Hydrodynamic and Water Quality Modeling Report for Peace River and Charlotte Harbor, Florida

September 2009

Region 4 serving the southeast

1. INTRODUCTION

Charlotte Harbor, Florida is on the west side of the peninsula, between Tampa Bay and The Keys. Charlotte Harbor is home the second largest estuary in the state of Florida and the 17th largest in the country. Charlotte Harbor is fed by the Peace and Myakka Rivers. These two watersheds include portions of Desoto, Hardee, Charlotte, Manatee, Sarasota, Polk, and Highlands counties. DO and nutrients criteria were violated in WBIDs 1774, 1948, 1995, 1997, 2054, 2071, 2056A, and 2056B. The impaired WBIDs are shown in Figure 1-1. The water bodies in these impaired WBIDs include Little Charlie Creek, Bear Branch, Myrtle Slough, Hawthorne Creek, Peace River Lower Estuary, and Peace River Mid Estuary. To establish the correct source-concentrations relationships between loadings of nutrients and the in-stream water quality conditions, a fate and transport model for water quality is required. This report documents the development and calibration of a hydrodynamic model and a water quality model to simulate the fate and transport of nutrients, organic materials, and dissolved oxygen (DO) in water bodies in the impaired WBIDs. The model domain covers more water bodies than the impaired WBIDs due to the tidal impact and the model is called Charlotte Harbor Hydrodynamic and Water Quality Model in this report. The EFDC grid does not cover Little Charlie Creek and Bear Branch.

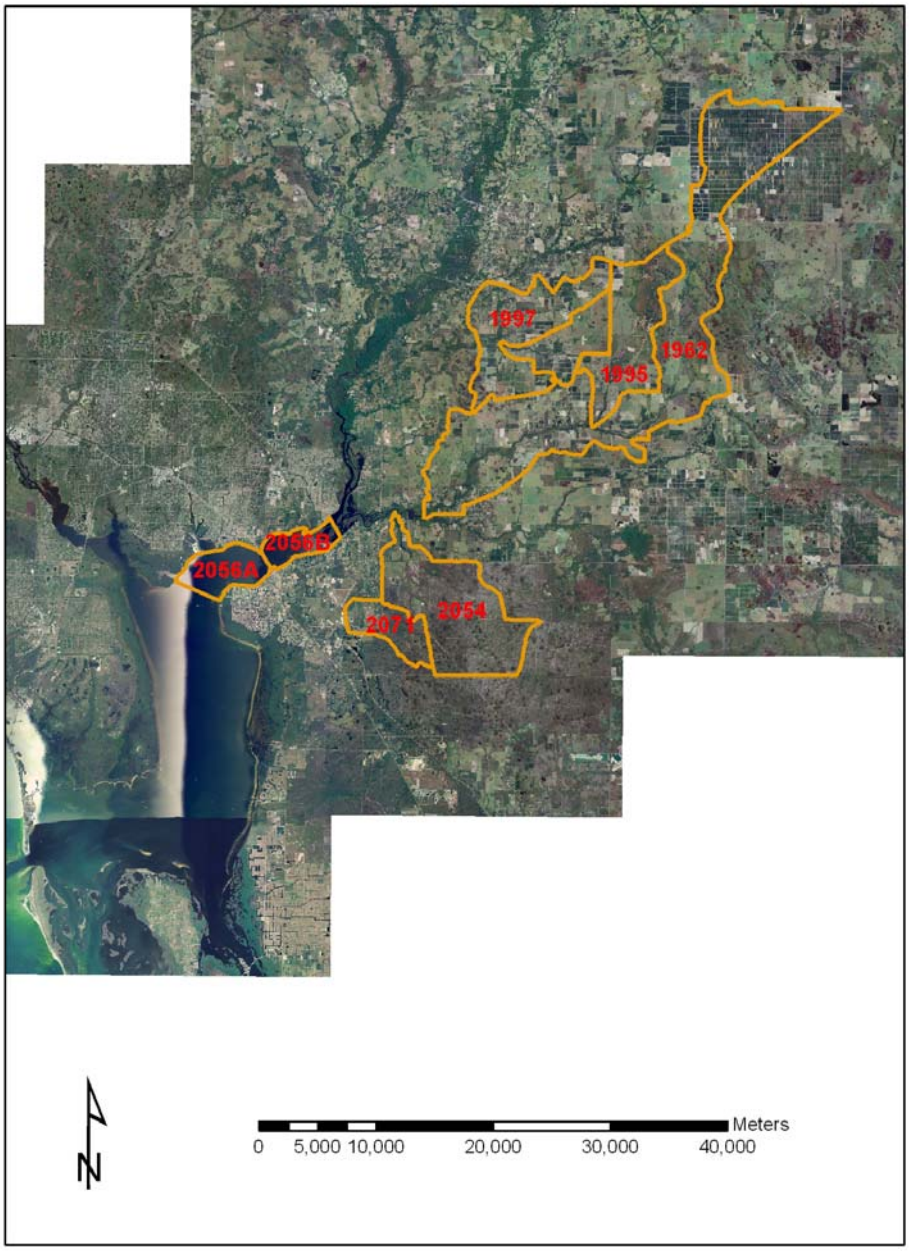

Figure 1-1. Impaired WBIDs in the Peace River Watershed and Charlotte Harbor

2. MODEL SELECTION

2.1 Hydrodynamic Model – EFDC

The Environmental Fluid Dynamics Code (EFDC) model was used to simulate the hydrodynamics and thermodynamics in the modeling domain under the influence of freshwater inflow and tides from the ocean. EFDC is a public domain, general purpose modeling package for simulating one-dimensional (1-D), two dimensional (2-D), and three-dimensional (3-D) flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The model has been extensively tested, documented, and applied to environmental studies worldwide by universities, governmental agencies, and environmental consulting firms. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications. This model is now being supported by the U.S. Environmental Protection Agency (EPA) and has been used extensively to support Total Maximum Daily Load (TMDL) development throughout the United States.

The physics of the EFDC model, and many aspects of the computational scheme, are equivalent to the widely used Blumberg-Mellor model. The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motions 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-Yamda level 2.5 turbulence closure scheme. The EFDC model uses a stretched or sigma vertical coordinate and Cartesian or curvilinear, orthogonal horizontal coordinates.

The numerical scheme employed in EFDC to solve the equations of motion uses second order accurate spatial finite differencing on a staggered or C grid. The model's time integration employs a second order accurate three-time level, finite difference scheme with an internal-external mode splitting procedure to separate the internal shear or baroclinic mode from the external free surface gravity wave or barotropic mode. 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 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, free radiation of an outgoing wave 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. The EFDC model implements a second order accurate in space and time,

mass conservation fractional step solution scheme for the Eulerian transport equations for salinity, temperature, suspended sediment, water quality constituents and toxic contaminants. The transport equations are temporally integrated at the same time step or twice the time step of the momentum equation solution. The advective step of the transport solution uses either the central difference scheme used in the Blumberg-Mellor model or a hierarchy of positive definite upwind difference schemes. The highest accuracy upwind scheme, second order accurate in space and time, is based on a flux-corrected transport version of Smolarkiewicz's multidimensional positive definite advection transport algorithm which is monotonic and minimizes numerical diffusion. The horizontal diffusion step, if required, is explicit in time, while the vertical diffusion step is implicit. Horizontal boundary conditions include time variable material inflow concentrations, upwinded outflow, and a damping relaxation specification of climatological boundary concentration. For the temperature transport equation, the NOAA Geophysical Fluid Dynamics Laboratory's atmospheric heat exchange model is implemented. Details of EFDC's hydrodynamic components are provided in Hamrick (1992) and Tetra Tech (2002, 2006a, 2006b, 2006c, 2006d).

In this study, EFDC was driven by watershed model LSPC generated freshwater inflows and tides, and the model provides transport information, water temperature, and salinity to water quality simulation in WASP. EFDC is able to output a WASP format external hydrodynamic file which can automatically identify WASP segments, linkage among WASP segments, and includes all the advection information, water temperature, and salinity.

2.2 Water Quality Model – WASP 7.3

The US EPA Water Quality Analysis Simulation Program (WASP) was used for water quality simulation in the Charlotte Harbor modeling domain. WASP model is a dynamic compartment-modeling program for aquatic systems and can consider the time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange. WASP model uses user specified transport information such as internally specified flow or externally generated hydrodynamic file to calculate the advection of dissolved materials. WASP 7.3 is able to read in the EFDC generated external hydrodynamic file to obtain segmentation information, advection information, water temperature, and salinity. The latest version 7.3 includes eight kinetic modules and the eutrophication module was selected to simulate the organic carbon, dissolved oxygen (DO), nutrients, and phytoplankton. The final parameters simulated include ammonia, nitrate/nitrite, organic nitrogen, orthophosphate, organic phosphorus, CBODu, phytoplankton, and DO. The details of the WASP model can be seen in it's user manual.

2.3 SOD Spreadsheet Model

In addition to WASP7, another model was used to establish a defensible link between instream loads versus SOD for Little Charlie Creek and Bear Branch. An SOD model developed by Quantitative Environmental Analysis (QEA) and modified by Dr. James Martin at Mississippi State University (MSU), was implemented to determine the relative change in SOD by altering the watershed load of CBODu and nutrients. Nutrient and

CBODu parameters were input to the model, and SOD was calibrated to the exiting WASP7 model.

3. HYDRODYNAMIC MODEL DEVELOPMENT

3.1 Overview

The hydrodynamic model for the Charlotte Harbor simulated circulation, water temperature, and salinity under the influences of watershed freshwater inflows and open boundaries. Key components of the hydrodynamic model development included:

- Grid Generation (section 3.2)
- Simulation Period (section 3.3)
- Boundary Conditions (section 3.4)
- Initial Conditions (section 3.5)
- Calibration (section 3.6)

3.2 Grid Generation

In order to configure the EFDC model for Charlotte Harbor, the modeling domain needs to be divided into grids so that the governing equations can be solved. EFDC is able to use boundary-fitted curvilinear-orthogonal grid to best represent the complex shoreline and to reduce the total amount of grids to save computation time. The Charlotte Harbor grid was generated using the EFDC tool gefdc program. For the harbor portion, a horizontally two dimension representation was used. For the narrow channels upstream, one dimension representation was used. The generated grid includes 445 cells and is shown in Figure 3-1. Vertically, the water columns were divided equally to two layers for all the cells.

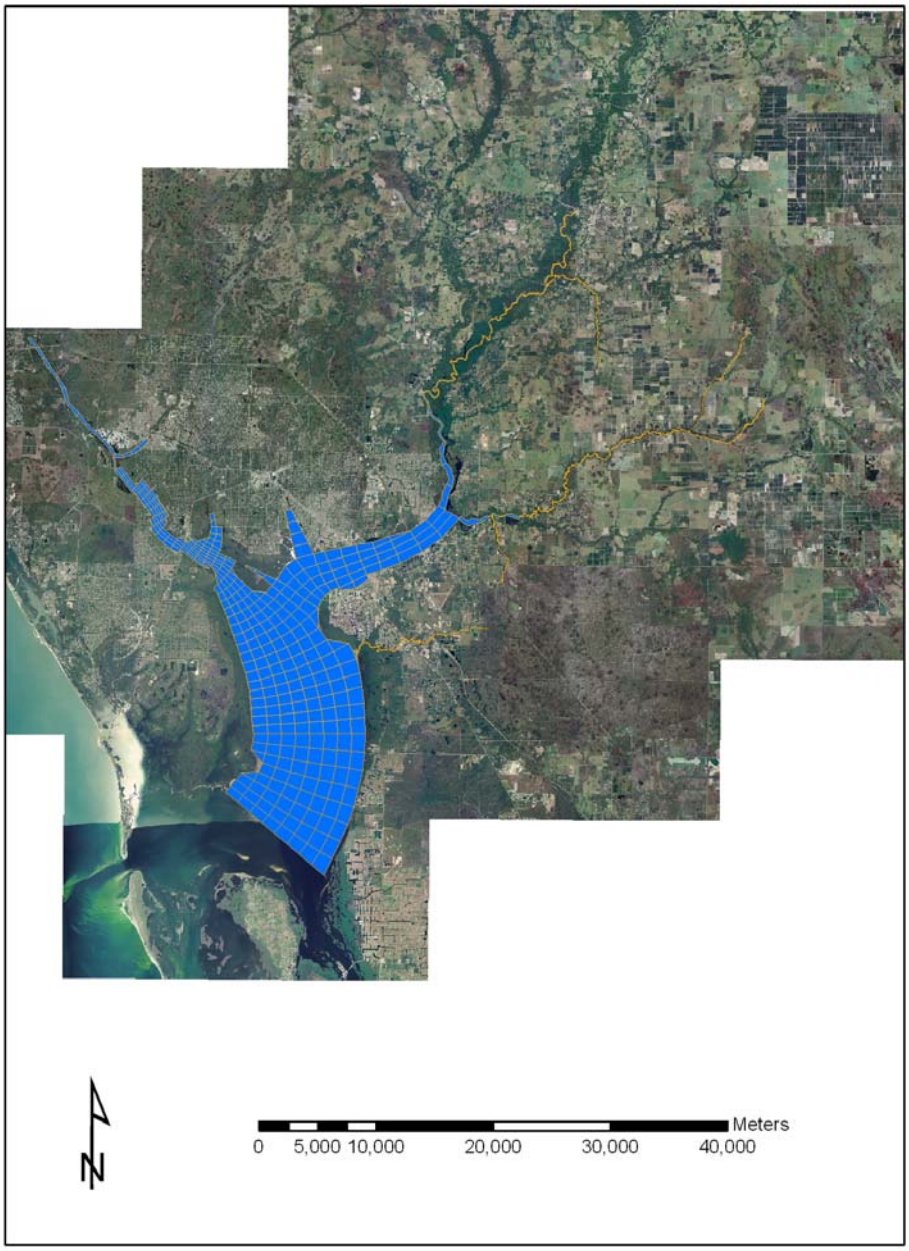

Figure 3-1. Generated grid for the hydrodynamic model EFDC

3.3 Simulation Period

Several factors were considered to determine the hydrodynamic model simulation period. Ideally, EFDC model could simulate the hydrodynamics in Charlotte Harbor for the same period as the LSPC model for entire watershed. However, the computation cost of EFDC is much higher than LSPC. Furthermore, the ultimate purpose of running EFDC is to provide information to drive the water quality simulation in WASP. The EFDC generated external hydrodynamic files include advection information, water temperature, and salinity for each time step for all the WASP segments. The file size can be extremely high that the current computer may not be able to handle. After reviewing the watershed inflow time series and the water quality data available for the entire watershed, we determined to run the EFDC model for three years from January 1, 2002 to December 31, 2004 with the first year as the spin-up period. Overall, 2003 is relatively dryer and 2004 is relatively wetter. Therefore, the simulation period covered both wet and dry conditions.

3.4 Boundary Conditions

The circulation of water and the thermodynamics in the modeling domain are driven by boundary conditions. Three types of boundary conditions are required for the Charlotte Harbor model including the upstream and lateral inflow boundary conditions, open boundary conditions, and the meteorological conditions. The details are presented below.

3.4.1 Upstream and lateral flow boundary conditions

Watershed inflows provide freshwater to the streams and harbor and are one key factor governing the circulation in the harbor. The watershed inflows are provided by the watershed model LSPC. For the upstream locations, the modeled flows out of LSPC reaches were converted to EFDC flow time series format. In addition to the upstream locations, some channels in the modeling domain receive water from the drainage sub-watersheds as the total runoff. The LSPC generated total runoff time series were converted to EFDC flow time series format.

In addition to flow, water temperature associated with the watershed inflows is required for modeling the thermodynamics in the Charlotte Harbor. The watershed model LSPC did not simulate water temperature, and the water temperature data measured at USGS gage station 0229700 were used for all the watershed inflows.

The watershed inflows are considered as pure freshwater and the salinity associated with these inflows were set to 0 psu.

3.4.2 Downstream open boundary conditions

The hydrodynamics in the Charlotte Harbor modeling domain is also influenced by the open ocean through tides. Flood tides bring salt water toward upstream and ebb tides flush material out of the harbor. The tide data at Port Boca Brande were used as the elevation boundary conditions as shown in Figure 3-2.

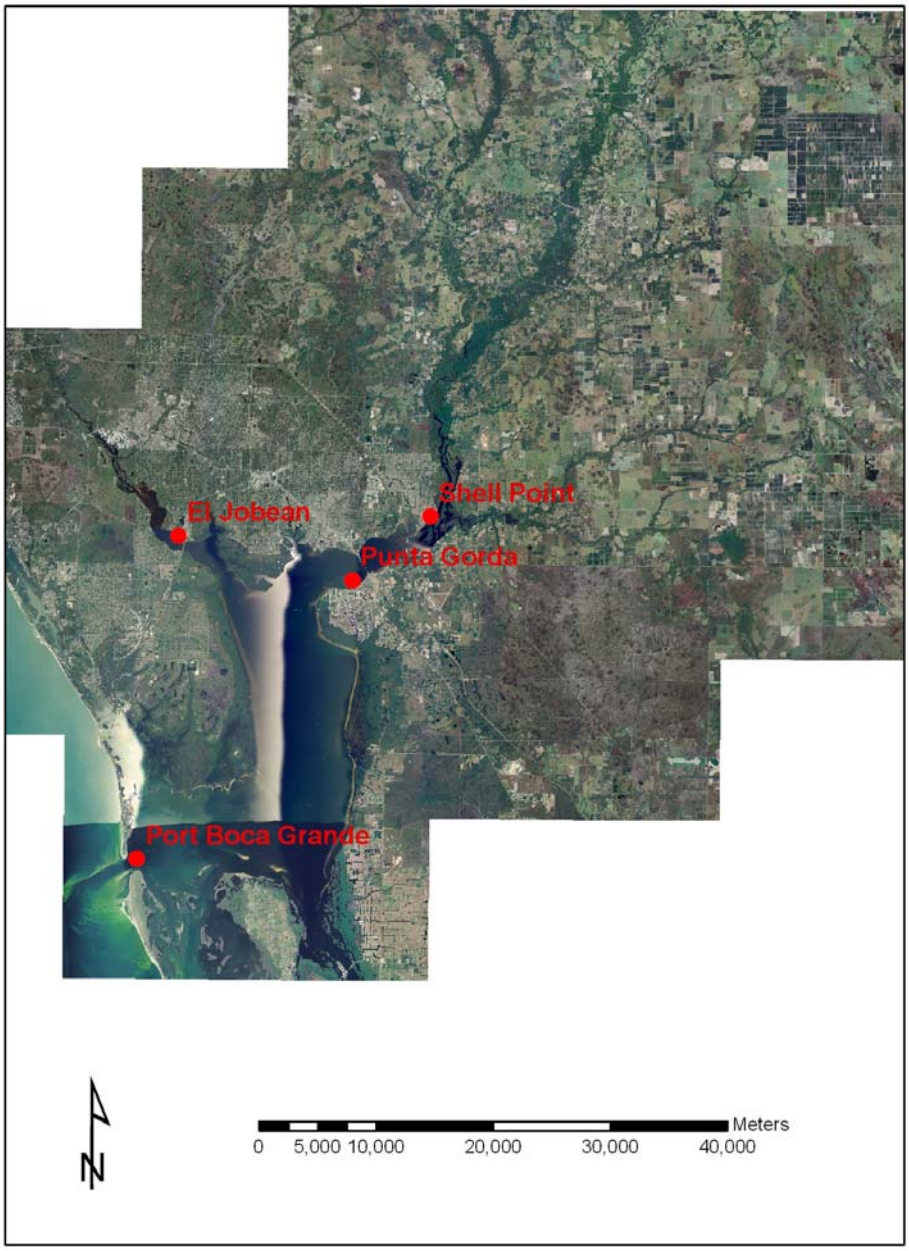

Figure 3-2. Tide stations in Charlotte Harbor

Water temperature and salinity from the open ocean along with tides can change the physical environment in the harbor too. The water temperature at the open boundary locations was assumed to be same as the observed water temperature at USGS station

0229700 because no observed water temperature data were available. Salinity boundary conditions were set to a constant 35 psu.

3.4.3 Meteorological conditions

Circulation of water and water temperature are strongly influenced by wind, air temperature, solar radiation, and air pressure. EFDC model requires input of wind speed, wind direction, air temperature, relative humidity, solar radiation, cloud cover, precipitation, and evaporation. Weather station at 12871 (Sarasota at Bradenton) was used. The raw data were obtained from this station and were processed to the EFDC time series format.

3.5 Initial Conditions

As a dynamic model, EFDC requires initial conditions to start the computation. Initial water surface elevations were set to 0; initial water temperatures were set to 20 degree Celsius; and salinities were set to 20 psu. Once the computation starts, the boundary conditions drive the model and the initial values were replaced with simulated values quickly.

3.6 Calibration and Validation

Once the hydrodynamic model was configured, model testing was performed. Traditionally, model testing is often carried out in two steps—calibration and validation. First, calibration is done for one period with adequate available field data. Calibration refers to adjusting or fine-tuning the modeling parameters to produce an adequate fit of the simulated output to the field observations. The calibrated model is then used to simulate an independent period for which field data under different environmental conditions are available for comparison. This is known as validation. For the validation run, most model process controlling parameters, except those for which field measurements are available, are held at values used during model calibration. Results of the validation run are then compared with field data for the same period, and a decision is made as to whether predictions and observations are close enough to consider the model valid for predictive purposes. If validation results are not adequately close, the model process controlling parameters are adjusted accordingly, and the calibration and validation process is repeated. This is done iteratively until the results are adequate to consider the model valid for predictive purposes. The Charlotte Harbor model simulates from 2003 to 2004, which covers both wet and dry years. Because the model was run continuously for this period, it was deemed appropriate to combine calibration and validation. That is, instead of dividing the data into two separate periods, one for calibration and another for validation, all available data were used to support model calibration for the entire period. This approach inherently considers validation because the model is optimized for the entire range of available data. Calibration of the Charlotte Harbor model involved examining the model water surface elevations, water temperature, and salinity to evaluate if the model reacts correctly to boundary conditions and the physical processes are represented reasonably.

3.6.1 Water surface elevations

Water surface elevations are determined by tides, freshwater inflows, and bathymetry in such local scale model. The influences of atmospheric pressure and wind storm are not significant. Three tidal stations are located inside the modeling domain as shown in Figure 3-2. Comparisons of modeled and observed water surface elevations are shown in Appendix A. Overall, the model captured the magnitudes and phases of the elevation change caused by tides and freshwater inflows. Discrepancies between model and data are due to several reasons. The open boundary location is still inside Charlotte Harbor and the tide data used as elevation boundary conditions are not strictly open ocean tide data. The LSPC generated flows agrees well with observed flow data in terms of the overall water volume. Higher or lower peak flows were generated from the watershed model than the actual flow and caused the deviation of modeled water surface elevations from the observed data.

3.6.2 Water temperature

Water temperature is a key parameter in both hydrodynamic and water quality simulation. Water density and water quality reaction kinetics are all related to water temperature. Water temperature is governed by temperatures associated with freshwater inflows, tidal flow, and meteorological conditions. Modeled water temperature results were compared to observed water temperature at 10 stations inside the modeling domain as shown in Figure 3-3. The comparisons of modeled and observed water temperature are shown in Appendix B. In general, modeled water temperature agrees well with data at all the stations. The model results also show that water temperature at the upstream locations are influenced significantly by the watershed inflows and changes more quickly than the lower harbor portion where tidal effect is strong.

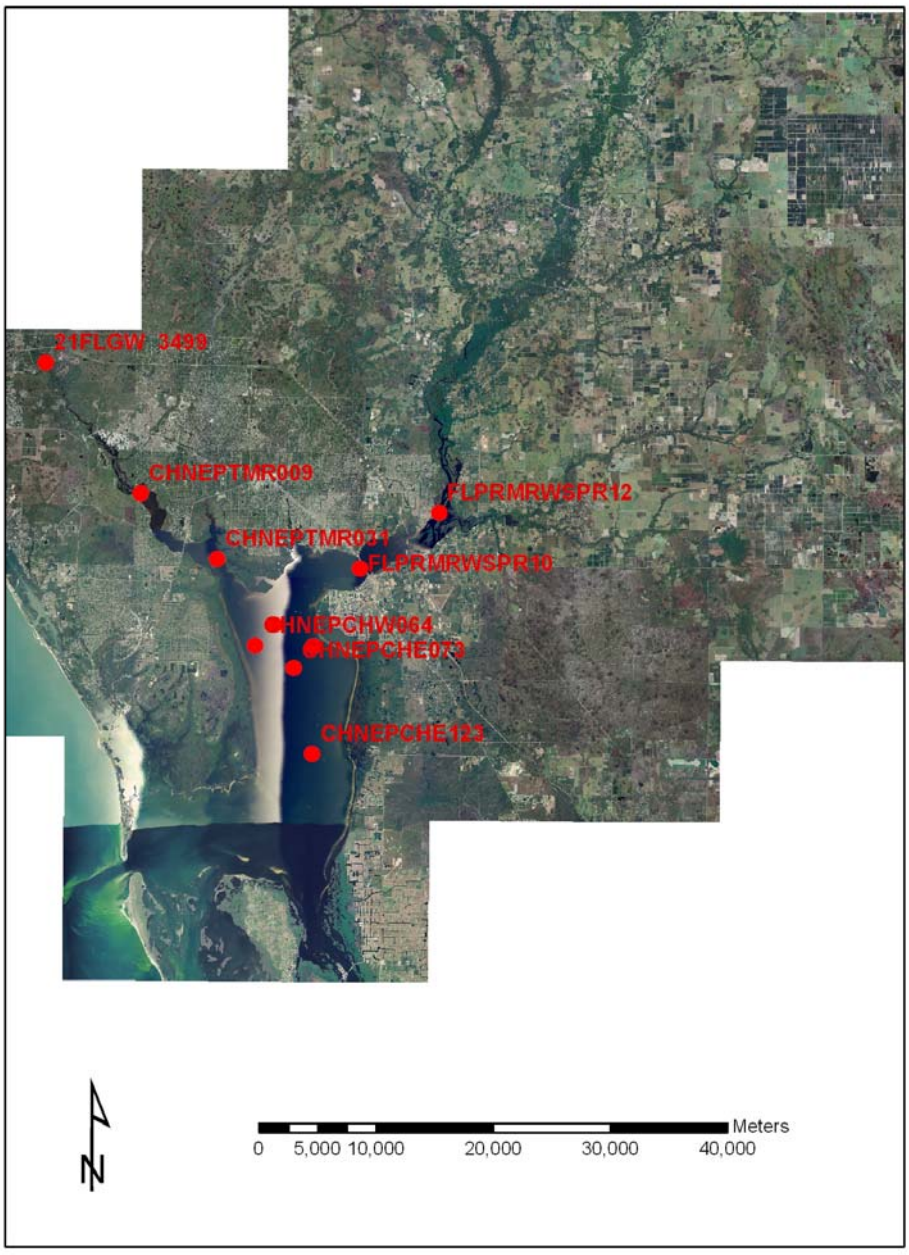

Figure 3-3. Calibration locations for the Charlotte Harbor Hydrodynamic and Water Quality Model

3.6.3 Salinity

Salinity can change water density and saturation level of DO, and is an important parameter in hydrodynamics simulation. Salinity levels in the model are determined by the freshwater inflows and tidal flows. Salinity in the freshwater inflows was set to 0 and from the tidal flows was set to 35. The modeled results of salinity were compared to data at 10 stations inside the harbor at the same locations for water temperature (Figure 3-3). The comparisons of modeled and observed salinity are shown in Appendix C. In general, salinity is very low at the upstream channels where freshwater inflows dominate. Salinity in the harbor can change dramatically in short time period due to the combination of freshwater inflow and tidal flow. Salinity levels at the lower harbor near the boundary are much higher than the upper harbor. However, the salinity levels are much lower than the open ocean salinity. The discrepancies between modeled and observed salinity are due to the uncertainties associated with modeled watershed inflows and lack of observed open boundary salinity.

4. WATER QUALITY MODEL DEVELOPMENT

4.1 Overview

The water quality model for the Charlotte Harbor simulated CBOD, DO, nutrients, and algae dynamics under the influences of point source and non-point source loadings. WASP is a pure water quality model that requires user defined advection terms among computational segments. WASP views each segment as a control volume and solves transport and reactions based on the control volumes. For the Charlotte Harbor model, segmentation, advection, water temperature, and salinity are provided by the hydrodynamic model EFDC using an externally generated file. Key components of the water quality model development included:

- Segmentation (section 4.2)
- Simulation Period (section 4.3)
- Boundary Conditions (section 4.4)
- Initial Conditions (section 4.5)
- Calibration (section 4.6)

4.2 Segmentation for WASP

Computational segments for WASP was determined by the EFDC generated external hydrodynamic file. The Charlotte Harbor model has a total of 858 segments with 429 segments corresponding to the surface layer and 429 segments corresponding to the bottom layer in the EFDC model. Because WASP can not deal with open boundary conditions, the elevation boundary conditions in the hydrodynamic model were converted to flow boundary conditions in the EFDC generated hydrodynamic file. The initial volumes of the segments are also provided by the hydrodynamic file.

4.3 Simulation Period

The simulation period was from January 1, 2003 to December 31, 2004. The EFDC generated hydrodynamic file stores the advection terms, water temperature, and salinity for each time step for all the segments. From the hydrodynamic simulation results, it appeared that the initial conditions disappear quickly due to the strong influence of watershed inflows and tidal flows.

4.4 Boundary Conditions and Loadings

For the segments with flow boundary conditions, concentrations of water quality constituents are required to provide external supply of nutrients, organic materials, and DO. The flow boundary locations include the watershed inflow locations and the tidal flow locations. LSPC modeled concentrations of ammonia, nitrate/nitrite, organic nitrogen, orthophosphate, organic phosphorus, and CBODu were input to WASP for the period from January 1, 2003 to December 31, 2004. For the tidal flows, observed water quality data were used even though the data are very limited.

In addition to the watershed inflows and tidal flows, one point source (PERMIT ID FL0035378) is located within LSPC sub-watershed 2, which directly enters the WASP segment. Daily mass loadings were directly assigned to the receiving WASP segment.

4.5 Initial Conditions

WASP is also a dynamic model which requires initial concentrations for the simulated constituents to start the computation. The initial concentrations of nutrients were set to 0.01 mg/L, initial DO concentrations were set to 8 mg/L, initial chlorophyll *a* concentrations for phytoplankton were set to 1 ug/L, and initial CBODu concentrations were set to 1 mg/L. As mentioned in section 4.3, the initial concentrations changed quickly after responding to the dynamic boundary conditions.

4.6 Calibration and Validation

Due to the same reason for hydrodynamic calibration and validation, the calibration and validation for the water quality model were combined together. The continuous simulation of the model ensures to capture water quality change under all combinations of different watershed inflow, tide, and weather conditions.

Water quality calibration involved examining the major reaction parameters and adjusting the parameters until model results agreed with the data. The model simulated ammonia, nitrate/nitrite, organic nitrogen, orthophosphate, organic phosphorus, DO, phytoplankton, and CBODu. The major kinetic constants adjusted include the nitrification rate, denitrification rate, CBOD decay rate, DO reaeration rate, phytoplankton growth and death rates, and half-saturation concentrations of nitrogen and phosphorus for phytoplankton growth. Calibration focused on comparing modeled and observed DO, nutrients, and phytoplankton. CBODu is also important for the DO concentrations due to the oxygen demand during decay of organic matter. However, there are no CBODu data available for comparison in the modeling domain. The kinetic constants were adjusted after comparing the model results to the observed data until the model results and

observed data agreed well. Table 4-1 lists the calibrated values for the major parameters for water quality simulation. Appendix D shows water quality results at 10 locations same as the hydrodynamic calibration locations (Figure 3-3). In general, the model captured the magnitudes of DO, phytoplankton, and nutrients, and the model responds to boundary conditions correctly. Discrepancies between model and data are mainly due to the uncertainties in the estimations of the watershed loadings.

Table 4-1. Major WASP Kinetic Constants for the Charlotte Harbor Water Quality Model

WASP Kinetic Constants	Values
Nitrification Rate (per day)	0.1
Denitrification Rate (per day)	0.01
Organic Nitrogen Mineralization Rate (per day)	0.03
Organic Phosphorus Mineralization Rate (per day)	0.03
Phytoplankton Maximum Growth Rate (per day)	1.7
Phytoplankton Carbon to Chlorophyll Ratio	33
Phytoplankton Half-Saturation Constant for Nitrogen Uptake (mg/L)	0.005
Phytoplankton Half-Saturation Constant for Phosphorus Uptake (mg/L)	0.001
Phytoplankton Respiration Rate (per day)	0.2
Phytoplankton Death Rate (per day)	0.15
Phytoplankton Phosphorus to Carbon Ratio	0.03
Phytoplankton Nitrogen to Carbon Ratio	0.21
CBOD decay rate (per day)	0.2

4.7 Natural Condition Scenarios

To further understand the causes of the impairments due to current DO and nutrients levels in the Charlotte Harbor modeling domain, an all natural condition scenario was designed. The all natural condition scenario replaced the developed land uses with forest land uses. The LSPC model was re-run to obtain the flow and concentrations of water quality constituents. Watershed inflows were processed to the EFDC format and the hydrodynamics was re-simulated and a new external hydrodynamic file was generated for the WASP model. The boundary concentrations in WASP were re-assigned using the LSPC modeled concentrations under the all natural condition scenario. The model results under the all natural condition scenario were compared with the results under the existing condition as shown in Appendix E. The figures in Appendix E show the results of DO, nutrients, CBODu, and phytoplankton in each WBID under the natural conditions and the results under the existing conditions. It can be seen that modeled DO concentrations in WBID 1997 and 2071 could reach much lower under the existing conditions than the natural condition scenario due to significantly higher watershed loadings of nutrients and organic matter. For other WBIDs, the differences of modeled water quality constituents between the existing condition and the all natural condition are not significant.

To investigate the point source contributions to the water quality, the all natural condition scenario was run again with point sources together. Again, the LSPC model, EFDC model were re-run to obtain the watershed inflows with the influence of point sources and the subsequent change of hydrodynamics. The WASP model was re-run with the updated modeled concentrations of water quality constituents with LSPC. The results are shown

in Appendix F. The figures in Appendix F show the results of DO, nutrients, CBODu, and phytoplankton in each WBID. The differences of modeled water quality constituents between the natural condition and the natural condition with point sources are minimal. Based on the model results, the contributions from point sources are not significant.

5. SUMMARY AND CONCLUSIONS

A hydrodynamic model and a water quality model were developed for the Charlotte Harbor area including the streams in WBIDs that violate DO and nutrient criteria. The hydrodynamic model is based on EFDC and the water quality model is based on WASP 7.3. A watershed model LSPC was developed for provide freshwater inflows to the hydrodynamic model and concentrations of nutrients and organic matters to the water quality model. Water surface elevations, water temperature, and salinity were used for calibration of the hydrodynamics. DO, nutrients, and phytoplankton were used for calibration of the water quality simulation. In general, the hydrodynamic model captured the major trends of circulation which is the result of combined tidal impact and freshwater inflows. Modeled water temperature results agree well with data. The water quality simulation results also show that the model can present the complex physical and biological processes in the modeling domain.

Scenarios were designed to further investigate the causes of the water quality impairments due to low DO and nutrient enrichment. Model results under the all natural condition scenario show that DO could violate the criteria even without developed land uses and contributions from point sources. Model results under the natural condition with point sources show that the point source contributions are not significant to the impairments of the WBIDs.

6. REFERENCES

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Appendix A: Comparison of Modeled and Observed Water Surface Elevations

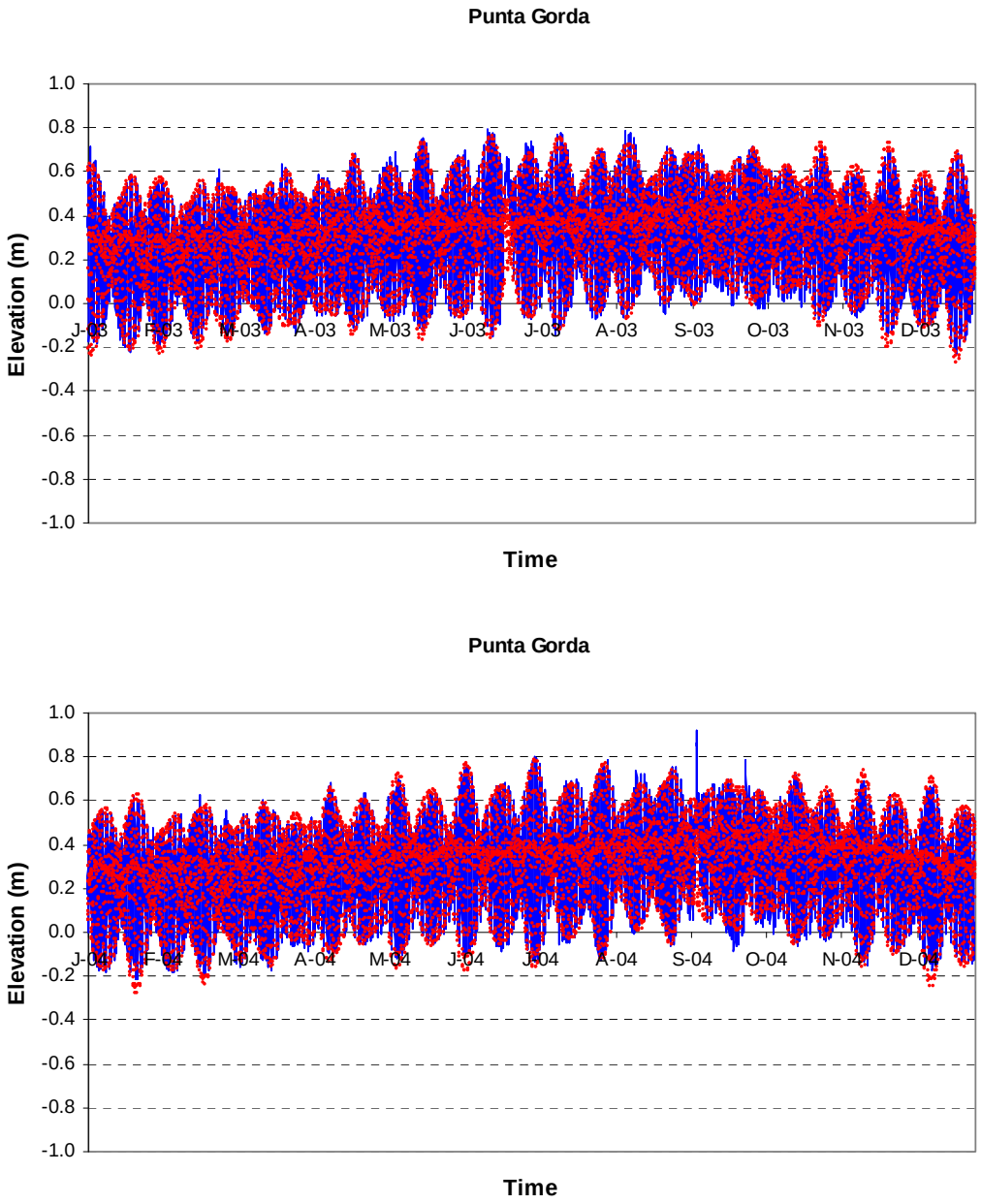


Figure A-1. Modeled vs observed water surface elevation at Punta Gorda, red dots are observed elevation, blue lines are modeled elevation.

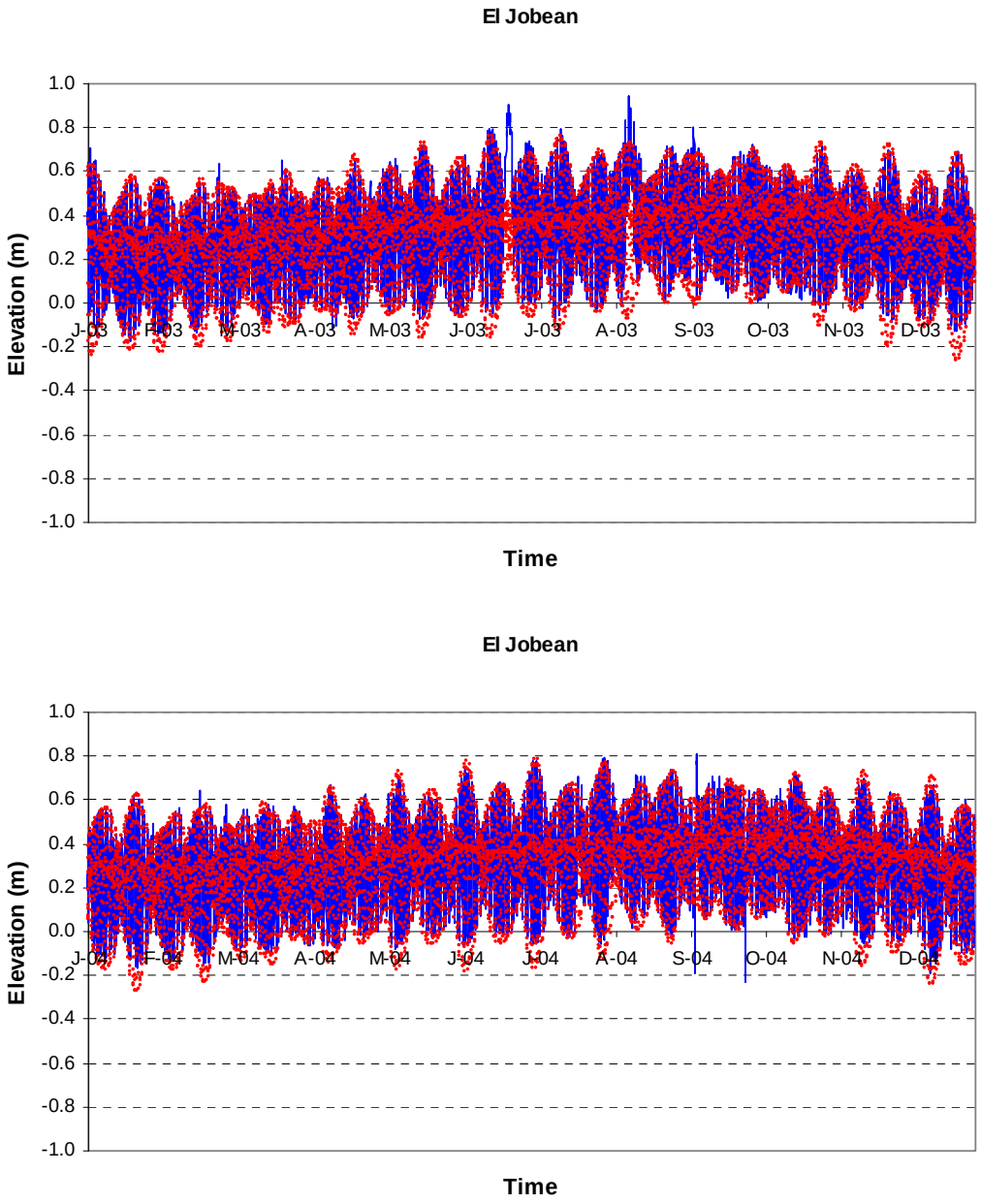


Figure A-2. Modeled vs observed water surface elevation at El Jobean, red dots are observed elevation, blue lines are modeled elevation.

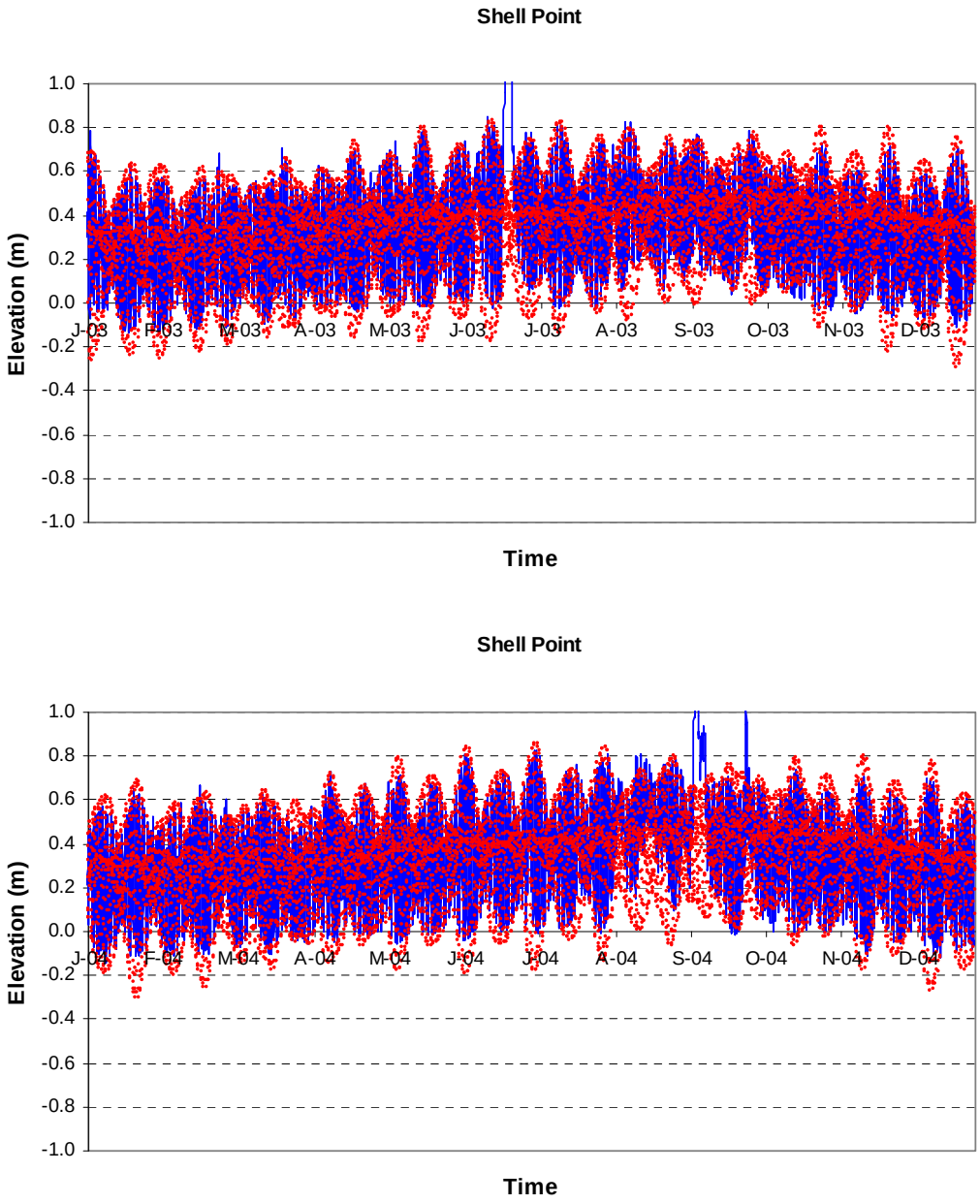


Figure A-3. Modeled vs observed water surface elevation at Shell Point, red dots are observed elevation, blue lines are modeled elevation.

Appendix B: Comparison of Modeled and Observed Water Temperature

Appendix C: Comparison of Modeled and Observed Salinity

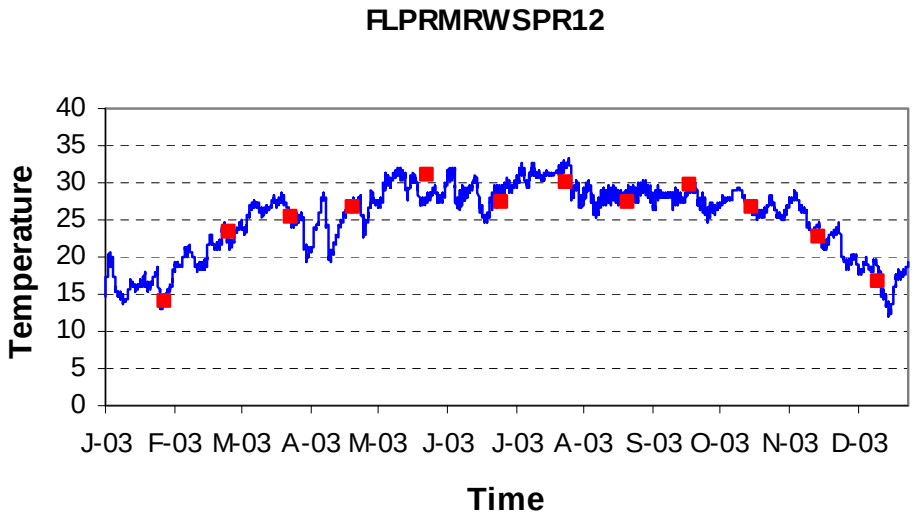
Appendix D: Comparison of Modeled and Observed Water Quality Constituents

Appendix E: Comparison of Modeled Water Quality Constituents between Existing Conditions and All Natural Conditions

Appendix F: Comparison of Modeled Water Quality Constituents between All Natural Conditions and Natural Conditions with Point Sources

Appendix B: Comparison of Modeled and Observed Water Temperature

Red dots are observed water temperature
Blue lines are modeled water temperature
Water temperature unit is Degree Celsius.



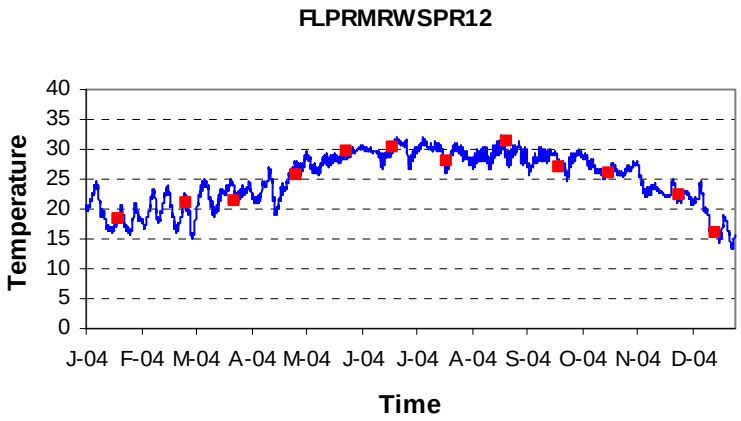
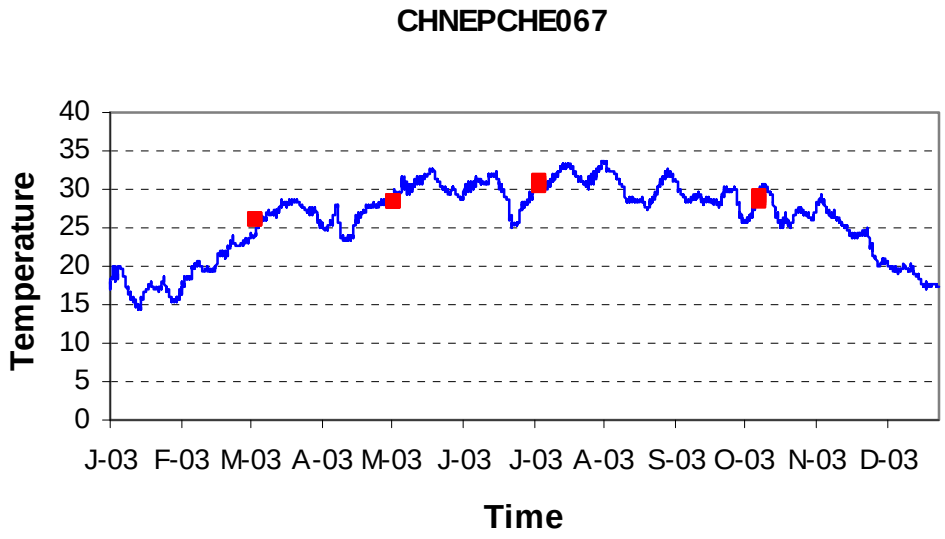


Figure B-1. Modeled vs. observed water temperature at FLPRMRWSPR12



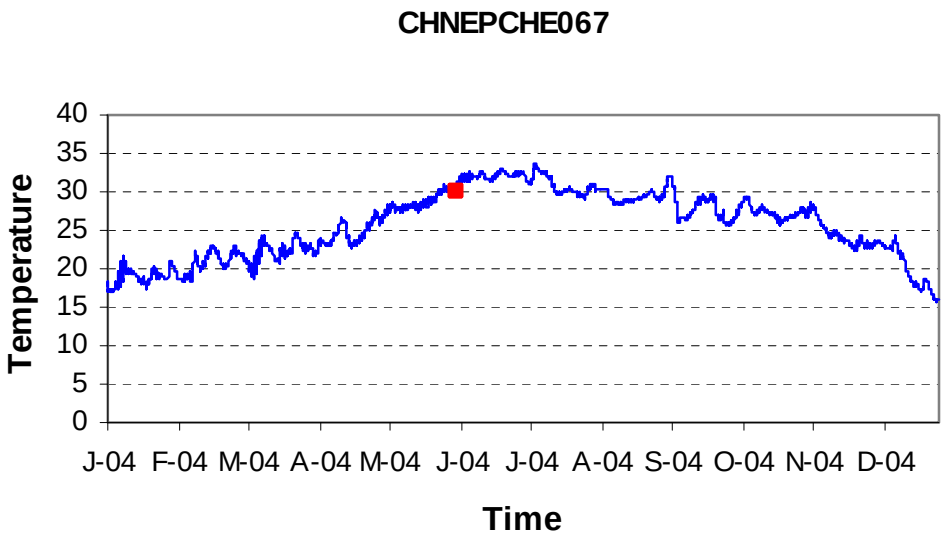
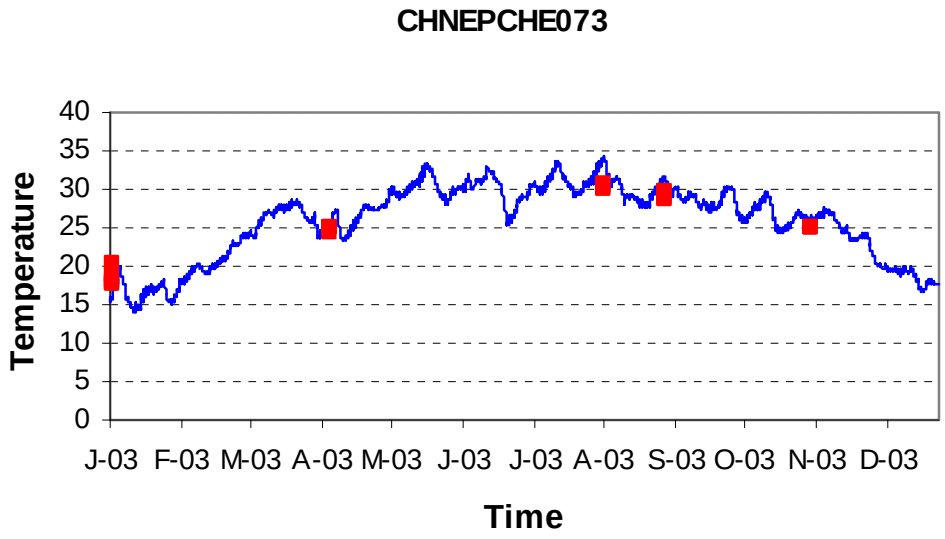


Figure B-2. Modeled vs. observed water temperature at CHNEPCHE067



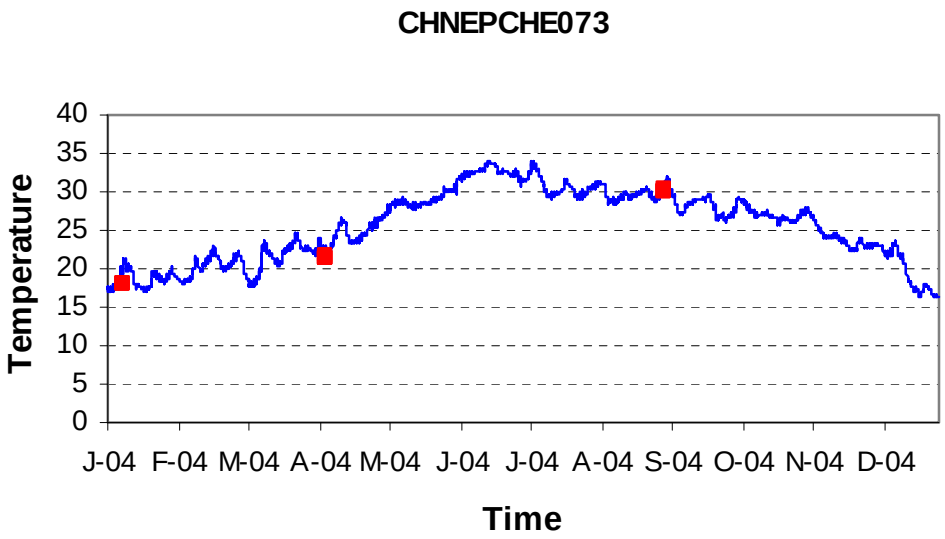
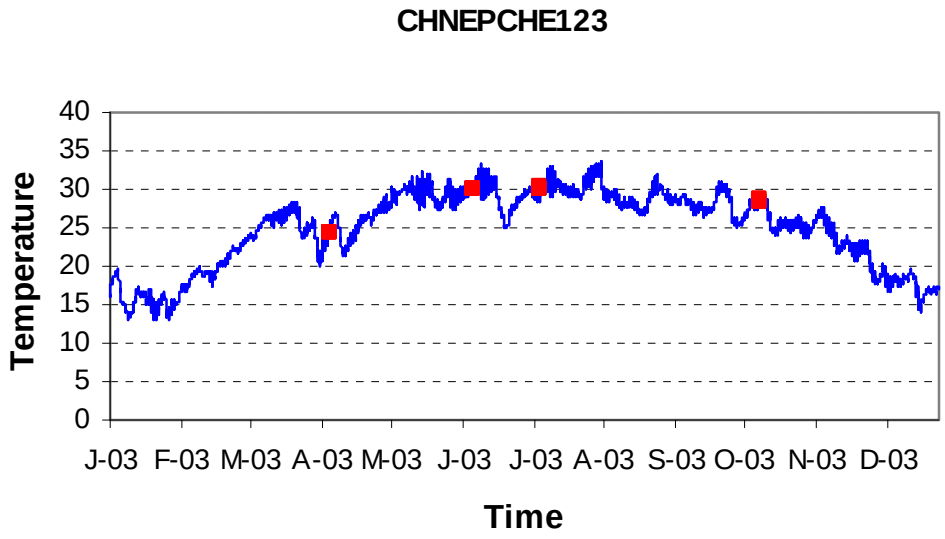


Figure B-3. Modeled vs. observed water temperature at CHNEPCHE073



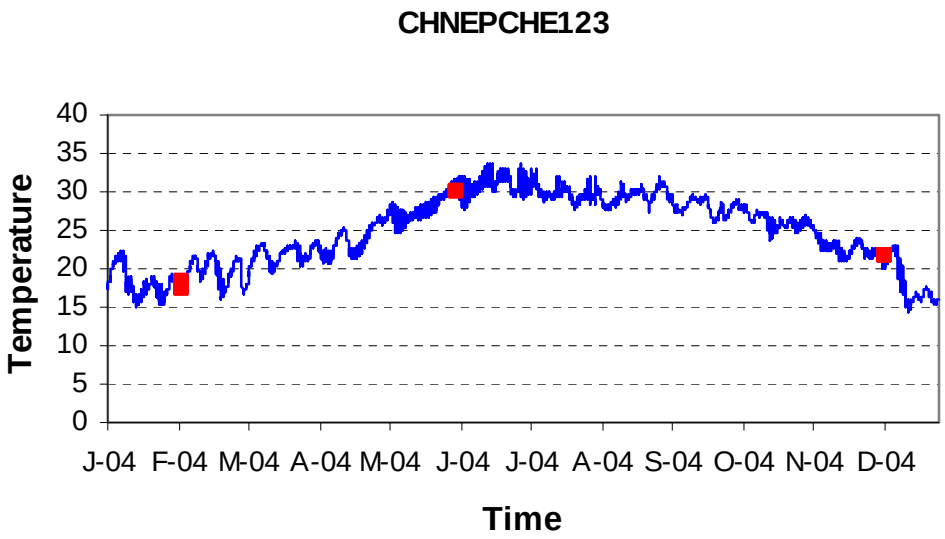
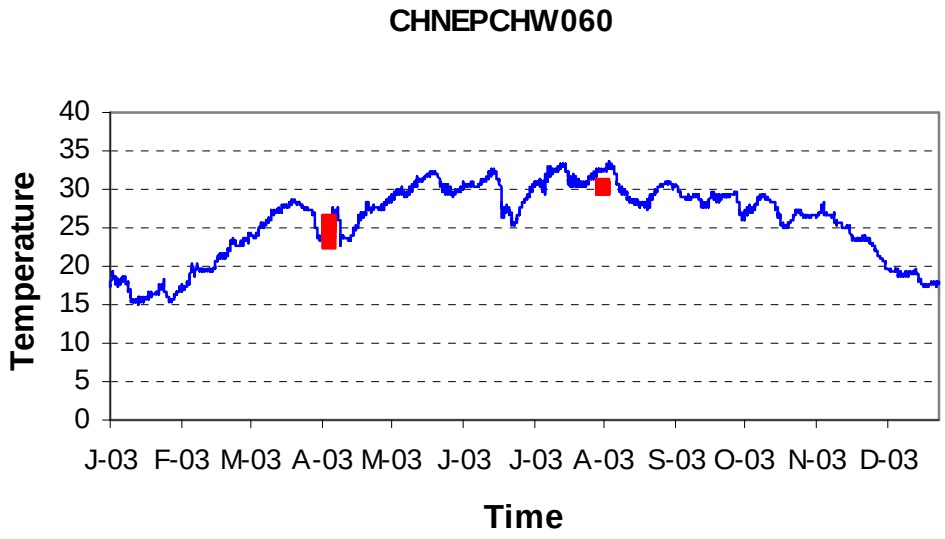


Figure B-4. Modeled vs. observed water temperature at CHNEPCHE123



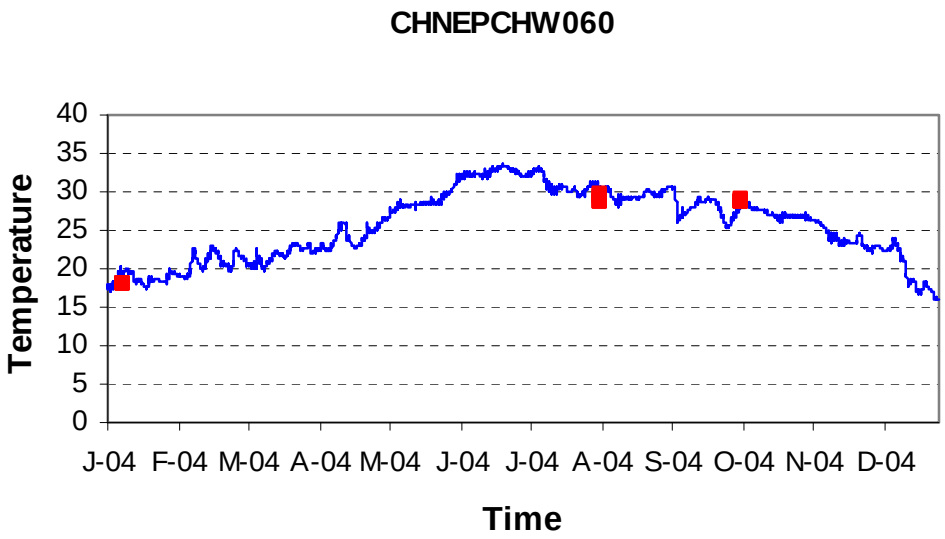


Figure B-5. Modeled vs. observed water temperature at CHNEPCHW060

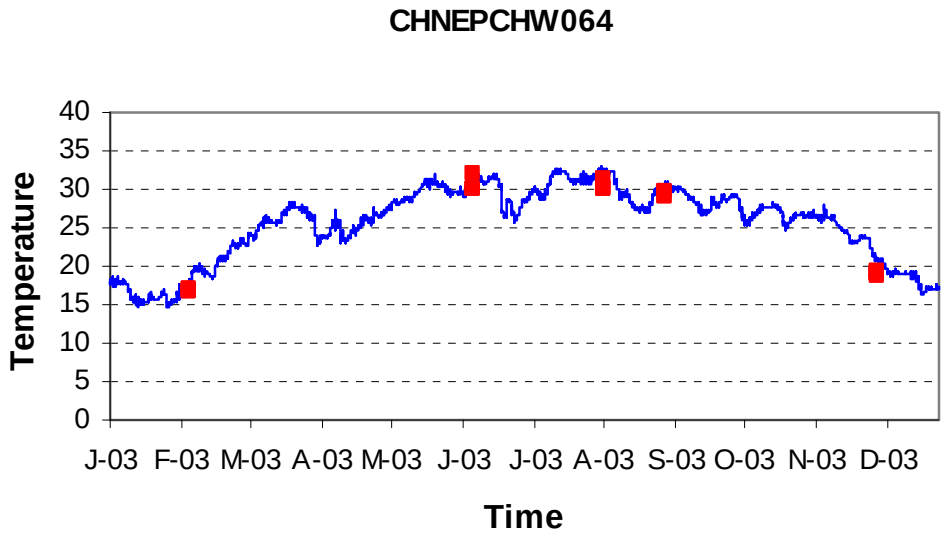
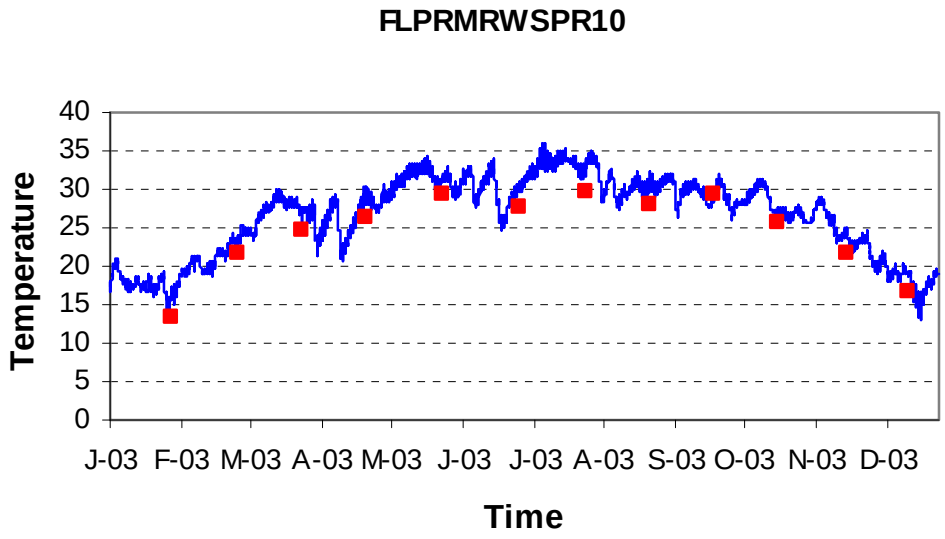


Figure B-6. Modeled vs. observed water temperature at CHNEPCHW064



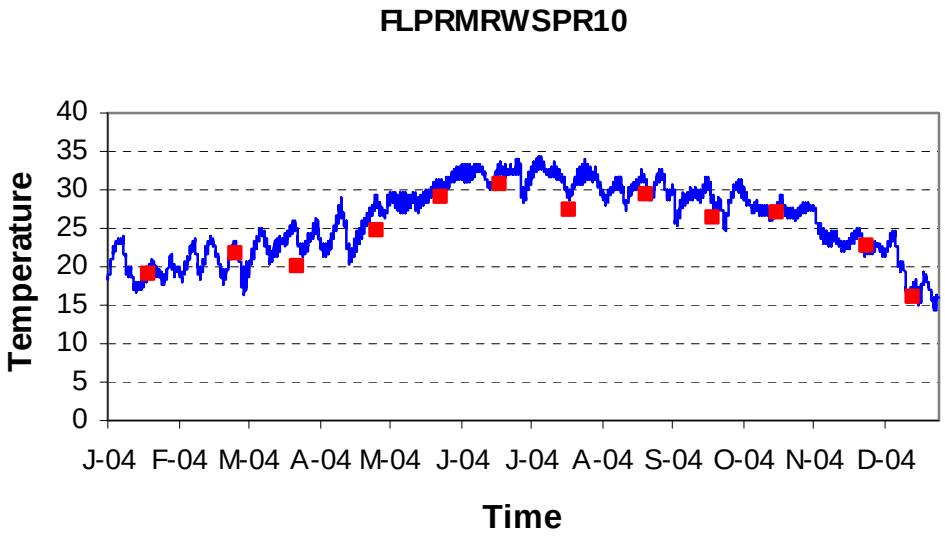
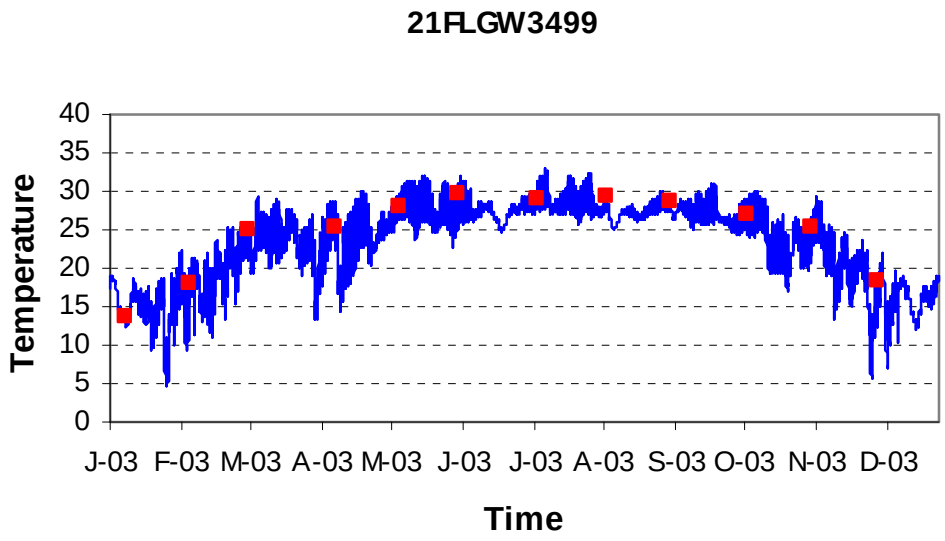


Figure B-7. Modeled vs. observed water temperature at FLPRMRWSPR10



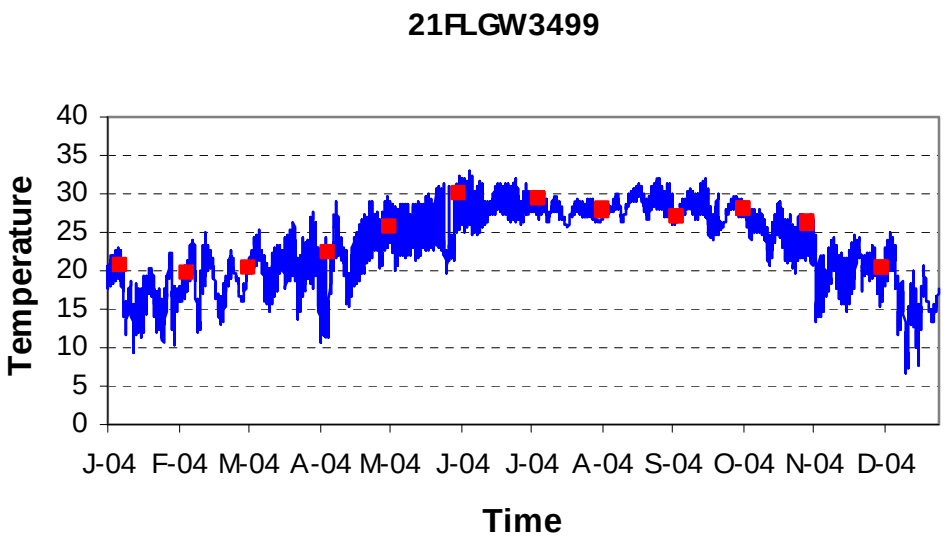
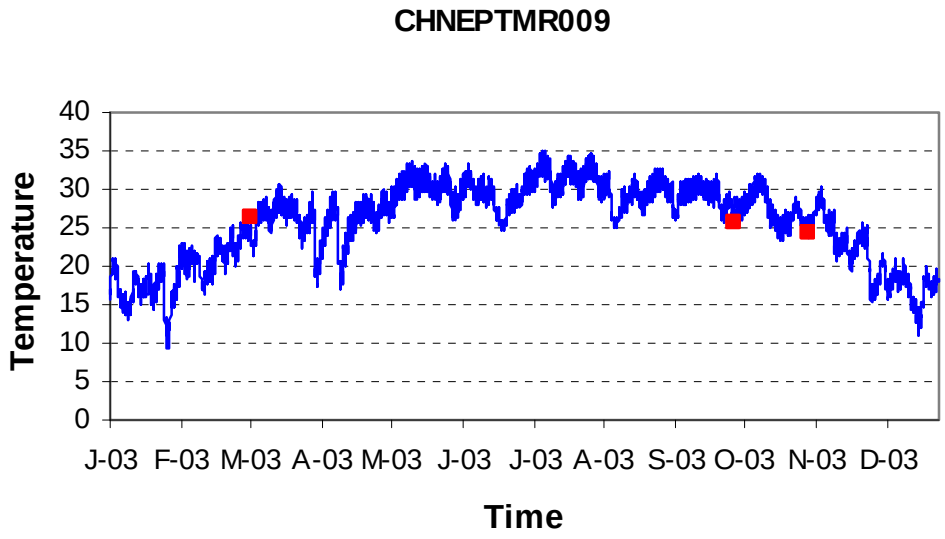


Figure B-8. Modeled vs. observed water temperature at 21 FLGW 3499



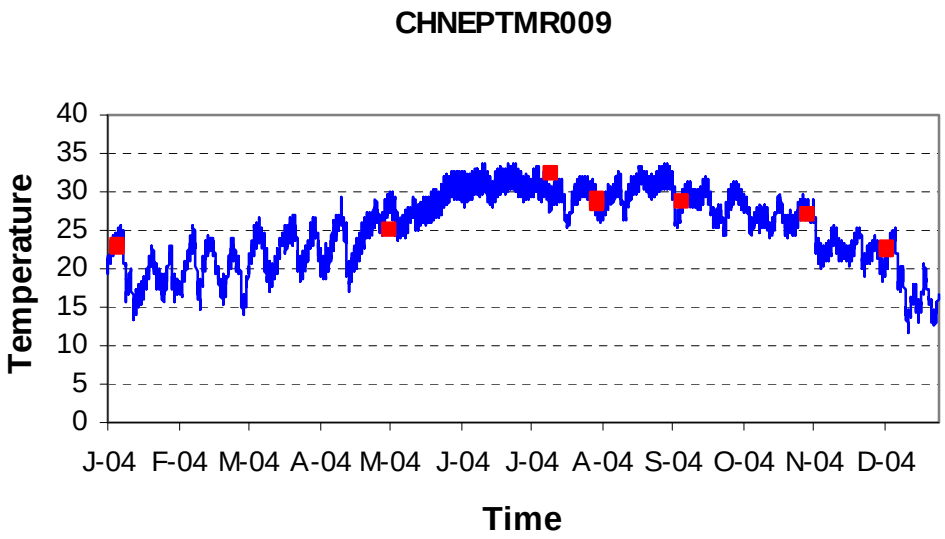
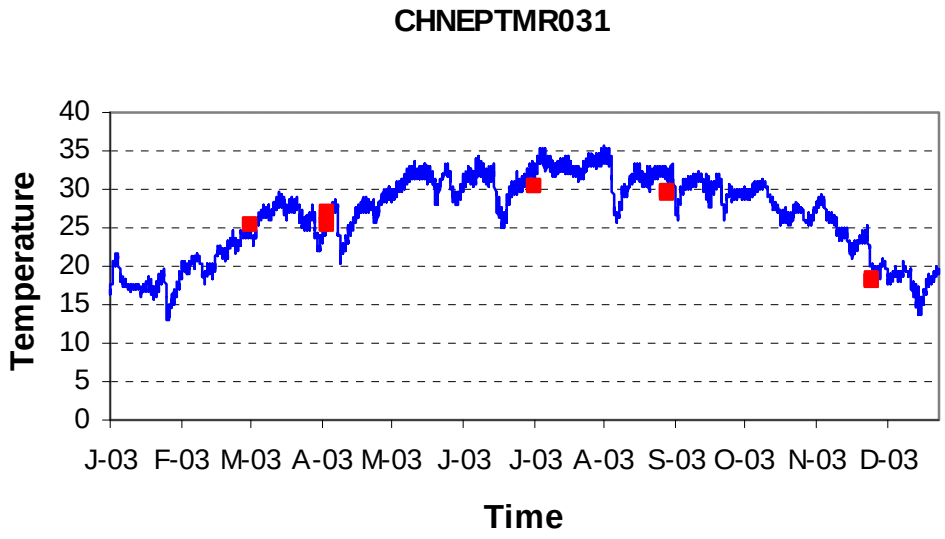


Figure B-9. Modeled vs. observed water temperature at CHNEPTMR009



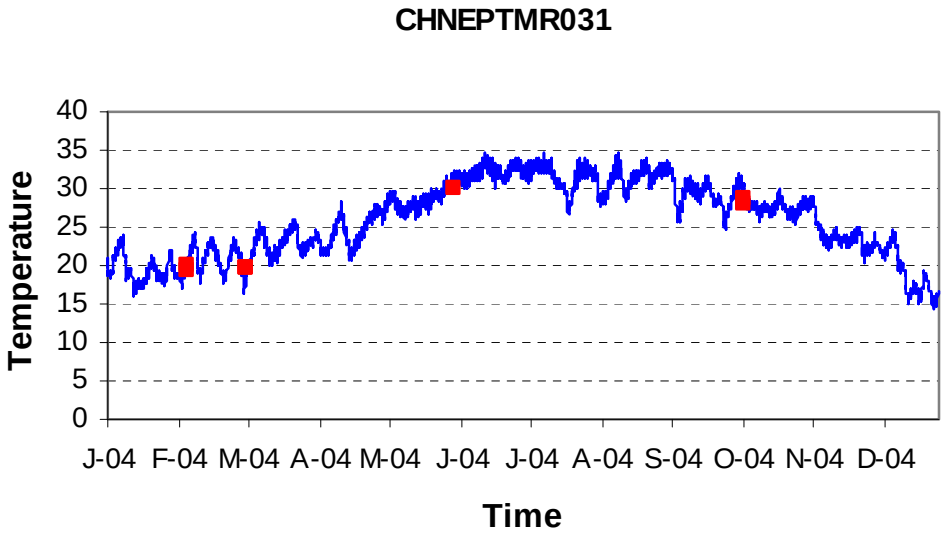
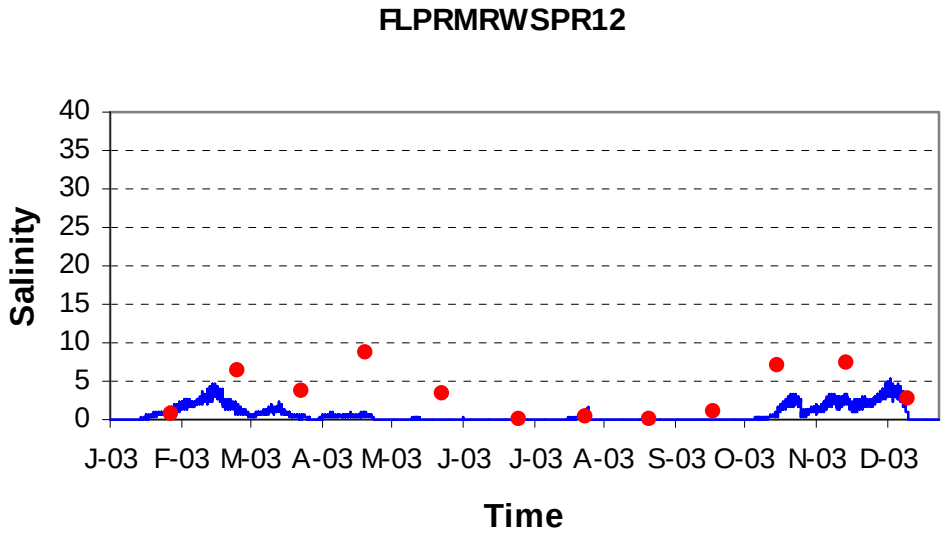


Figure B-10. Modeled vs. observed water temperature at CHNEPTMR031

Appendix C: Comparison of Modeled and Observed Salinity

Red dots are observed salinity
Blue lines are modeled salinity



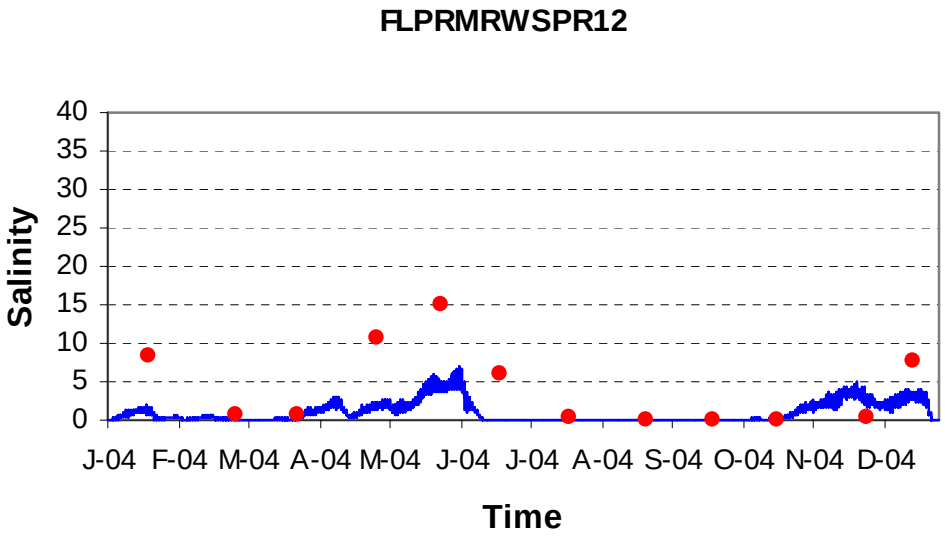
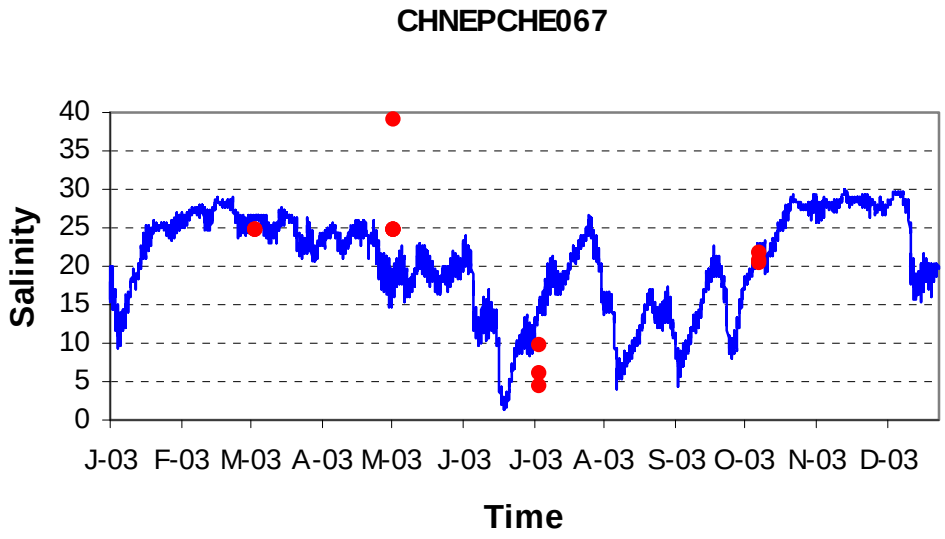


Figure C-1. Modeled vs. observed salinity at FLPRMRWSPR12



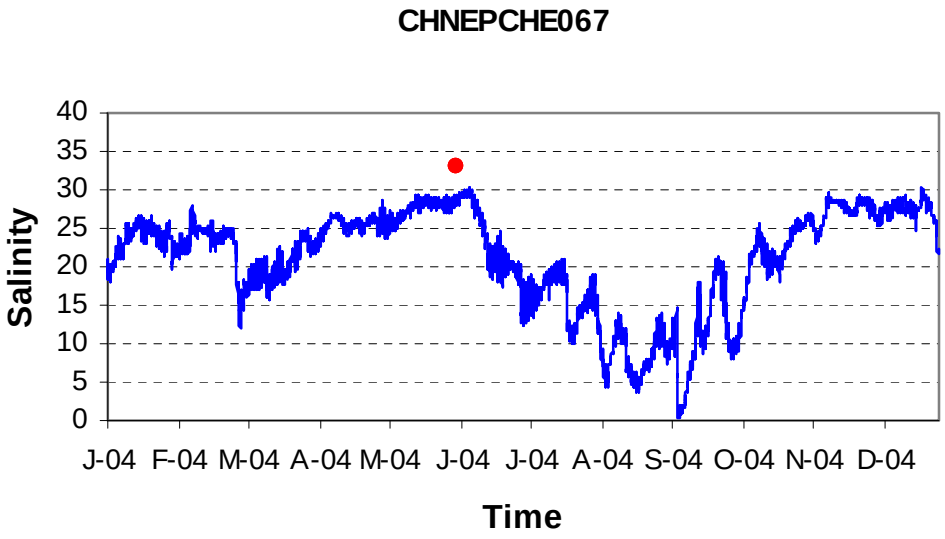
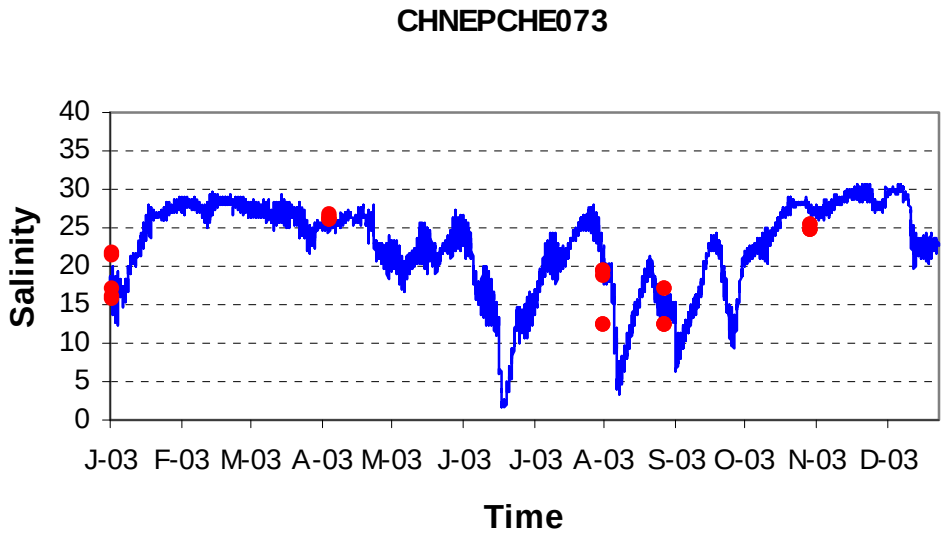


Figure C-2. Modeled vs. observed salinity at CHNEPCHE067



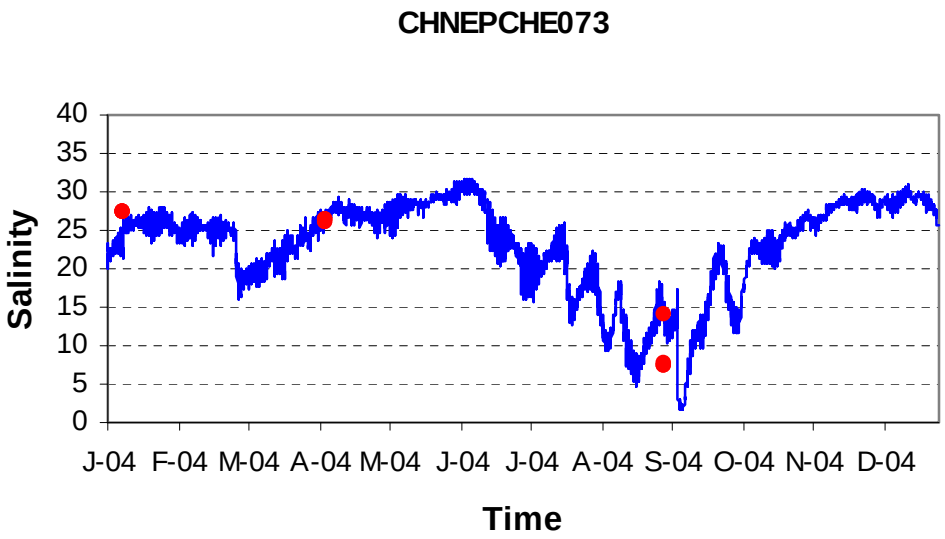
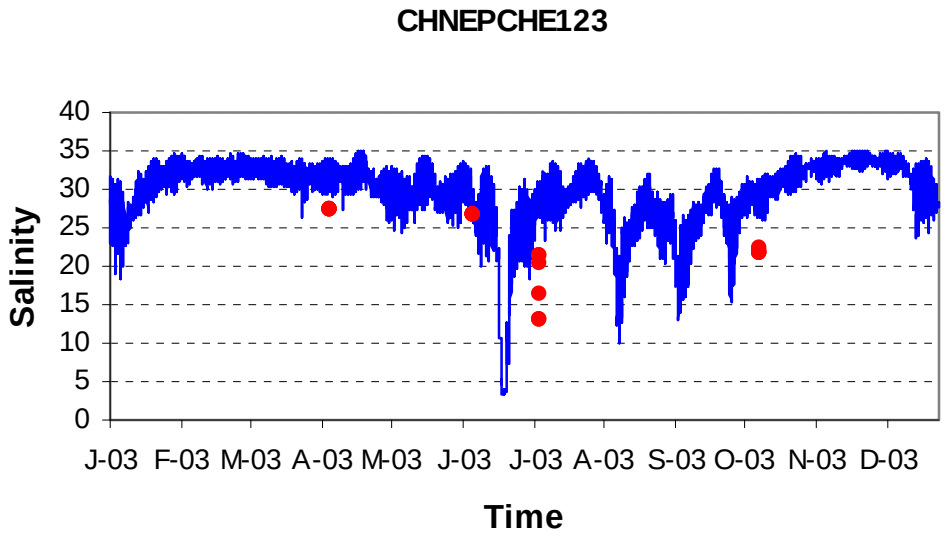


Figure C-3. Modeled vs. observed salinity at CHNEPCHE073



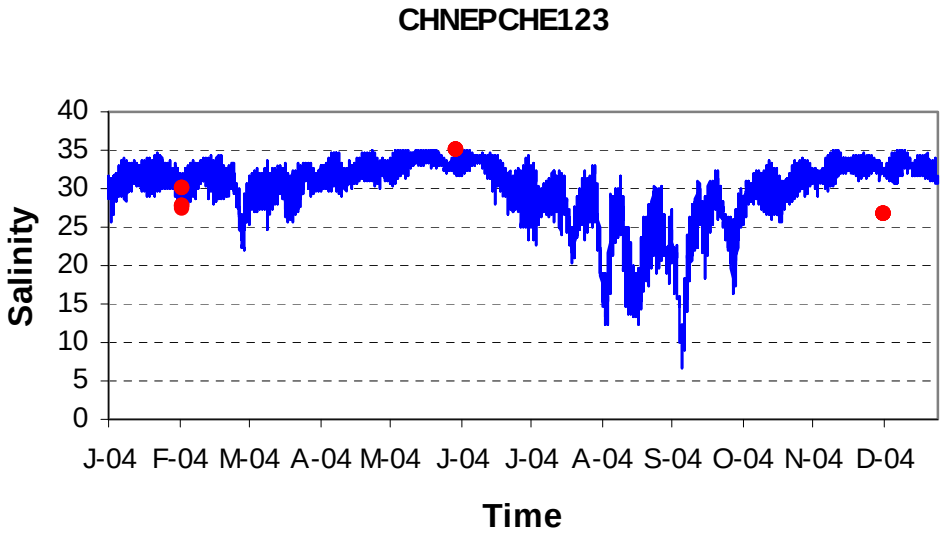
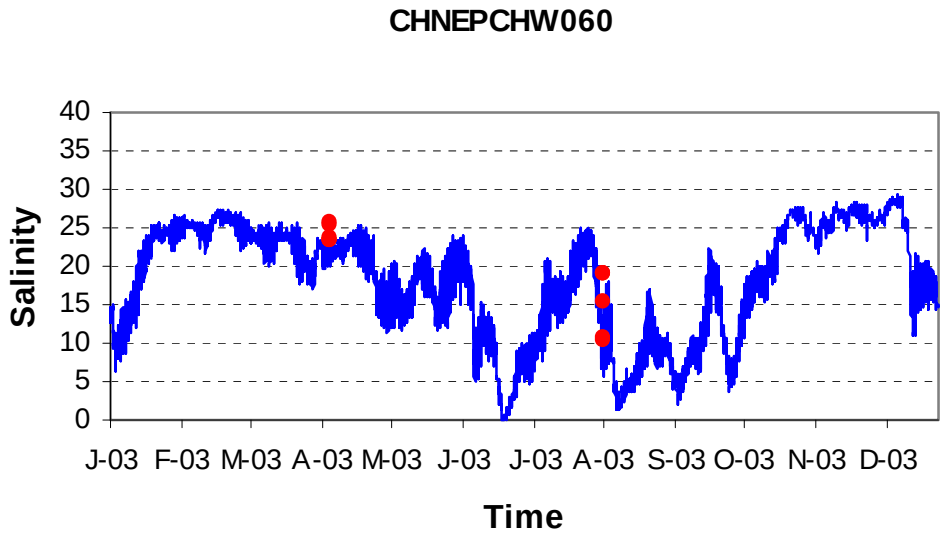


Figure C-4. Modeled vs. observed salinity at CHNEPCHE123



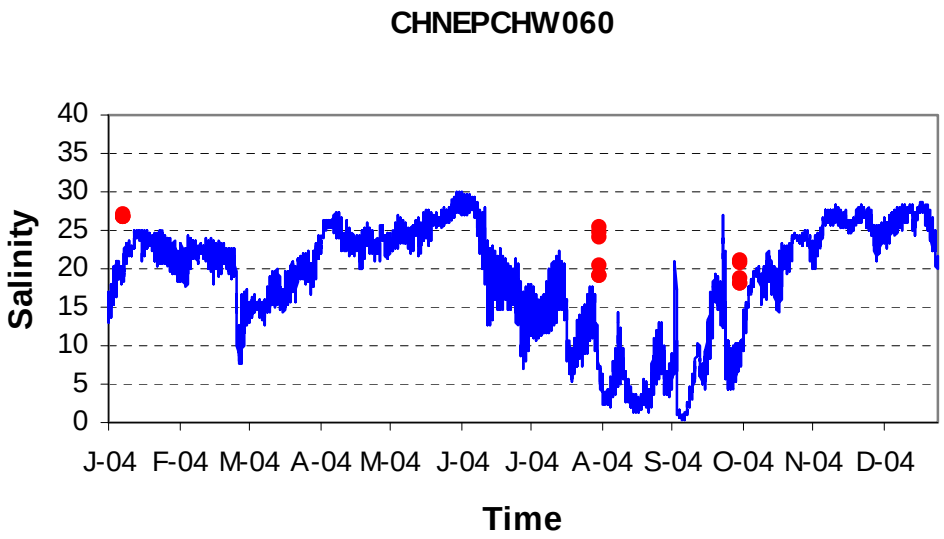


Figure C-5. Modeled vs. observed salinity at CHNEPCHW060

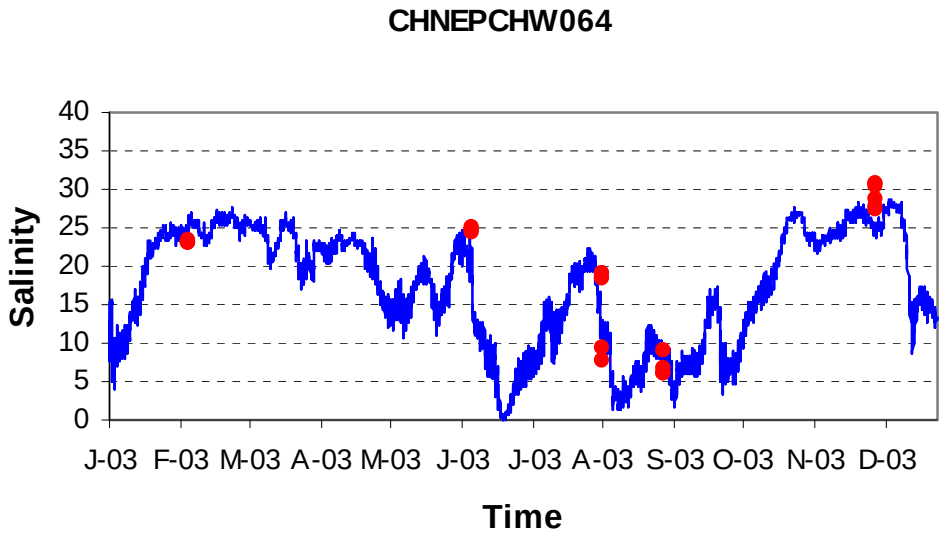
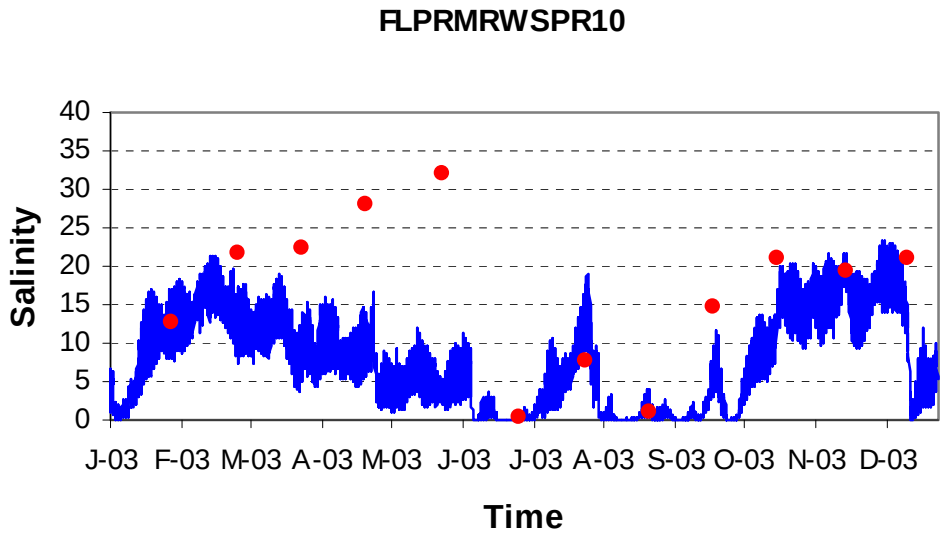


Figure C-6. Modeled vs. observed salinity at CHNEPCHW064



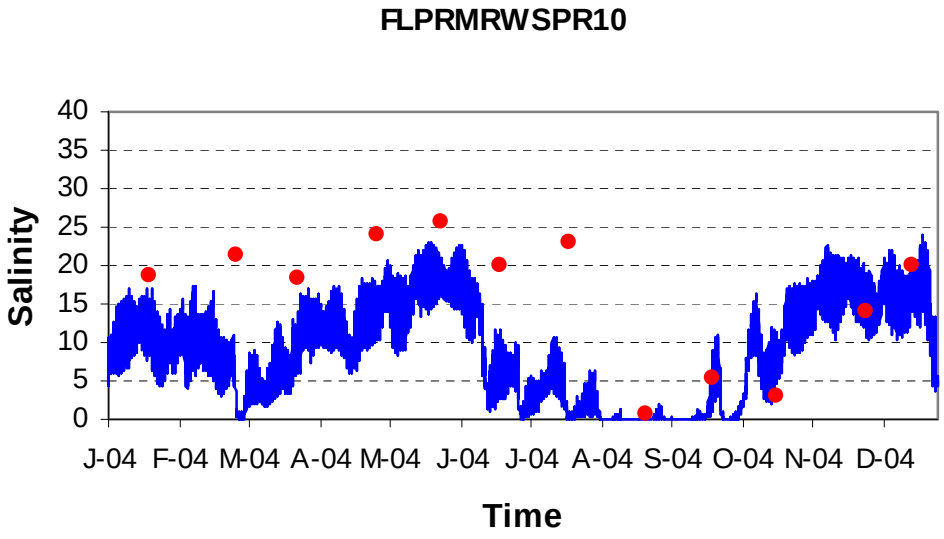
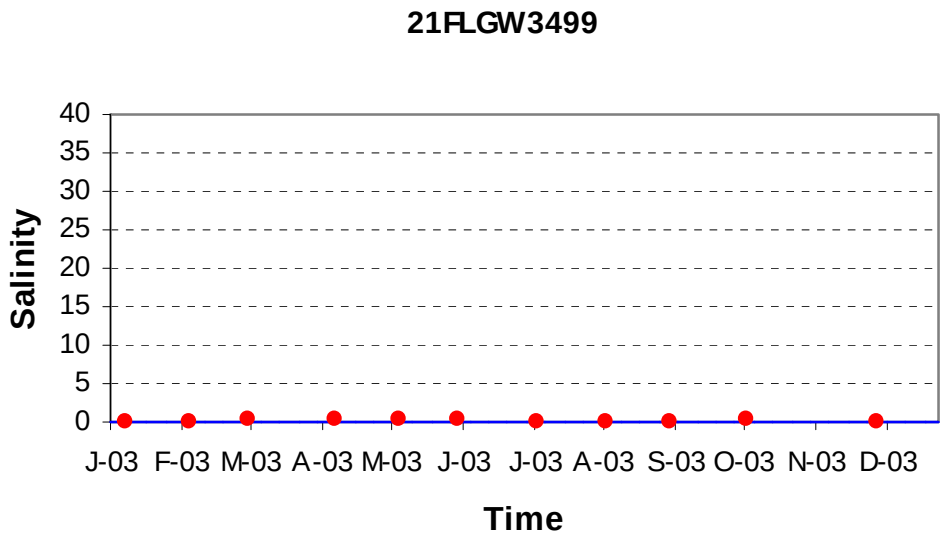


Figure C-7. Modeled vs. observed salinity at FLPRMRWSPR10



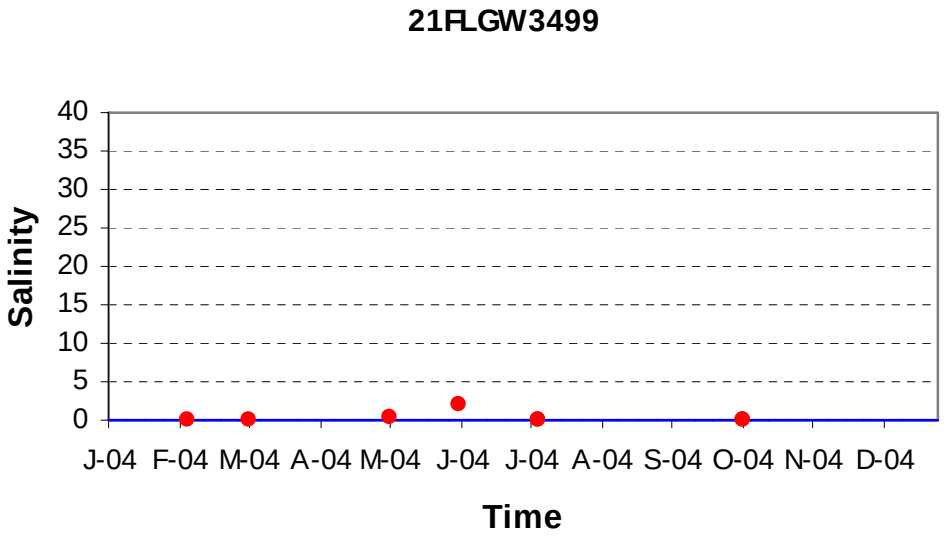
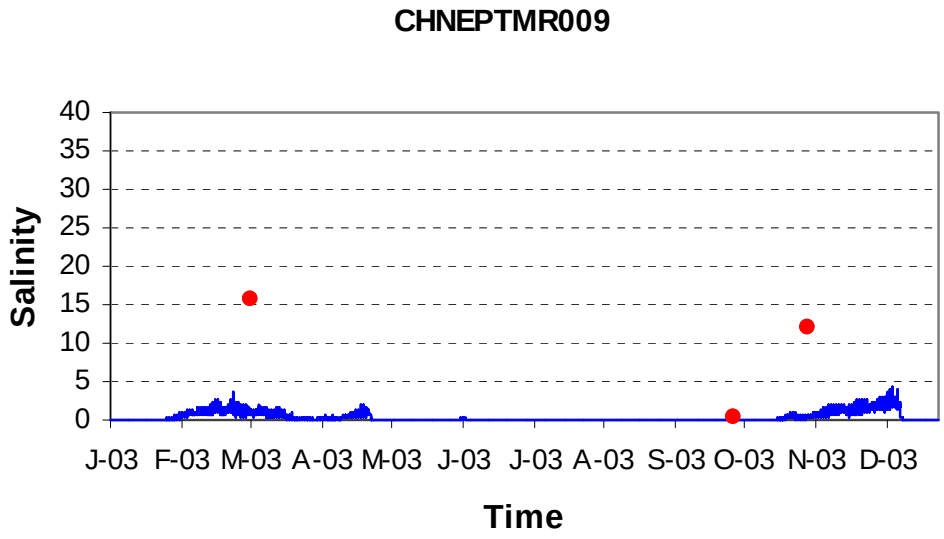


Figure C-8. Modeled vs. observed salinity at 21 FLGW 3499



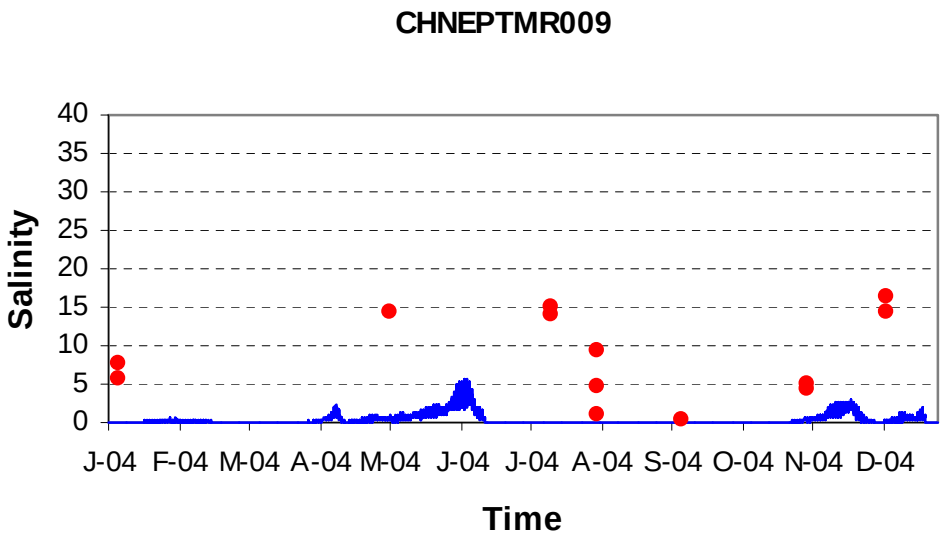
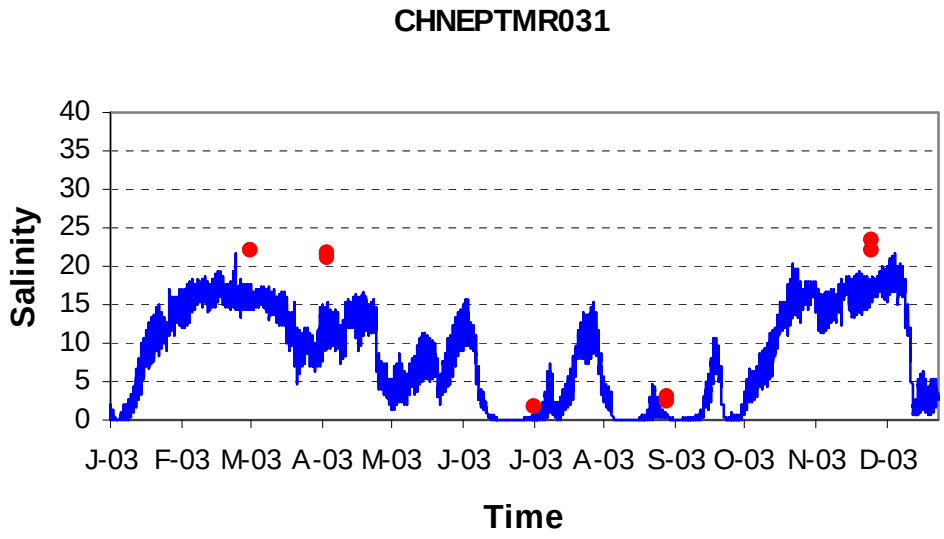


Figure C-9. Modeled vs. observed salinity at CHNEPTMR009



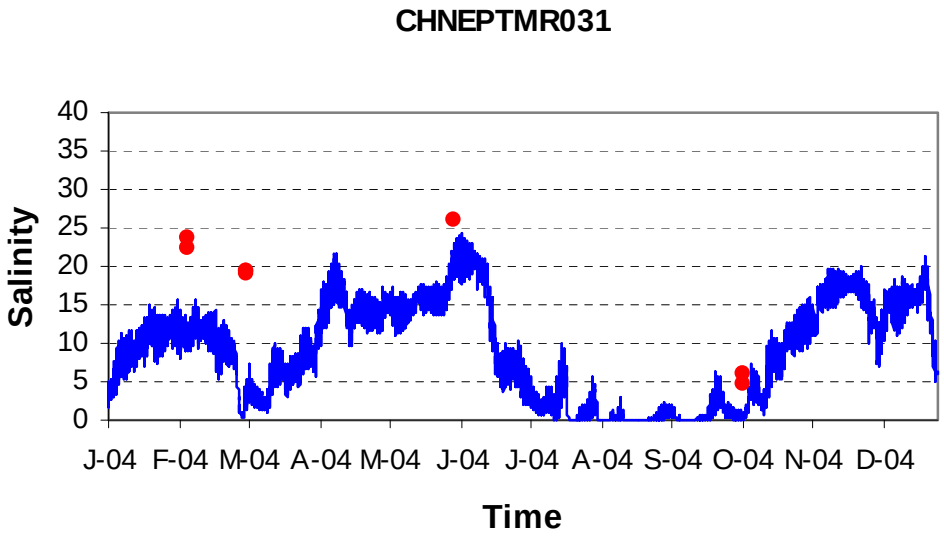
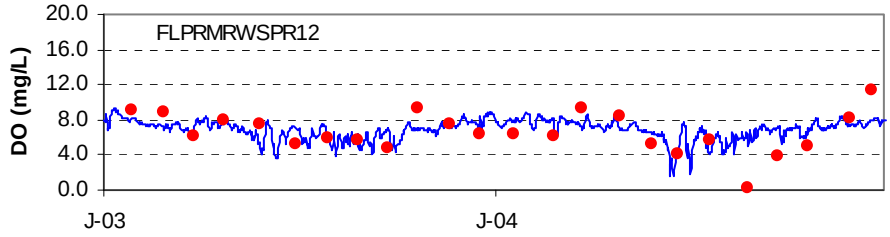
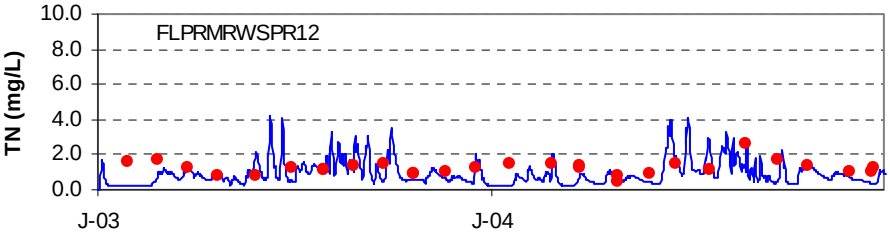


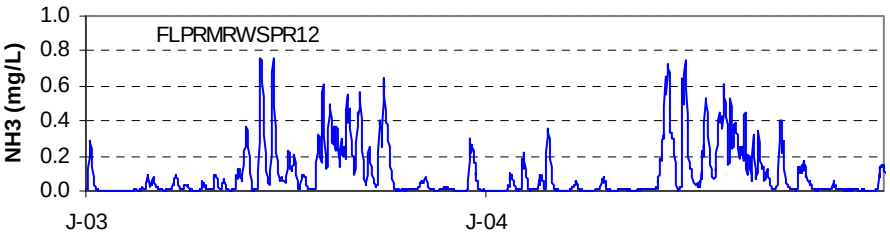
Figure C-10. Modeled vs. observed salinity at CHNEPTMR031

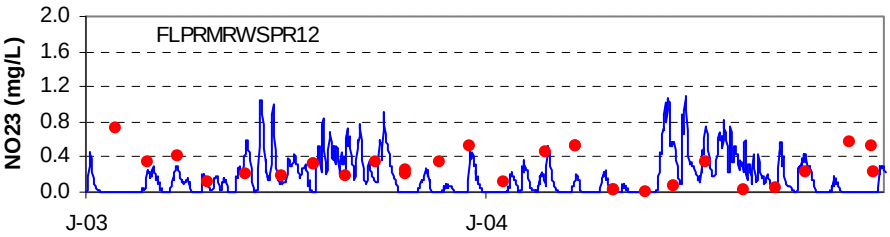
Appendix D: Comparison of Modeled and Observed Water Quality Constituents

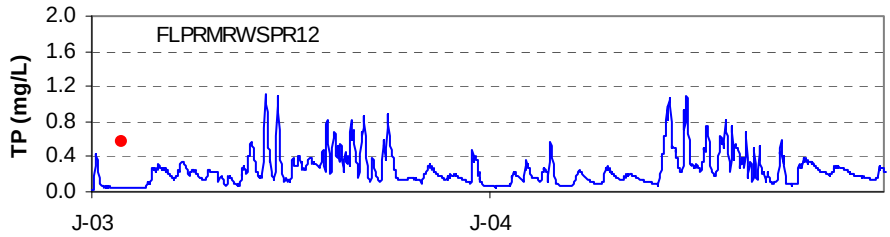
Red dots are observed data
Blue line are model results

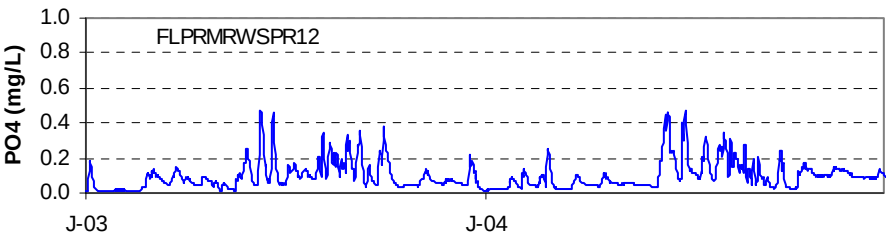












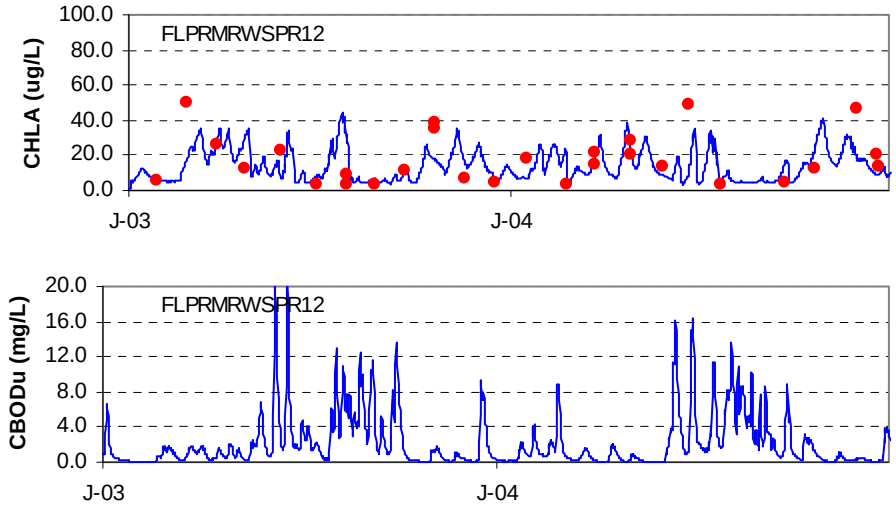
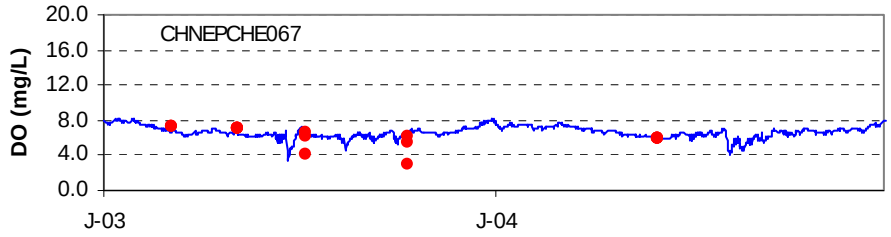
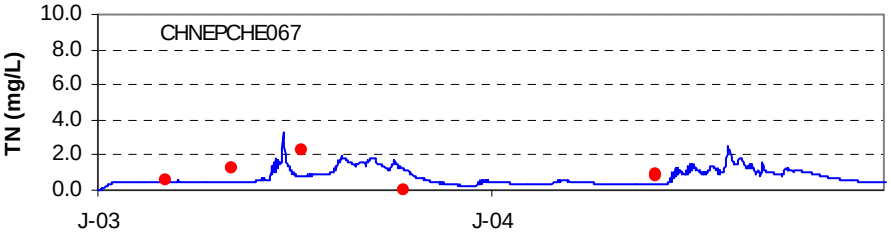
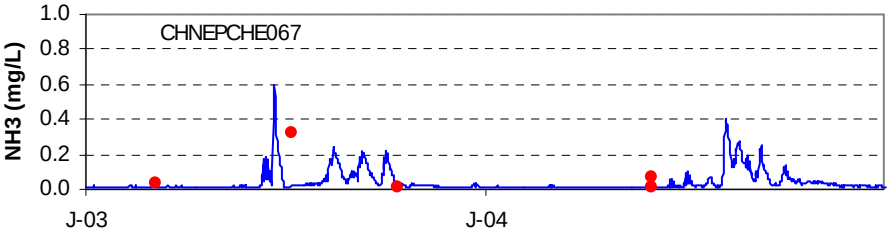
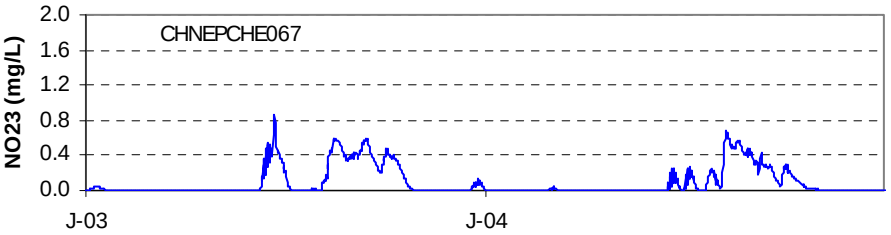


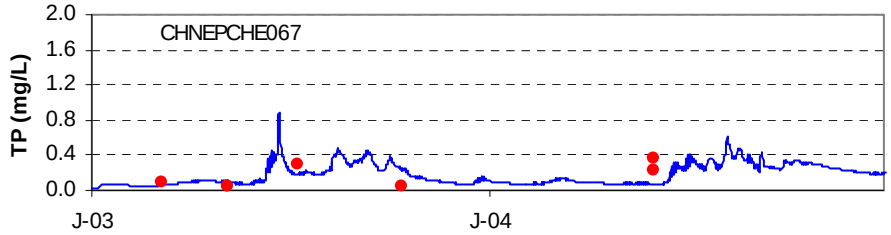
Figure D-1. Modeled vs. observed water quality constituents at station FLPRMRWSPR12

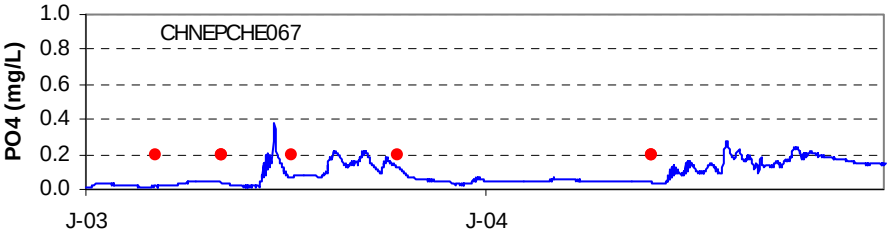

CHNEPCHE067
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPCHE067
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPCHE067
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPCHE067
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHE067
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHE067
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

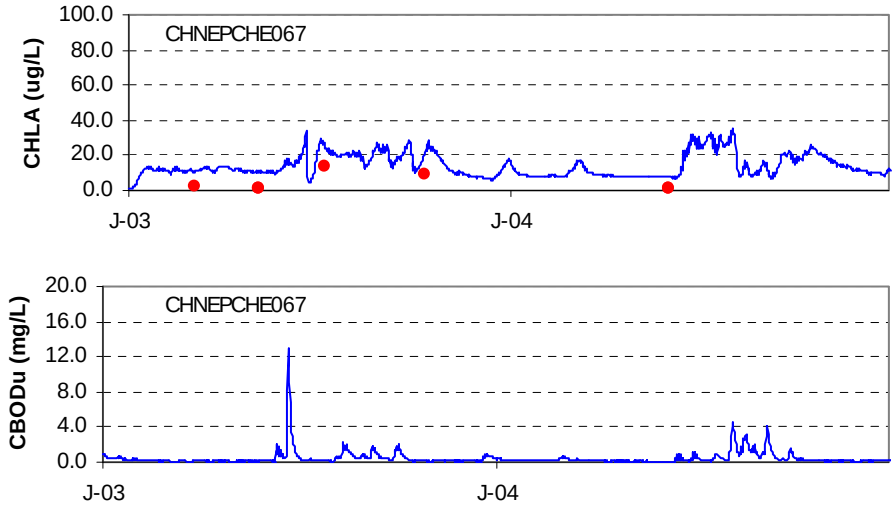
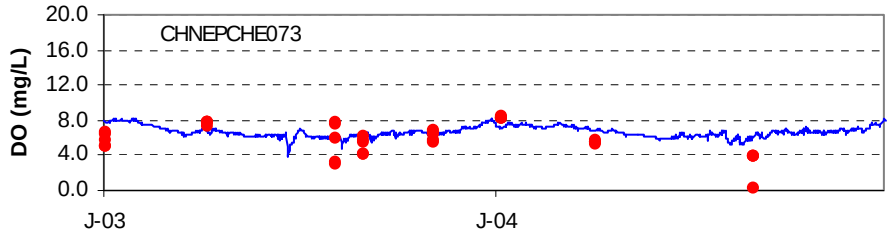
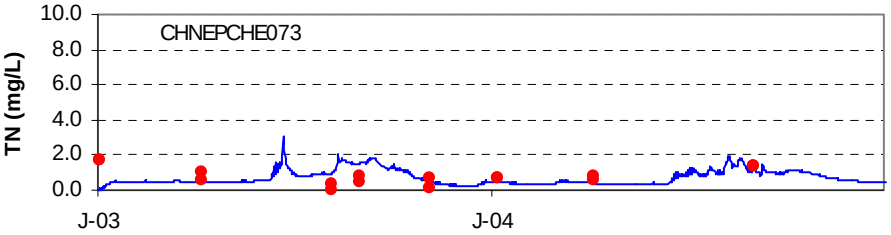
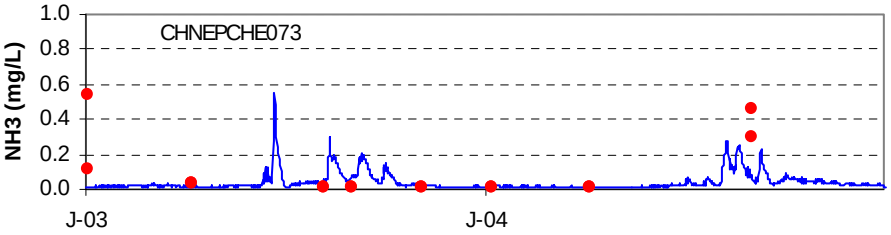
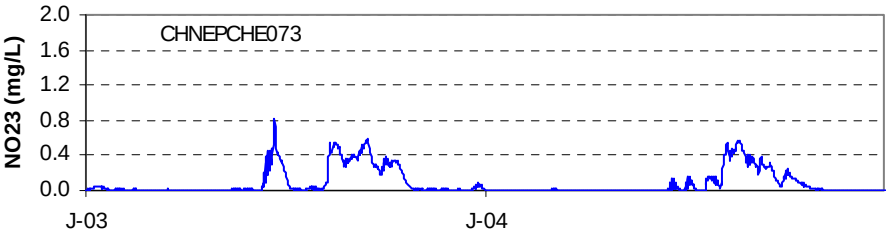


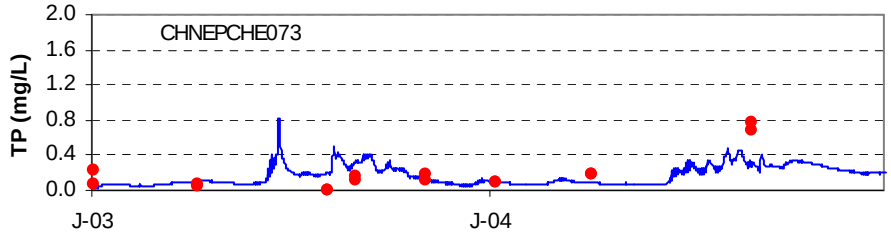
Figure D-2. Modeled vs. observed water quality constituents at station CHNEPCHE067

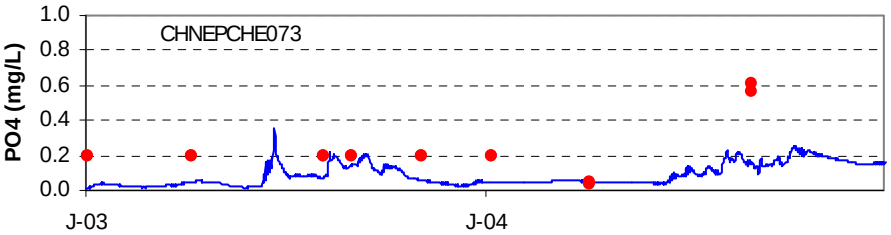

CHNEPCHE073
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPCHE073
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPCHE073
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPCHE073
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHE073
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHE073
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

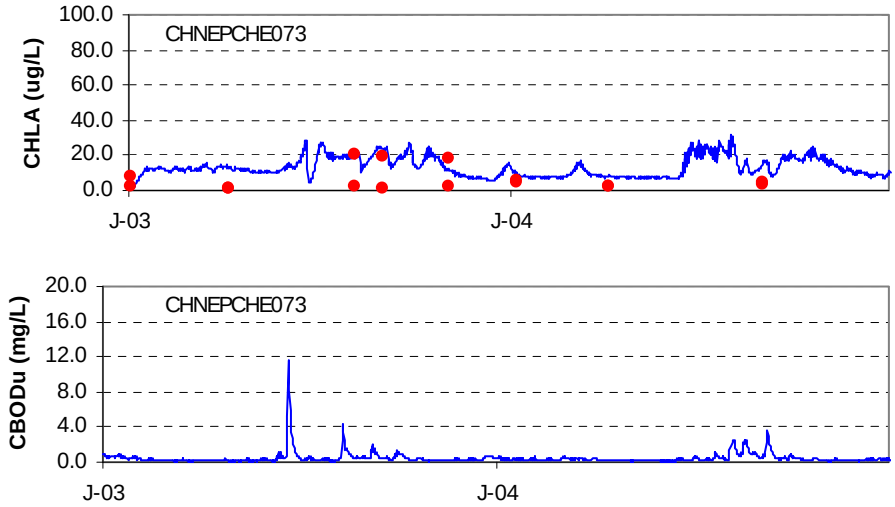
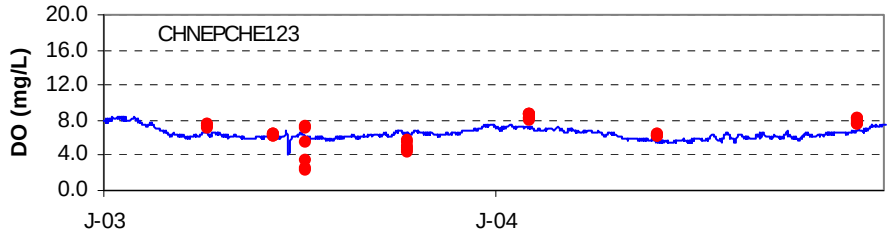
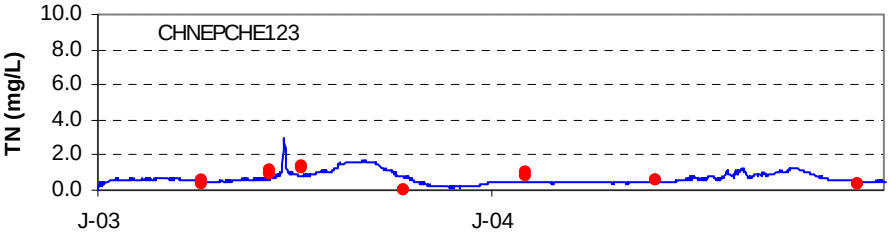
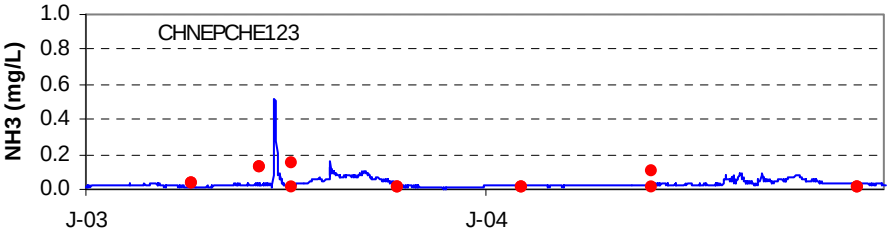
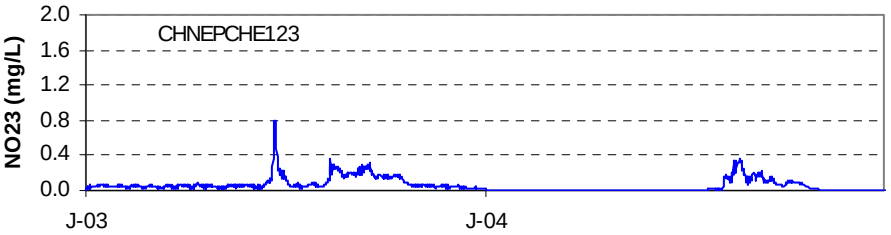


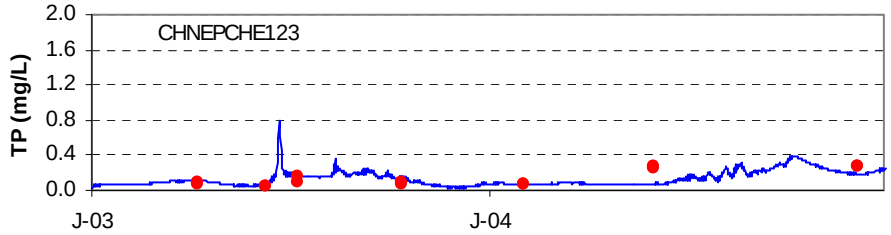
Figure D-3. Modeled vs. observed water quality constituents at station CHNEPCHE073

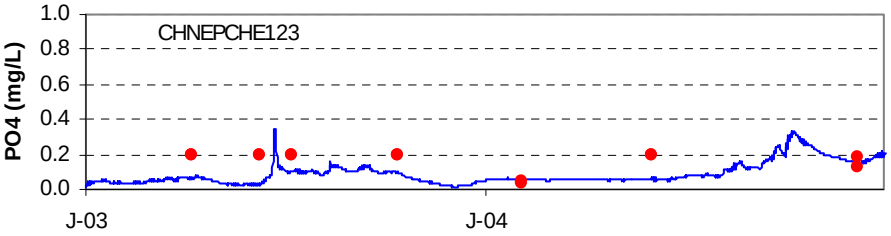

CHNEPCHE123
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPCHE123
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPCHE123
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPCHE123
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHE123
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHE123
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

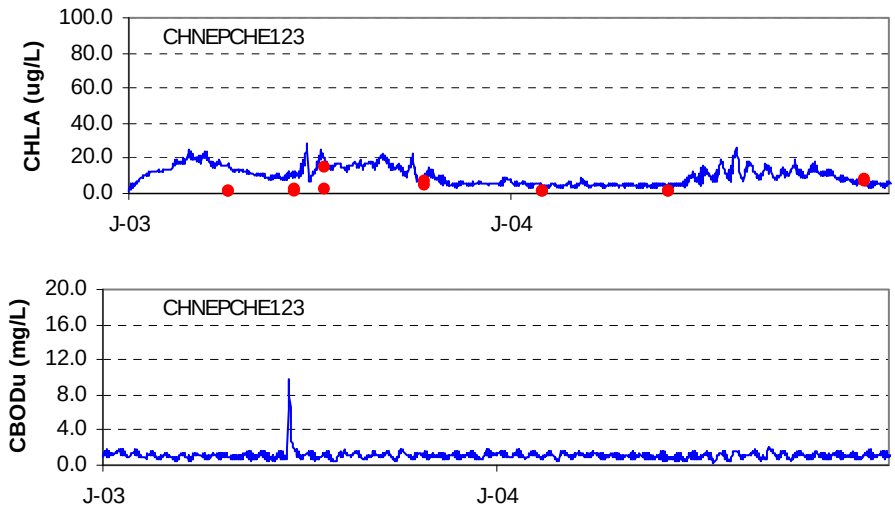
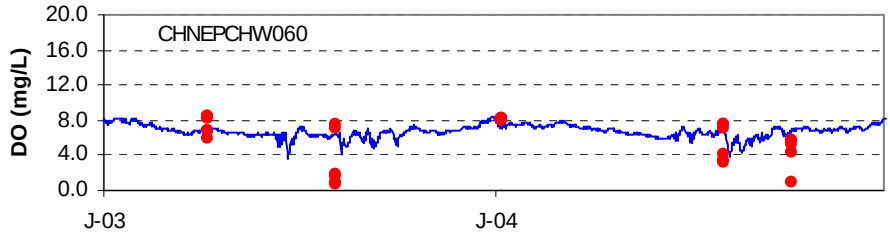
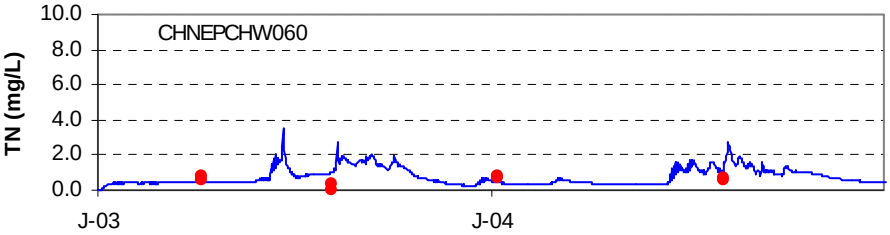
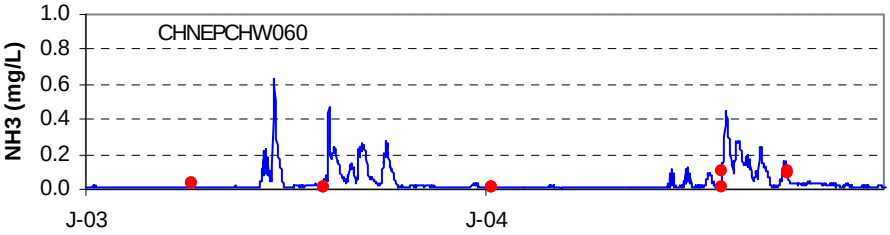
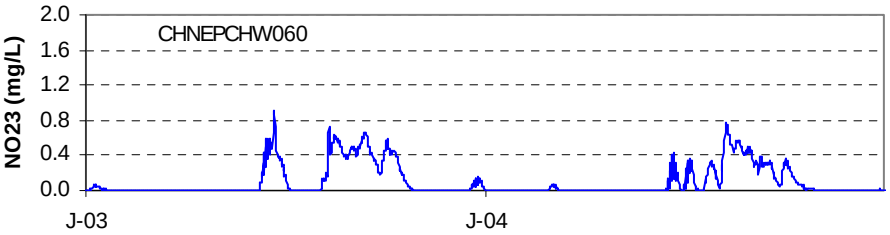


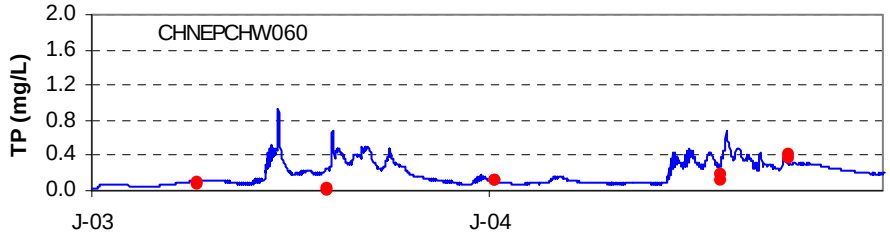
Figure D-4. Modeled vs. observed water quality constituents at station CHNEPCHE123

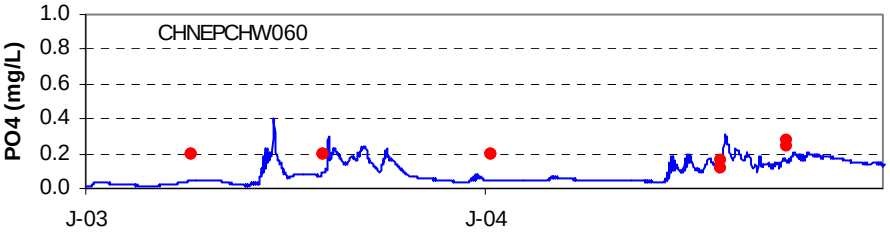

CHNEPCHW060
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPCHW060
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPCHW060
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPCHW060
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHW060
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHW060
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

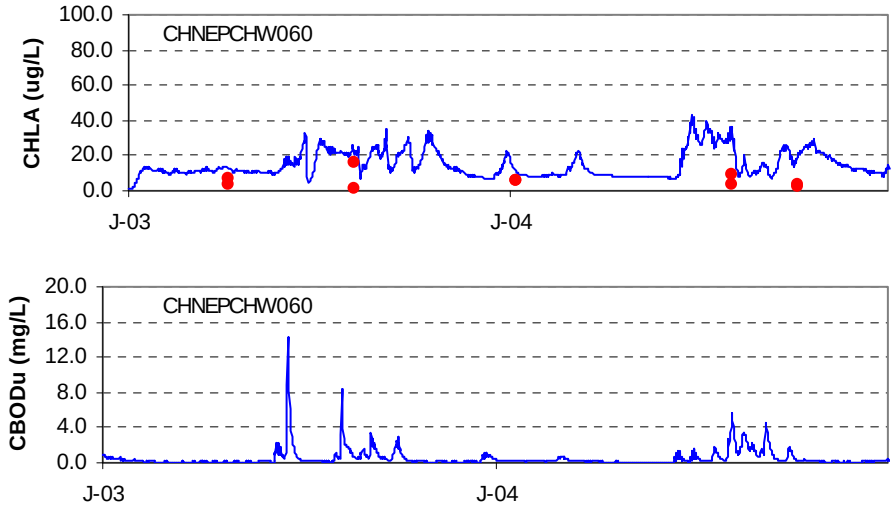
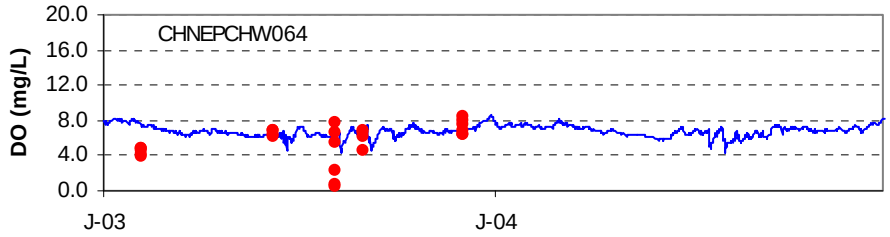
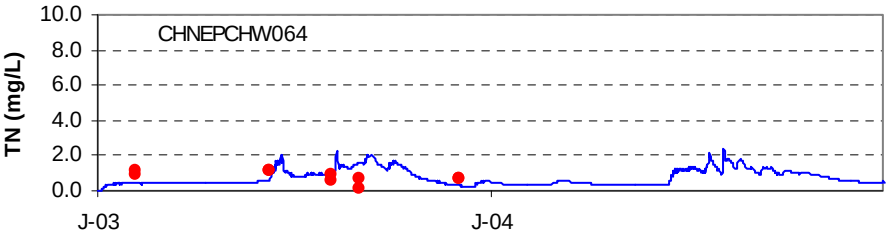
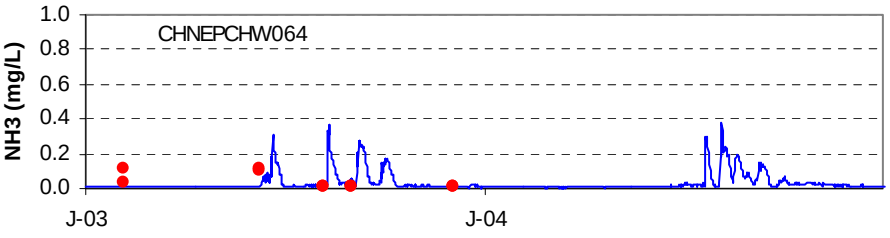
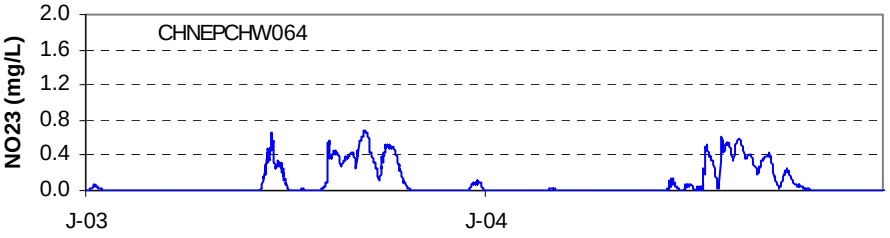


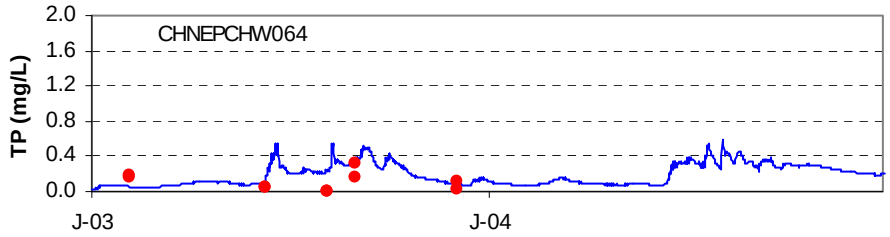
Figure D-5. Modeled vs. observed water quality constituents at station CHNEPCHE060

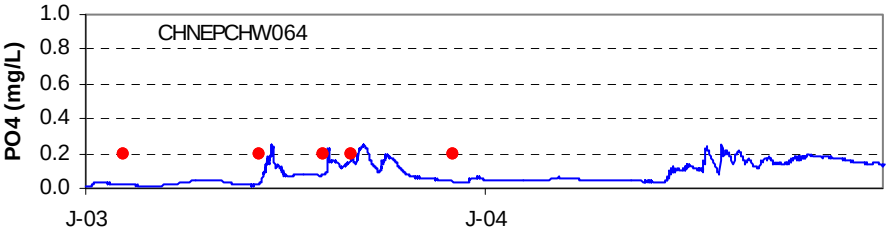

CHNEPCHW064
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPCHW064
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPCHW064
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPCHW064
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHW064
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPCHW064
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

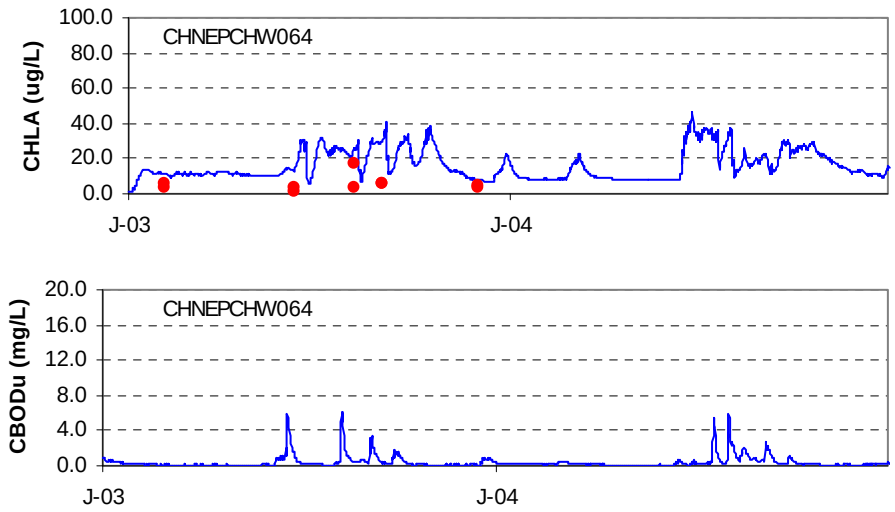
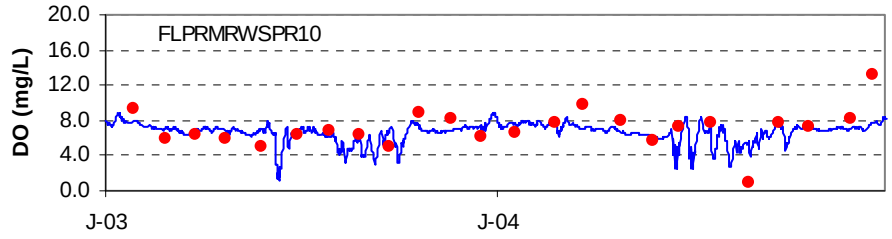
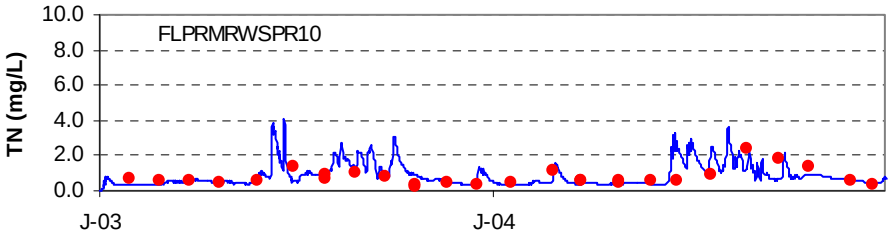
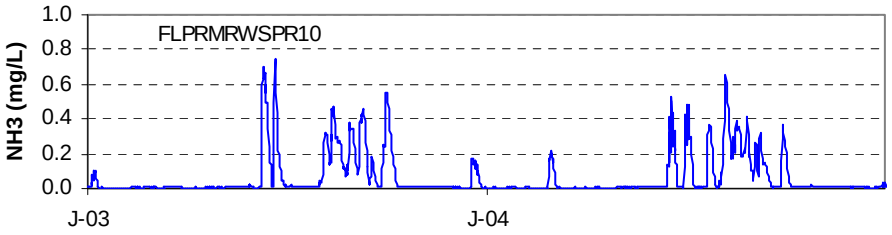
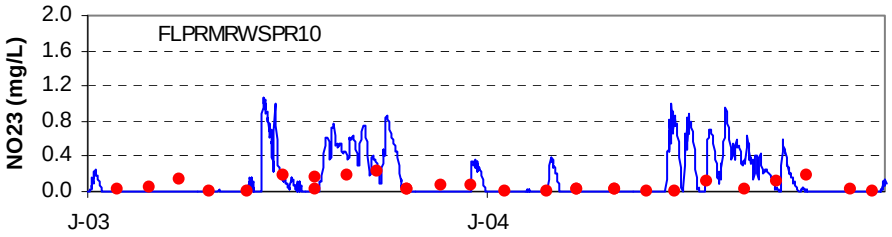


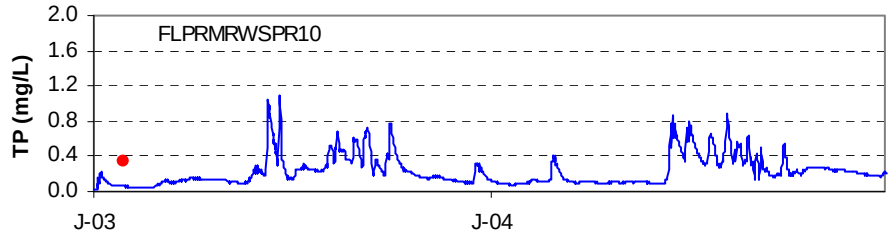
Figure D-6. Modeled vs. observed water quality constituents at station CHNEPCHW064

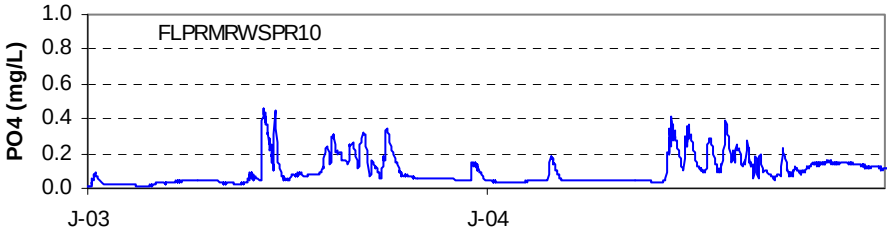

FLPRMRWSPR10
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


FLPRMRWSPR10
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


FLPRMRWSPR10
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


FLPRMRWSPR10
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


FLPRMRWSPR10
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


FLPRMRWSPR10
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

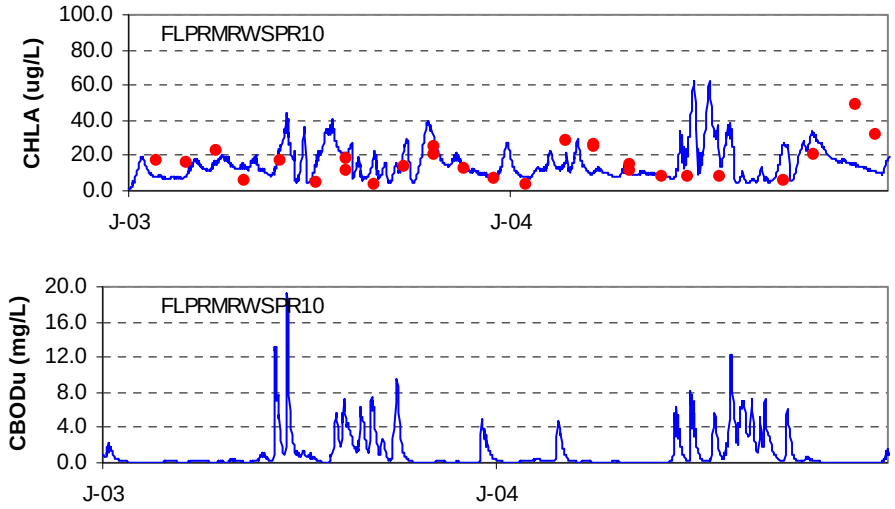
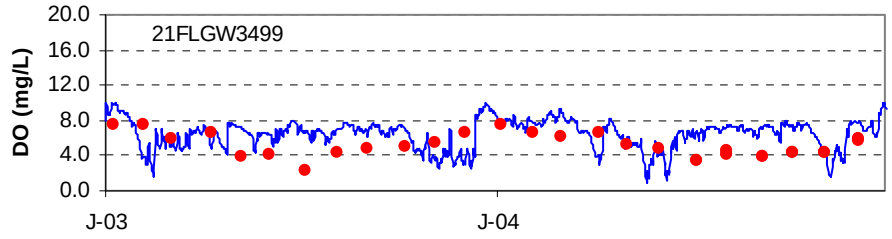
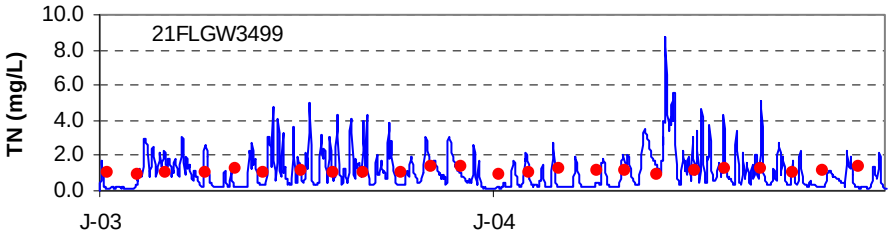
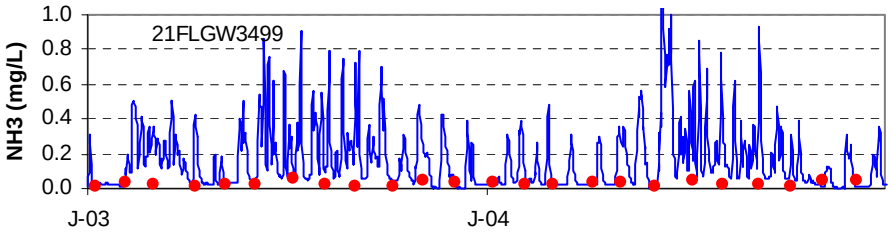
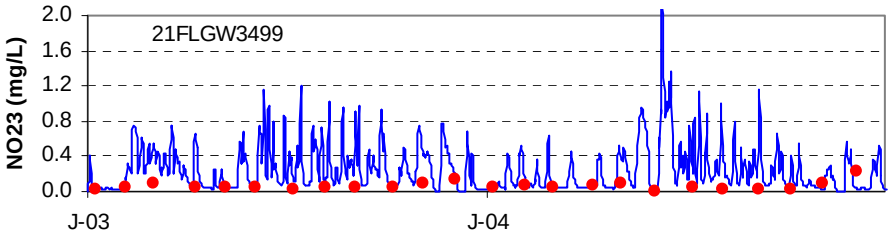


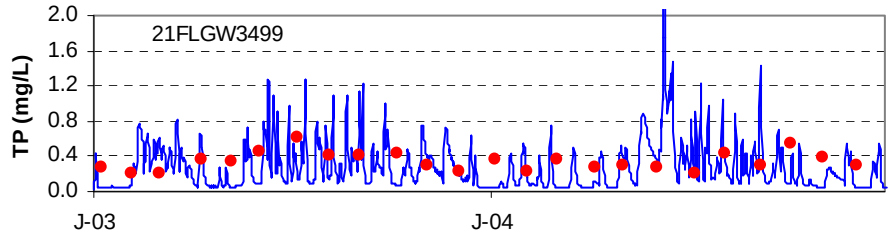
Figure D-7. Modeled vs. observed water quality constituents at station FLPRMRWSPR10

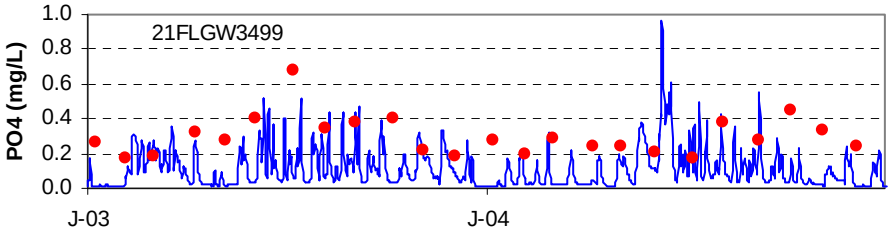

21FLGW3499
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


21FLGW3499
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


21FLGW3499
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


21FLGW3499
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


21FLGW3499
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


21FLGW3499
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

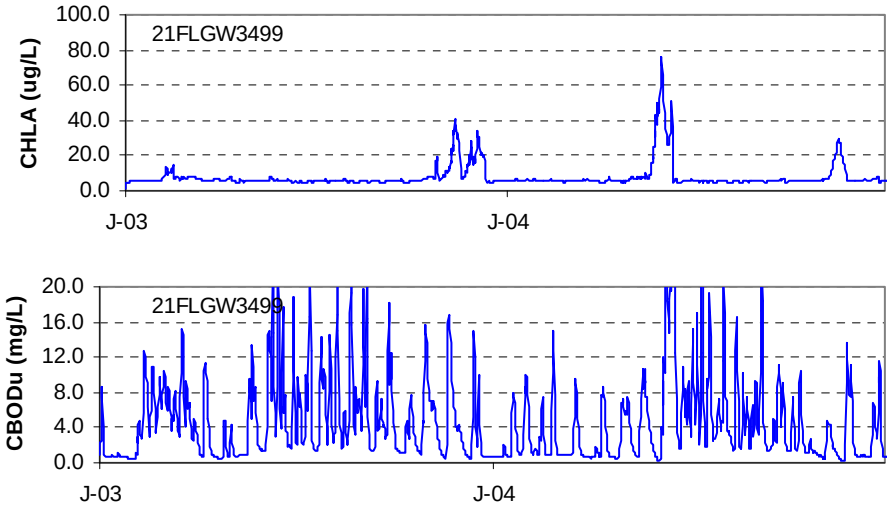
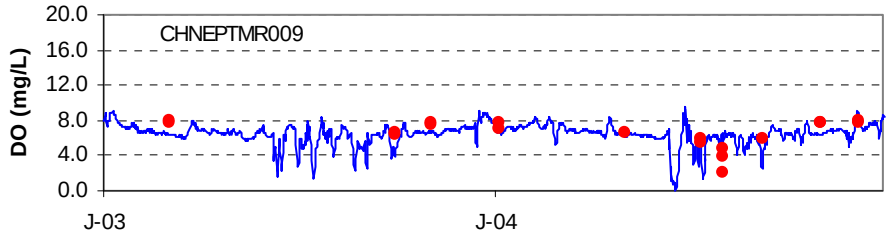
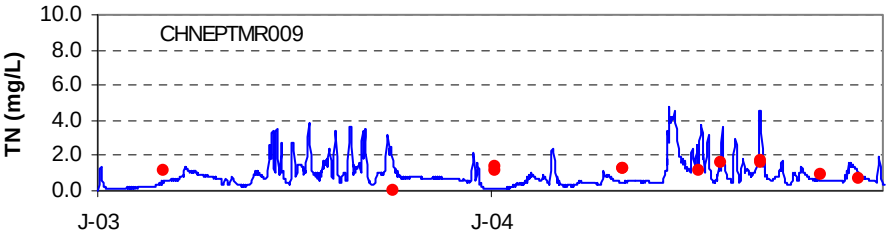
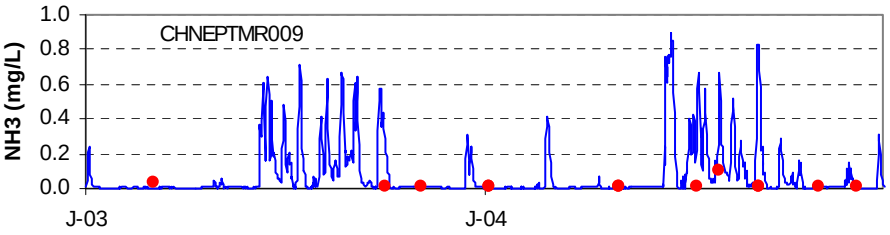
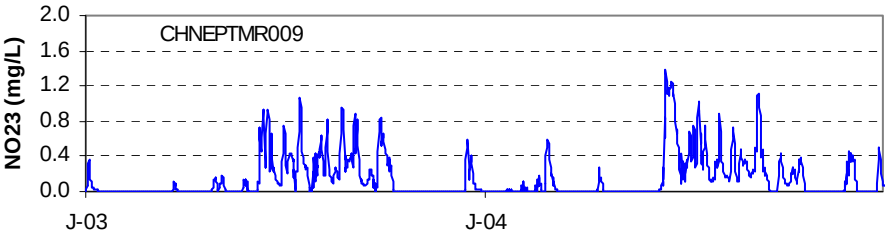


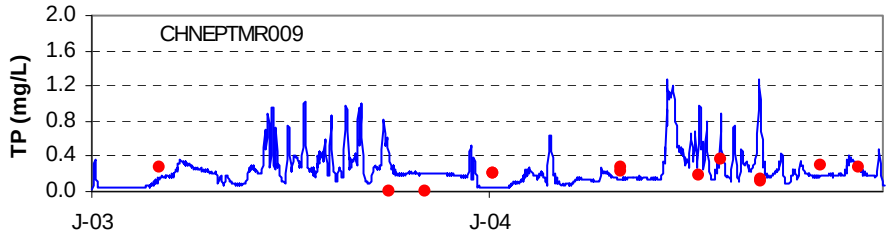
Figure D-8. Modeled vs. observed water quality constituents at station 21 FLGW 3499

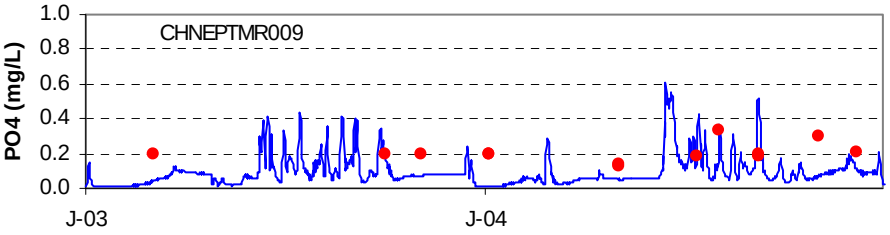

CHNEPTMR009
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPTMR009
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPTMR009
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPTMR009
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPTMR009
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPTMR009
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

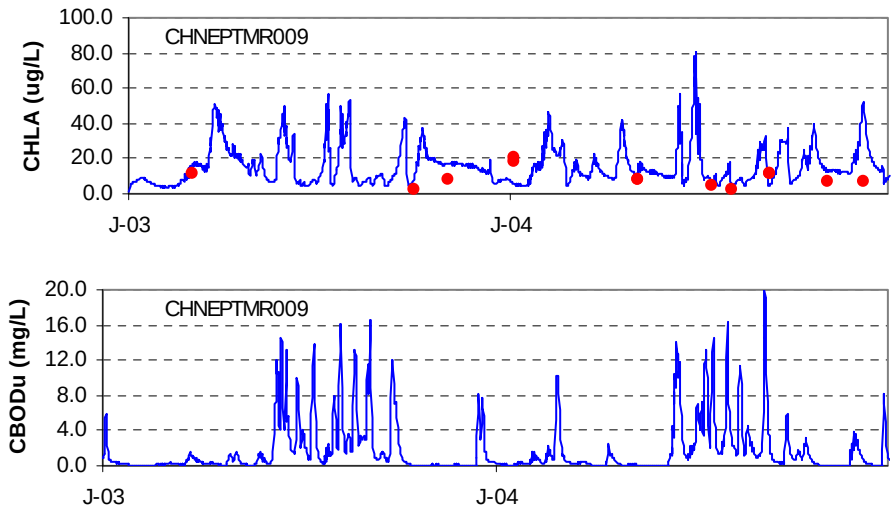
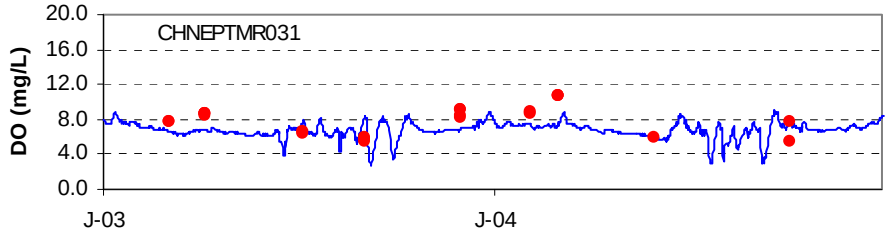
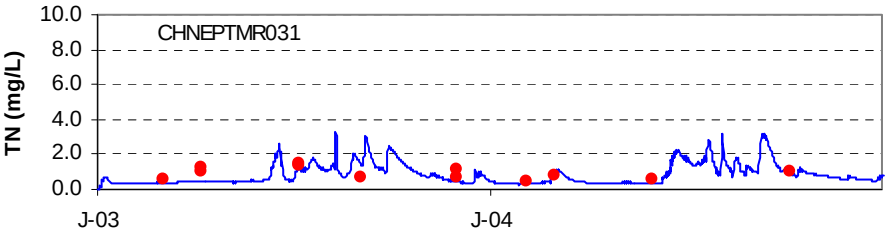
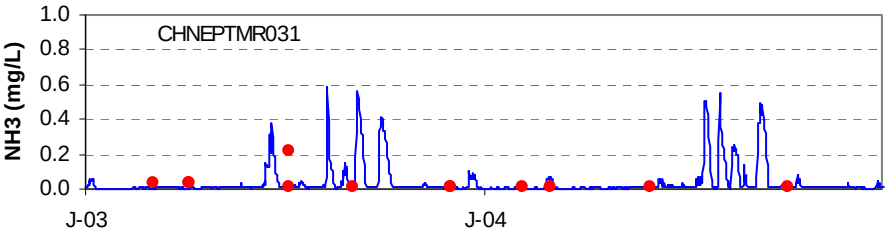
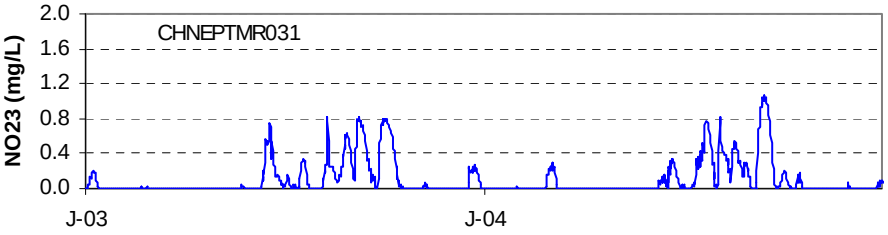


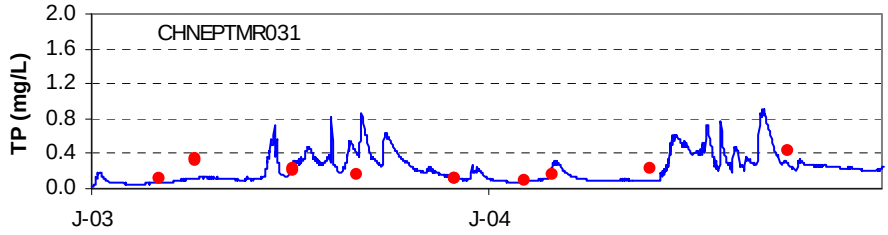
Figure D-9. Modeled vs. observed water quality constituents at station CHNEPTMR009

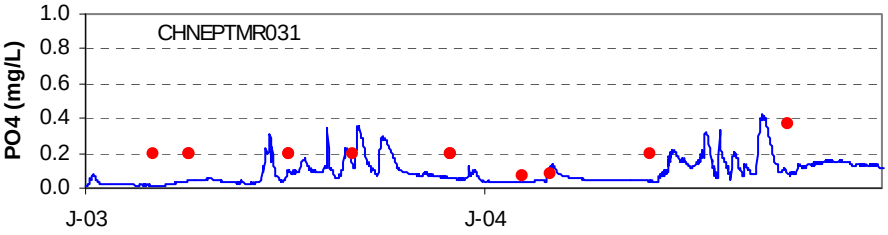

CHNEPTMR031
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


CHNEPTMR031
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


CHNEPTMR031
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


CHNEPTMR031
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPTMR031
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


CHNEPTMR031
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

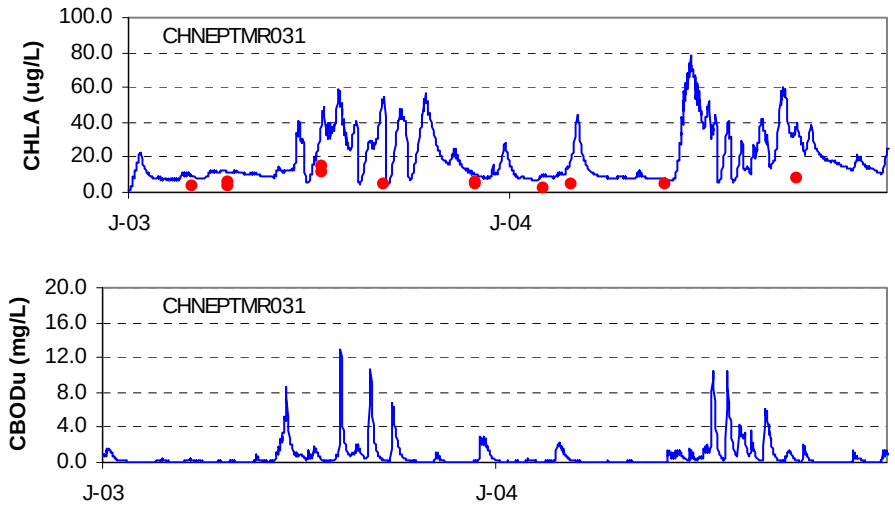
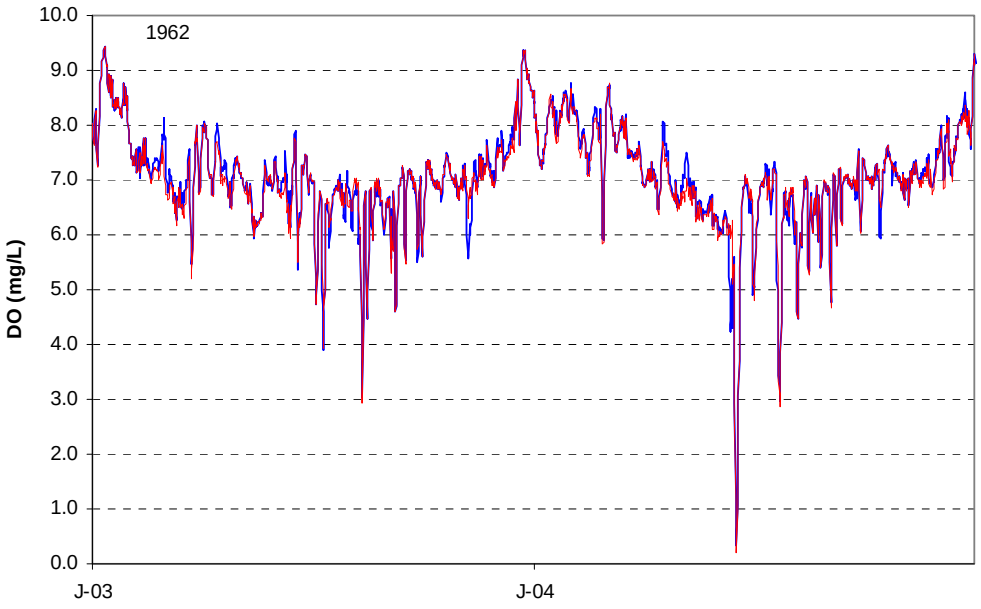
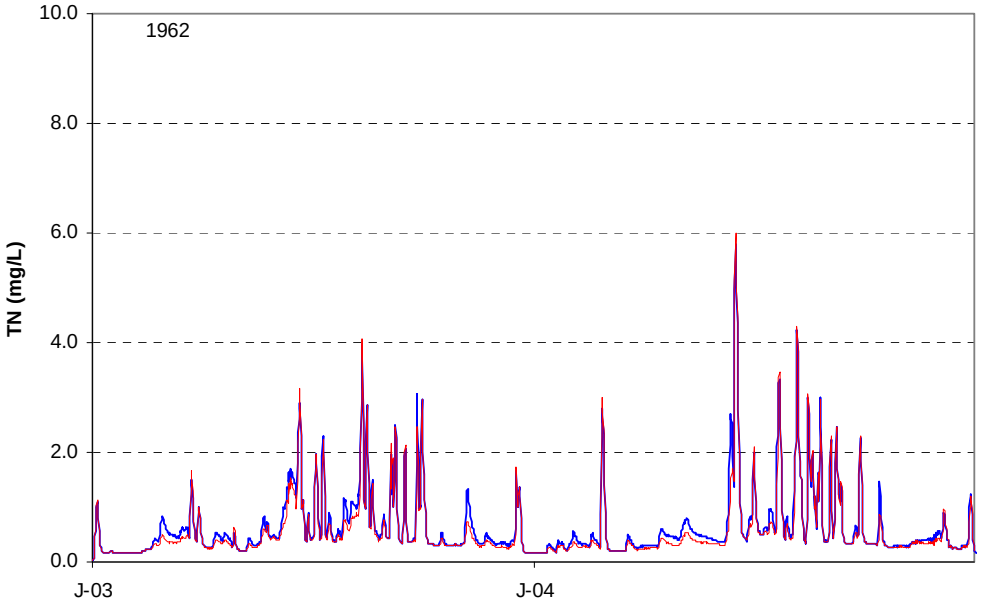


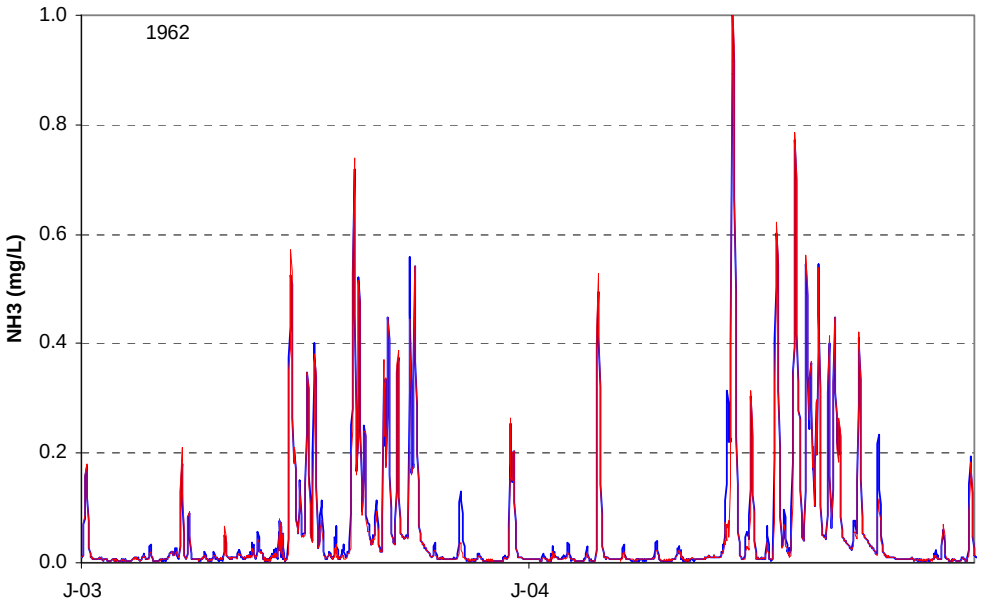
Figure D-10. Modeled vs. observed water quality constituents at station CHNEPTMR031

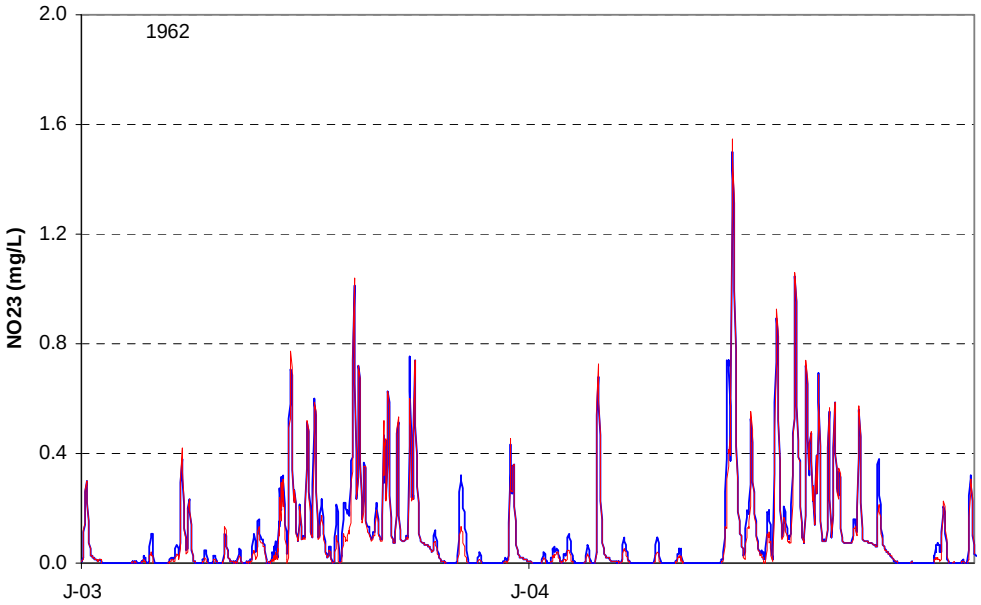
Appendix E: Comparison of Modeled Water Quality Constituents between Existing Conditions and All Natural Conditions

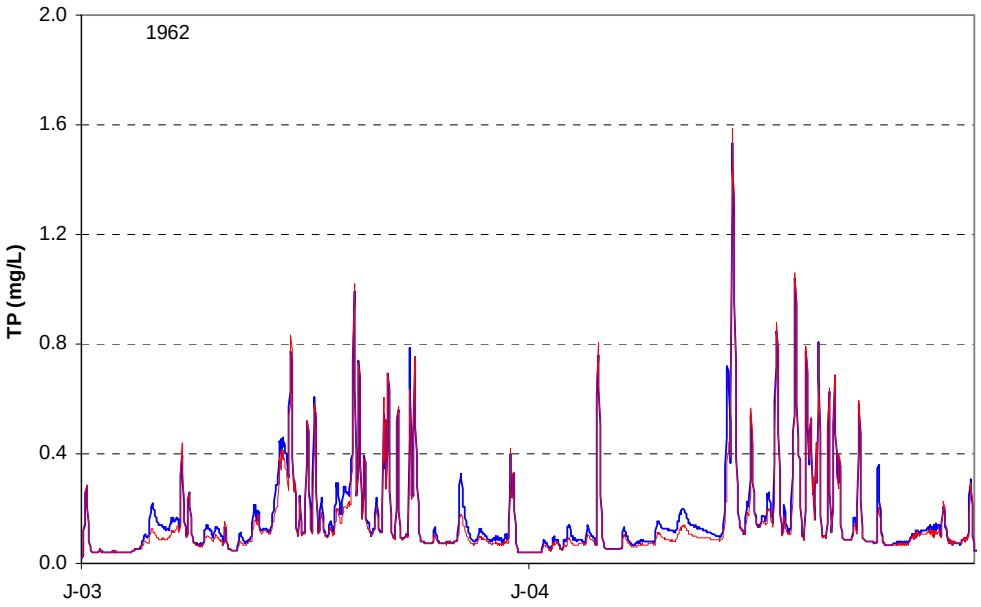
Blue lines: Existing Conditions (Calibration)
Red lines: All Natural Conditions

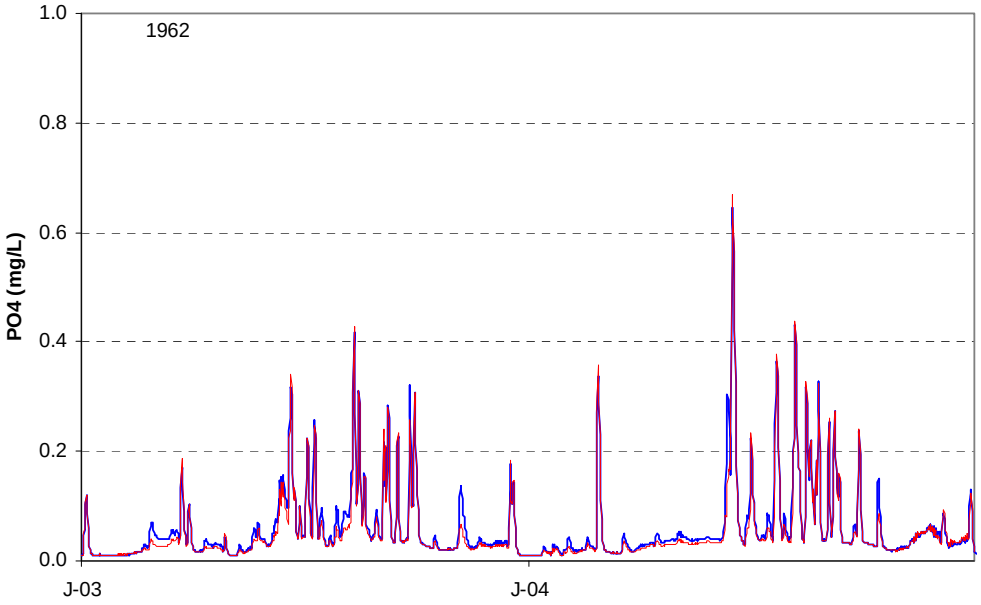





1962
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


1962
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1962
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1962
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

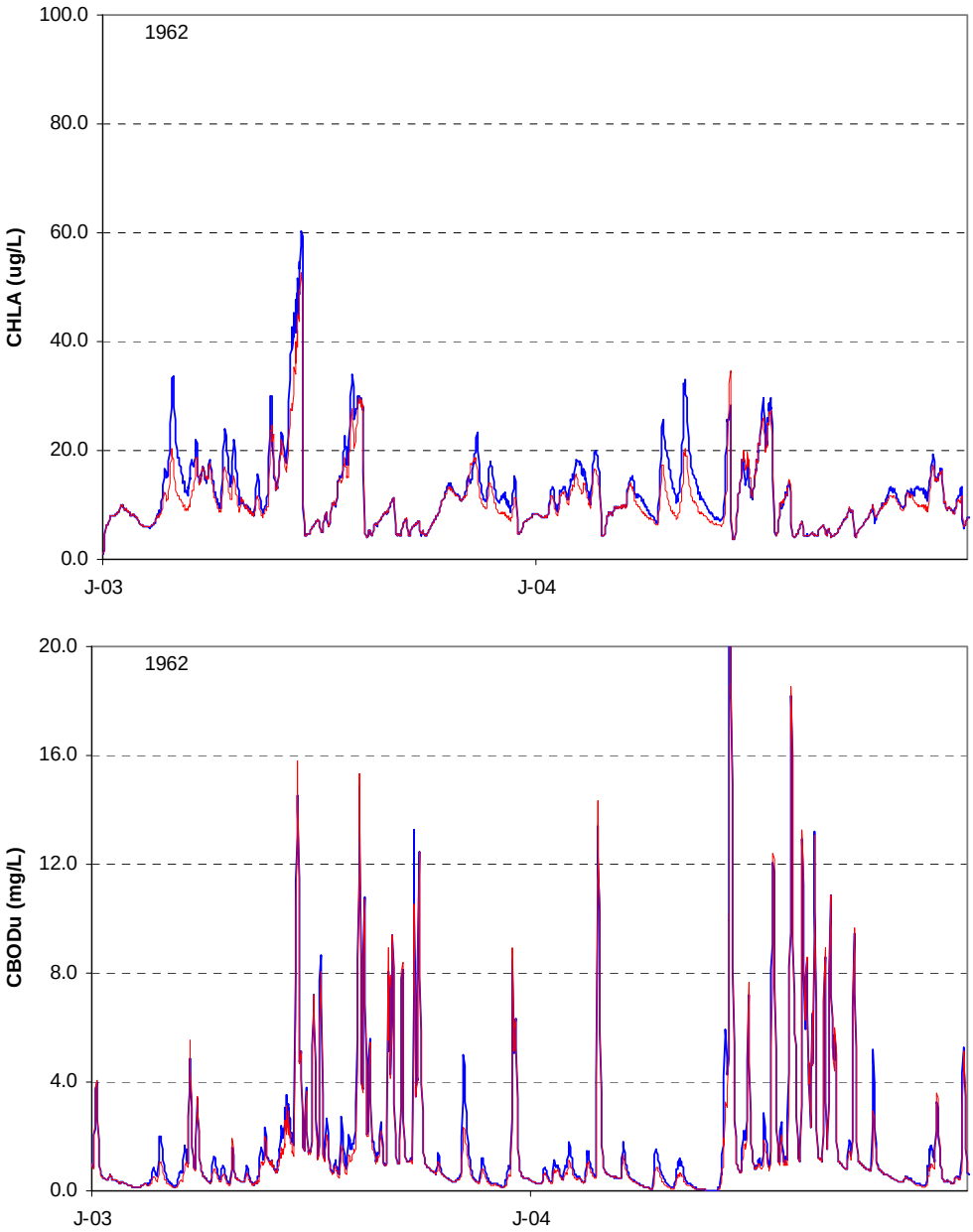
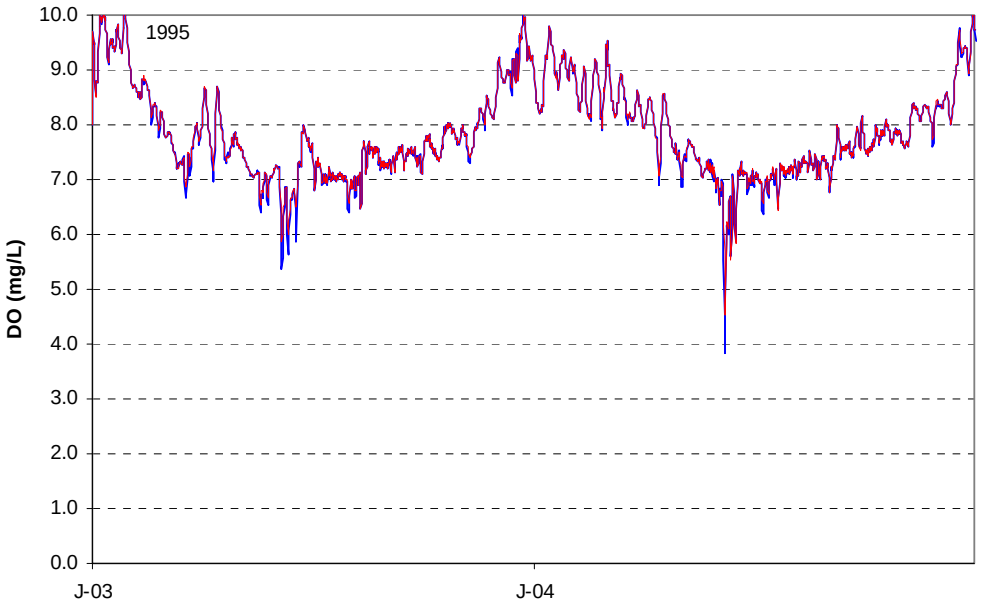
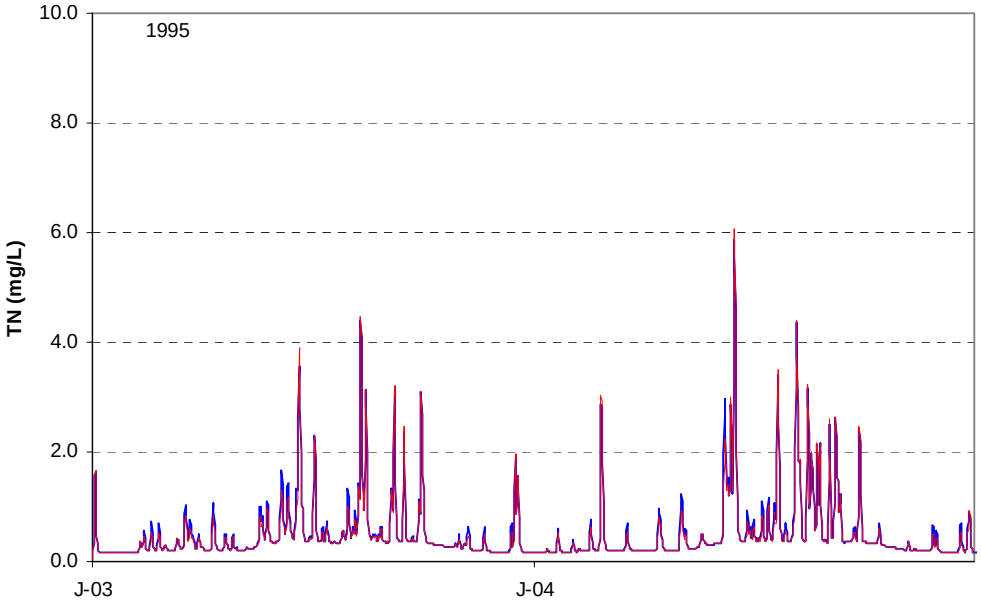
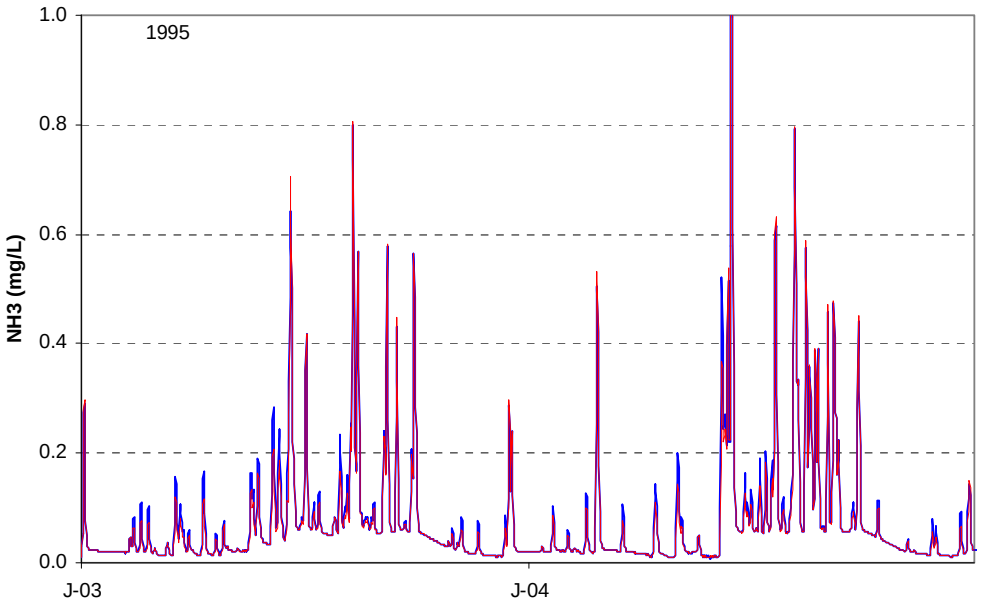
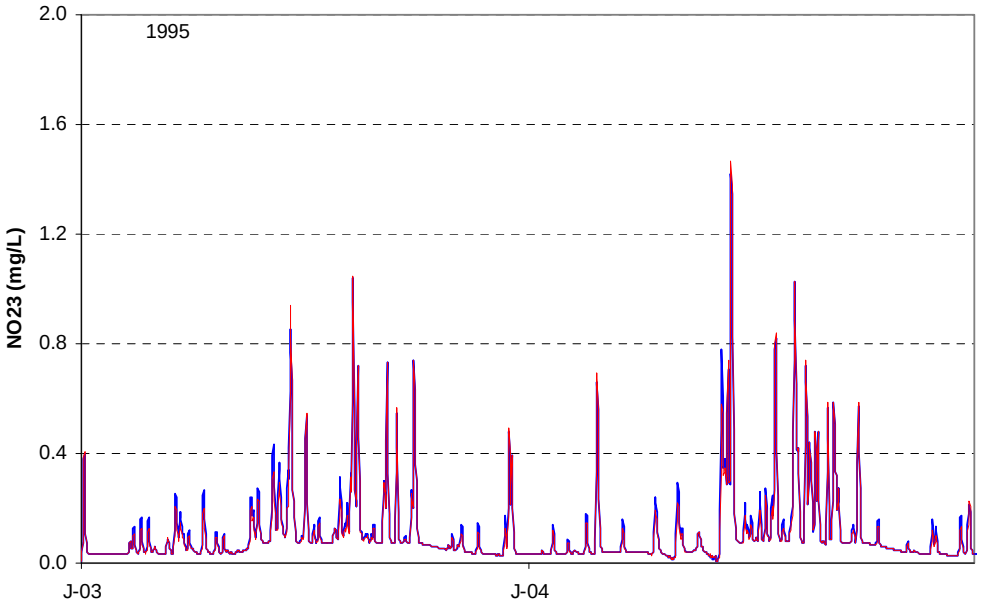


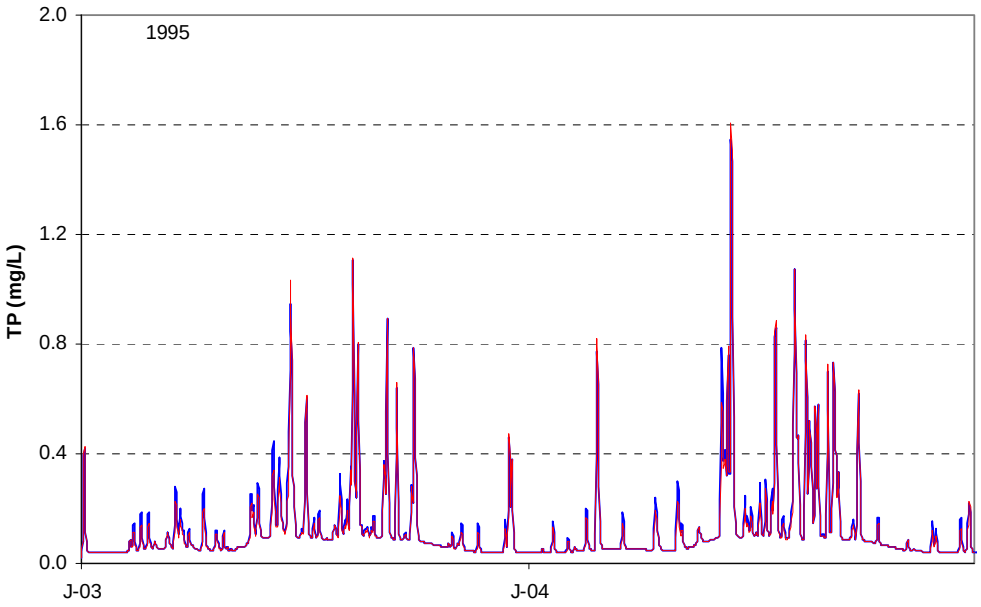
Figure E-1. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 1962

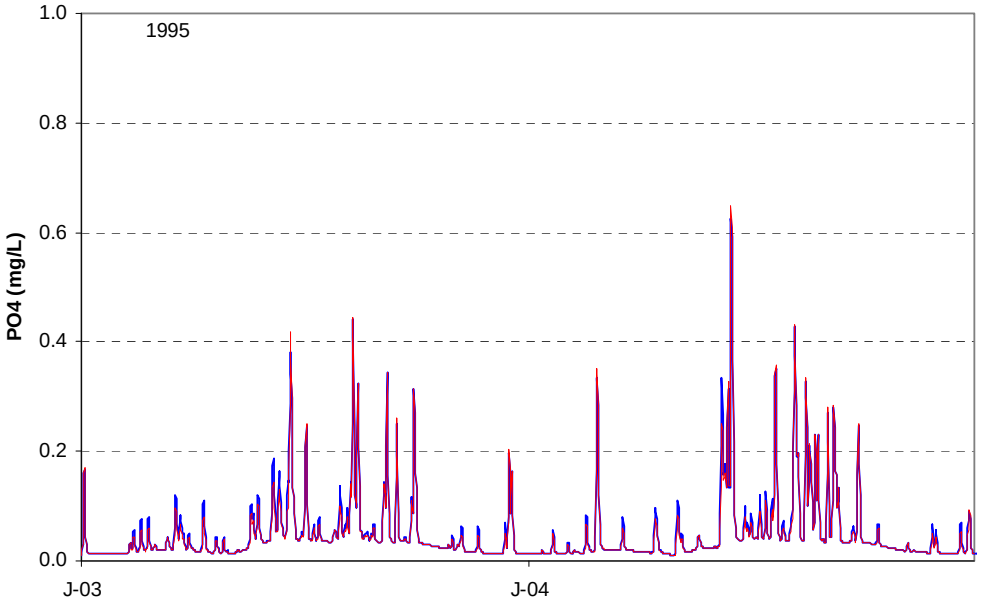

1995
DO (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-03
J-04


1995
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


1995
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


1995
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1995
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1995
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

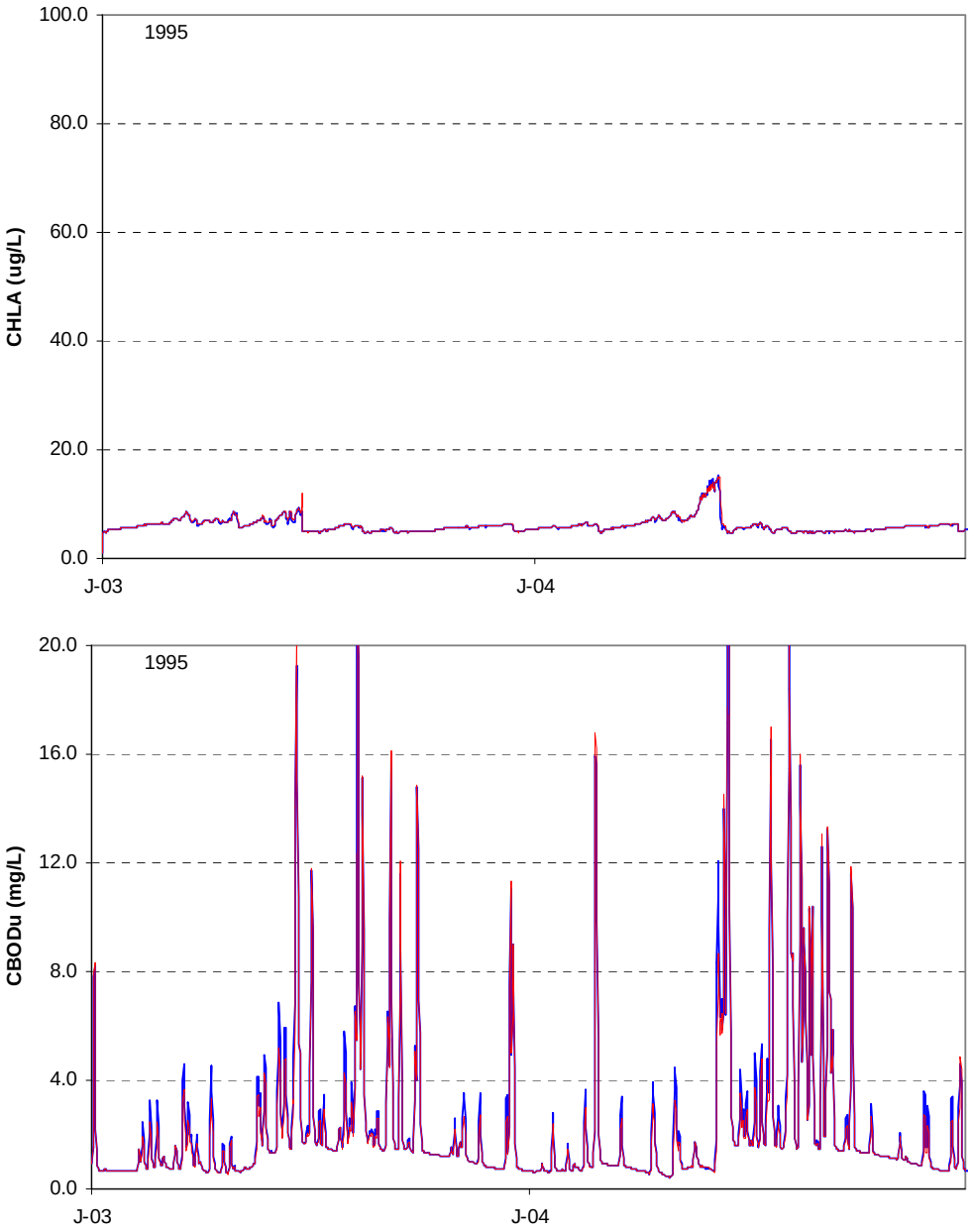
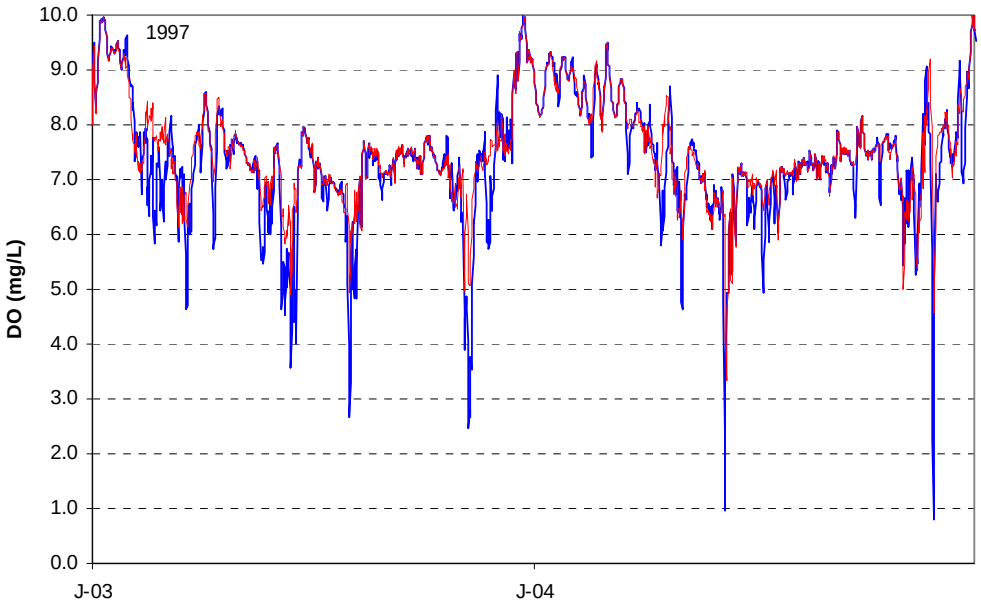
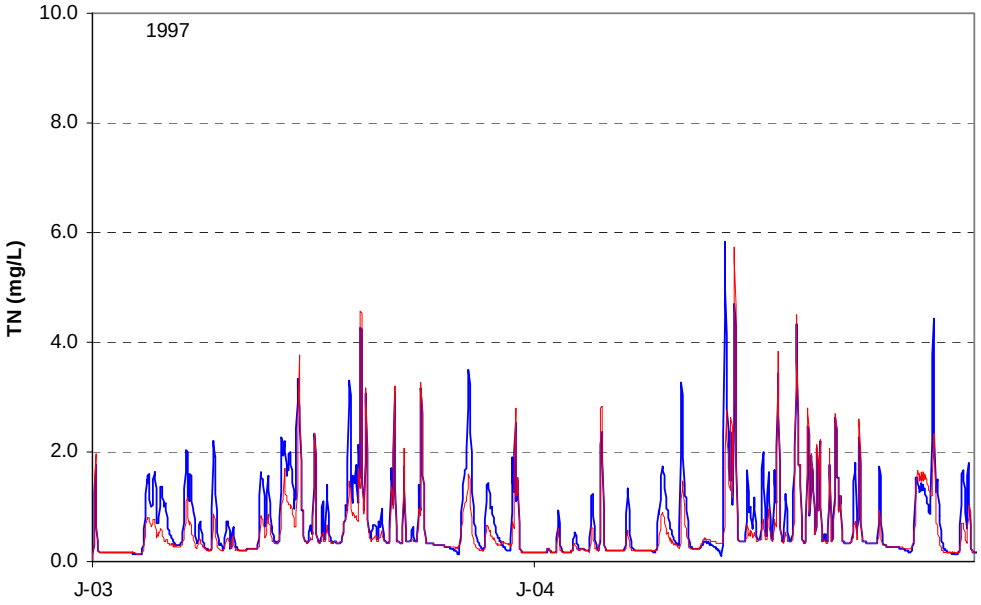
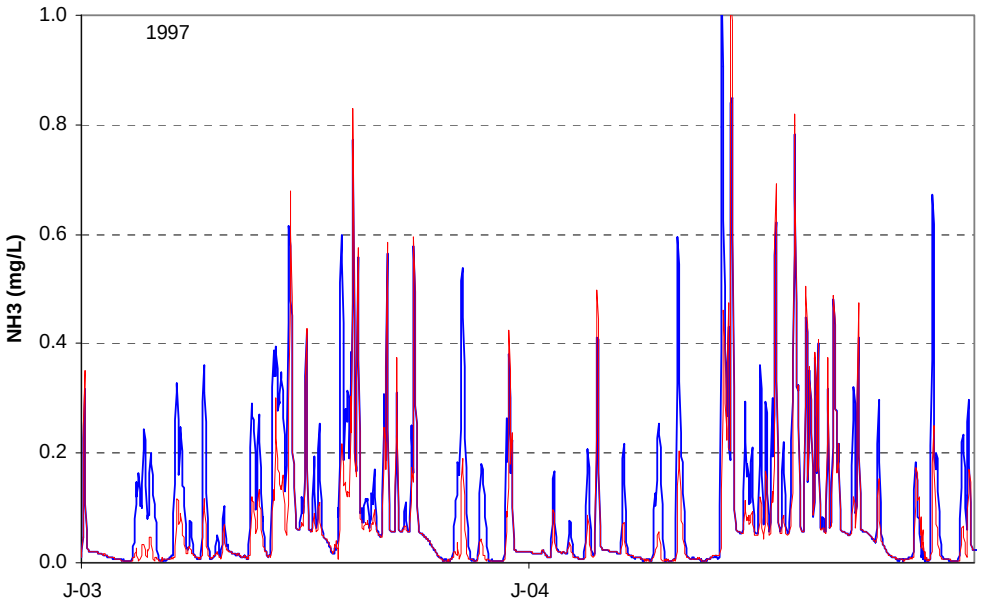
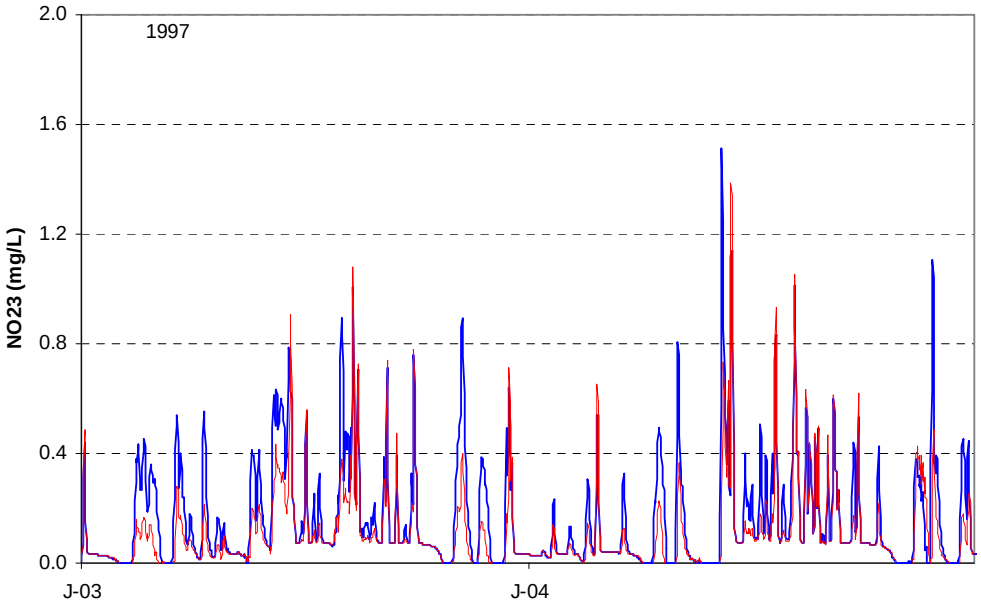


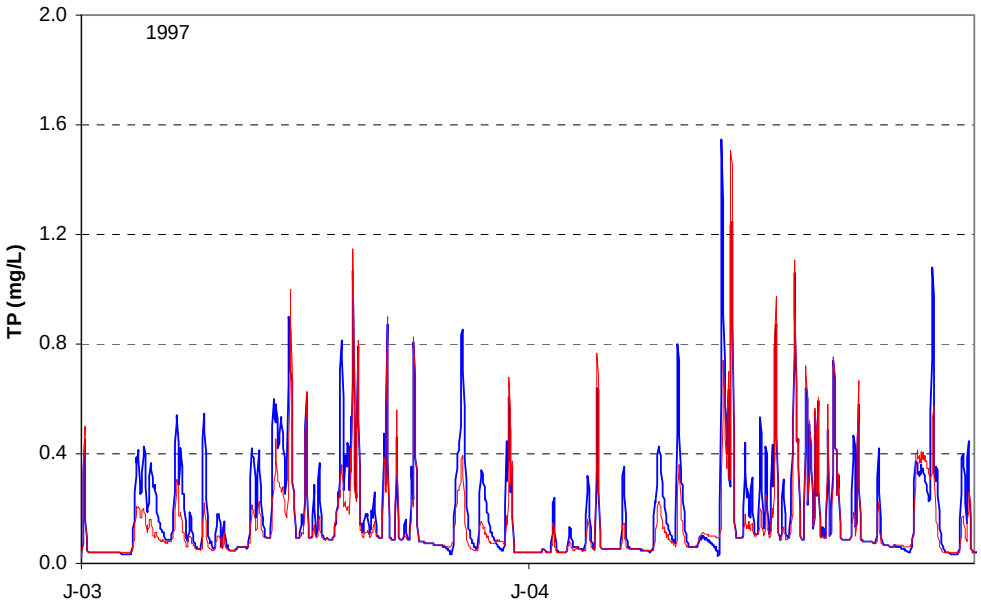
Figure E-1. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 1995

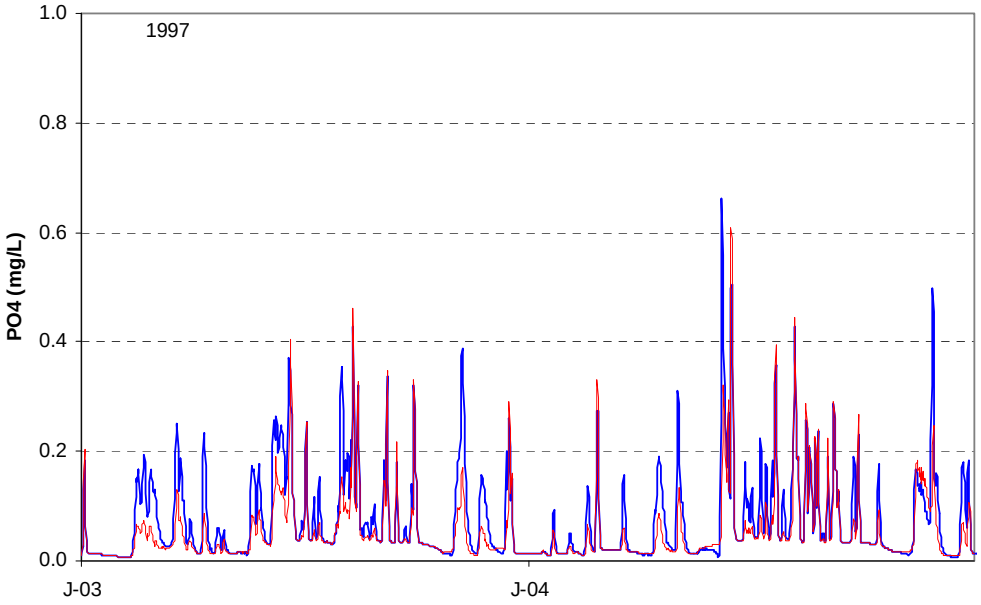

1997
DO (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-03
J-04


1997
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


1997
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


1997
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1997
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1997
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

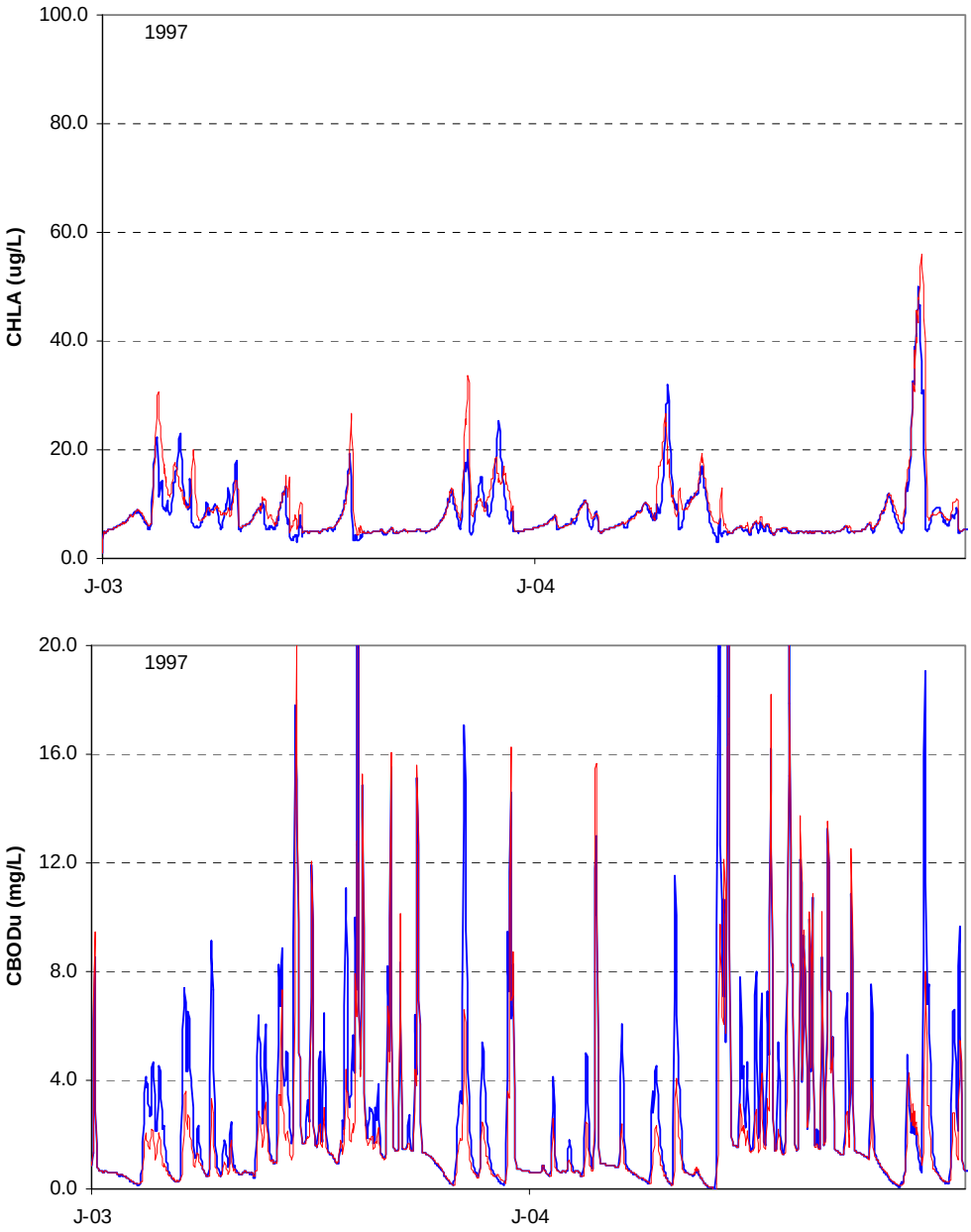
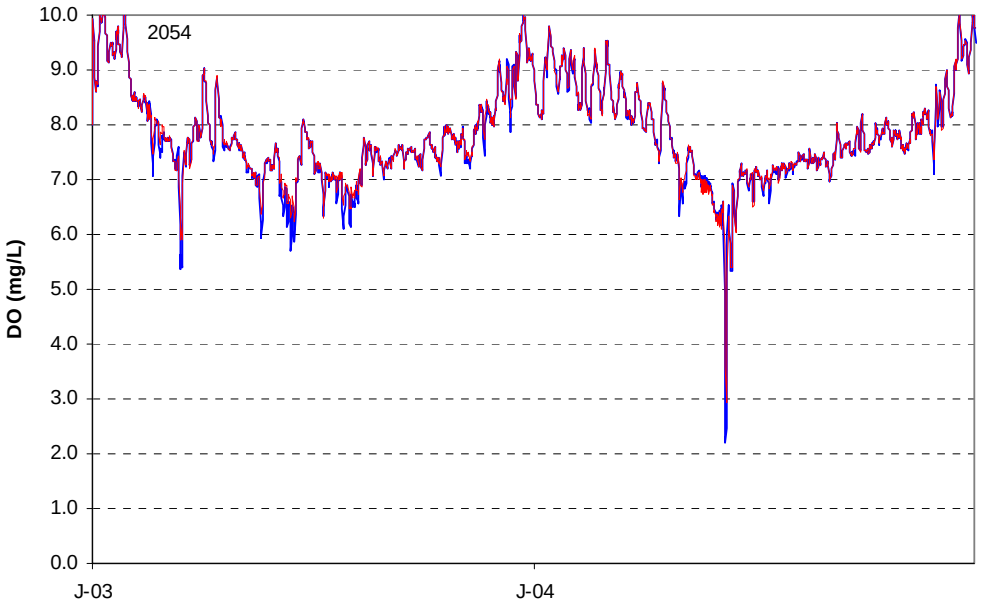
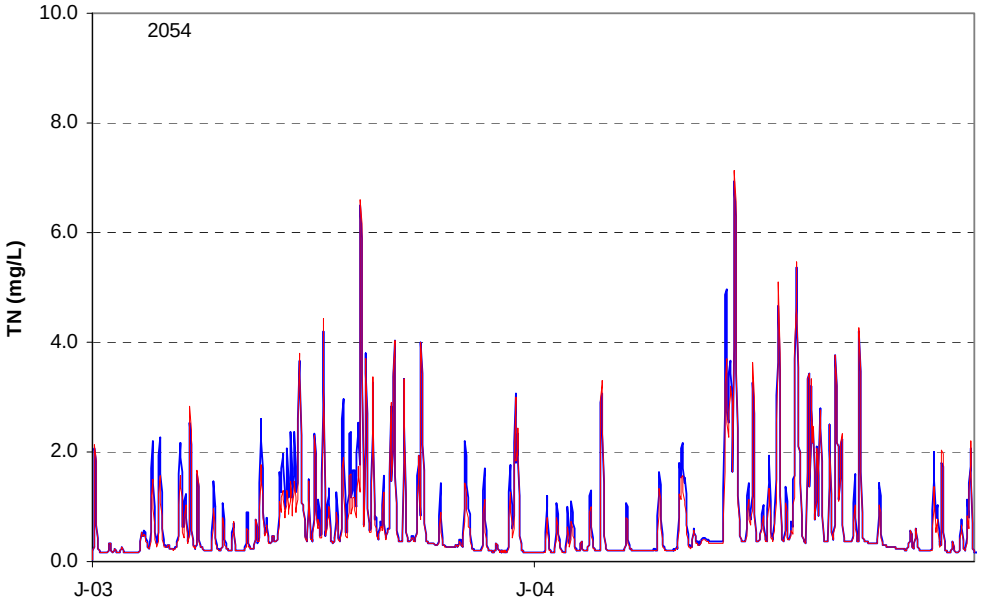
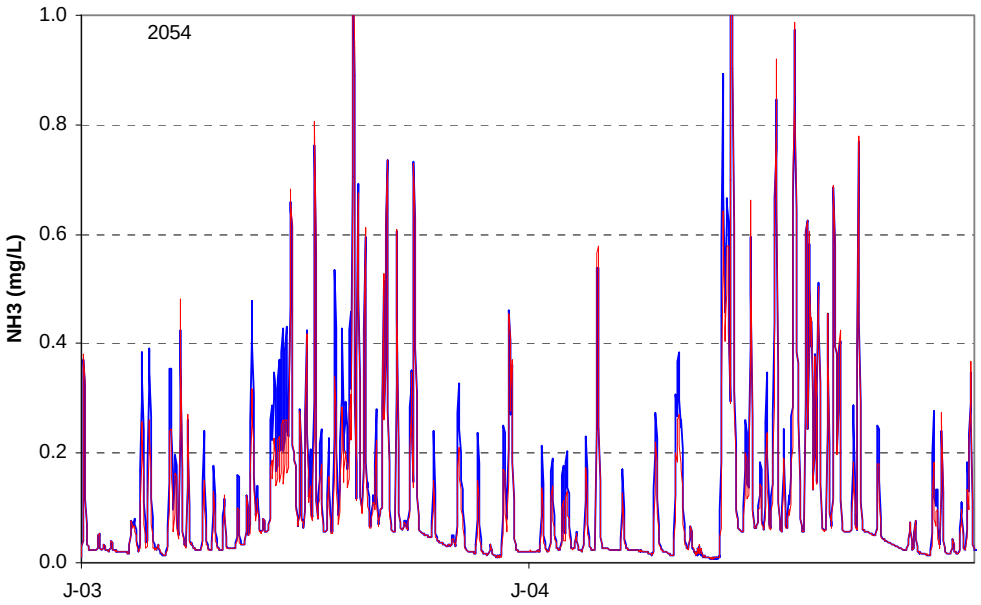
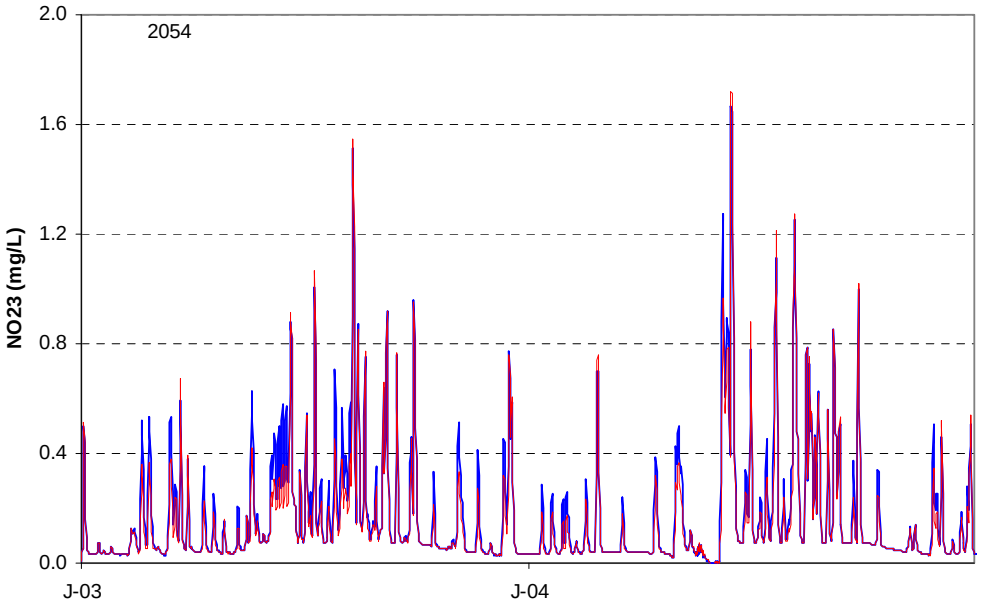


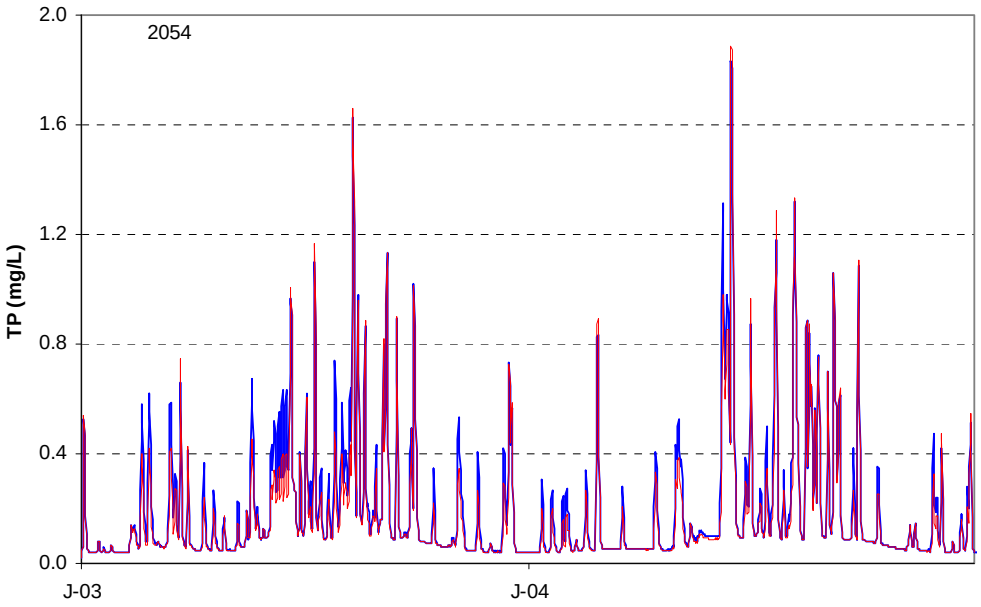
Figure E-3. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 1997

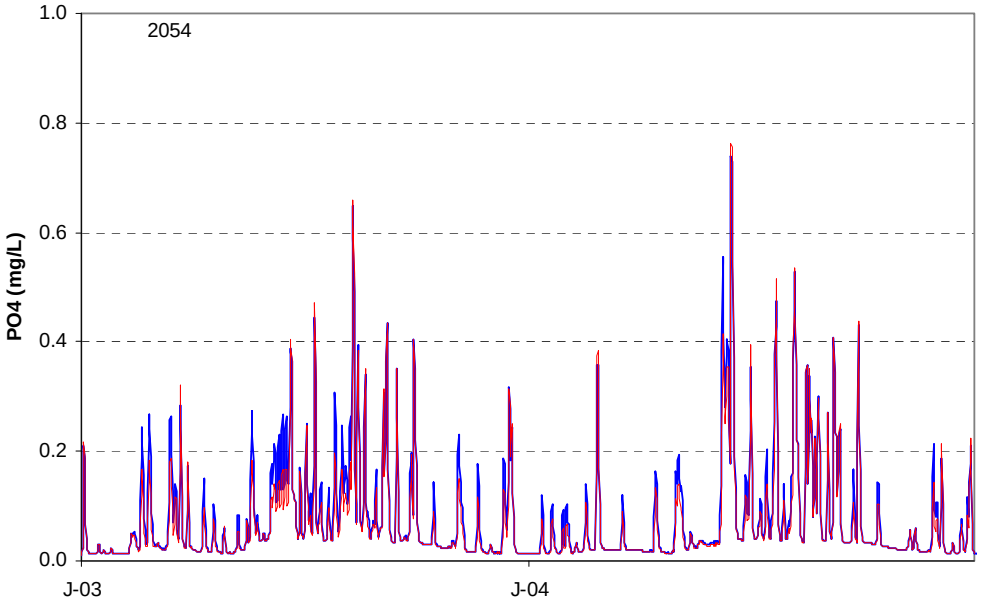

2054
DO (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-03
J-04


2054
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


2054
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


2054
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2054
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2054
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

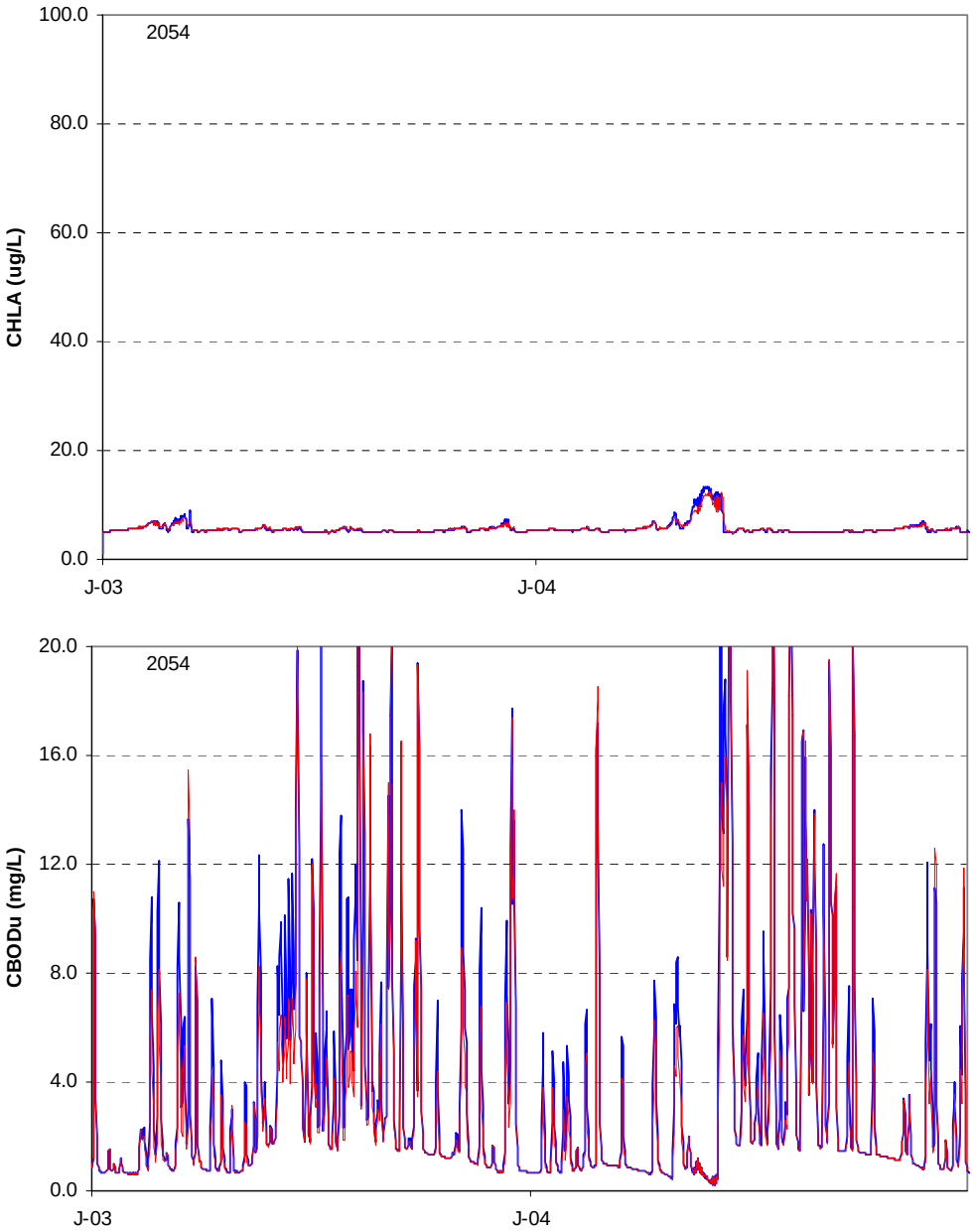
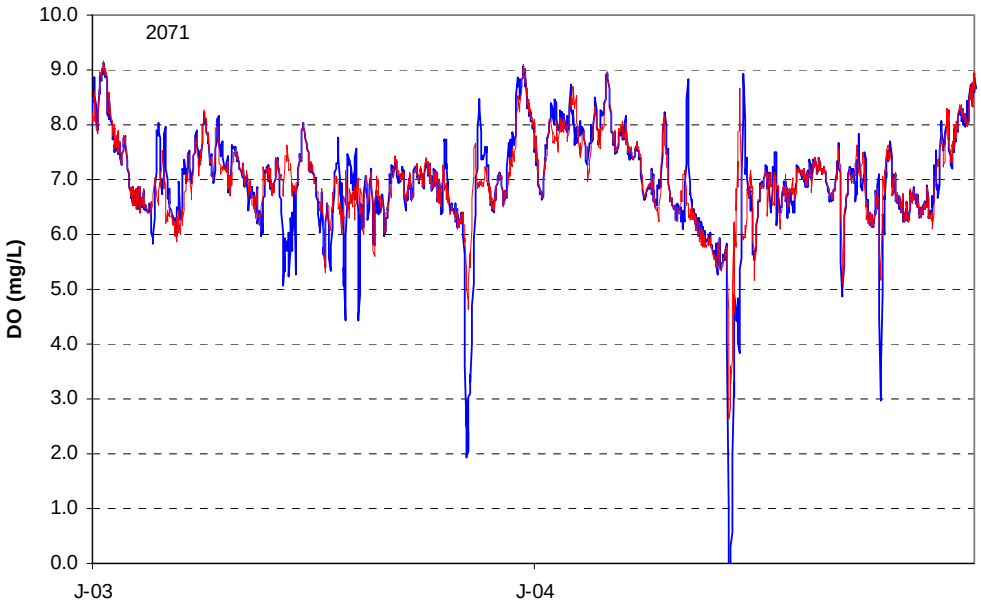
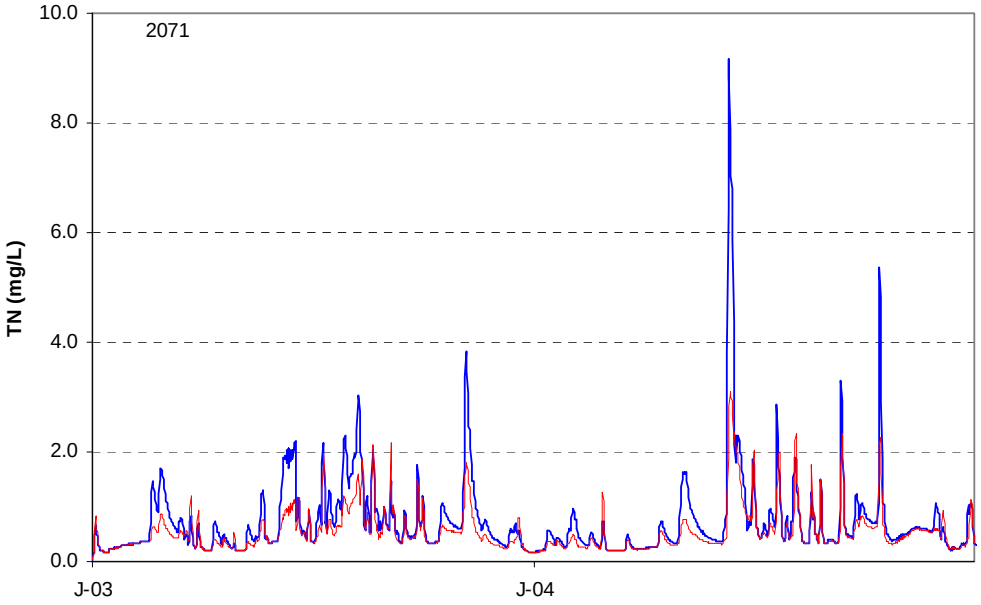
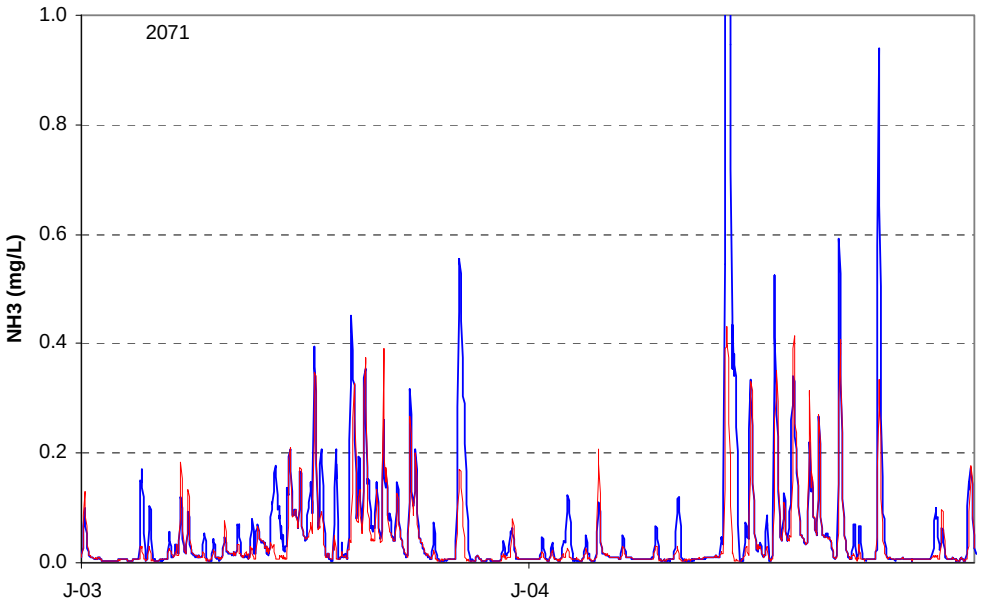
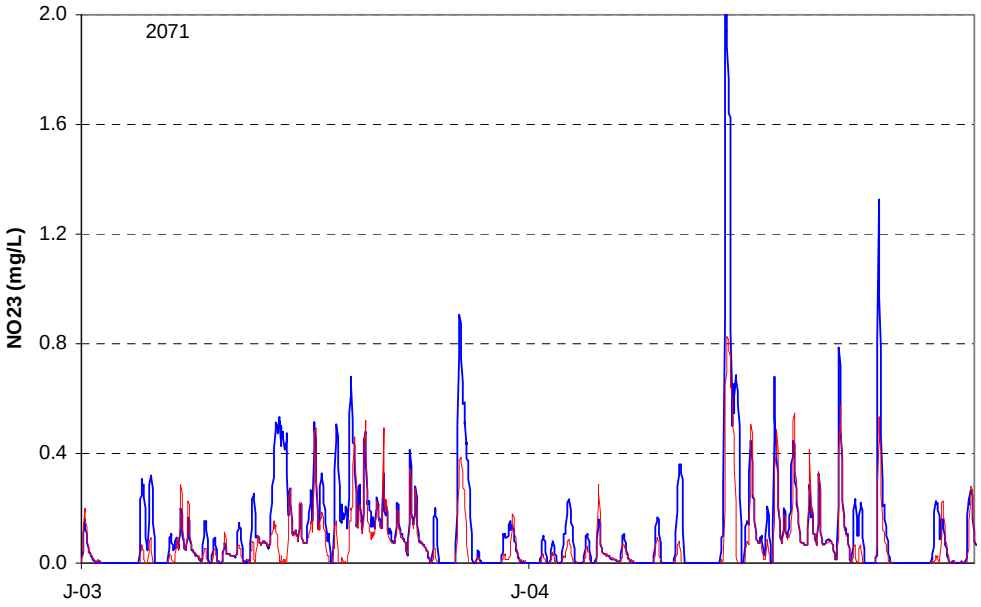


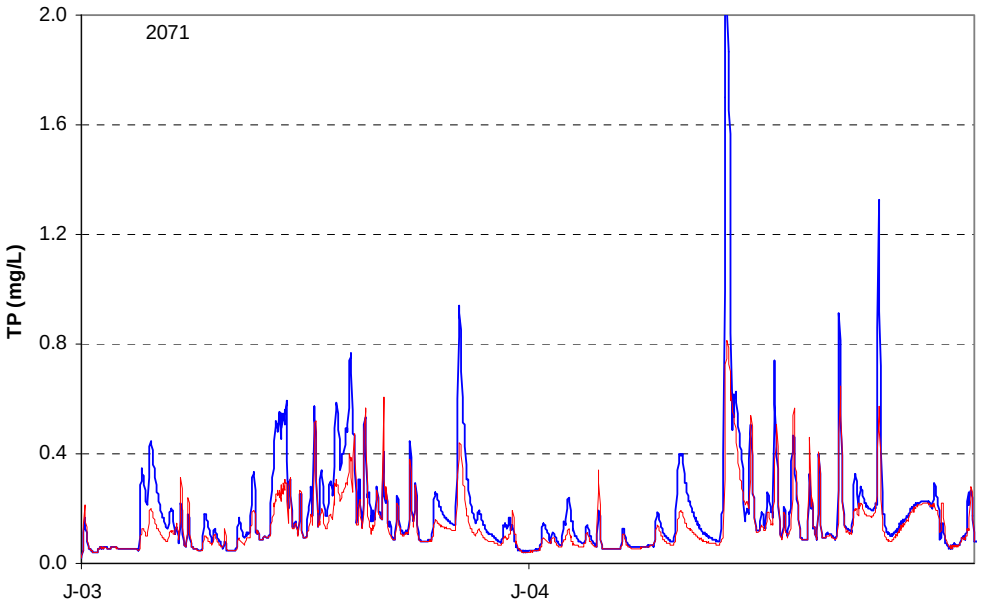
Figure E-4. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 2054

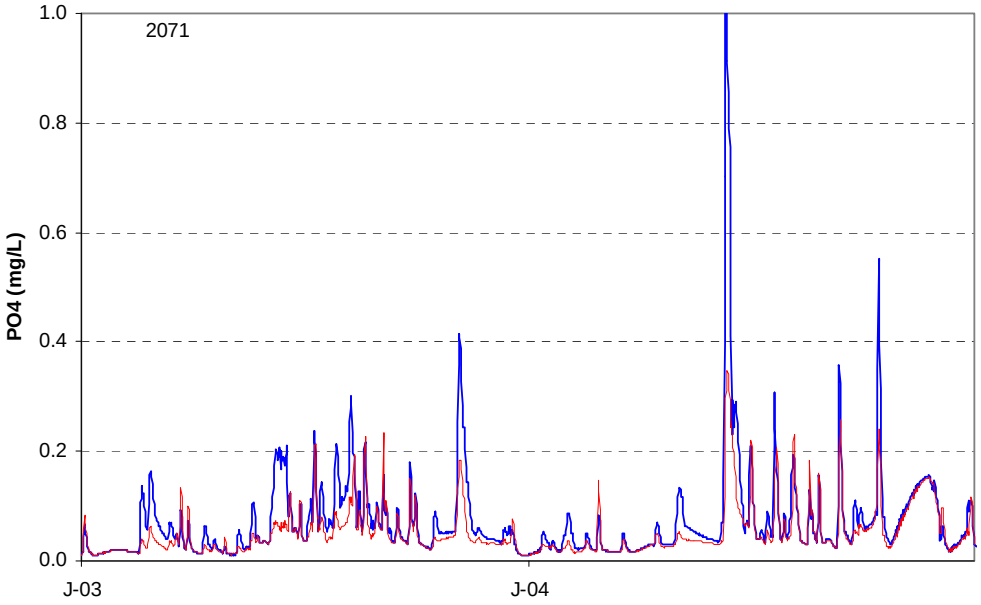

2071
DO (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-03
J-04


2071
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


2071
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


2071
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2071
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2071
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

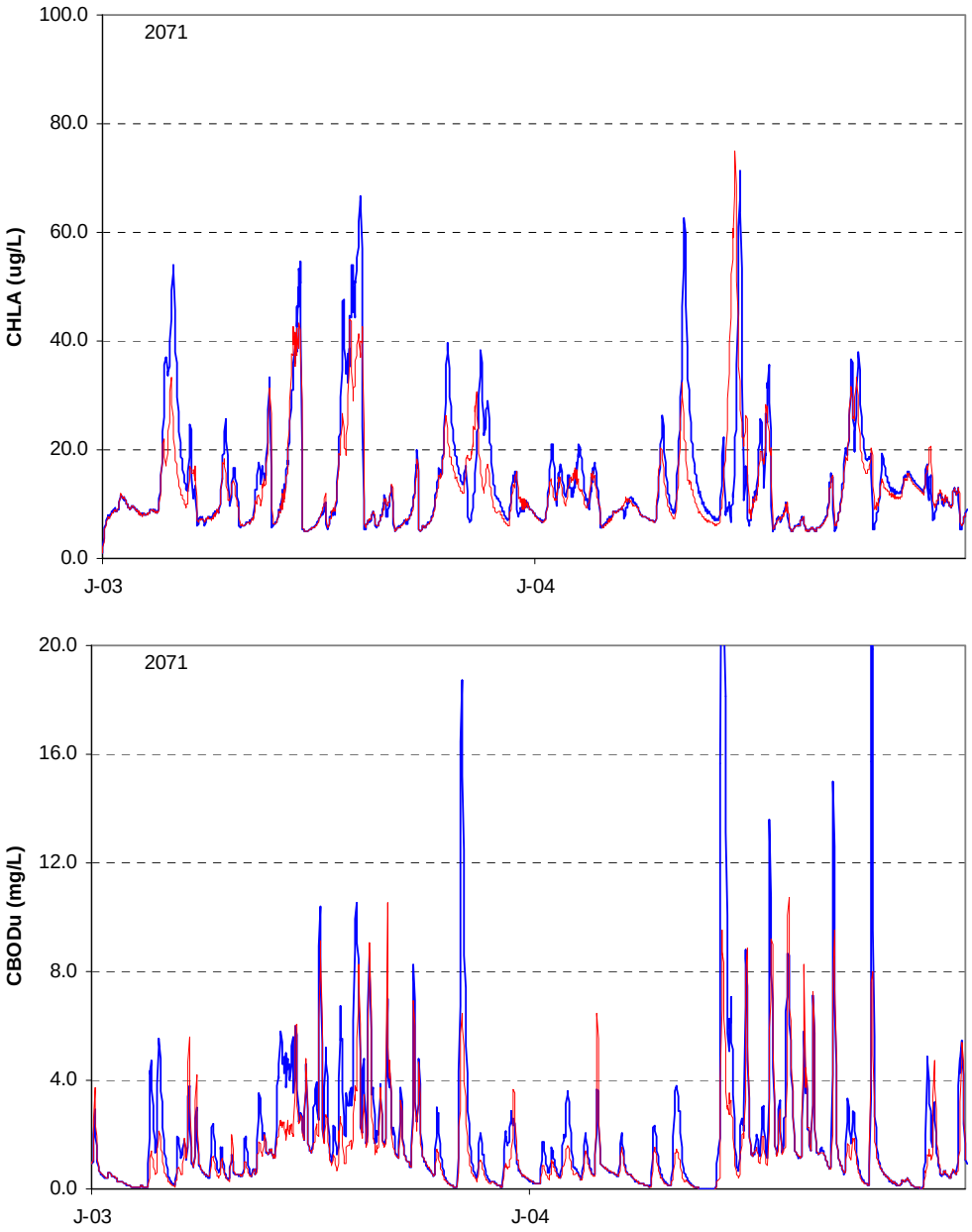
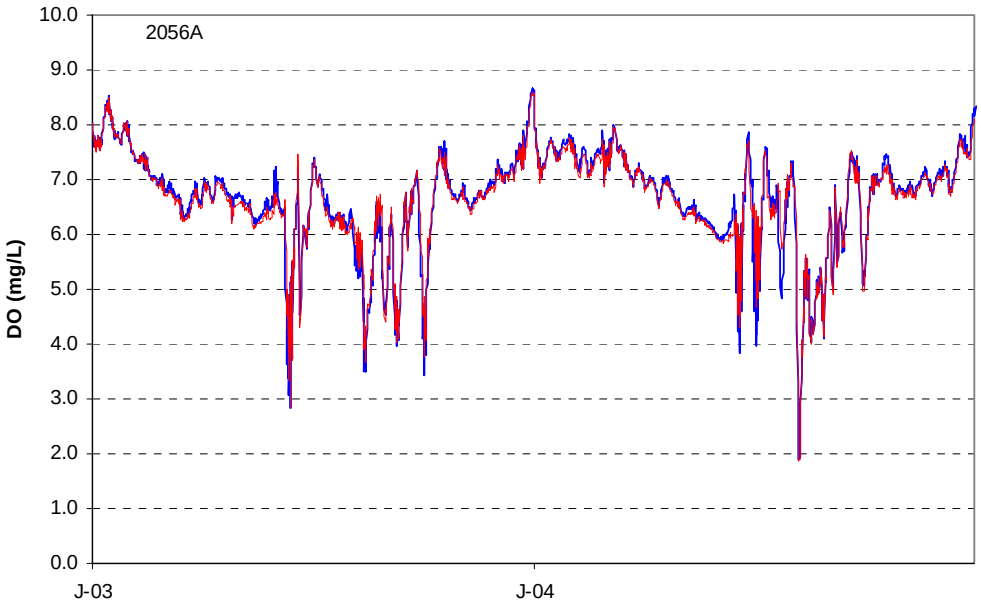
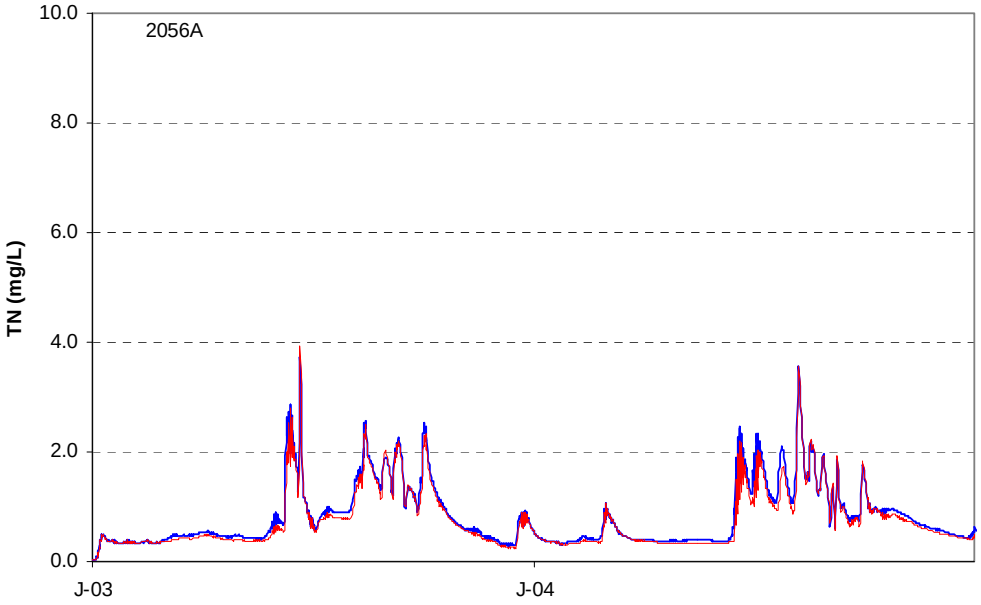
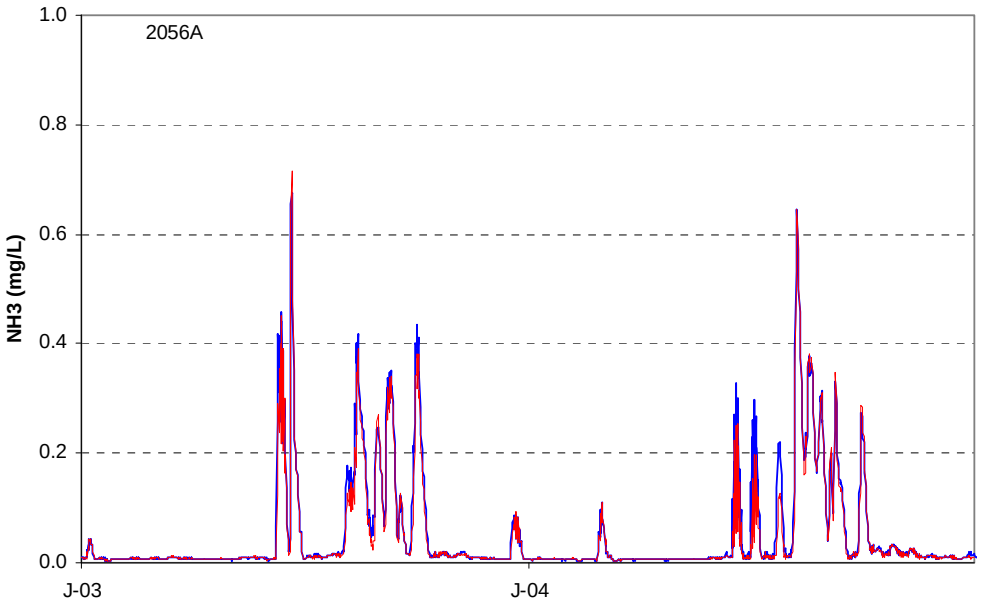
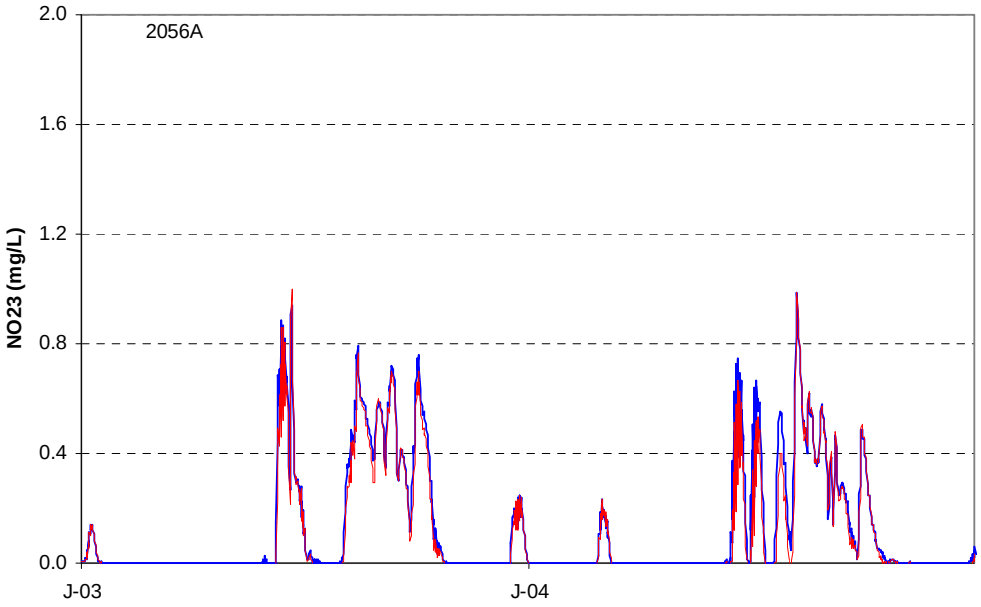


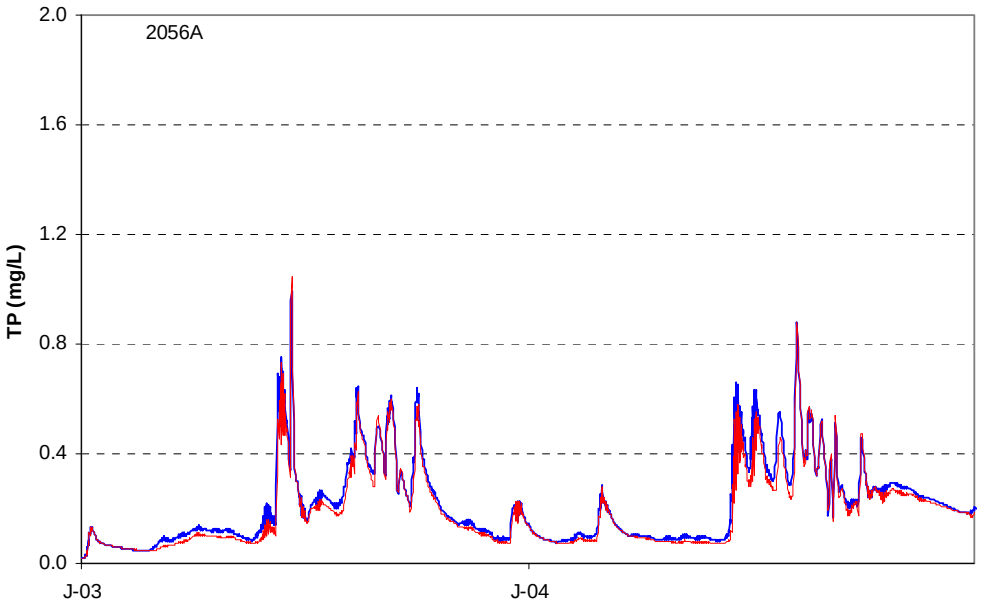
Figure E-5. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 2071

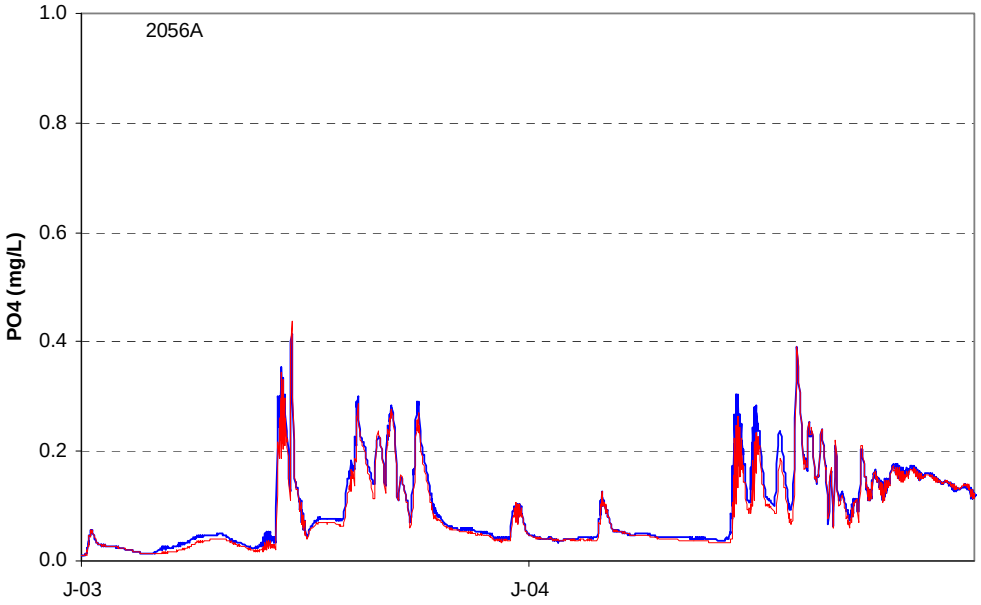

2056A
DO (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-03
J-04


2056A
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


2056A
1.0
0.8
0.6
0.4
0.2
0.0
NH3 (mg/L)
J-03
J-04


2056A
2.0
1.6
1.2
0.8
0.4
0.0
NO23 (mg/L)
J-03
J-04


2056A
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2056A
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

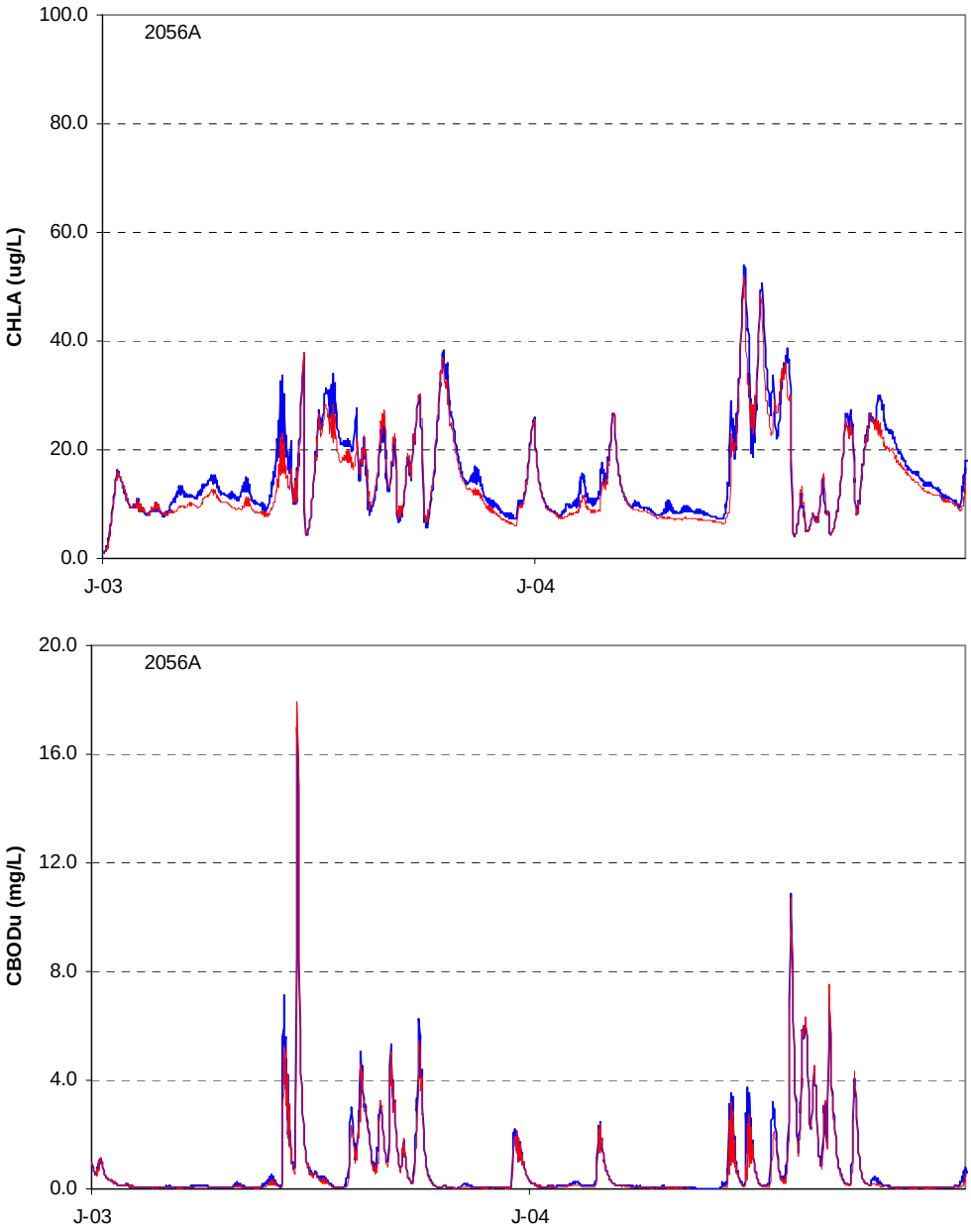
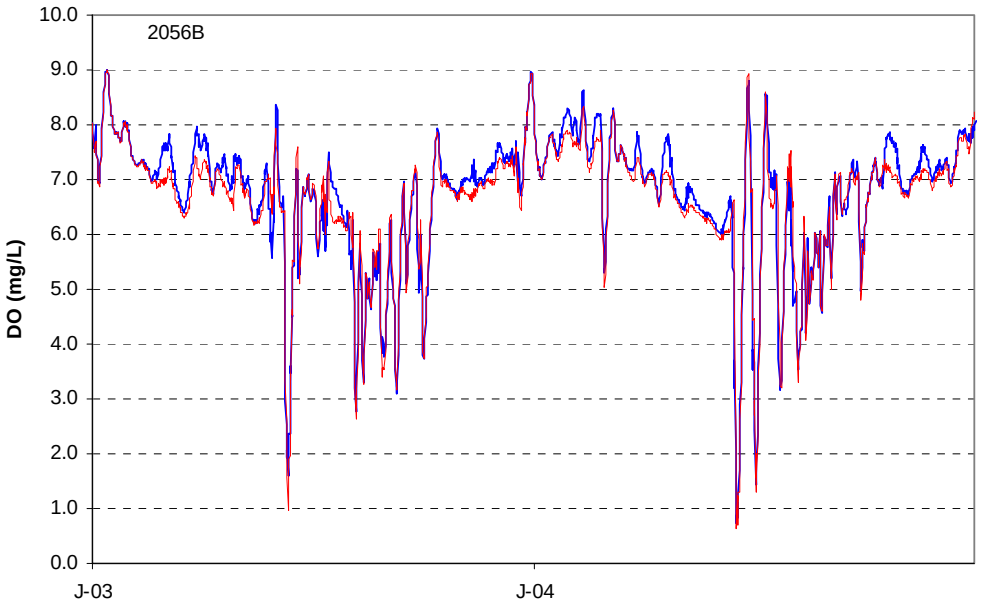
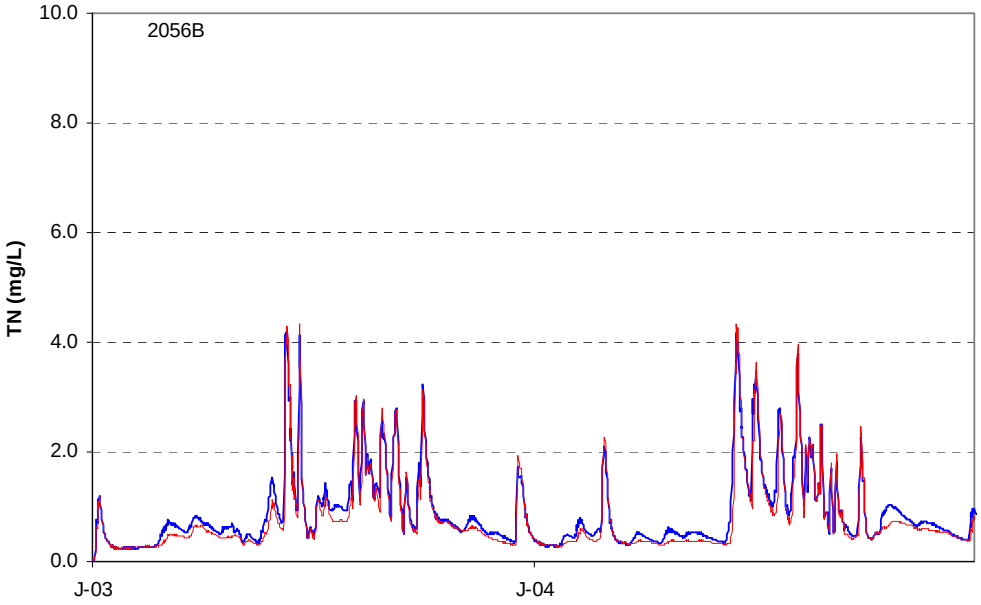
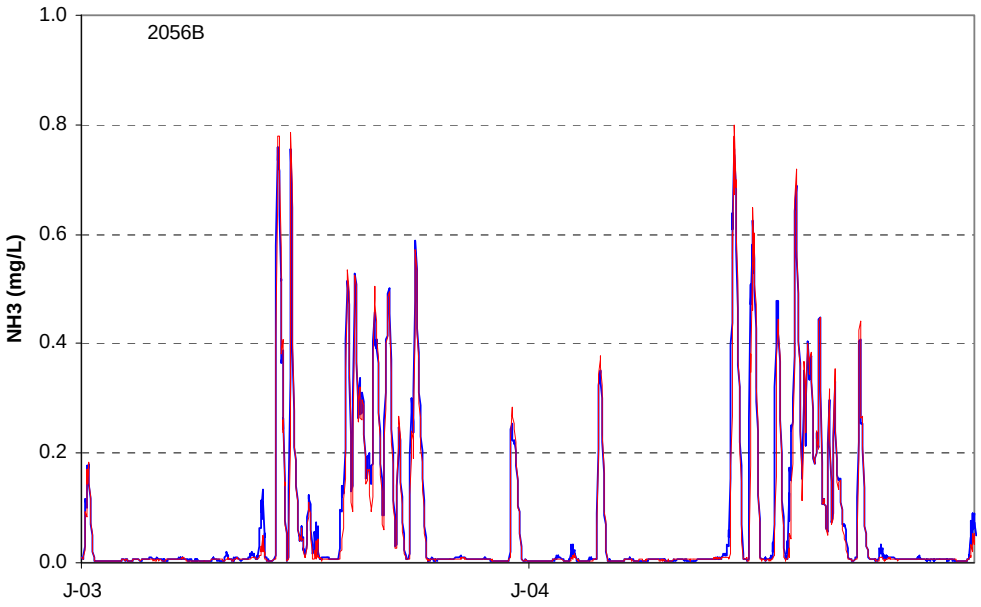
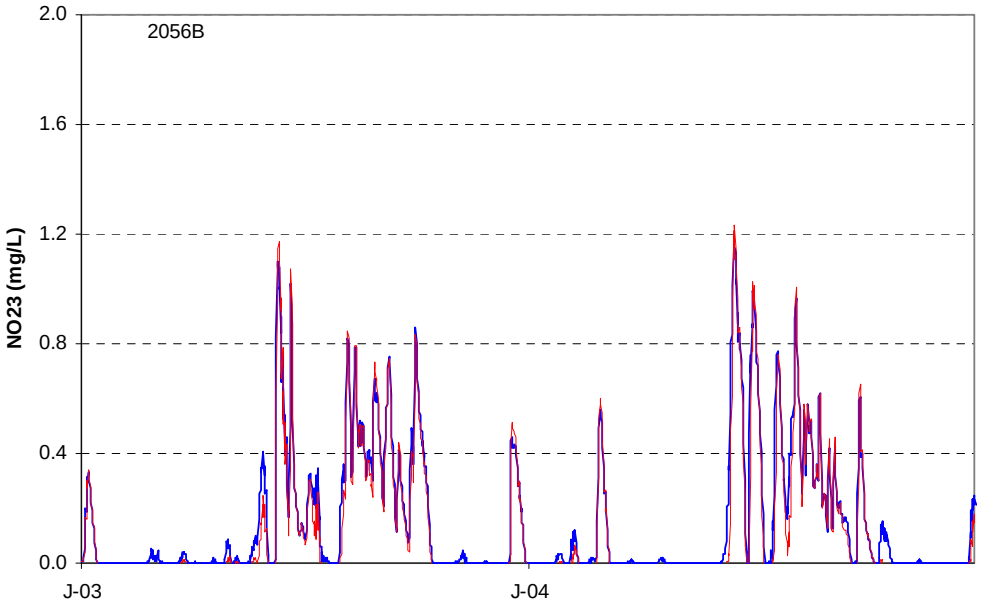


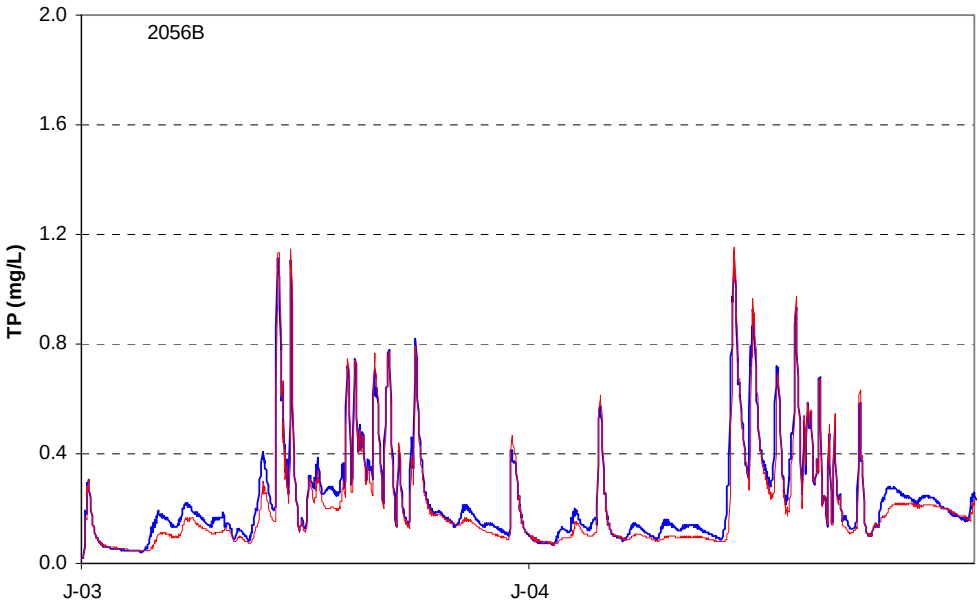
Figure E-6. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 2056A

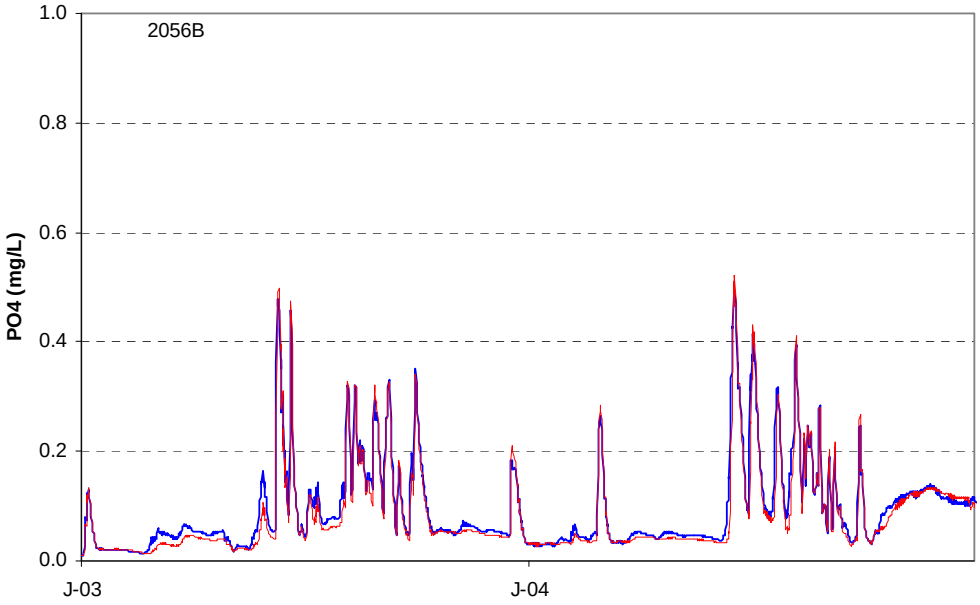

2056B
DO (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-03
J-04


2056B
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


2056B
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


2056B
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2056B
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2056B
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

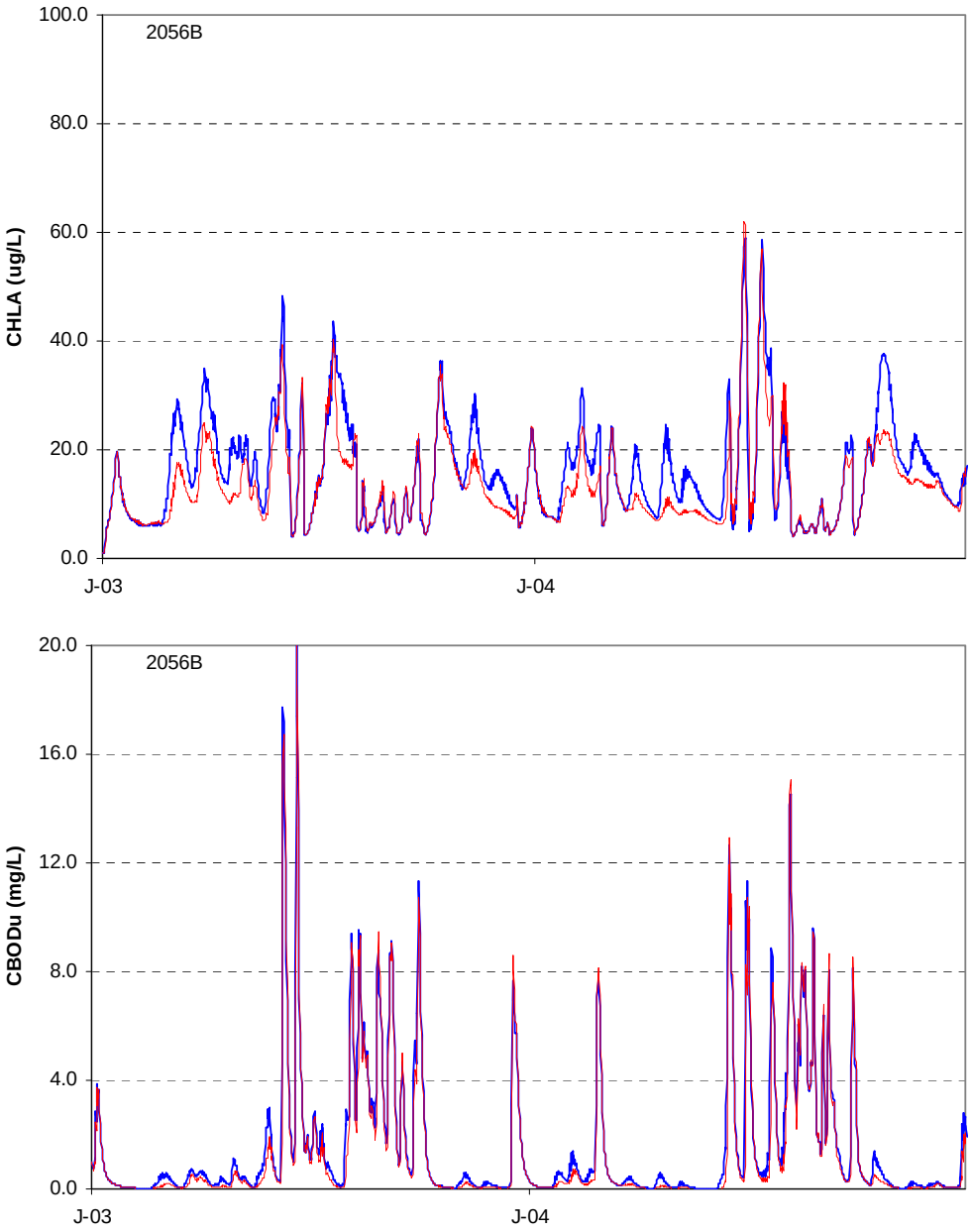
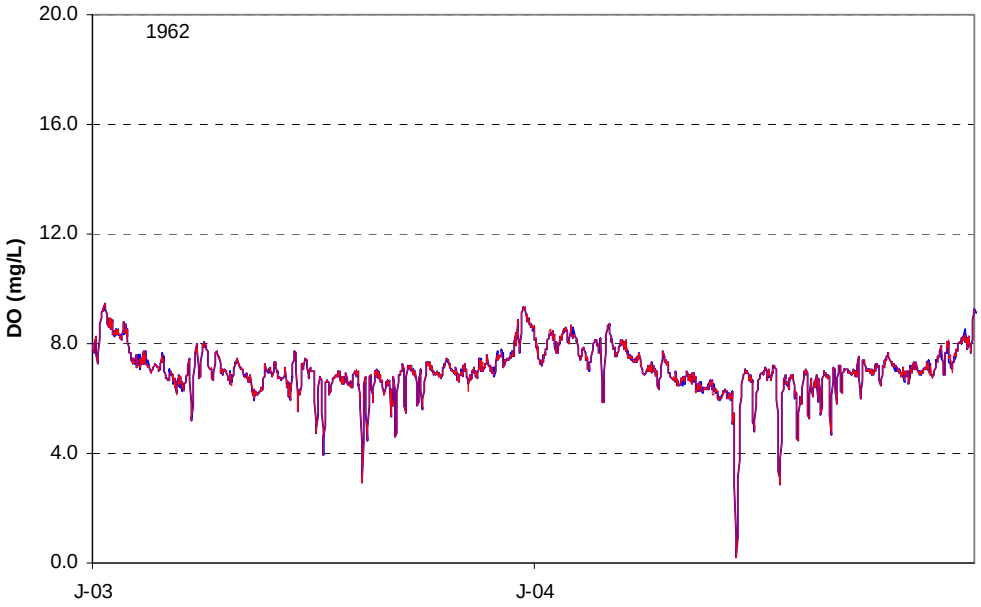
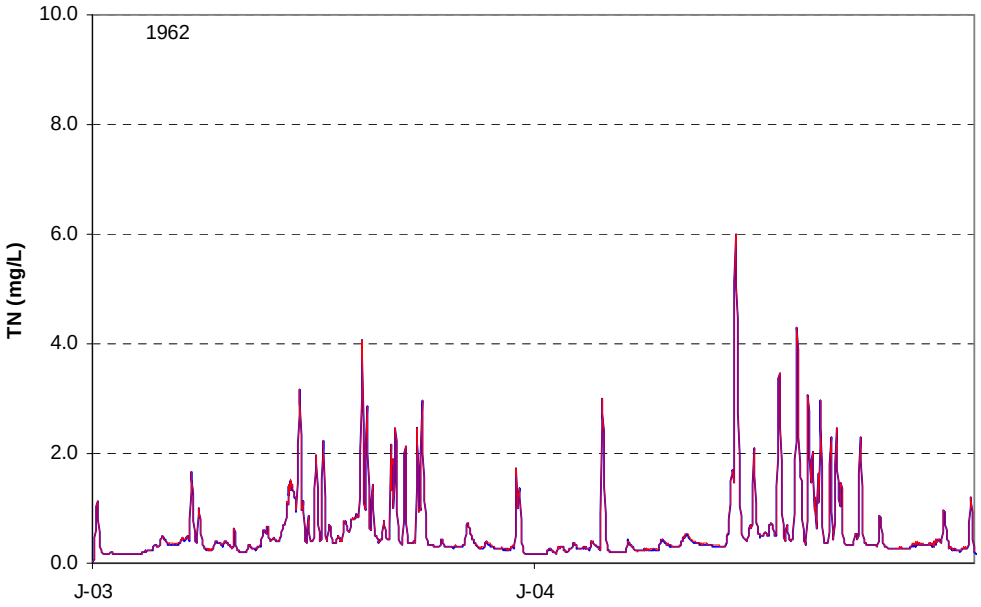


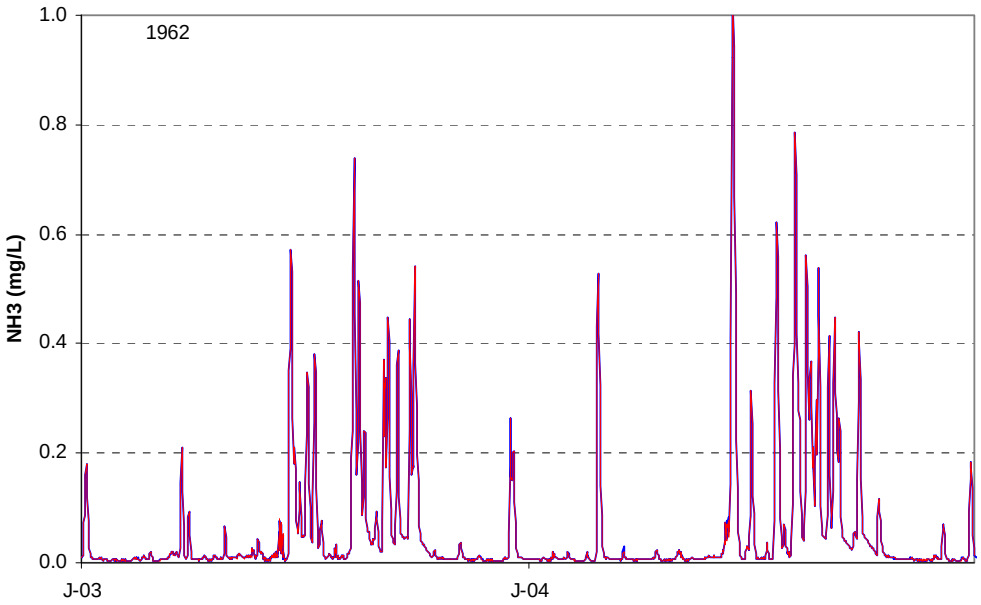
Figure E-7. Comparison of modeled water quality under existing conditions vs. natural conditions in WBID 2056B

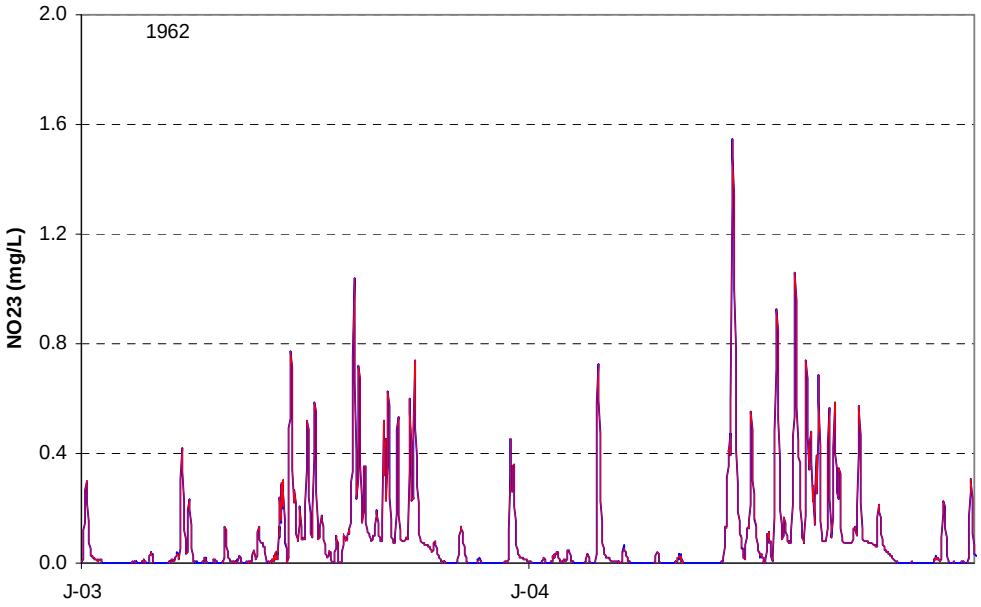
Appendix F: Comparison of Modeled Water Quality Constituents between All Natural Conditions and Natural Conditions with Point Sources

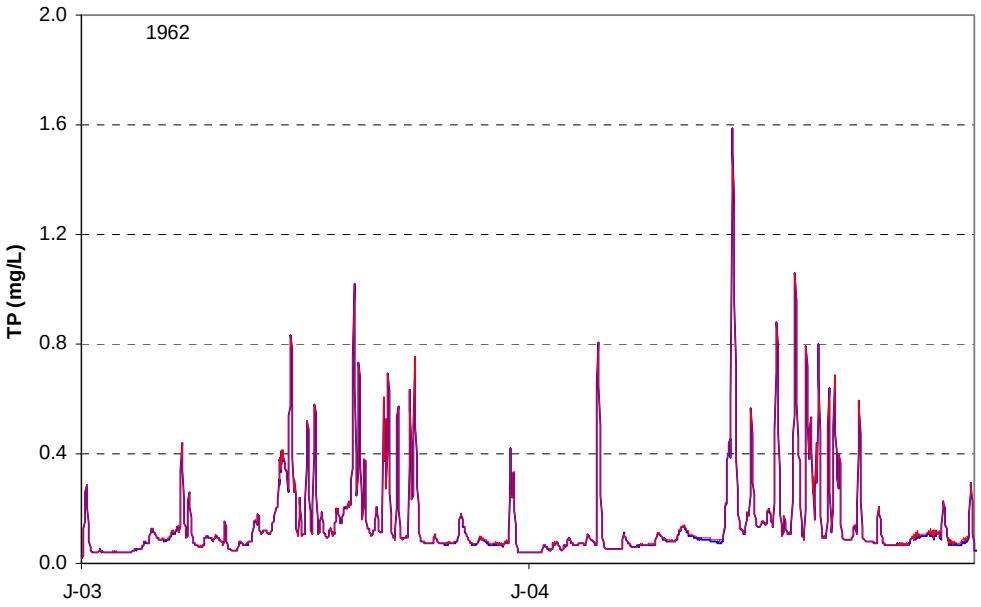
Blue lines are natural conditions with point sources.
Red lines are natural conditions.

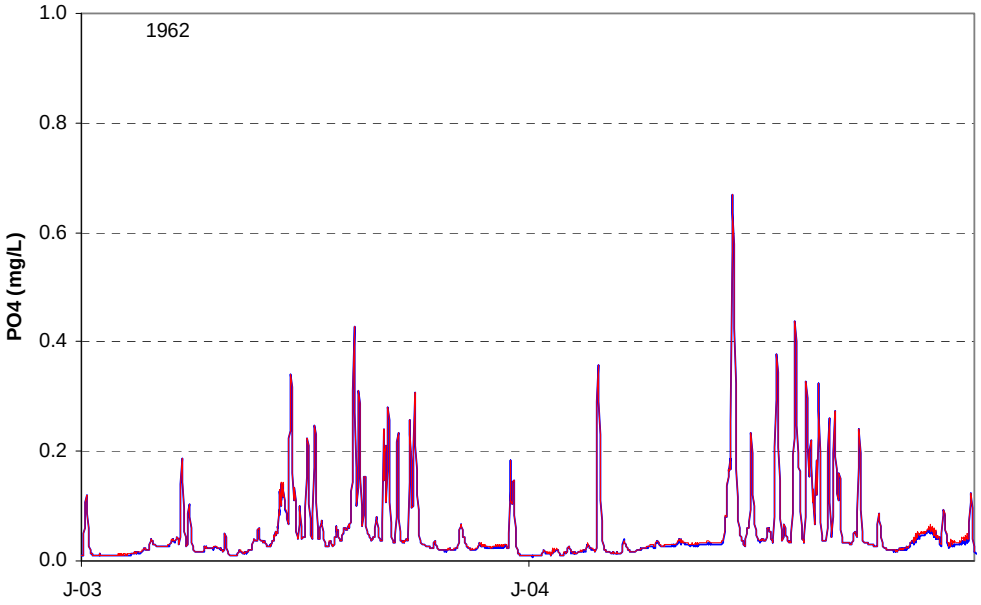





1962
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


1962
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1962
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1962
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

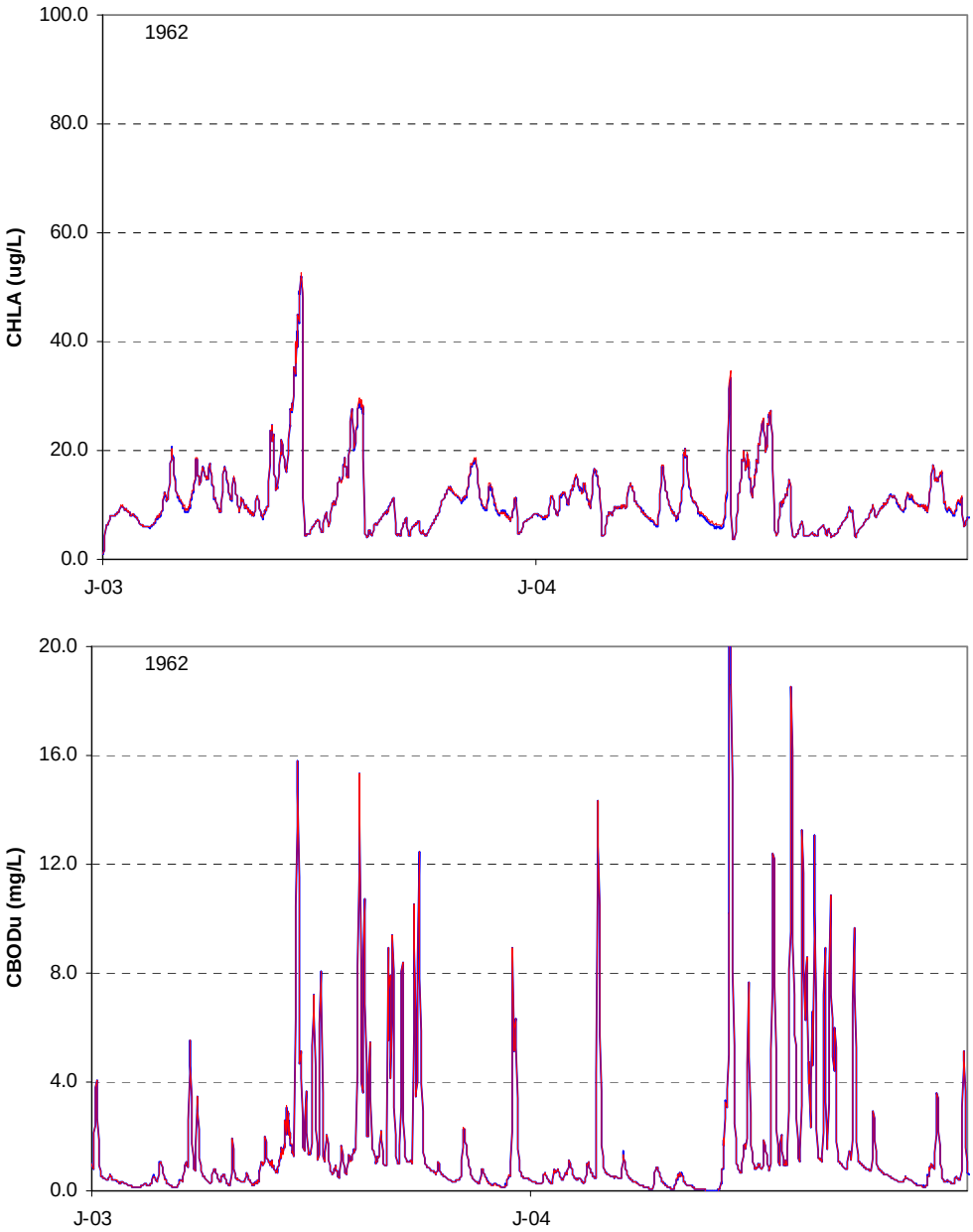
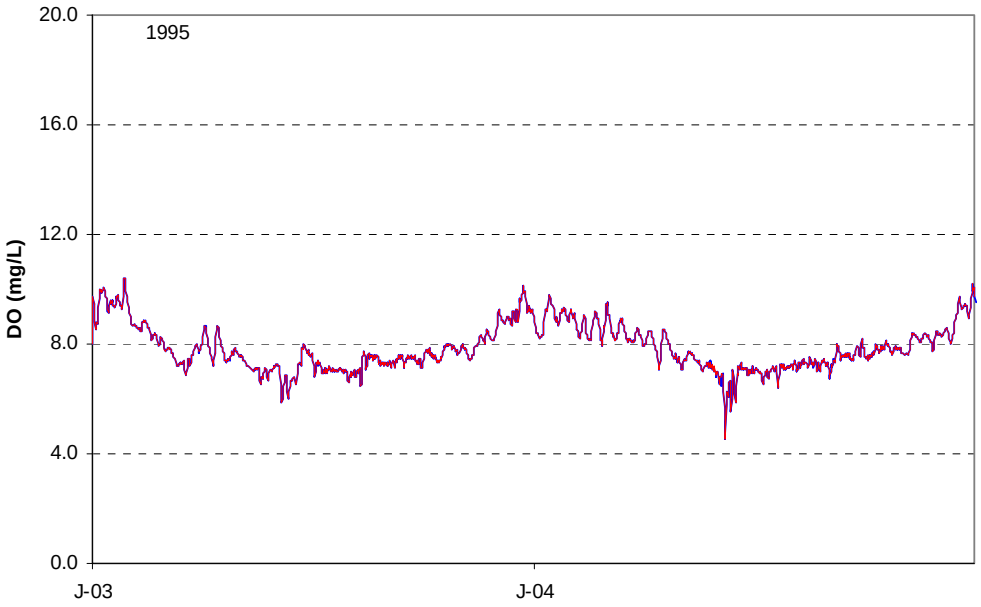
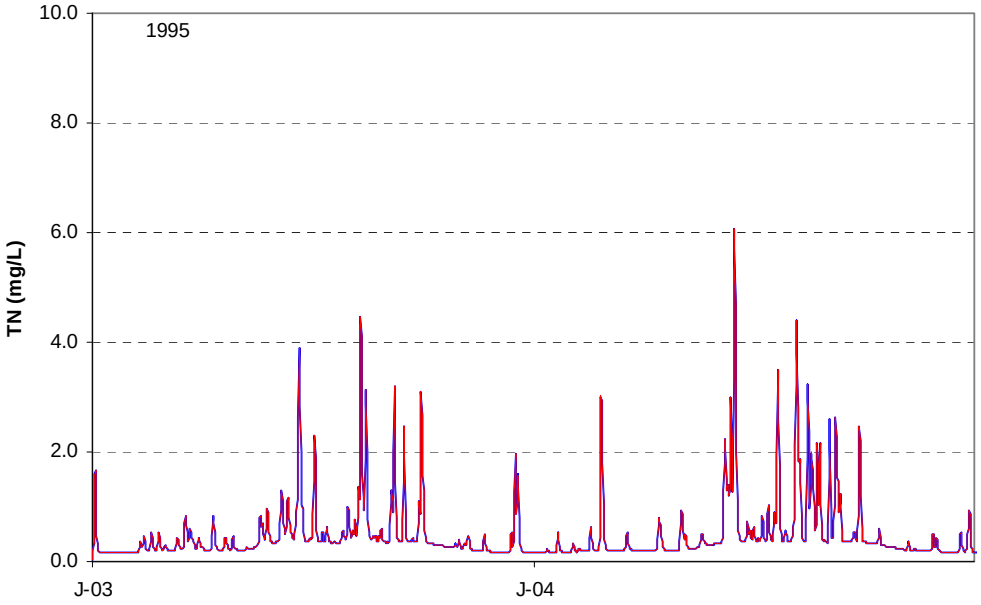
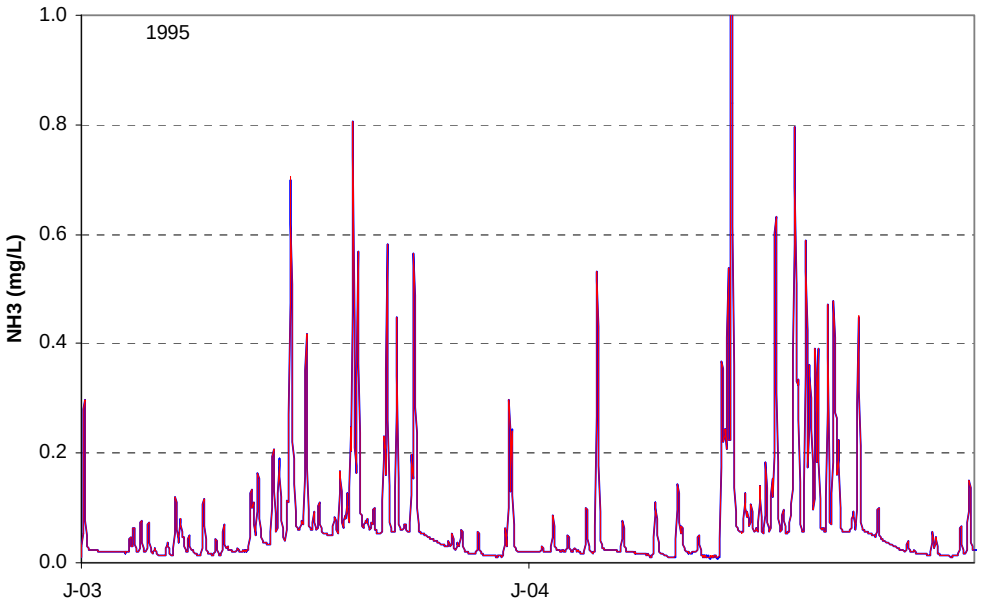
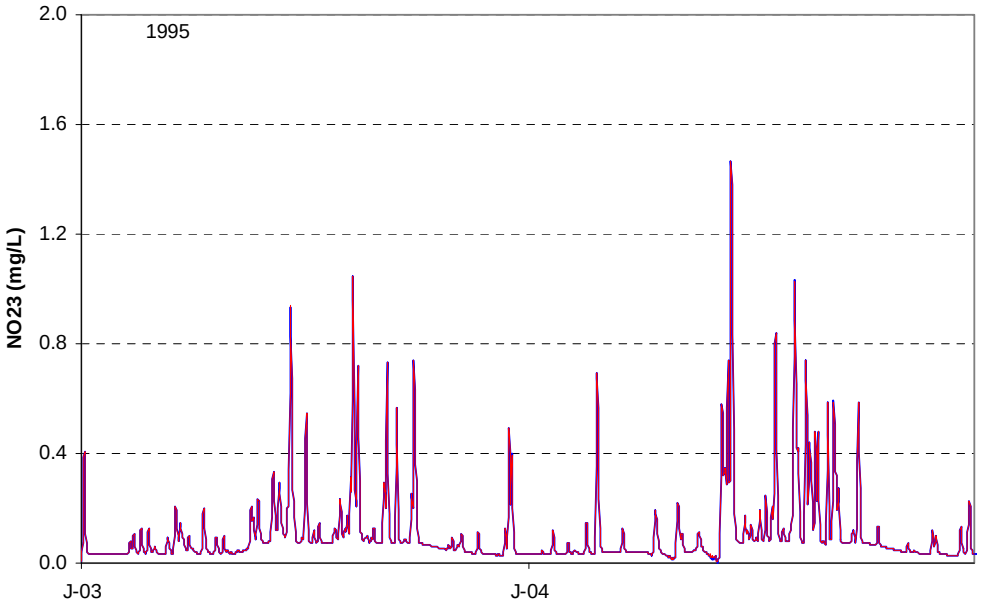


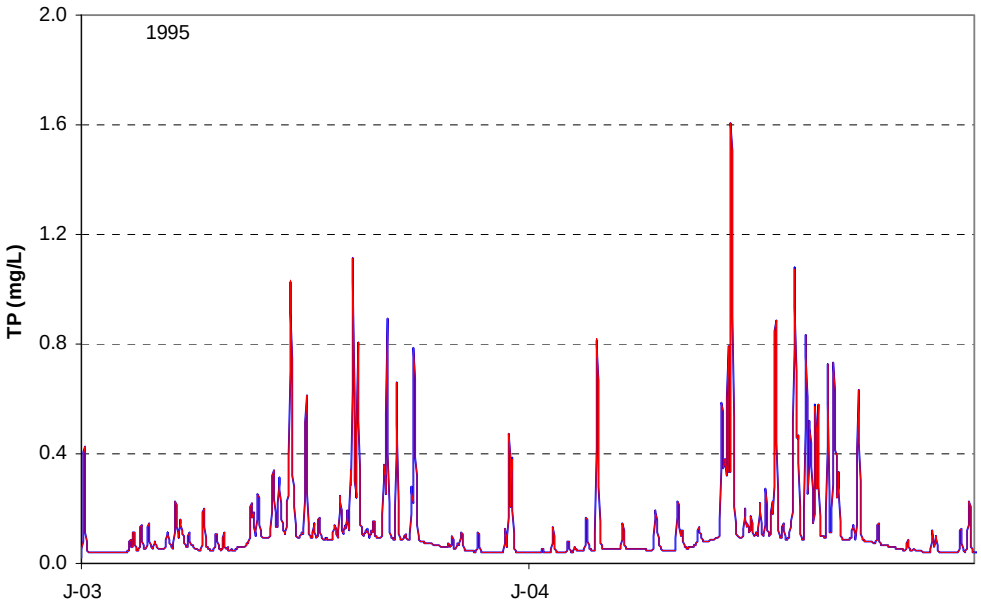
Figure F-1. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 1962


1995
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


1995
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


1995
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


1995
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1995
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04

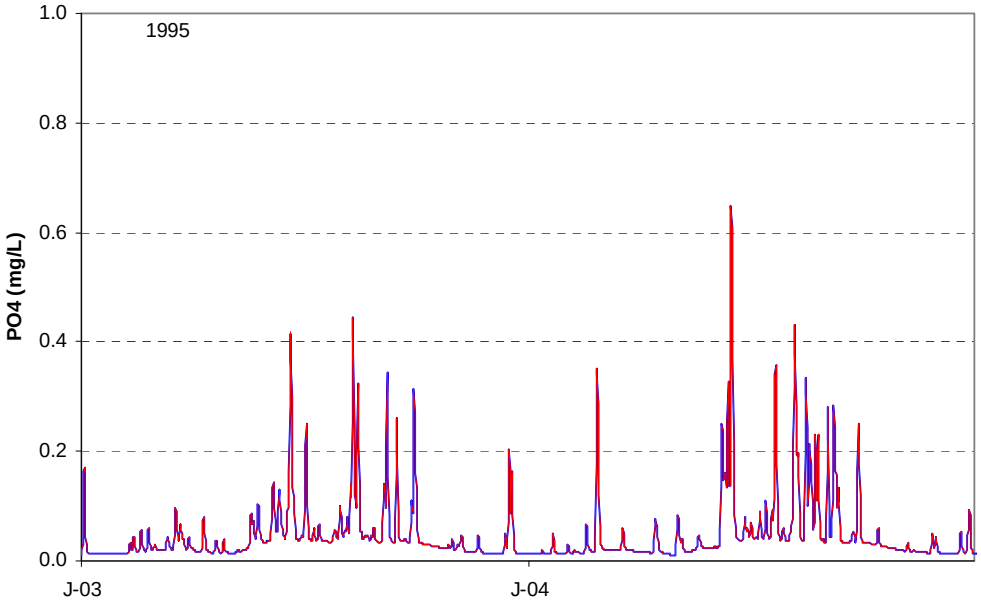
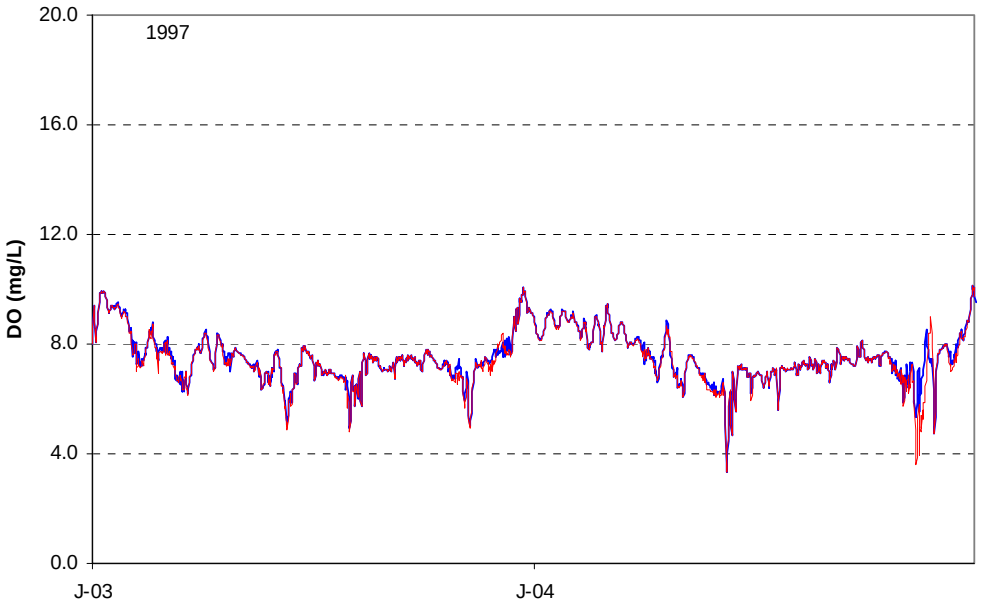
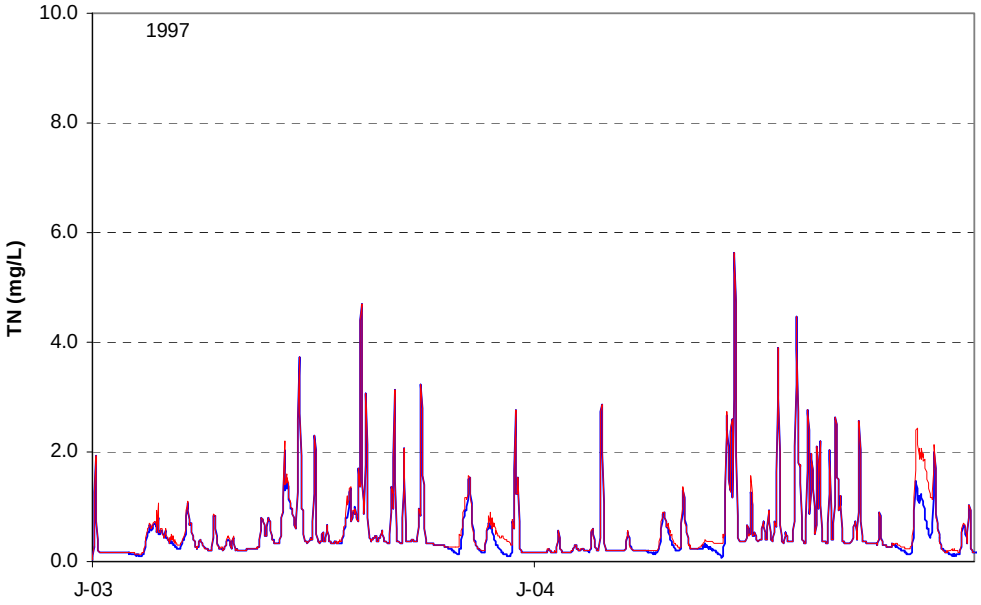
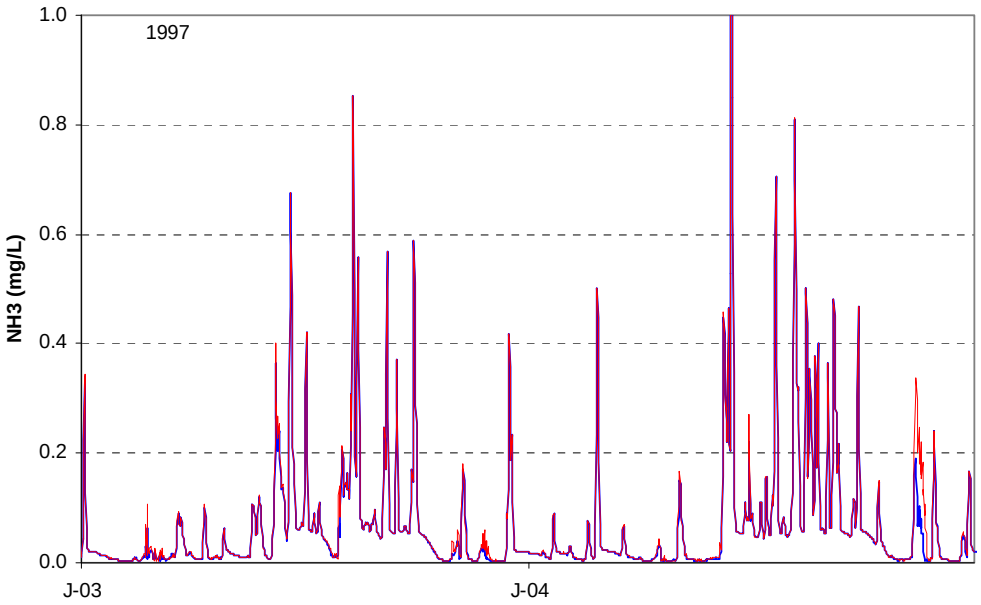
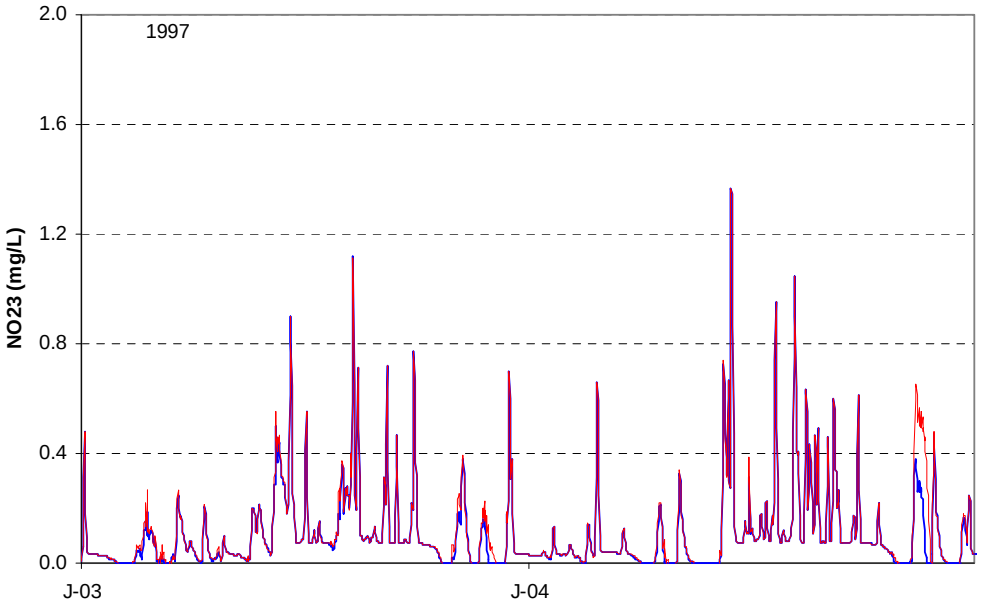

1995
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

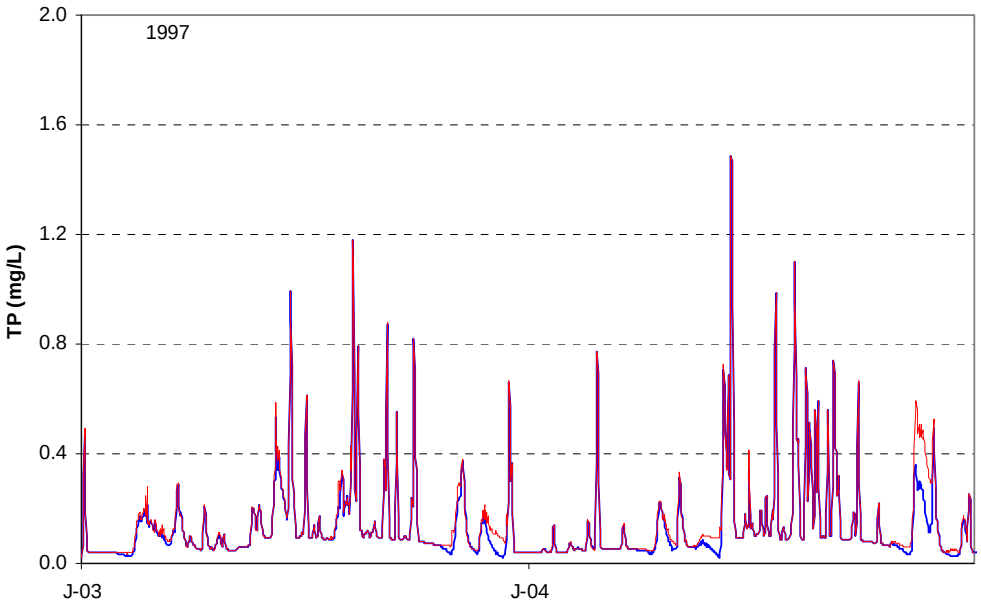
Figure F-2. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 1995

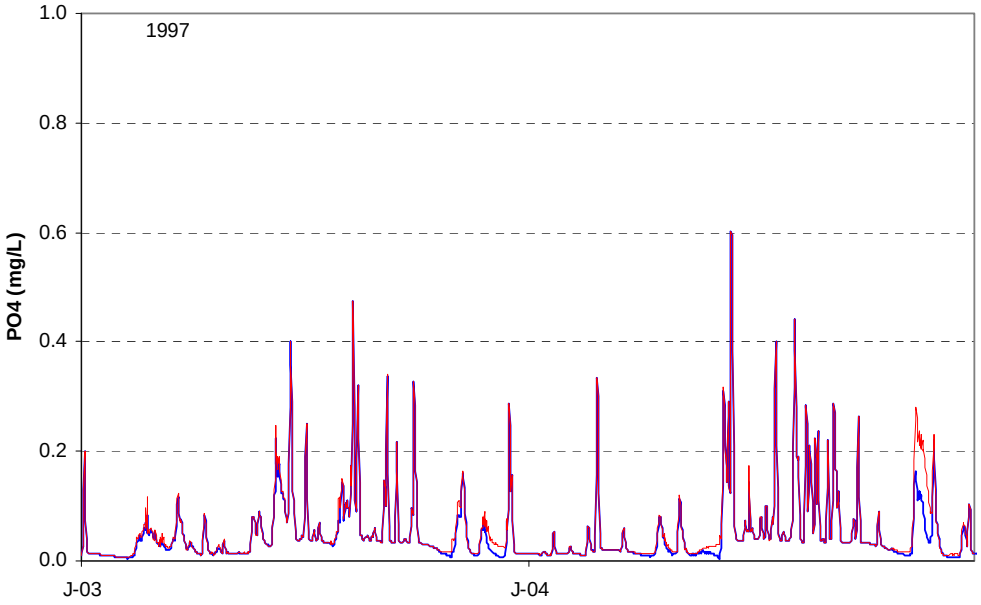

1997
DO (mg/L)
20.0
16.0
12.0
8.0
4.0
0.0
J-03
J-04


1997
TN (mg/L)
10.0
8.0
6.0
4.0
2.0
0.0
J-03
J-04


1997
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


1997
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1997
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


1997
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

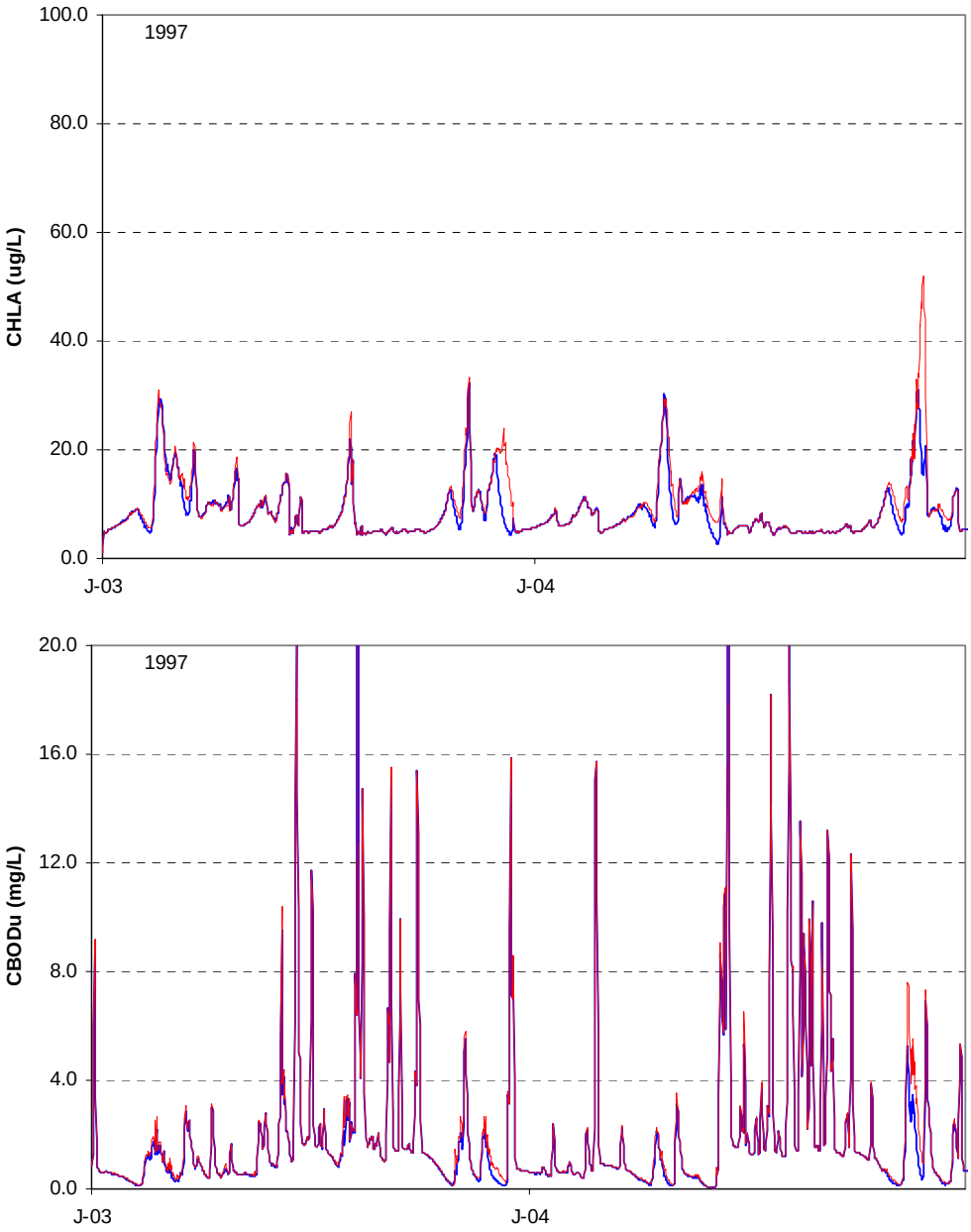
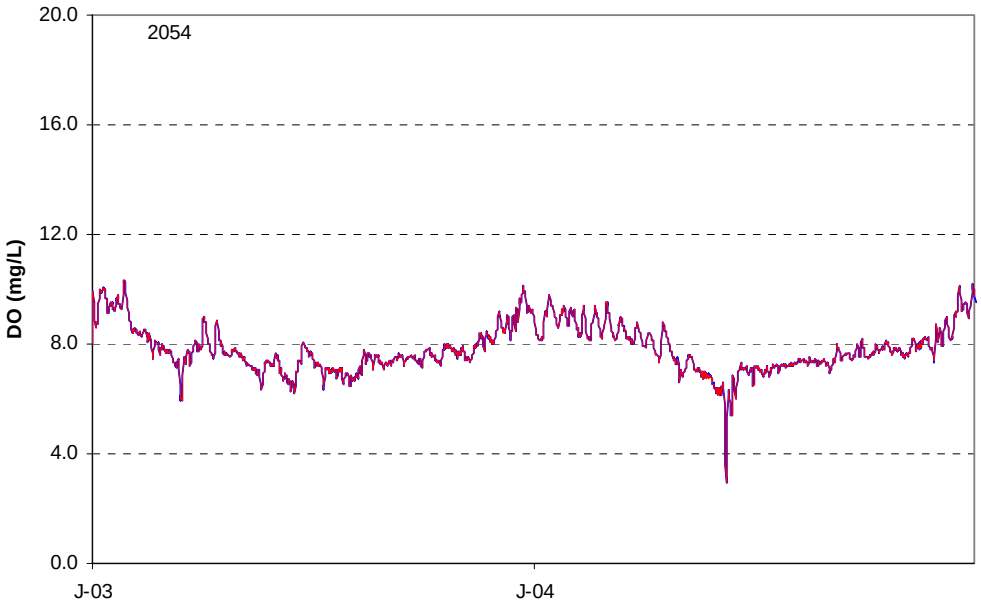
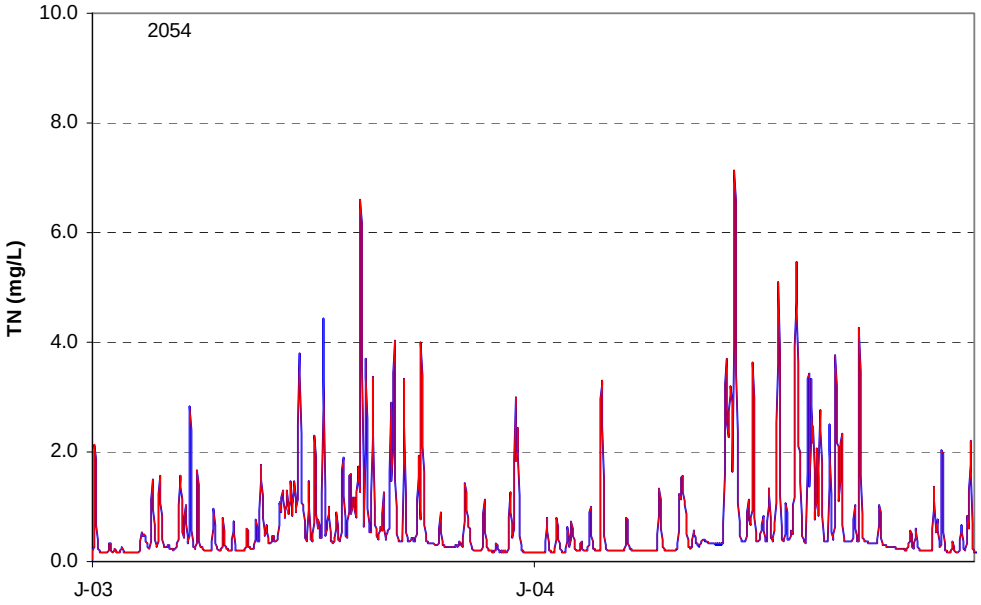
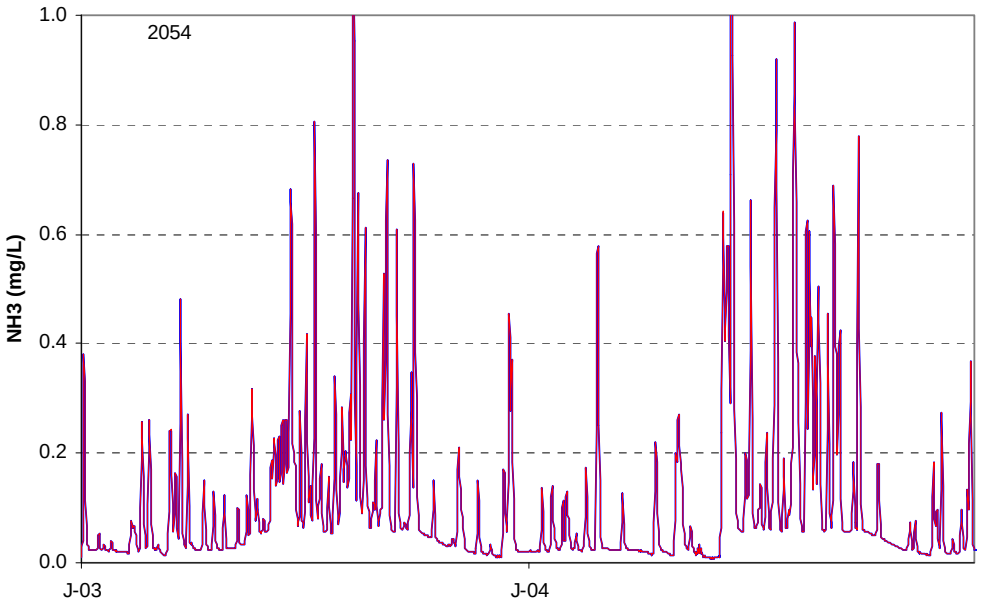
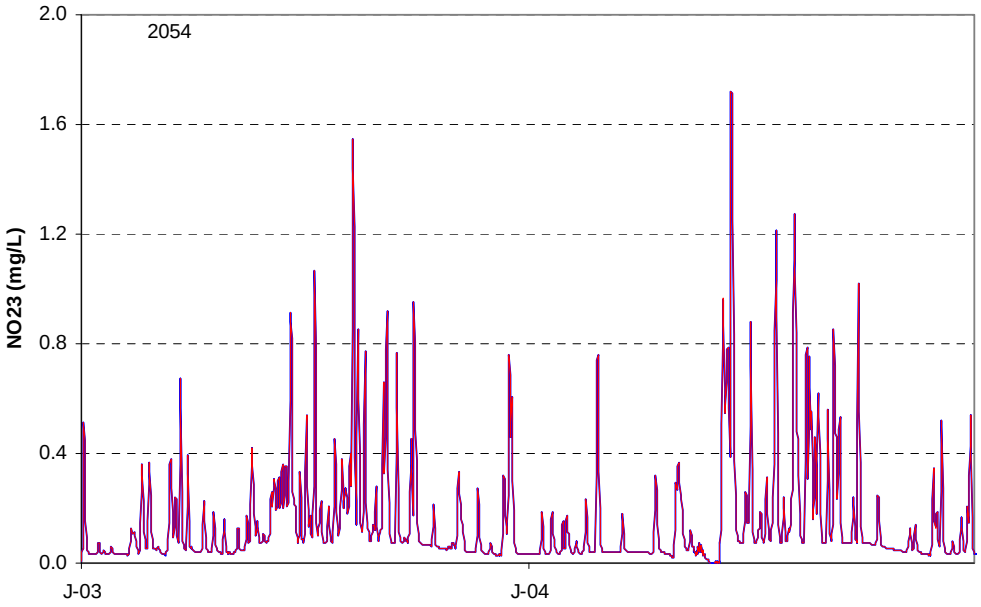


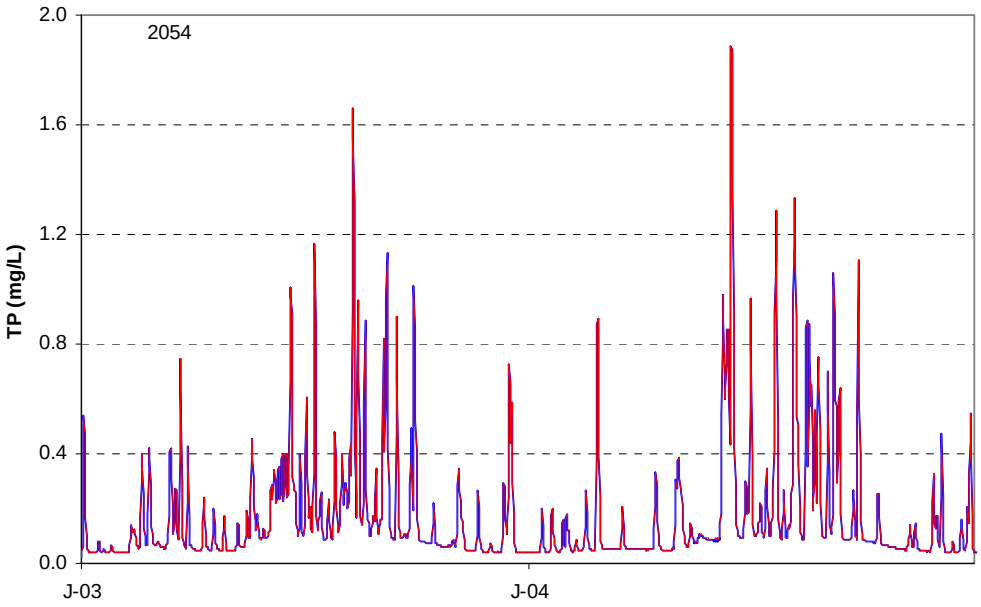
Figure F-3. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 1997

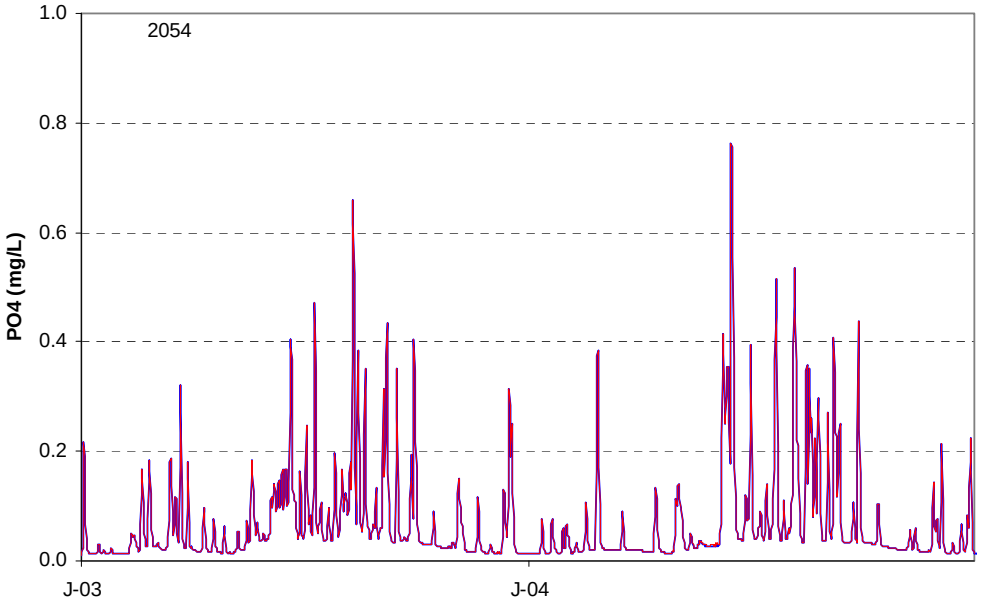

2054
20.0
16.0
12.0
8.0
4.0
0.0
DO (mg/L)
J-03
J-04


2054
10.0
8.0
6.0
4.0
2.0
0.0
TN (mg/L)
J-03
J-04


2054
NH3 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04


2054
NO23 (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2054
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2054
PO4 (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
J-03
J-04

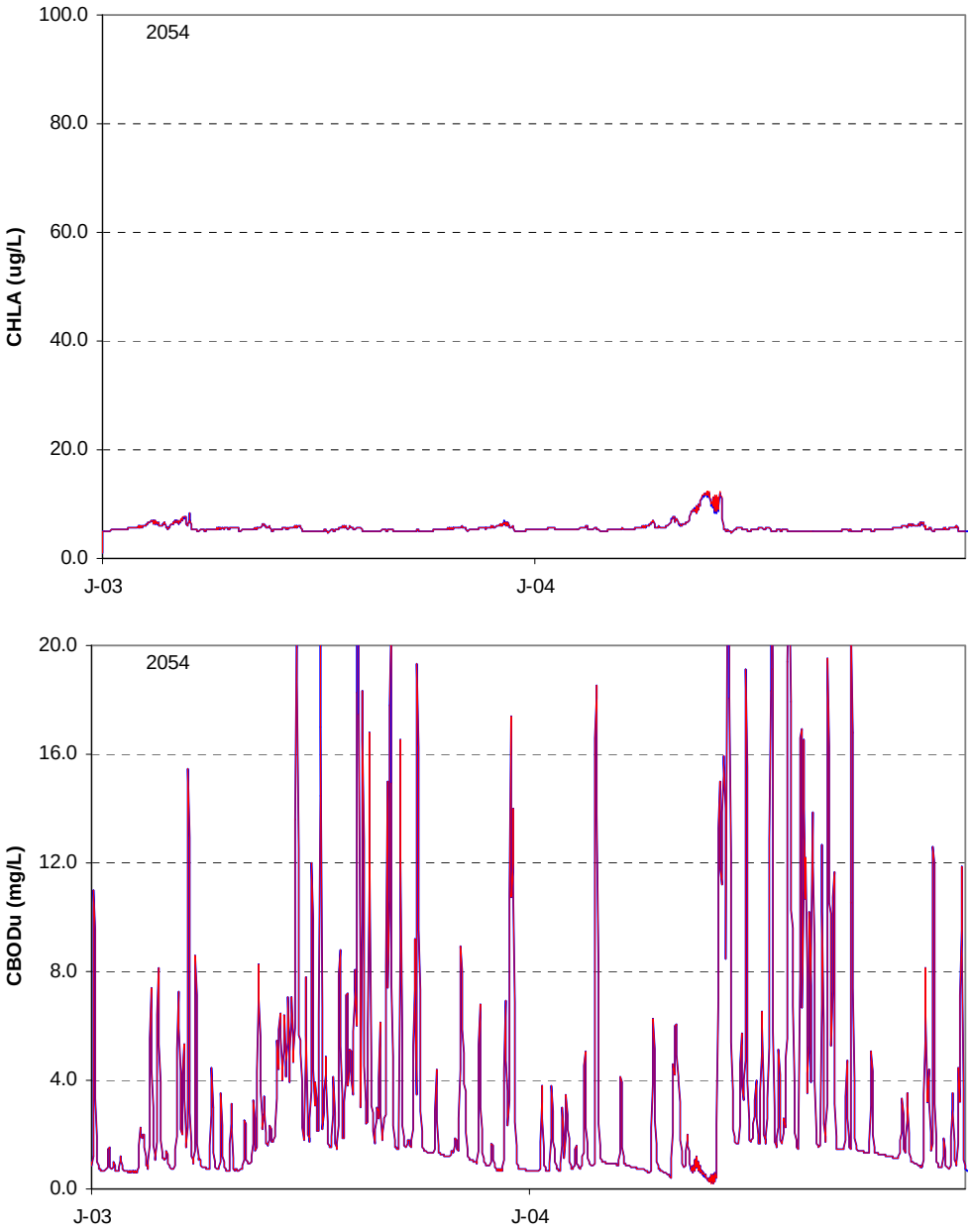
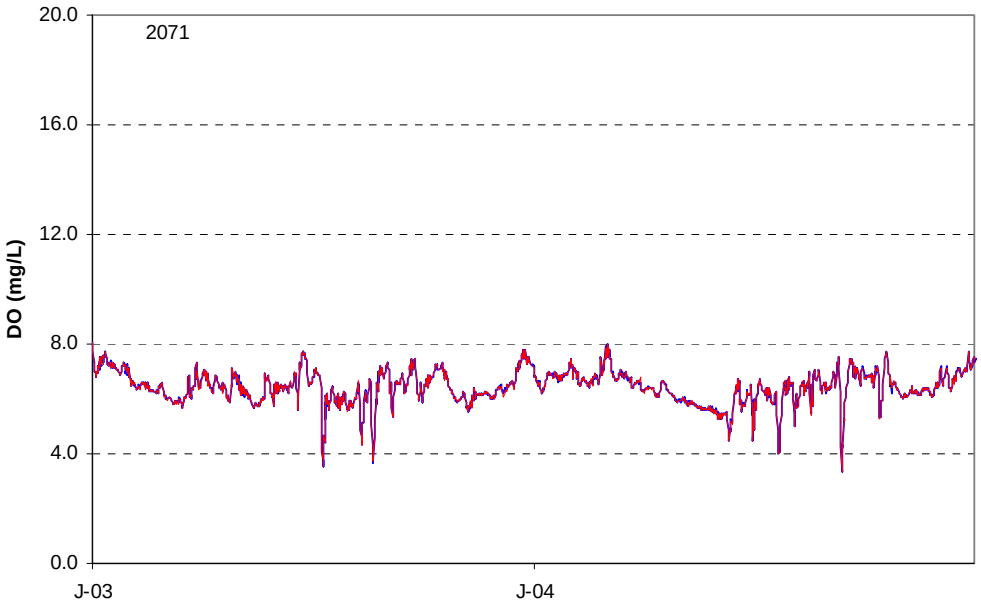
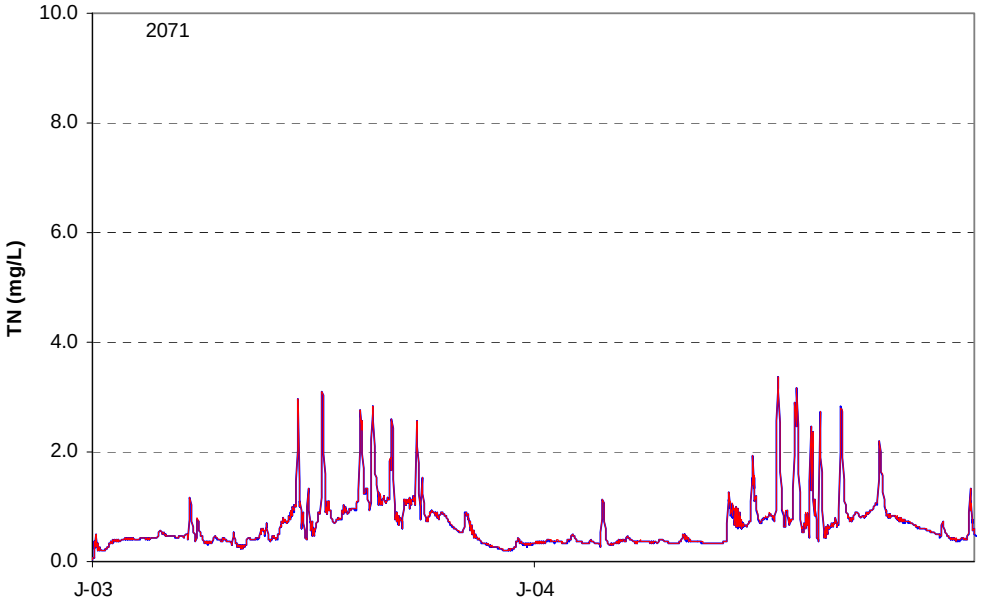


Figure F-4. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 2054


2071
20.0
16.0
12.0
8.0
4.0
0.0
DO (mg/L)
J-03
J-04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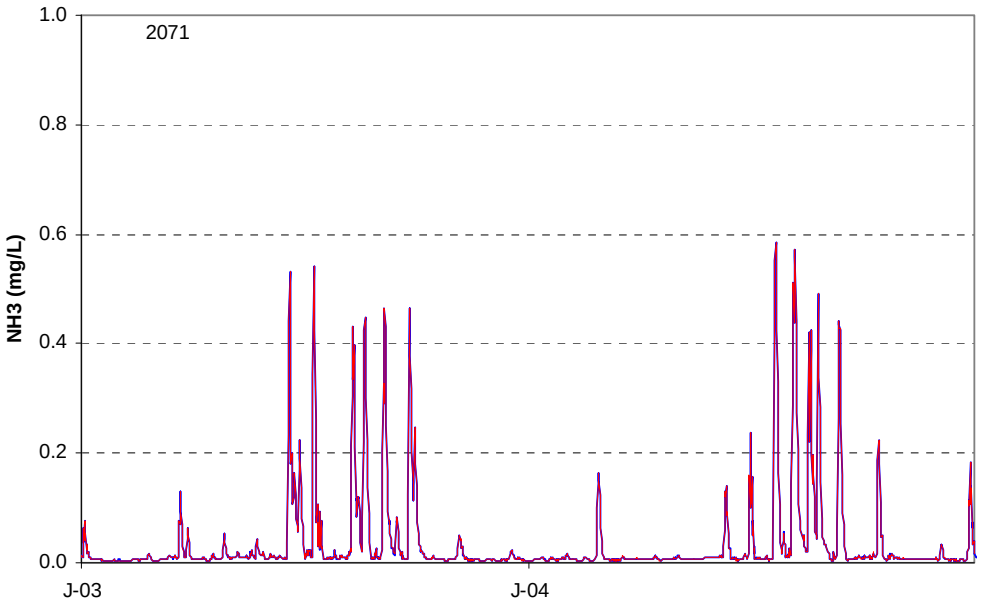
10.0
8.0
6.0
4.0
2.0
0.0
TN (mg/L)
J-03
J-04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NH3 (mg/L)
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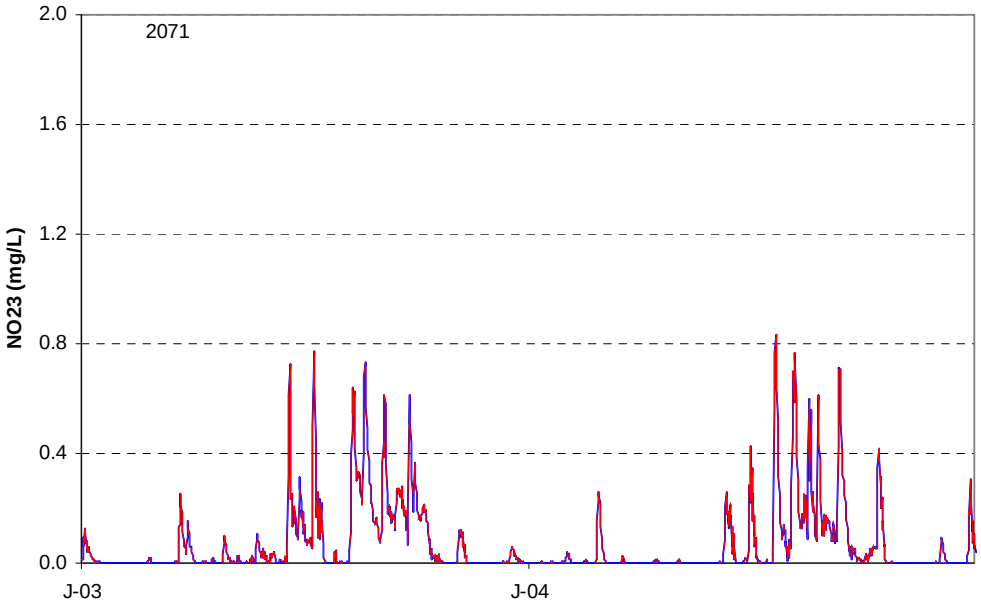
0.8
0.6
0.4
0.2
0.0
J-03
J-04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NO23 (mg/L)
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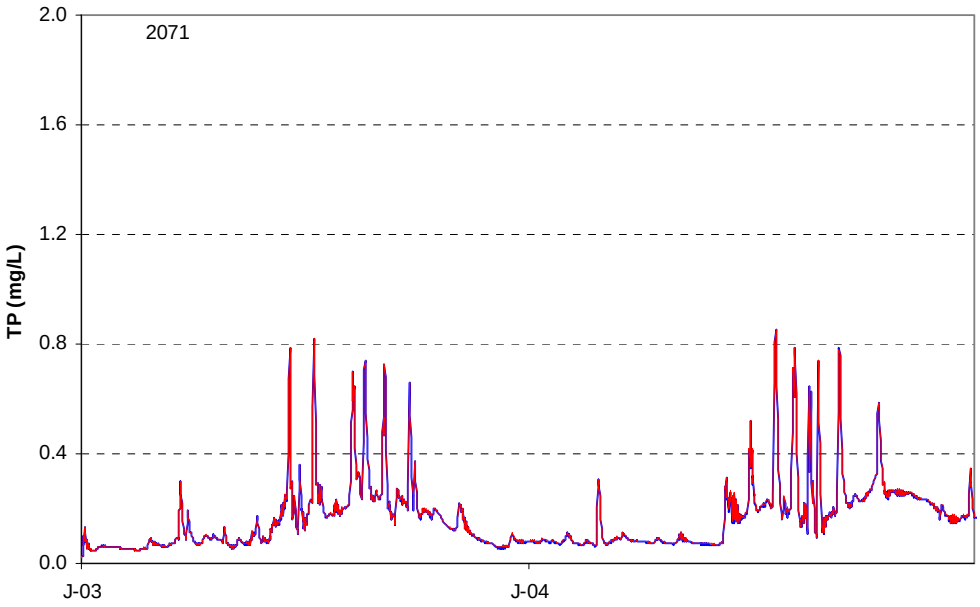
1.2
0.8
0.4
0.0
J-03
J-04


2071
TP (mg/L)
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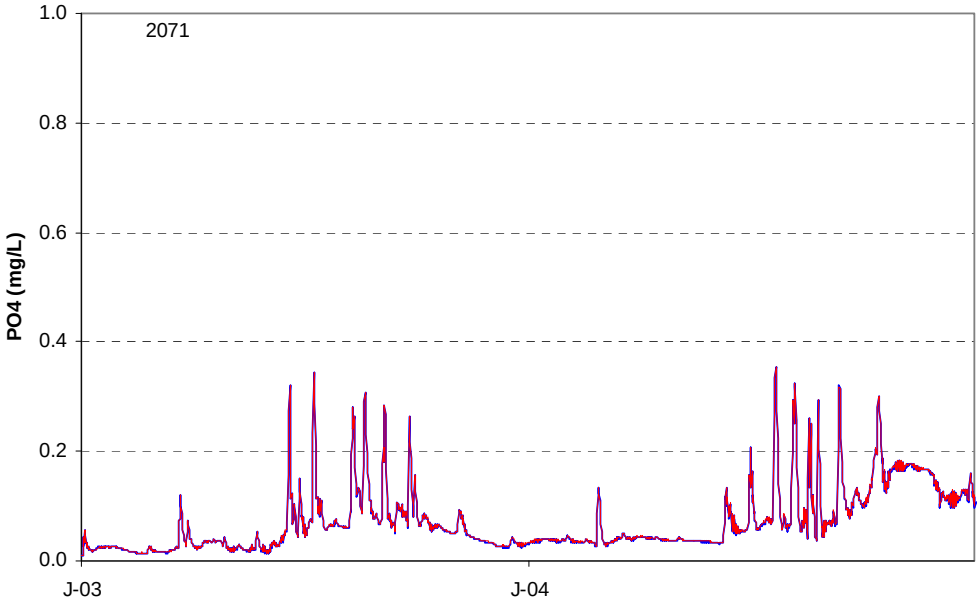
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2071
PO4 (mg/L)
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0.8
0.6
0.4
0.2
0.0
J-03
J-04

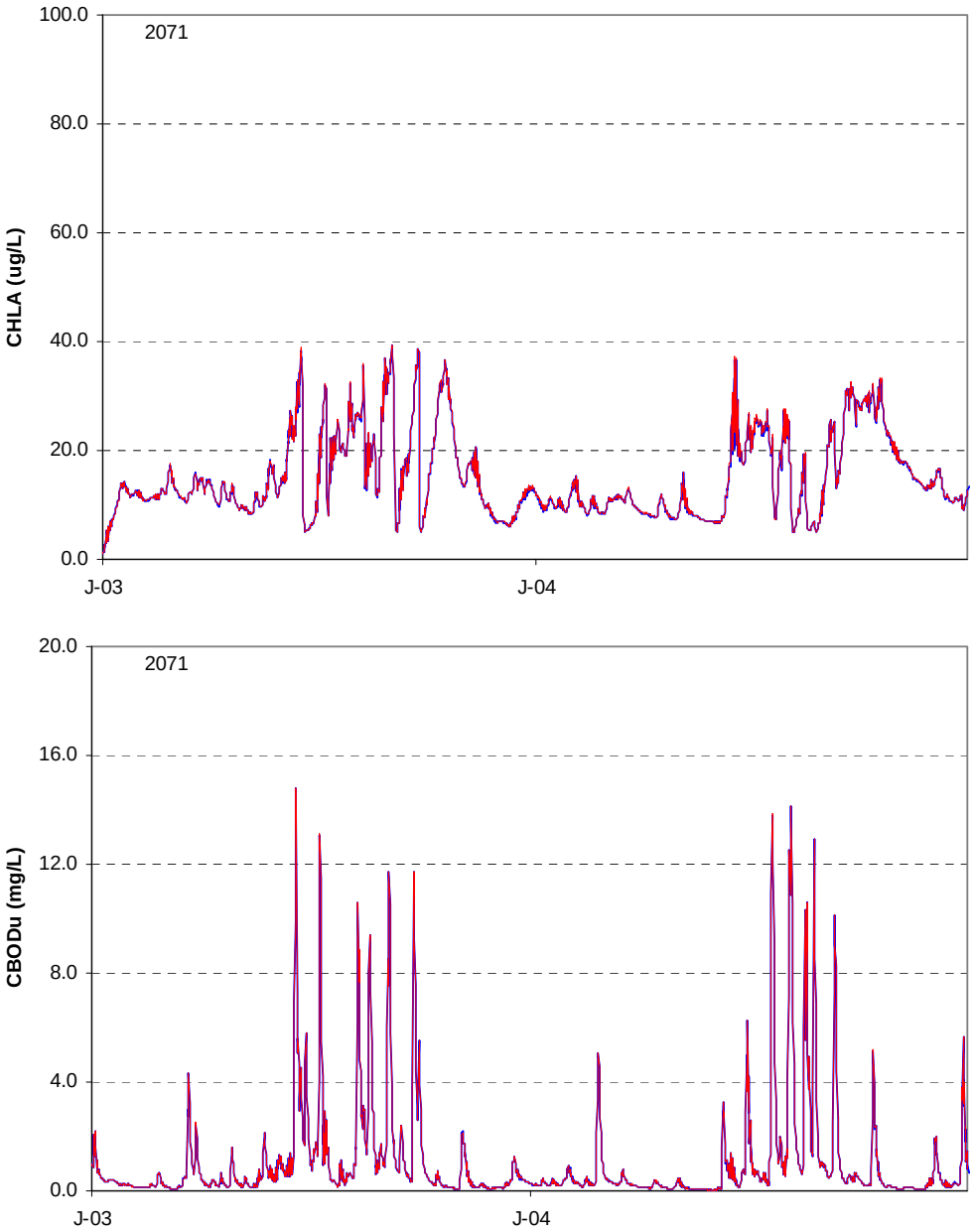
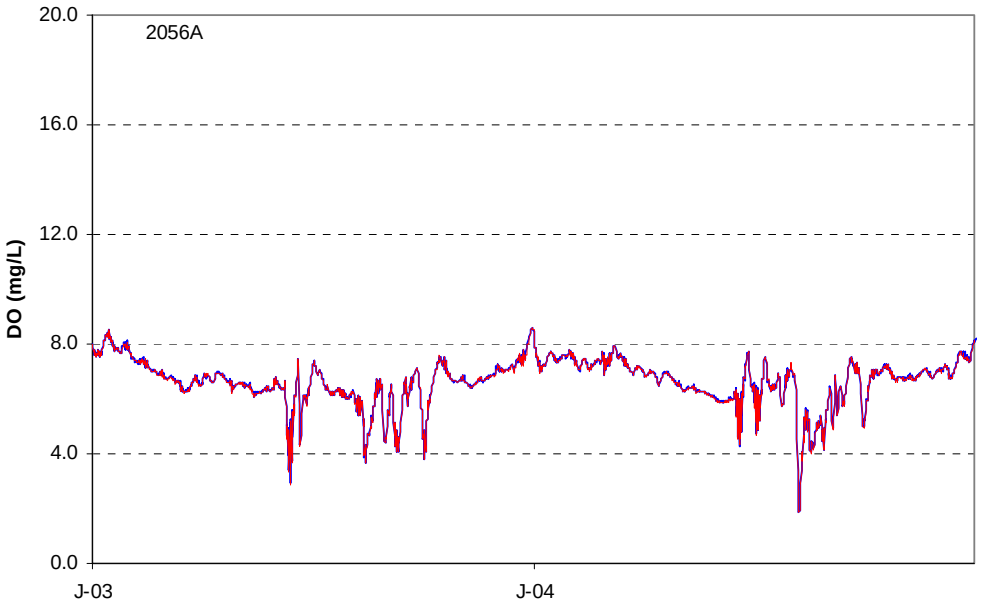


Figure F-5. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 2071


2056A
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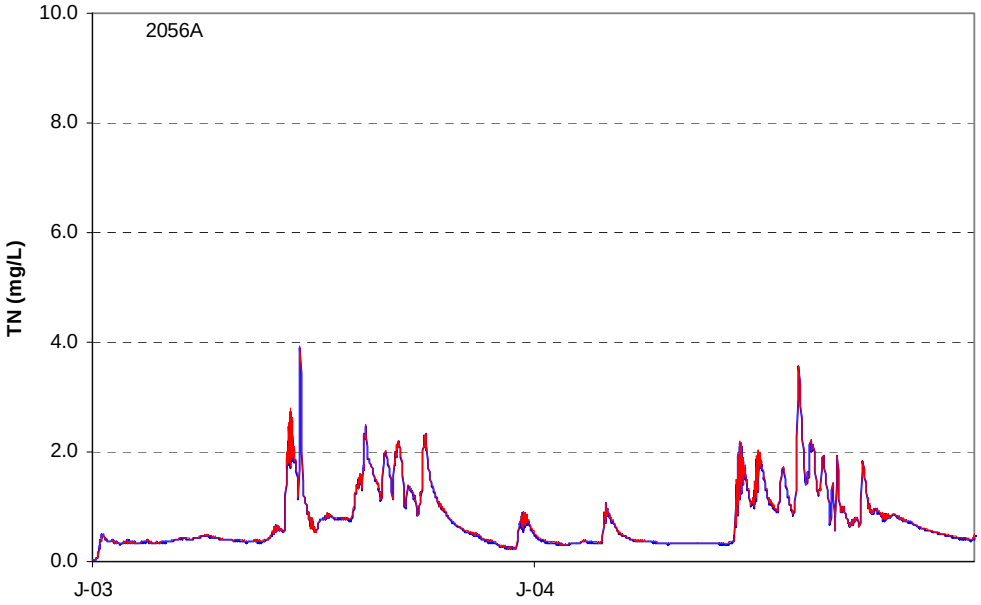
16.0
12.0
8.0
4.0
0.0
DO (mg/L)
J-03
J-04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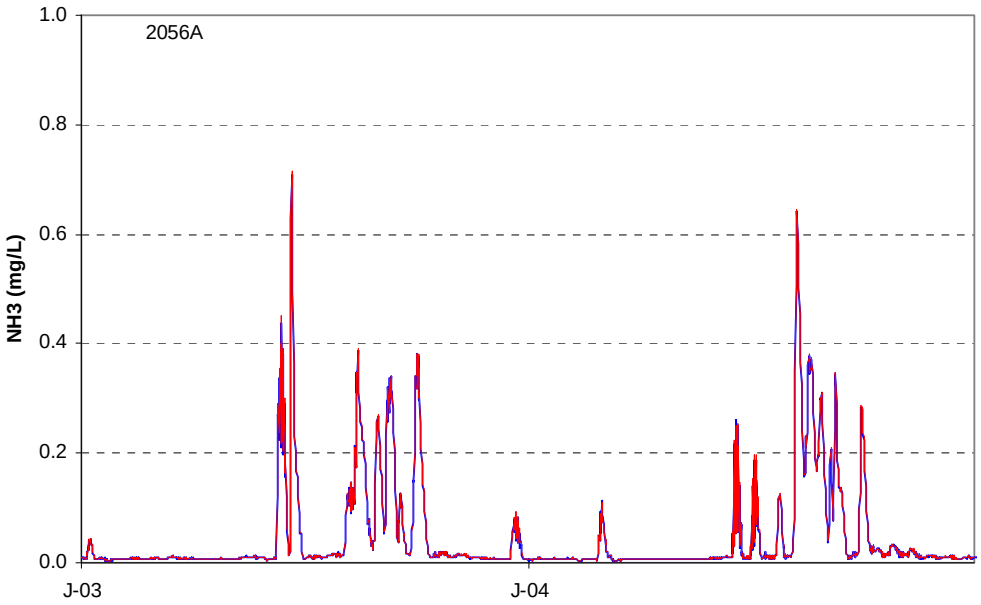
8.0
6.0
4.0
2.0
0.0
TN (mg/L)
J-03
J-04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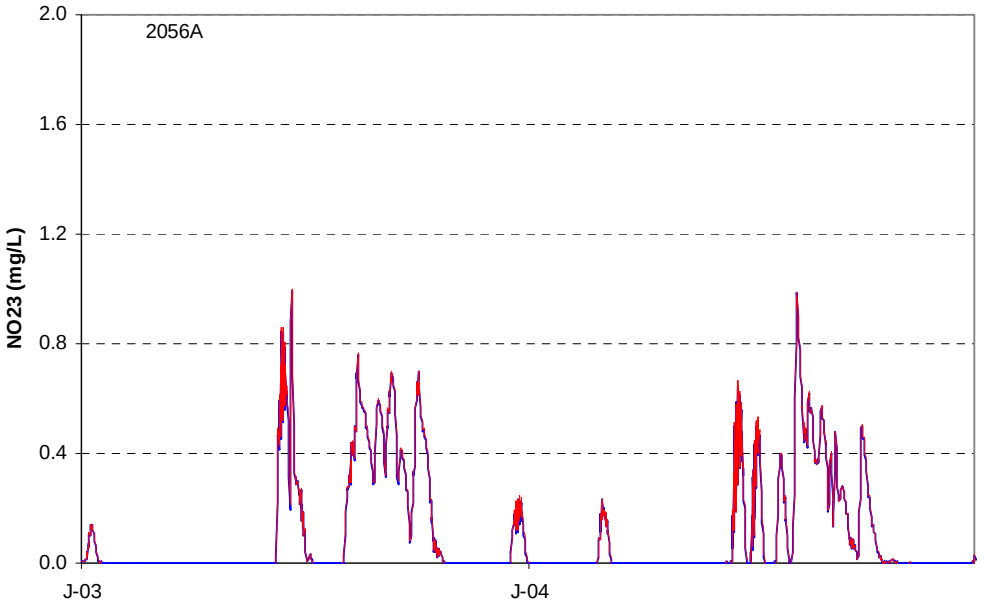
0.8
0.6
0.4
0.2
0.0
NH3 (mg/L)
J-03
J-04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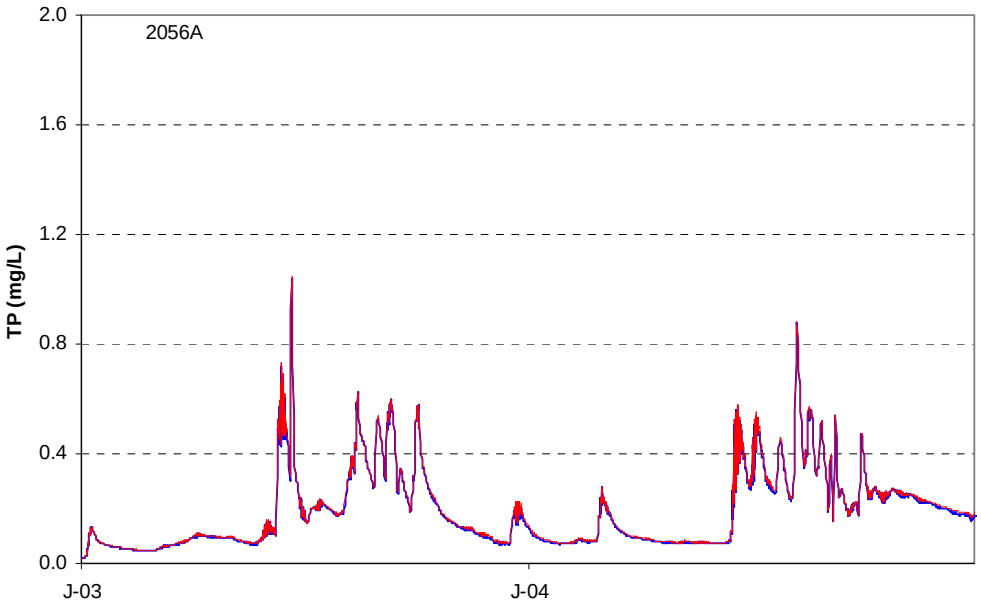
1.2
0.8
0.4
0.0
NO23 (mg/L)
J-03
J-04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TP (mg/L)
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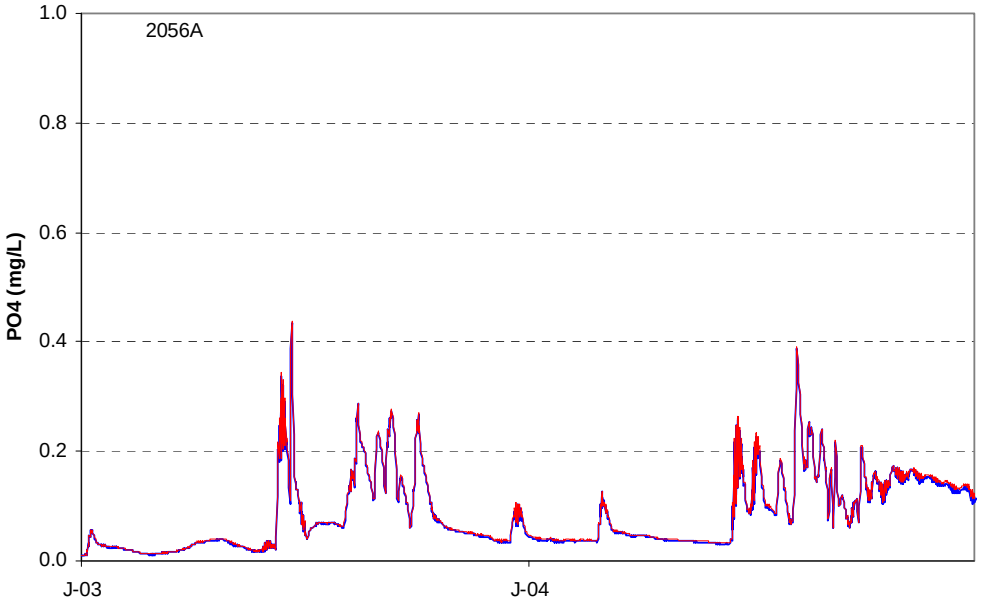
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2056A
PO4 (mg/L)
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0.6
0.4
0.2
0.0
J-03
J-04

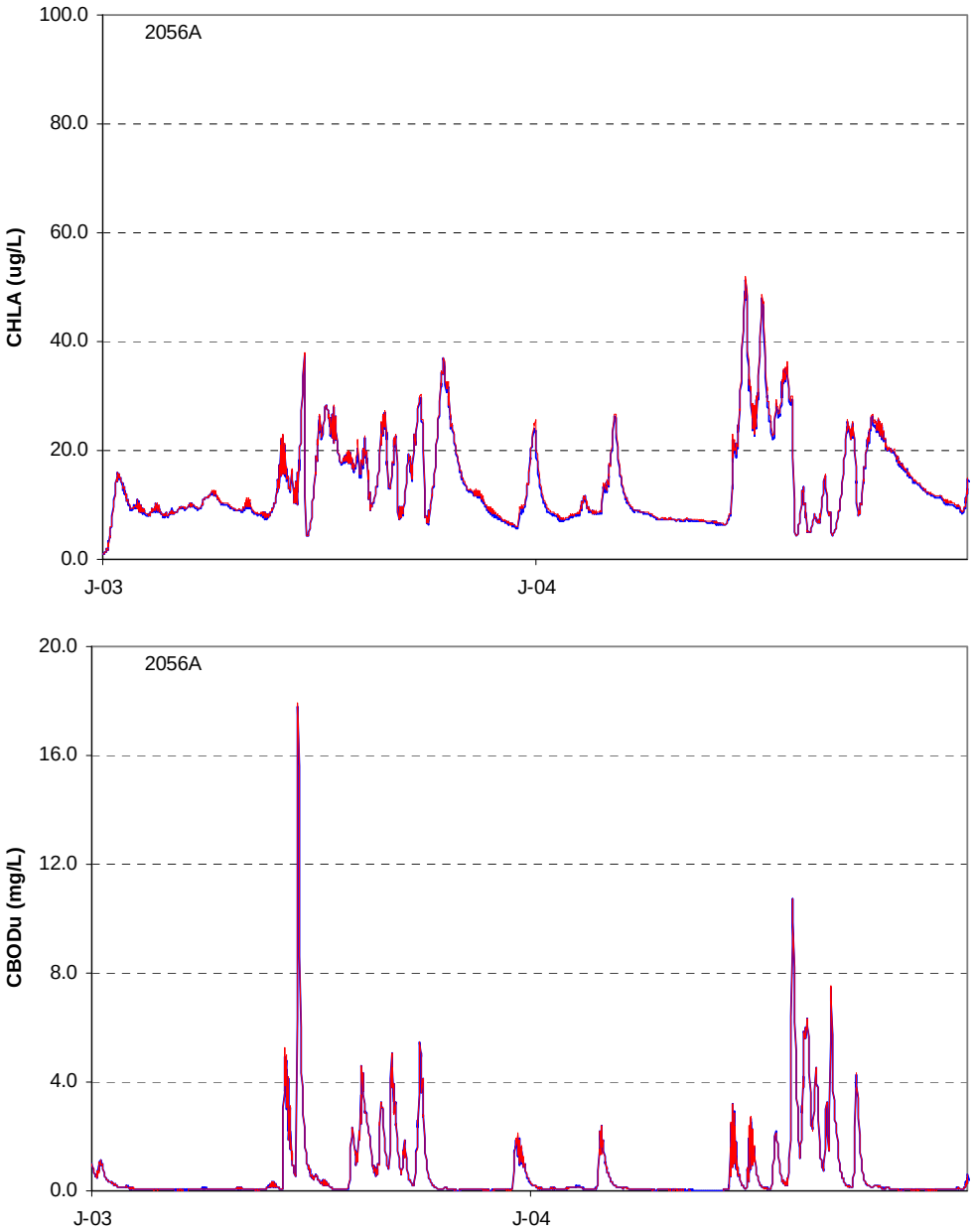
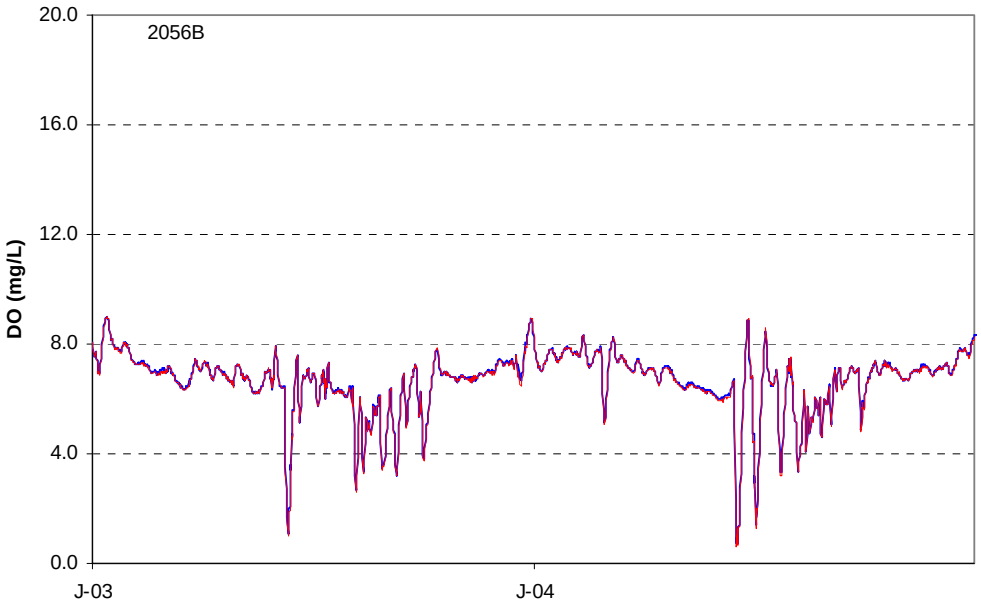


Figure F-6. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 2056A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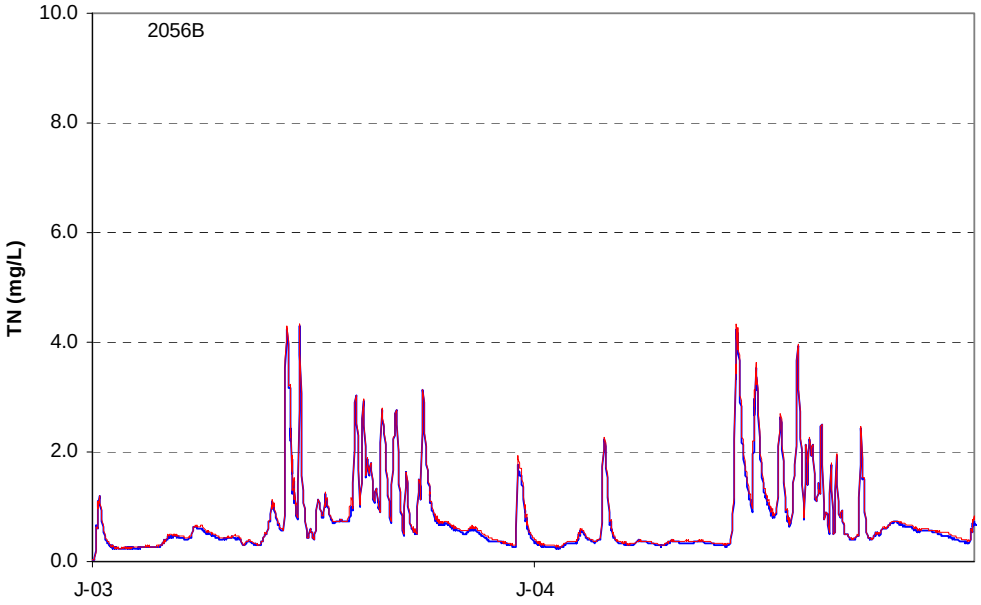
4.0
0.0
DO (mg/L)
J-03
J-04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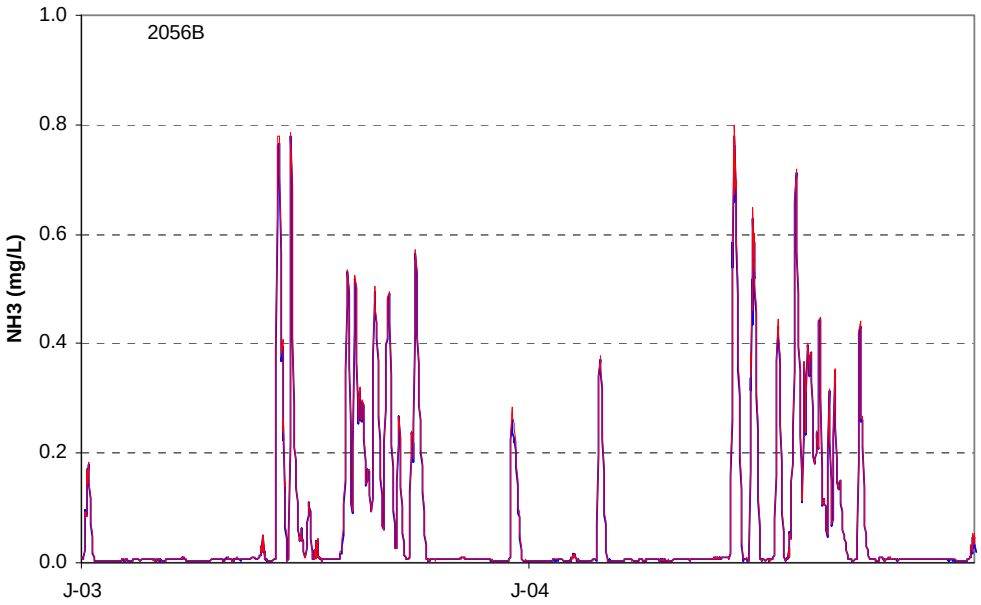
6.0
4.0
2.0
0.0
TN (mg/L)
J-03
J-04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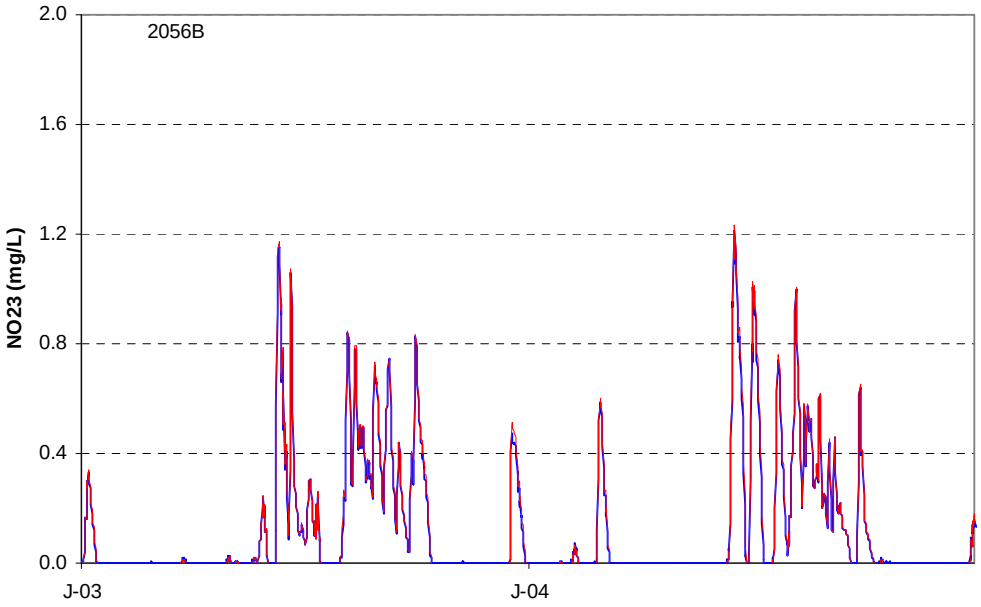
0.8
0.6
0.4
0.2
0.0
NH3 (mg/L)
J-03
J-04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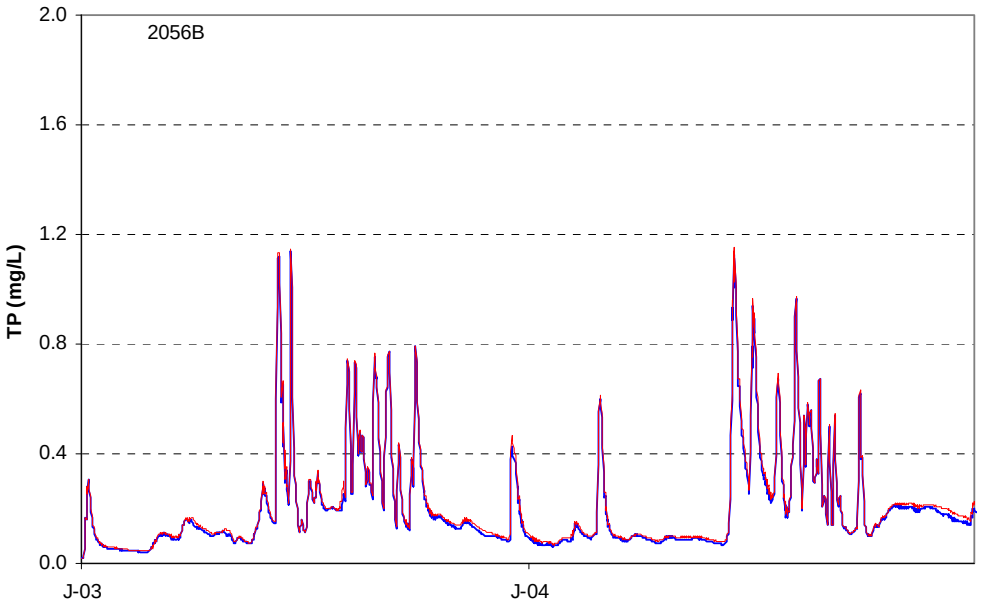
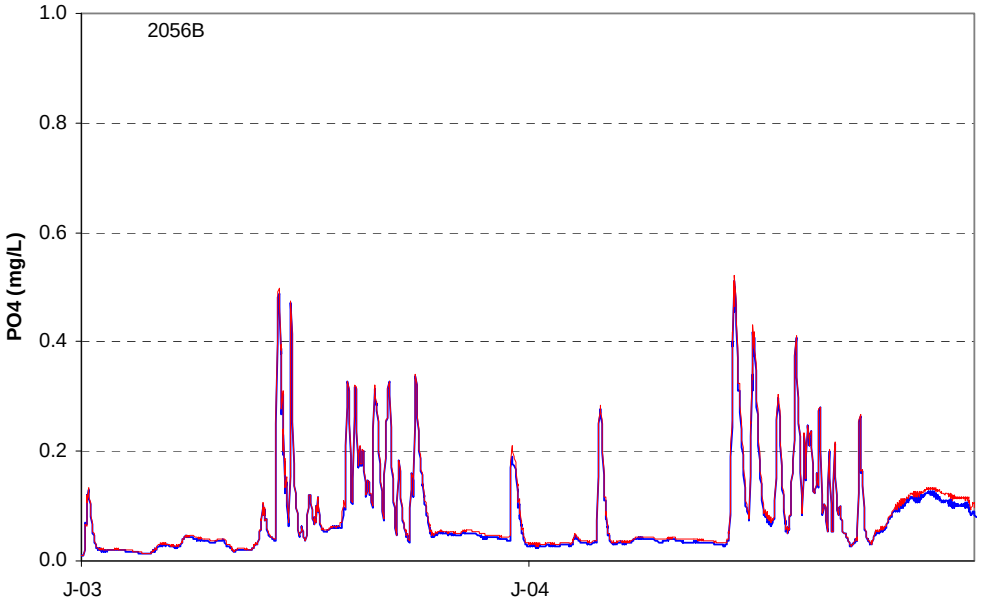
1.6
1.2
0.8
0.4
0.0
NO23 (mg/L)
J-03
J-04


2056B
TP (mg/L)
2.0
1.6
1.2
0.8
0.4
0.0
J-03
J-04


2056B
PO4 (mg/L)
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0.8
0.6
0.4
0.2
0.0
J-03
J-04

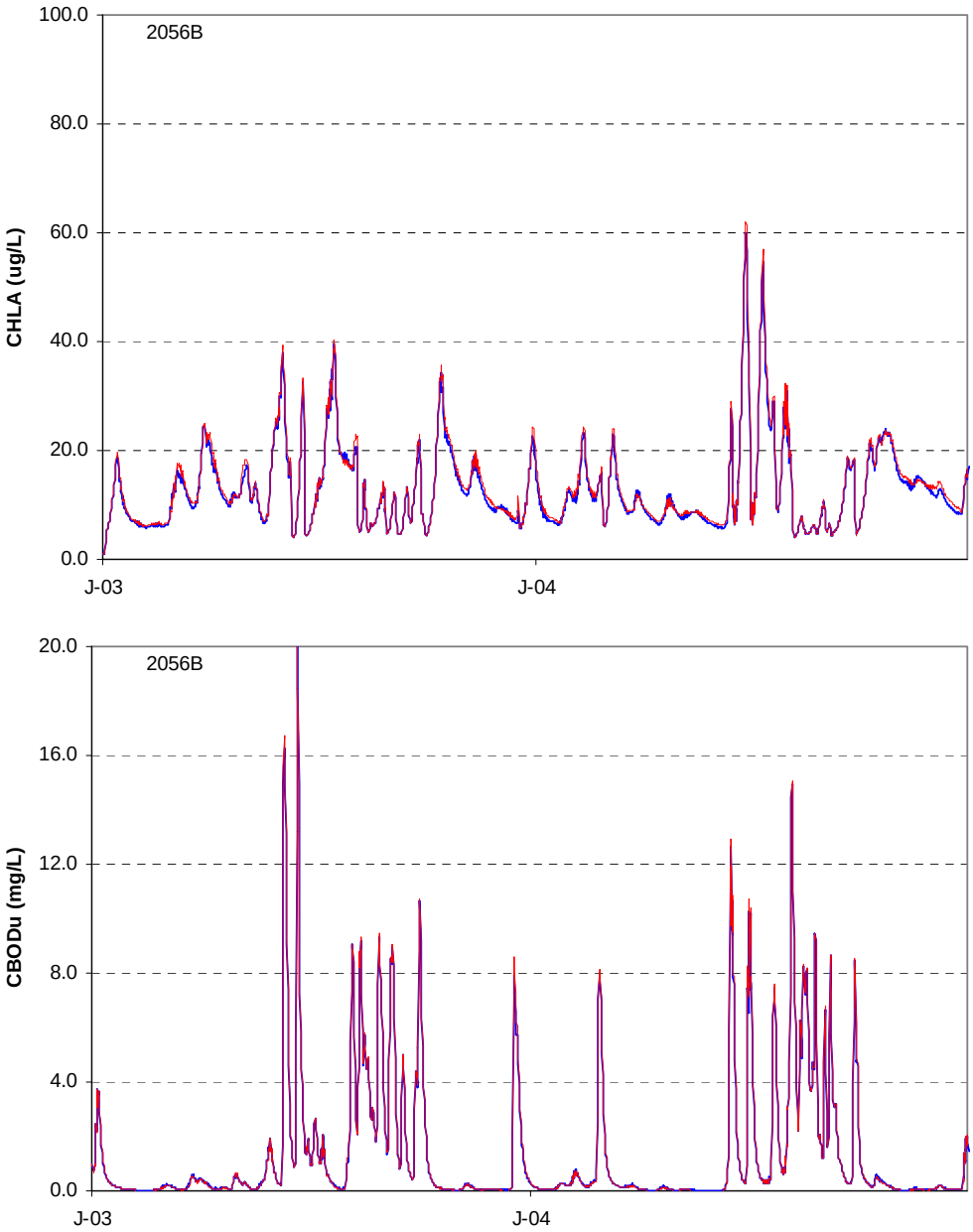

Figure F-6. Comparison of modeled water quality under natural conditions vs. natural conditions with point sources in WBID 2056B

Appendix G: Water Quality Calibration for Bear Branch and Little Charlie Creek

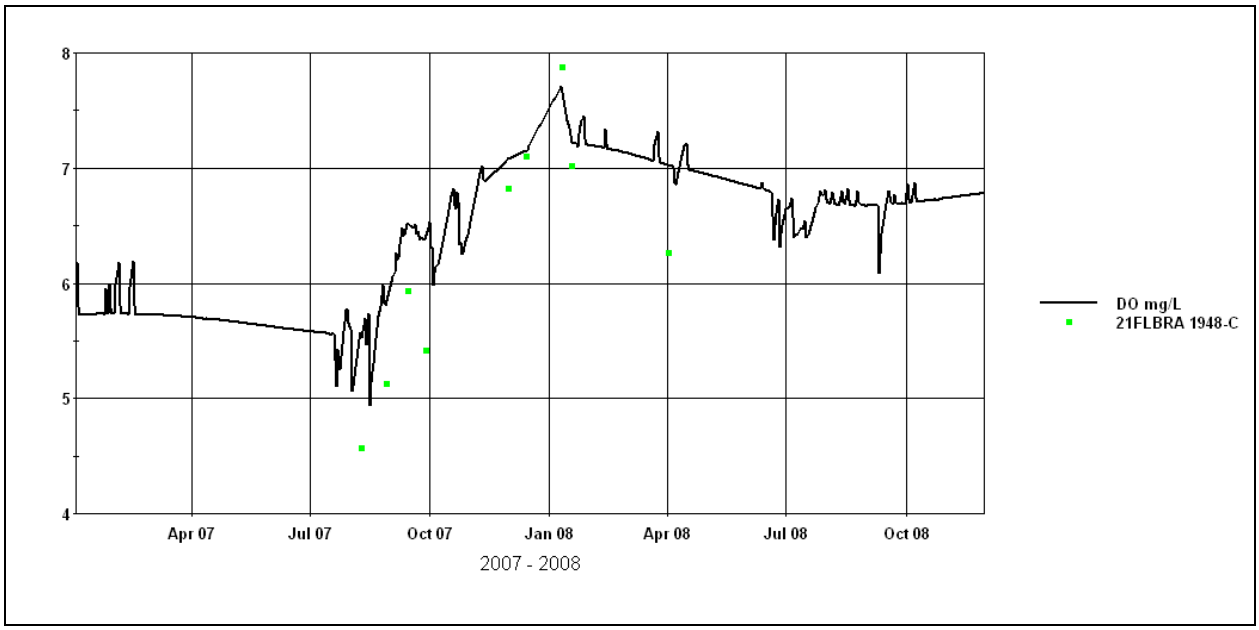

Figure G-1 Segment 1 Bear Branch Dissolved Oxygen Calibration (2007-2008).

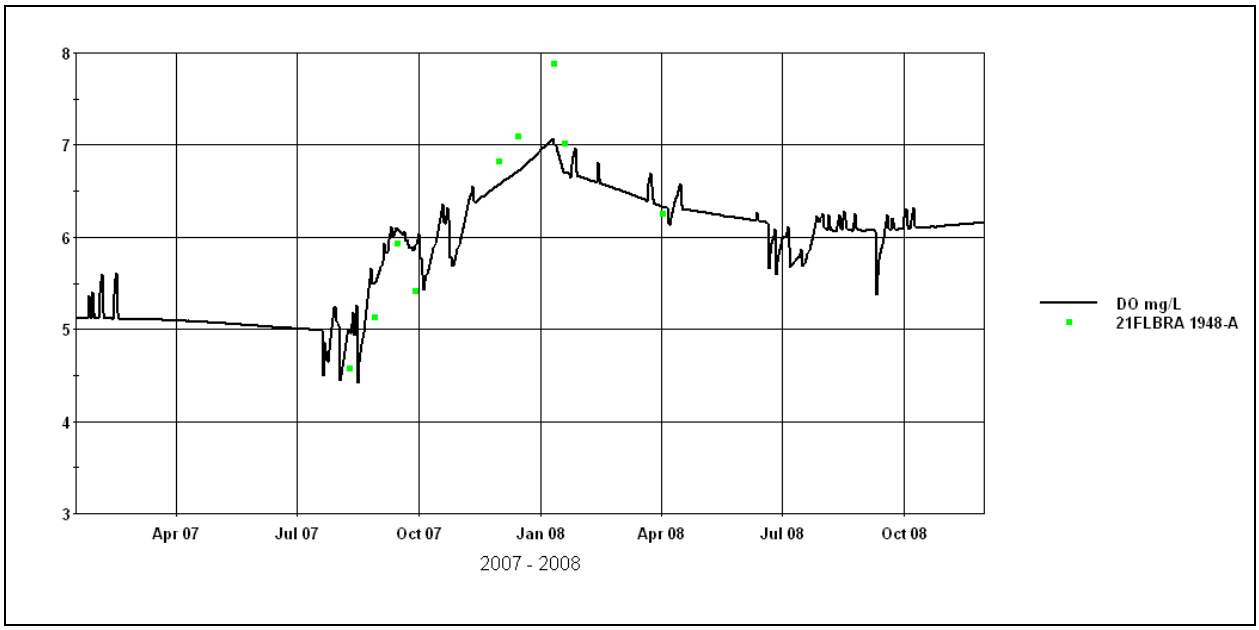

Figure G-2 Segment 3 Bear Branch Dissolved Oxygen Calibration (2007-2008).

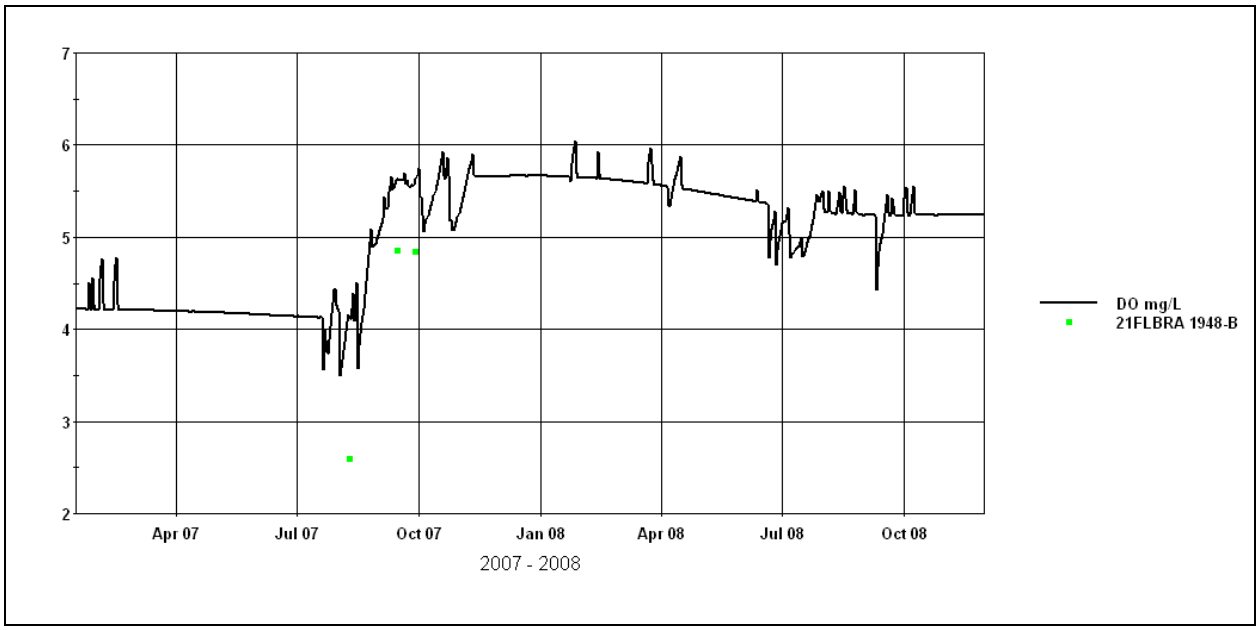

Figure G-3 Segment 5 Bear Branch Dissolved Oxygen Calibration (2007-2008).

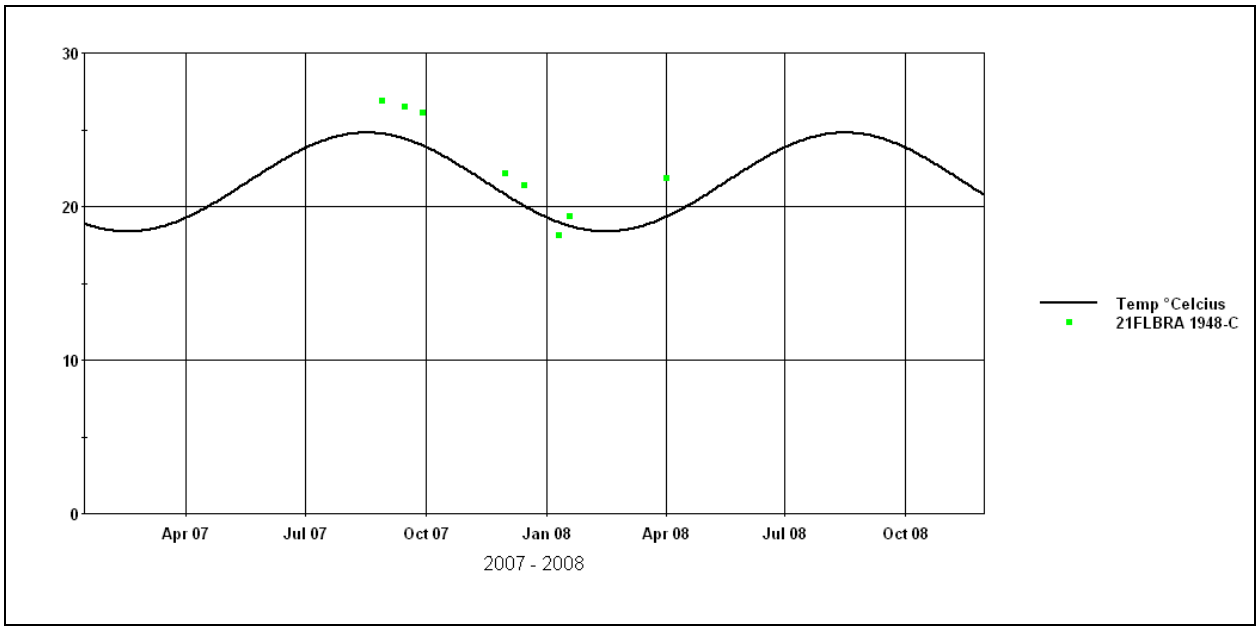

Figure G-4 Segment 1 Bear Branch Water Temperature Calibration (2007-2008).

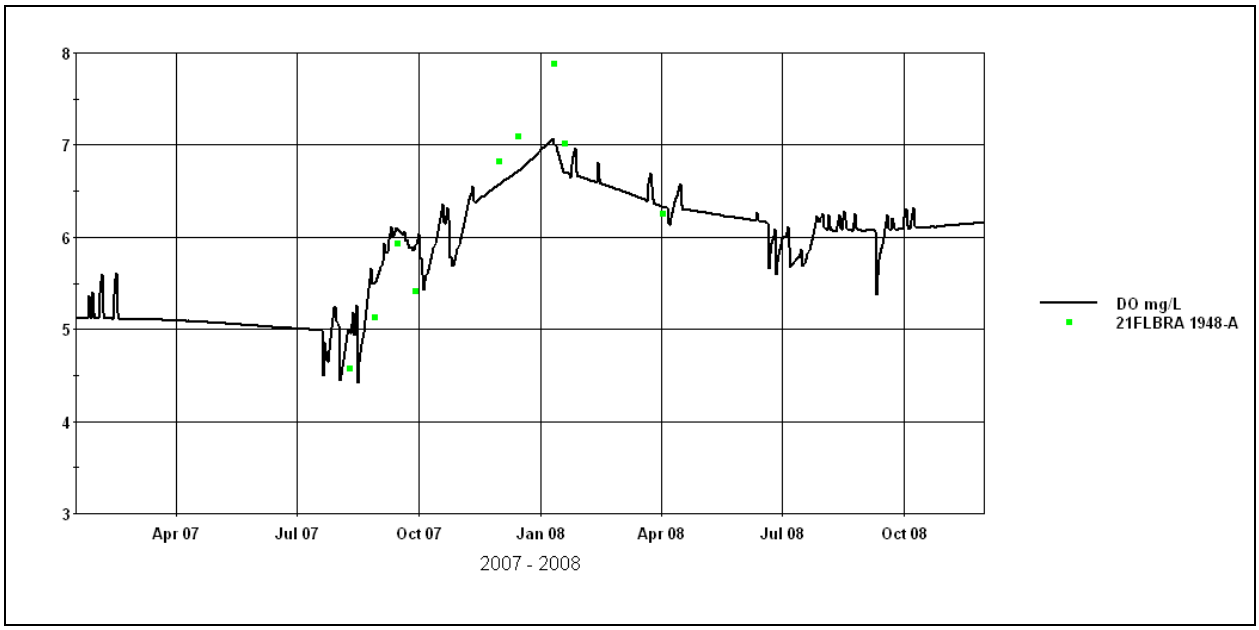

Figure G-5 Segment 3 Bear Branch Water Temperature Calibration (2007-2008).

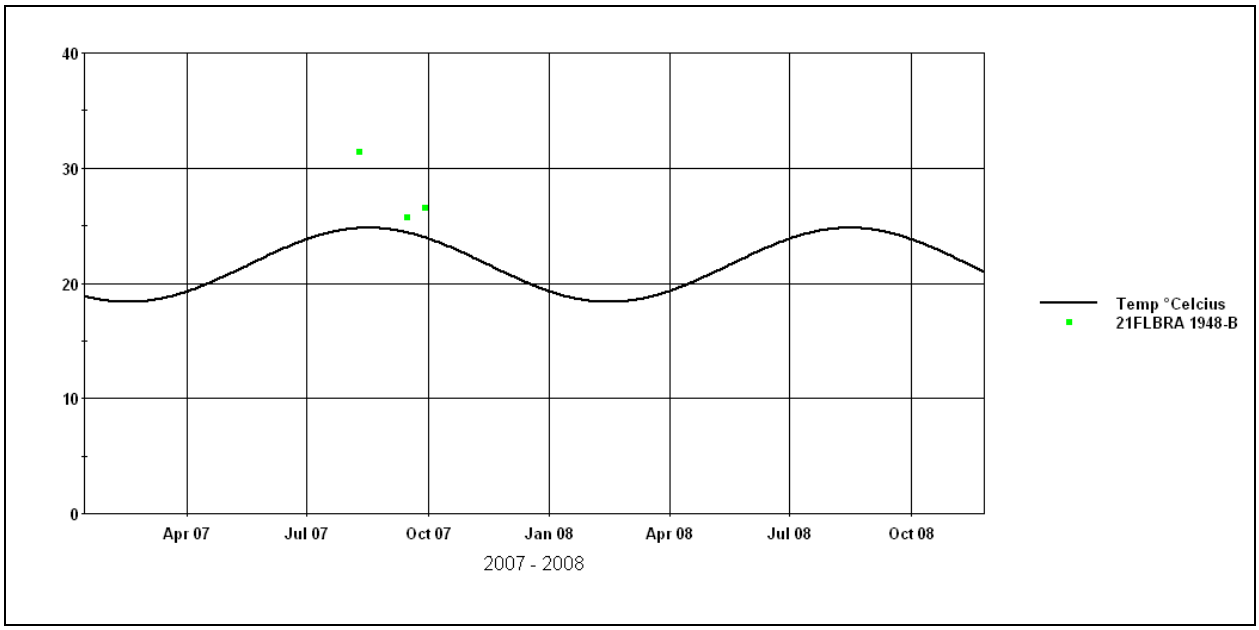

Figure G-6 Segment 5 Bear Branch Water Temperature Calibration (2007-2008).

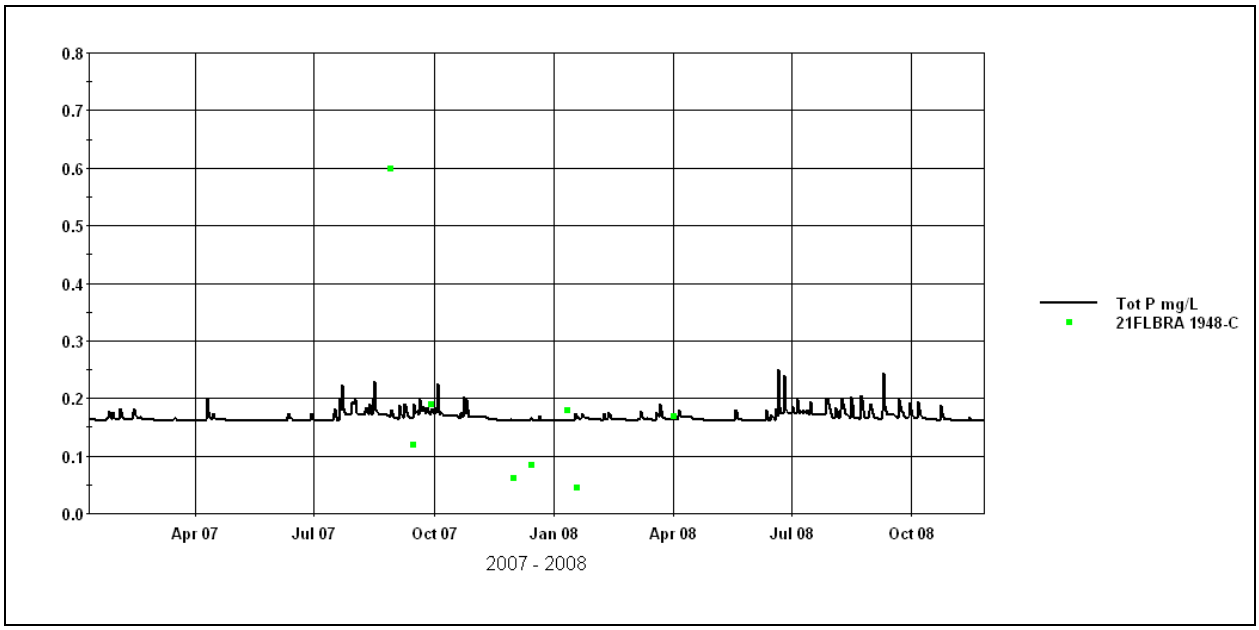

Figure G-7 Segment 1 Bear Branch Total Phosphorus Calibration (2007-2008).

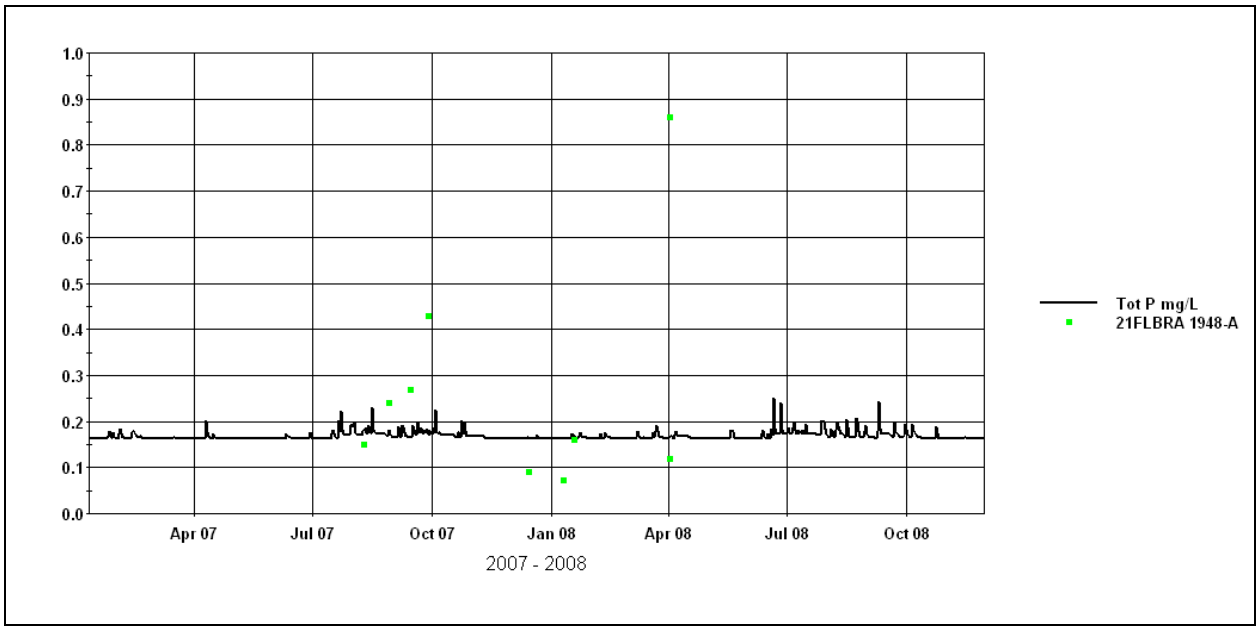

Figure G-8 Segment 3 Bear Branch Total Phosphorus Calibration (2007-2008).

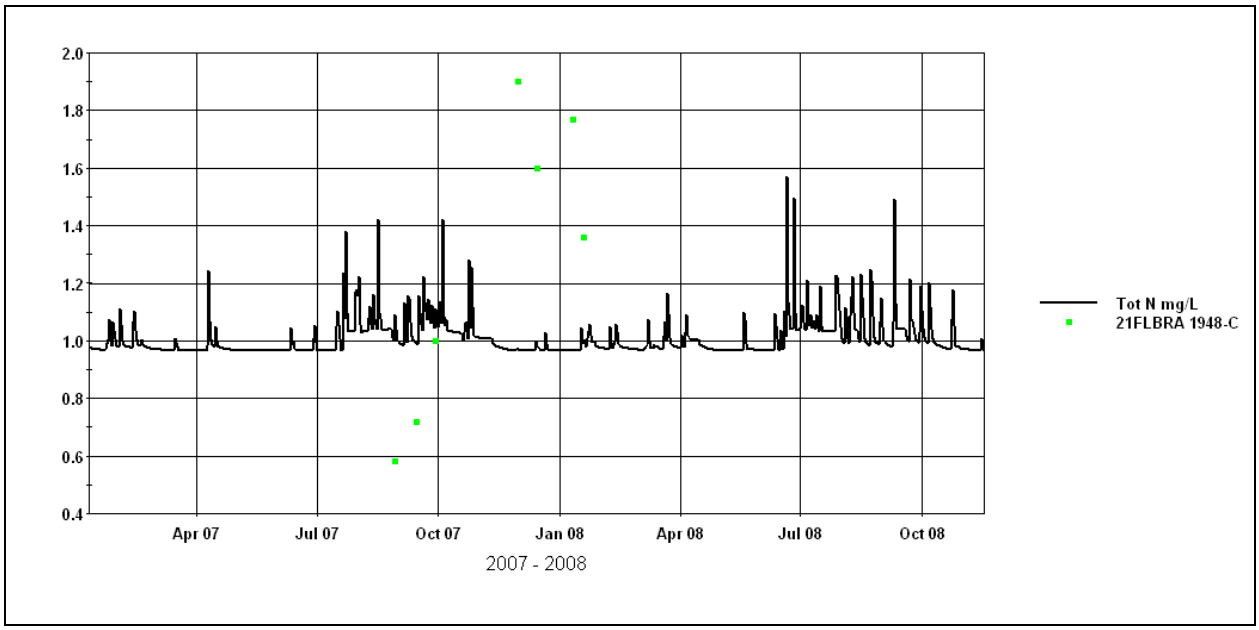

Figure G-9 Segment 1 Bear Branch Total Nitrogen Calibration (2007-2008).

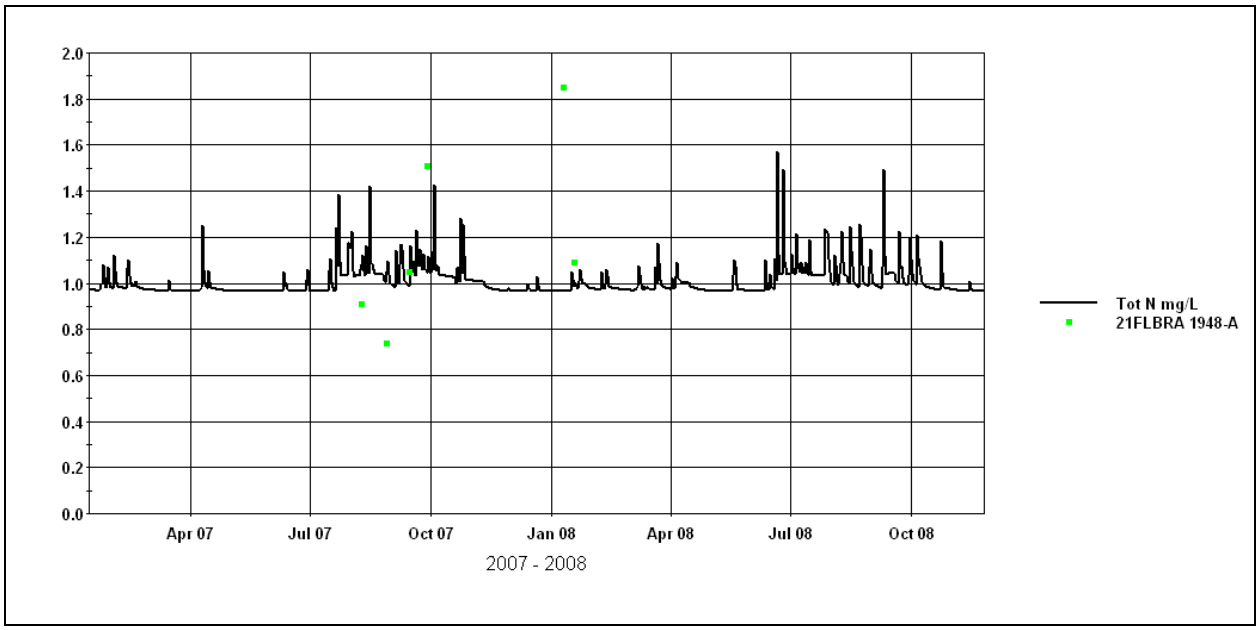

Figure G-10 Segment 3 Bear Branch Total Nitrogen Calibration (2007-2008).

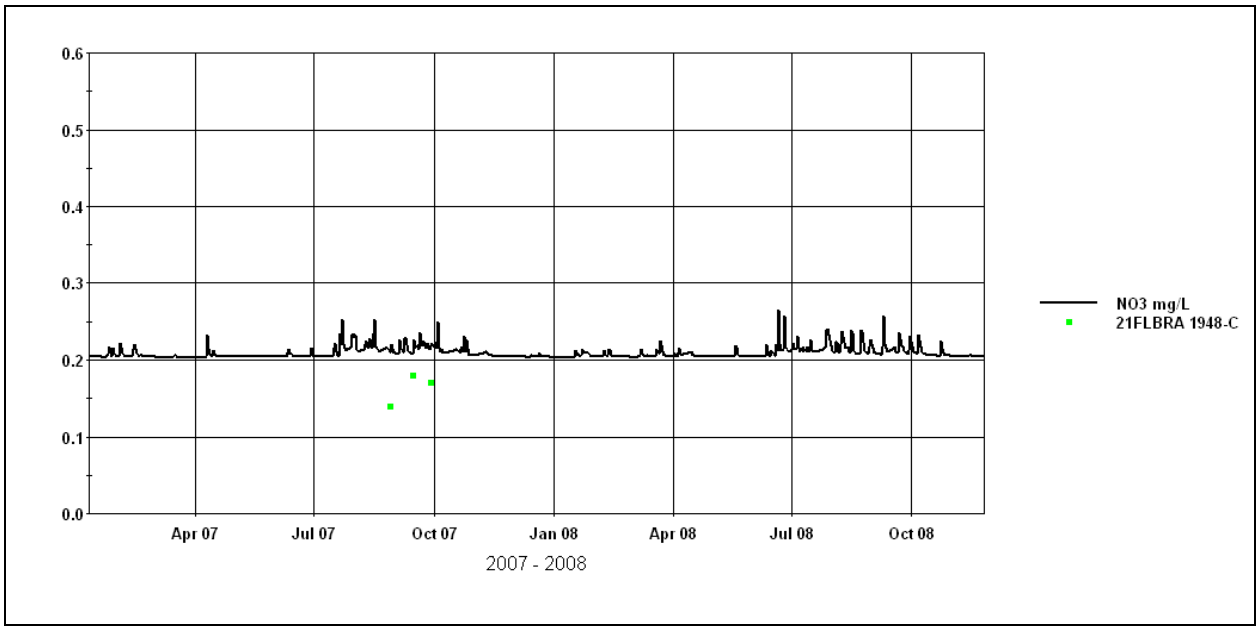

Figure G-11 Segment 1 Bear Branch Nitrate Calibration (2007-2008).

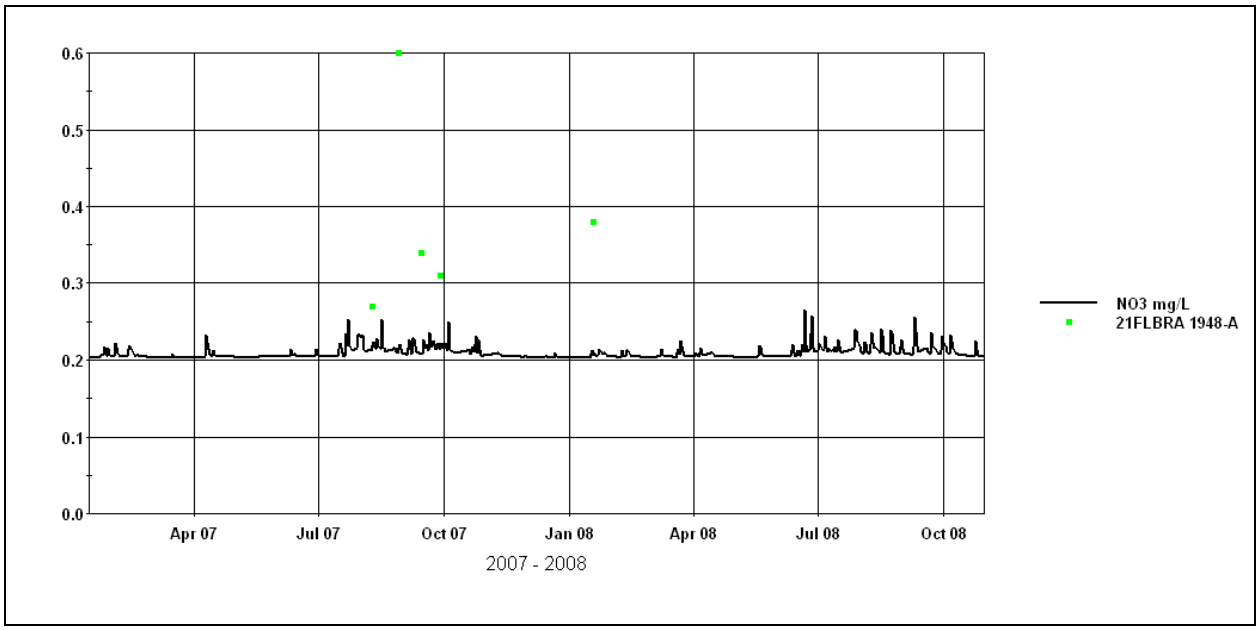

Figure G-12 Segment 3 Bear Branch Nitrate Calibration (2007-2008).

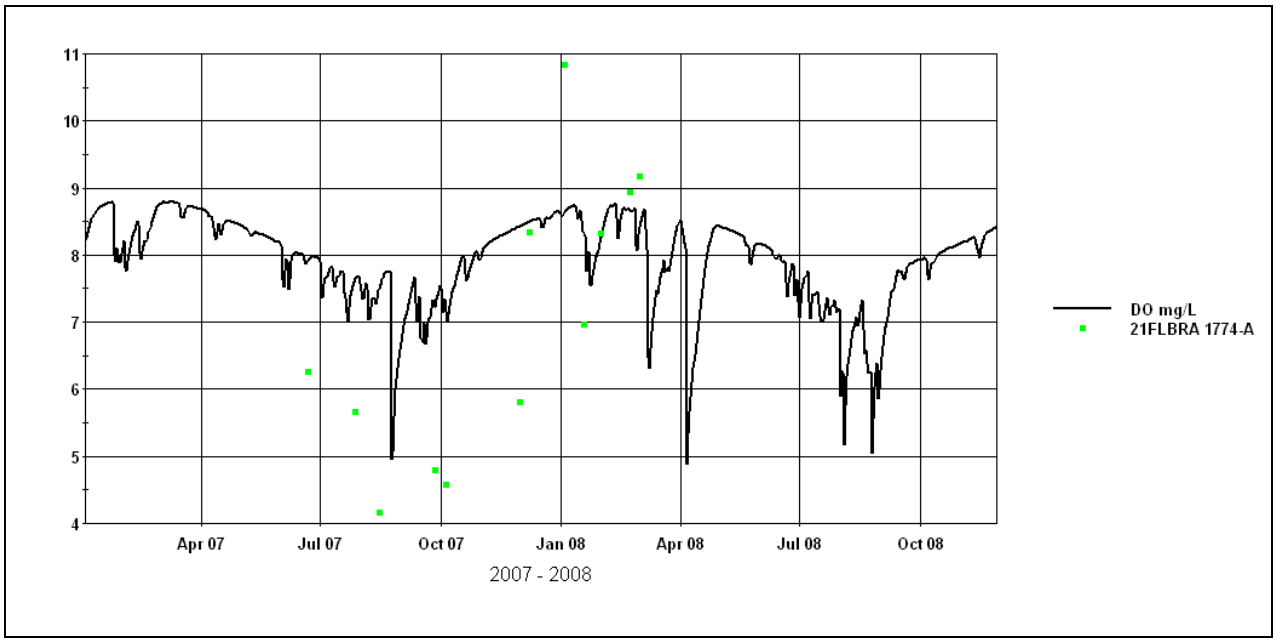

Figure G-13 Segment 2 Little Charlie Creek Dissolved Oxygen Calibration (2007-2008).

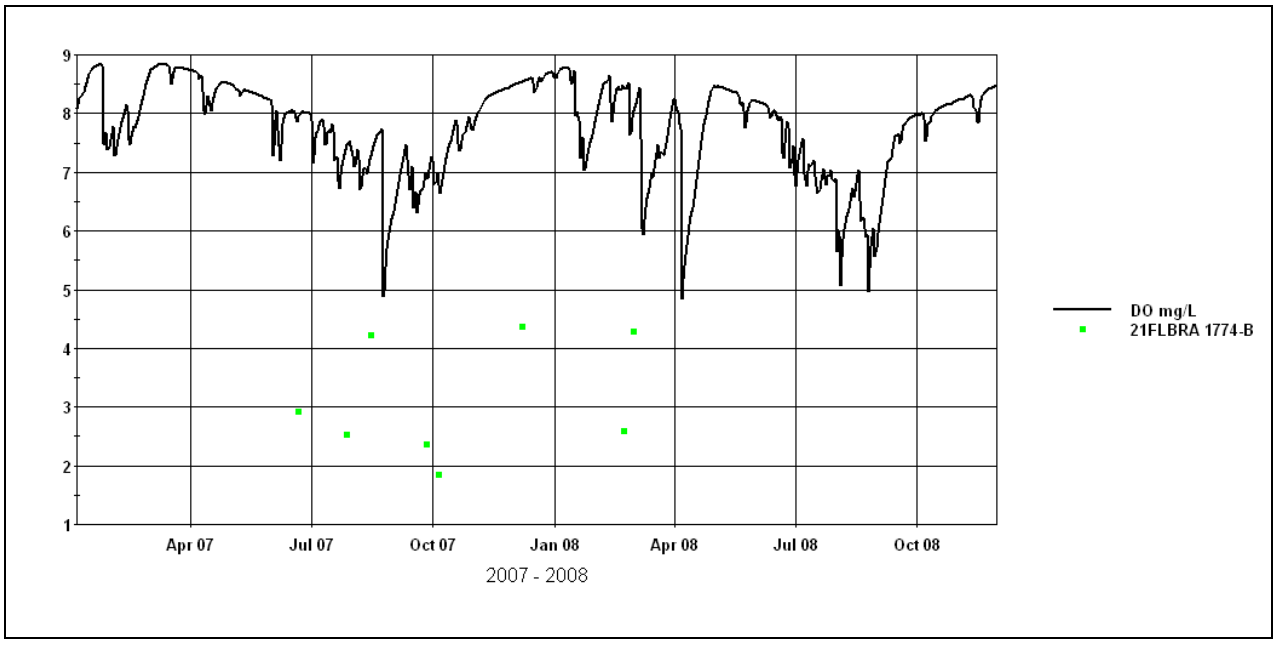

Figure G-14 Segment 3 Little Charlie Creek Dissolved Oxygen Calibration (2007-2008).

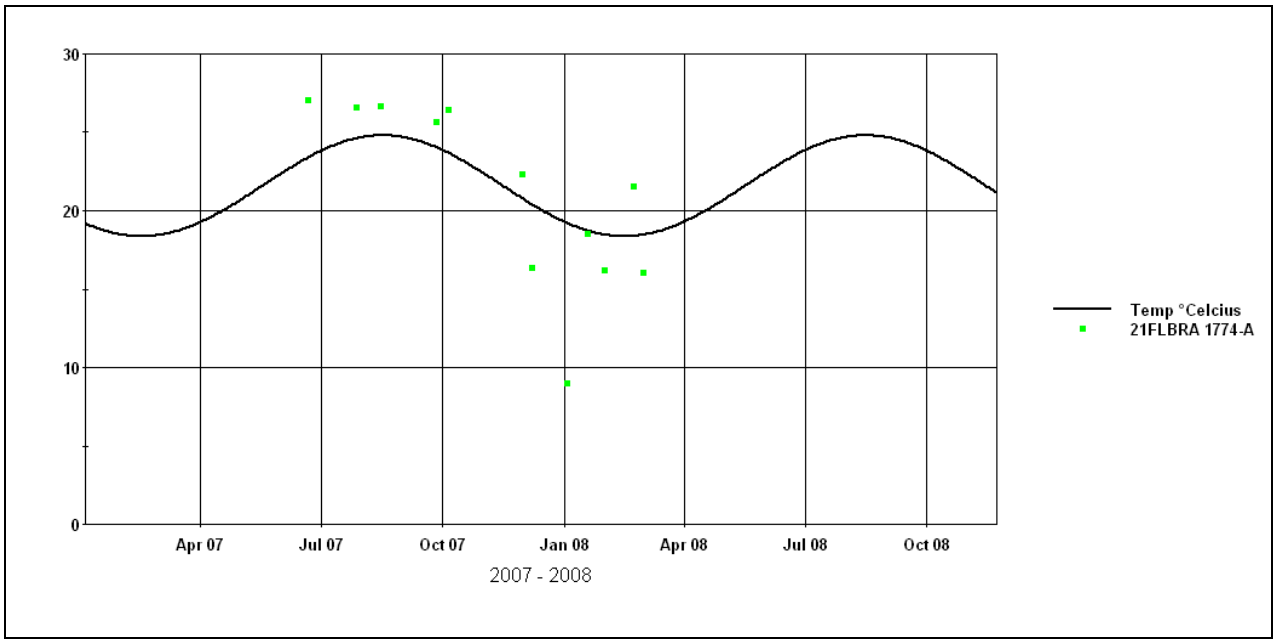

Figure G-16 Segment 2 Little Charlie Creek Water Temperature Calibration (2007-2008).

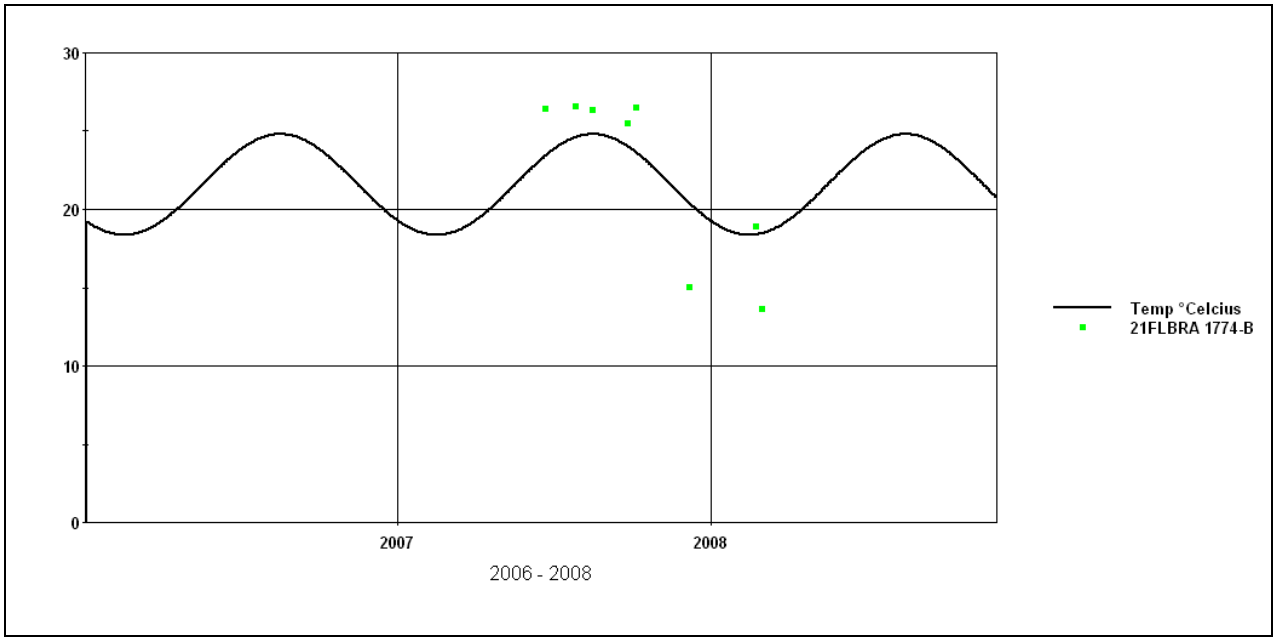

Figure G-17 Segment 3 Little Charlie Creek Water Temperature Calibration (2007-2008).

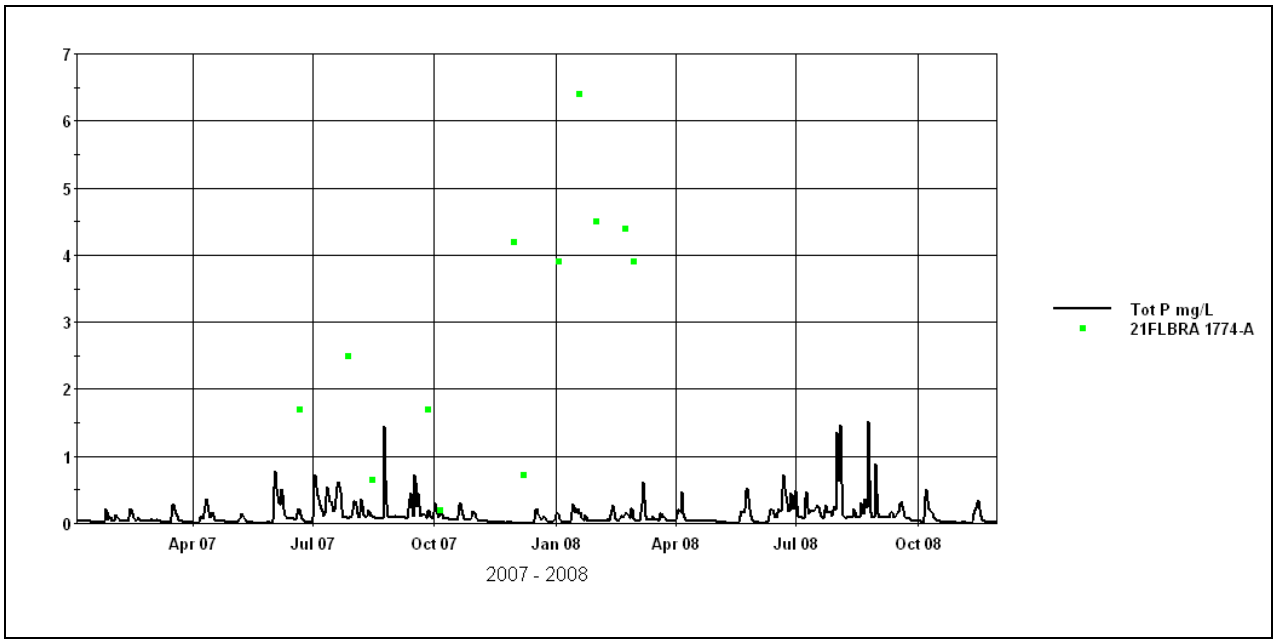

Figure G-19 Segment 2 Little Charlie Creek Total Phosphorus Calibration (2007-2008).

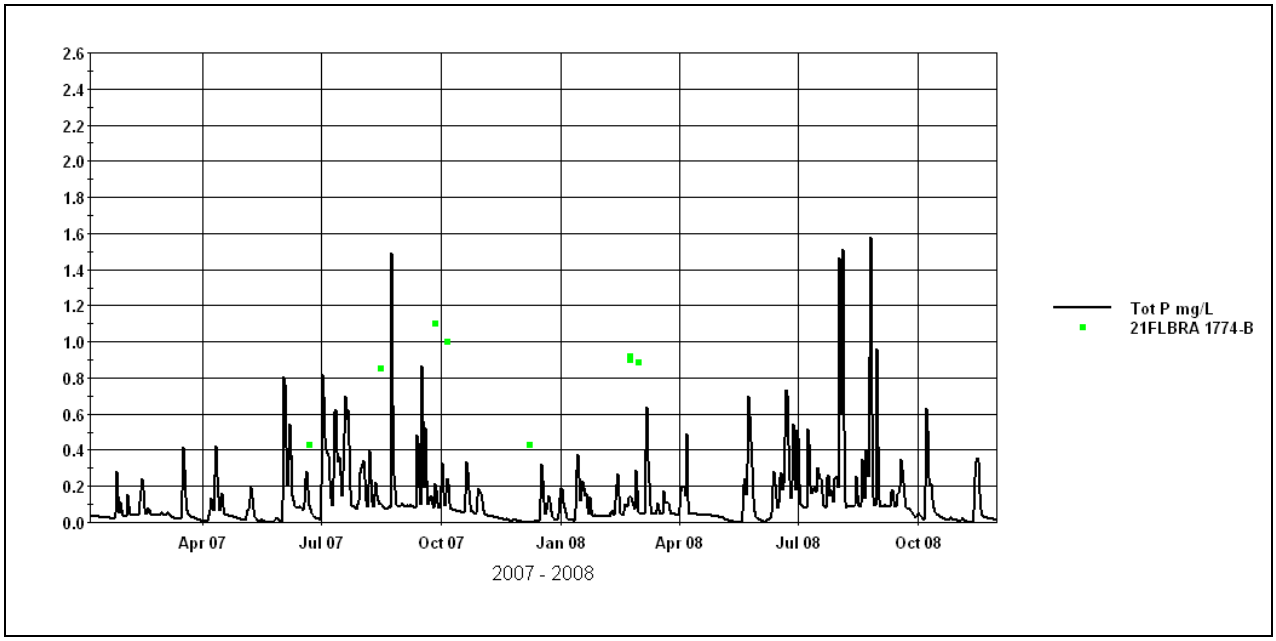

Figure G-20 Segment 3 Little Charlie Creek Total Phosphorus Calibration (2007-2008).

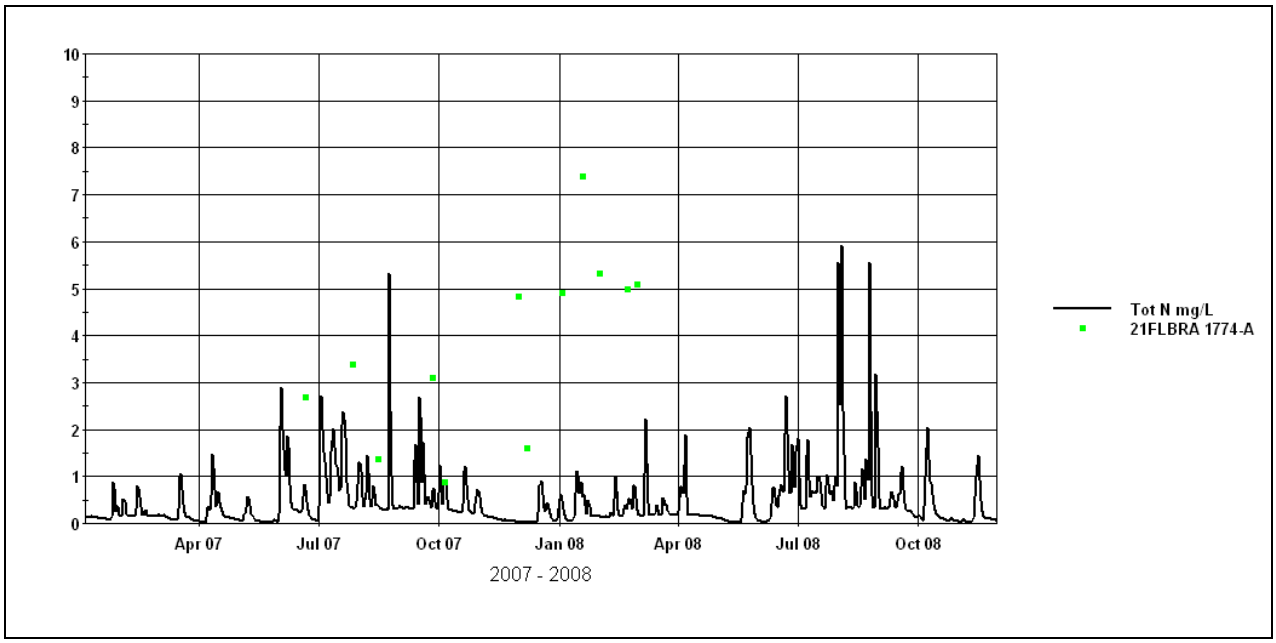

Figure G-21 Segment 2 Little Charlie Creek Total Nitrogen Calibration (2007-2008).

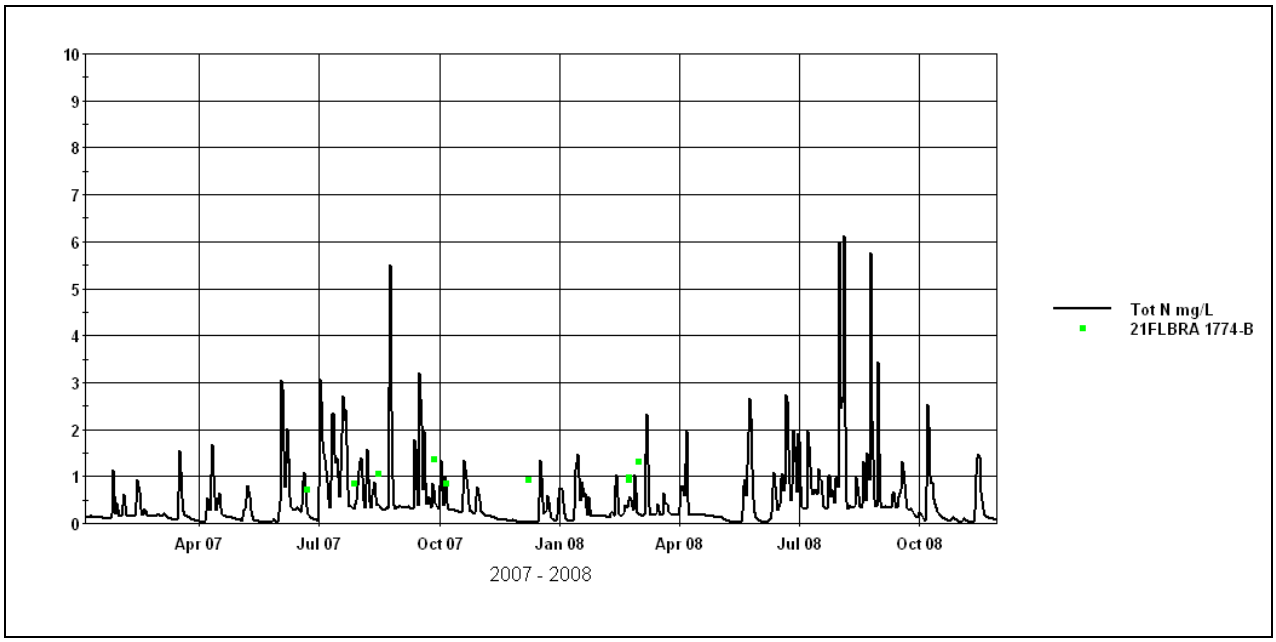

Figure G-22 Segment 3 Little Charlie Creek Total Nitrogen Calibration (2007-2008).

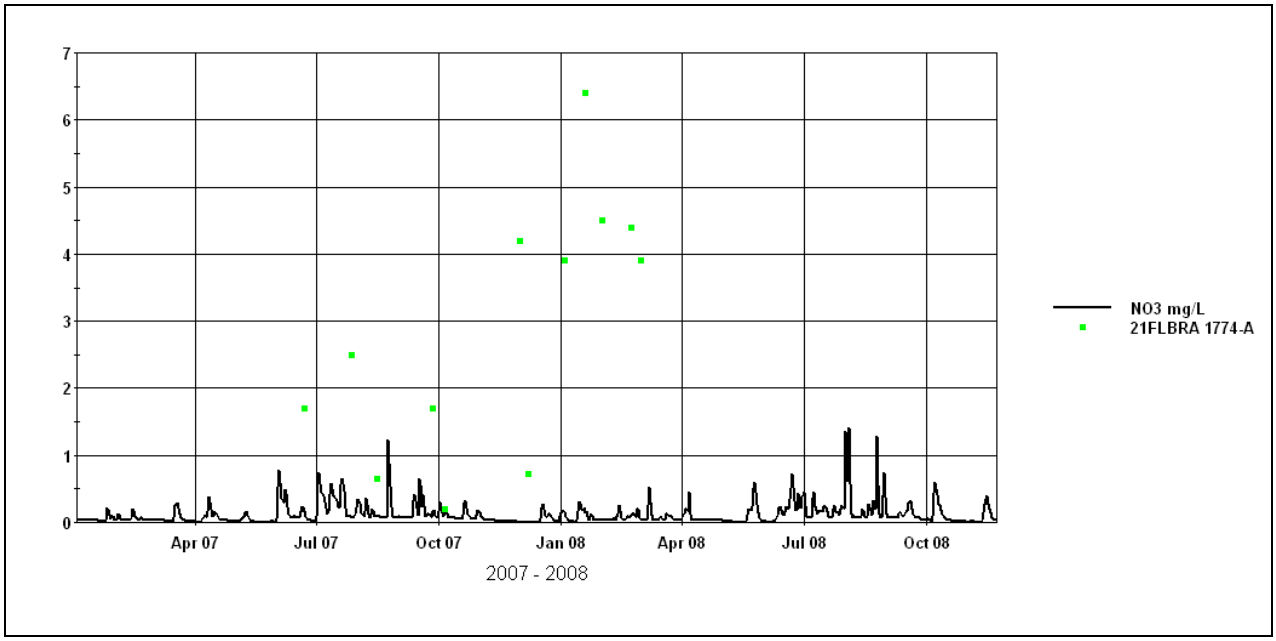

Figure G-23 Segment 2 Little Charlie Creek Nitrate Calibration (2007-2008).

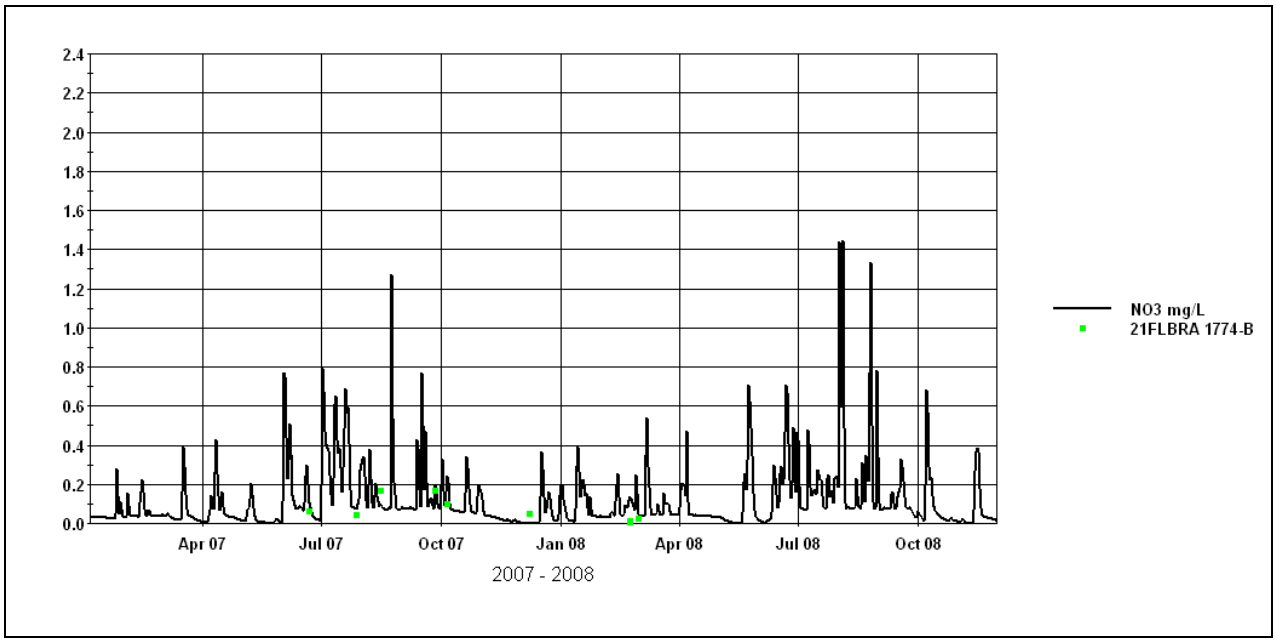

Figure G-24 Segment 3 Little Charlie Creek Nitrate Calibration (2007-2008).

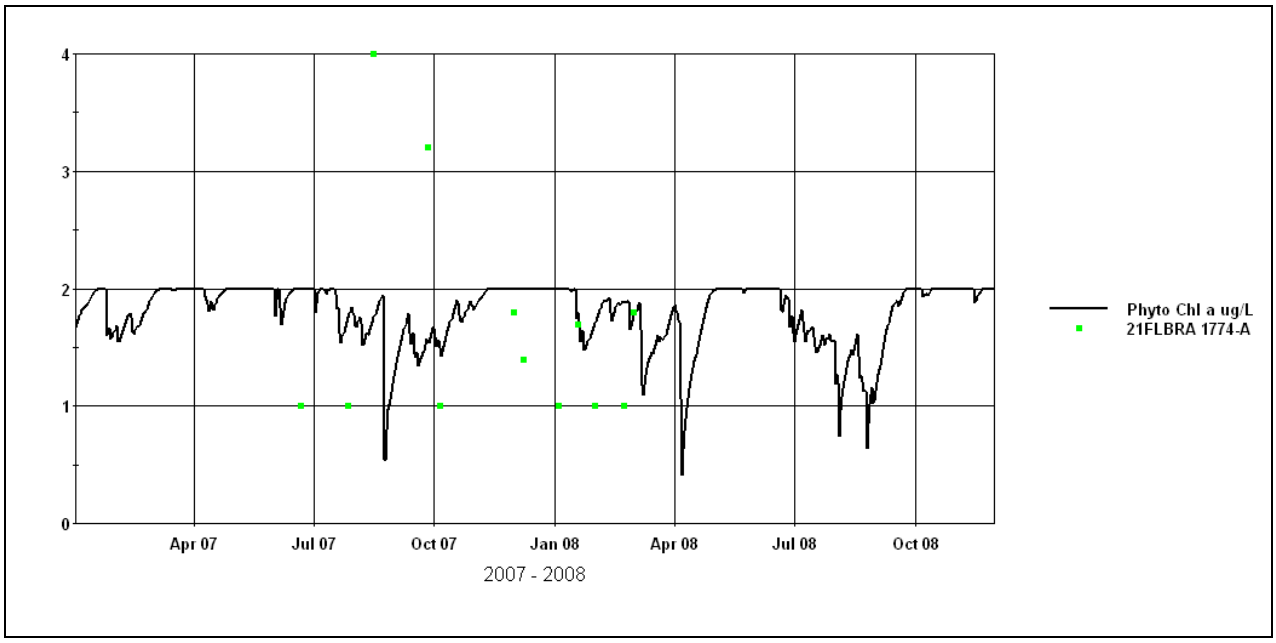

Figure G-25 Segment 2 Little Charlie Creek Chlorophyll a Calibration (2007-2008).

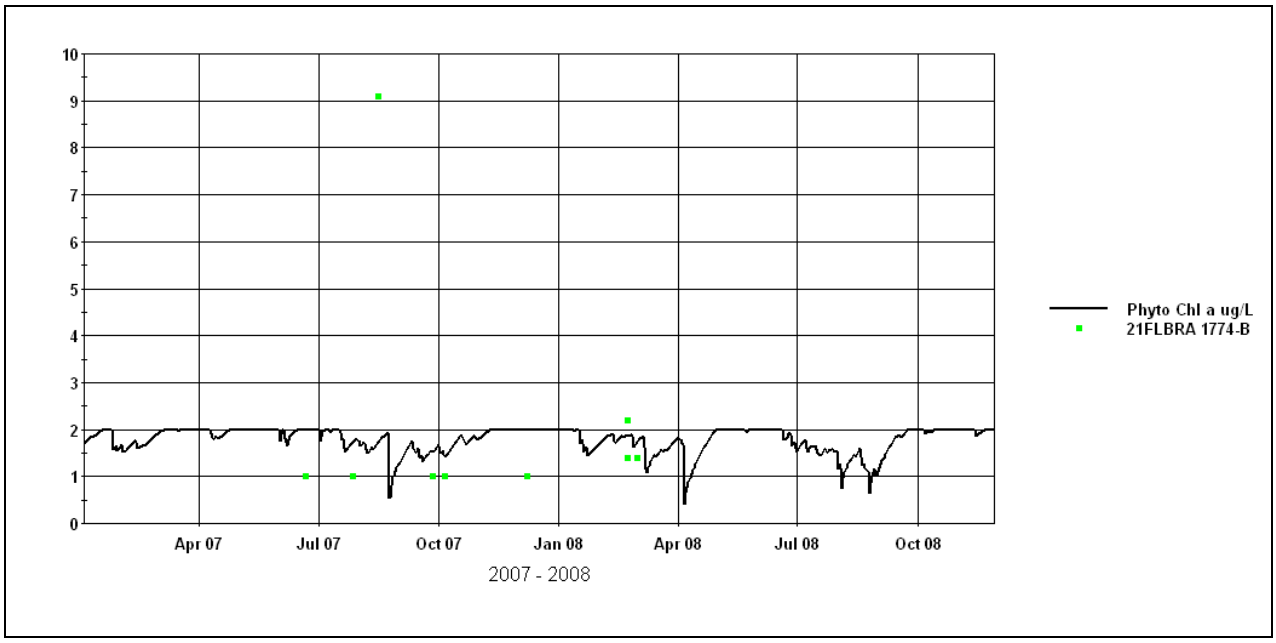

Figure G-26 Segment 3 Little Charlie Creek Chlorophyll a Calibration (2007-2008).