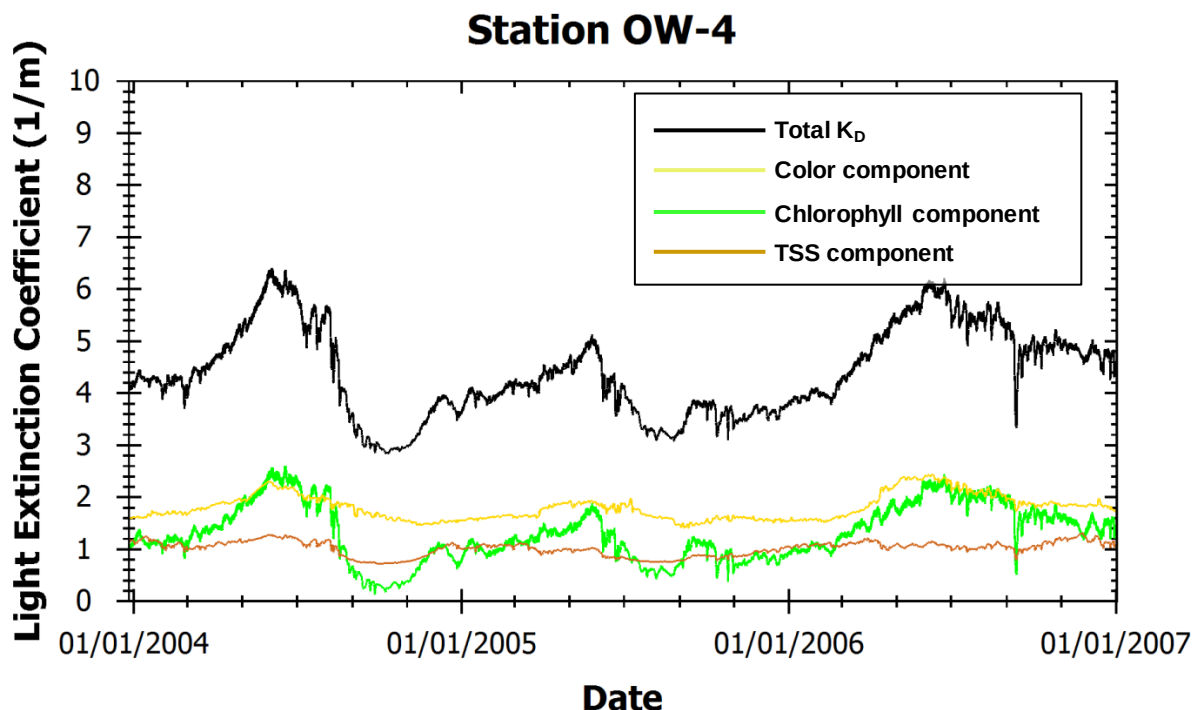


Figure 5–23. Total light extinction coefficient (black line) and partial light extinction coefficient due to color (yellow line), TSS (brown line) and phytoplankton self-shading (green line). (A background extinction coefficient of 0.3 m^{-1} is not shown).

Color & Dissolved Organic Carbon

Dissolved organic carbon in Lake Jesup is the primary source of color (colored dissolved organic matter or CDOM) in the lake. CDOM is simulated in the WASP model application of Lake Jesup by the state variable BOD3. CDOM enters the model from tributary inflow by means of temporally constant concentrations of BOD3 associated with each tributary. Simulated and observed DOC at station OW-4 are compared in Figure 5–24 for the calibration period and in Figure 5–25 for the confirmation period. The fit is sufficient to account for the effect of CDOM on light extinction.

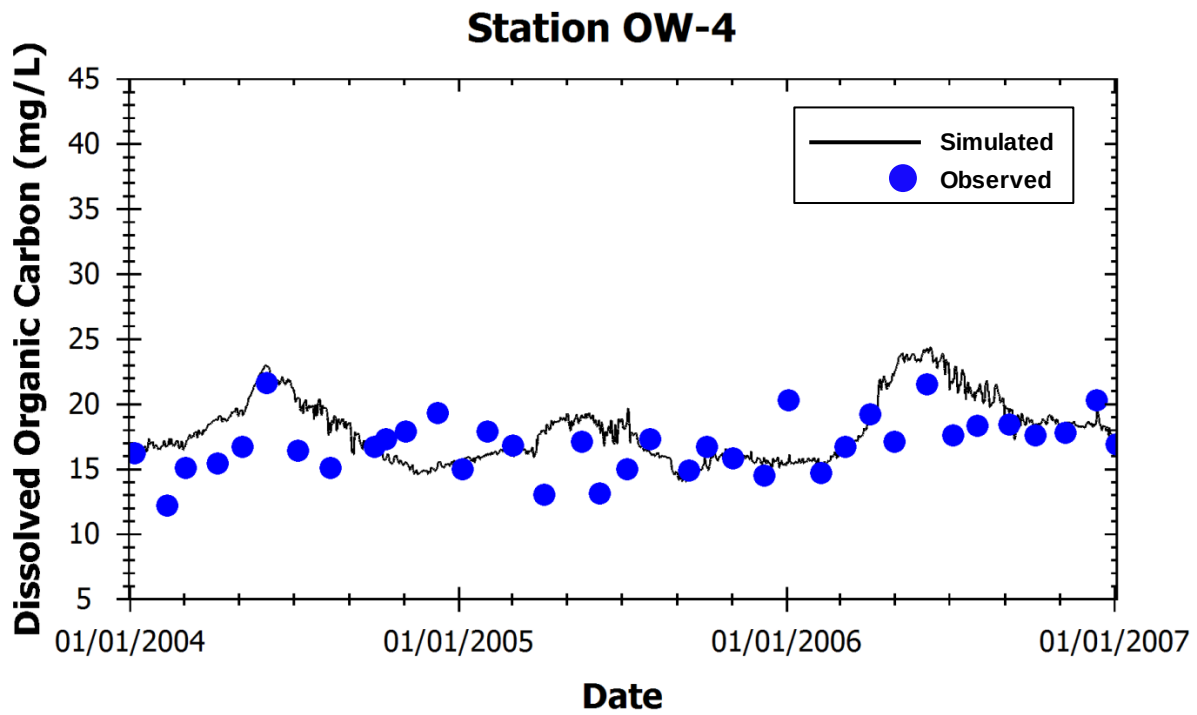


Figure 5–24. Comparison of simulated and observed dissolved organic carbon (DOC) at station OW-4 for the calibration period of 2004 to 2006.

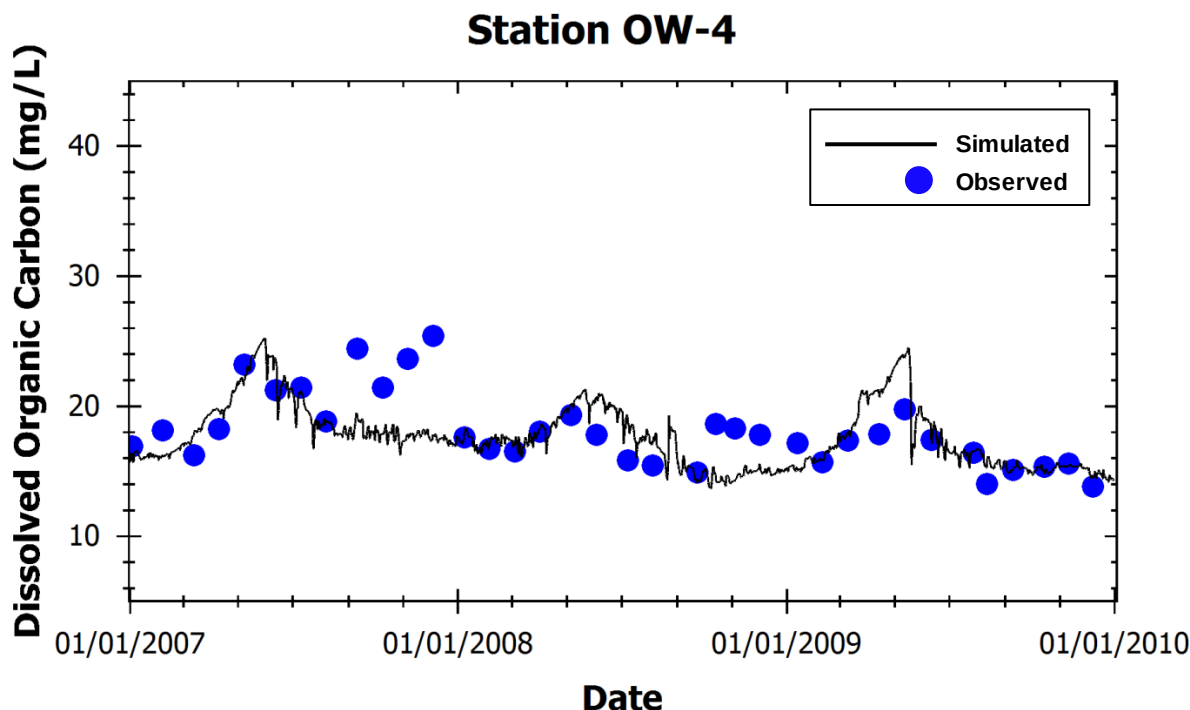


Figure 5–25. Comparison of simulated and observed dissolved organic carbon (DOC) at station OW-4 for the confirmation period of 2007 to 2009.

Total Suspended Solids

Total suspended solids (TSS) in Lake Jesup is high and typically ranges from 20 to 55 mg L⁻¹. A proper accounting for TSS in the lake would require a sediment modeling approach with assessment of both allochthonous and autochthonous sources, settling rates of various particle types, and resuspension of sediment by currents and waves.

A sediment model was not used for Lake Jesup. For this model application, sources of TSS are generation by phytoplankton and an allochthonous “Wash Load” from tributaries. The “Wash Load” represents very fine, near colloidal material that defines a background sediment concentration within the lake.

As expected, this simple sediment model results in simulated TSS concentrations with less temporal variability than observed concentrations (Figure 5–26 and Figure 5–27). Care should be taken in interpreting the observed TSS values shown in the figures, however. If wind-wave effects are important in causing resuspension in the lake, then TSS variability could be appreciable at short, hourly time scales. The apparent trends in the observed TSS data from monthly samples would then be highly aliased and essentially meaningless.

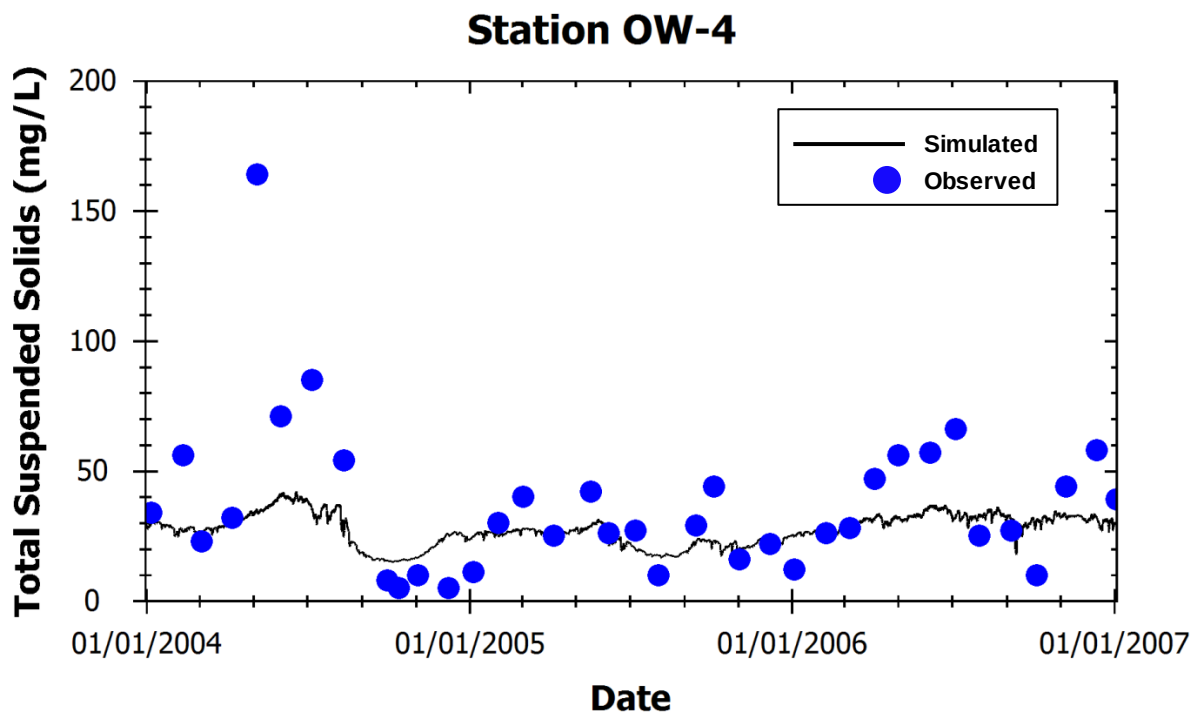


Figure 5–26. Comparison of simulated and observed total suspended solids (TSS) at station OW-4 for the calibration period of 2004 to 2006.

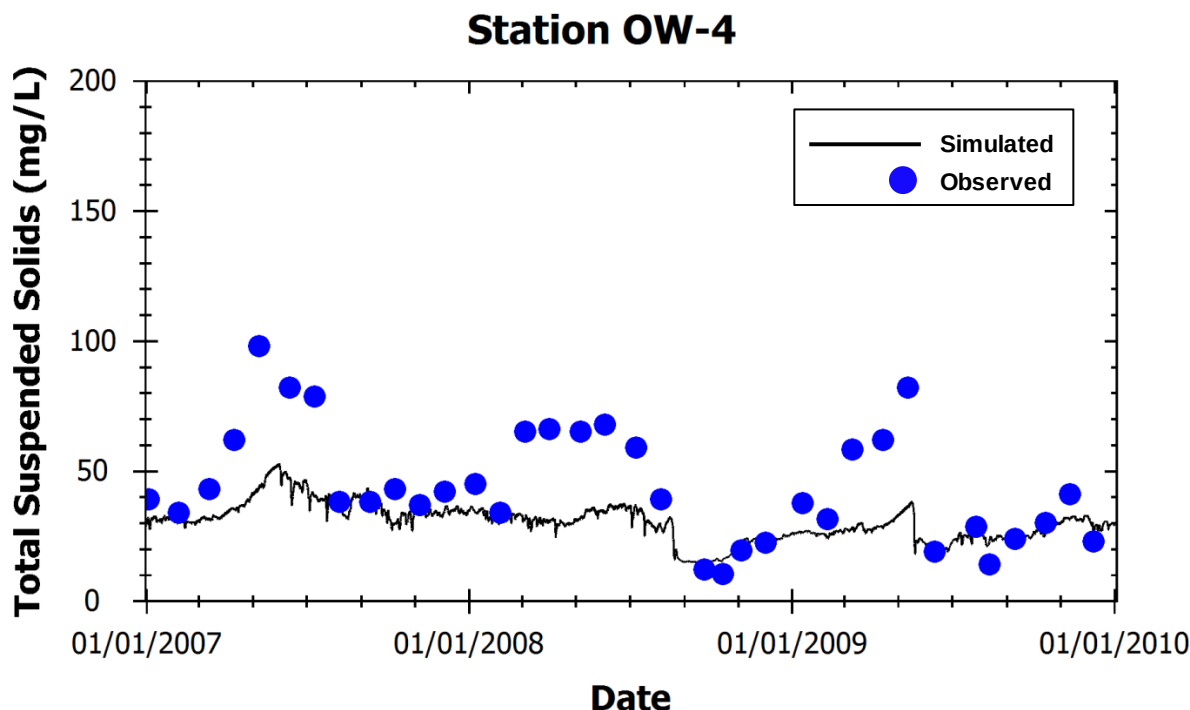


Figure 5–27. Comparison of simulated and observed total suspended solids (TSS) at station OW-4 for the confirmation period of 2007 to 2009.

5.8 CHLOROPHYLL-*A*

The simulation of phytoplankton biomass is a key skill of the Lake Jesup WASP model because excessive growth of phytoplankton as a response to excessive nutrient loading is of primary concern for the lakes's water quality. The WASP model predicts phytoplankton biomass as mass of carbon (concentration units of mg C L^{-1}). The living phytoplankton also have an associated mass of phosphorus and nitrogen determined by a fixed stoichiometry. For the Lake Jesup WASP model the fixed stoichiometry is 0.175 for the N:C ratio and 0.025 for the P:C ratio. In addition, the model defines a fixed ratio of carbon mass to chlorophyll mass (C:CHL) of 40. The C:CHL ratio allows for the conversion of phytoplankton biomass concentration from carbon mass per liter to chlorophyll-*a* per liter with units of $\mu\text{g L}^{-1}$. Chlorophyll-*a* concentration is a readily available, easily observed index of phytoplankton biomass, whereas direct measurements of phytoplankton biomass are uncommon. Practicality, then, dictates that chlorophyll-*a* is used for comparison between simulated and observed values of phytoplankton biomass.

A source of uncertainty in using chlorophyll-*a* as an index of phytoplankton biomass is that phytoplankton communities can alter their C:CHL ratio over an order of magnitude, 10 to 100 (Bowie et al., 1985). This means that the same biomass of 1 mg C m^{-3} could have an associated chlorophyll-*a* range of 10 to $100 \mu\text{g L}^{-1}$! Fortunately such wide ranges of C:CHL are not

expected within a single system, however, I will consider the uncertainty of C:CHL ratios ranging over 20 to 80.

A similar source of uncertainty in simulating phytoplankton biomass is the assumption of a fixed stoichiometry for carbon and phosphorus. During bloom periods, cyanobacteria can lower their P:C ratio to 0.01, thus more than doubling their biomass and chlorophyll-*a* concentrations for the equivalent utilization of phosphorus. This source of uncertainty is also considered below.

A comparison of simulated and observed chlorophyll-*a* at station OW-4 is shown in Figure 5–28 for the calibration period. The model simulation assumes a C:CHL ratio of 40 and a P:C ratio of 0.025. The model accurately simulates chlorophyll-*a* during 2004 and 2005, including the low event in the fall of 2004. During 2006 the model overpredicts chlorophyll-*a* for eight of the twelve monthly observations.

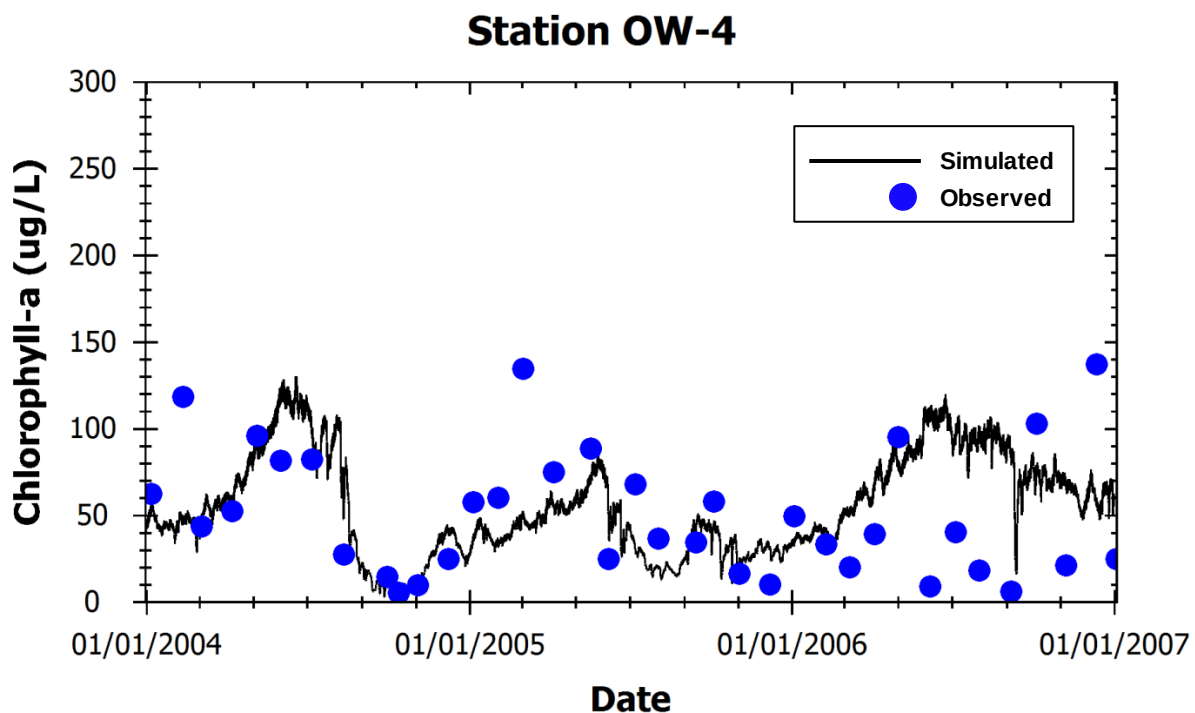


Figure 5–28. Comparison of simulated and observed Chl-*a* at station OW-4 for the calibration period of 2004 to 2006.

For the confirmation period (Figure 5–29) the overprediction of chlorophyll-*a* continued for the first half of 2007, but underprediction occurred during the 2007-8 winter. The model then accurately captures the low event in the fall of 2008, the slow increase in chlorophyll-*a* from fall 2008 to June of 2009, and the rapid drop in chlorophyll-*a* in July 2009. The model underpredicts chlorophyll-*a* again in the early fall of 2009, but becomes quite close to observed values in November and December of that year.

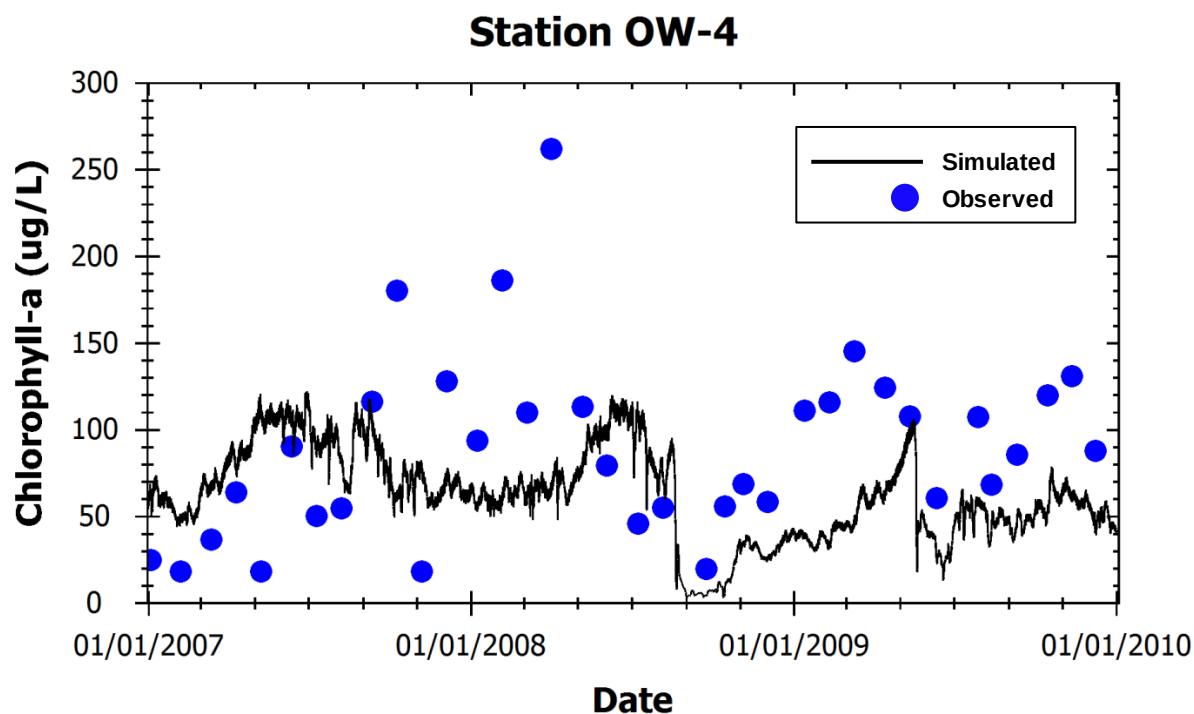


Figure 5–29. Comparison of simulated and observed Chl-*a* at station OW-4 for the confirmation period of 2007 to 2009.

Figure 5–30 is the identical plot of chlorophyll-*a* for the calibration period shown in Figure 5–28, above, except this plot shows the range of chlorophyll-*a* when C:CHL ratios are allowed to vary from 20 to 80. These are the two gray lines confining the black line from the previous plot (Figure 5–28). The red line shows the chlorophyll-*a* levels resulting from a P:C ratio of 0.01 while maintaining a C:CHL ratio of 40. The gray lines can be considered as error bands for the simulated chlorophyll-*a*, while the red line represents the magnitude of extreme bloom potential.

For the calibration period, most observations fall within the gray lines from 2004 to the summer of 2006. The extreme high chlorophyll events of early 2004 and early 2005 fall along the red line. The low chlorophyll in fall 2004 and fall 2005 show insensitivity to the altered parameters, indicating that these events are hydraulically controlled. The model still overpredicts chlorophyll-*a* in the latter half of 2006 possibly indicating that controlling factors during this period are not represented in the model. Examples of other controlling factors might include an increased predation rate, light limitation due to greater sediment resuspension during low water levels, a community shift away from N-fixers, or micronutrient limitation (Dobberfuhl, 2003).

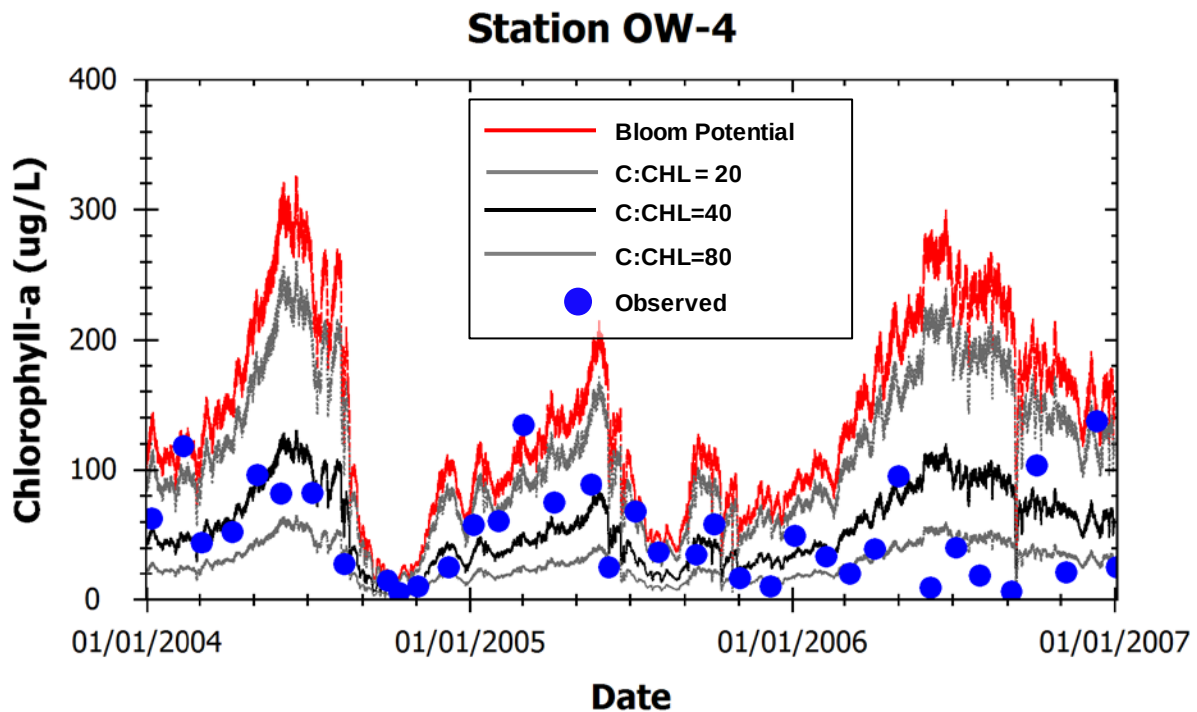


Figure 5–30. Comparison of simulated and observed Chl-*a* at station OW-4 for the calibration period of 2004 to 2006. The black line is a C:CHL ratio of 40; the gray lines confining the black lines are a C:CHL ratio of 80 (lower) and C:CHL ratio of 20 (upper). The red line represents a bloom potential with a P:C ratio of 0.01. The blue circles are observed values of chlorophyll-*a*.

For the confirmation period, observed chlorophyll-*a* generally lies within the gray lines (Figure 5–31). The red line is, again, a good indicator of the highest chlorophyll levels with but one exception in the Spring of 2008.

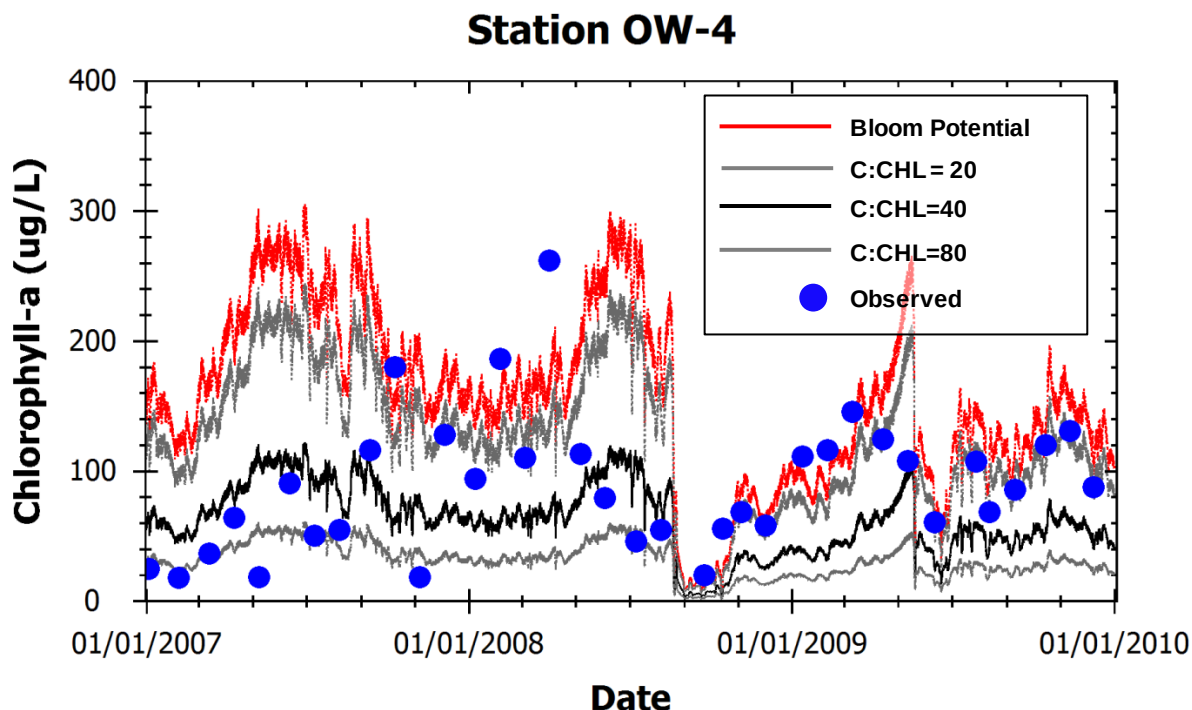


Figure 5–31. Comparison of simulated and observed Chl-*a* at station OW-4 for the confirmation period of 2007 to 2009. The black line is a C:CHL ratio of 40; the gray lines confining the black lines are a C:CHL ratio of 80 (lower) and C:CHL ratio of 20 (upper). The red line represents a bloom potential with a P:C ratio of 0.01. The blue circles are observed values of chlorophyll-*a*. Limitations on Growth

5.9 LIMITATIONS TO GROWTH

Figure 5–32 shows the prediction of limitation to phytoplankton growth for the calibration period of 2004 to 2006 with the assumption of no nitrogen limitation because of nitrogen fixation. For this condition (the calibrated model), the lake is generally light limited, although mild phosphorus limitation occurs in late winter and early spring.

If no nitrogen fixation were occurring, the lake would be appreciably N-limited throughout the dry season of late winter to early summer, but would remain light limited during the wet season of late summer to fall (Figure 5–33). Note that phosphorus limitation does not occur without nitrogen fixation. Nitrogen-fixing phytoplankton are presently taking full advantage of their competitive advantage over non-nitrogen-fixing phytoplankton in the presence of an abundance of phosphorus.

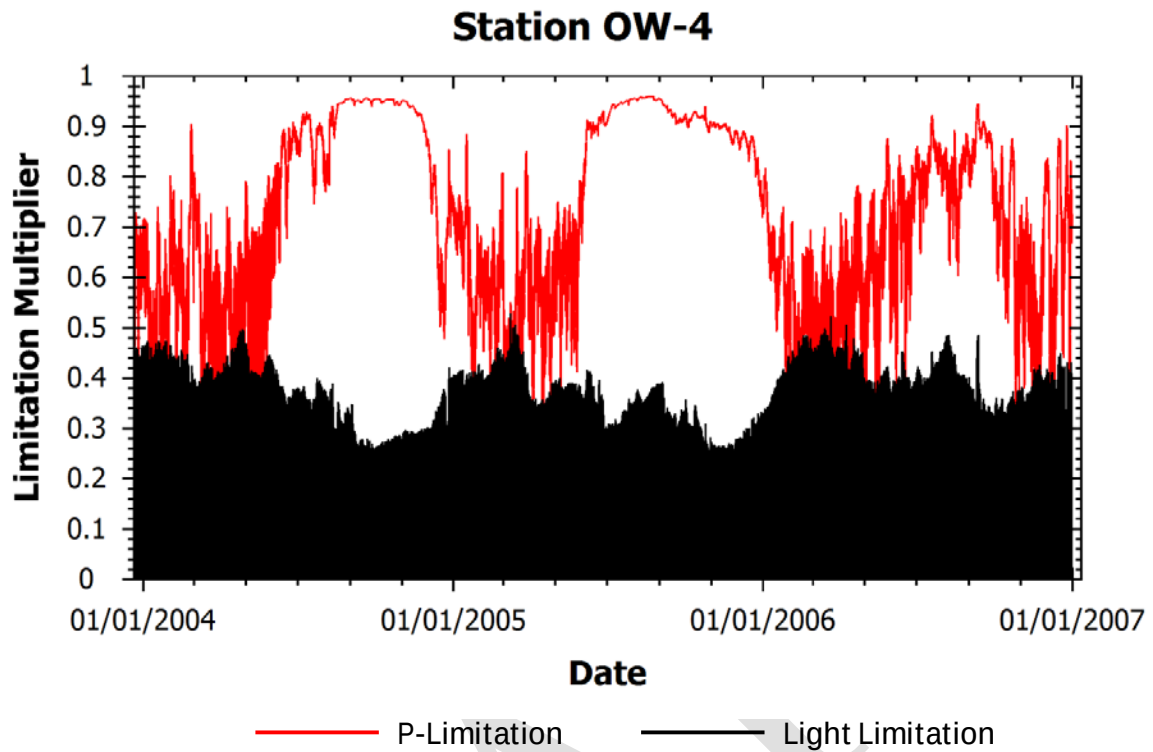


Figure 5–32. Simulated phosphorus (red line) and light (black line) limitation under present conditions at station OW-4 for the calibration period of 2004 to 2006. The lake is generally light limited. Mild phosphorus limitation occurs in late winter and early spring.

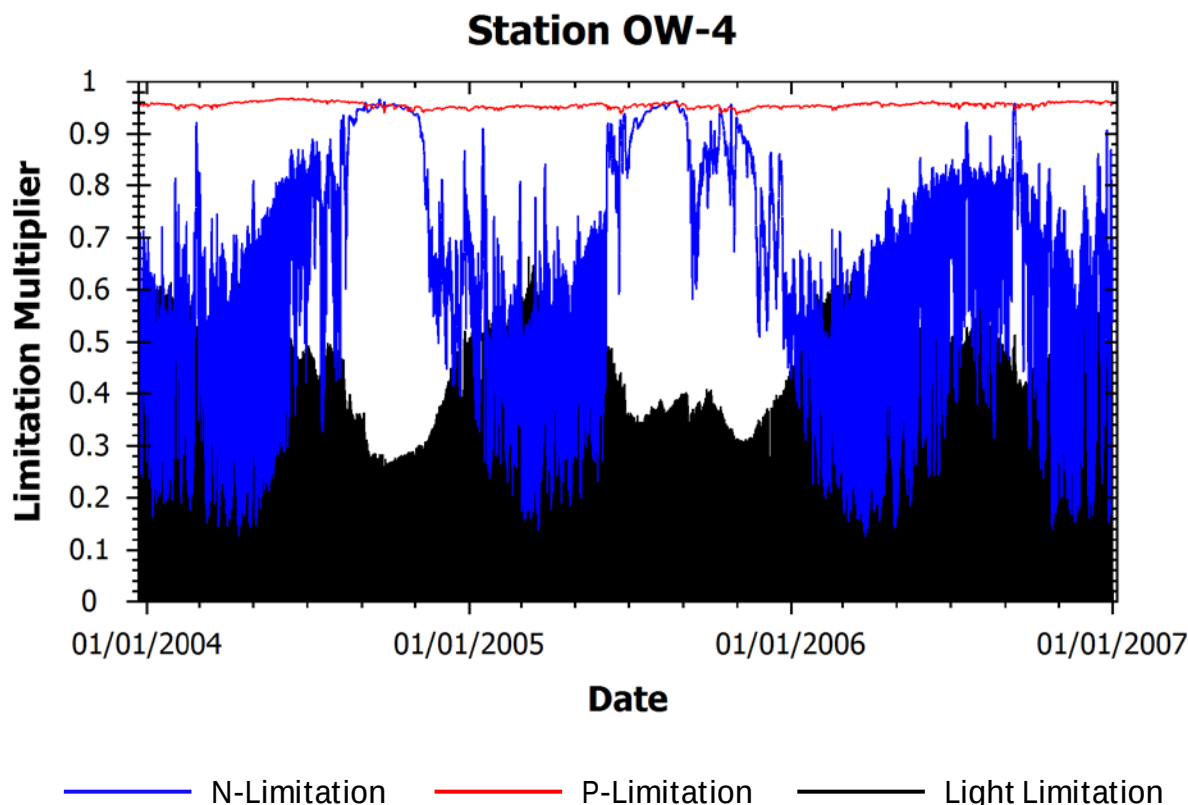


Figure 5–33. Simulated phosphorus (red line), nitrogen (blue line) and light (black line) limitation at station OW-4 under hypothetical conditions of zero N-fixation for the calibration period of 2004 to 2006. If no N-fixation occurs, the lake becomes severely nitrogen limited throughout the winter to early summer (dry season). The lake is generally light limited in late summer to fall (wet season). Phosphorus limitation does not occur in the absence of nitrogen fixation.

5.10 PHOSPHORUS REDUCTION SCENARIOS

Table 5–14 compares average concentrations of total phosphorus, total nitrogen, and chlorophyll-*a* for present day conditions and for total phosphorus reductions of 25%, 50%, and 75% of present day conditions exclusive of atmospheric deposition. Total phosphorus reductions were made to both tributary sources and diffuse ground water flux. For each variable the concentrations are lake-wide averages over the period 2004 to 2006. Total phosphorus is reduced by nearly the magnitude of the tested reduction. The full percentage of reduction is not obtained because no reduction was made to atmospheric deposition. External inputs of total nitrogen were not altered in these scenarios. Reduction of total nitrogen in the scenarios due solely to a reduction of nitrogen fixation as algal production declines. Chlorophyll-*a* (algal biomass) is reduced at a slightly greater magnitude than the percentage reduction in total phosphorus.

Table 5–14. Lake-wide mean total phosphorus (TP), total nitrogen (TN), and chlorophyll-*a* (Chl-*a*) for the period 2004 to 2006 for the present-day scenario and three different levels of phosphorus load reduction. The percent load reduction for TP is exclusive of atmospheric deposition.

Reduction Scenario	TP ($\mu\text{g L}^{-1}$)	Percent TP Reduction	TN (mg L^{-1})	Percent TN Reduction	Chl- <i>a</i> ($\mu\text{g L}^{-1}$)	Percent Chl- <i>a</i> Reduction
0%	186	0.0	3.18	0.0	56	0.0
25%	143	23.1	2.63	17.3	43	23.2
50%	100	46.2	2.08	34.6	29	48.2
75%	57	69.4	1.86	41.5	15	73.2

5.11 SEDIMENT TRANSPORT, DIAGENESIS AND DIFFUSE GROUND WATER FLUX

The WASP surface water quality model application of Lake Jesup presented in this report was designed to examine the response of phytoplankton biomass to nutrient loadings. The focus of the model set-up, then, was on those mechanisms that directly control phytoplankton growth: temperature, light, and nutrient (nitrogen and phosphorus) concentration. Because Lake Jesup is shallow and broad and contains an appreciable quantity of unconsolidated sediment (Anderson et al., 2011), sediment processes are important to both the light regime and nutrient cycling within the lake. In addition, nutrient loads from diffuse ground water seems to be important to the total nutrient budget of the lake (Harper, 2013). The present WASP application does not directly simulate the mechanistic sediment processes of Lake Jesup, not because they are not important, but because of the practicality of focusing on model mechanisms that achieve the desired model objective. In place of simulating directly the complex, detailed mechanisms of sediment transport and sediment diagenesis, this model makes assumptions that, at first-order, mimic these processes.

Sediment Transport

Sediment in the water column (total suspended solids or TSS) is required to determine light attenuation and ultimately the light available to the phytoplankton for photosynthesis. Much of the sediment in the water column is derived from the lake sediments (Anderson et al., 2011) by resuspension caused by winds and wind waves. A sediment transport model can be used to directly simulate resuspension, settling, and deposition of sediments to predict total suspended solids under various conditions of water level and wind speed and direction. (The sediment

transport model must also simulate the height and period of waves generated by the wind.) Such a model would be particularly useful for examining whether resuspension of sediments under varying conditions affects phytoplankton growth, for example, to answer the question of whether periods of low lake stage or high winds can suppress phytoplankton growth.

Resuspension of unconsolidated sediments in Lake Jesup occurs frequently. Anderson et al. (2011) report that the entire unconsolidated mass of floc in the lake resuspends completely 38 to 47 times per year. In place of mechanistically simulating this continued resuspension and deposition of sediments, the present model assumes the net effect of this process is to maintain a high level of suspended solids within the water column at all times. Since sediment is being resuspended daily, and is constantly settling, these two processes are actually occurring simultaneously. Over a time-scale of days relevant to phytoplankton growth, the net effect of these simultaneous processes is suspended sediment in the water column with a very small, or even, zero net settling rate; that is, as much mass of sediment is resuspended as is deposited at daily time scales.

The model simulates this effect by specifying a concentration of total suspended sediments to the tributaries without settling. This is termed a “wash load” in the report referring to the colloidal characteristic of this virtual sediment. This method results in a reasonable average level of total suspended solids for simulation of light attenuation within the model (see Figure 5–23). Of course, the tributaries are not the actual source of the sediment, they are used here only as a practical means of entering the sediments as a source. The source of sediments is likely autochthonous production. Likewise, the lake suspended sediments are not actually colloidal; they can settle and deposit to the bottom. The assumption of zero settling is employed only to simulate the effect of a small net settling rate as described above.

This method of simulating total suspended solids in Lake Jesup for calculating light attenuation is reasonable given that suspended solids are not generally the primary factor controlling light attenuation in the lake because of high color and chlorophyll. The method could be improved by setting TSS boundary conditions based on regression relationships between TSS and dependent physical variables, for example, lake depth or wind speed. Management questions other than phytoplankton response to nutrients would likely dictate different model goals and could require implementation of a mechanistic sediment transport model.

Sediment Diagenesis

Nutrients enter Lake Jesup as tributary (surface water) loads, by dry and wet atmospheric deposition, by spring discharge, by diffuse ground water seepage, and by exchange with the St. Johns River. These are the only pathways in the model by which phosphorus enters the lake. Nitrogen has one additional pathway: from atmospheric N_2 gas to cyanobacteria cells via N-fixation. Once nutrients enter the lake, they are internally recycled both in the water column and through the sediments. The model represents this recycling as nitrogen and phosphorus cycles. The model nutrient cycles track the mass of nutrients through a loop: (a) dissolved inorganic nutrients are assimilated into phytoplankton cells, (b) upon death or grazing of phytoplankton particulate organic nutrients enter the water column, (c) particulate organics are broken down to dissolved organic nutrients, (d) dissolved organic nutrients are mineralized back to dissolved inorganic nutrients. These processes all occur in the water column, but since much of the

particulate organic material (and living phytoplankton) can settle and be deposited to the sediment, much of the recycling back to dissolved inorganic nutrient forms occurs in the sediment. The transformation of organic nutrients back to inorganic nutrients within the sediment is termed *sediment diagenesis* and is an important mechanistic process for nutrient recycling in both freshwater and marine systems (DiToro, 2001).

Sediment diagenesis processes can be modeled mechanistically. The water quality models of CE-QUAL-ICM (Cerco and Cole, 1993), EFDC (Park et al., 2000), and WASP 7.3 (Martin and Wool, 2012) all use a mechanistic sediment diagenesis model developed by DiToro (2001). Inclusion of sediment diagenesis processes in a surface water quality model is most often used for

- (a) prediction of altered sediment oxygen demand following nutrient reduction,
- (b) estimation of response time of the system following nutrient reduction (because the sediments must deplete or bury their stored nutrients), and
- (c) simulation of seasonal storage and release of nutrients (for example, storage of organic nitrogen in the sediments during cooler periods and subsequent rapid release as ammonia upon warming of the sediment in Spring).

The DiToro sediment diagenesis model is principally a mass balance model. All inorganic nutrients that are released from the sediments as dissolved ammonia, nitrate, or phosphate originate from nutrients that entered the sediments, most often, but not exclusively, as particulate organic nutrients. These particulate organic nutrients, of course, originated from the sources of external nutrient loads to the lake that were listed previously. The sediment diagenesis processes transform, they do not create, nutrients. As such, the use of the term “loading” to describe nutrients entering the water column can be misleading, particularly if this diagenesis “loading” is equated to the source loadings. The diagenesis loading arises from the source loadings; it does not govern the sources. Mass balance dictates that nutrient fluxes out of the sediment resulting from sediment diagenesis cannot, on average, exceed the nutrient loading to the sediment. Even more, the nutrient fluxes can only be less, since losses occur through burial (for nitrogen and phosphorus) and denitrification of pore water nitrate (for nitrogen).

That the nutrient recycling in the lake is large is evident from downward flux measurements of particulate nitrogen of 500 to 15000 mg m⁻² day (Anderson et al., 2011). These values far exceed depositional flux measurements for other systems with similar nutrient loading rates (see, for example, Fig 15.4, DiToro, 2001). Sediment flux measurements out of the sediments of 100 mg N m⁻² day⁻¹ and 4.7 mg P m⁻² day⁻¹ (HydroO₂, 2006), on the other hand, are consistent with literature values. An explanation for the apparent discrepancy between these observations could be that much of the measured depositional flux remains as unconsolidated floc that is intimately connected to the water column.

The present WASP model does not directly simulate sediment diagenesis processes. Simulation of dissolved oxygen, and hence sediment oxygen demand, was not a model goal. In addition, the nearly constant bloom condition of the lake makes questions regarding seasonality of secondary importance to the larger question of the average response of phytoplankton to nutrient loading.

In place of a sediment diagenesis model, the present model keeps all nutrients in the water column and all nutrient recycling takes place there. The possible large recycling of nutrients through the unconsolidated floc layer argues for the present model's conceptualization that much of the recycled particulate organic material essentially remains in the water column. Organic nutrients, of course, are deposited to the sediment and return to the water column as inorganic nutrient fluxes. The implication of not accounting for this mechanism in the present model application is that (a) the model does not account for loss of nutrients, particularly of nitrogen, to the sediments, and (b) the model does not allow for seasonal storage and release of nutrients. At first order these implications are acceptable to the model goal: the first (a) because loss of nitrogen to denitrification in the sediments is likely rapidly compensated for by an increase in N-fixation by phytoplankton, and the second (b) because of the lakes generally persistent bloom conditions.

Perhaps the most important disadvantage of the model's lack of sediment diagenesis mechanisms is the inability to address response time to a reduction of phosphorus source loads. Phosphate fluxes from sediments typically exhibit long response times, taking more than 20 years to equilibrate to a new loading regime (DiToro, 2001).

Diffuse Ground Water Flux

The middle St. Johns River lakes, including Lake Jesup, are known to receive diffuse ground water discharge from the upper Floridan Aquifer (Belaine et al., 2012). The effect of diffuse ground water on chloride and salinity in Lake Jesup is demonstrated in Figure 5-5, Figure 5-6, and Figure 5-7 above. Harper (2013) attempted to quantify nitrogen and phosphorus fluxes associated with diffuse ground water by means of seepage meters. Although this study could not definitively separate the fraction of observed flux that was an additional, new nutrient loading from ground water compared with recycled diagenetic flux, his measurements, when considered as completely new loading from ground water, explained total phosphorus concentrations well (Figure 5-11). Harper's observed nutrient fluxes were thus used in the present WASP model to represent a nutrient load from diffuse ground water. This load is an additional, new external load to the model and not a recycled nutrient flux. Harper's flux estimates are used because he specifically designed his measurement methodology towards estimating new sources of nutrient load. This experimental design is in contrast to HydroO₂ (2006) that measured recycled fluxes from sediment diagenesis processes and Anderson et al. (2011) that primarily measured downward depositional flux of particulate organic nutrients. Both these latter studies would be applicable to implementing a sediment diagenesis component to the present WASP model, but are not useful to estimating the new loading source from diffuse ground water entering the lake.

Nutrient flux from diffuse ground water was entered into the WASP model as a benthic bottom flux of ammonia and phosphate. This method was employed for convenience and ignores that Harper observed other nutrient forms associated with fluxes into the seepage meters. The assumption for the model, then, is that (a) all the seepage flux measured by Harper is a new external nutrient source, and (b) all the observed nutrient flux is bioavailable.

5.12 SUMMARY OF KEY RESULTS

A WASP surface water quality model was applied to Lake Jesup for the six-year period 2004 to 2009. The WASP water quality model is linked to an EFDC hydrodynamics model for simulation of lake stage, circulation, and mixing. Surface water tributary discharge and nutrient loading are provided by an HSPF hydrologic model. The WASP water quality model is designed to estimate the response of phytoplankton biomass to external phosphorus loads. Key findings are as follows:

- A 12 month spin-up is sufficient to eliminate the influence of surface water quality initial conditions on prediction of surface water quality state variables
- On average, approximately 17 cfs of diffuse ground water enters Lake Jesup and is required to explain high chloride levels within the lake
- On average, approximately 9.5 MT/yr of total phosphorus enters the lake as diffuse ground water and is required to explain the total phosphorus concentration levels in the lake
- Nitrogen fixation by phytoplankton contributes about 45% of the total nitrogen sources to the lake
- The WASP water quality model successfully predicted the high total phosphorus and chlorophyll levels in the lake
- In its present condition, phytoplankton in the lake are nearly always light-limited due to self-shading
- In the absence of nitrogen fixation, phytoplankton in the lake would experience severe nitrogen limitation
- The WASP model application of Lake Jesup could be improved by better temporal resolution of TSS and its affect on light
- In the absence of a sediment diagenesis submodel, the WASP model application of Lake Jesup cannot predict the response time of lower phytoplankton biomass following nutrient control

6 BIBLIOGRAPHY

Ambrose, B., Jr. and T.A. Wool. "WASP7 Nutrient Cycling Processes". Power Point presentation file from WASP Training Class. July, 2010.

Ambrose, B, Jr., T.A. Wool, and J.L. Martin, "The Water Quality Analysis Simulation Program, WASP5; Part A: Model Documentation," U.S. Environmental Protection Agency, Center for Exposure Assessment Modeling, Athens, GA, June, 1993.

Anderson, W., L. Scinto, S. Nielsen, S. Thomas, D. Fugate, and R. Corbett. 2011. "Assessment of the Cycling and Compartmentalization of Nitrogen and Phosphorus in Saturated Soils, Sediments and the Water Column in Lake Jesup, Florida." Final Report, Contract # 25044, St. Johns River Water Management District, Palatka, FL. 168 pp.

Appadu, A. Numerical solution of the 1D advection-diffusion equation using standard and nonstandard finite difference schemes. J. Applied Math. 2013: 1-14.

Belaine, G., J. Stewart, P. Sucsy, L. Motz, K. Park, S. Rouhani and M. Cullum. Groundwater Hydrology. Chapter 4 of the St. Johns River Water Supply Impact Study. St. Johns River Water Management District, Palatka, FL. 2012. 100 pp.

Bicknell, B. R., J. C. Imhoff, J. L. Kittle, A. S. Donigian, and R. C. Johanson. Hydrologic Simulation Program - FORTRAN, User's Manual for Version 11. Athens, GA: U.S. EPA, National Exposure Research Laboratory, 1997.

Bowie, G., W. Mills, D. Porcella, C. Campbell, J. Pagenkopf, G. Rupp, K. Johnson, P. Chan, S. Gherini, and C. Chamberlin. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. Environmental Research Laboratory, Office of Research & Development, U.S. EPA, Athens, GA. 1985: 450 pp.

Cera, T., D. Smith, M. G. Cullum, M. Adkins, J. Amoah, D. Clapp, R. Freeman, M. Hafner, X. Huang, Y. Jia, T. Jobes, L.-T. Mao. Watershed Hydrology. Chapter 3 of the St. Johns River Water Supply Impact Study. St. Johns River Water Management District, Palatka, FL. 2012. 223 pp.

Cerco, C. and T. Cole. 1993. User's Guide to the CE-QUAL-ICM Three-Dimensional Eutrophication Model. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MI Report EI-94-4.

Chapra, S.C. 1997. Surface Water-Quality Modeling. WCB/McGraw-Hill, New York.

DiToro, D.M. 2001. Sediment Flux Modeling. Wiley-Interscience, New York. 624 pp.

Dobberfuhl, D. 2003. *Cylindrospermopsis raciborskii* in Three Central Florida Lakes: Population Dynamics, Controls, and Management Implications. Lake and Reservoir Management, 19(4): 341-348.

FDEP. Biological and Chemical Assessment of Water Quality in Tributaries of Lake Jesup, Seminole-County, Florida. FDEP, Central District Surface Water Assessment and Monitoring Section, 1997.

Gallegos, C. 2005. Optical water quality of a blackwater river estuary: the lower St. Johns River, Florida. *Estuarine Coastal and Shelf Science*, Vol. 63: 57-72.

Hamrick, J. M. A three-dimensional environmental fluid dynamics code: Theoretical and computational aspects. Special Report 317. Gloucester Point, VA: The College of William and Mary, Virginia Institute of Marine Sciences, 1992.

Harper, H. Evaluation of Hydrologic and Nutrient Loadings from Groundwater Seepage to Lake Jesup. Final Report. Environmental Research & Design, Belle Isle, FL. July 2013. 83 pp.

HydroO₂, Inc. 2006. Lake Jesup, Seminole County, Florida: In situ Assessment of Sediment Nutrient Flux Assessment and Sediment Oxygen Demand. HDR Engineering, One Blue Hill Plaza, Pearl River, NY. 31 pp.

Jacobs, J., J. Mecikalski and S. Paech. 2008. Satellite-based solar radiation, net radiation, and potential and reference evaporation estimates over Florida.
http://fl.water.usgs.gov/et/publications/GOES_FinalReport.pdf

Jia, Y. Draft Report: Hydrologic and Water Quality Modeling of the Lake Jesup Watershed. St. Johns River Water Management District, Palatka, FL. 2014. 85 pp.

Keller, T. Middle St. Johns River Basin Water Quality Status and Trends: 2002. . St. Johns River Water Management District, Palatka, FL. SJ2004-1. 2004: 181 pp.

Lewis, E. L. "The practical salinity scale and its antecedents." *IEEE Journal of Ocean Engineering* OE 5, no. 1 (1980): 3-8.

Martin, J.L. and T.A. Wool. 2012. WASP Sediment Diagenesis Routines: Model Theory and User's Guide. U.S. EPA, Office of Research and Development, Washington D.C. 44 pp.

Martin, J. L., and S. C. McCutcheon. Hydrodynamics and Transport for Water Quality Modeling. Boca Raton, FL: CRC Press, Inc., 1999.

Mitchell, K.E., D. Lohmann, P.R. Houser, E.F. Wood, J.C. Schaake, A. Robock, B.A. Cosgrove, J. Sheffield, Q. Duan, L. Luo, R.W. Higgins, R.T. Pinker, J.D. Tarpley, D.P. Lettenmaier, C.H. Marshall, J.K. Entin, M. Pan, W. Shi, V. Koren, J. Meng, B. H. Ramsay, and A.A. Bailey. The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system. *J. Geophys. Res.* 2004: 109.

NOOA. 2014. "*Cylindrospermopsis raciborskii* Fact Sheet". NOAA Great Lakes Environmental Research Laboratory. http://www.glerl.noaa.gov/res/waterQuality/cylindro_factsheet.html.

Odum, H. T. "Factors controlling marine invasion into Florida fresh waters." *Bulletin Marine Science*, 1953: 3(2): 134-156.

Paech, S., Mecikalski, J., Sumner, D., Pathak, C., Wu, Q., Islam, S., and Sangoyomi, T. A calibrated, high-resolution GOES satellite solar insolation product for a climatology of Florida evapotranspiration. *J. AWRA*, 2009: 45(6): 1328-1342.

Park, R, A.Y. Kuo, J. Shen and J. Hamrick. 2000. A Three-Dimensional HydrodynamicEutrophication Model (HEM-3D): Description of Water Quality and Sediment Process Submodels. Special Report 327 in Applied Marine Science and Ocean Engineering, School of Marine Science, Virginia Institute of Marine Science, the College of William and Mary, Gloucester Point, Virginia.

Phlips, E.J., M. Cichra, F.J. Aldridge, J. Jembeck, J. Hendrickson, and R. Brodie. 2000. Light availability and variations in phytoplankton standing crops in a nutrient-rich blackwater river. *Limnol. Oceanogr.*, 2000: 45(4): 916-929.

Pirkle, W. A. "The offset course of the St. Johns River, Florida." *Southeastern Geology*, 1971: Vol. 13: 39-59.

Scott, T. M. The Geology of the Hawthorne Formation of Northeastern Florida. Report of Investigation No. 94. Florida Bureau of Geology, 1983.

Spechler, R. M. Saltwater Intrusion and Quality of Water in the Floridan Aquifer System, Northeast Florida. Washington, D.C.: USGS Water-Resources Investigations Report 92-4174., 1994.

St. Johns River Water Management District. 2014. Radar rainfall.
<http://webapub.sjrwmd.com/agws10/radrain/index.htm>

Sucsy, P., E. Carter, D. Christian, M. Cullum, K. Park, J. Stewart and Y. Zhang. River Hydrodynamics Calibration. Chapter 5 of the St. Johns River Water Supply Impact Study. St. Johns River Water Management District, Palatka, FL. 2012. 344 pp.

U.S. EPA Region 4. 2006. Total maximum daily load (TMDL) for dissolved oxygen and nutrients in Butcher Pen Creek (2322) Lower St. Johns River Basin, Florida. U.S. EPA Region 4, Atlanta, GA. 50 pp.

Winkler, S. Status and Trends in Water Quality at Selected Sites in the St. Johns River Water Management District. Palatka: SJRWMD Tec. Pub. SJ2004-3, 2004.

7 APPENDIX: ADDITIONAL PLOTS

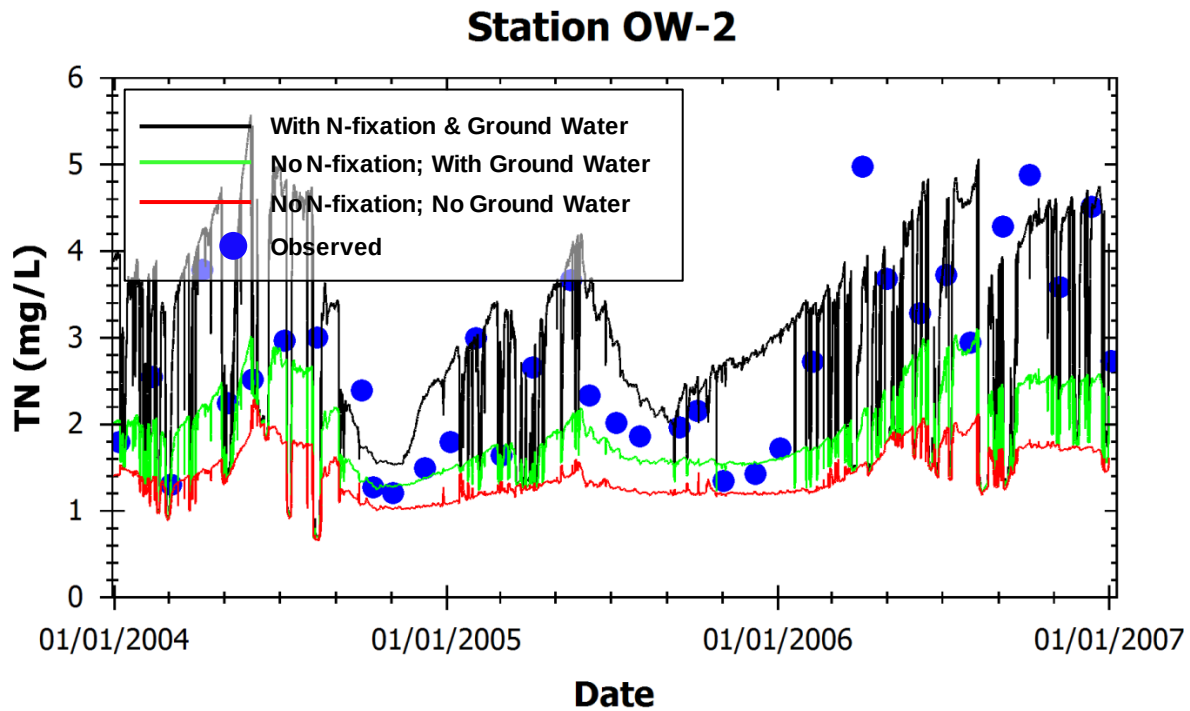


Figure 7–1. Comparison of simulated and observed total nitrogen at station OW-2 during calibration period of 2004 to 2006. The black line is the model with inclusion of nitrogen fixation and benthic ammonia flux. The red line is the model without nitrogen fixation but with a benthic ammonia flux. The blue line is the model without either nitrogen fixation or benthic ammonia. Blue circles are observed values.

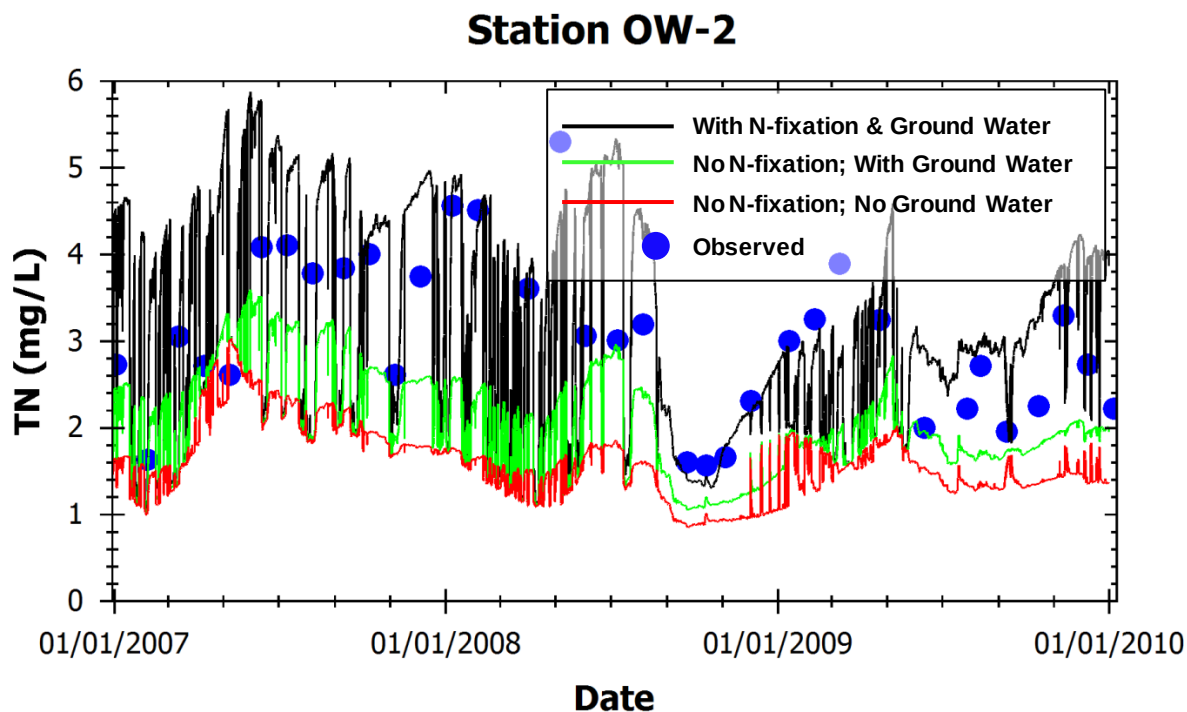


Figure 7–2. Comparison of simulated and observed total nitrogen at station OW-2 during confirmation period of 2007 to 2009. The black line is the model with inclusion of nitrogen fixation and benthic ammonia flux. The red line is the model without nitrogen fixation but with a benthic ammonia flux. The blue line is the model without either nitrogen fixation or benthic ammonia. Blue circles are observed values.

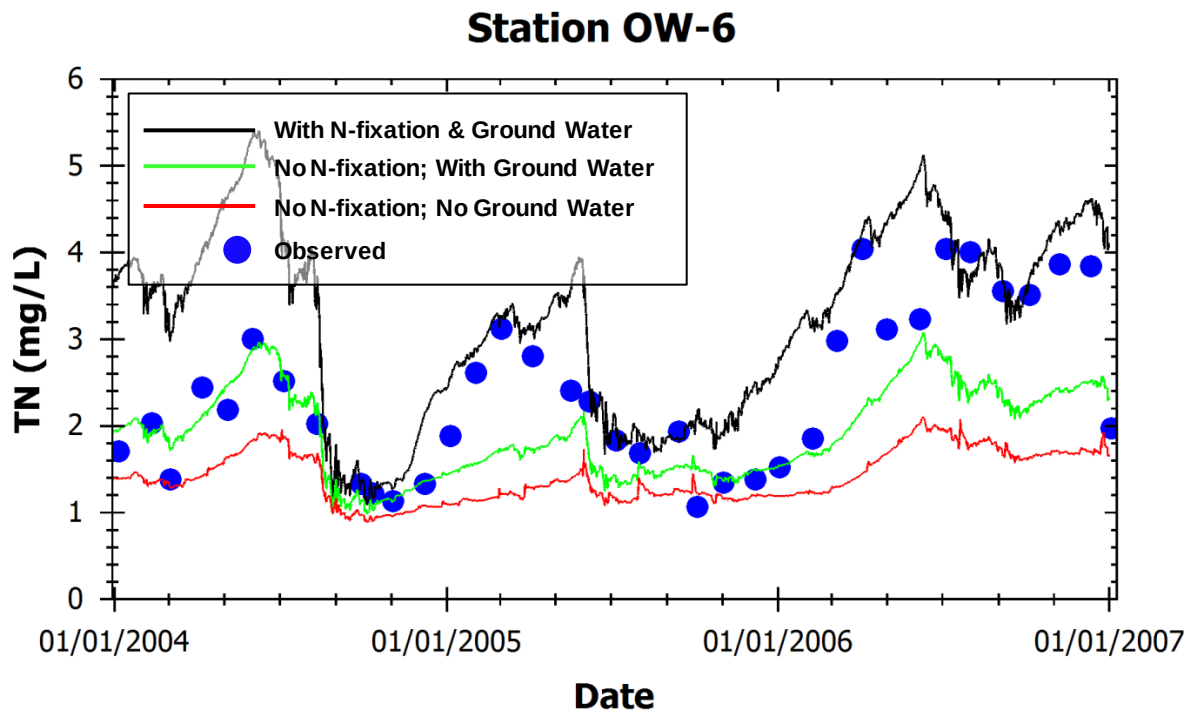


Figure 7–3. Comparison of simulated and observed total nitrogen at station OW-6 during calibration period of 2004 to 2006. The black line is the model with inclusion of nitrogen fixation and benthic ammonia flux. The red line is the model without nitrogen fixation but with a benthic ammonia flux. The blue line is the model without either nitrogen fixation or benthic ammonia. Blue circles are observed values.

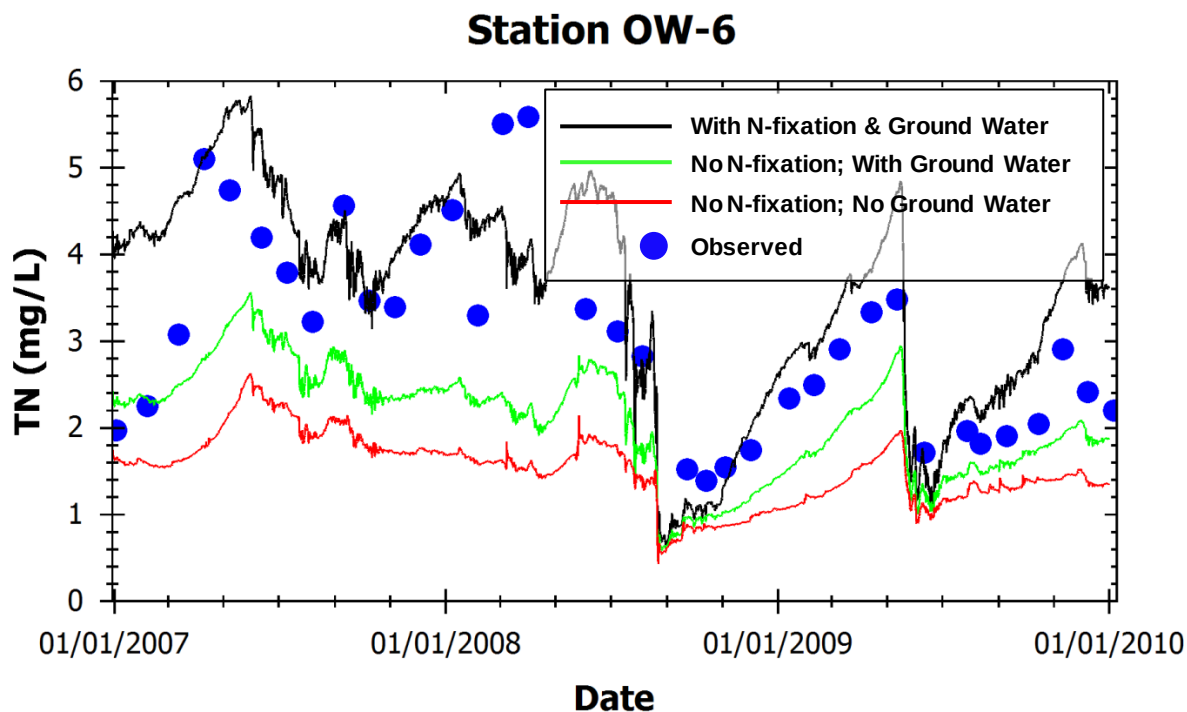


Figure 7–4. Comparison of simulated and observed total nitrogen at station OW-6 during confirmation period of 2007 to 2009. The black line is the model with inclusion of nitrogen fixation and benthic ammonia flux. The red line is the model without nitrogen fixation but with a benthic ammonia flux. The blue line is the model without either nitrogen fixation or benthic ammonia. Blue circles are observed values.

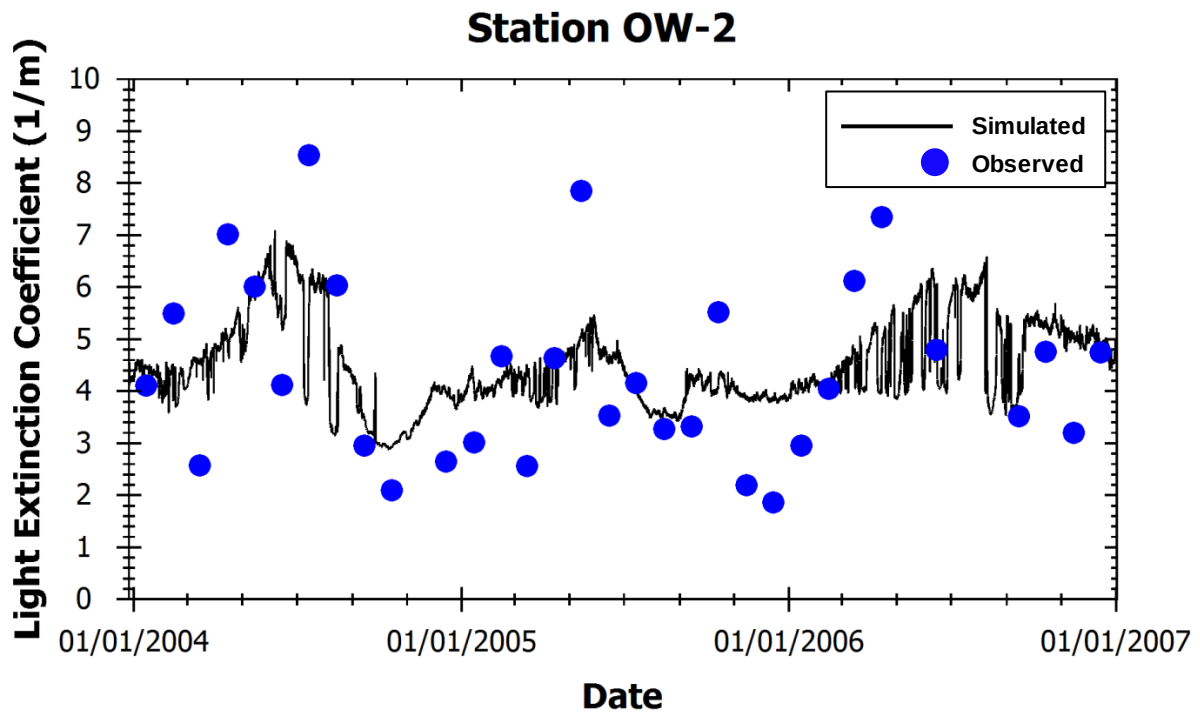


Figure 7–5. Comparison of simulated and observed light extinction coefficient (K_D) at station OW-2 for the calibration period of 2004 to 2006.

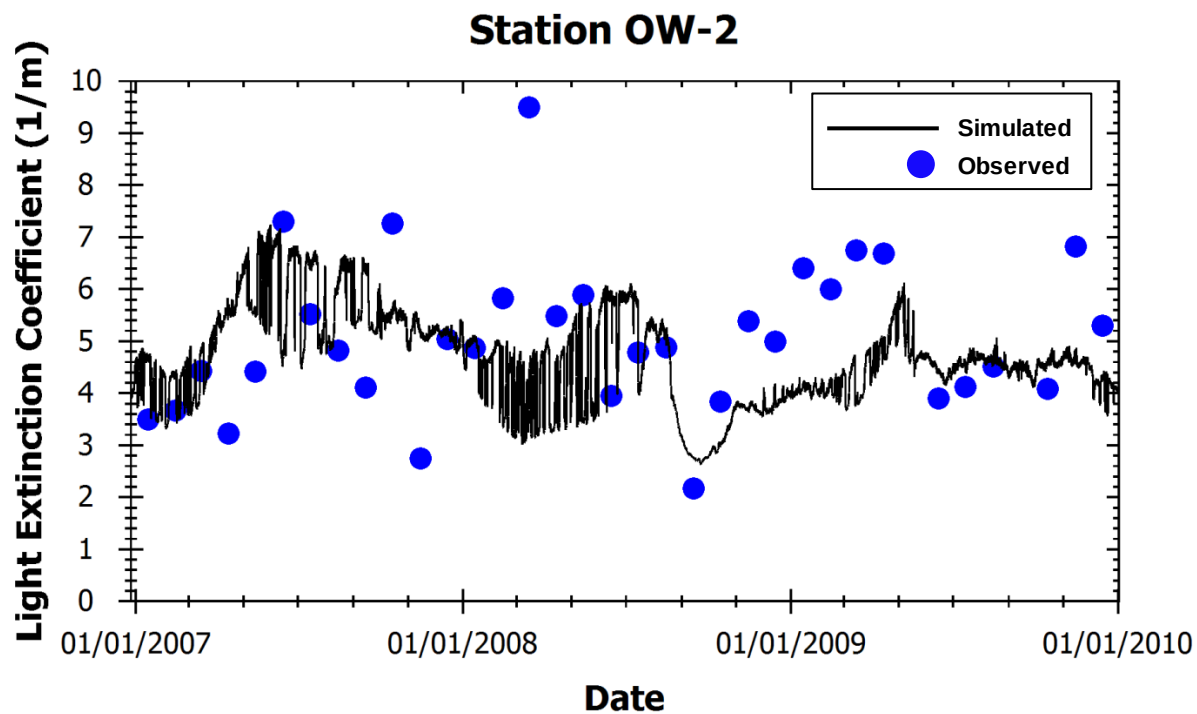


Figure 7–6. Comparison of simulated and observed light extinction coefficient (K_D) at station OW-2 for the confirmation period of 2007 to 2009.

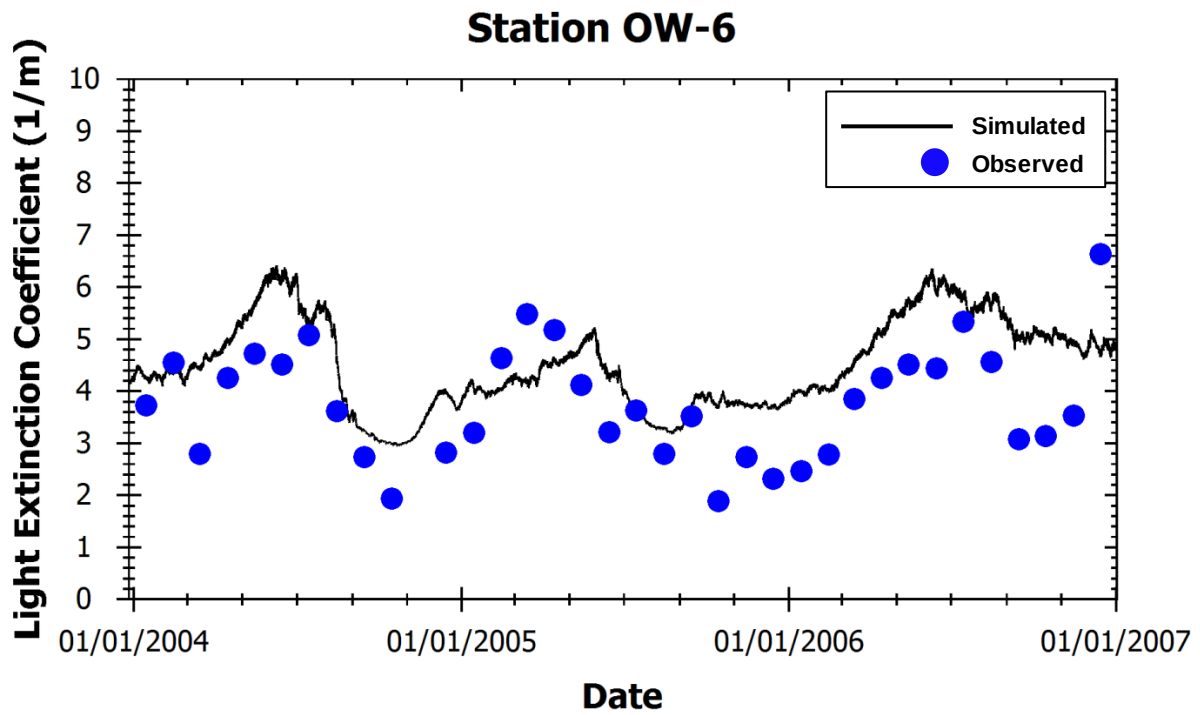


Figure 7–7. Comparison of simulated and observed light extinction coefficient (K_D) at station OW-6 for the calibration period of 2004 to 2006.

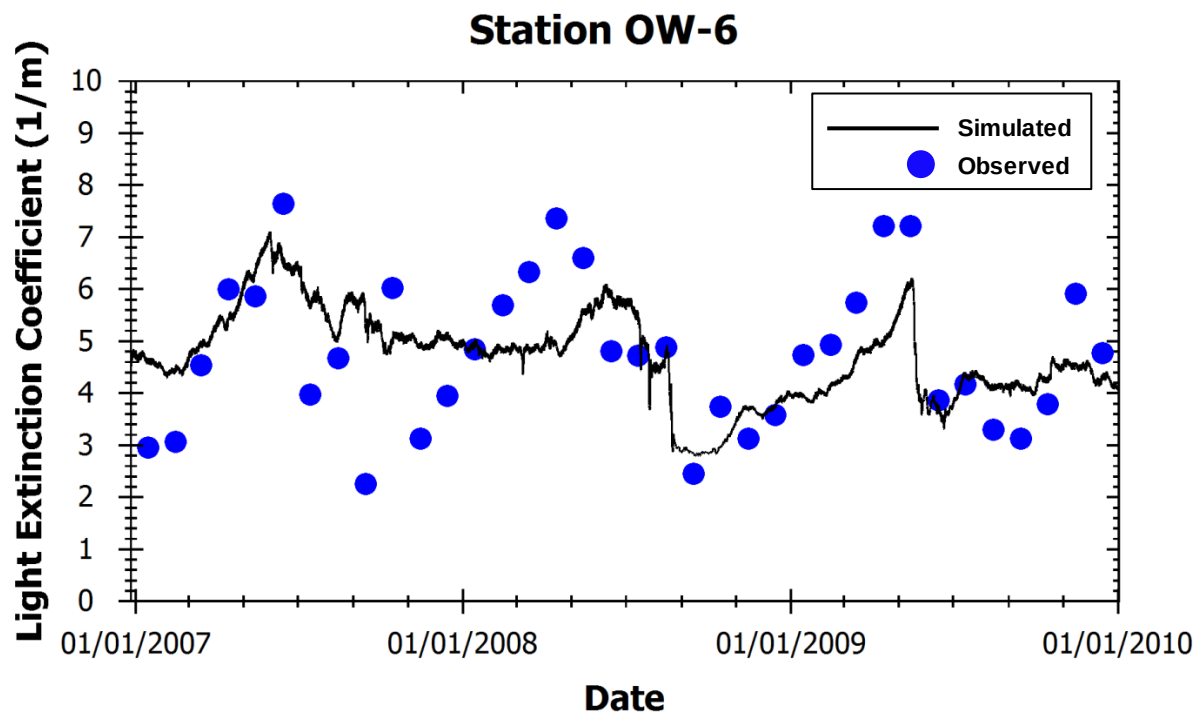


Figure 7–8. Comparison of simulated and observed light extinction coefficient (K_D) at station OW-6 for the confirmation period of 2007 to 2009.

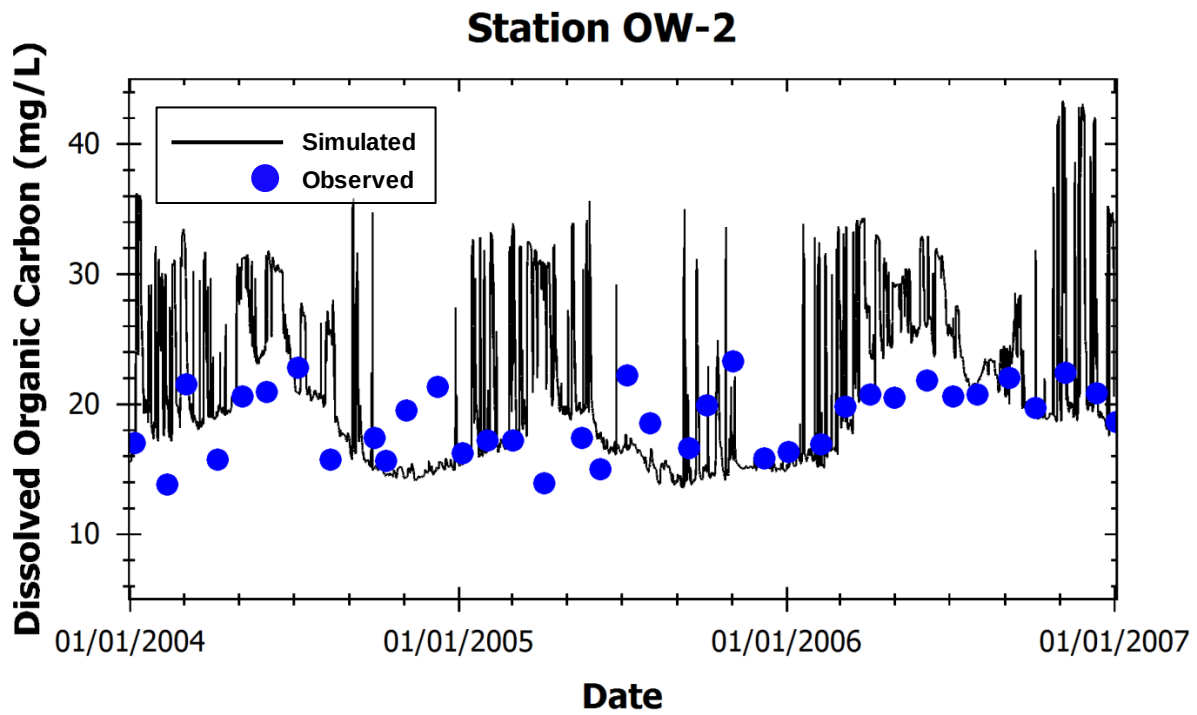


Figure 7–9. Comparison of simulated and observed dissolved organic carbon (DOC) at station OW-2 for the calibration period of 2004 to 2006.

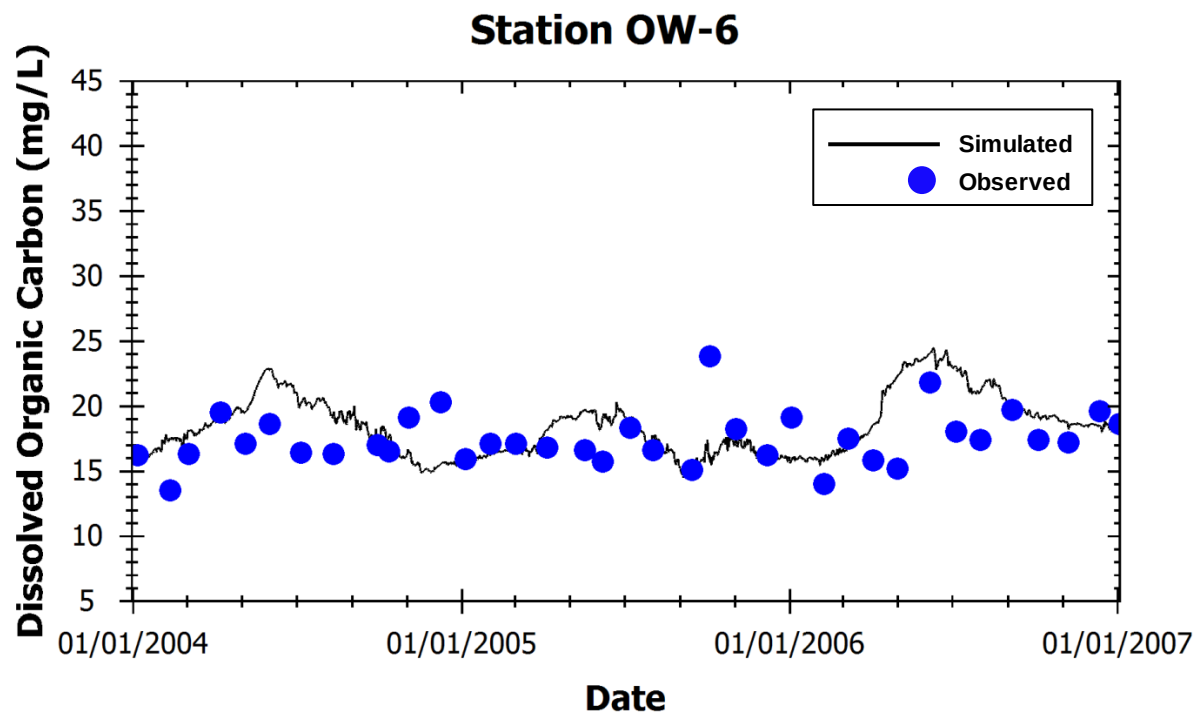


Figure 7–10. Comparison of simulated and observed dissolved organic carbon (DOC) at station OW-6 for the calibration period of 2004 to 2006.

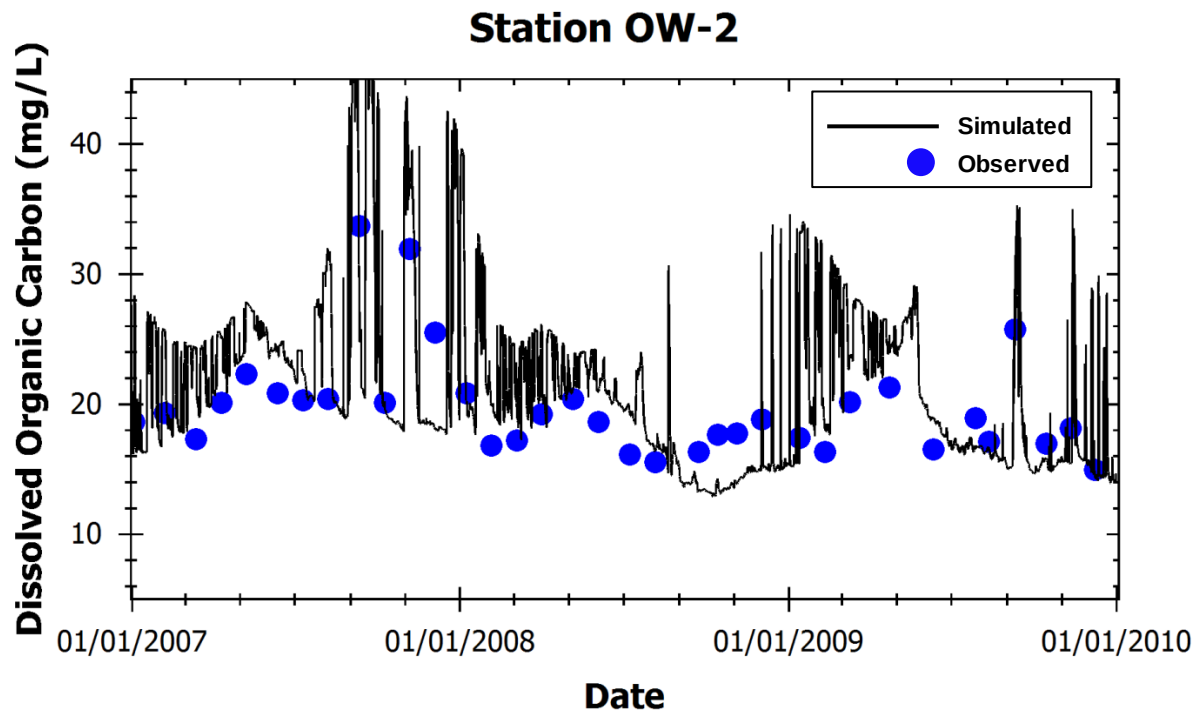


Figure 7–11. Comparison of simulated and observed dissolved organic carbon (DOC) at station OW-2 for the confirmation period of 2007 to 2009.

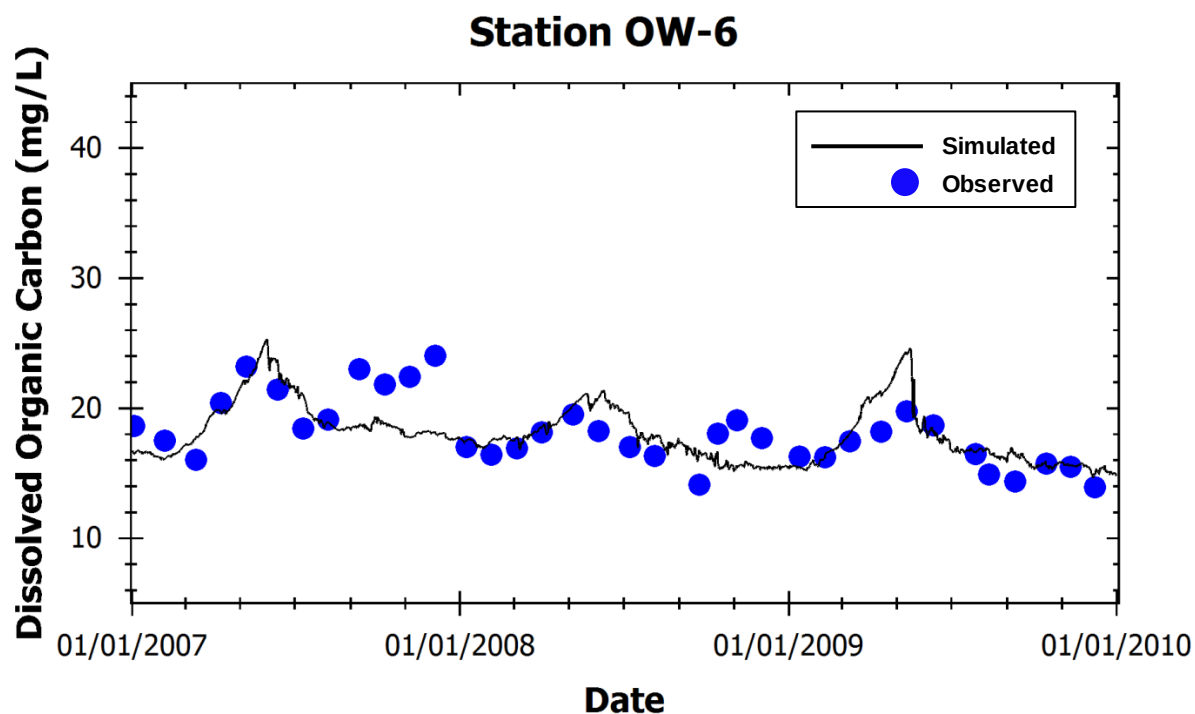


Figure 7–12. Comparison of simulated and observed dissolved organic carbon (DOC) at station OW-6 for the confirmation period of 2007 to 2009.

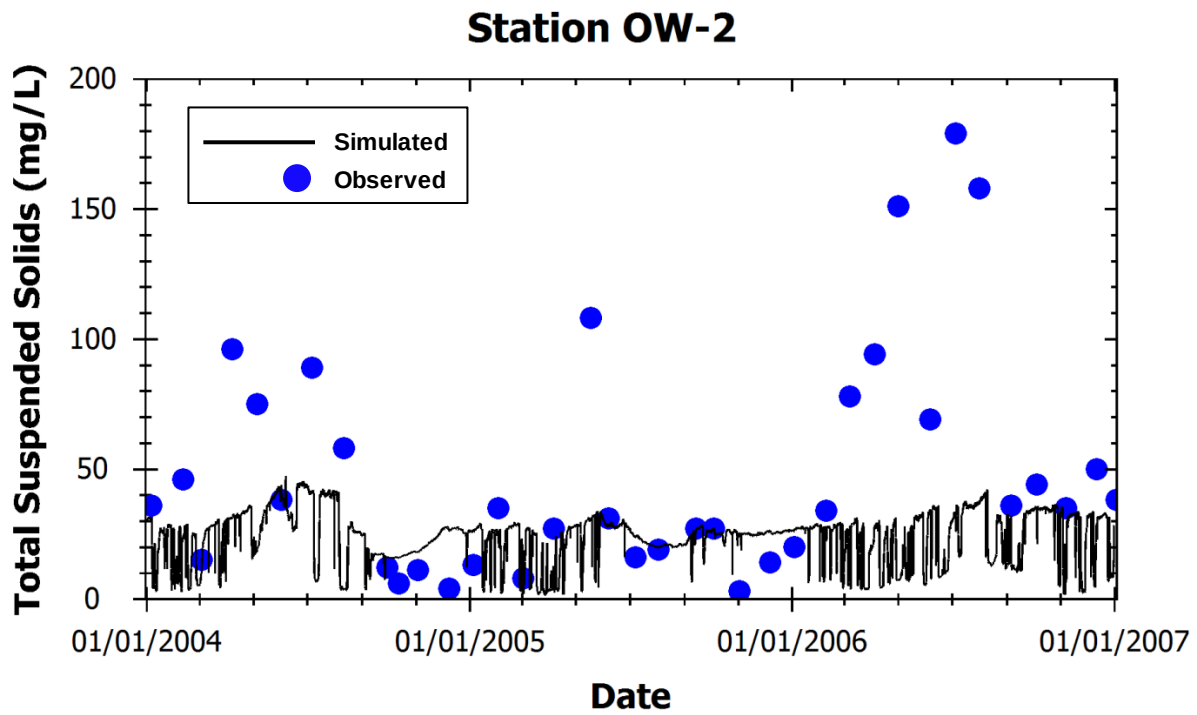


Figure 7–13. Comparison of simulated and observed total suspended solids (TSS) at station OW-2 for the calibration period of 2004 to 2006.

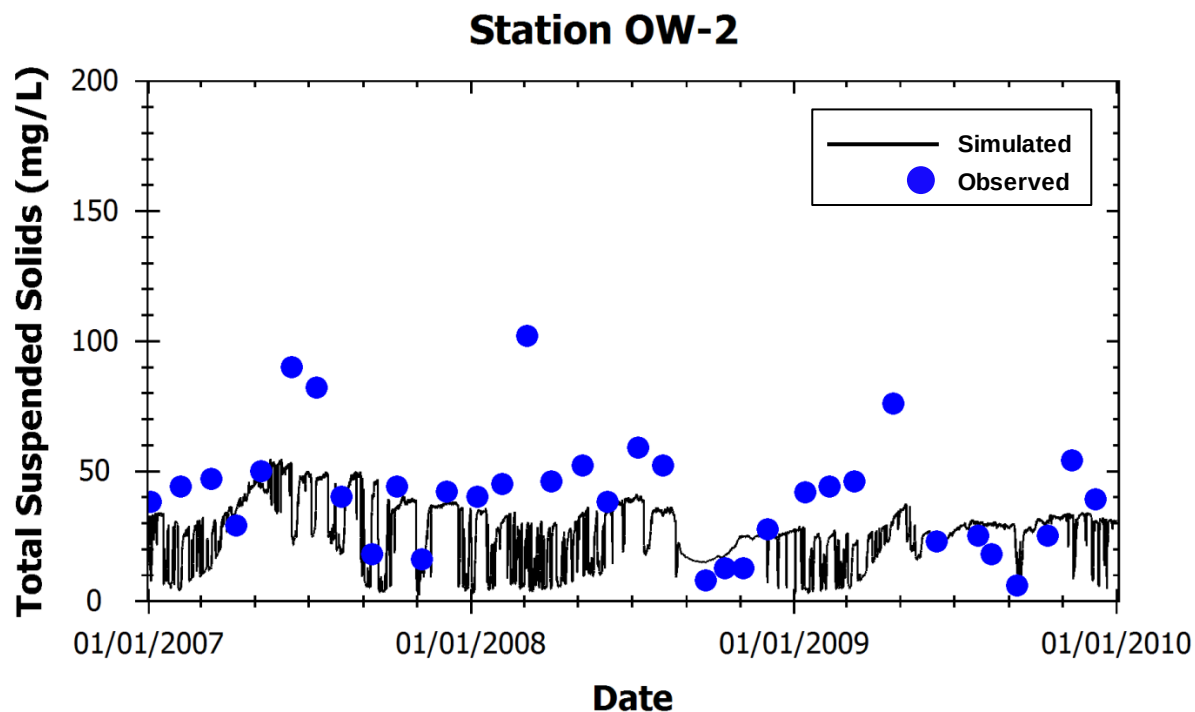


Figure 7–14. Comparison of simulated and observed total suspended solids (TSS) at station OW-2 for the confirmation period of 2007 to 2009.

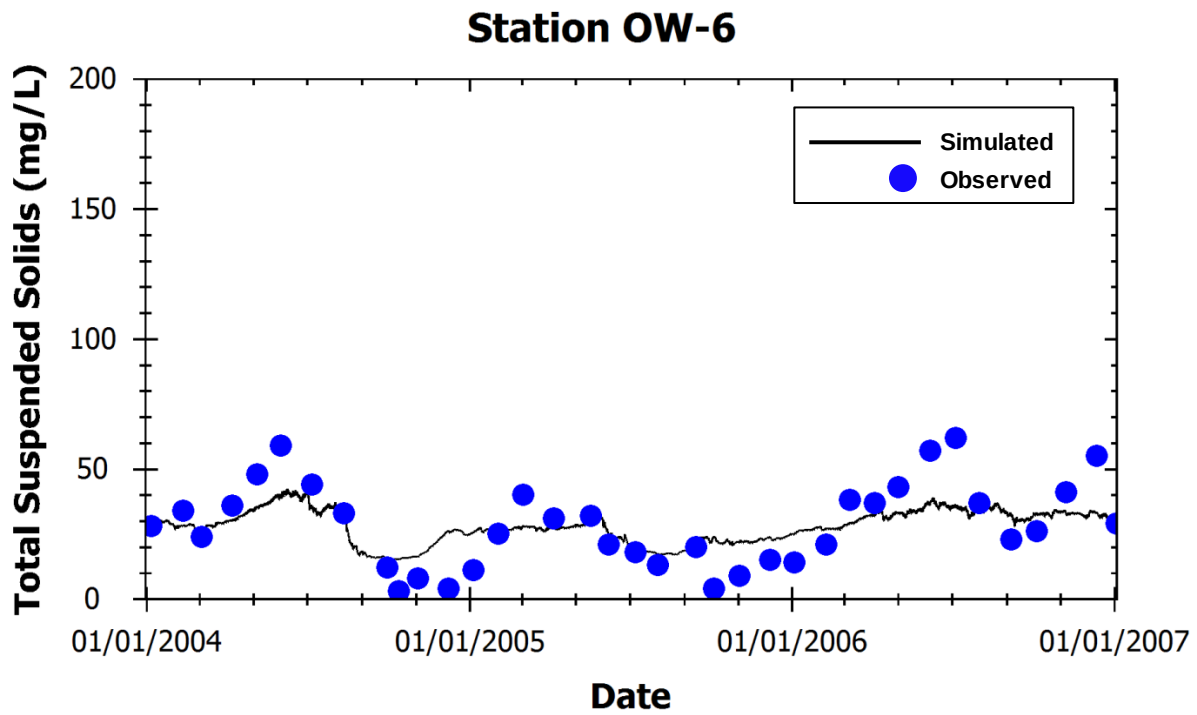


Figure 7–15. Comparison of simulated and observed total suspended solids (TSS) at station OW-6 for the calibration period of 2004 to 2006.

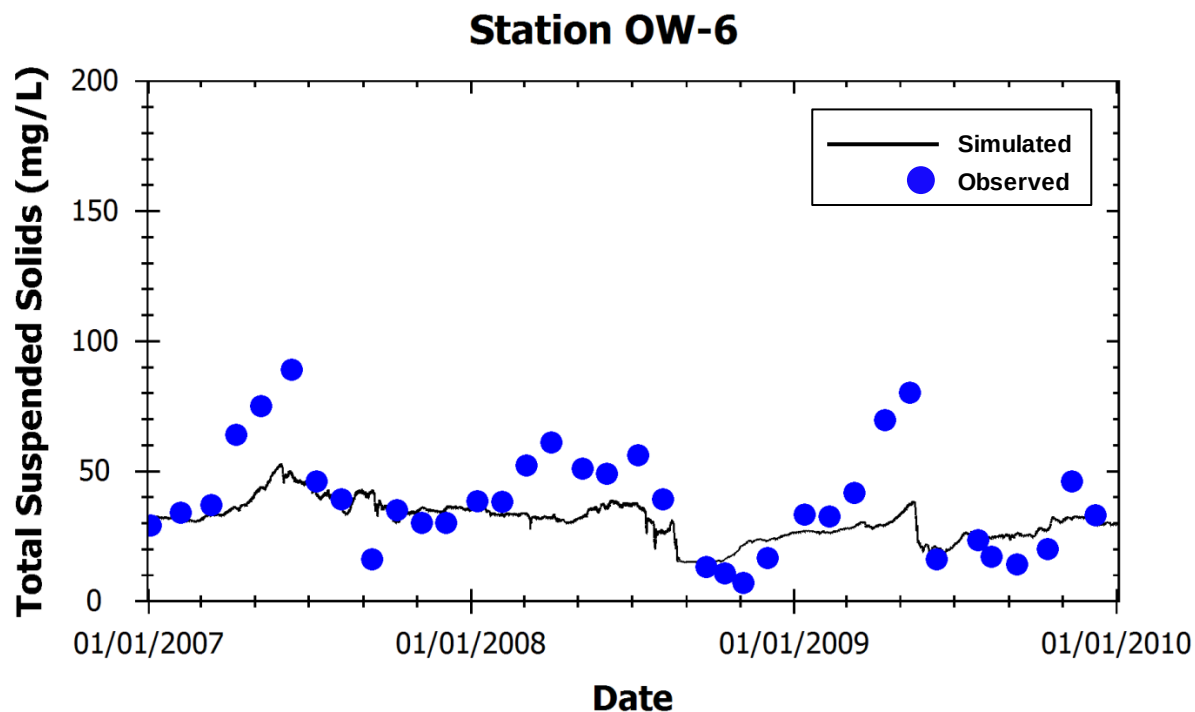


Figure 7–16. Comparison of simulated and observed total suspended solids (TSS) at station OW-6 for the confirmation period of 2007 to 2009.

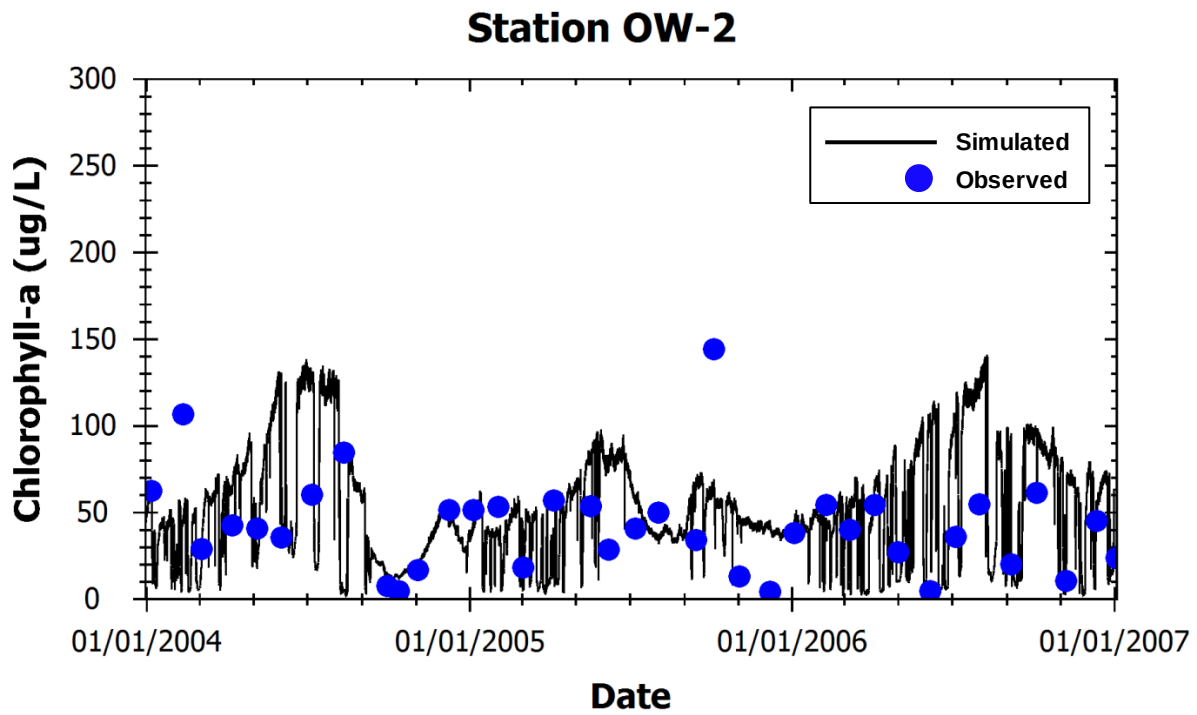


Figure 7–17. Comparison of simulated and observed Chl-*a* at station OW-2 for the calibration period of 2004 to 2006.

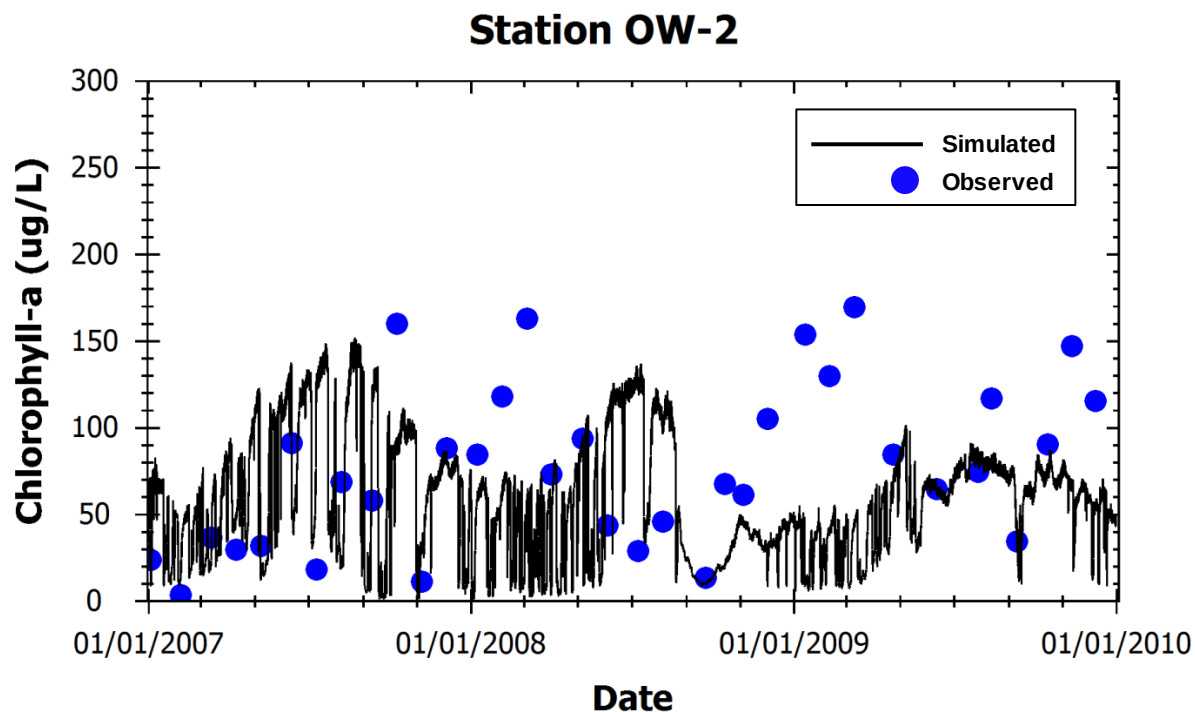


Figure 7–18. Comparison of simulated and observed Chl-*a* at station OW-2 for the confirmation period of 2007 to 2009.

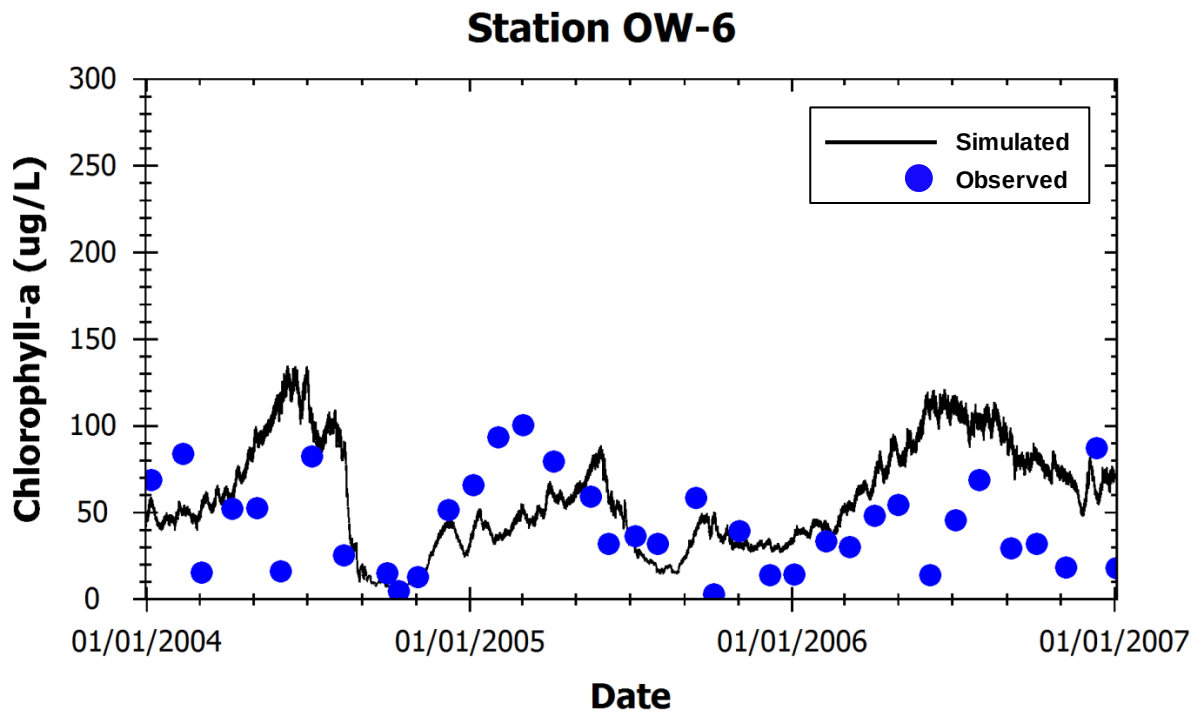


Figure 7–19. Comparison of simulated and observed Chl-*a* at station OW-6 for the calibration period of 2004 to 2006.

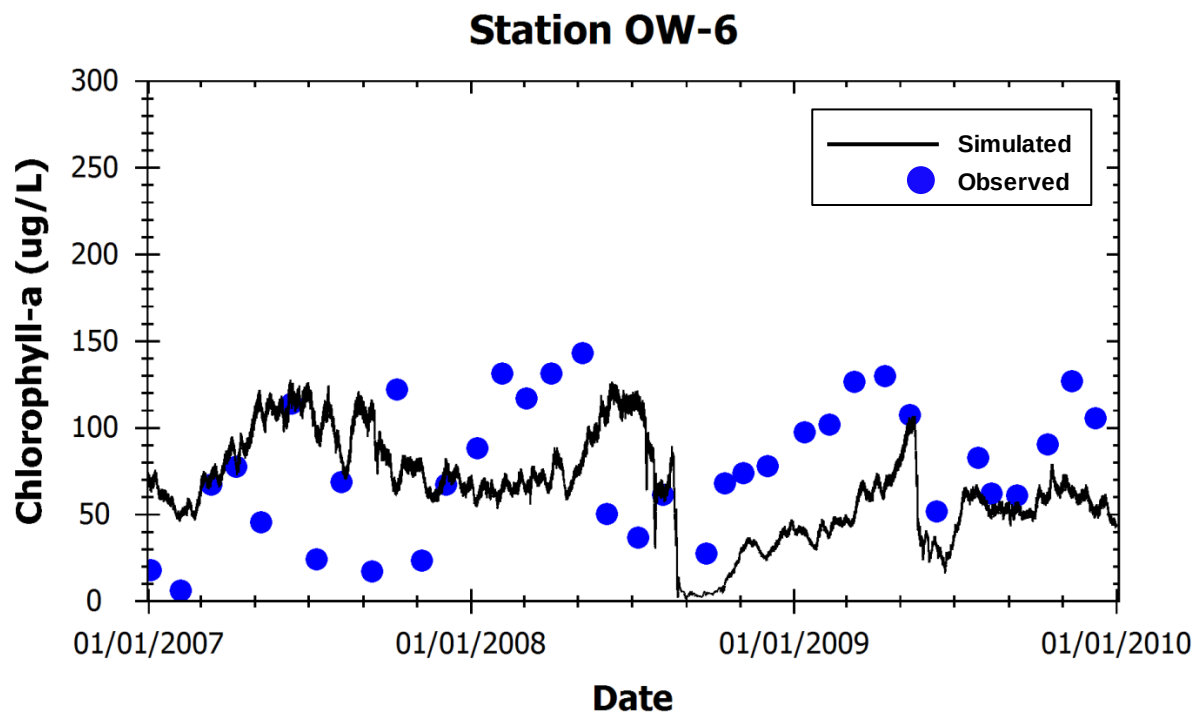


Figure 7–20. Comparison of simulated and observed Chl-*a* at station OW-6 for the confirmation period of 2007 to 2009.