Mobile Bay Modeling Report

Submitted to: Mobile Bay National Estuary Program
Alabama Department of Environmental Management

Submitted by: Tetra Tech

December 2012

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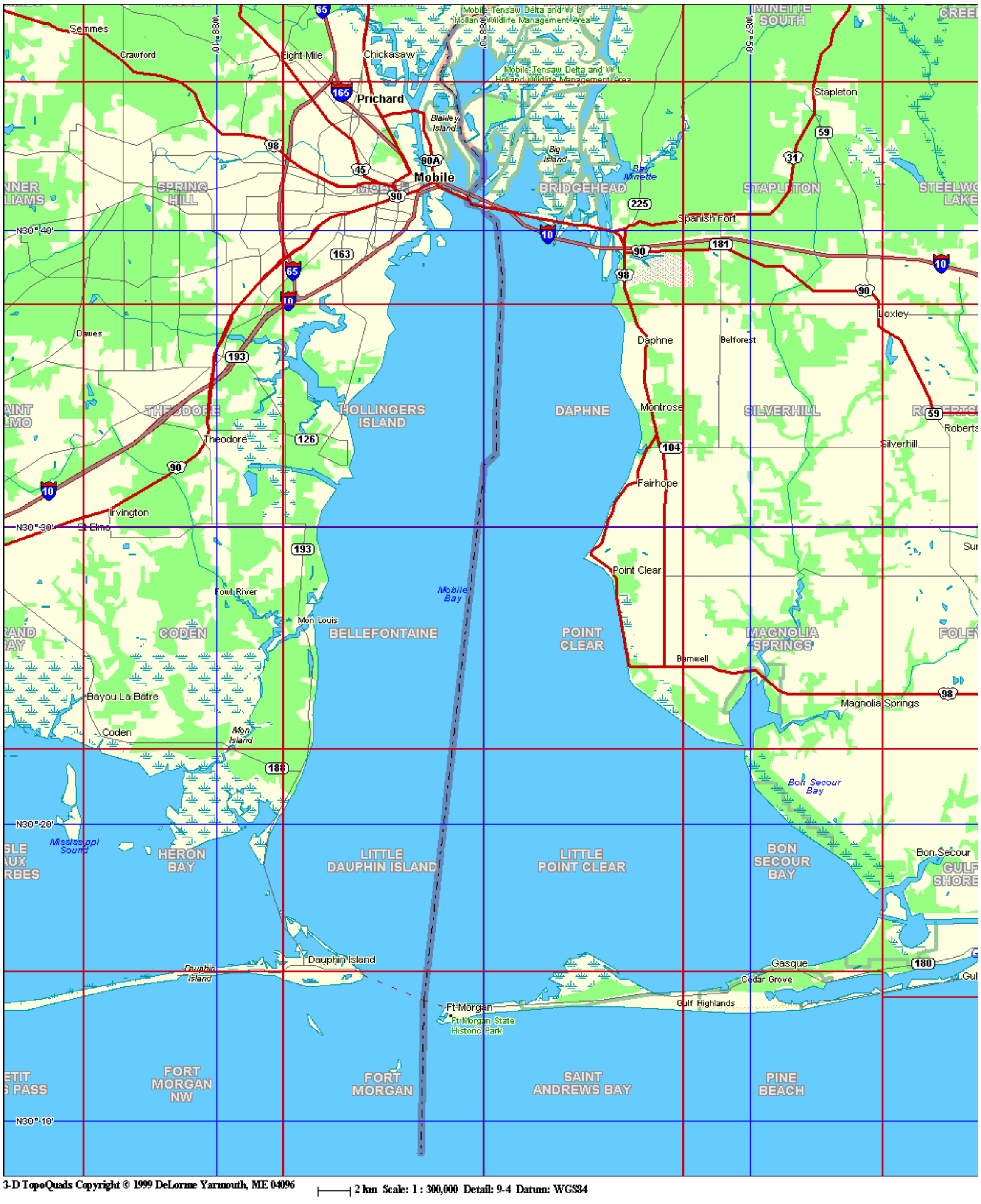

Figure 1-1 Mobile Bay Geographical Map

1.0 INTRODUCTION

This report is an update to previous work completed for the Alabama Department of Environmental Management (ADEM) and U.S. Environmental Protection Agency (EPA) Region 4. The EPA National Estuary Program (NEP) contracted Tetra Tech to update previously developed watershed and hydrodynamic models through 2011 with the most recent data and to provide a series of linked watershed, hydrodynamic, and water quality models to ADEM. These models will ultimately be used to make management decisions for Mobile Bay and are intended to be built upon based on agency needs.

2.0 STUDY AREA

Mobile Bay is located on the northern coast of the Gulf of Mexico (Fig. 1-1). It is 45 to 50 km long, with an average width of 17 km and an average depth of 3 meters. The surface area and volume of the bay, at mean high water, is calculated to be 1,058 km^2 and $3.2*10^9$ m^3, respectively. Geomorphologically, Mobile Bay is a combination of drowned river valley and bar-built estuary, which makes it a bathymetrically and hydrologically complex estuary. There are two openings in the lower part of the bay: one to the Gulf of Mexico, the other to the Mississippi Sound. A shipping channel 14 meters deep cuts through the Main Pass with the Gulf of Mexico to the Port of Mobile in the Mobile River. The Gulf Intercoastal Waterway also connects Mobile Bay with Perdido Bay to the east. The Mobile River system delivers 95 percent of the freshwater input to the bay. The average discharge of the system is about 1,512 m^3/s, but during winter through spring rainfalls it can exceed 9,000 m^3/s and during summer low-flow season decrease to 80 m^3/s.

The surface tides in Mobile Bay are predominantly diurnal with an average range of 0 to 20 cm; the maximum tidal range is of the order of 100 cm. Water temperatures range from highs of 20^o to 25^o C to a low of 6^o C (ice). The salinity regime of Mobile Bay encompasses direct, bay-wide influence of high salinity Gulf of Mexico waters during extended periods of low river discharge at one extreme to near dominance by freshwater under flooding conditions at the other extreme. Within the day, both the absolute values and salinity bottom-to-surface differences have been observed to change during a tidal cycle. Schroeder and Wiseman (1986) report that strong vertical stratification occurs under the following conditions:

1. Moderate to high river discharge and weak winds; and
2. Persistent southward-directed wind stress and low river discharge.

Mobile Bay's water quality is highly influenced by its natural geographic location, weather patterns of the watershed, and human uses. Human uses influencing water quality include expansion of the industrial complex within Alabama's coastal zone and increased commercial shipping, as a function of the growth of the Port of Mobile (e.g., use of the Tennessee-Tombigbee Waterway and the U.S. Navy Homeport development), as well as petroleum recovery enterprises, increased shoreline development, and recreational boating sewage disposal. The Mobile Bay drainage system is the nation's sixth largest in area and fourth largest in discharging volume. As a result, urban and agricultural development in the surrounding watershed and in areas far outside the coastal region, impact Mobile Bay's water quality characteristics.

Hypoxic and anoxic conditions are common in Mobile Bay and are generally prevalent during the summer months. These frequently stressed water quality conditions are marked by stratification with low dissolved oxygen. Specific to the bay environmental problems, is the 'Jubilee' (local name) phenomenon. The 'Jubilee' is the east shoreward movement of dense concentrations of fish and invertebrates observed in Mobile Bay since at least 1867, before any significant man-made environmental impact has been registered. Presumably this phenomenon associates with the formation and shoreward movement of a low oxygen zone. This persistent pattern of hypoxia occurs when winds blowing from the mainland drive surface waters from shore, causing deeper, poorly oxygenated water to move into the shallows.

The list of impaired waters created under section 303(d) of the 1972 Clean Water Act (CWA) includes parts of Mobile Bay impaired by organic enrichment/low DO and pathogens. CWA mandates an application of a Total Maximum Daily Load (TMDL) as a framework to scientifically understandable control of the sources of pollutants that impair water quality and create detrimental conditions for aquatic ecosystems. TMDLs provide a restoration plan designed to reduce the amount of pollution contributing to the degradation of biotic and abiotic components of aquatic ecosystems.

TMDLs are, by definition, the sum of the individual wasteload allocations for point and nonpoint sources and natural background with a margin of safety. The optimal solution of the wasteload allocation problem typically requires the application of mathematical models to estimate unknown loads, relate loads to target concentrations, and to evaluate implementation strategies to achieve water quality targets. The EPA directs and supports efforts of development, testing, and applications of special TMDL modeling tools. The EPA offers training on these tools and makes them available to partner states and other interested parties. The most recent TMDL Toolbox can be found on the EPA Region 4 website (http://www.epa.gov/athens/wwqtsc). It is a collection of standalone models for dynamic simulation of hydraulics, hydrodynamics and water quality in surface waters, including overland flow, streams, rivers, lakes, estuaries, coastal embayment and offshore. All of the models in the Toolbox have a proven record in TMDL determination.

Essential parts of the Toolbox are the watershed model LSPC (Loading Simulation Program C++), the hydrodynamic model Environmental Fluid Dynamics Code (EFDC) and Water Quality Analysis Simulation Program (WASP). The water quality model, WASP, applies nutrient enrichment, eutrophication, dissolved oxygen depletion, and fecal coliform organism dynamics. It enables the user to predict chlorophyll-a response, dissolved oxygen, and pathogen concentrations as a function of various loading and transport scenarios. The water circulation information is critically important for simulation of transport of water quality constituents. WASP has the option of adopting the hydrodynamic information from the output of the EFDC. EFDC is a modeling package used to simulate three-dimensional flow and transport in complex environments including rivers, estuaries, and offshore. The highly accurate transport scheme provides the capability to resolve sharp gradient problems that are typical of salinity regimes in shallow estuaries. The LSPC model provides watershed flows to EFDC and concentrations or loads to WASP.

The LSPC-EFDC-WASP models provide a versatile tool in predicting the response of water quality on changes in management practices and use as support in the development of wasteload allocations, TMDLs, and setting nutrient criteria for Mobile Bay.

Watershed and hydrodynamic modeling are decisive aspects in developing a water quality model for an estuary with the complex system of hydrological and meteorological factors influencing water dynamics. The failure to mimic the characteristic features of water circulation in the estuary most often is the main cause of failure in creating a dependable water quality model.

In 2003, a LSPC watershed model and three-dimensional hydrodynamic model were developed for Mobile Bay. Since that time more data has been collected by ADEM, U.S. Geological Survey (USGS), and other agencies. These more recent data have also been used to revise the previous modeling effort.

3.0 MODEL BACKGROUND

3.1 LSPC Watershed Model

The LSPC was used to develop a watershed model to represent the hydrological and water quality conditions in the watershed surrounding Mobile Bay. LSPC is a comprehensive data management and modeling system that is capable of representing loading, both flow and water quality, from point and non-point sources and simulating in-stream processes. It is a dynamic watershed model driven by time-variable weather input data and is capable of simulating flow, sediment, metals, nutrients, pesticides, and other conventional pollutants, as well as temperature and pH for pervious and impervious lands and waterbodies. LSPC was configured to simulate the watershed as a series of hydraulically connected sub-watersheds in which the model will estimate the surface water runoff and the advective transport of constituents. LSPC is based on the Mining Data Analysis System (MDAS), with modifications for non-mining applications such as nutrient and fecal coliform modeling. MDAS was developed by EPA Region 3 through mining TMDL applications.

The previously developed LSPC model was used to represent areas adjacent to the Mobile Bay. Areas of the Mobile River Delta were not included in the watershed modeling effort because of the uncertainty associated with transport and exchange between the Mobile and Tensaw Rivers. Instead major waterways in the Mobile Delta were simulated in EFDC to simulate waterway hydrodynamics and the transport of freshwater from upstream into Mobile Bay.

3.2 EFDC Hydrodynamic Model

The three-dimensional hydrodynamics of the Mobile Bay were modeled using EFDC. EFDC was applied with water surface elevation forcing at the Gulf of Mexico, to the west in the Mississippi Sound and to the east in Perdido Bay boundaries and freshwater inflows at the Mobile River just upstream of the Mobile-Tensaw split and various watersheds surrounding the bay including Chickasaw Creek. Water surface elevation, flows, currents, salinity, and temperature were previously simulated for 2003 through 2006 using EFDC. A newly updated model now extends the time period to 2011.

EFDC is a hydrodynamic modeling package for simulating one-dimensional, two-dimensional, and three-dimensional flow and transport in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands, and near-shore to shelf scale coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software (Hamrick, 1992).

The physics of the EFDC model, and many aspects of the computational scheme, are equivalent to the widely used Blumberg-Mellor model (Blumberg & Mellor, 1987) and the U.S. Army Corps of Engineers' CH3D or Chesapeake Bay model (Johnson, et al., 1993). The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are also solved. The two turbulence parameter transport equations implement the Mellor-Yamada level 2.5 turbulence closure scheme (Mellor & Yamada, 1982; Galperin et al., 1988).

The external mode solution is semi-implicit, and simultaneously computes the two-dimensional surface elevation field by a preconditioned conjugate gradient procedure. The external solution is completed by the calculation of the depth average barotropic velocities using the new surface elevation field. The model's semi-implicit external solution allows large time steps that are constrained only by the stability criteria of the explicit central difference, or high order upwind advection scheme (Smolarkiewicz and Margolin, 1993) used for the nonlinear accelerations. Horizontal boundary conditions for the external mode solution include options for simultaneously specifying the surface elevation only, the characteristic of an incoming wave (Bennett & McIntosh, 1982), free radiation of an outgoing wave (Bennett, 1976; Blumberg & Kantha, 1985) or the normal volumetric flux on arbitrary portions of the boundary.

The EFDC model's internal momentum equation solution, at the same time step as the external, is implicit with respect to vertical diffusion. The internal solution of the momentum equations is in terms of the vertical profile of shear stress and velocity shear, which results in the simplest and most accurate form of the baroclinic pressure gradients and eliminates the over-determined character of alternate internal mode formulations. Time splitting inherent in the three time level scheme is controlled by periodic insertion of a second order accurate two time level trapezoidal step.

3.3 WASP Water Quality Model

The Water Quality Analysis Simulation Program Version 7.4.1 (WASP7) is an enhanced Windows version of the EPA Water Quality Analysis Simulation Program (WASP) (Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988), with upgrades to the user's interface and the model's capabilities. The major upgrades to WASP have been the addition of multiple BOD components, addition of sediment diagenesis routines, and addition of periphyton routines. The hydrodynamic file generated by EFDC is compatible with WASP7 and it transfers segment volumes, velocities, temperature and salinity, as well as flows between segments. The time step is set in WASP7 based on the hydrodynamic simulation.

WASP7 helps users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions. WASP7 is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the basic program. Water quality processes are represented in special kinetic subroutines that are either chosen from a library or written by the user. WASP is structured to permit easy substitution of kinetic subroutines into the overall package to form problem-specific models. WASP7 comes with two such models, TOXI for toxicants and EUTRO for conventional water quality.

WASP7 was used to simulate water quality in Mobile Bay. This model was developed for use by EPA NEP and ADEM. As more data becomes available, this model can be continuously updated as updated to make management decisions. The assumptions, water quality parameters, and calibration methods used in previous efforts were used to develop this model.

4.0 MODEL DEVELOPMENT

The sections to follow describe data used in model development. The measured data used in this study were archived within the Water Resources Database (WRDB) platform as a project specific dataset. These data include effluent, flow, meteorological, tide, and water quality. As a part of the TMDL Toolbox the WRDB software is available to download for free at www.wrdb.com.

4.1 Meteorological Data

Meteorologic data collected for rainfall, air temperature, relative humidity, solar radiation, barometric pressure, wind speed, wind direction, and evaporation are essential parameters in watershed, hydrodynamic, and water quality modeling. In Mobile, Alabama the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) provides meteorology from both the Regional Airport (MOB) and the Downtown Airport (BFM). Air temperature and wind data are also collected at the Dauphin Island Sea Lab near the mouth of Mobile Bay. These data were used applied to the lower part of model domain while the wind speed and direction data from the Mobile Regional Airport station were applied to the upper part of the model domain. Other meteorological parameters were considered spatially uniform throughout the hydrodynamic model domain. Figure 4-1 shows the locations of the meteorological stations in Mobile Bay. These stations were combined for input into the series of LSPC-EFDC-WASP models developed for Mobile Bay.

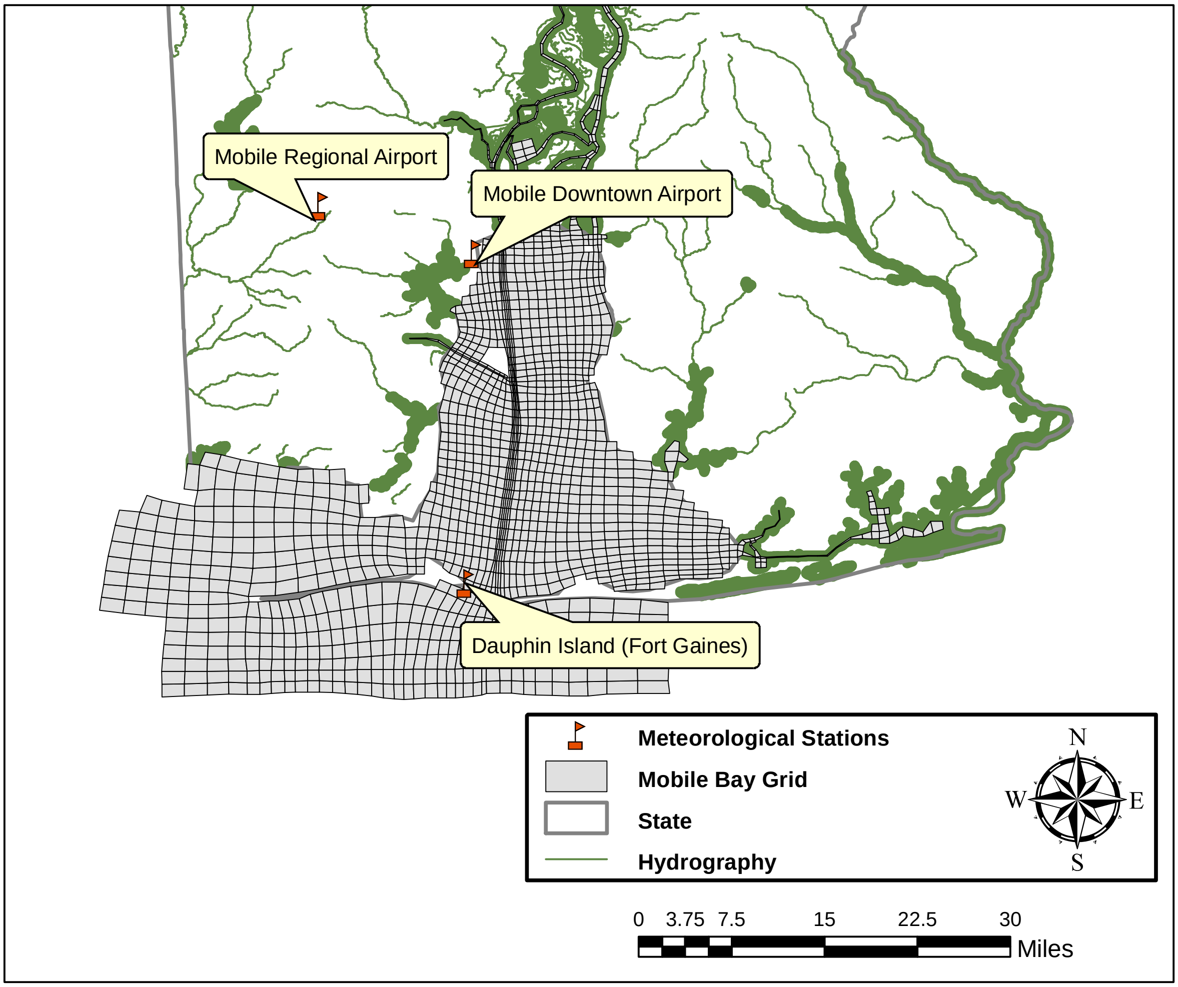

Figure 4-1 Locations of Meteorological Station

4.2 Watershed Conditions

In addition to meteorological data and hydrographic data of the watershed (the location of rivers and streams), topography and landuse information are also necessary to characterize watershed conditions. Previously developed subwatersheds delineated based on topography were used in this effort. Subwatersheds were delineated based on the size and shape of watersheds and to match the location of flow and water quality monitoring stations. Figure 4-2 illustrations the subwatersheds modeled in LSPC.

The topography data used to delineate watersheds was collected from the USGS National Elevation Dataset. USGS flow data was also used to calibrate watershed flows. Historic flow measured at several stations throughout the watershed were found and downloaded from the USGS website. These data include flow collected on Chickasaw Creek (02471001), Three Mile Creek (02471013), Fowl River (02471078), Fish River (02471078), and Magnolia River (02478300). The location of these stations is illustrated in Figure 4-2.

In updating the watershed model, three USGS stations were used to confirm model calibration from 2007 through 2011; Chickasaw Creek (02471001), Fish River (02471078), and Magnolia River (02478300). These USGS stations were not influenced by tides from Mobile Bay to represent freshwater flows. These stations represent the diversity of landuse, vegetation, and soils in the watershed. Landuse data from previous model efforts was updated to data from 2006 available from the USGS National Land Cover Dataset. Table 4-1 presents the watershed area and period of record for each of these three USGS flow stations. Appendix A presents the flow calibration.

In the watershed modeling effort rainfall and temperature data collected at the Mobile Regional Airport (MOB) were found to most accurately represent conditions in the watershed. Given the available data and the use of input parameters from previous modeling efforts, the final watershed hydrology calibration was found to adequately represent low flows and the rising and recession limbs of storm events. These flows were used as inputs to the Mobile Bay EFDC hydrodynamic model.

Flows and water quality conditions from the watershed are also influenced by point sources. Facilities included in the watershed model are listed in Table 4-2. Discharge monitoring reports (DMRs) for these facilities, and those included in the EFDC and WASP models, were provided by ADEM. These data were archived in WRDB.

ADEM presently collects data at several ambient monitoring sites throughout Mobile Bay; however, few of these stations are in areas not influenced by tidal action. To quantify the contribution of land use activities from the watersheds surrounding Mobile Bay it is important that locations outside the tidal influence are examined. Four sites were found in the watershed with water quality data collected between 2003 and 2011 for BOD5, total nitrogen (or TKN and NH3), total phosphorus, and dissolved oxygen; Station DR1+21AWIC at Dog River, Station TM1+21AWIC at Three Mile Creek, Stations WB1+21AWIC at Weeks Bay, and WO1A+21AWIC at Wolf Bay.

Like hydrology, LSPC has been applied in previous modeling efforts to watersheds surrounding Mobile Bay to establish nutrient loads. Given the limited data available, parameters used in a previous modeling effort were applied to the LSPC model and run from 2003 through 2011. Modeled concentrations for BOD5, total nitrogen, and total phosphorus were validated using the above stations. These calibration results are presented in Appendix B. Watershed loads were ultimately used as inputs to the Mobile Bay WASP water quality model.

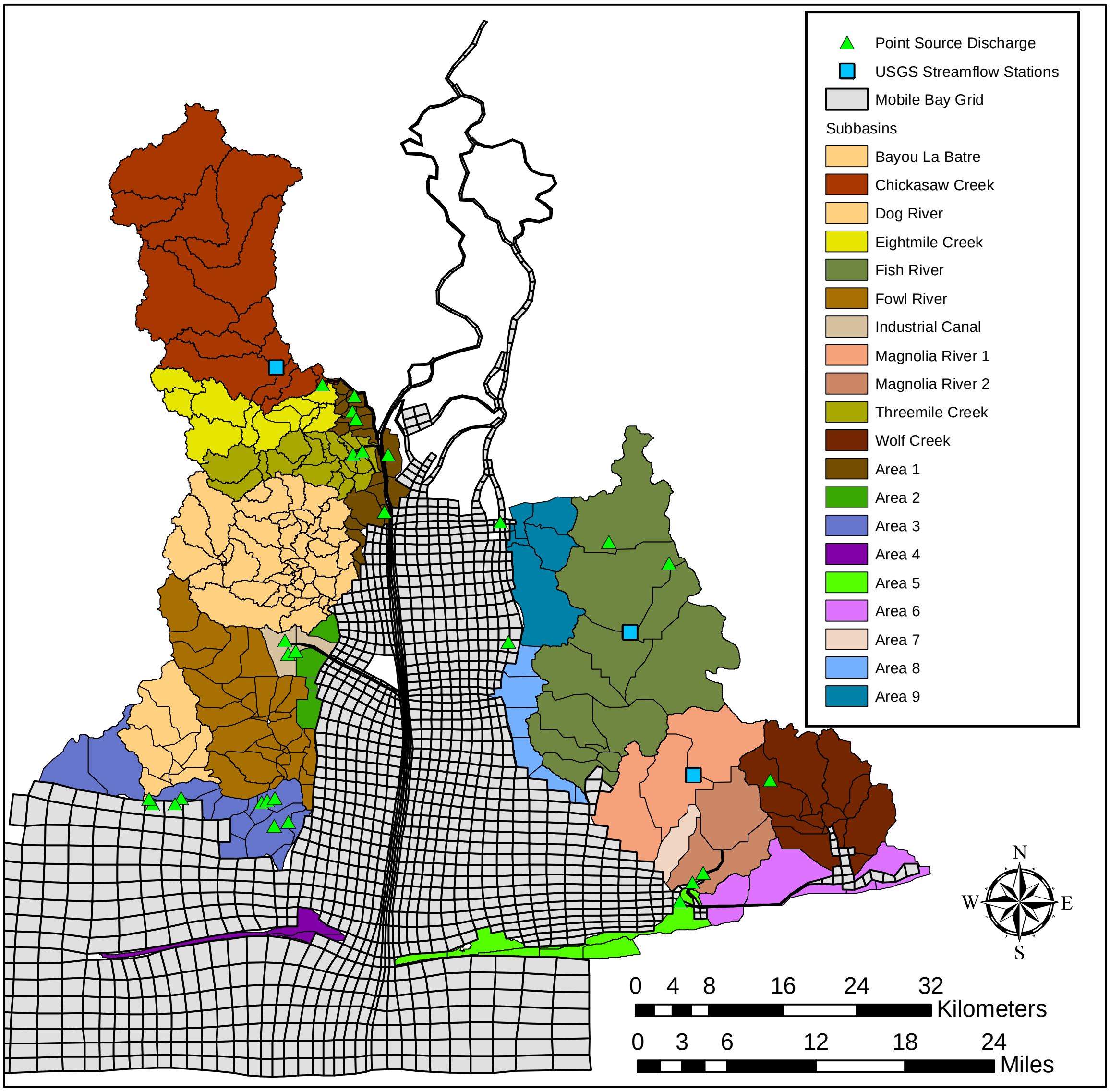

Figure 4-2 Mobile Bay Surrounding Watersheds Simulated with LSPC

Table 4-1 Landuse Activities for Subwatersheds Discharging to USGS Stations

Station ID	**02378300**	**02378500**	**02471001**
Station Description	Magnolia River at US 98	Fish River near Silver Hill	Chickasaw Creek near Kushla, AL
Watershed Area (km^2/mi^2)	135.1/52.2	146.6/56.6	319.2/123.3
Period of Record	2007-2012	2007-2009	2007-2012
2011 Landuse			
All Other Impervious	0.01%	0.00%	0.00%
Barren	0.24%	0.41%	0.10%
Crop	35.72%	20.12%	0.41%
Forest	12.49%	35.26%	73.35%
Beach	0.00%	0.00%	0.00%
Grassland	3.79%	7.50%	5.69%
High Development Impervious	0.06%	0.29%	0.00%
High Development Pervious	0.01%	0.05%	0.00%
Low Development Impervious	0.68%	0.83%	0.13%
Low Development Pervious	9.04%	10.10%	3.35%
Medium Development Impervious	0.20%	0.46%	0.03%
Medium Development Pervious	0.17%	0.39%	0.02%
Pasture	17.38%	11.63%	2.10%
Water	1.15%	0.03%	0.23%
Wetlands	19.07%	12.92%	14.58%

Table 4-3 Watershed Point Sources

NPDES PERMIT	FACILITY	AVERAGE DISCHARGE (MGD)
AL0002666	UOP Molecular Sieve Plant	1.36
AL0002976	Mud Lakes (Port Authority)	0.50
AL0003298	Bon Secour Fisheries LLC	0.07
AL0003514	Occindental Chemical	0.07
AL0020842	Fairhope WWTP	1.80
AL0020885	Chickasaw Lagoon	0.72
AL0022632	Bayou La Batre WWTP / Industrial Board	0.50
AL0023086	Clifton C Williams WWTP	22.40
AL0023094	Wright Smith WWTP	9.50
AL0023205	Carlos A Morris WWTP	2.41
AL0023272	Degussa Evonik	1.65
AL0026328	Tronox LLC	0.31
AL0027561	Daphne Water Reclaimation Facility	2.49
AL0042234	Spanish Fort Sewer WWTP	0.56
AL0048194	Carson & CO INC	0.27
AL0049042	Foley WWTP	1.2700
AL0055204	Stanley Brooks	0.71
AL0055379	Bayou La Batre Utilities Board	0.14
AL0055441	Coast Seafood INC	0.0033
AL0057941	Donald Johnson Seafood	0.0010
AL0058530	Captain Collier Seafood	0.0030
AL0060283	Loxley WWTP	0.25
AL0062511	Southern Crabshell CO	0.0010
AL0063142	H & M Seafood	0.0002
AL0064335	Miller Johnson Seafood	0.0002
AL0068497	Billy's Seafood	0.017
AL0070220	Zirlotts Gulf Products	0.0002
AL0072290	Alabama Power Theodore Cogeneration Plant	0.18

4.3 Bathymetry and Grid Development

Accurate bathymetry is important to adequately predict salinity intrusion particularly through the shipping channel and overall circulation patterns in the bay. Bathymetry data were obtained from the National Geophysical Data Center. The bathymetry used in Mobile Bay and its adjacent waterbodies (Gulf Intercoastal Waterway to Perdido Bay and a portion of the Mississippi Sound) is presented in Figure 4-3. The Mobile River Delta bathymetry was assembled with very limited data. The accuracy of bathymetry was checked against known bottom elevations in the Mobile Bay navigation channel (14 meter depth) and the Gulf Intercoastal Waterway.

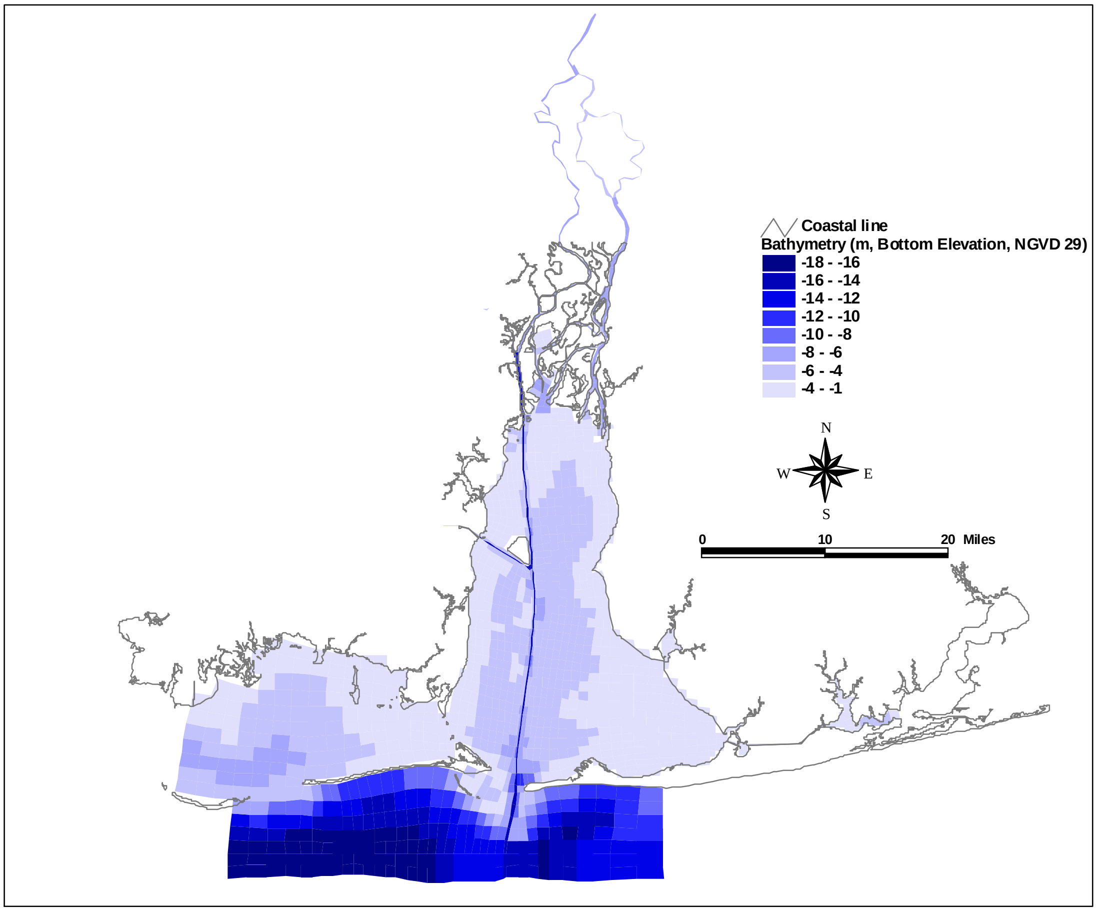

Figure 4-3 Mobile Bay Bathymetry

The Mobile Bay, Mobile River Delta, modeled portion of Mississippi Sound, and Gulf Intracoastal Waterway to Perdido Bay were segmented into curvilinear orthogonal computational grid cells representing horizontal dimension for the hydrodynamic and water quality model. As shown in Figure 4-3, most of the water body in the bay is shallow with a depth of 2 to 6 meters. The shipping channel, however, is maintained to a depth of 14 meters. Therefore, to better simulate the hydrodynamics of the system, a Z (or hybrid) grid was used. This grid allows for varying horizontal layers to allow for more layers in deeper portions of the bay. The model grid was designed with four layers in the navigation channel and 1 to 3 layers in the shallower areas. The modeled area was segmented into 1758 horizontal grid cells (Figure 4-3).

4.4 Conditions in Mobile Bay

As previously described LSPC flows and loads from the watershed surrounding Mobile Bay were input to EFDC and WASP. This section describes conditions in Mobile Bay and other data used as inputs directly to the EFDC hydrodynamic model and the WASP water quality model. Water surface elevation, salinity, and water temperature were utilized in the development of the EFDC hydrodynamic boundary conditions and for the purpose of model calibration. Biochemical oxygen demand (5-day), total nitrogen, total phosphorus, total suspended solids, chlorophyll-a, dissolved oxygen, ammonia, organic phosphorus, nitrogen oxide, organic nitrogen and phosphate concentrations and loads were utilized in the development of the WASP water quality boundary conditions. Data provided to ADEM from discharge monitoring reports, and assumptions made by ADEM when data were not provided, were used to represent point sources that discharge directly to Mobile Bay.

In 2002, after Tetra Tech completed a calibrated EFDC and WASP model for the EPA Region 4 from a 1992 dataset, there were several deficiencies defined in the calibration data, such as minimal salinity data in the navigation channel, lack of dissolved oxygen data in the channel, and the need to recognize adjacent areas of the bay. To characterize the bay better and provide sufficient calibration datasets, Tetra Tech consulted with ADEM and EPA Region 4 to come up with a monitoring plan. Salinity, temperature, dissolved oxygen, and nutrients throughout Mobile Bay were collected from 2003 through 2006. Since that time, additional data has been collected by a number of agencies including ADEM to provide more data to generate a more in depth and long term water quality model.

4.4.1 Hydrodynamic boundary conditions

Prior to the 2003 monitoring effort assumptions were being made about the distribution of flows between the Mobile and Tensaw Rivers. These measured upstream flows are a critical component of hydrodynamics in Mobile Bay. Freshwater flows down the Mobile River (from the Tombigbee and Alabama Rivers) represent 94% of the freshwater inputs to Mobile Bay.

In 2003, the USGS added a stream flow station to Mobile River at Bucks (02470629). This station was added and partially funded by ADEM to support future modeling efforts in Mobile Bay. Data from the Mobile River station at Bucks (02470629) were received from the USGS and used in modeling. Flow measured at Coffeeville on the Tombigbee River (02469761) and at Claiborne on the Alabama River (02428400) were also received and used as inputs to the most upstream boundary of the EFDC model.

The Mobile River discharges are computed using USGS flows from the Tombigbee River at Coffeeville (02469761), Alabama, and from the Alabama River at Claiborne (02428400), Alabama. In accordance with the widely accepted approach of Schroeder (1978) to calculate the discharge of the system, the flows at these two gaging stations are added together and multiplied by 1.07. Because of the distance (~125,300 meters) between Mobile Bay and these gaging stations, a lag period for transit time is about 2 to 4 days.

Figure 4-5 presents the dynamics of freshwater discharge into Mobile Bay from 2003 through 2011 that was chosen for the EFDC calibration.

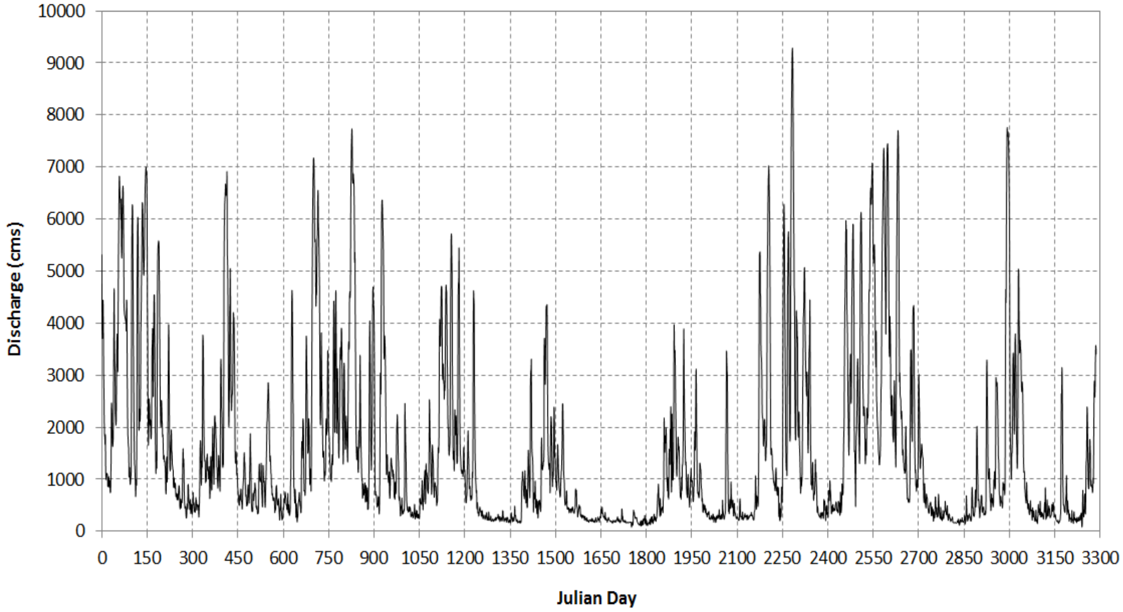

Figure 4-5 Combined Discharges from Coffeeville (02469761) and Claiborne (02428400) Stations

The boundary at the mouth of Mobile Bay is represented by tidal or water surface elevation. Water surface elevation data were not available as direct measurements in the Gulf of Mexico at the extent of our model boundary or from the east and west model boundaries in the Mississippi Sound and Perdido Bay for the modeled period. In order to generate the water surface elevation boundary forcing conditions, NOAA water surface elevation measurements at Dauphin Island, AL (Fig. 4-6) were utilized as the initial values for the south, west, and east boundaries. Values at the south offshore boundary were then calibrated by adjusting amplitudes and phasing to achieve the best comparison with measured data at Dauphin Island. For the east boundary at Perdido Bay, values were calibrated by adjusting amplitudes to achieve the net westward flow in the Gulf Intercoastal Waterway. Previous work documented this flow equal to ~ 1000 cfs (ADEM, 1983), but data collected by ADEM during neap and spring tides in 2007 measured average flows between 2,500 and 3,500 cfs.

It should be also noted that the two abnormally high tides were associated with two hurricanes, Ivan and Katrina, that occurred around September 15, 2004 (Julian day 623) and August 29, 2005 (Julian day 971), respectively (Figure 4-6). Other spikes in water surface elevation are due to smaller hurricanes that occurred around that time.

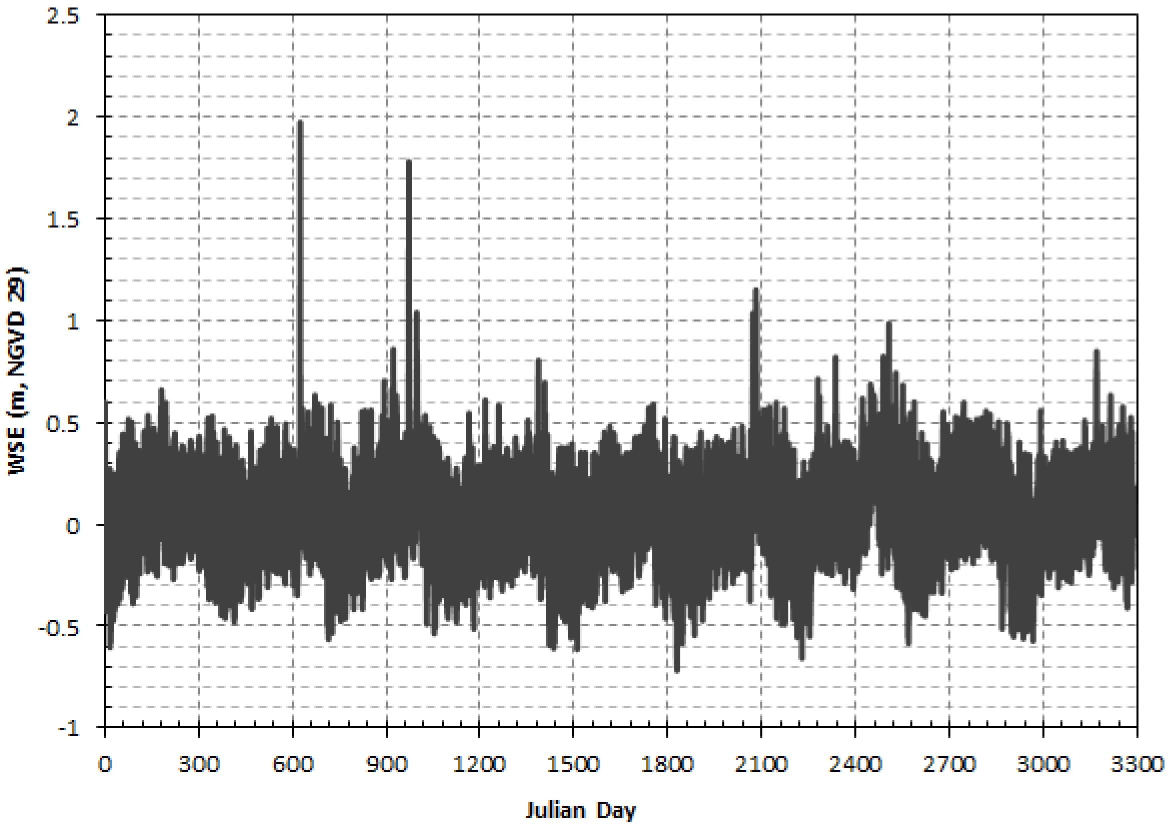

Figure 4-6 Hourly Water Surface Elevations at Dauphin Island, AL

Direct measurements of salinity and water temperature at the boundaries were not available. Initially, different constant salinity values assigned to the offshore open boundaries, i.e., west, south, and east boundaries, were adjusted during the model calibration such that overall better agreement between the simulated and measured salinity at various stations was achieved. The water temperature measured in the Mobile Shipping Channel at station (MB-2A+21AWIC) was applied to the Main South open boundary. Figure 4-7 shows the water temperature data collected by ADEM in the Mobile Shipping Channel from 2006 to the end of 2008. Due to the lack of data, the trend curve seen in Figure 4-7 was copied for the portion of years missing data, namely from 2003 to the end of 2005 and from 2009 to the end of 2011. Figure 4-8 shows how this process provides a sufficient trend curve for the open boundary in the open channel.

The salinity value was set to 0 for all upstream river flows from Mobile River, Chicksaw Creek, Three Mile Creek, etc. and watershed flows. Because no water temperature data were measured at Coffeeville on the Tombigbee River (02469761) and at Claiborne on the Alabama River (02428400) from 2003 to 2011, other stations along the Mobile River (MOBM-1+21AWIC, MO1A+21AWIC, and MO2+21AWIC) with water temperature measurements were gathered and complied to meet this need.

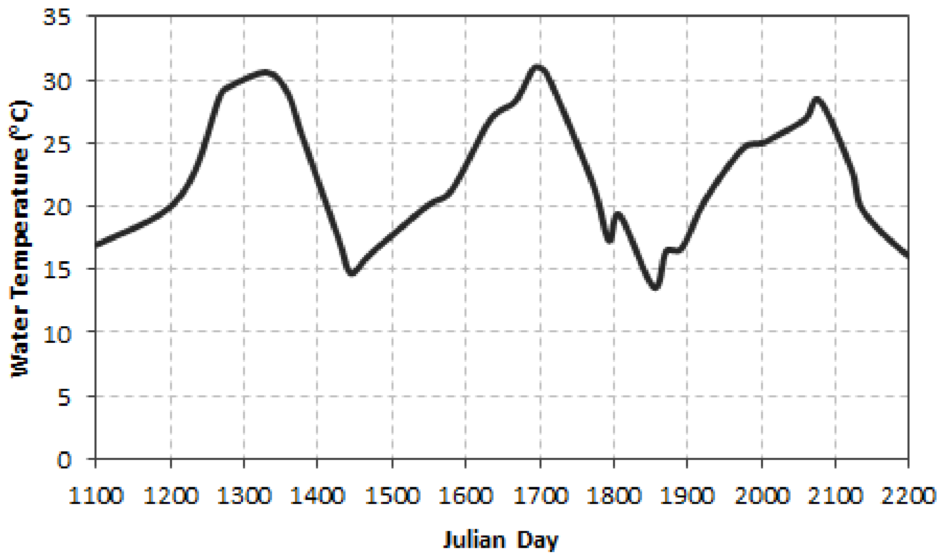

Figure 4-7 Water Temperatures at Mobile Shipping Channel (MB-2A+21AWIC)

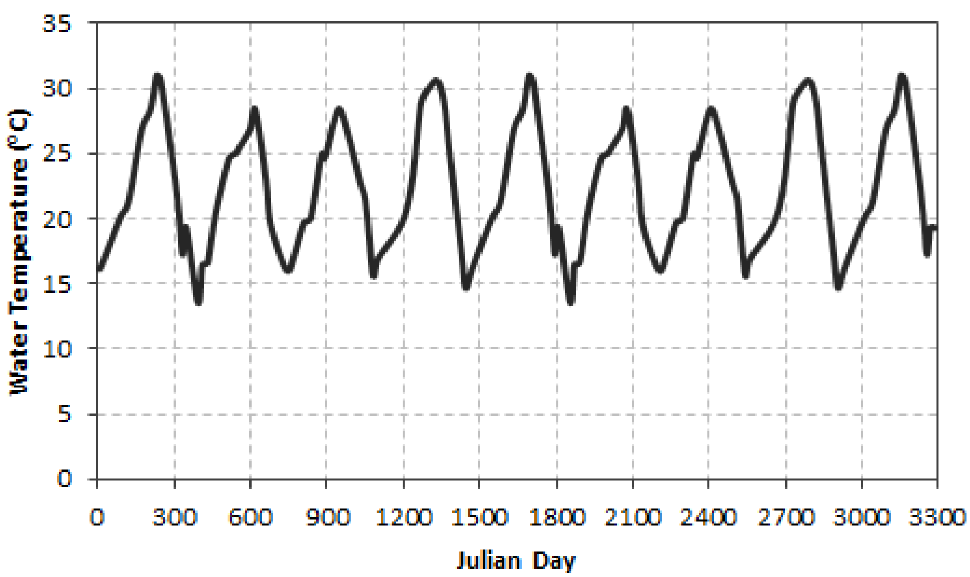

Figure 4-8 Water Temperature Used in the EFDC Model for the Mobile Shipping Channel

Comparisons of the EFDC model with measured data are presented in Appendix C. Results of water surface elevation simulations from 2003 to 2011, along with the measurements at the Dauphin Island station are presented in Figure C-1 in Appendix C. As shown in the figure, the simulated water surface elevations match the measured reasonable well across the entire time period. Only one amplitude multiple factor and a phase time shift value were used to adjust the water surface elevations at the south offshore boundary, and water surface elevations at the Dauphin Island station. This was initially used for the south offshore boundary. The south offshore boundary is not linearly correlated, therefore, it was not expected that the simulated water surface elevations at Dauphin Island would match the measured well for the whole calibration period unless a set of measured water surface elevation data at the boundaries was applied in the model simulation.

The calibration of salinity and water temperature are shown in Figures C-6 to C-16.

All the figures shown in Appendix C depict that the hydrodynamic model well predicts the hydrodynamic actions as well as salinity and temperature values within Mobile Bay.

4.4.2 Water quality boundary conditions

For WASP, biochemical oxygen demand, total nitrogen, total phosphorus, total suspended solids, chlorophyll-a, dissolved oxygen, ammonia, nitrate, organic nitrogen, phosphate, and organic phosphorus were modeled. A concentration or loading of the parameters listed had to be assigned to each model input (Mobile River, surrounding watersheds, the Gulf of Mexico, Mississippi Sound and Perdido Bay) to create a boundary condition. A concentration is simply the mass the nutrient per volume of water. A loading is the mass of nutrient constituent times the volume of water. Since WASP processes both concentrations and loads, each input had to be assigned either a concentration value or a loading value. When considering certain flows, the WASP boundary conditions were entered as concentrations and the load values were recorded as zero. This was done since WASP takes into account the flows inserted into the EFDC model and multiplies them by the boundary concentrations entered into WASP. For all of the other inputs processed where flows and concentrations had to be aggregated (the watersheds surrounding Mobile Bay), the WASP boundary conditions were entered as loads. This was mostly applied to input coming from LSPC since the flows and nutrients are automatically aggregated and multiplied together through LSPC, which is then used as a loading input in WASP.

4.4.3 Point Sources

A total of 10 industrial and 4 municipal dischargers were considered in the EFDC model. Both flow and temperature data were input to the model simulation. Figure 4-9 shows the locations of all point source discharger considered in the hydrodynamic model.

Discharge monitoring reports were provided by ADEM. ADEM generally provided monthly data for flow and nutrients as required by their permits. If monthly data were not provided, permit values were used.

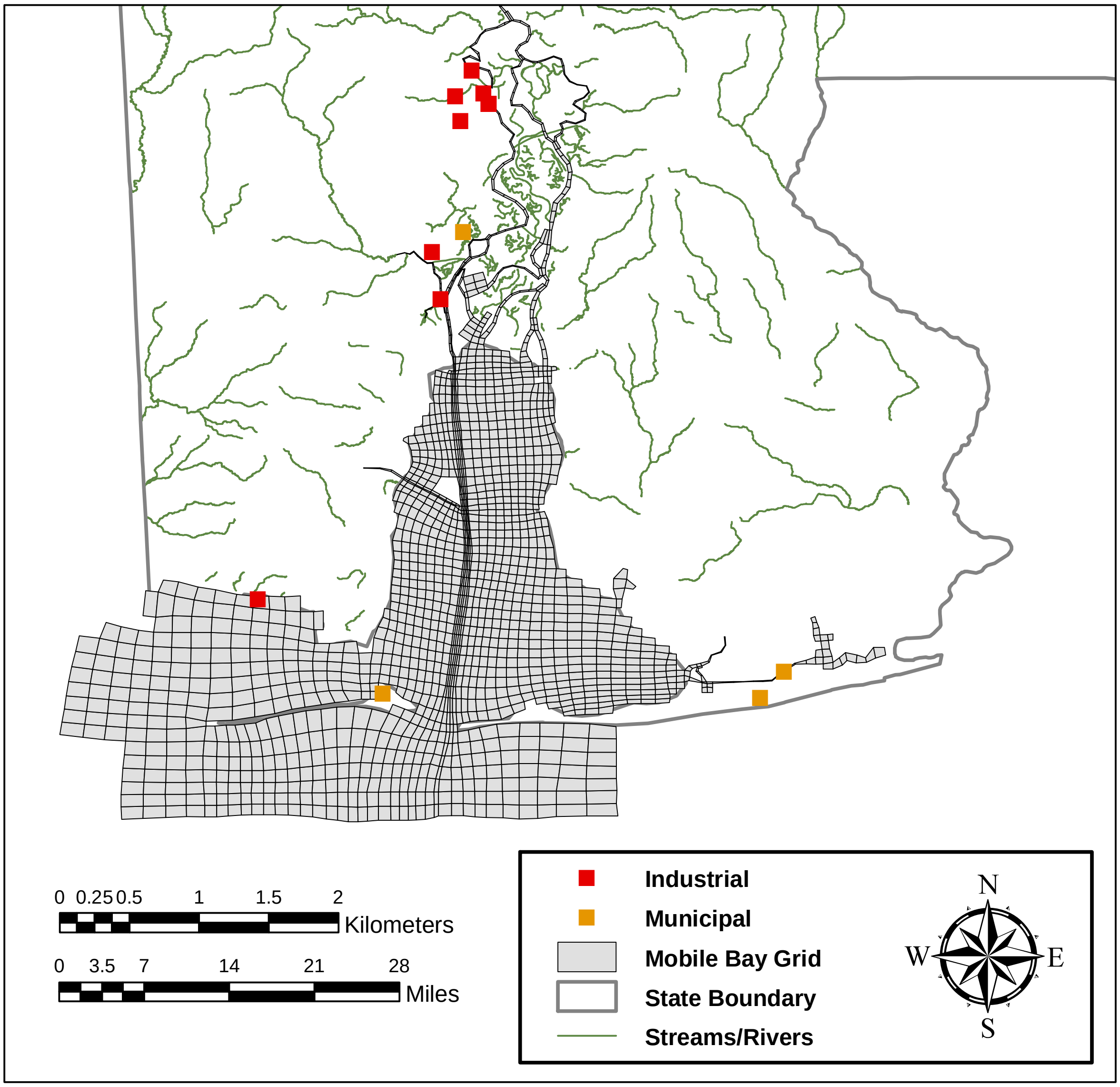

Figure 4-9 Locations of Point Source Dischargers

5.0 Summary and Conclusions

The Mobile Bay NEP requested that Tetra Tech take the existing LSPC, EFDC, and WASP models that has been applied to the Mobile Bay watershed and waterbody and update the models through 2011. In addition to data gathered from USGS, NOAA, and Mobile NEP, ADEM provided measured data and discharge monitoring reports from municipal and industrial point sources and water withdrawal rates to Tetra Tech. Tetra Tech used these data to update an existing LSPC model through December 2011. In addition to updating point source information, the model landuse was updated to 2006 NLCD and the LSPC model code was updated to the most recent version that allows calibration of instream water quality dynamics. Tetra Tech also updated the existing EFDC hydrodynamic model through December 2011. This included extending the upstream flow boundary (USGS gage 02428400 on the Alabama River and the USGS gage 02469761 on the Tombigbee River), the open boundary (water surface elevation and salinity), and point sources and water withdrawals with the most recent available data. A hydrodynamic linkage file was generated for 2006 through 2011 for use in the WASP water quality model.
Tetra Tech built a WASP water quality model for the period from January 2006 through December 2011 using inputs from the watershed and hydrodynamic models and data provided by ADEM.

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APPENDIX A – Watershed Hydrology Calibration

Figure B-1 Magnolia River at US 98 (USGS 02378300) LSPC Hydrology Calibration for Water Year 2003

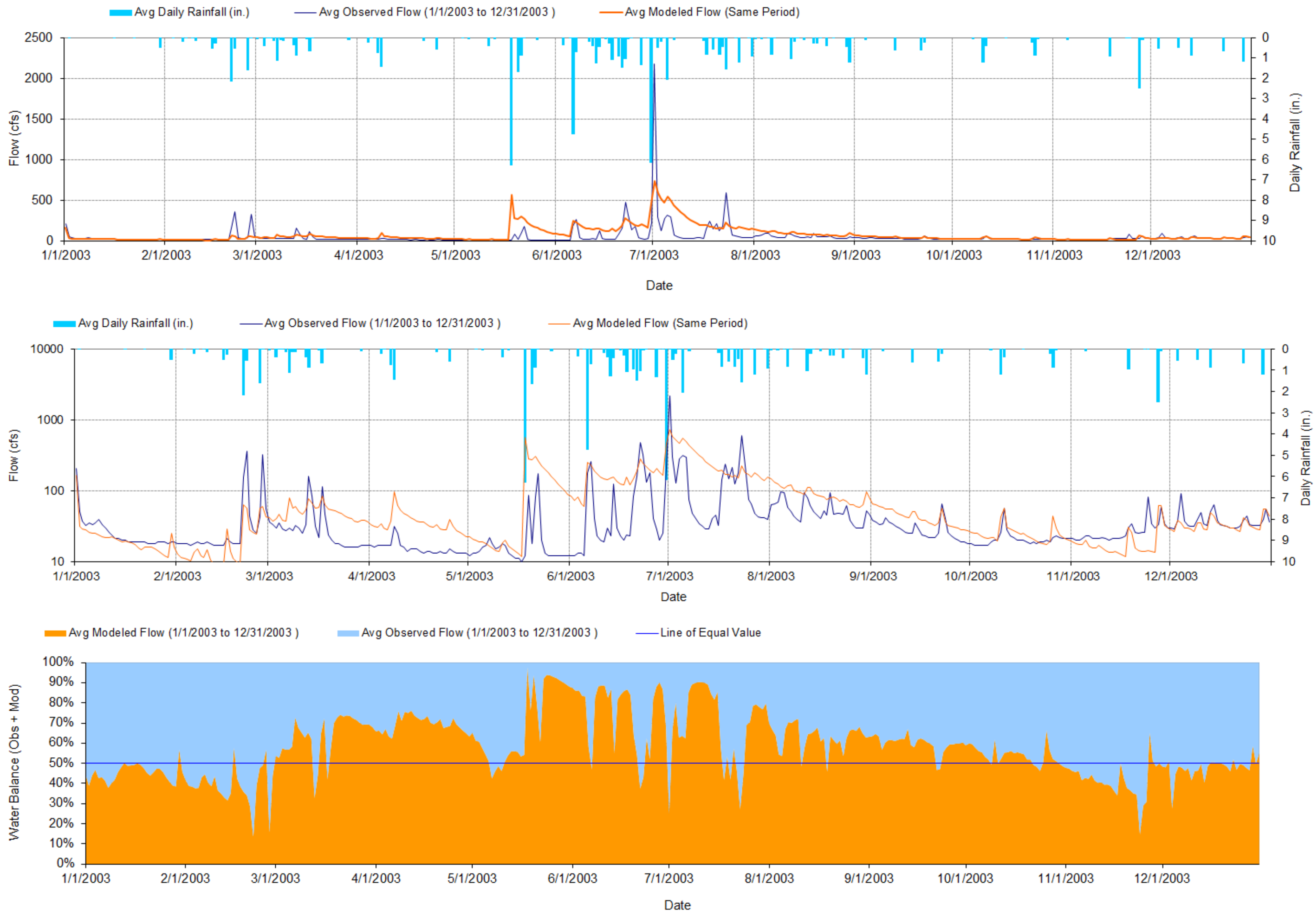


Figure A-2 Magnolia River at US 98 (USGS 02378300) LSPC Hydrology Calibration for Water Year 2004

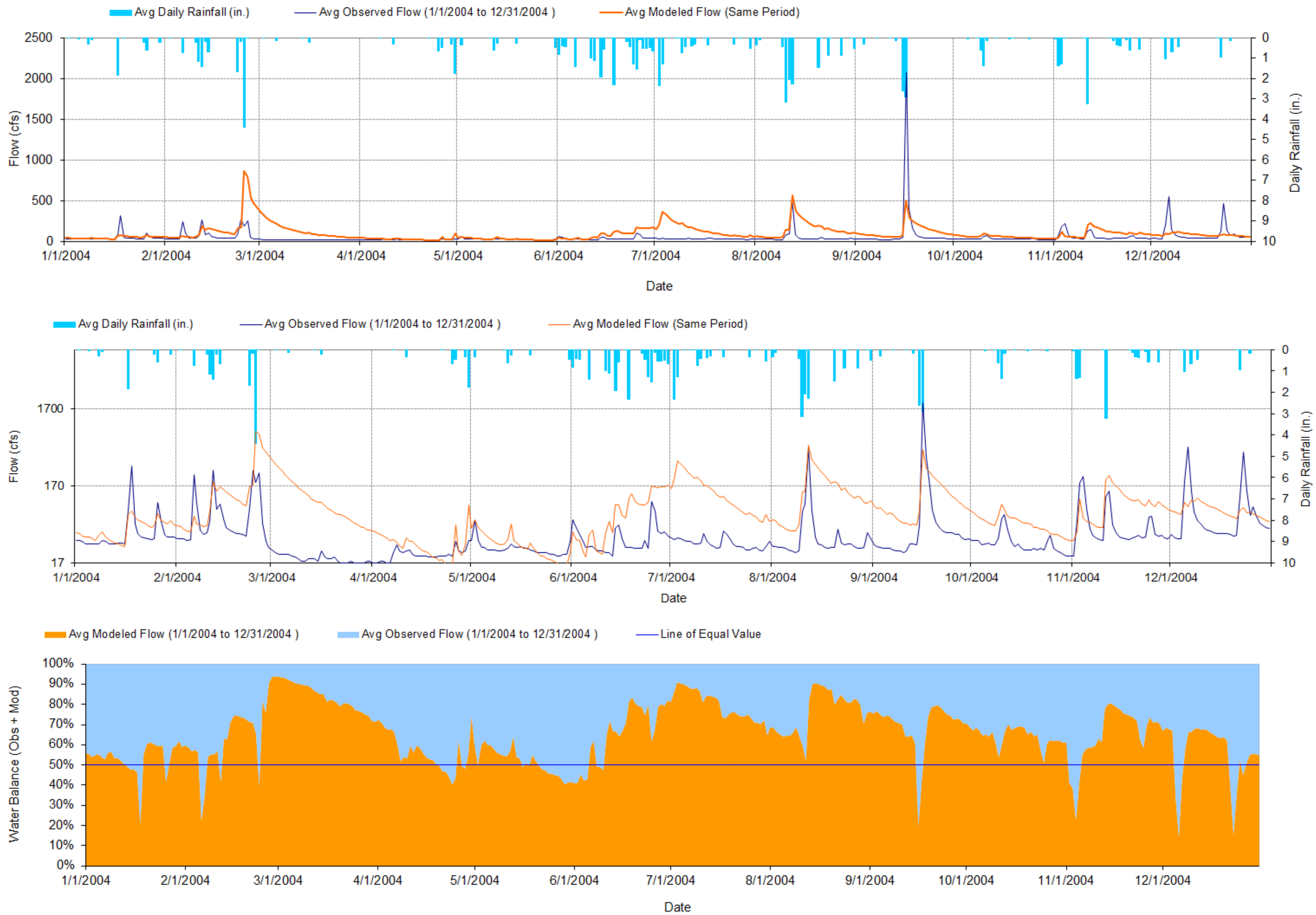


Figure A-3 Magnolia River at US 98 (USGS 02378300) LSPC Hydrology Calibration for Water Year 2005

Figure A-4 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2003

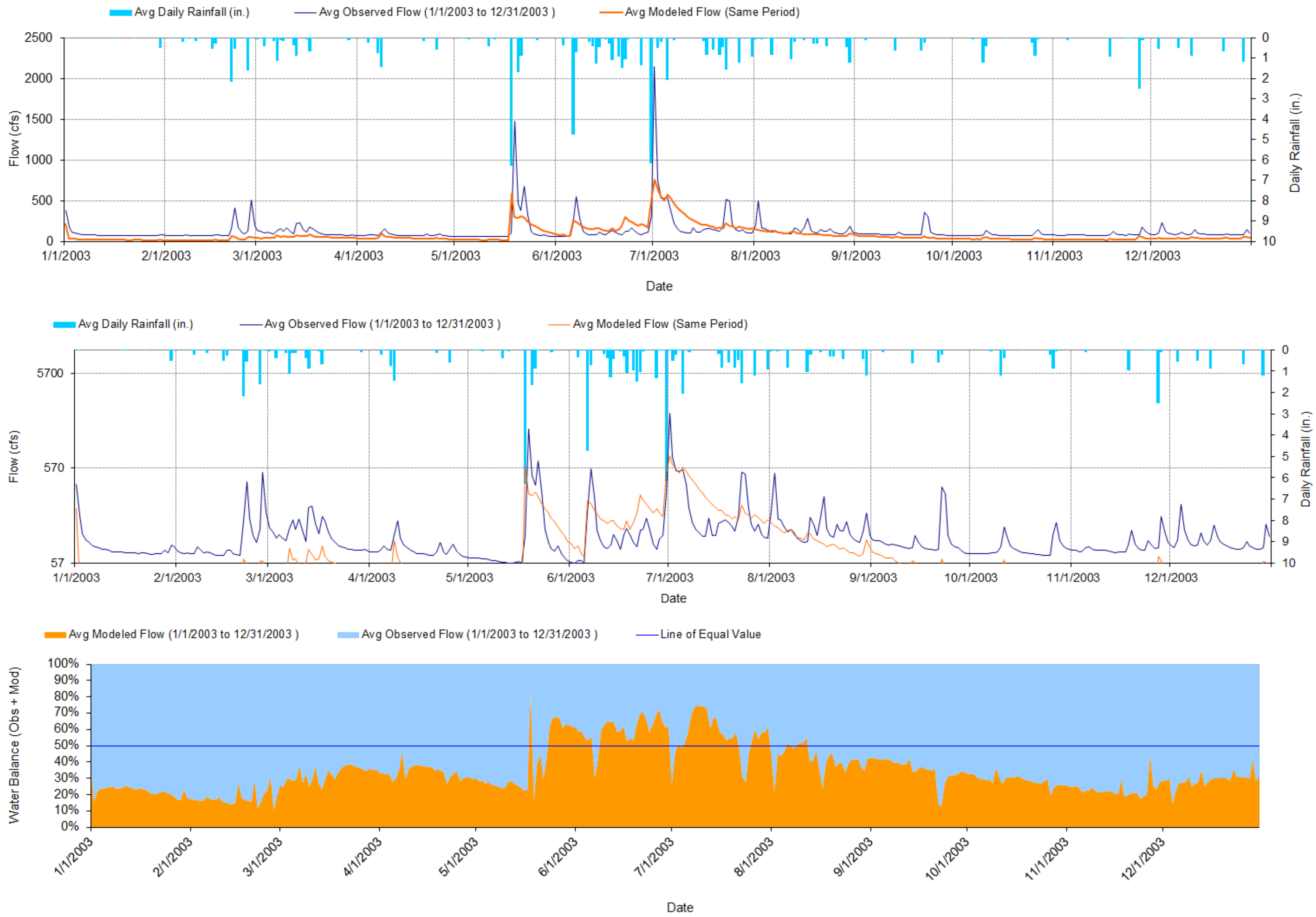


Figure A-5 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2004

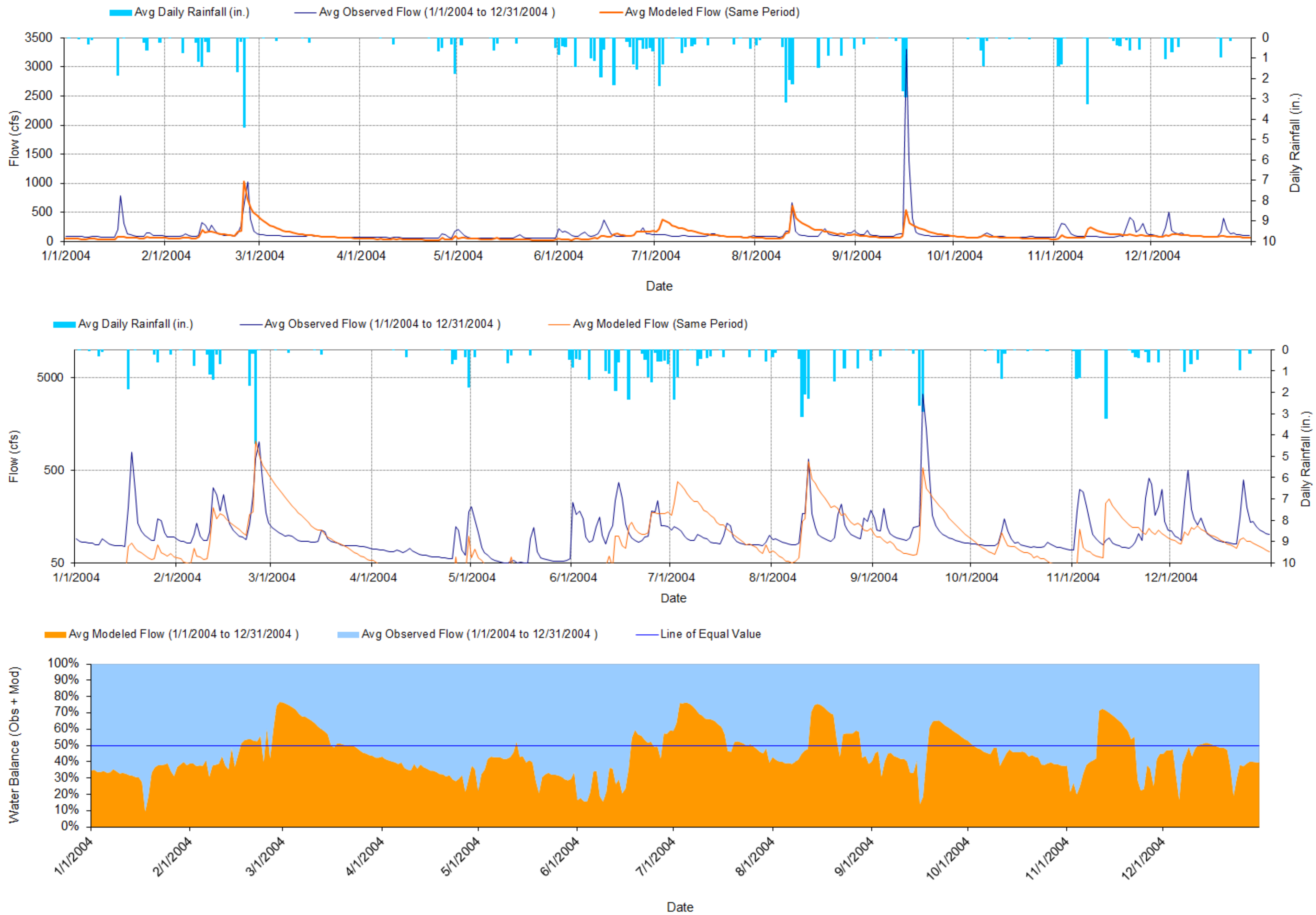


Figure A-6 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2005

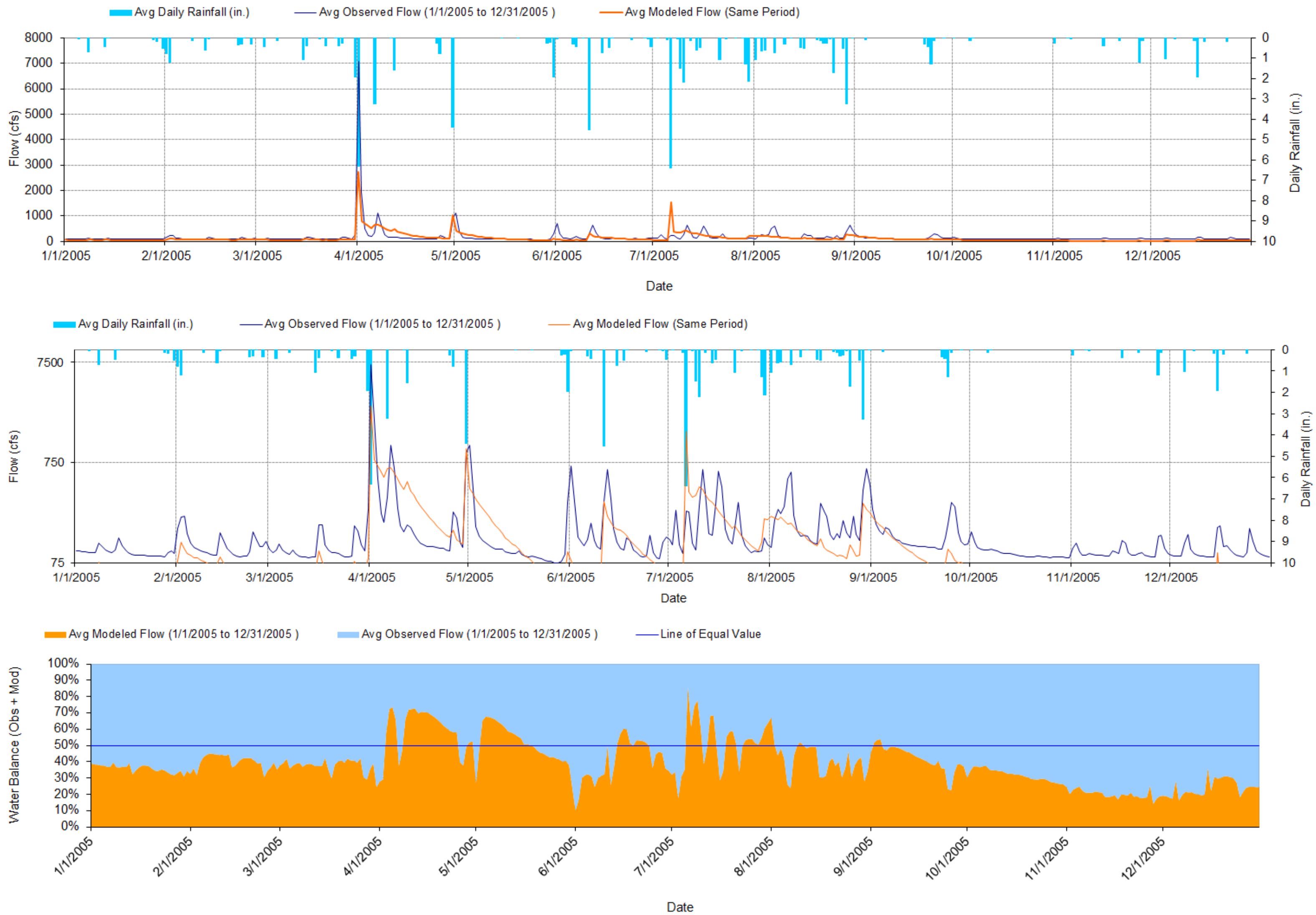


Figure A-7 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2006

Figure A-8 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2007

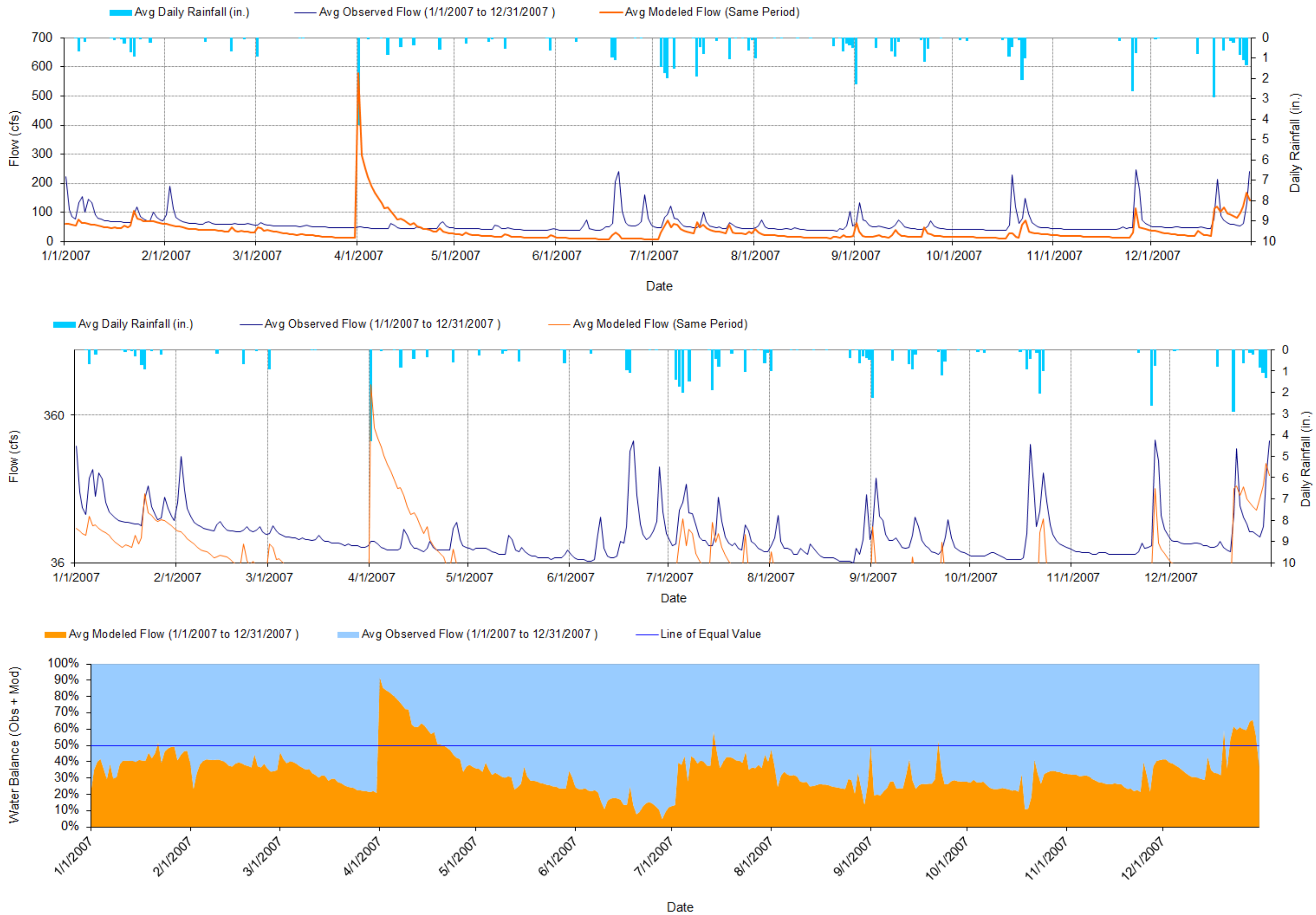
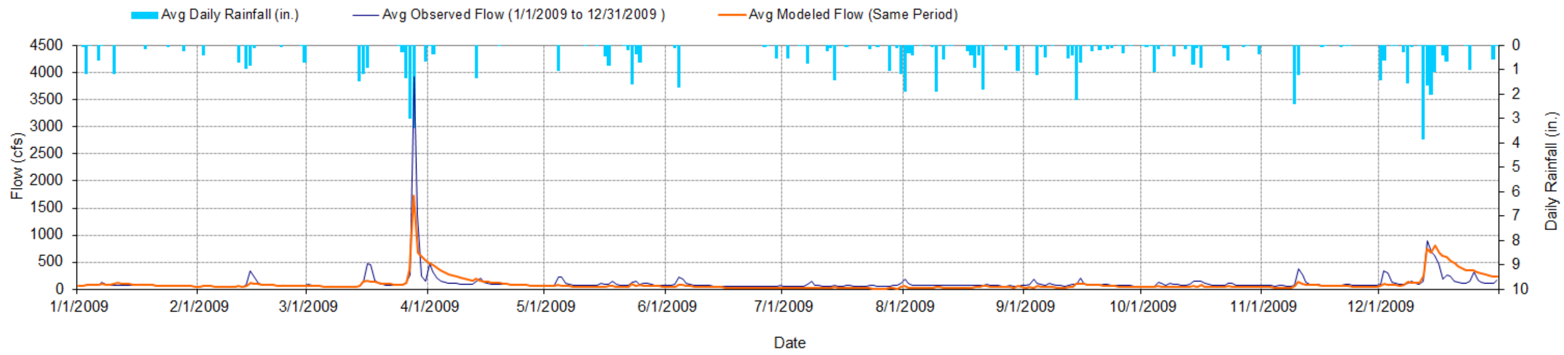
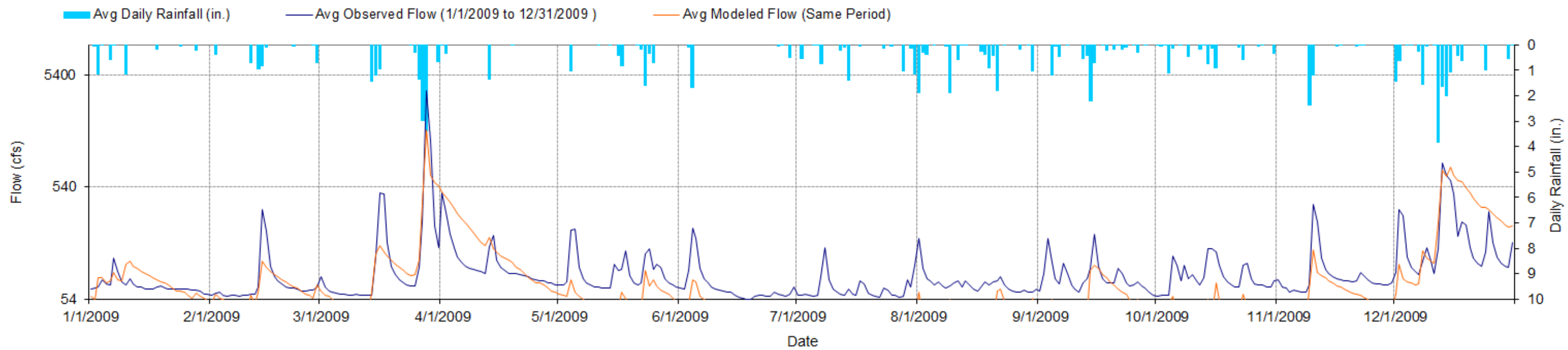


Figure A-9 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2008

Figure A-10 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2009





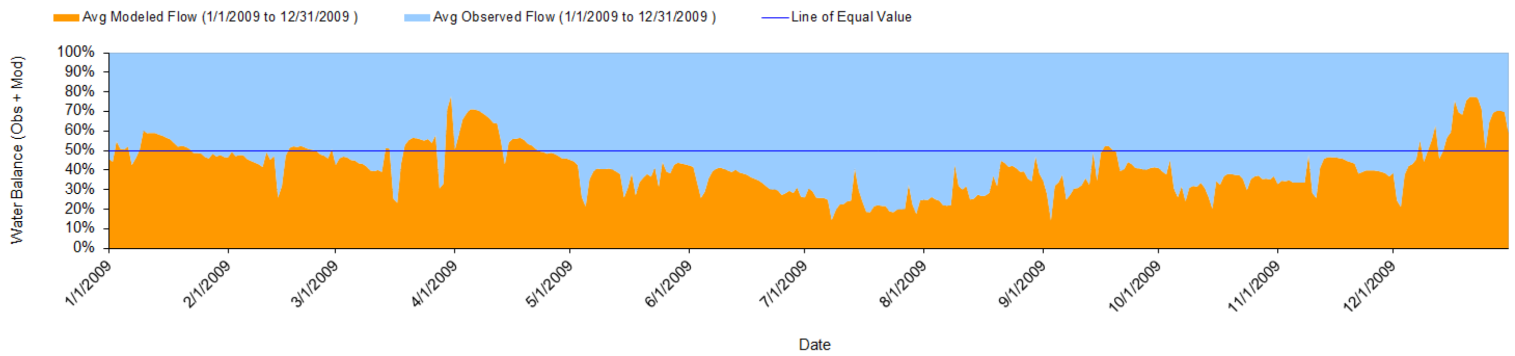


Figure A-11 Fish River (USGS 02378500) LSPC Hydrology Calibration for Water Year 2010

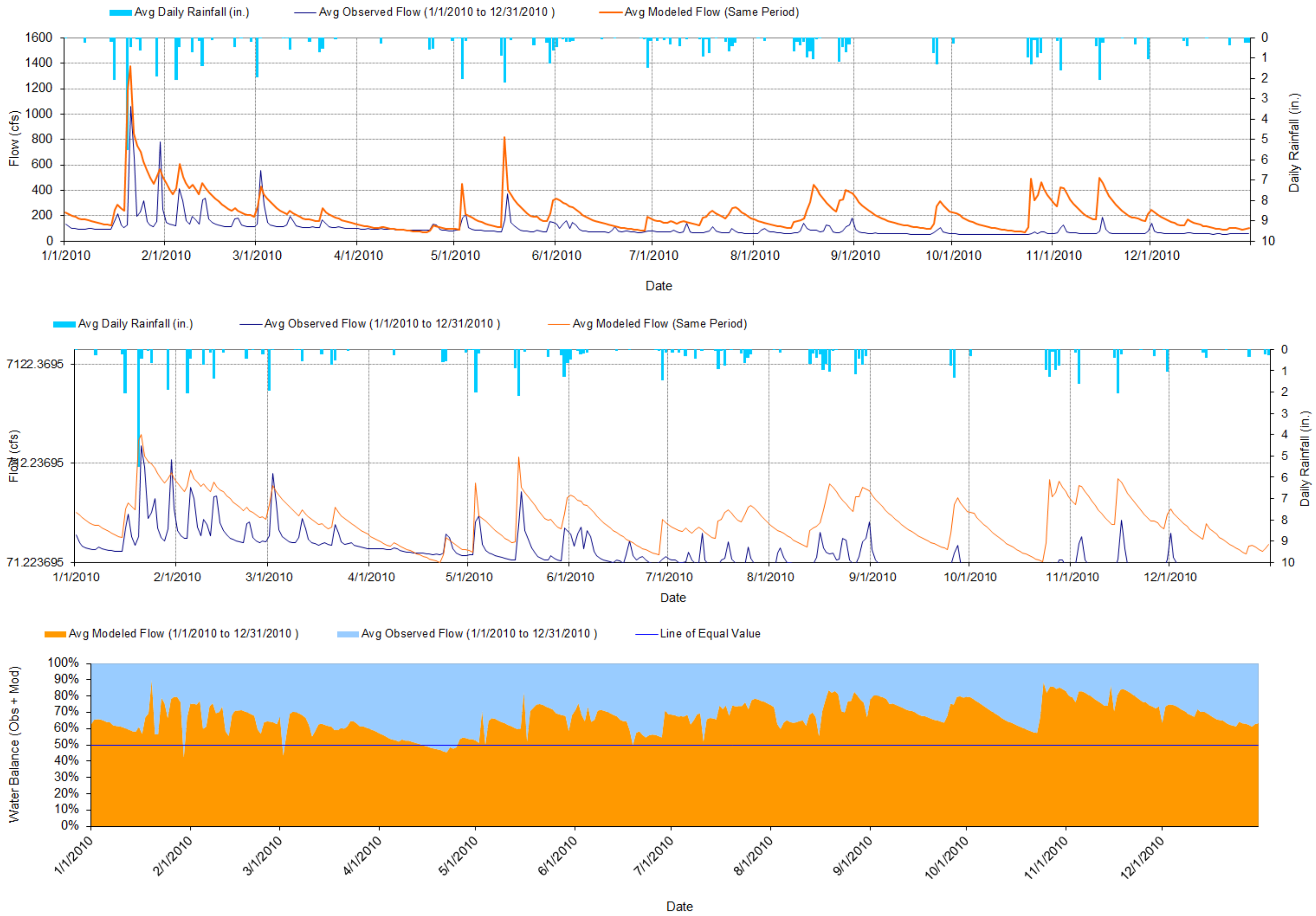
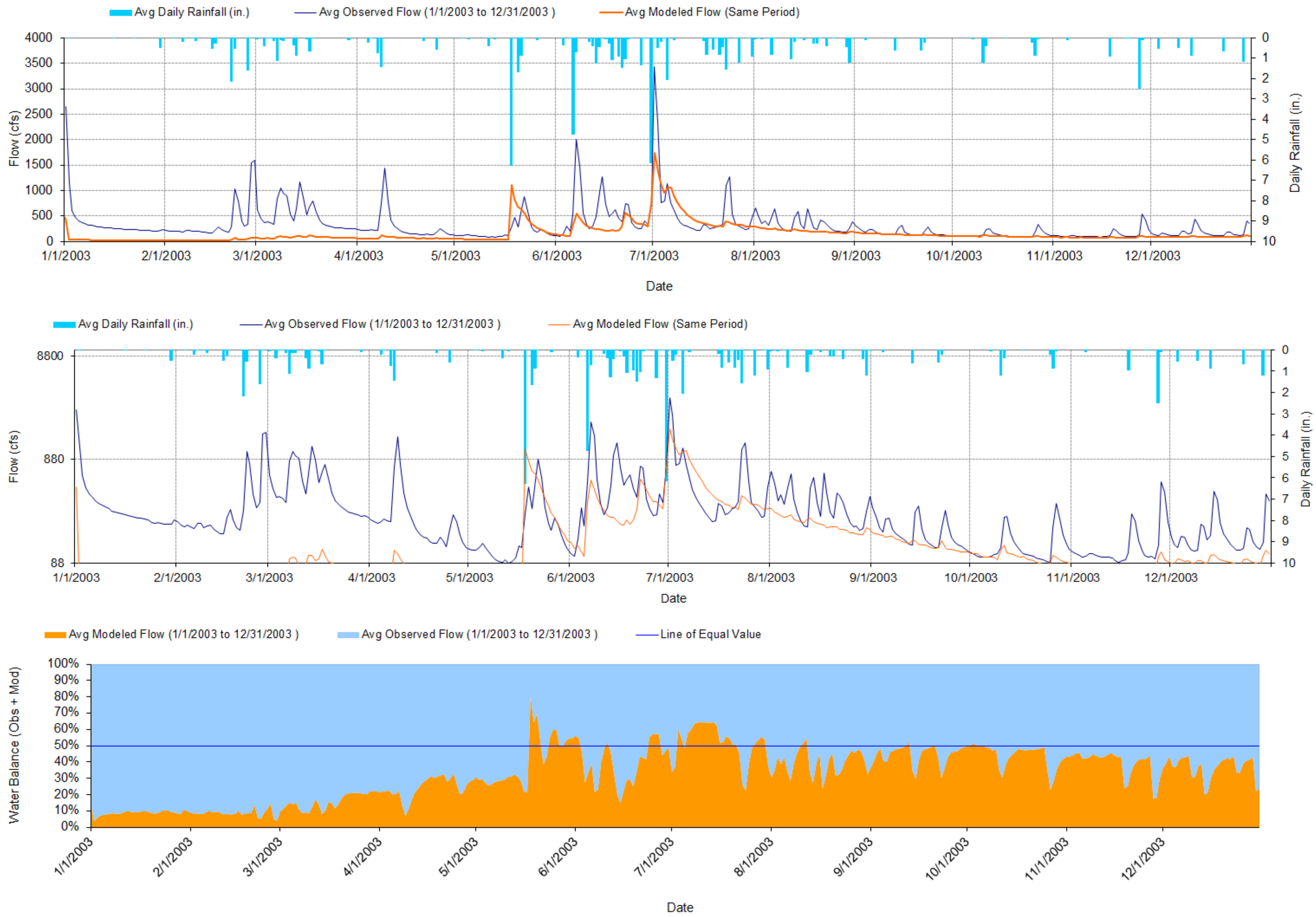


Figure A-12 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2003



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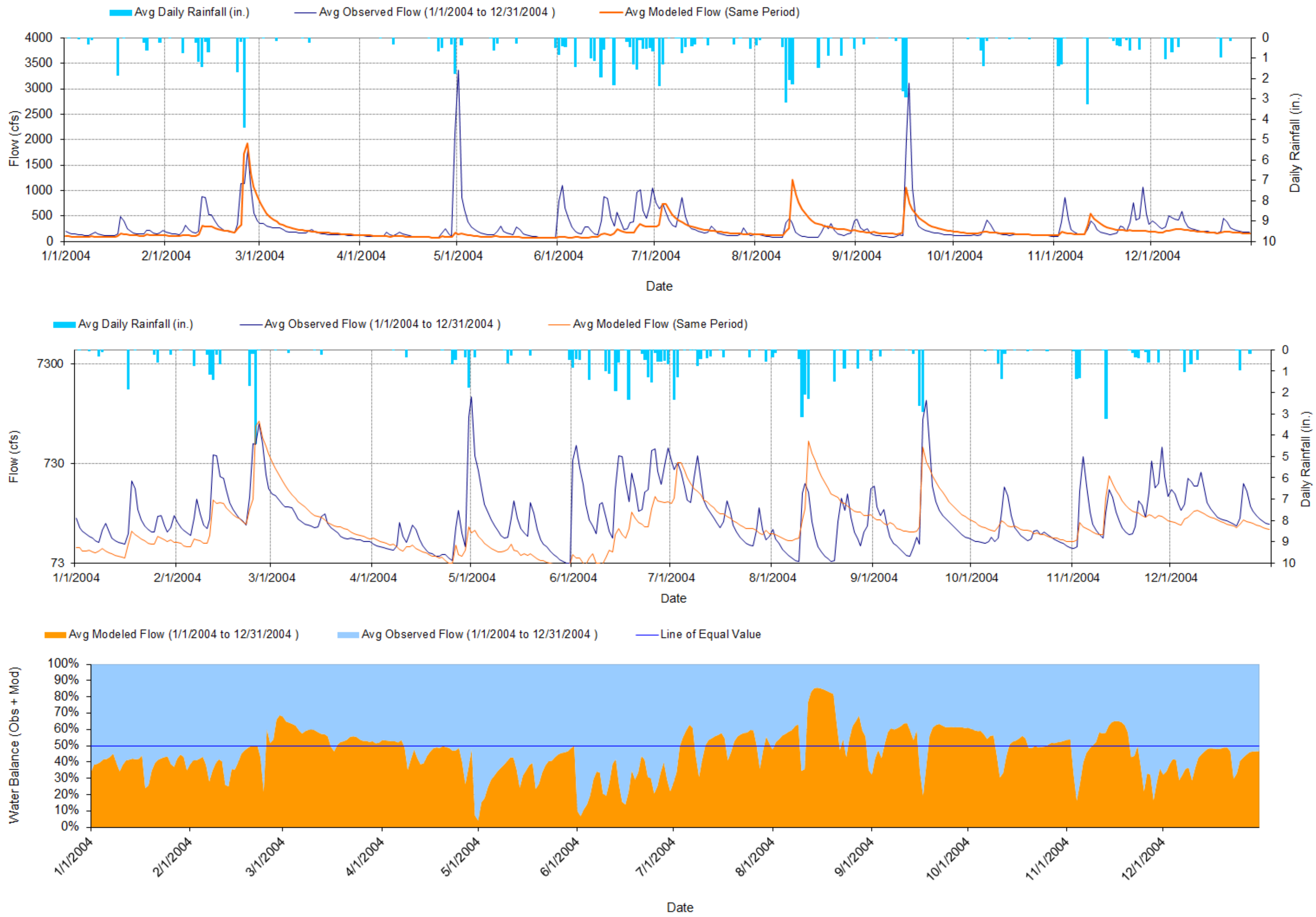

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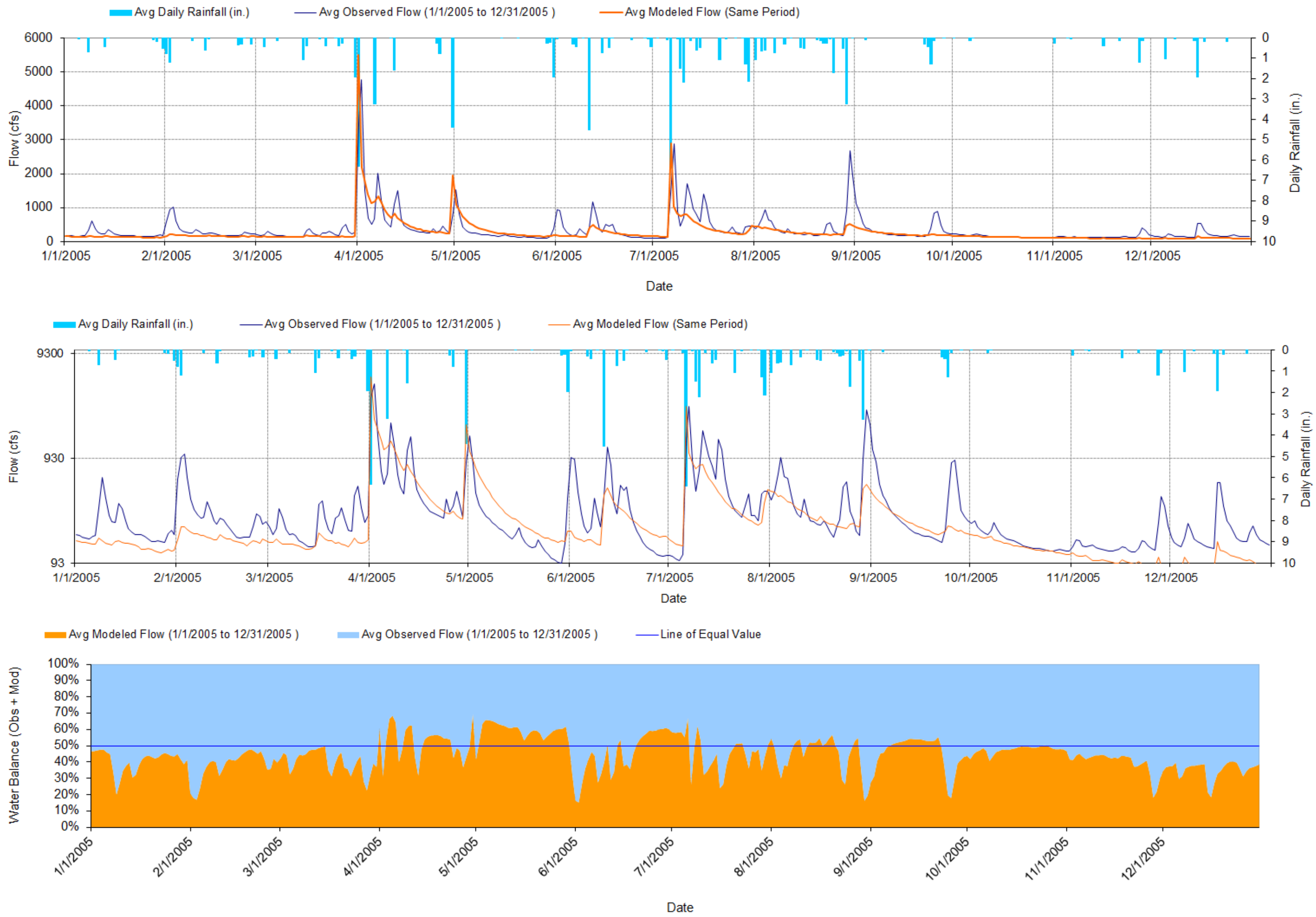


Figure A-15 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2006

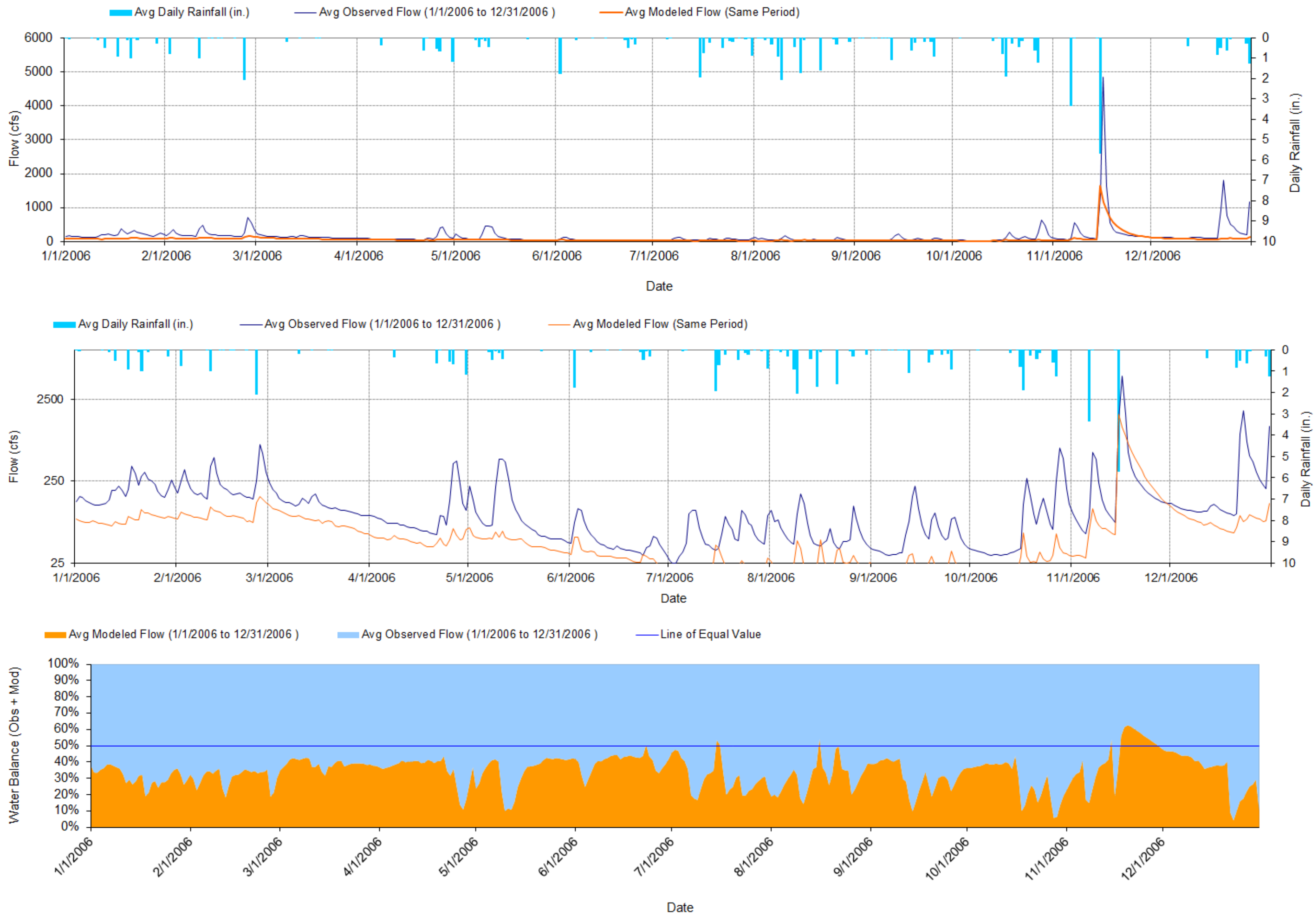


Figure A-16 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2007

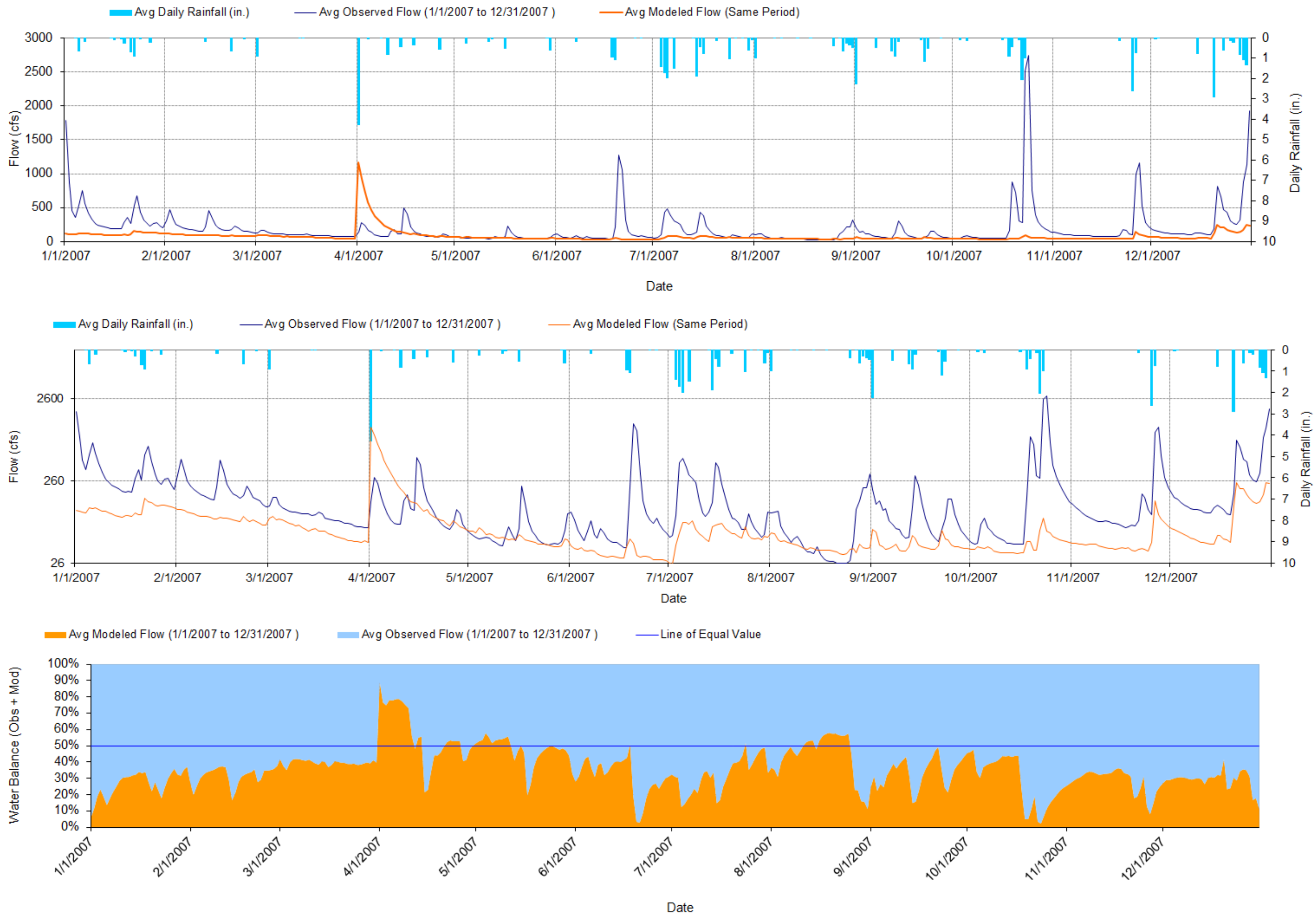


Figure A-17 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2008

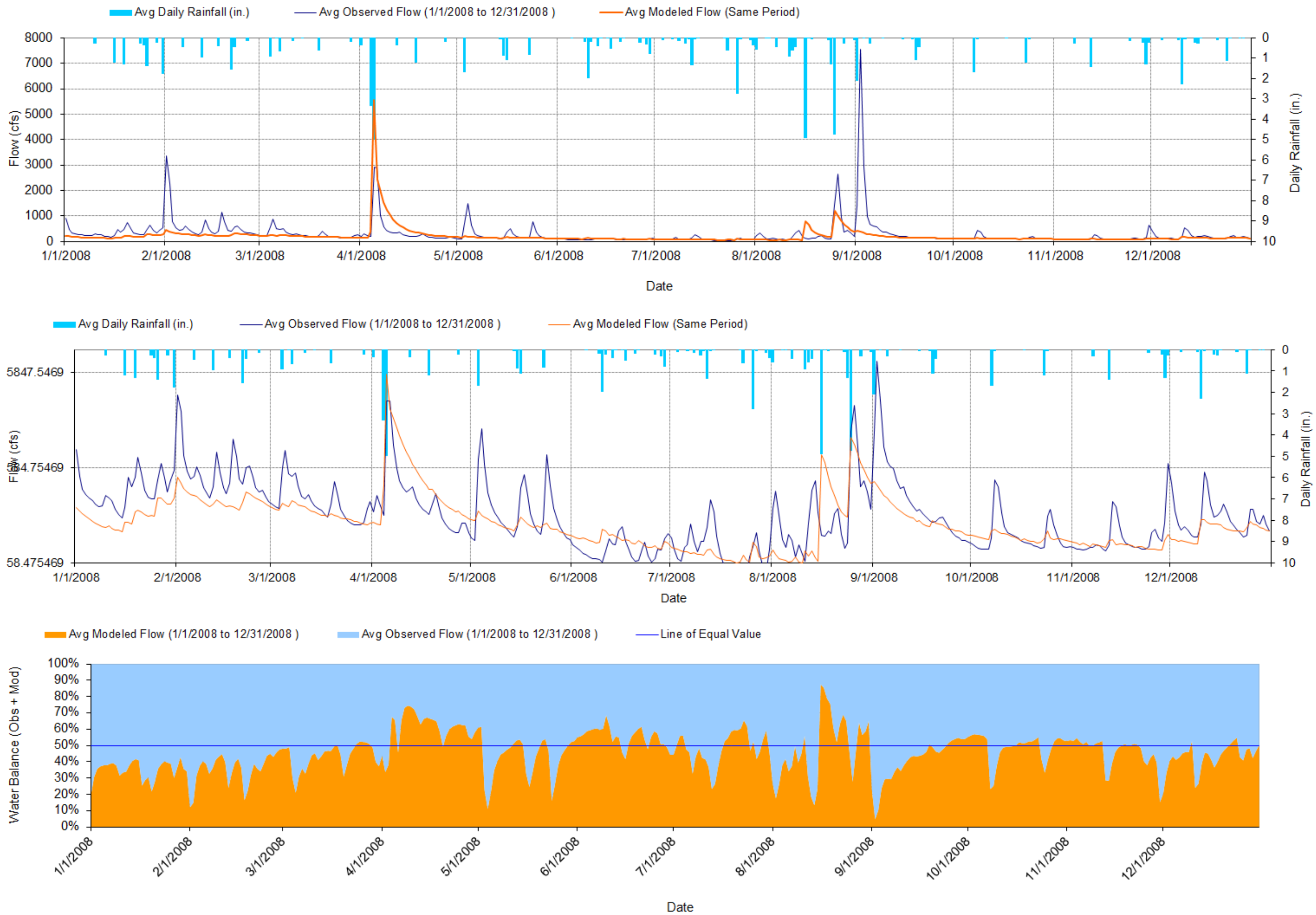


Figure A-18 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2009

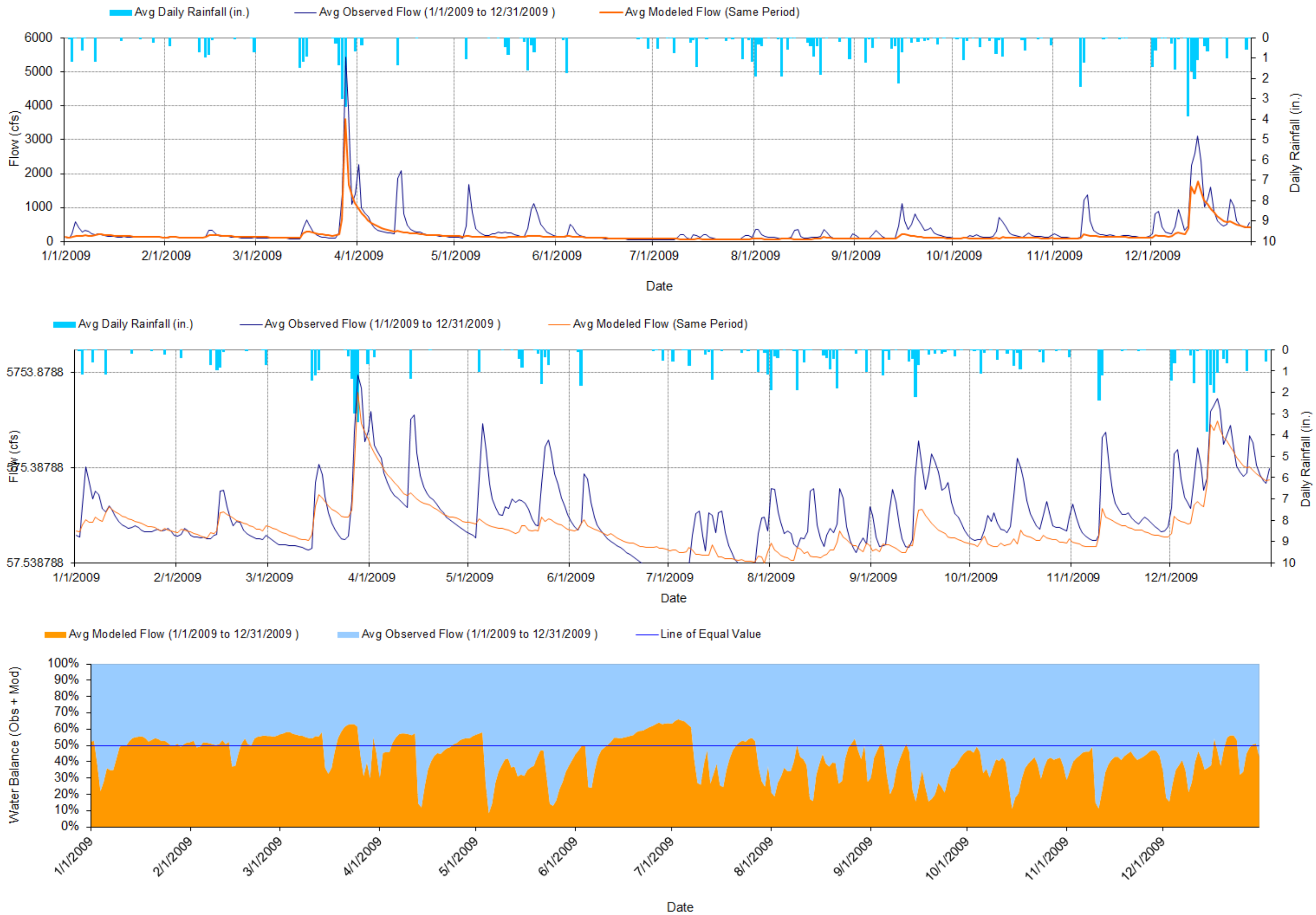


Figure A-19 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2010

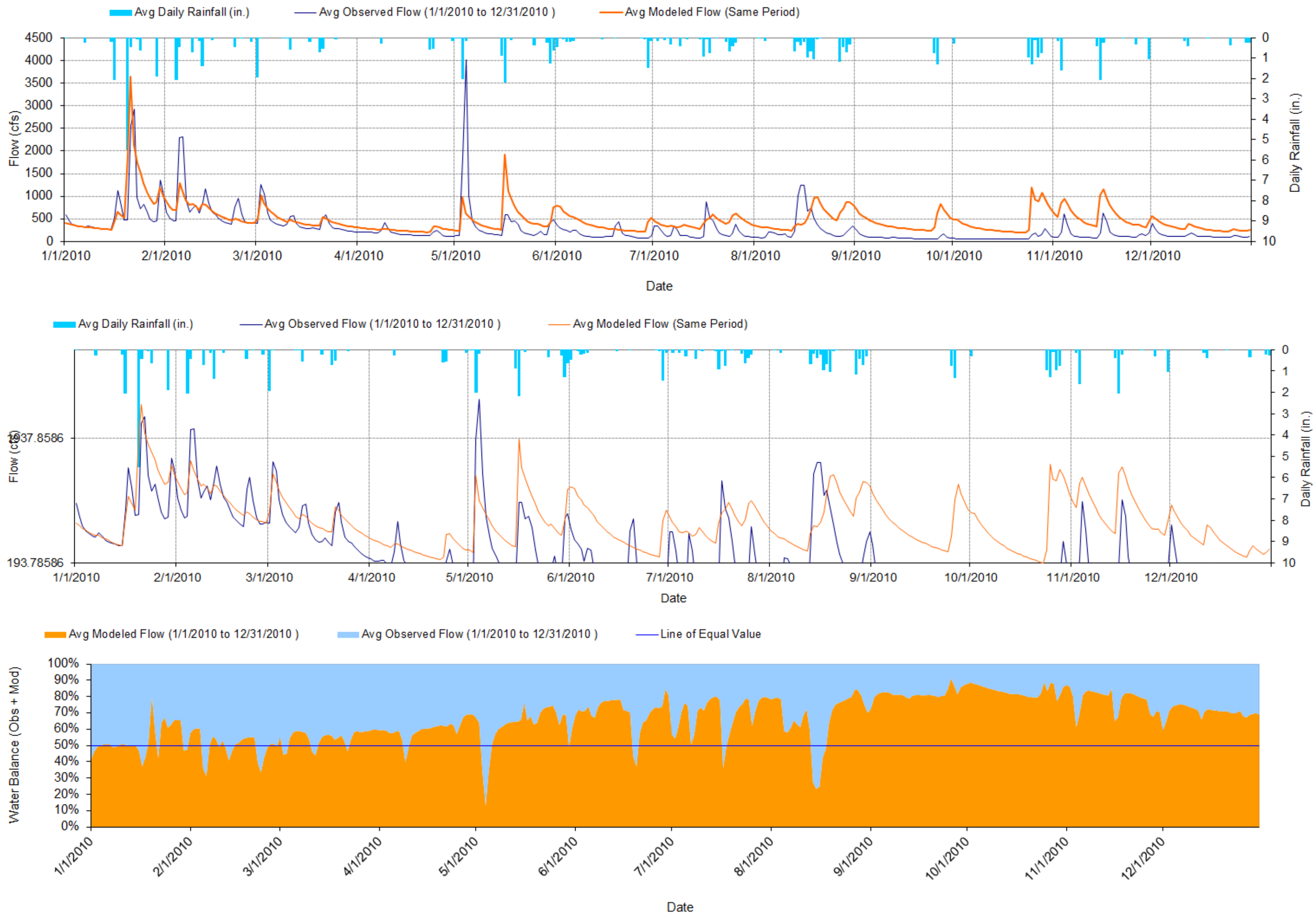
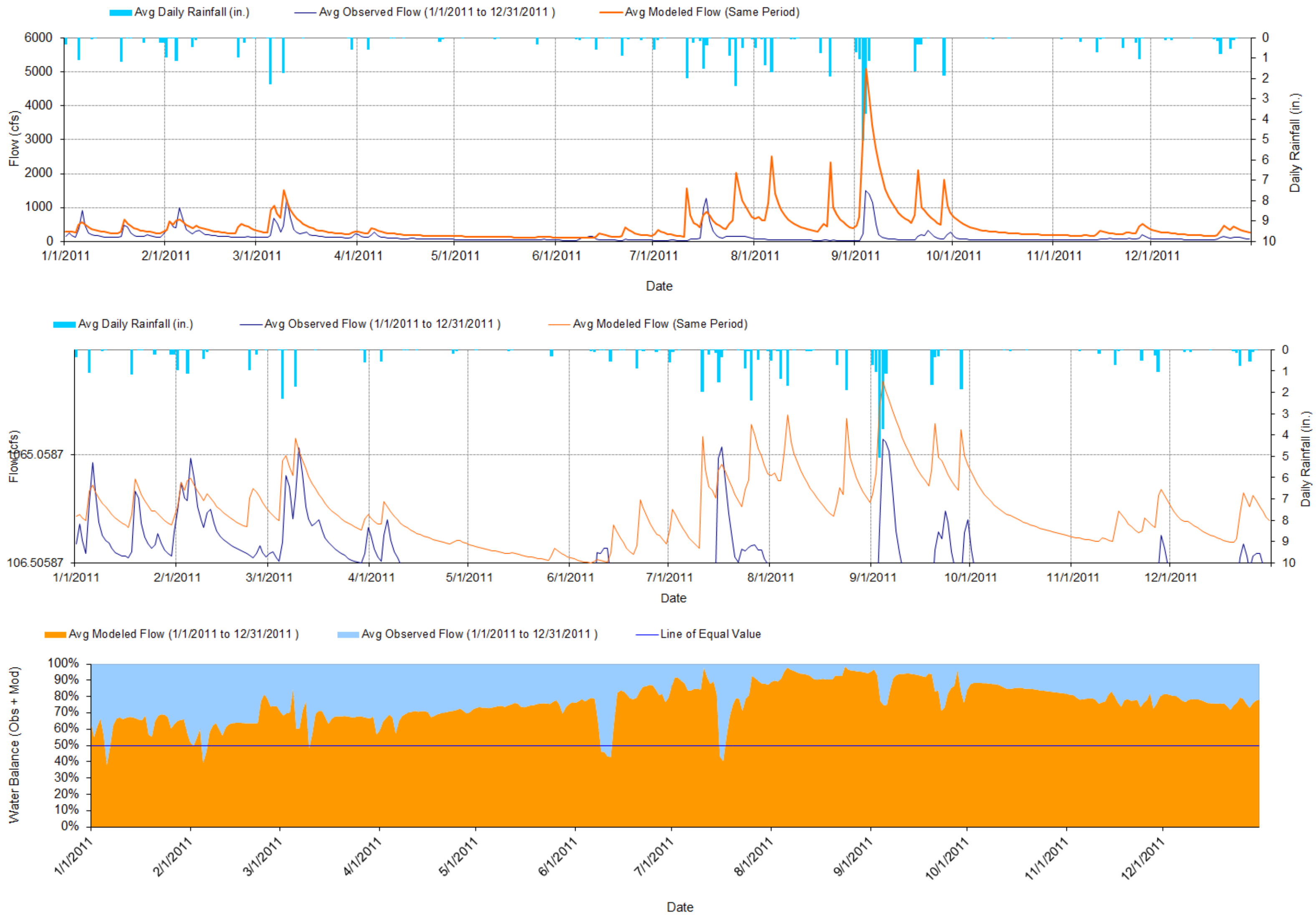


Figure A-20 Chickasaw Creek (USGS 02471001) LSPC Hydrology Calibration for Water Year 2011



APPENDIX B – Watershed Water Quality Calibration

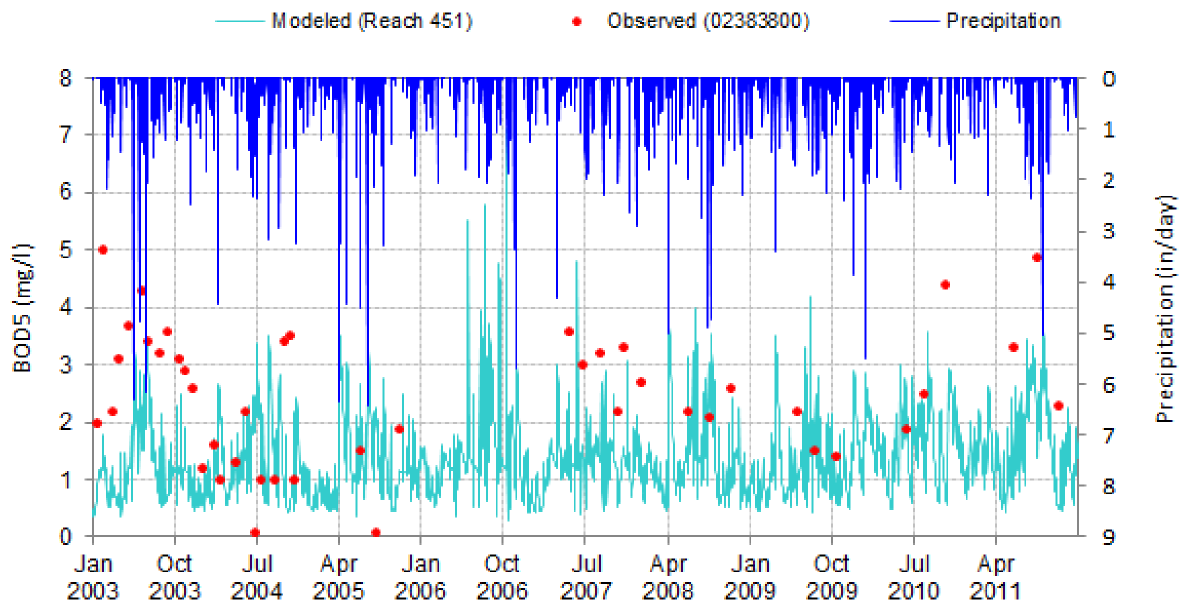


Figure B-1 Dog River BOD5 Calibration at DR1+21AWIC

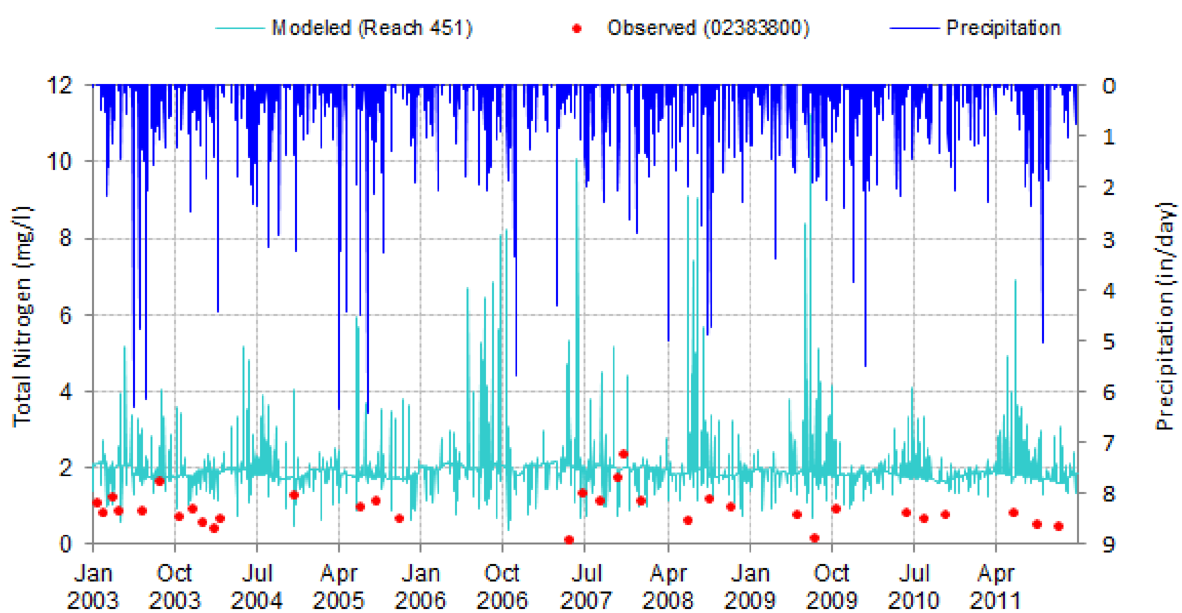


Figure B-2 Dog River Total Nitrogen Calibration at DR1+21AWIC

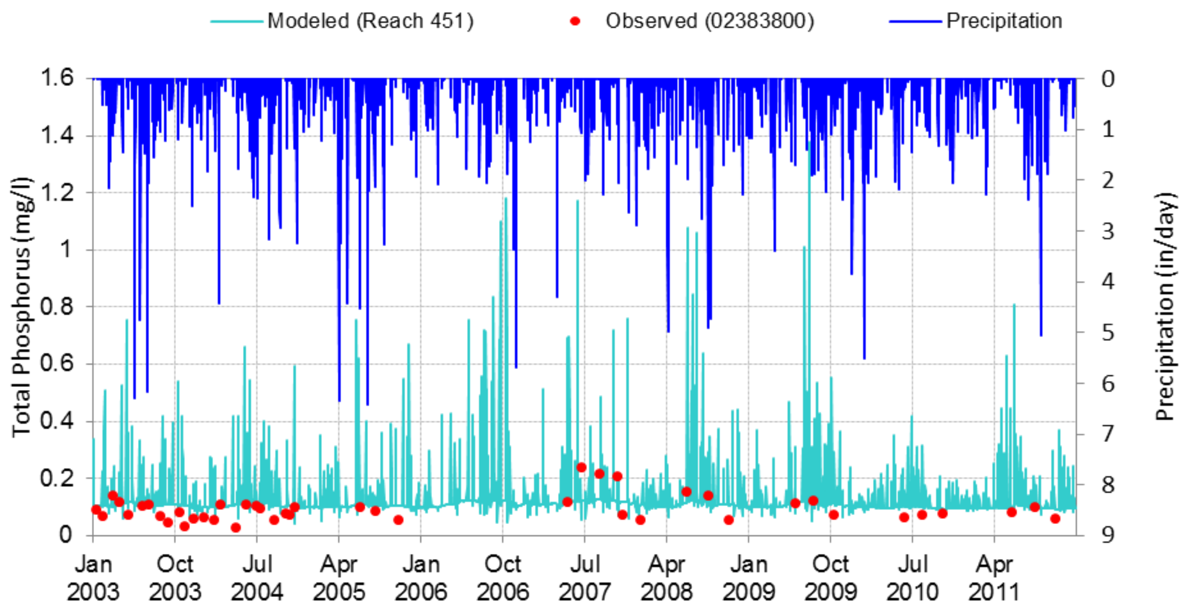


Figure B-3 Dog River Total Phosphorus Calibration at DR1+21AWIC

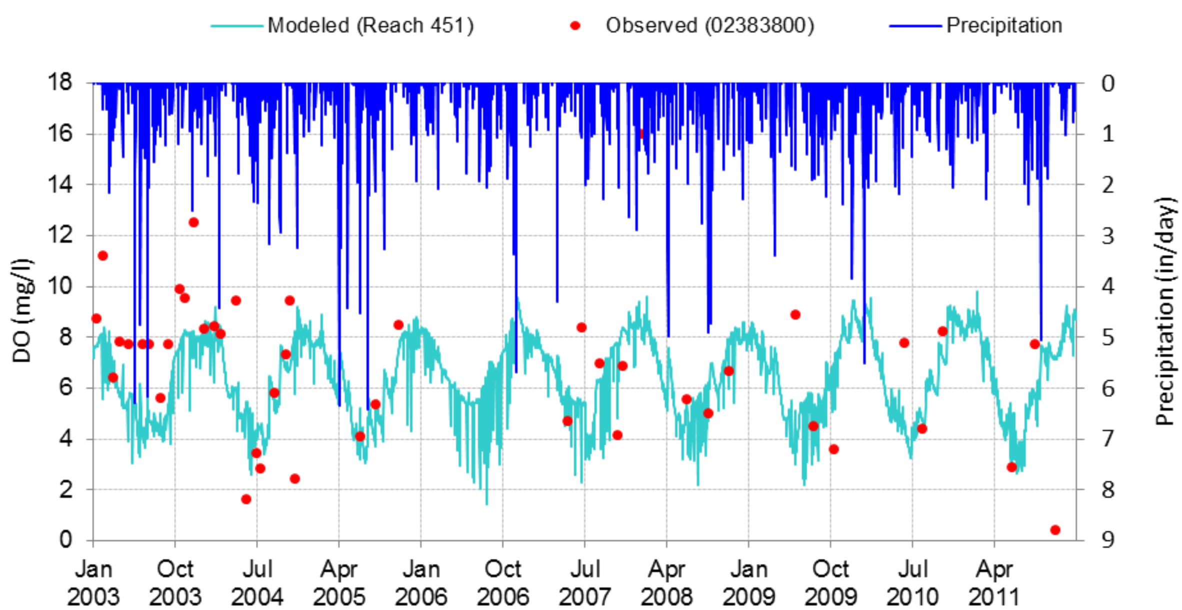


Figure B-4 Dog River Dissolved Oxygen Calibration at DR1+21AWIC

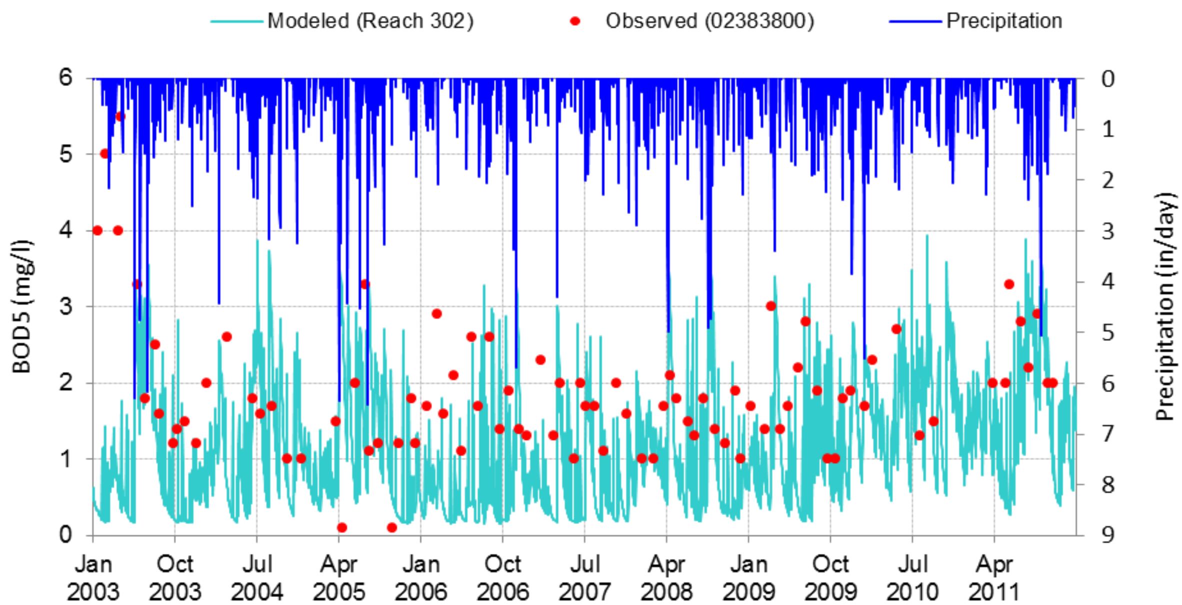


Figure B-5 Three Mile Creek BOD5 Calibration at TM1+21AWIC

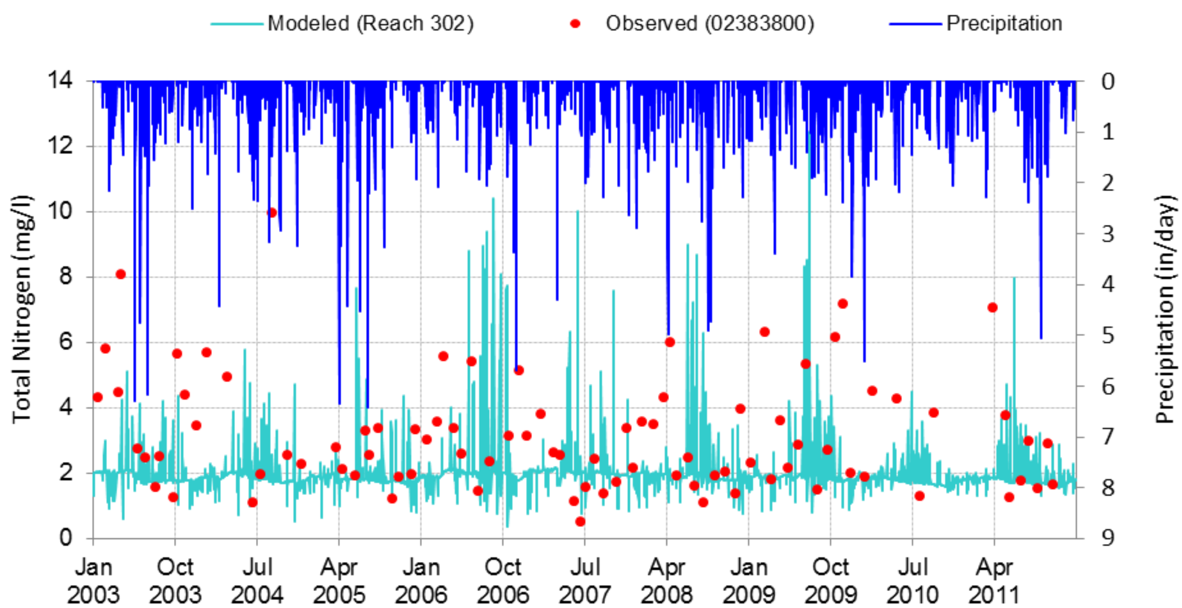


Figure B-6 Three Mile Creek Total Nitrogen Calibration at TM1+21AWIC

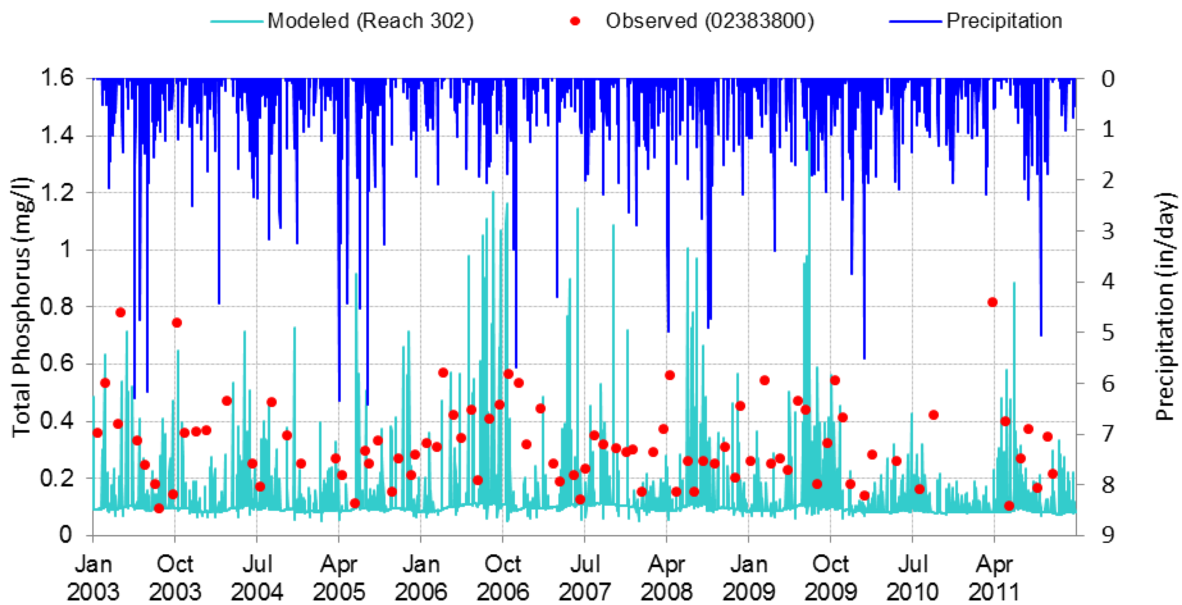


Figure B-7 Three Mile Creek Total Phosphorus Calibration at TM1+21AWIC

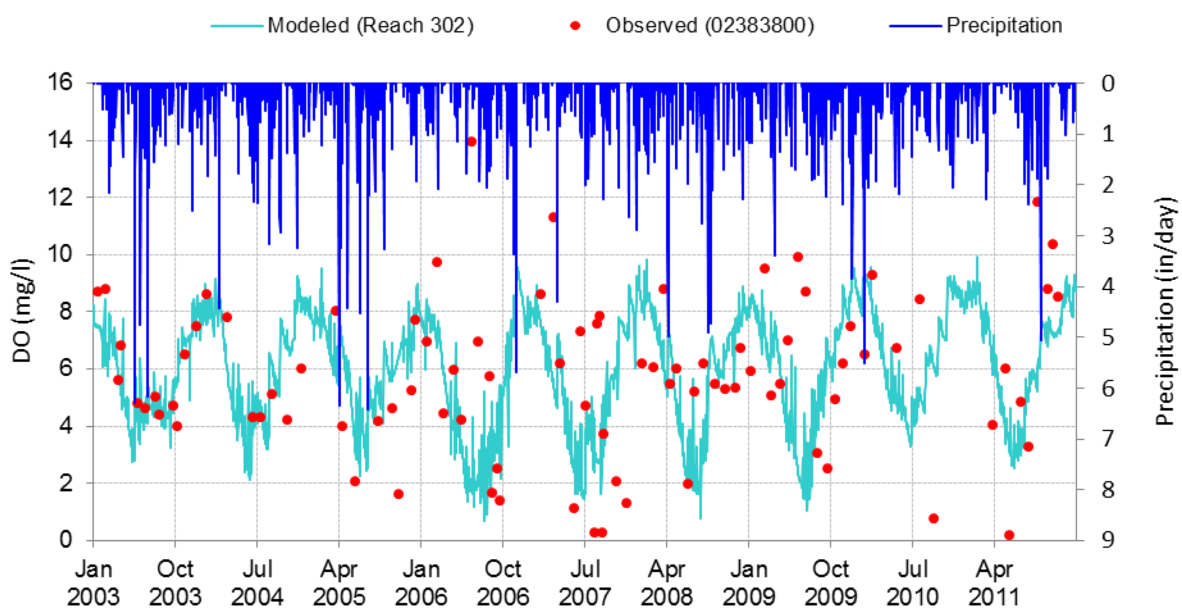


Figure B-8 Three Mile Creek Dissolved Oxygen Calibration at TM1+21AWIC

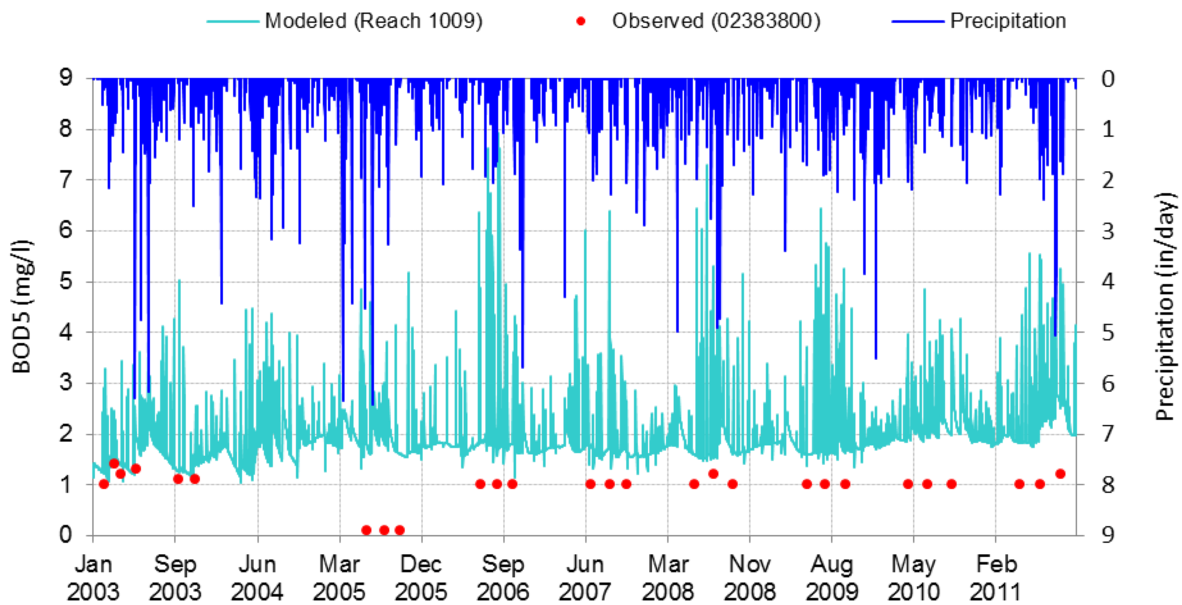


Figure B-9 Weeks Bay BOD5 Calibration at WO1A+21AWIC

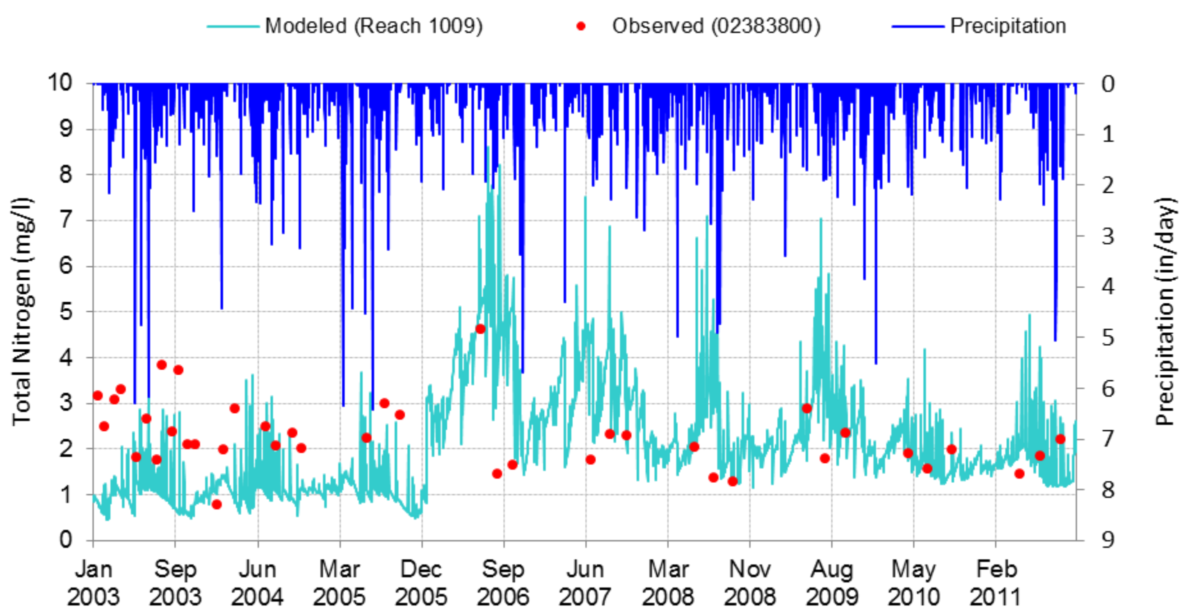


Figure B-10 Weeks Bay Total Nitrogen Calibration at WO1A+21AWIC

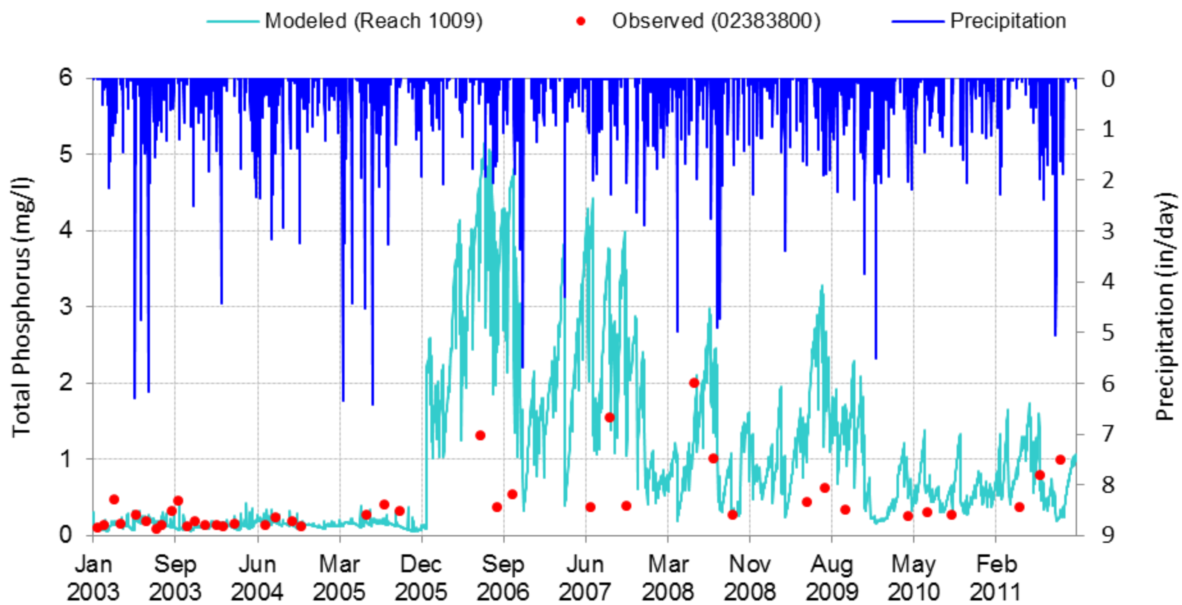


Figure B-11 Weeks Bay Total Phosphorus Calibration at WO1A+21AWIC

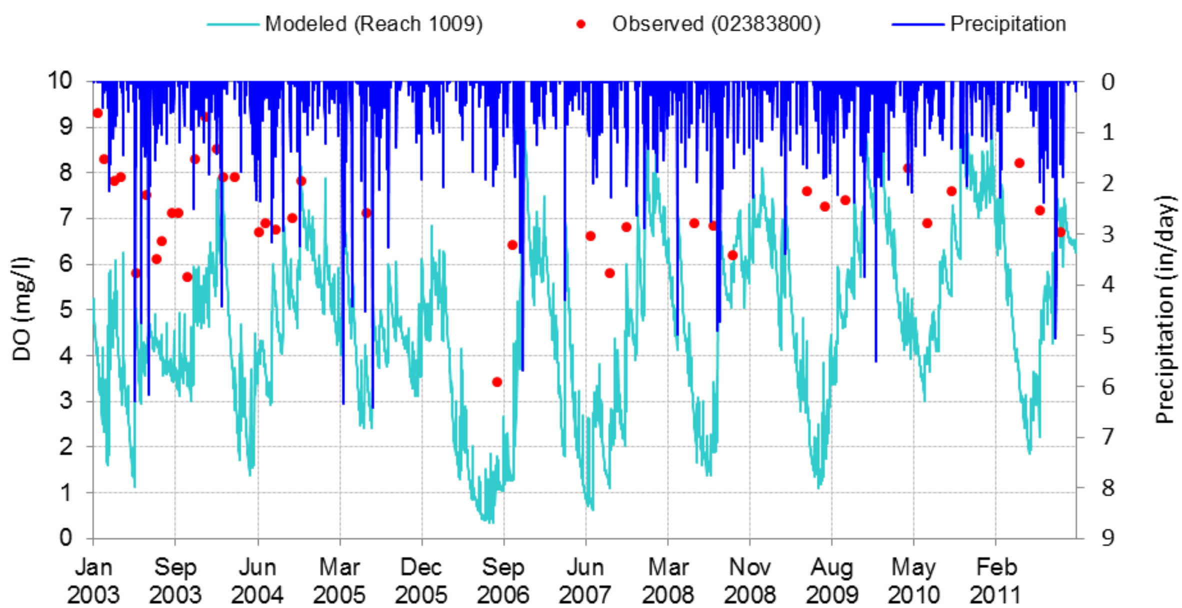


Figure B-12 Weeks Bay Dissolved Oxygen Calibration at WO1A+21AWIC

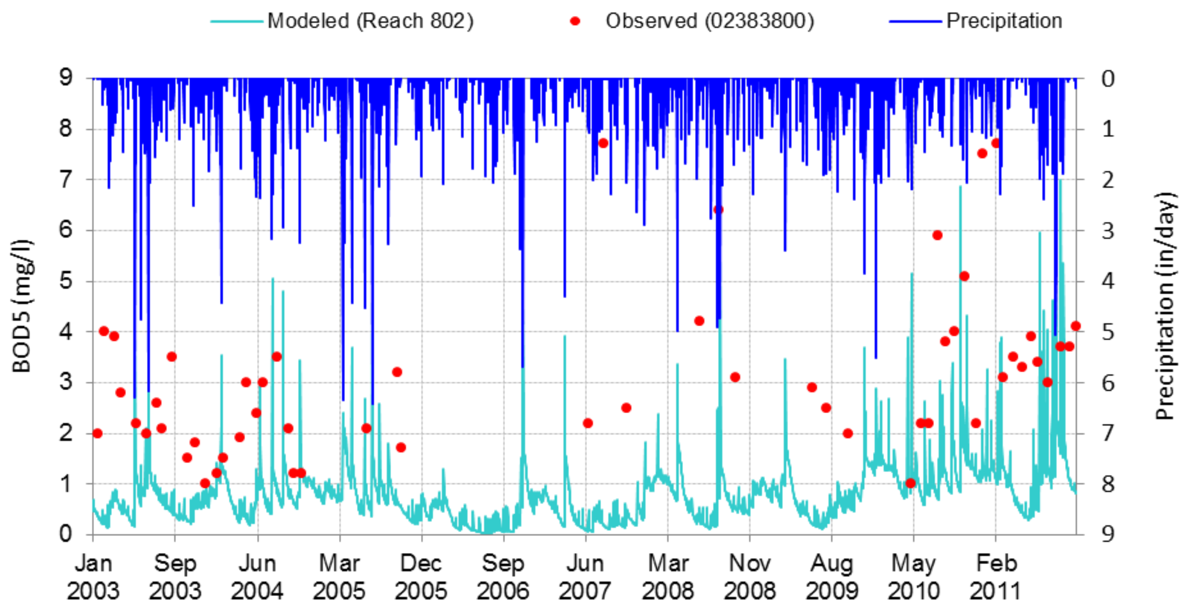


Figure B-13 Wolf Bay BOD5 Calibration at WB1+21AWIC

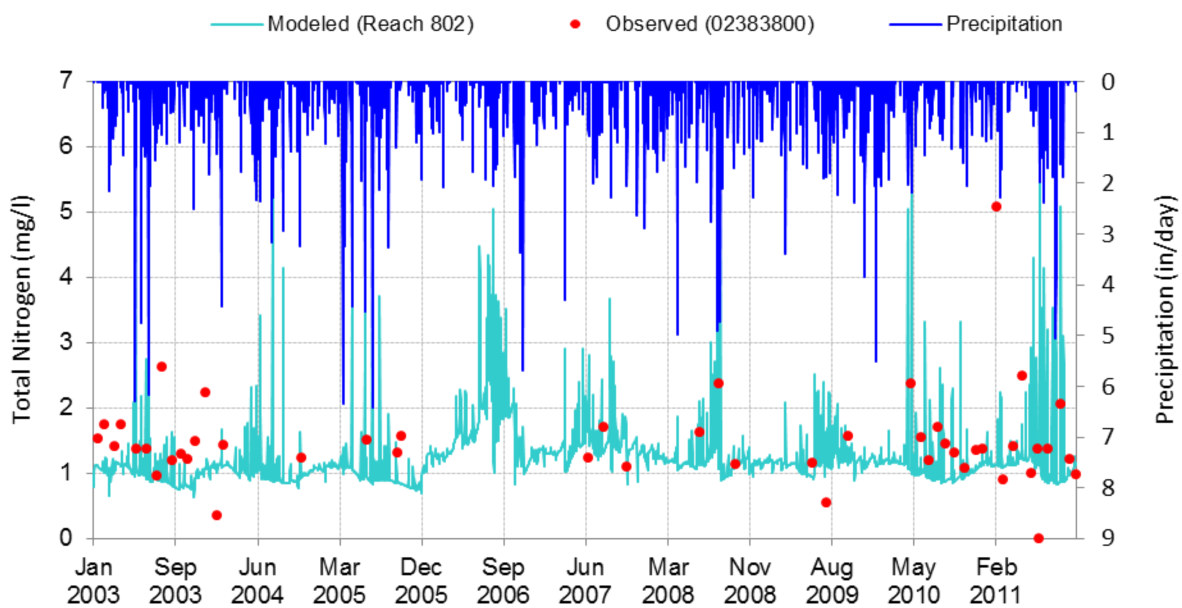


Figure B-14 Wolf Bay Total Nitrogen Calibration at WB1+21AWIC

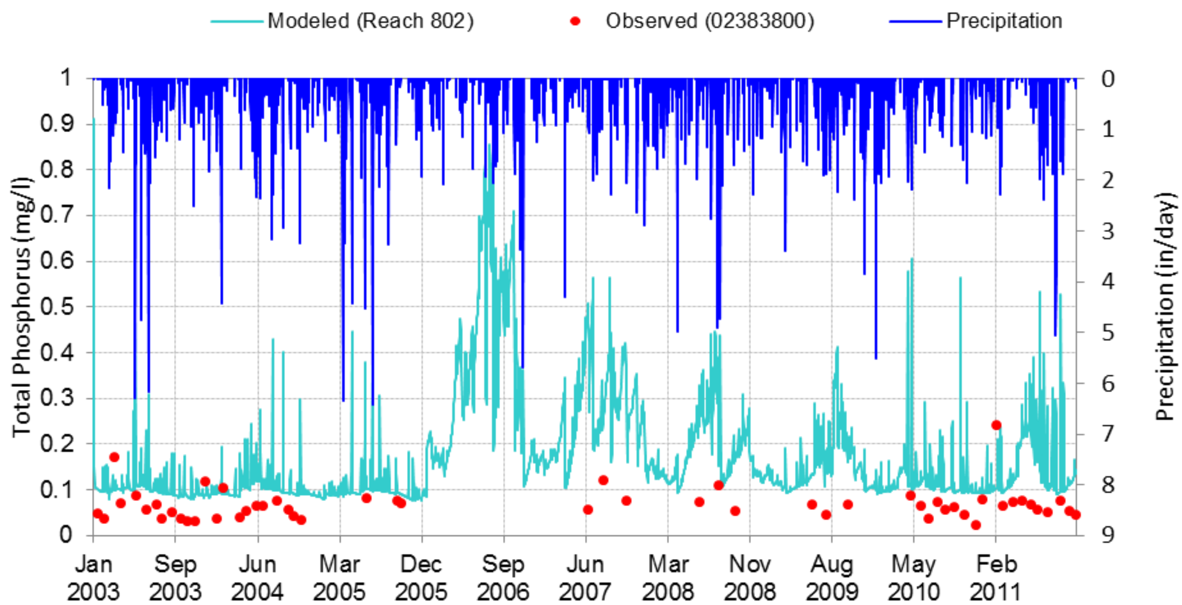


Figure B-15 Wolf Bay Total Phosphorus Calibration at WB1+21AWIC

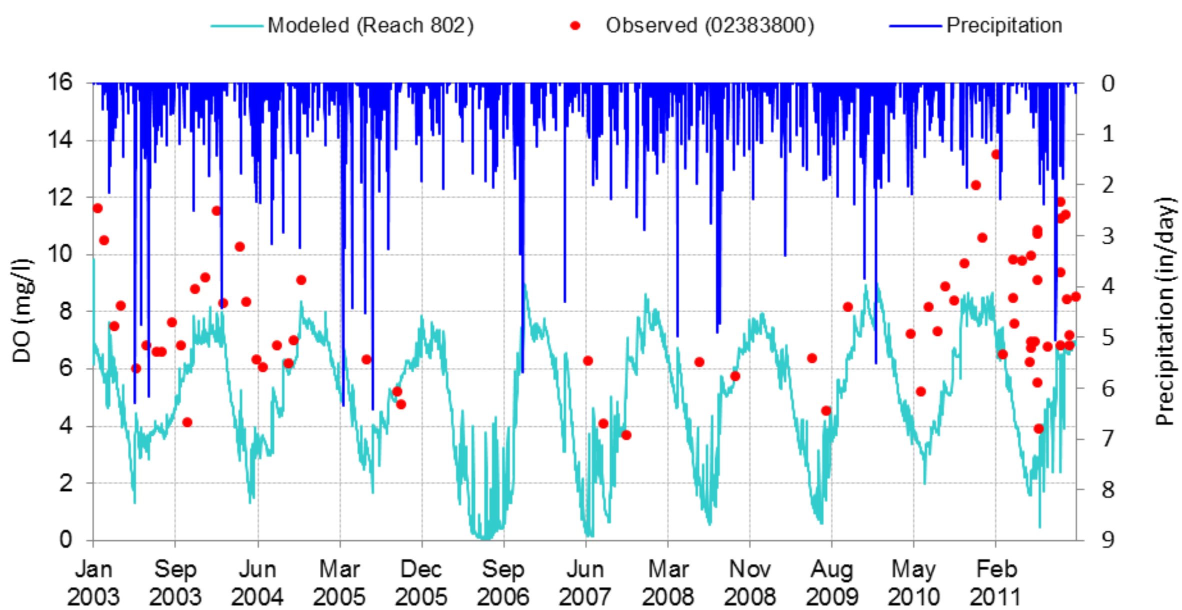


Figure B-16 Wolf Bay Dissolved Oxygen Calibration at WB1+21AWIC

APPENDIX C – EFDC Calibration

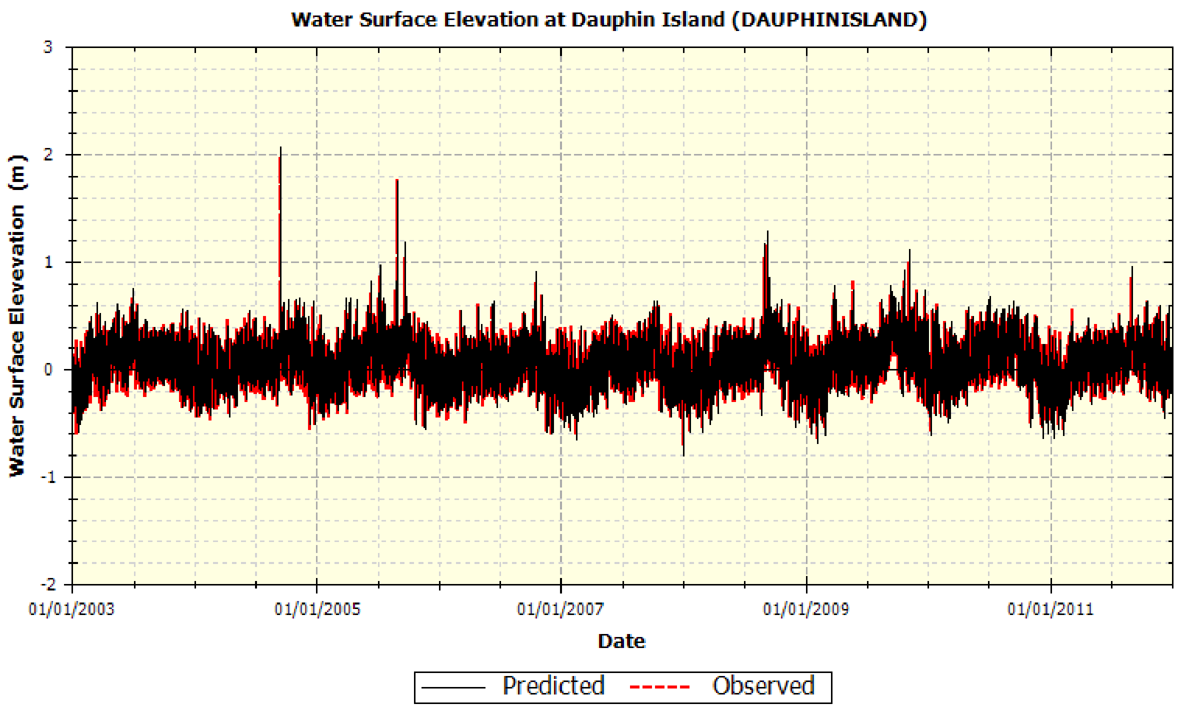


Figure C-1. Water Surface Elevation from 2003 to 2011 at Dauphin Island

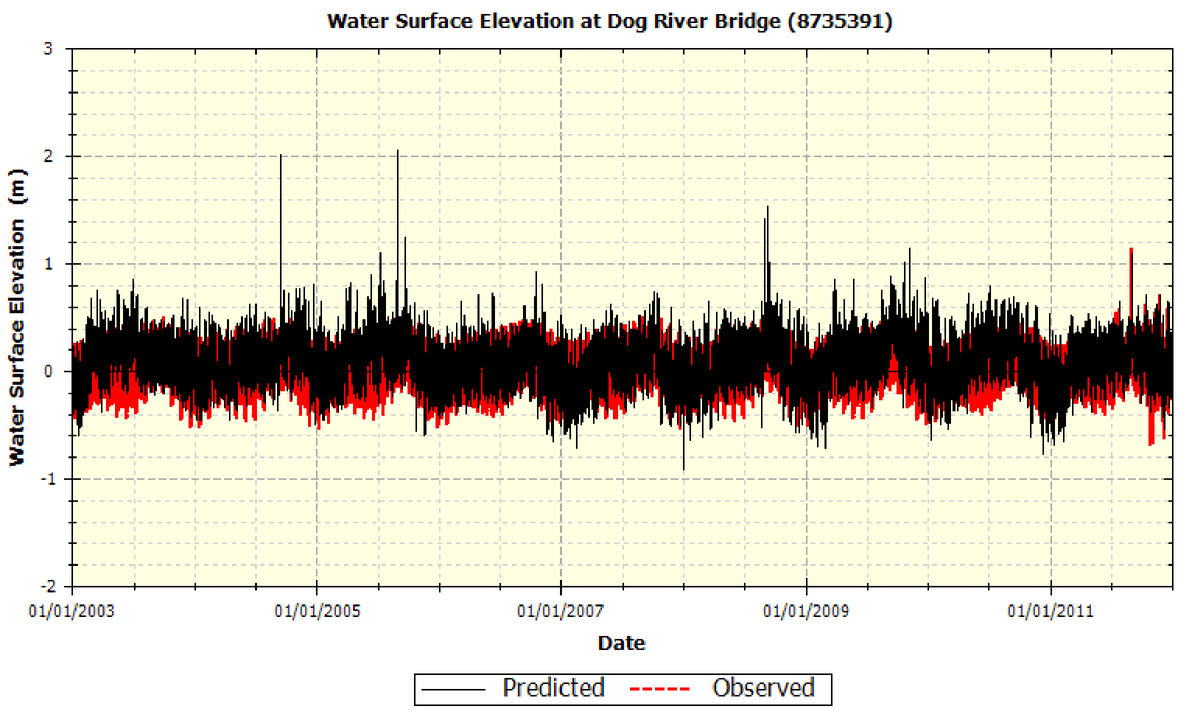


Figure C-2. Water Surface Elevation from 2003 to 2011 at Dog River Bridge

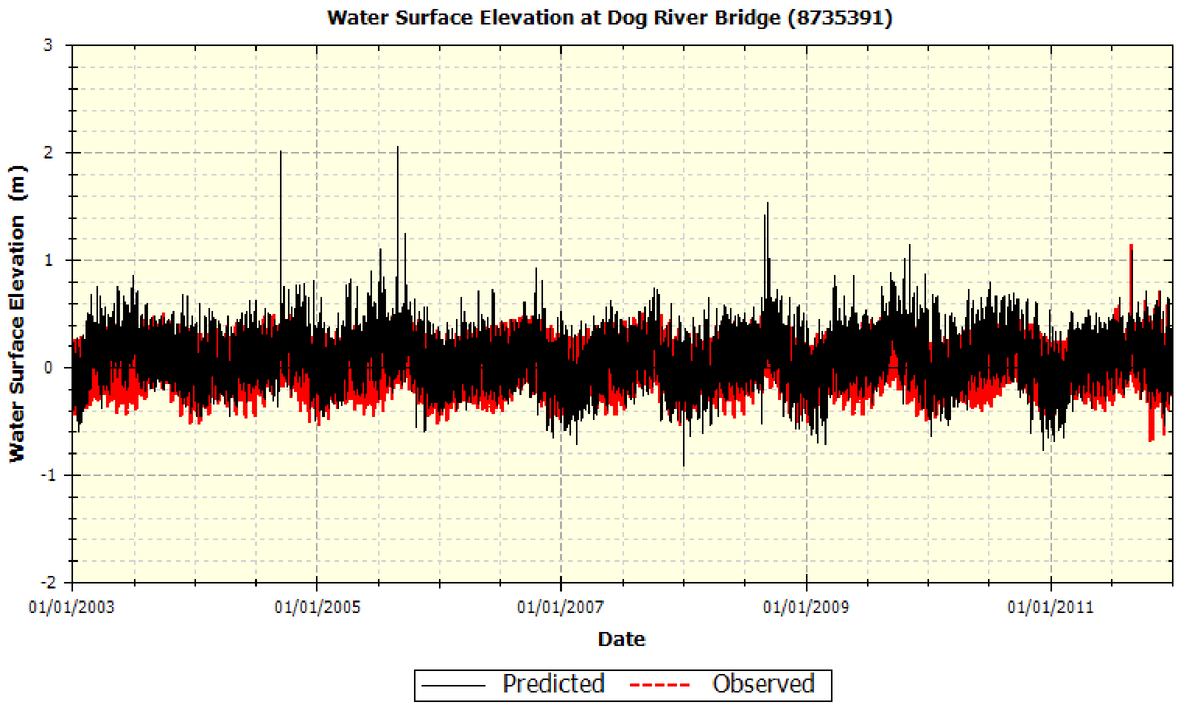


Figure C-3. Water Surface Elevation from 2003 to 2011 at USCG Sector, Mobile Bay

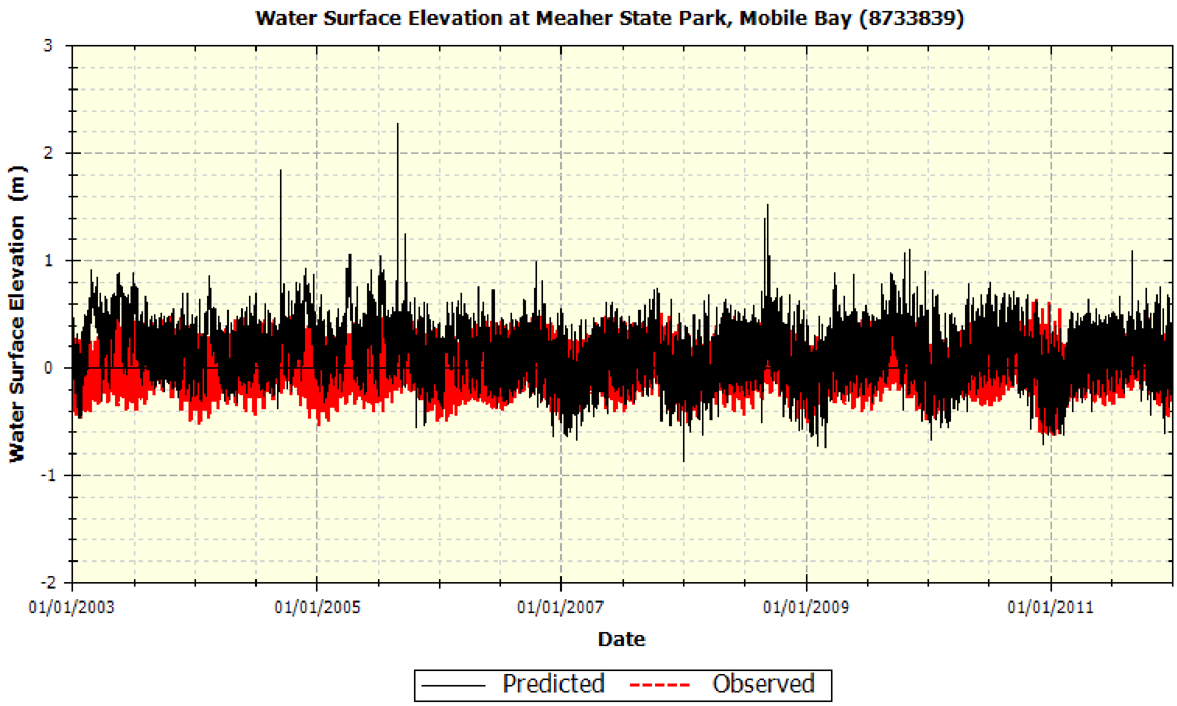


Figure C-4. Water Surface Elevation from 2003 to 2011 at Meaher State Park, Mobile Bay

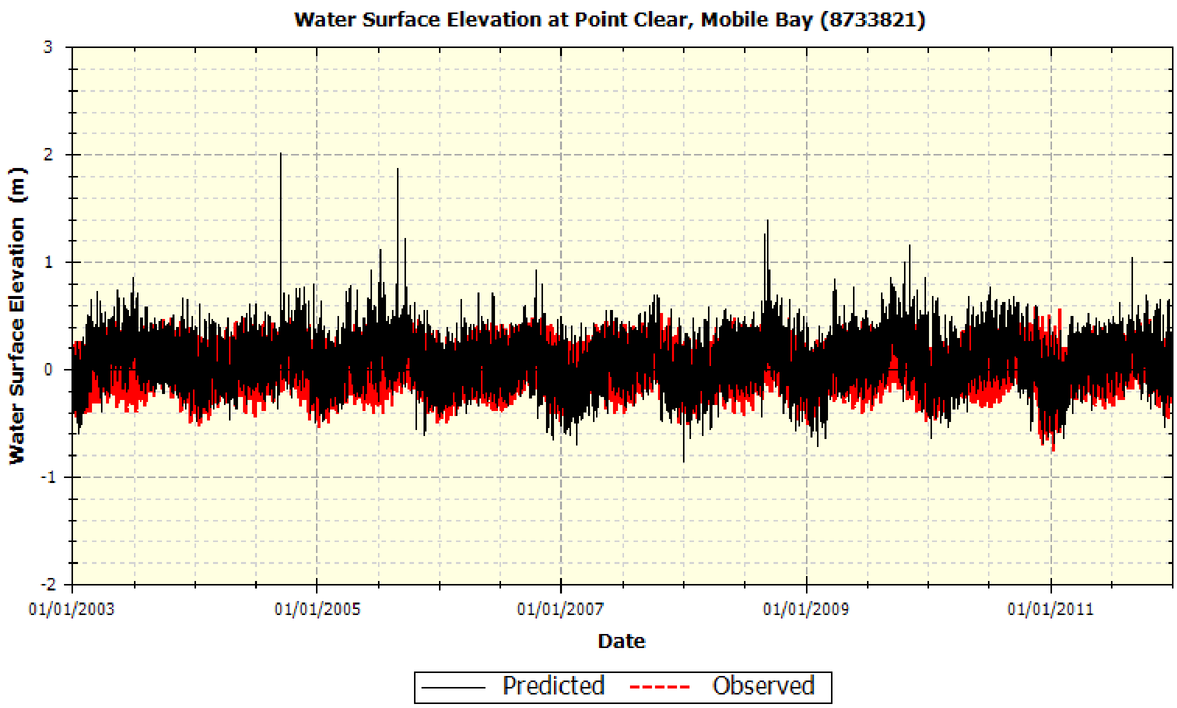


Figure C-5. Water Surface Elevation from 2003 to 2011 at Point Clear, Mobile Bay

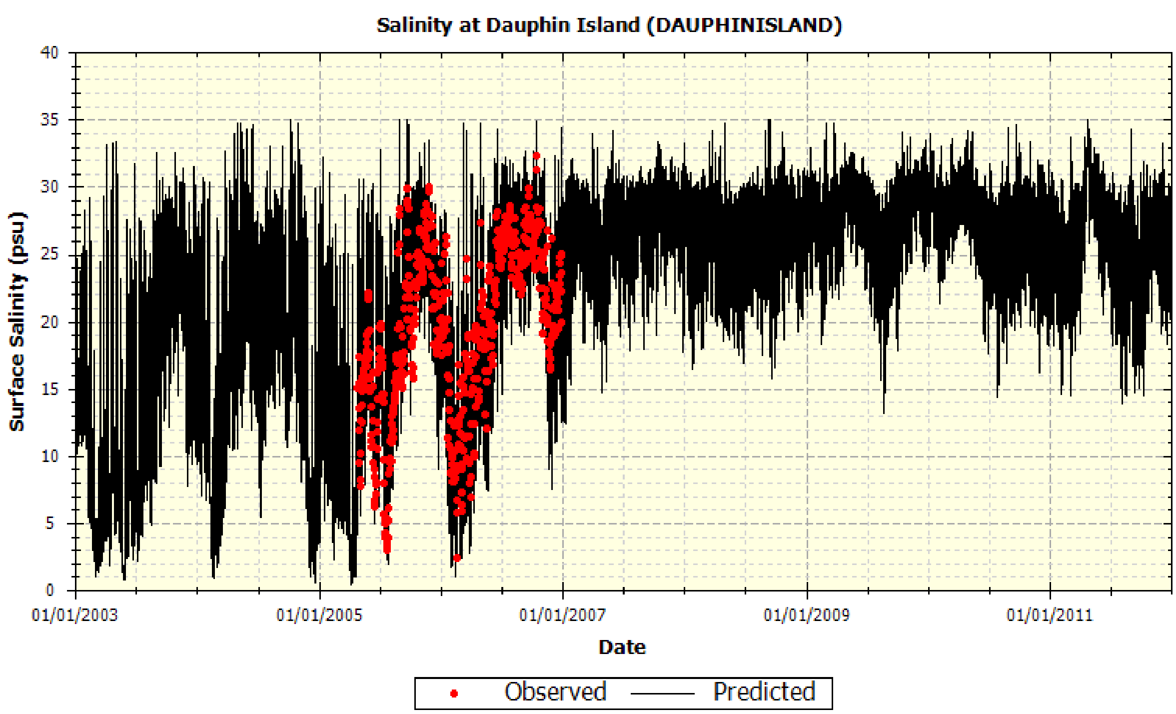


Figure C-6. Salinity from 2003 to 2011 at Dauphin Island

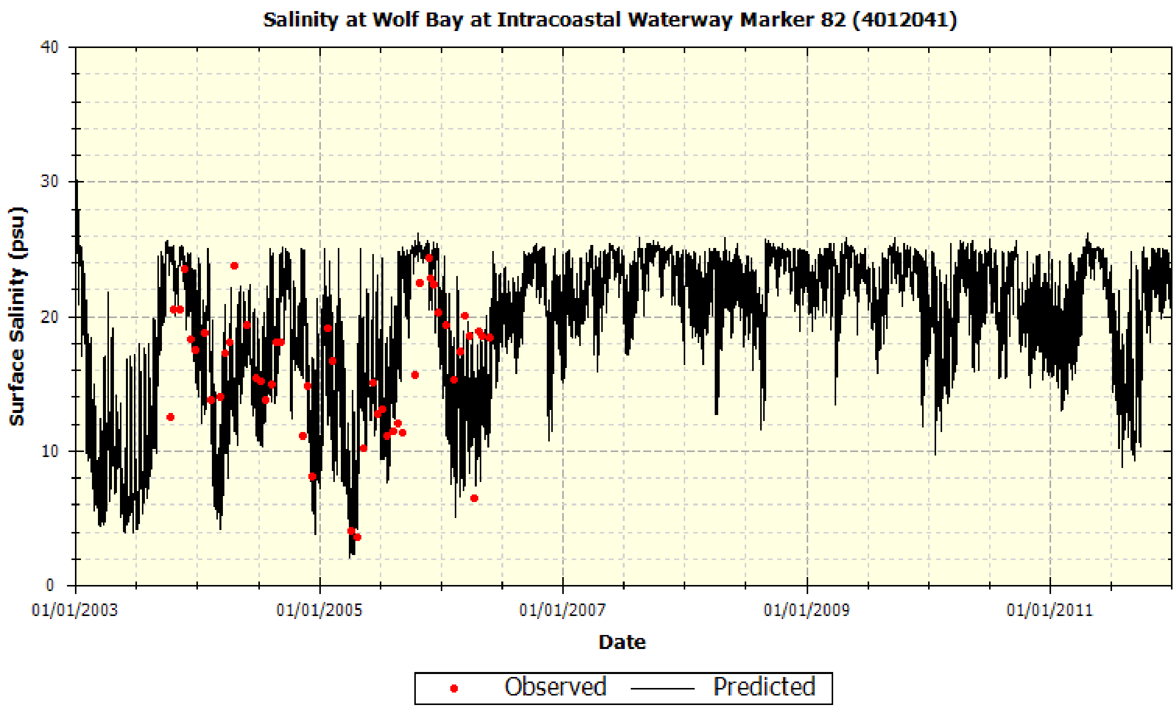


Figure C-7. Salinity from 2003 to 2011 at Intracoastal Water Way Marker 82

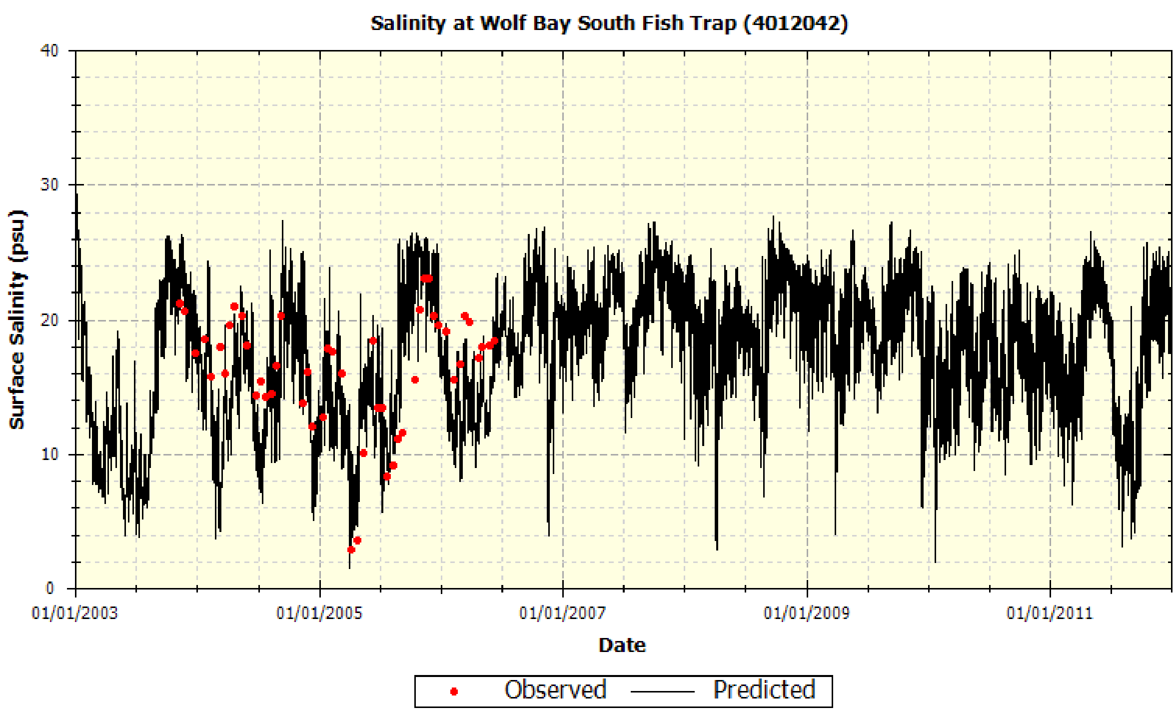


Figure C-8. Salinity from 2003 to 2011 at Wolf Bay South Fish Trap

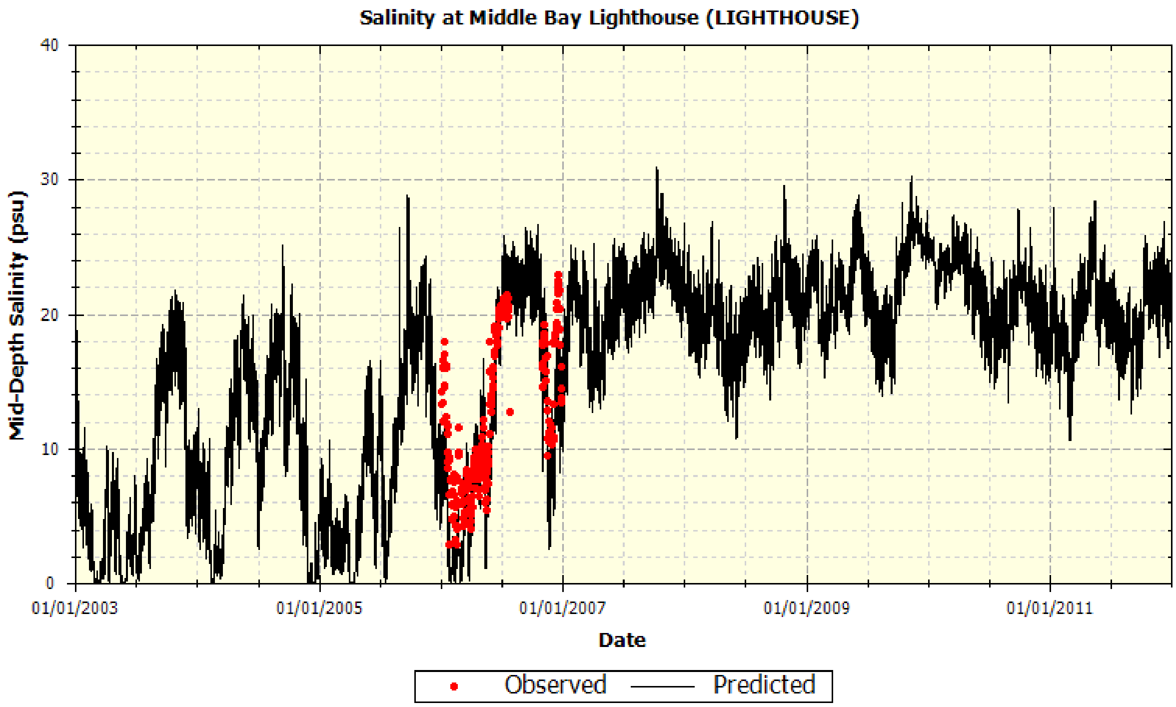


Figure C-9. Salinity from 2003 to 2011 at Middle Bay Lighthouse

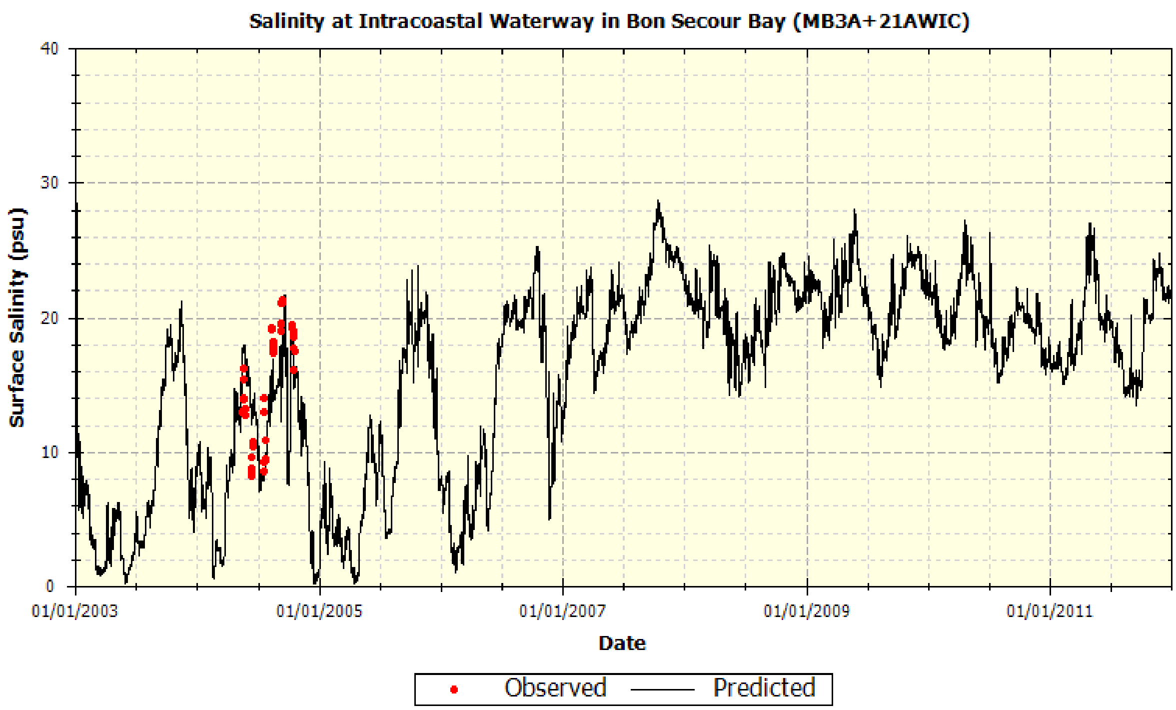


Figure C-10. Salinity from 2003 to 2011 at Intracoastal Waterway in Bon Secour Bay

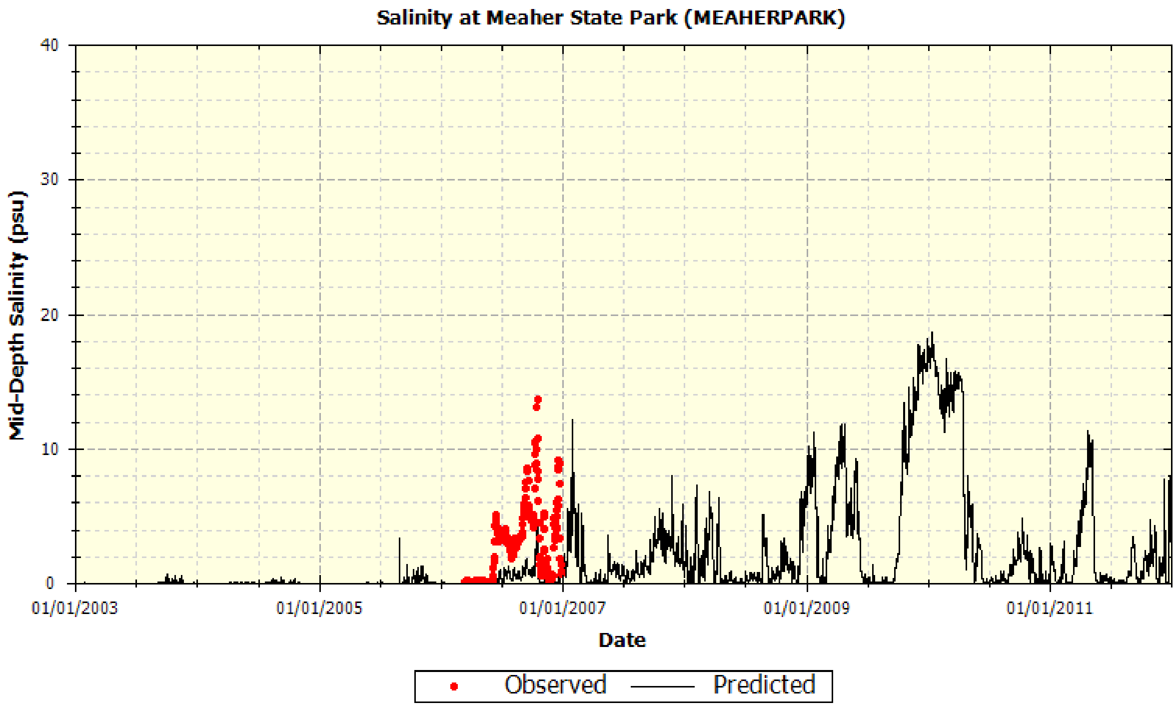


Figure C-11. Salinity from 2003 to 2011 at Meaher State Park

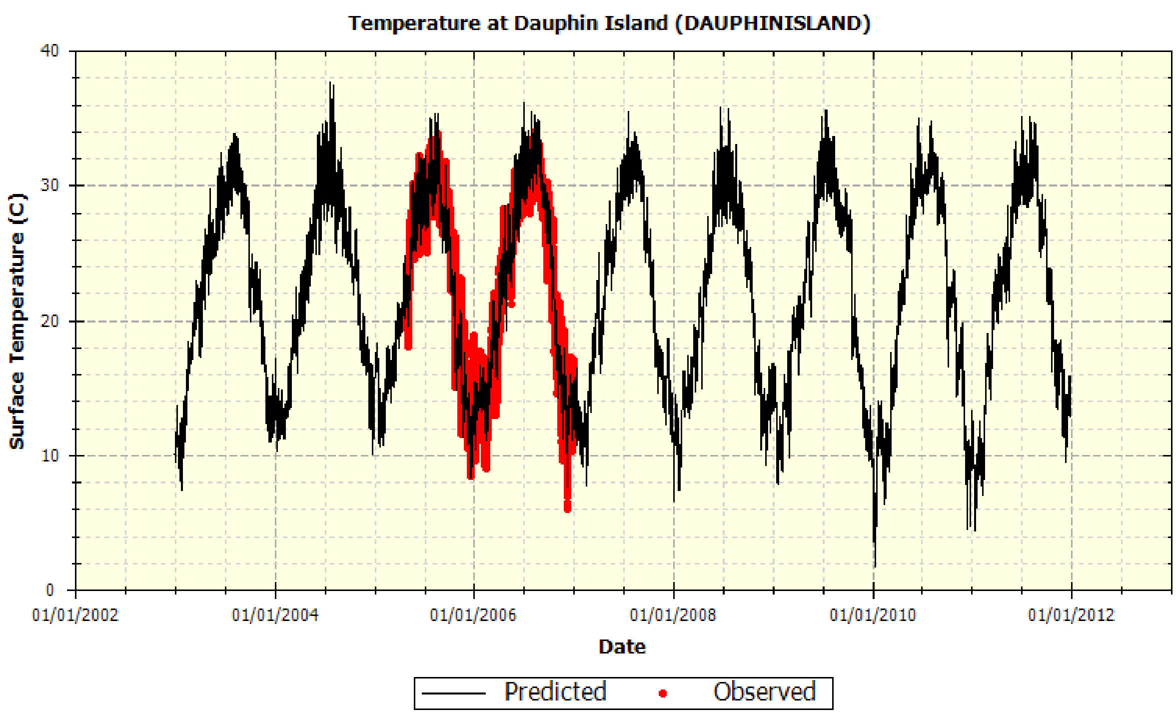


Figure C-12. Temperature from 2003 to 2011 at Dauphin Island

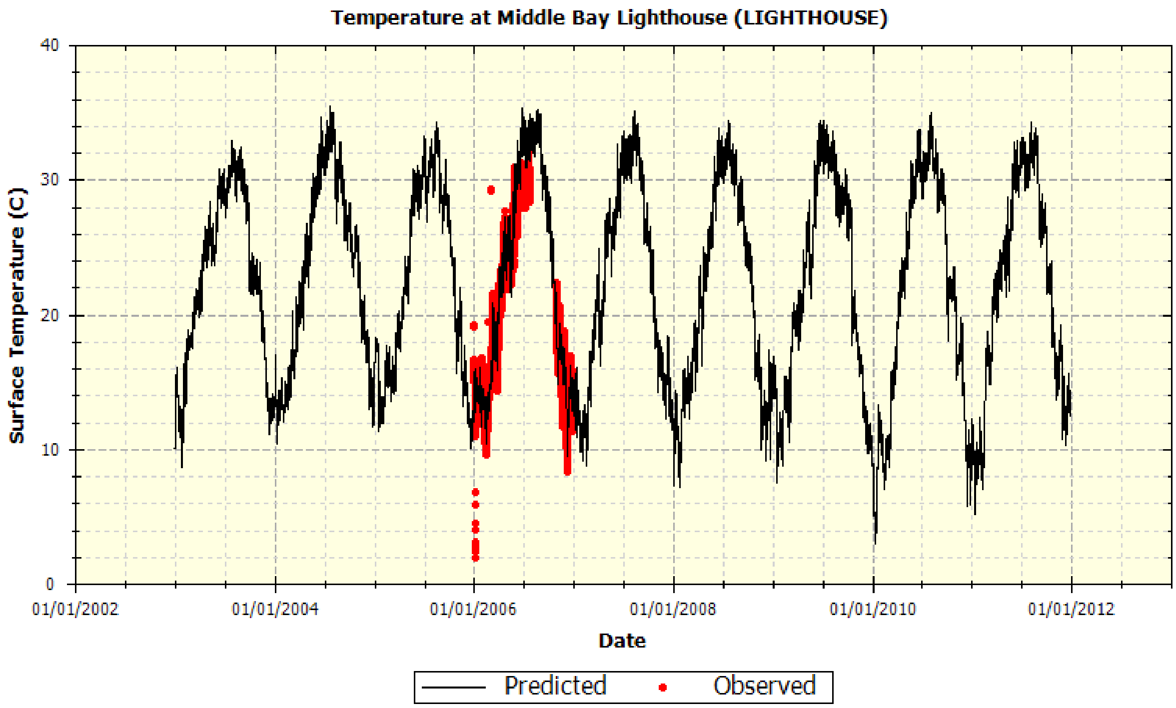


Figure C-13. Temperature from 2003 to 2011 at Middle Bay Lighthouse

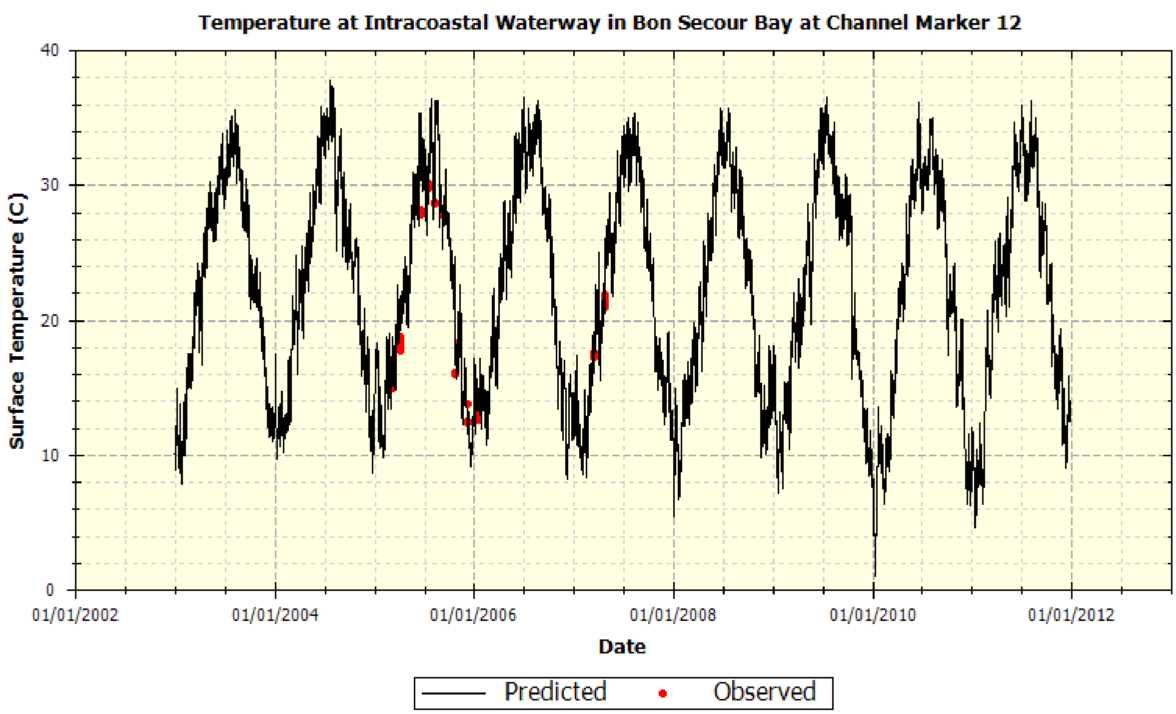


Figure C-14. Temperature from 2003 to 2011 at Intracoastal Waterway in Bon Secour Bay

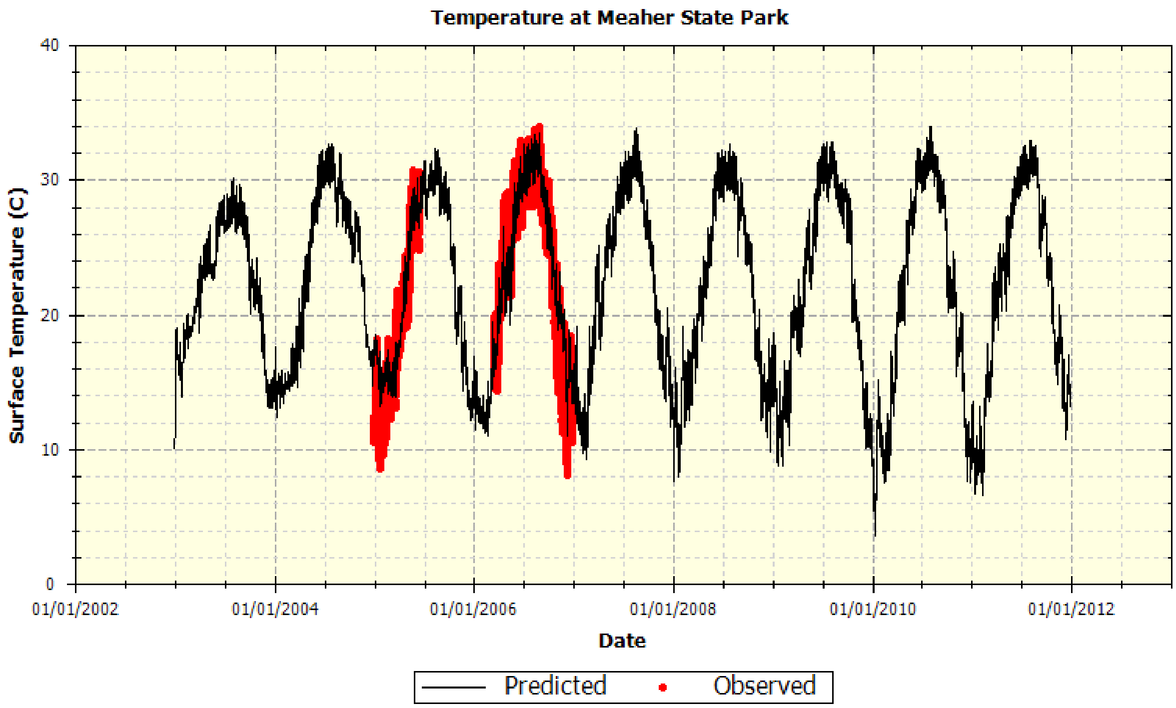


Figure C-15. Temperature from 2003 to 2011 at Meaher State Park

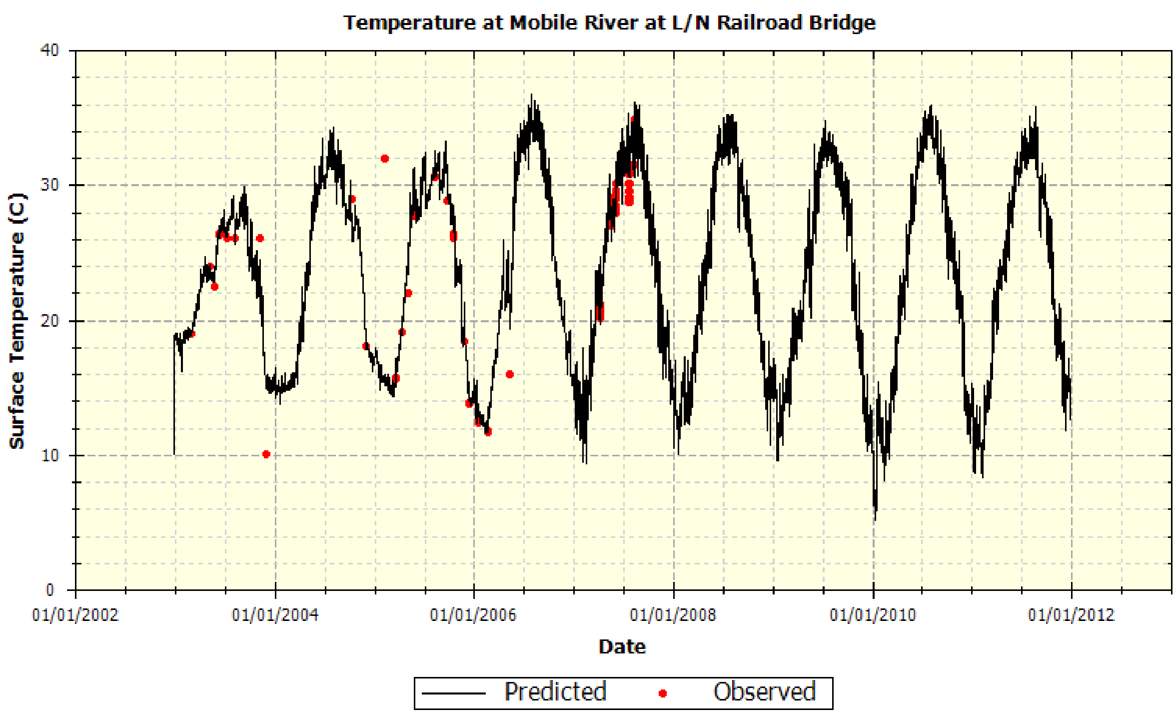


Figure C-16. Temperature from 2003 to 2011 at Mobile River at L/N Railroad Bridge